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1998

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Prosecuting Science

Simulating Molecules

Observing Anniversaries

London Bridge? The Manhattan skyline? No, it's an oil refinery. Figuring out how to squeeze more gasoline from a barrel of crude is just one project a group of theoretical chemists at Caltech have taken on in a series of academic-industrial collaborations. For more on this partnership, see the story on page 20. Photo courtesy of Chevron Corporation.

California Institute of Technology

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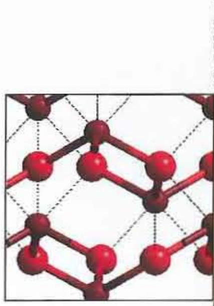

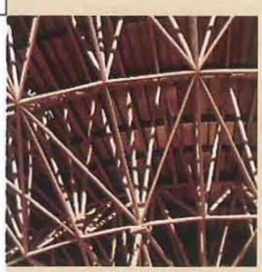

On the Cover: The six 10.4-meter antennas (one is hidden behind the others here) of the Owens Valley Radio Observatory millimeter-wave array can receive signals from up to 10 billion light years away. Designed by the late Bob Leighton (BS '41, MS '44, PhD '47), the millimeter-wave array is the latest addition to OVRO, which celebrated its 40th anniversary in October. Palomar Observatory also celebrated its 50th; the two stories begin on page 30.

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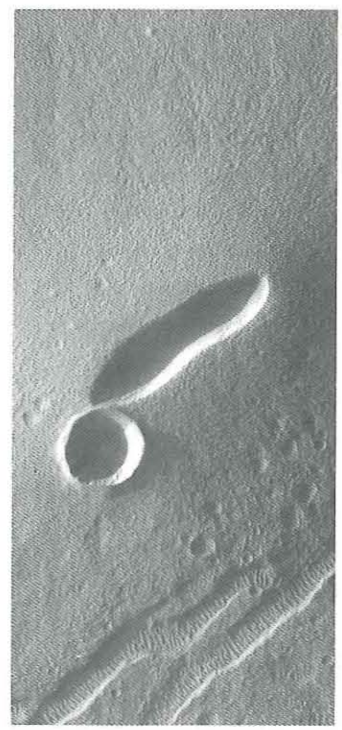
Surveying Mars



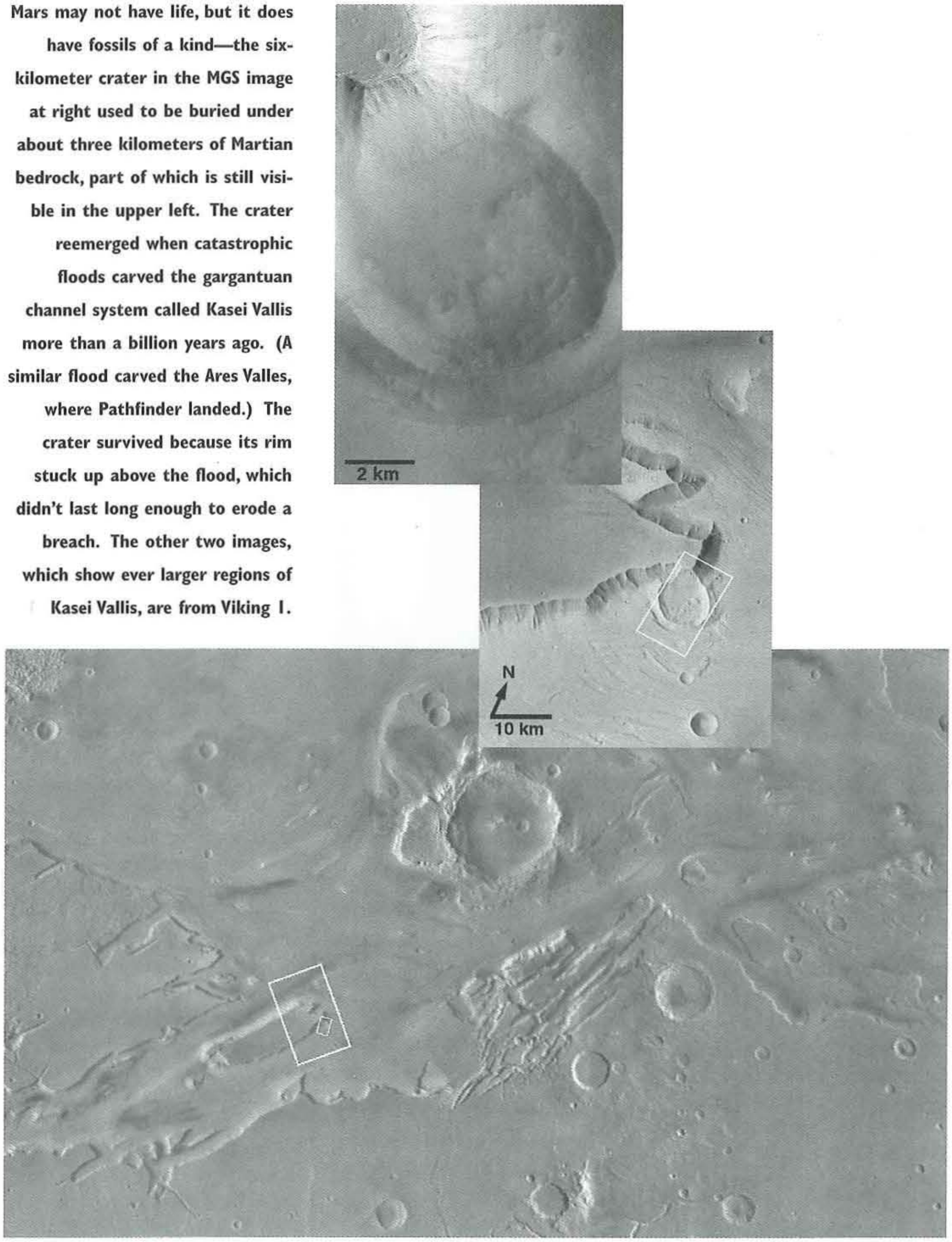
Right, top: Mars's largest volcano, Olympus Mons, is as big as Arizona and taller than three Everests. A "shield" volcano, formed by the gentle oozing of very fluid lava, Olympus Mons is very nearly as flat as a pancake—once one surmounts the cliffs ringing the volcano, typical slopes are 2–5 degrees. Mars Global Surveyor (MGS) took this enhanced-color image on a cool, crisp, Martian-winter morning. Note the clouds lapping against the mountain's flanks on the east (top) side. Bottom: Martian volcanoes come in all sizes. This is the first-ever close-up view of one of the small shield volcanoes that dot the planet. This one has a two-kilometer-long, 150-meter-deep, paramecium-shaped caldera at its summit, and the whole volcano would fit unnoticed in Olympus Mons's 75-kilometer-diameter caldera.

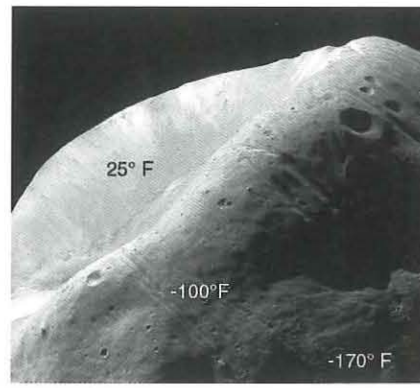
Broad Building Announced

Eli Broad, one of Southern California's most prominent civic and business leaders, has donated $18 million to create the Broad Center for the Biological Sciences, which will provide 100,000 square feet of space for 10 research groups that will work at the cutting edge of the biological sciences. The new building, shown above in a preliminary rendering, will be located in the northwest quadrant of campus near the Beckman Institute. As the cornerstone capital project of the Biological Sciences Initiative, the building will provide crucial infrastructure underpinning the Institute's new capabilities for magnetic imaging, structural chemistry, and genetics. Broad's gift is the largest donation so far in Caltech's new Biological Sciences Initiative, which aims to raise $100 million for new faculty and resources. A total of $56 million has been raised since the initiative was announced this past May.

Left: Mars's north polar cap as seen by MGS on September 12, early in the Martian spring. The permanent cap, believed to be water ice mixed with dust, has a scalloped, layered look due to channels eroded on its surface. (It actually has layers, but they're far too fine to be seen here.) The ground throughout this image is covered with carbon dioxide frost, which appears pink rather than white—probably for the same reason that springtime snow on Earth is often a dirty brown.

Mars may not have life, but it does have fossils of a kind—the six-kilometer crater in the MGS image at right used to be buried under about three kilometers of Martian bedrock, part of which is still visible in the upper left. The crater reemerged when catastrophic floods carved the gargantuan channel system called Kasei Vallis more than a billion years ago. (A similar flood carved the Ares Valles, where Pathfinder landed.) The crater survived because its rim stuck up above the flood, which didn't last long enough to erode a breach. The other two images, which show ever larger regions of Kasei Vallis, are from Viking 1.





Above: This MGS close-up of Stickney, Phobos's largest crater—at 10 kilometers, nearly half the diameter of Phobos itself—shows features as small as four meters (the length of a VW Beetle), and is one of the highest-resolution views ever of Mars's moons. At the same time, MGS was mapping Phobos's surface temperature, as shown. The fact that the night side gets so cold so quickly (Phobos rotates in seven hours) hints that the surface is covered with a meter-thick layer of very fine particles, which would lose heat rapidly. In other words, Phobos is hip-deep in powder from millions of years of meteor impacts, and getting around on it is going to be a royal pain, even though the gravitational field is only 1/1000 that of Earth's.

Left: Make way! Make way! Make way for the Sojourner rover! This diorama showcases a system for clearing intersections in advance of ambulances, fire trucks, and other emergency vehicles (note the police car behind the rover). The vehicle carries a transponder that commandeers the traffic signals and causes a warning sign (arrowed) to flash at cross traffic.

What Next—Techno-Trousers From NASA?

Getting technology that was developed at taxpayer expense into the commercial arena is all the rage these days, but the Technology Affiliates Program at JPL has been doing it since before it became fashionable. This decade-old program has agreements with some 120 companies, and about 200 technology-transfer projects under way or completed.

A lot of these projects are what you might expect: robotic surgical assistants that have a steadier hand than any human; remote sensing of hazardous waste sites, oil spills, and land-use patterns; putting on CD-ROM the positions of the sun, moon, and planets (what astronomers call an ephemeris) from 3000 BC to AD 3000; and integrating Global Positioning System data into the next generation of the nation's air-traffic control system. But some JPL spinoffs have taken odder twists.

For example, an aural thermometer based on JPL infrared-sensor technology is now in widespread use. The thermometer, which gives a reading in seconds and is held to the patient's ear instead of being inserted somewhere, is especially useful on fidgety kids. And an infrared camera is being used to detect cherry pits (or parts thereof) in pie filling.

Speaking of cherries, a JPL-designed imaging system periodically scans the Constitution, the Bill of Rights, and the Declaration of Independence for signs of deterioration. Another system was used to examine the Dead Sea Scrolls in the far infrared, revealing lettering that had faded to invisibility at shorter wavelengths.

And JPL's experience in dealing with the icy cold of space has led to more efficient refrigerated display cases for supermarkets, and a superior insulator for the mail-order meat business.

Then there's the fun stuff. There are the Hot Wheels, of course. JPL radar data has been used to create a collectible three-dimensional model of the asteroid Toutatis, with one of Castalia on the way. JPL scientists and engineers are providing technical information for *Crusade*, a new TV series from the producers of *Babylon 5*. And data from Pathfinder's weather station have been converted into sounds that, woven into the strains of J. S. Bach, are out on CD as *Winds of Mars*. □

Above: Jo Pitesky of JPL's Commercialization Program Office holds more spinoffs—the Mars Pathfinder and John Glenn Hot Wheels Action Packs; a rearview mirror that automatically dims in proportion to the amount of headlight glare; and a world map, published by the National Geographic Society, that has a political map on one side and a high-resolution photomosaic (each pixel is one square kilometer) on the other.

Double Manhattan

The stuff on the chips in your computer is essentially laid out in two dimensions, like a city. Oh, sure, the buildings stick up, and there are subways and pipes and cables underground (and the devices on a chip stick up, while some connectors are buried beneath the surface), but you can't stack the Empire State Building atop the Chrysler Building. Now Caltech researchers have found a way to layer multiple copies of the entire borough of Manhattan, as it were, in silicon. Thomas McGill (MS '65, PhD '69), the Fletcher Jones Professor of Applied Physics, and colleagues report the work in the October issue of the *Journal of Vacuum Science and Technology B*.

The method employs a widely used process called molecular-beam epitaxy to grow carefully controlled layers of various materials on a chip. The method begins with a silicon wafer, onto which an insulating layer of cerium dioxide just a few atoms thick is grown. Then a single crystal of silicon is grown back onto the cerium dioxide, resulting in a three-dimensional device containing a cerium dioxide insulator and having a fresh layer of crystalline silicon on top. The wafer is then ready to begin the process again. Layer upon layer of devices may be grown, one after another, on the same chip.

"The implications are very significant," says McGill. "For years there have been predictions that progress will eventually stop in silicon electronics because the devices will have been shrunk as much as they can. But this new technology could allow you to get the functionality increase by stacking instead of shrinking."

McGill says the group has stacked only a single extra layer of silicon so far. However, the key is the demonstration that the cerium oxide is indeed acting as an insulator, and that the silicon on top is one single crystal, suitable for further growth. "In principle, you can stack forever," he says.

According to grad student Joel Jones, another member of the team, this technique is especially interesting because it also allows the fabrication of a new group of novel silicon devices. "We've already fabricated a primitive tunnel-switched diode from the multilayered chips," Jones explains. "This is a single device that exhibits memory. At a given voltage, you can have two different stable currents depending on how you've switched the device." This phenomenon is called negative differential resistance, allowing two current states of different amperage to exist at the same voltage. Similar effects can be found in other devices enabled by this new technique, including resonant tunneling diodes. These devices can be exploited for novel memory storage, as well as used to enhance the performance of numerous other microelectronic circuits.

"The silicon industry is a $100 billion industry," says McGill. "This could be a major contributor in 10 to 15 years."

In addition to McGill and Jones, the authors of the paper are Visiting Associate in Applied Physics Edward Croke III (PhD '91), Member of the Professional Staff Carol Garland, and Visiting Associate in Applied Physics Ogden Marsh. □—*RT*

If you hit enough balls out of the park, one of them is bound to bounce off the ivory tower. Franklin Monzon, a grad student in Professor of Physics Michael Roukes's lab, used a scanning electron microscope to create what he calls "the world's smallest tribute to the world's biggest slugger." (In case your window in the tower doesn't face the ballpark, this would refer to Mark McGwire's hitting a record-breaking 70 home runs last summer.) Monzon drew these size-X^{X}-small jerseys on a gallium arsenide wafer using electron beam lithography, a standard chipmaking technique. The scale bar across the bottom of the photo is 10 millionths of a meter long. It would take more than a billion of these nanojerseys to cover McGwire's real jersey.

There's still time to get a set of punk rats, suitable for framing, of your very own. Artist Erika Oller has graciously given us permission to sell prints at cost—approximately $25 each. Call us at (626) 395-6730 for details.

Good-bye, Cruel World

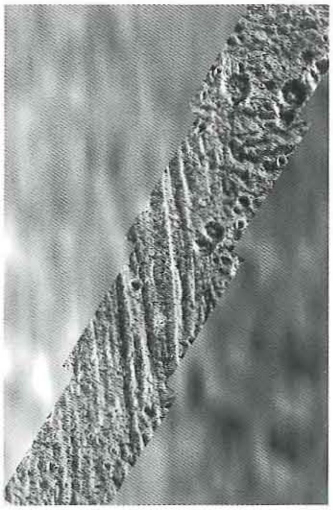
Biologists at MIT and Caltech have uncovered the chemical details of a mechanism that cells use to commit suicide. Caltech President David Baltimore's lab at That Other Institute of Technology has succeeded in describing how roundworms known as nematodes kill off unwanted cells. The work is especially interesting, Baltimore says, because human beings have very similar proteins to those causing cell suicide in nematodes and, in fact, his lab can often substitute human proteins with the same results. "All cells contain the machinery to commit suicide," he says. "You can see this in a wide variety of events, such as a tadpole's resorption of its tail, local ischemia in a stroke victim's brain, and tissue destruction after a heart attack. Cell suicide is also one of the great protections against cancer." The hallmark of cancer is uncontrollable cell proliferation, so precancerous cells, whose regulatory machinery has been damaged in such a way that the cells might soon begin to run amok, frequently opt to immolate themselves for the good of the organism.

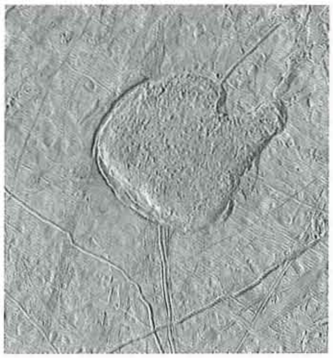
The mechanism involves three stable proteins found in nematode cells. These proteins are normally quiet, but can be readily triggered by death signals in such a way that the cell digests itself. The three proteins are known as CED-3, CED-4, and CED-9. None of these proteins alone will kill cells, the research shows, but the three interact in such a way that CED-4 can signal CED-3 to begin the destruction process, while CED-9 acts as an inhibitor to CED-4. The general outline of this particular pathway of apoptosis, as cell suicide is technically called, was discovered by MIT professor Robert Horvitz some years ago, but the details have never been understood until now, says Baltimore. The human equivalent of these nematode proteins are Apaf-1, which is very similar to CED-4; Bcl-2, which is a homolog of CED-9; and mammalian cysteine protease zymogens that are analogous to CED-3.

The work, which was supported by the National Institutes of Health, appeared in the August 28 issue of the journal *Science*. In addition to Baltimore, the authors are Xiaolu Yang and Howard Y. Chang. Yang is currently at the University of Pennsylvania; Chang, a PhD, is now finishing his MD at Harvard. □—*RT*

Galileo Gallery

Right: Voyager images of Ganymede showed two basic types of terrain: dark, heavily cratered regions; and bright regions of parallel grooves that are presumably much younger. This view of the boundary between a bright, grooved region called Philae Sulcus and the dark area called Galileo Regio superimposes a Galileo image, with a resolution of about 92 meters per pixel, on the best Voyager shot of the region, with a resolution of about 1.4 kilometers per pixel. Surprisingly, Galileo sees no overall brightness difference between the two landforms—bright and dark patches occur in both. The bright patches tend to occur on north- and east-facing slopes, which, in this north polar region, get the least sun and hence the most frost. The grooves in the "bright" terrain, however, are very visible; the "dark" terrain proved to be gently rolling hills.



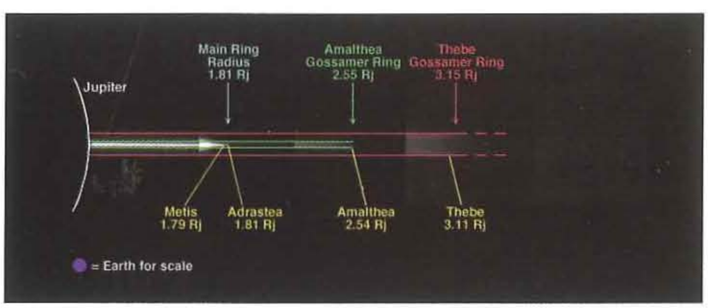


Above: This "catcher's mitt" on Jupiter's icy moon Europa is about 100 kilometers wide, as measured across the palm to the tip of the thumb. The mitt appears to be made of frozen slush and seems to bulge up from the adjacent surface, which is bent downward and cracked, most visibly along the lower left (southwest) side. This feature may be the result of an upwelling of viscous, icy "lava," or perhaps even liquid water, melting its way to the surface from the ocean that is hypothesized to exist below the surface.

Left: Wait a minute—this isn't Europa! As a matter of fact, it's the Monterey Bay Aquarium, where a probe that may one day look for life on Europa took its maiden voyage in August. Then, in October, JPL scientists lowered the probe into Lo'ihi, an undersea volcano off the Big Island of Hawaii. Next comes Antarctica's Lake Vostok, which is covered with ice four kilometers thick. The probe currently carries a camera and a thermometer, with chemical and spectroscopic instruments under development for next year.

Above: In this banner hanging from the front porch of JPL's Space Flight Operations Facility, the Galileo team wished bon voyage to the Lab's newest spacecraft, Deep Space One, which was launched on October 24. Deep Space One's mission is to test a dozen innovative technologies, including an ion-propulsion system, for possible use on future spaceflights.

Above: The Great Red Spot is Jupiter's best-known storm, but several smaller ones are noteworthy, too. For the last half century, scientists have been watching three white ovals, each about two-thirds Earth's diameter, that lie to the south of the Red Spot. In early October, two of the ovals merged to form this new Earth-sized storm, second in power in the solar system only to the Red Spot itself. Unfortunately, the collision itself happened on Jupiter's night side, out of view.



Above: This composite view of Jupiter's ring system, taken when Galileo was in the planet's shadow and in the plane of the rings, proved that the very fine dust that forms the rings comes from comets and other things hitting four of Jupiter's moons—the moons' orbital distances are shown in yellow. Rj stands for Jupiter's radius (71,398 kilometers). And the "gossamer" rings' thickness, marked by the red and green lines, coincides with the deviation of Amalthea's and Thebe's orbits from the rings' plane.

Beam Me Up, Scotty

An international collaboration of physicists has succeeded in the first true teleportation of a quantum state. In the October 23 issue of *Science*, H. Jeff Kimble, Valentine Professor and professor of physics, and colleagues reported transporting a quantum state of light from one side of an optical bench to the other without traversing any physical medium in between. Instead of actually propagating the light beam across the bench, the physicists exploited a phenomenon known as "quantum entanglement," the quintessential ingredient in the emerging field of quantum information science. Teleportation of this kind was first proposed theoretically by IBM scientist Charles H. Bennett and colleagues in 1993.

The Caltech experiment is the first quantum teleportation to be performed with a high degree of fidelity, which describes how well a receiver, "Bob," can reproduce quantum states from a sender, "Alice." (Quantum teleportation was recently announced by two independent labs in Europe, but neither experiment achieved a fidelity sufficient to unambiguously demonstrate the use of quantum entanglement between Alice and Bob.)

The work uses an exotic form of light known as a "squeezed vacuum," which is split in such a way that Alice and Bob each receive a beam that is the quantum mechanical "twin" of the other. [See *E&S*, Summer 1993.] The photons in these beams share information that has no independent existence in either beam alone. Because of the Heisenberg Uncertainty Principle, this information—the numeric value of a quantum variable such as the amplitude of the beam, for example—is indeterminate until it is measured. The act of measurement, however, "freezes" the variable simultaneously in both beams. Thus, through quantum entanglement, the act of measurement in one place can influence the quantum state of light in another. Such beams—called EPR beams for the Einstein-Podolsky-Rosen paradox of 1935, which conjectured their existence—are among the strangest predictions of quantum mechanics. In principle, it would be possible for a measurement on an EPR beam at Caltech to alter the quantum state of the beam's twin at MIT—a spooky "action at a distance" that led Einstein to reject the idea that quantum mechanics might be a fundamental physical law.

In this case, once Alice and Bob have received their spatially separate, but quantum-entangled halves of the EPR beam, Alice performs certain measurements on a second light beam she wishes to teleport and on her half of the EPR beam. This destroys the second beam, but she sends both sets of measurements to Bob via a non-quantum means (over an ordinary wire, for example). Since Bob's half of the EPR beam is now "frozen" in the state in which Alice measured her half, he can use the correlations she sent him to transform his half of the beam into one that mimics Alice's second beam, resurrecting at a distance the original, unknown quantum state.

A unique feature of the experiment is a third party, "Victor," who verifies various aspects of the protocol performed by Alice and Bob. It is Victor who generates and sends an input to Alice for teleportation, and who afterward inspects the output from Bob to judge its fidelity with the original input. "It's sort of like having a quantum telephone company managed by Alice and Bob," says Kimble. "Having opened an account with an agreed upon protocol, a customer (in this case, Victor) uses Alice and Bob's service to teleport quantum states without revealing these states to the company. And Victor can independently assess the quality of the service Alice and Bob provide."

The experiment shows that the strange connections that exist between entities in the quantum realm can be employed for tasks that have no counterpart in the "classical," macroscopic world known to our senses. "The distance was only a meter, but the scheme would work just as well over much larger distances," says coauthor Samuel Braunstein (MS '85, PhD '88), of the University of Wales in Bangor, United Kingdom, who, with Kimble, conceived the scheme. "Our work is an important step toward the realization of networks for distributing quantum information—a kind of 'quantum Internet.'"

In recent years, Kimble's group has worked on several aspects of quantum computing, including showing that individual photons can interact to form a quantum logic gate—the basic element of a microprocessor chip. Kimble's work suggests that the quantum nature of light may someday be exploited for the quantum processing and distribution of information to accomplish tasks otherwise impossible for classical systems. □—*RT*

Methuselah Revisited

Caltech biologists have discovered a gene that increases the life span of fruit flies by one-third when mutated. Dubbed "the Methuselah gene," after the Biblical figure who lived for 969 years, the gene's discovery was announced in the October 30 issue of the journal *Science*. According to the authors, postdocs Yi-Jyun Lin and Laurent Seroude, and Seymour Benzer, the Boswell Professor of Neuroscience, Emeritus, the research strengthens the view that such a gene or genes might also be found in humans. The work also lends additional credence to the view that the wear and tear of aging can be exacerbated by molecular stresses, such as tissue-damaging free radicals. "If we mutate the gene, which we can do experimentally, the fruit flies have an increase in life span," says Benzer, who has won the Crafoord Prize of the Royal Swedish Academy of Sciences for his work on the relation of genes to behavior in the fruit fly *Drosophila melanogaster*. "If we take the mutation out again, the life span goes back to normal."

This is not the first time a gene has been found that affects an organism's life span, Benzer says, explaining that the roundworm *Caenorhabditis elegans* can also be given a longer life in the lab through genetic manipulation. Nor is this the first time that scientists have demonstrated that the life spans of fruit flies are genetically determined. However, the earlier work on *Drosophila* focused on selective breeding—individual long-lived flies were mated over many generations to produce a strain of flies that lived longer. In selective breeding, even though the effects are obviously genetic in nature, it is difficult to pinpoint which genes are responsible.

In contrast, once an individual gene is identified as important to aging, the gene can be cloned by molecular methods and its specific function studied, implying that it eventually might be used to manipulate the aging process. "Very often indeed, fruit fly genes have human homologues," Benzer says. "The basic idea of our research is to use the fruit fly as a model system and look for human equivalents." "Now it's inescapable that aging is regulated deliberately by genes," said UC San Francisco molecular geneticist

Above: The Winnett Student Center got a major face-lift over the summer. The new exterior harmonizes with the Andalusian look of other buildings along the Olive Walk. The remodeled interior features a bookstore twice the size of the old one, a computer store called Caltech Wired, and a much-expanded Red Door Cafe.

Above: Who says only undergrads can pull a good prank? The spiffy teakwood furniture outside the Red Door inspired some grad students, who, with help from Blacker, Ricketts, and Fleming Houses, one night replaced the chairs with 56 toilets from campus storage—the Housing Office having just finished rehabbing a bunch of bathrooms.
Top, right: (from left) Custodians Bill Schouten and Efrain Hernandez and elevator mechanic Moty Zahavi take the porcelain seats in stride, as it were.
Bottom, right: Kate Finigan manages the Red Door.

Cynthia Kenyon in a *Science* news brief describing the Benzer group's results. "Since it happens in both worms and fruit flies, you have to be crazy not to think it won't happen in vertebrates."

The Caltech team singled out the Methuselah gene by manipulating a small, transposable piece of DNA that can cause mutations at the gene in which it lands. The researchers then tracked the mutated flies to their natural deaths. *Drosophila* normally live about 60 to 80 days, but the flies with a mutation at the Methuselah gene lived more than 100 days. These flies were also better able to resist various types of stress that can cause aging in flies or kill them outright. From the identified sequence of the Methuselah gene DNA, the biologists speculate that it may code for a protein that is part of a signaling pathway that controls how well cells deal with stress. This would explain the fact that the flies with a Methuselah gene mutation can better withstand such external stresses as food deprivation, excessive heat, and exposure to oxidative damage.

Kenyon, who identified the daf-2 gene that increases longevity in roundworms, said in the news review that the Benzer lab's results give experts in the field another gene to work with. "Now," she says, "we have another experimental system to investigate" for understanding how a gene or several genes can affect an organism's life span. □—*RT*

We're Number One! And Number Two, And Number Three...

The magazine *Science Watch* periodically ranks universities by their scientific "impact," as measured by how often their papers are cited in other people's papers, which shows what people in the field think is important work. In the most recent rankings, Caltech neuroscience was #1 in its field in the nation, chemistry and materials science were #2; economics #3; computer science, geosciences, and physics #4; astrophysics #5; biology/biochemistry and mathematics #6; and engineering #7.

It's not surprising that the physical sciences placed well, but for the economics program—which followed the University of Chicago and That Other Institute of Technology, both of which have substantial economics departments—to score so highly is quite a tribute. Especially considering that the program is less than 25 years old, and even today has only a dozen faculty members and a handful of grad students and postdocs. □


Nobelist Entangled in Fraud Case Resigns as Head of Rockefeller U.

President of Rockefeller U. Retracts Scientific Paper That NIH Office Says Contains Fabricated Data

By DAVID L. WHEELER

David Baltimore, president of Rockefeller University, last week retracted a scientific paper that has been the centerpiece of a three-year Congressional investigation into scientific fraud.

Mr. Baltimore, a Nobel Prize ... had long defended the ...

'I Am Innocent,' Embattled Biologist Says

The Baltimore affair

Ignoble

CAMBRIDGE, MASSACHUSETTS

WHEN it was published in a journal called Cell in April 1986, "Altered Repertoire of Endogenous Immunoglobulin Gene Expression in Transgenic Mice Containing a Rearranged Mu Heavy Chain ..."

The New York Times

A Scientific Watergate?

Five years after disturbing questions were raised about a research paper written in part by the Nobel laureate David Baltimore, the celebrated case is finally moving toward a verdict. Federal investigators have concluded, in a draft report, that the paper contained fraudulent data and ... accurately reflect the laboratory ... which it was sup...

hands. A graduate student independently ... suspicious. But neither got sat... tried to get correc... scientific ...

Hero in Exposing Science Hoax Paid Dearly

By PHILIP J. HILTS

WASHINGTON, March 21 — When Dr. Margot O'Toole, a junior researcher in molecular biology, raised uncomfortable questions in 1986 about the validity of a senior colleague's work, she felt alone.

Dr. David A. Baltimore, a Nobel laureate who was a co-author of a research paper that used the disputed work, described her as a "disgruntled postdoctoral fellow." She lost her job and her house and feared that her husband's job was in jeopardy as well. She took work answering phones at her brother's moving company.

Dr. Baltimore, who is president of Rockefeller University in New York, was a senior adviser on the paper who ...

For challenging her boss's data, a scientist lost her job and home.

Did Imanishi-Kari Get a Fair "Trial"?

The National Institutes of Health's Office of Scientific Integrity (OSI) must be reeling under the onslaught of bad publicity it has received in recent weeks. A group of 143 scientists, including some eminent ... nologists, recently compl... denied basic rights ... Imanishi-K...

US finds fraud in research at MIT

Report also assails Nobel laureate

By Peter G. Gosselin
GLOBE STAFF

Most scientists rallied around Dr. B...

'Always Had a Level...'

Challenging Dr. Imanishi... search was not the first ... O'Toole had taken on ... "She's always had a level ... know what I mean," Mrs. ... "If she wanted an answer you'd better give it or she ... you. I wouldn't say it was ... honesty exactly, it ... it was practical or ...

Nobel Scientist Apologizes to Whistle-Blower

Co-Author of Flawed Study Concedes His Oversight Was Inadequate

Associated Press

David Baltimore, a Nobel laureate who was co-author of a study that prompted a prolonged investigation of possible scientific misconduct, has apologized to the young scientist who prompted the investigation and admitted that he made mistakes in defending the flawed work of a co-author.

Baltimore, now president of Rockefeller University in New York ... nology, where O'Toole was her research associate.

When O'Toole challenged the accuracy of data reported by her boss in the article in Cell, there were investigations first at MIT and later at Tufts University, where Imanishi-Kari now works.

The university investigations uncovered only minor errors. O'Toole was fired.

When NIH and the House Energy ... Office of Scientific Integrity concluded that Imanishi-Kari "repeatedly presented false and misleading information" and made statements she knew to be false.

Baltimore responded then that the findings raised "very serious questions." He withdrew the Cell paper.

In his 14-page statement to NIH investigators, Baltimore acknowledged that "for too long" he had defended the now discredited paper.

Scientific Fraud and Misconduct in American Political Culture: Reflections on the Baltimore Case

by Daniel J. Kevles

The so-called Baltimore case first surfaced publicly in 1988, but it had been simmering in part of the biomedical research community for almost two years. The case originated in May 1986 with a young scientist named Margot O'Toole. She was a postdoctoral fellow in the laboratory of Thereza Imanishi-Kari, a cellular immunologist then on the faculty at MIT. O'Toole found serious fault with a paper that Imanishi-Kari and five coauthors, including David Baltimore, had published in the journal *Cell* in April of that year. O'Toole protested that the paper's central claim was not supported by the raw data. Investigations of her contentions at Tufts Medical School and at MIT concluded that the paper suffered only from minor, inconsequential errors and that O'Toole's quarrels with it amounted to a scientific dispute that could only be resolved by further research.

Why did scientific fraud become such a salient issue in American political culture during recent years?

What kept the case simmering was the zealous pursuit of it by two scientists at the National Institutes of Health, Walter Stewart and Ned Feder, and they reported it to the staff of Congressman John Dingell, a Michigan Democrat. Dingell in turn brought it to the public's attention in April 1988, when it was featured in hearings that he called "Fraud in NIH Grant Programs." In January 1989, a panel appointed by NIH to investigate the matter cleared Imanishi-Kari of fraud, but later that year the new Office of Scientific Integrity reopened the investigation. In 1991 the OSI found Imanishi-Kari tentatively guilty of fraud, a conclusion that was reiterated by its renamed successor, the Office of Research Integrity. In 1991, Baltimore was forced to resign the presidency of Rockefeller University for having defended Imanishi-Kari. As the result of an appeal, however, in June 1996 Imanishi-Kari was exonerated on all charges of fraud that had been leveled against her, and Baltimore was widely recognized for the courage he had shown—and for the costs he had borne—in resolutely defending her for a decade.

During the same period, several other cases of scientific fraud and misconduct achieved comparable salience, if not so prolonged a life. And in almost every one of them, the defendants were ultimately found not guilty. Each had been victimized by procedural flaws that denied them elemental rights of due process. Taken together, the scientific fraud cases of the late 1980s and early 1990s are puzzling, for two reasons. First, many observers say, and I think they are right, that scientific fraud is rare. Second, at the time scientific fraud as such compelled little if any attention in other scientifically vital nations. Why did scientific fraud become such a salient issue in American political culture during recent years?

One answer is that scientific fraud and misconduct were made and sustained as a public issue primarily by Congressman John Dingell. Dingell did not stop with the 1988 hearing. He held additional hearings on scientific fraud, focusing on the case of Imanishi-Kari, in 1989, 1990, and 1991. These hearings occurred with such regularity in successive springs that Imanishi-Kari's lawyer got mixed feelings about the blooming of the cherry blossoms in Washington; their opening meant it was time to testify, yet again.

Another answer is the media. The Baltimore Case, which both advanced attention to the issue of misconduct and was taken to be exemplary of it, provided a delicious target for the press. The whistle-blower, Margot O'Toole, was a compelling, highly articulate figure, a woman who, as one of Dingell's staffers put it, just "reeked with integrity." O'Toole's dogged insistence that she

Nobelist Entangled in Fraud Case Resigns as Head of Rockefeller U.

By PHILIP J. HILTS

d Baltimore said yesterday ould resign as president of University after an 18-ure dogged by a case of fraud against a colleague he wrote a disputed scien-

r to the trustees, Dr. Balt- that the controversy over had "created a climate of s among some in the uni- could not be dispelled."

ten N. Wiesel, an eminent ologist, is expected to be y as acting president of the in New York City until a an be found. Dr. Baltimore, l, will remain a professor at ity.

ller Defense of Paper

more, who won a Nobel his discovery of a crucial

would become such an extended personal travail for everyone involved. Trying to govern the university under these conditions has taken a personal toll on me and my family which I can no longer tolerate."

The spectacle of a Nobel laureate and president of one of the most prestigious American research universities fighting day by day over scientific fraud made the whole matter larger than life, with an effect greater than that of any case of science fraud in memory.

Dr. Baltimore's handling of the dispute led to controversy at Rockefeller University in 1989 when he was being considered for the job of president, and the dispute among faculty members

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June 23, 1996: Thereza Imanishi-Kari and David Baltimore celebrate her exoneration on all charges two days earlier. A year later Imanishi-Kari was associate professor with tenure at Tufts University, and Baltimore had been named president of Caltech.

was right and Imanishi-Kari was wrong lay at the heart of the affair. In the media, she became a symbol of the heroic young scientist who takes a stand against the system and prevails over powerful figures like David Baltimore. In a column in *Time* magazine, the commentator Barbara Ehrenreich captured the overall take of most of the media. "Baltimore pooh-poohed O'Toole's evidence and stood by while she lost her job. Then, as the feds closed in, he launched a bold, misguided defense of the sanctity of science." She added, "What he lost sight of, in the smugness of success, is that truth is no respecter of hierarchy or fame. It can come out of the mouths of mere underlings, like the valiant O'Toole."

Yet neither John Dingell nor the media would have gotten anywhere with the fraud issue if it hadn't resonated with broader concerns in American life. The fact of the matter is that in the 1980s it struck a chord in recent developments in American political culture and the relationship of science—in particular, biomedical science—to those developments.

* * *

Remember the '80s? At the opening of the decade, some of the most powerful forces operating in American political culture were energized in the legacy of Watergate and the war in Vietnam. Both had generated a deep distrust of public and governmental authority and institutions. That distrust by no means diminished during the 1980s. Its continuation was fueled by the savings and loan scandals, evidence of waste and profiteering in the huge defense buildup, the sale of political favors in episodes such as Abscam, the indulgence in influence peddling, and the Iran/Contra controversy. Corruption in high places has been a constant motif of American life, but some eras have been worse than others. The '80s will likely be recorded in the history books as among the worst because, as in the era of Ulysses S. Grant, the corruptions of public life seemed to echo loudly the *Bonfire-of-the-Vanities* values—greed and careerism often coupled to lying and deception—that were so manifest in the private sphere, including the regions that touch on public interests.

This is not to indict the '80s but to place the emergence of the fraud and misconduct issue in its larger historical frame. That issue was, in fact, first broached publicly in the late 1970s in several post-Watergate-flavored articles in *Science* magazine by Nicholas Wade and William Broad, who collected their case studies into a book that was published in 1982 under the title *Betrayers of the Truth*. And the issue was not introduced into Congress by John Dingell. It was first explored on Capitol Hill in April 1981, in hearings titled "Fraud in Biomedical Research," by then-Representative Al Gore, the Tennessee Democrat.

Most of the Gore hearings and most of Broad and Wade's book were devoted to tales of individual cases of fraud and misconduct. Certain common themes ran through them: whistleblowers were not listened to and some suffered retaliation; academic institutions tended to be desultory in their response to whistle-blowing

As an ally of business and a ward of government, science, too, was vulnerable to suspicion, and the biomedical sciences were especially so. During the era of Vietnam and Watergate, they had prospered steadily, more than did the physical sciences, obtaining enormous support from public and private sources.

challenges and to be reluctant to jeopardize grants by acting on those challenges and, when they did act on them, tended to deliver minimal punishments, if any at all. Taken together, such outcomes appear to have prompted Gore, as well as Broad and Wade, to pose questions about the scientific enterprise in the U.S., questions that resonated with the distrust of authority and dissatisfaction with the emerging culture of the '80s.

As an ally of business and a ward of government, science, too, was vulnerable to suspicion, and the biomedical sciences were especially so. During the era of Vietnam and Watergate, they had prospered steadily, more than did the physical sciences, obtaining enormous support from public and private sources. But that period was also the time of the wars over recombinant DNA. Recombinant DNA opened the door to the transformation of organisms—plants, animals, and possibly even human beings—at the core of their hereditary essence. Many people, including many scientists, found these prospects unsettling. A number of biologists worried that recombinant micro-organisms might threaten life or health or whole ecosystems. Some questioned the reconfiguring of life itself as an act of hubris that would lead to unpredictable and dangerous consequences.

In the later 1970s, local and state governments and the United States Congress geared up to legislate tough, mandatory restrictions on such research. Norton Zinder, a biomedical scientist at Rockefeller University, denounced some of the recombinant regulatory bills in Congress for setting up "vast bureaucracies, cumbersome licensing, harsh penalties and tedious reporting procedures." By 1980, biomedical scientists had beaten back the threat of intrusive bureaucratic controls and obtained even a major relaxation of the strict guidelines that NIH itself had initially imposed on recombinant research. Nevertheless, the recombinant DNA wars left many of them skittish about anything that smacked of government intrusion into the practice of research.

Congressman Gore, a sturdy moral liberal, had gotten involved with policy making for recombinant DNA when he entered the House, in 1977. He held that the corruption of fraud raised serious questions about the ability of scientists to deal reliably with the "ethical judgments" that now confronted biological science "in great magnitude"—by which he meant genetic engineering, including the "spectre of cloning." At the 1981 hearings, Congressman Gore emphasized the importance of maintaining the American people's trust in science, especially given the billions of dollars they were providing it. Gore said he suspected that one reason for the persistence of scientific misconduct was "the apparent reluctance of people high in the science field to take these matters very seriously." The principal scientific witnesses were not reassuring on the point. They were Philip Handler, the head of the National Academy of Sciences, and Donald Fredrickson, the head of NIH. Handler acknowledged that the scientific community, both at large and in its local institutions, had "never adopted standardized procedures of any kind to deal with these isolated events [of misconduct]. We have no courts, no sets of courts, no understandings among ourselves as to how any one such incident shall be treated." Both Handler and Fredrickson implied that such courts or understandings were unnecessary and might even be dangerous. They insisted that fraud in science was rare and that false claims were exposed by the scrutiny that scientists gave each other's work. Fredrickson contended that the perpetration of fraud shook scientists "to our very core": when fraud did occur, the penalties were harsh, the equivalent of "excommunication" for the sinner.

The biomedical community's post-1970s supersensitivity to government controls was evident in the testimony. Fredrickson called it "frightening" that the larger, lay culture might intrude "roughly" upon scientific affairs while "failing to understand the requirements of the scientific method or the fact that its own correctives are in place." Although Fredrickson acknowledged that NIH had to be sensitive and responsive to changing public perceptions of science, he held that the agency "certainly cannot guarantee the behavior of scientists, or certify the quality of their work through a whole system of independent analyses or fraud squads, or even special statutes."

The Handler-Fredrickson defense prompted Congressman Robert Walker, a Republican member of the Gore subcommittee from Pennsylvania, to find "a certain amount of arrogance" in "a lot of the testimony." He doubted that a policy of "self-policing" was adequate for oversight of the rapidly burgeoning biomedical community. Alluding to Abscam, he warned: "We in politics would like to think that the people who stuck $50,000 into their pockets at some townhouse here in Washing-


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A Scientific Watergate?

Five years after disturbing questions were raised about a research paper written in part by the Nobel laureate David Baltimore, the celebrated case is finally moving toward a verdict. Federal investigators have concluded, in a draft report, that the paper contained fraudulent data and did not accurately reflect the laboratory experiments on which it was supposedly based. Worse yet, data subsequently published by the Baltimore group to amend and justify its original paper were almost certainly fabricated.

The verdict may well destroy the career of the scientist accused of the misrepresentations and

hands. A graduate student independently became suspicious. But neither got satisfaction when they tried to get corrective action from academic and scientific leaders.

Had the case not been dragged into public view by a fraud-hunting gadfly at the National Institutes of Health, Walter Stewart, and a Congressional committee headed by Representative John Dingell, the truth might never have emerged.

The initial investigations of Dr. O'Toole's complaints smacked of an old-boy network drawing up the wagons to protect scientific reputations. Investi-


Rep. John Dingell of Detroit, whose House committee claimed jurisdiction over NIH, used his Subcommittee on Oversight and Investigation to pursue the Imanishi-Kari case.


Margot O'Toole and Walter Stewart (middle) and Ned Feder, the two NIH staff scientists who brought O'Toole's complaint to Dingell's attention, testify at the Dingell Subcomittee Hearing on Fraud in NIH Grant Programs.


US finds fraud in research at MIT

Report also assails Nobel laureate

By Peter G. Gosselin
GLOBE STAFF

WASHINGTON – Capping one of the most bitter controversies in modern science, investigators for the National Institutes of Health have concluded that a former MIT immunologist fabricated crucial data in a 1986 scientific paper that she co-

ton are an aberration in our profession, too. It doesn't mean . . . that we should not be conscious of the need to clean up problems of that kind. . . ." Walker predicted that if the press continued to report these aberrations and nothing was done, the "credibility [of science] will decline pretty quickly and the public will think of everybody in science as they think of everybody in politics—that is, as somehow a little crooked."

In the course of revising the health services act in 1985, Congress required institutions expecting to receive grants on behalf of their faculty to establish administrative processes for dealing with reports of fraud in biomedical research sponsored by the Public Health Service, the parent agency of NIH. The PHS promulgated the necessary specific regulations in June 1986, but in the meantime, American universities had been dilatory in establishing reliable local procedures. By the time John Dingell began to take an interest in the matter, in 1988, seven years after the Gore hearings, NIH itself had gotten around to assigning about 1.5 staff people to oversee the matter in all its grantee institutions.

By the late 1980s John Dingell was a hero to many Americans, especially those who opposed the decade's careering and corruption. To be sure, Dingell, whose district is in the area of greater Detroit, fought hard to protect the auto industry from foreign competition and to thwart the imposition of stricter emissions and safety controls on American car manufacturers. Nevertheless, Dingell is an unashamed liberal, particularly on economic issues; in 1989 he tallied a 75 percent rating from Americans for Democratic Action. During the 1980s, by dint of hard work, high intelligence, and political flint, he built the Energy and Commerce Committee, which he chaired, into one of the most powerful committees in the House, the gateway to some 40 percent of the bills that went through the chamber. It claimed "jurisdiction," it was said, "over everything that moves, burns, or is sold," including securities markets, energy, railroads, telecommunications, defense contractors, consumer protection—and the NIH.

Dingell, who is the son of a New Deal Democratic congressman, is shrewd and knowledgeable in the ways of Capitol Hill, and during the 1980s he used his committee chairmanship to counter some of the chief injuries that careerism and greed in and out of government were doing to the public interest. He aggressively exploited the chairmanship of his committee's Subcommittee on Oversight and Investigation to raise questions about former Reagan aide Michael Deaver's influence peddling; to skewer EPA administrator Anne Burford for selling environmental policy to the highest bidder; to expose the Pentagon for apparent extravagances like the $640 toilet seat; and to reveal that General Dynamics deemed a dog's kennel fees a defense contracting expense worthy of federal reimbursement. Civil libertarians, especially those of a conservative bent, deplored Dingell's methods, including trial by press leak, intimidation of witnesses, and the pit-bull tactics of some of his huge staff. But many people tended to overlook the prosecutorial and persecutorial means he used, partly because he was so powerful but also, I think, because in the circles of those out of sorts with the political culture of the 1980s, he pursued the right enemies.

But then the Dingell subcommittee took on scientific fraud. Whatever NIH and its grantee universities might have done since the Gore hearings to establish reasonable procedures for dealing with fraud and misconduct, Dingell and his staff believed, not without reason, that it was flabby and inadequate. More cases of fraud had surfaced in the press, along with accompanying evidence of dilatory institutional responses. Two of Dingell's key staff members—Peter Stockton and Bruce Chafin—tell of people coming to them with stories about scientific corruption going unpunished and research institutions covering up to protect themselves. Chafin holds that the system failed to deter wrongdoers or to take whistle-blowers seriously. In 1988, Dingell declared that he was "shocked to find out that the National Institutes of Health relies completely upon the universities to investigate themselves. Apparently here we have the possibility of the fox actively investigating the chicken coop."

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Congressman Dennis Eckart, of Ohio, another member of Dingell's subcommittee, explicitly identified the seeming trends in science with the '80s culture of corruption, noting that defense contractors tell us they have systems to catch fraud, but the rest of us know those systems don't work. "What is at issue here, much in the same way [as] within the defense industry, over at NASA, over at the accounting profession, over at savings and loans, are the adequacy of safeguards which will give you and me and the public confidence that waste, fraud, abuse, or misconduct do not occur with taxpayers' dollars." Dingell and his subcommittee colleagues said they initiated the hearings on fraud in NIH grant programs so as to expose the ongoing flaws in the system and get the academic community to heal itself.

Dingell had a special way of doing such public business, however. He was not known as a legislative initiator, and he did not hold hearings mainly to gather information for the purpose of drawing up bills. It is a longstanding tradition in Congress that committees use the instrument of hearings to get the attention of the executive branch and to pressure it to change policy without legislation. Dingell was a man of that tradition. He used the hearing room to spotlight an issue by probing into someone, or some case, or some practice exemplifying the matter. When he and his staff began gearing up to take on the issue of scientific misconduct, they followed their normal operating procedure, which was to seek out an ongoing high-profile case that would show the system still in need of repair. They found it in the challenge that Margot O'Toole had raised against MIT, Tufts, Thereza Imanishi-Kari, and David Baltimore.

Dingell's subcommittee pursued the matter relentlessly—by subpoena, by leak, and by bullying. "We do not wear lace on our drawers as we conduct our investigations," Dingell told a reporter. "I'm not paid to be a nice guy. I'm paid to look after the public interest. Our purpose is simply to compel universities and scientists to clean up their act and to see to it that public money is properly spent." Ostensibly to that end, the Dingell subcommittee pursued the Imanishi-Kari case implacably.

The congressional criticism that began in April 1988 had, in the meantime, prompted NIH to initiate reforms of the way it handled allegations of scientific misconduct. In the fall of 1988, the agency announced that it was contemplating the creation of an office of scientific integrity and invited comment on the scope and definition of scientific misbehavior. Contemplation turned into action in the face of moves on Capitol Hill that winter, including a draft bill from John Dingell's subcommittee, to legislate the creation of such an office with powers that would include random audits of the notebooks of NIH grantees. James Wyngaarden, then head of NIH, worried that

O'Toole said several times that she deserved no special credit for her courageous whistle-blowing, that she did only what an honest scientist should do. But at other times she engaged in a kind of self-fashioning that resonated with the sort of heroes that many people hungered for in the 1980s.

congressional action would give control of misconduct cases to an inspector general, a lawyer who knew nothing about science. "We needed a preemptive strike," he said later. On March 8, 1989, NIH created an Office of Scientific Integrity on its own. OSI would monitor inquiries at its grantee institutions, conduct its own investigations when necessary, and be run by scientists.

Wyngaarden picked Brian Kimes to head the office temporarily, until a regular director could be found. Kimes is a biochemist by training who loves science and the NIH, where he had been a research administrator in the National Cancer Institute for almost 15 years. He took the job of setting up OSI reluctantly, telling Wyngaarden that he would stay only until November 1, and that "it was not my ambition to send scientists up the river." What *could* send scientists up the river was spelled out in the definition of scientific misconduct that the Public Health Service issued in midsummer. It included "fabrication, falsification, plagiarism." It also included "other practices that seriously deviate from those that are commonly accepted within the scientific community"—a feature that a number of scientists had objected to, no doubt fearing that it raised "serious risks of undue pressure for scientific conformity," as an official in the Office of Management and Budget had put it when the proposition first came up. Many scientists were likely relieved, however, by the Public Health Service's stipulation that misconduct "does not include honest error or honest differences in interpretations or judgments of data."

The small OSI staff was burdened with a backlog of 80 to 100 cases. "We were over our heads . . . ," Kimes says. "We had to figure out where the political issues were and where the scientific issues were." But they knew that one case dominated all the rest. Congressman Dingell had told Wyngaarden that he regarded the matter of Imanishi-Kari as a "crucial test" of the ability of NIH "to deal with cases of questioned science." NIH officials were concerned that the agency not appear to be remiss. "We were taking a lot of hits from Dingell on this with the public," Kimes notes. "Wyngaarden was extremely worried about the politics of it because those are things that could impact all of NIH. It was a very uncomfortable situation."

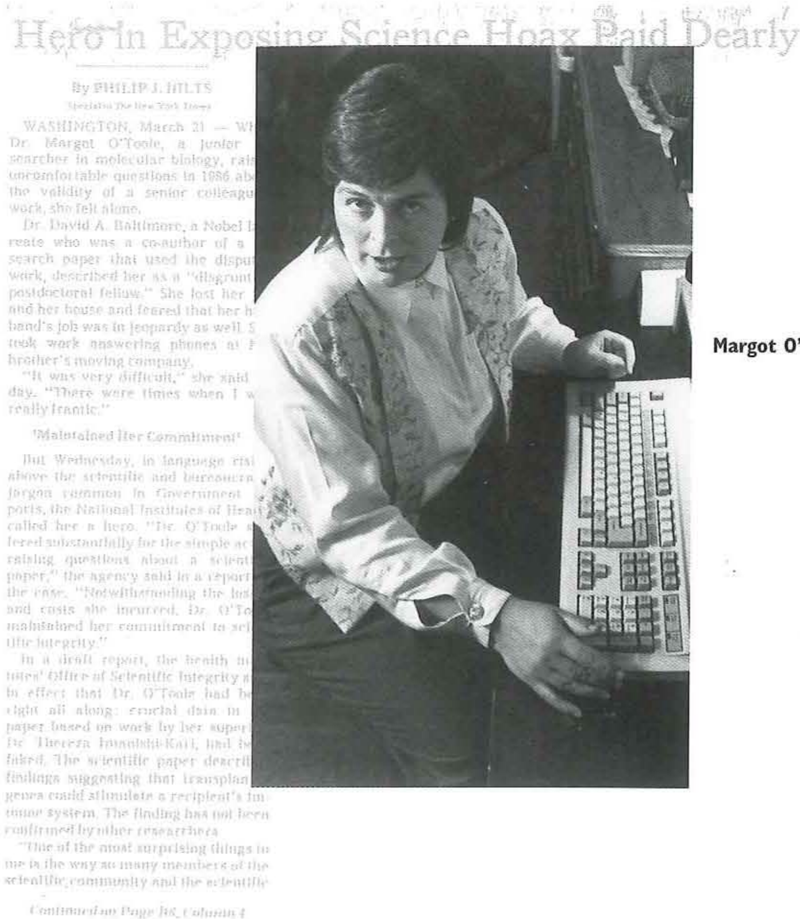
OSI had not issued a set of rules and procedures. Kimes says that the staff was so busy that they had to make them up as they went along. Kimes himself wanted OSI investigations to be open, with everyone having access to all the data and testimony. In August, he assured Baltimore and Imanishi-Kari that once the allegations were completely formulated, they would be made available to "all subjects of the investigation," together with all related evidence. He told Imanishi Kari's lawyer, Bruce Singal, that Imanishi-Kari would have "every opportunity to see and comment" on all the relevant information and that she could be confident that OSI's inquiry would be "conducted independently" of the subcommittee's. Dingell, however, was reportedly very upset by the scenario. To Kimes, it was evident that Congressman Dingell "did not want the process to be open; he wanted us to investigate."

Toward the end of October, OSI revised its plans for handling the allegations against Imanishi-Kari. They would be presented to OSI and its scientific panel, not to the coauthors. Both would evaluate the evidence she provided and then conduct an investigation, talking with the other principals in the dispute. The new dispensation meant that Imanishi-Kari would be given only indirect access to the allegations and no access at all to the material evidence or testimony against her.

Imanishi-Kari was, to all intents and purposes, prevented from mounting a genuine defense. The OSI combined the duties of investigator, prosecutor, judge, and jury and pursued them in the manner of the Star Chamber. During the investigation, it did not provide the accused a list of specific charges. The charges "are revealed to you as time goes on," a lawyer familiar with the agency's ways remarked. "It is as if there is an indictment you can't see." Both during and after the investigation, Imanishi-Kari was denied the right to see the evidence, the right to learn what witnesses said, and the right to cross-examine them. The burden of proof was on the accused rather than on the accuser. The NIH's Office of Scientific Integrity was as Orwellian in procedure as it was in name.

In early 1991, OSI put its tentative conclusion that Imanishi-Kari was guilty of fraud into a draft report. The report, though strictly confidential, was leaked to many newspapers, provoking a flood of media response. Analysis of it, along with the pre-leak representation and commentary on the case, reveals just how integral belief in scientific fraud and misconduct had become to the post-Watergate political culture of the 1980s. The trope of Watergate itself ran through what was said by influential representatives of the national press, such as *The New York Times*, which savaged Baltimore for "stonewalling" and, likening the long affair to a huge cover-up, declared that "the Baltimore case started with apparent fraud by a single scientist and soon led to a widespread denial of wrongdoing by almost everyone in a position to right the wrong." The report also happened to be leaked at the same time that the university overhead scandals were breaking, particularly the alleged ripping off of the government by Stanford University. A number of observers melded the Baltimore case together with misuse of public funds. Like a reporter for *Chemical and Engineering News*, they held that "a major problem is that universities today are not only knowledge centers but also financial conglomerates," with all the incentives to corner-cutting behavior that mark such enterprises.

But no single person did more to tie the case to the features of post-Watergate political culture than Margot O'Toole—not by design but simply by refracting it through the language and suspicions of the culture of Watergate, which came naturally to her, and by having been portrayed as a victim of powerful scientific and institutional interests by Congressman Dingell, his staff, and the press. "Here was someone chewed up by the system," Bruce Chafin says. "Here was a perfect object lesson." O'Toole herself indicted Tufts, MIT, and the *Cell* paper's coauthors for responding to her complaints with "the knee-jerk reaction of cover-up" and with displaying "contempt for the labor of people trying to repeat the work" of the experiment. In an article in the *Chronicle of Higher Education*, she claimed that the Tufts and MIT investigators "told me the corrections I proposed [to the paper] were 'out of the question' because they could adversely affect the authors' careers and financial support."


Hero in Exposing Science Hoax Paid Dearly

By PHILIP J. HILTS

Margot O'Toole

O'Toole said several times that she deserved no special credit for her courageous whistle-blowing, that she did only what an honest scientist should do. But at other times she engaged in a kind of self-fashioning that resonated with the sort of heroes that many people hungered for in the 1980s. In an interview with a sympathetic reporter for *Mirabella*, a prominent women's magazine of fashion and chic, she contrasted herself to David Weaver, who was another of the coauthors on the *Cell* paper when he was a postdoc with Baltimore: "We both could have made the choice to keep quiet for the sake of our own careers. He did and I didn't. . . . The science was more important to me than the career and . . . the career was more important to him than the science."

Parts of the media, including some with enormous influence in scientific affairs, were willing and enthusiastic collaborators in the representation of the case as exemplary of a scientific Watergate. Some could almost be termed collaborators with Congressman Dingell. Dingell's subcommittee shrewdly leaked documents, many of them confidential, to favored reporters, who published the committee's version of events, and published them uncritically. Donald Kennedy, the former president of Stanford who was uncritically brutalized by the press during the overhead controversies at his university, recently observed, "Press accounts frequently refer to unnamed subcommittee members and quote from documents obtained before they were made public. When such material comes regularly from one side of a controversy, it amounts to news management—and no responsible reporter should be captured in that way."

The capture is partly explained by the overwhelming enthusiasm of many journalists since Watergate for investigative reporting. Since the 1960s, that trend has come to mark some science reporting, and it has created a genre of science reporting that displays the strengths and weaknesses, including the often unfairly injurious weaknesses, that are characteristic of investigative reporting in general. I don't mean to disparage investigative reporting. The public interest has been advanced by it. But it would seem that investigative reporting in science, like investigative reporting in general, demands getting the facts right. Equally important in this special genre, it demands getting the science right, too.

"When such material comes regularly from one side of a controversy, it amounts to news management—and no responsible reporter should be captured in that way."

Even though the leaked draft report was just that—a draft—Baltimore and Imanishi-Kari were tried and convicted in the press. In this affair—as likely in other high-profile cases of scientific misconduct—influential reporters often got both the nonscientific and the scientific facts wrong. I will cite just one example, Philip Hilts of *The New York Times*, but it is a salient one, because the *Times* is arguably the most influential paper in the country, and its science reporting is excellent on the whole. Donald Kennedy has indicted Hilts for bias in the Baltimore case, pointing to an attack article that Hilts published in *The New Republic* in 1992 and alluding to his important coverage of the case in the newspaper. Hilts has responded that no one has pointed to any specific bias in his coverage of the case. I don't know anything about Philip Hilts's motives, but I do know that his article in *The New Republic* was riddled with errors about how the case was investigated at MIT, all of them mistakes that reinforced one of the main points of his piece, which was that the investigation was designed to save the reputation of David Baltimore at the expense of Margot O'Toole.

Baltimore could take care of himself. Imanishi-Kari was far less able to defend herself against a fundamental point that Hilts reported about the *Cell* paper in a profile of her in the *Times* on June 4, 1991. To quote from his article: "The central claim of the paper depends on how many mice showed the unexpected antibody properties. But the statement in the paper that said this work was done, she has admitted, was false. 'We did not do it,' she said." Hilts's story continued: "But in explanation she said a similar characterization was done on other mouse samples."

The fact of the matter is that an enormous amount of work was done by Imanishi-Kari that demonstrated that the mice had abnormal antibody properties. What was *not* done was an additional test—the isotyping of the antibodies generated by one set of mouse cells. That data would have added weight to the paper's central claim, but it was not decisive for it, a crucial point of the science that Hilts missed entirely. He also did not report that the statement about the isotyping had gotten into the paper inadvertently—as the result of a miscommunication between Baltimore and Imanishi-Kari in the drafting of it to the effect that the test had been done on that set of cells when, in fact, it had been done, but on another set. The bottom line is that, by not paying attention to the science, Hilts's story misrepresented Imanishi-Kari as having declared that the test was crucial to the experiment's central claim, which she had not and which it was not. His story also gave the impression that in the published paper she had asserted knowingly and deliberately that she had performed the test. Imanishi-Kari protested Hilts's misrepresentation in a letter to the science editor of the *Times*, but she got neither an apology nor a correction.

* * *

Recall that it was the legacy of the war over recombinant DNA that helped prompt the emergence of fraud as an issue in American political culture. Before that, people had tended to think that science was perhaps the least corruptible institution in American life, certainly less corruptible than certain branches of the evangelical churches. One of the things that prompted Al Gore to call his hearings in 1981 was the evidence, mounting as he saw it, that science, in fact, might be corruptible, and that the potential for fraud raised serious questions about the ability of scientists to deal reliably with the fraught ethical questions that the advance of molecular biology was raising. Philip Handler claimed that there was "absolutely no relationship" between fraud, even as a minor problem, and what Gore called "the other questions involving ethical judgments which now

Scientific fraud is a kind of late-20th-century morals charge, in a branch of morality that large parts of the public perceive as central to human health and human fate.

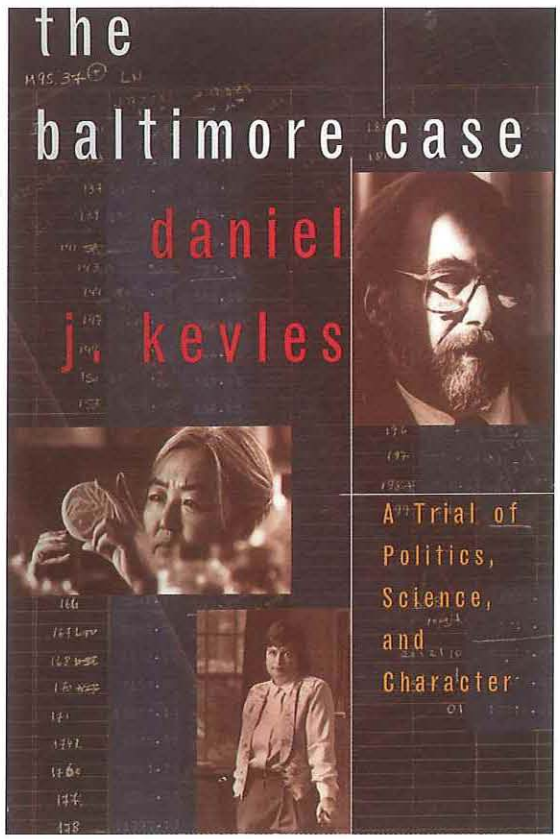
confront science in great magnitude." But Gore asked: "If the scientists who have been found in this recently reported outbreak of seemingly unconnected events to be making these kinds of judgments with respect to arguably small matters, shouldn't we be concerned about the decisions they are making elsewhere?" Handler said, no we should not, whereupon Gore retorted, "Well, I disagree strongly."

My guess is that, at least tacitly, many people continue to disagree strongly. Scientists have long resembled a secular priesthood in American culture—originally as mediators between man and God's universe, but now as explorers, interpreters, and commanders of nature's powers. It should not be surprising that many people display high trust and confidence in science, which they do. But it should not be surprising either that many develop comparably high suspicion of it if evidence—or a claim of evidence—emerges that its celebrated concern for truth is violated, particularly among biomedical scientists.

To be sure, much of the concern with scientific fraud stems from the fact that biomedical science is lavishly supported with public money. Nevertheless, the exposure of fraud in the biomedical sciences is tantamount to revelations of pederasty among priests perhaps more than of embezzling among bankers. Scientific fraud is a kind of late-20th-century morals charge, in a branch of morality that large parts of the public perceive as central to human health and human fate. The fact that it's freighted with all that such charges connote—violation of a moral code and exploitation of innocents—helps explain why scientific fraud and misconduct has become a powerful issue in the United States, a country that more than any other expects its public shamans to behave consistently with their declared moral commitments. The public perception of both the behavior and powers of biomedical scientists may be exaggerated, but it is a fact of life for the fortunes of science in the American political culture of the late 20th century. As such, it is something that the scientific community cannot afford to ignore, no matter how rarely fraud may occur. □

Dan Kevles first wrote about this case for The New Yorker *in May 1996, arguing that Thereza Imanishi-Kari was not guilty and that David Baltimore had been right to defend her. The following month she was exonerated on all counts. He then expanded that article into a book,* The Baltimore Case: A Trial of Politics, Science, and Character, *which was published by W. W. Norton early this fall. The book made the bestseller list of the* Los Angeles Times, *which, in a review, praised the book as a "brilliant, unsparing and meticulously researched account of a controversy that helped reshape how scientific misconduct is handled in the United States."* The New York Times *called it "a splendid study of a major contemporary scientific scandal."*

Kevles, the J. O. and Juliette Koepfli Professor of the Humanities, is head of Caltech's program in Science, Ethics, and Public Policy. He has been a member of the Caltech faculty since 1964, after receiving his AB and PhD degrees from Princeton, and is the author of several books and numerous articles and reviews.



The book can be ordered from the Caltech Bookstore for $29.95 plus $5.00 for shipping and handling. Send check or credit card number to Caltech Bookstore, Mail Code 1-51, Pasadena, CA 91125. Or order the book by phone at 1-800-514-2665, or by e-mail at citbook@caltech.edu.

"Have Method, Will Travel"

by Douglas L. Smith

Chevron's refinery in Pascagoula, Mississippi. The United States consumed some 123 billion gallons of gasoline in 1997, according to the American Petroleum Institute—at 20 miles per gallon, enough to drive the family minivan to Neptune and back 439 times. Photo courtesy of Chevron Corporation.

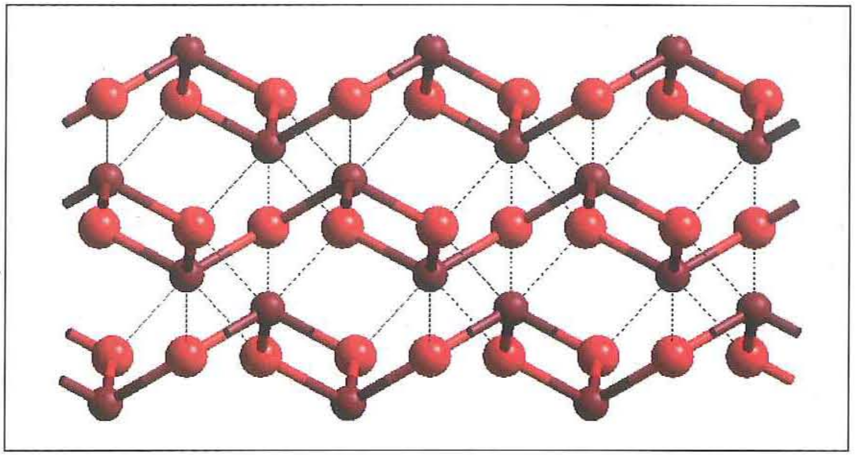
If it weren't for the oil in your engine, it would seize up in just a few miles of freeway driving. Trust me—I know this for a fact. But if it weren't for a dash of zinc dithiophosphate in that oil, the engine would grind its camshaft and valve train down to nubbins within a few thousand miles. This additive has been standard equipment in all high-quality motor oils since the late '40s, says William A. Goddard III (PhD '64), the Ferkel Professor of Chemistry and Applied Physics, but nobody knew why it prevented wear. "People weren't that interested in why, because it always worked. So why waste your money figuring out how? Problem solved." The problem is rapidly coming unsolved, however, because federal law requires that by the year 2000, catalytic converters will have to last 200,000 miles. They don't last that long now, because the phosphorus in the additive slowly poisons the catalyst. Furthermore, the additive slowly gets burned along with the oil, and the oxidized zinc becomes part of the particulate ash that goes out of the tailpipe and into the smog. So the oil industry is scrambling to invent a replacement—a phosphorus- and zinc-free ashless inhibitor. Now, replacing something when you don't know how it works is a pretty good trick, so in 1995, the folks at Chevron Research and Technology Company in Richmond, California called on Goddard, the director of the Materials and Process Simulation Center (MSC) at Caltech's Beckman Institute, to help them out.

As the name implies, the center does simulations of materials, chemistry, and biology, making predictions before the experiment is actually done. It's the only chemistry lab at Caltech where the video tubes outnumber the test tubes. The center runs reactions in supercomputers, while collaborating experimentalists and engineers then perform the physical experiments and check the results. Now, you can't throw a brick in a chemistry department without hitting a theorist, and there are a goodish number of people doing computational chemistry these days. (In fact, this year's Nobel Prize in chemistry went to Walter Kohn and John Pople for developing the mathematical and programming techniques that make computational chemistry possible.) What sets the Goddard group apart is that it applies chemical theory to real, industrial problems—real enough that industry underwrites half of Goddard's research.

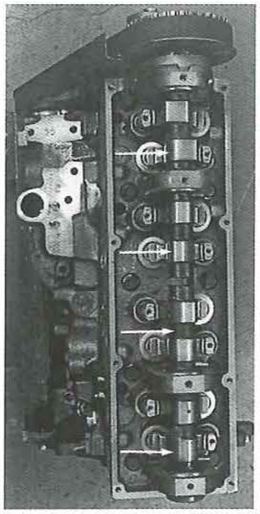
Most university chemists prefer well-defined problems with sparse data (it's easier to get your own data published that way), whereas industrial chemists are often handed ill-defined problems with lots of data—sometimes several decades' worth. In the case of the chewed-up camshafts, Chevron's files bulged with some 50 years of engine-wear experiments. People would take an engine apart, measure all the clearances with a micrometer, put everything back together again, top off the oil, and run it on a test stand for 60 days. Then they'd tear the engine apart again, compare the clearances to the previous measurements, change the oil, and do it all over again. This isn't a very fast method, and it's not cheap, either—a complete set of tests on one inhibitor costs $150,000. The relative wear-resistance of various additives had been ranked this way, providing performance trends among similar molecules.

But now Chevron needed to know if some unknown, radically different molecule might be better. In the search for a fast, cheap predictive method, Goddard recalls, "They tried pouring oil over an iron ball and rubbing it. They tried spectroscopy; they tried lots of different things, but nothing correlated with the engine experiments. So they turned to us, and for less per year than the cost of one engine experiment, we came up with a model they could use."

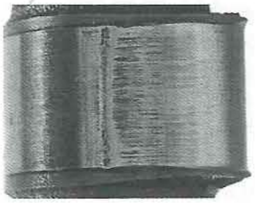
The first thing the Goddard group did was step back and take a fresh look at all the data, and try to work out what might be going on "from the



Above: The crystal structure of hematite predicted by the MSC's model. Iron atoms are rust-colored; oxygen atoms are red. Crystallographic data had shown that each iron atom is bound to six adjacent oxygen atoms, and that the bonds came in two lengths. It had been assumed that the bonds were all of roughly equal strength, but the model showed that the longer bonds (dashed lines) were fundamentally different in character, and significantly weaker, than the shorter bonds. This is why hematite flakes—the weak bonds between the layers break more easily than the strong bonds within a layer.



Above: A top view of an engine on a test stand. The arrows point to the camshaft.
Below: A single cam, close up. The parallel scratches on what should be a nice, shiny, smooth surface are the wear marks.

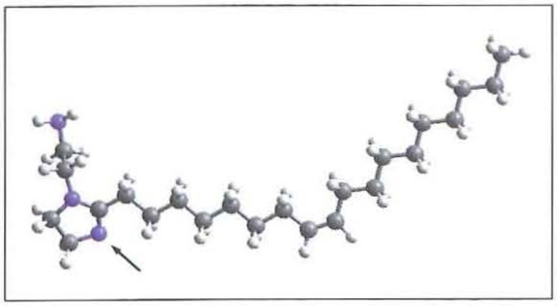


viewpoint of what's plausible to us as chemists." This step back before plunging in is vital, because what the industrial collaborator thinks is the problem may not really be the problem. The theorists already had an inkling of the real problem on this one, having just finished designing some improved corrosion inhibitors for Chevron's Petroleum Technology Center at La Habra, just 30 miles from Caltech. Crude oil contains stuff that tends to adhere to and react with the inside surface of a pipe, rusting it away until it eventually begins to leak, causing costly oil-well shutdowns. And it turns out that keeping stuff from sticking to a surface has a lot more in common with keeping a surface from wearing away than you might think.

In the corrosion case, the Chevron chemists had assumed that the dissolved ions in the oil were the instigators, and tried to trap or somehow disable them. Nobody paid much attention to the properties of the pipe itself, and when they did look at it, says MSC project manager Mario Blanco, "People concentrated on modeling pure steel surfaces. We conjectured, and later found to be correct, that hematite was the mechanistically relevant surface." Hematite is one of iron oxide's several guises, and a thin skin of it forms naturally on the pipe's interior—and on the interior surfaces of an internal combustion engine—as soon as there's a trace of moisture. In other words, unless you're working in the vacuum of outer space, the hematite layer will form even as the pipeline (or engine) is being put together.

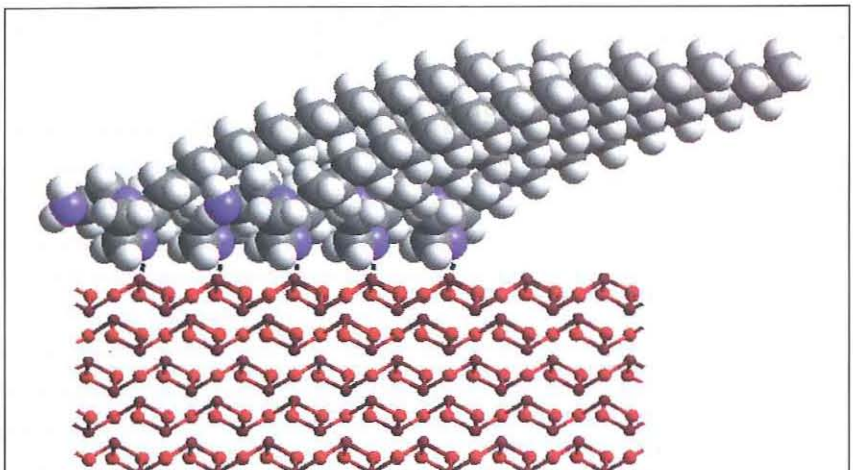
So postdoc Sunder Ramachandran, Bao-Liang Tsai (PhD '97), and Blanco developed a quantum-mechanical model of hematite from first principles, which, as faithful readers of *E&S* will know, means the dreaded Schrödinger equation, which provides a complete mathematical description of every particle in any atom. Undergraduates have been solving the Schrödinger equation for the one-proton, one-electron hydrogen atom since the 1920's, but as you add more particles to the system the number of terms in the calculation quickly spirals out of control. Recalls Goddard, "When I started in this business some 30 years ago, three atoms was difficult. We've made a lot of progress since then. Now it's hard to do more than about 50 atoms or so." Fortunately, hematite has a simple, repeating crystalline structure, so the investigators were able to model a unit cell, as the basic repeating structure is called, with a few dozen iron and oxygen atoms. The model hematite formed two-dimensional layers, explaining the flaky nature of the real crystal, and the crystallographic coordinates of the atoms in the model matched those derived from the real thing by X-ray diffraction studies—two reassuring reality checks. Once quantum mechanics had nailed down all the atoms' exact positions, the trio of scientists, aided by Member of the Beckman Institute Siddarth Dasgupta, derived a mathematical representation of a force field that numerically described every dimple and dome in the iron-oxide surface, and predicted the force with which that

The best inhibitors snapped into place like Lego blocks, paving the surface one molecule deep—forming a self-assembled monolayer, in the parlance of the trade.



Above: The best corrosion-inhibiting molecules look like tadpoles wearing party hats, with round heads and long, floppy tails. Carbon atoms are shown in gray, hydrogen atoms in white, and nitrogen atoms in blue. The nitrogen atom (arrowed) in the tadpole's chin is the part that actually sticks to the hematite surface.

Below: Atoms don't really have solid surfaces, but if you pretend that they do, it's easier to see how they pack. As the tadpoles line up with the "grain" of the surface, their tails overlap like shingles. The dashes are the nitrogen-iron bonds.

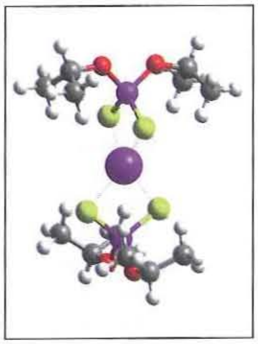


surface would attract or repel any other atom anywhere in space. Such a force-field model, which is much simpler computationally than the original quantum-mechanical model, can be scaled up to perhaps a million atoms more than enough for this project.

This million-atom level—called the nanoscale, because a cluster of a million atoms is about 50 nanometers in size—is where all the action is today, according to Goddard. "Integrated-circuit components are starting to get down to the nanometer scale, so the applied physicists and electrical engineers are approaching it from above. And chemists are starting to manipulate structures that assemble themselves into objects in that size range, so chemists and materials scientists are approaching it from below. And molecular biologists—a rhinovirus, the common cold virus, has half a million atoms in its outer coat. We've done simulations of that. So it's really the frontier, and the computational techniques and modeling methods that apply are not very well understood. Below us is quantum mechanics, and above us are finite-element analysis and other standard engineering methods. So it's open territory for theorists."

With the force-field model of the hematite surface up and running, the next step was to pour water molecules and a candidate corrosion inhibitor on it and see what would happen. The best inhibitors snapped into place like Lego blocks, paving the surface one molecule deep—forming a self-assembled monolayer, in the parlance of the trade. The molecules resembled tadpoles, having round heads and floppy, oily tails 12 to 20 carbon atoms long. Each tadpole would plant itself face-first onto an iron atom, shoving aside the water molecules already nuzzling there. And as rank upon rank of tadpoles lined up with the "grain" of the surface, their tails overlapped like shingles and created a waterproof roof that kept the corrosive ions at bay. "The self-assembled mono-

Zinc dithiophosphate is more avian than amphibian—the dithiophosphate portion looks like an eagle in flight, with the zinc atom clutched between its talons.

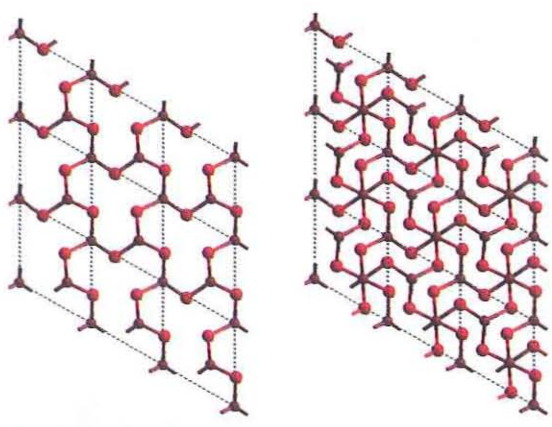


Zinc dithiophosphate looks like an eagle in flight, with the zinc atom (blue) clutched between its talons. Atoms of sulfur are shown in yellow; phosphorus is purple. Actually, because a zinc atom has four binding sites, there are always two eagles on opposite sides of the zinc, sort of like a face card in a poker deck. If you tore the card almost in half and twisted it 90 degrees, that is—the eagles are flying in perpendicular directions.

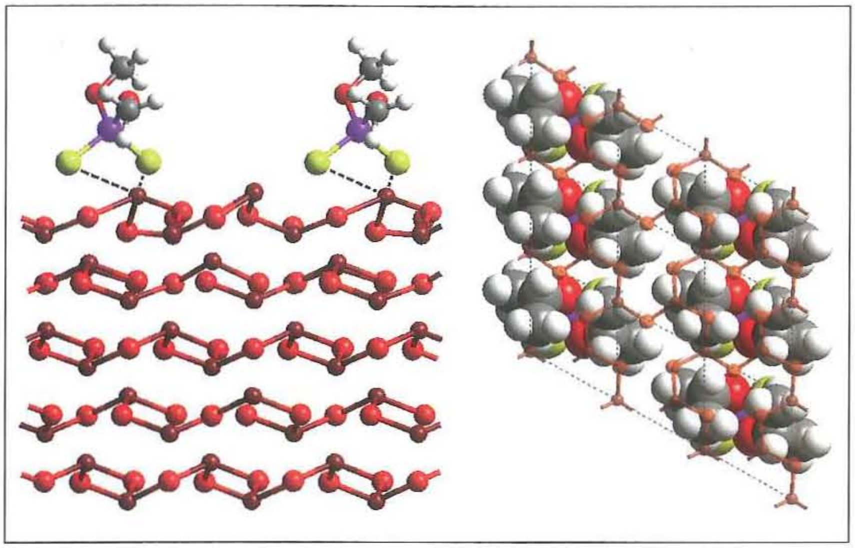
layers form an exquisite, geometrically regular pattern," says Blanco. "Molecules with the wrong shape don't fit the underlying structure and are not inhibitors at all."

Could the same mechanism be involved in wear inhibitors? The two types of molecules are vastly different. Zinc dithiophosphate is more avian than amphibian—the dithiophosphate portion looks like an eagle in flight, with the zinc atom clutched between its talons. The wings are stubby, branched three-carbon hydrocarbon units called isopropyls. So postdoc Shaoyi Jiang released a flock of dithiophosphate eagles into the hematite model, and confirmed what had only been suspected—that once the swooping eagle struck, it let go of the zinc atom and sank its talons into an exposed iron atom instead. Says Goddard, "We calculated the monolayer's cohesive energy, and found that it correlated inversely with the cam wear." In other words, the eagle that gripped the tightest protected the best. But Jiang discovered that unlike the tadpoles' overlapping tails, the eagles' wings lay flat across the surface, wingtip touching wingtip. So he tried different wings on the same body, and behold! the isopropyl wings fit best. Smaller ones didn't cover the surface completely, exposing some iron atoms to wear. And larger hydrocarbons got in each other's way, like fledglings getting too big for the nest. And just as overgrown fledglings tend to fall out, so did these dithiophosphates have a lower cohesive energy. "So we did that the first year," Goddard says. "And Chevron was very pleased, because it was the first time that they had anything that actually correlated with the engine-wear experiments."

In the contract's second year, Chevron suggested 13 new families of potential wear inhibitors, and asked the Goddard group to predict how these untried additives would work. (The MSC works in three-year contracts, cancelable at the end of each year if the client doesn't feel sufficient progress has been made—to date, not one of



These graceful trefoils, like a window in a Gothic cathedral, appear when the hematite model is seen from above. In the left view, only the very top layer—the surface atoms to which corrosive molecules (or corrosion inhibitors) can bind—is shown. The dashed lines mark the "unit cells," or repeating units, of the crystal structure. Each successive layer is offset by half a unit cell, so when a second layer is added (right), the trefoils turn to arabesques and the cathedral becomes a mosque. A third layer (not shown) converts the arabesques to hexagons.



How the isopropyl eagles stick to the hematite. In the figure at left, the bonds between the sulfur talons and the iron atoms are shown as dashed lines. Note how the top two layers of the hematite surface are actually distorted by the presence of the inhibitor molecule. The figure at right shows how the isopropyl wings cover the surface and shield the iron atoms from harm.

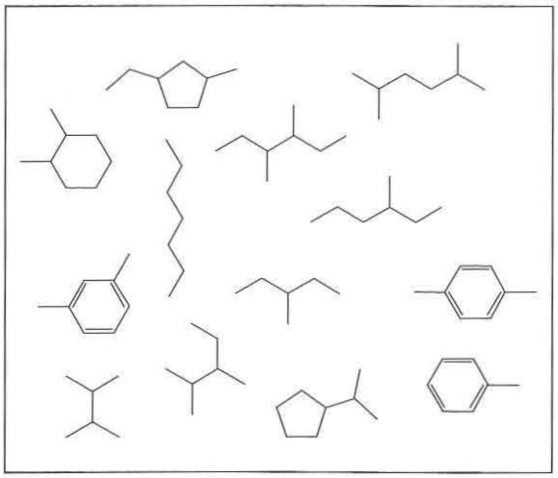
two dozen or so contracts has ever been canceled.) Jiang ran all 13 families through the model, and one family emerged as the leading contender. Instead of zinc and phosphorus, these birds were built around an environmentally friendly carbon-nitrogen body. However, a little more testing revealed that the isopropyl wings weren't going to fly any longer. Because the new body contained more atoms, it sat up higher on the hematite, so longer, floppier chains of six or seven carbon atoms were needed to drape down and completely cover the surface.

Jiang rated the 13 body types in his second end-of-the-year presentation to the Chevron folks, and explained how the wings altered the performance. After the talk, he and Goddard learned that Chevron had gone ahead and done some experiments already, based on preliminary results Jiang had given them earlier. The best-performing body in these experiments proved to be the one that the model had predicted, and the wings behaved in real life the same way that they had in the model. "The boss of the whole operation was a couple of feet off the ground," Goddard recalls. "He took a risk to fund us, and we came back with a model that actually made useful predictions. The Chevron group included several very good organic chemists, but they hadn't been thinking about wear inhibitors as chemists because they had no model for what properties of the molecule were important. So they'd try things similar to what they had already studied, instead of reasoning, 'Well, on this surface, this molecule is likely to do this, and it's likely to fit in this way.' So they asked us to put together a graphic interface that would let them look at our results on their own computers, see how the molecules fit, and start thinking about them as chemists." Blanco and Sarah Sanders (BS '98), working as a Summer Undergraduate Research Fellow (SURF), obliged, making the model much easier to use in the process.

Unfortunately, many molecules that work well in the model may be too expensive to be practical, so now, in the project's final year, the theorists are collaborating with synthetic chemists at Chevron to try to pick compromise molecules. "We'll show them a molecule that we think will have really good properties," says Blanco. "And they'll say, 'No, we can't make that. But we can make this, which is kind of close—do you think it will work?'" In the meantime, postdoc Yanhua Zhou and Tahir Çagin, the MSC's director of simulation technology, are adding more detail to the model. Says Goddard, "We're applying pressure and looking at the dynamics of shear as one hematite surface moves past another, just as in a real camshaft. We are learning how shear resistance works. This is the first time that such dynamical studies have ever been done, thanks to some computational breakthroughs that Tahir has made."

The key to the group's creativity, says Blanco, "is the presence of other researchers doing unrelated work. Self-assembled monolayers—thioalkanes on gold—were a curiosity back when we started looking at the corrosion problem, but Jim Gerdy (PhD '96) was doing some work on them. A hallway meeting combined my knowledge of how surfactants work and Jim's ideas on monolayers in a way that applied to these projects. To someone on the outside, things would appear a lot messier (and to some extent they still are), but we could focus on the essential features of these compounds and learn how to improve on them. We call this process 'finessing the problem.'" To that end, the group is home to about 20 grad students and as many postdocs—roughly equal numbers of physicists, chemists, and materials scientists, with a sprinkling of applied physicists, biologists, and biochemists thrown in for spice.

And if ever a project called for finesse, it was another assignment from Chevron that the group took on at about the same time: helping to wring the most gasoline from a barrel of crude oil. Whether you're filling up your Ferrari or topping off your Toyota, you expect what's going into your tank to be pretty consistent. So does your engine, which is designed to burn gasoline with a specific octane rating. But no two samples of crude oil are completely alike. Even crude from a single well changes as the well gets pumped down, says Anil Patel, lead planning engineer at Chevron Research and Technology Company—the dregs are always thicker, as anyone who has ever drunk homemade chocolate milk through a straw knows. To try to limit the variability, most refineries were originally designed specifically for the crude from a given region, or even a particular oil field. But in today's global economy, the crude can come



The naphtha fraction of gasoline is a wild assortment of hydrocarbons containing between five and eight carbon atoms per molecule, some of which are shown at left. In these diagrams, each line segment represents a carbon-carbon bond, with a carbon atom and a full complement of hydrogen atoms sitting at each vertex and endpoint.

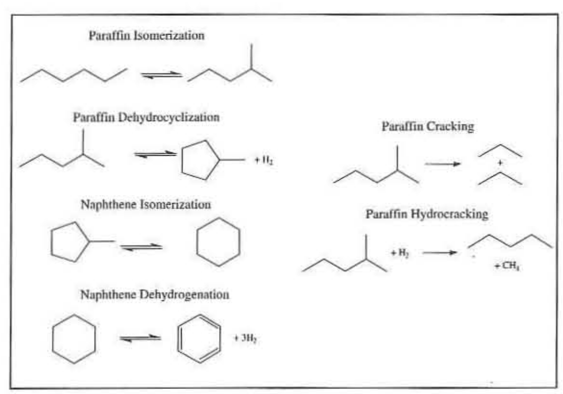
from anywhere. So refineries are always resetting their process controls to maximize the amount of consistent product that can be made from this inconstant raw material. Chevron wanted a model that would use an analysis of the feedstock to predict how the controls should be set, which is not as easy as it sounds. To see why, we need to take a quick look at how gasoline is made.

Crude oil is a mishmash of molecules containing up to 60-something carbons, so the refinery distills the crude into fractions containing successively larger molecules with successively higher boiling points. The so-called "naphtha" fraction, with five to eight carbons per molecule, becomes a major component of gasoline. Actually, gasoline includes hydrocarbons containing up to 12 carbon atoms, because the distillation process is not 100 percent efficient and a few heavier molecules sneak in. In fact, because of the voracious demand, a lot of the even heavier stuff eventually becomes gasoline, too, through a process called "cracking," which breaks big molecules down into smaller ones. More on that later.

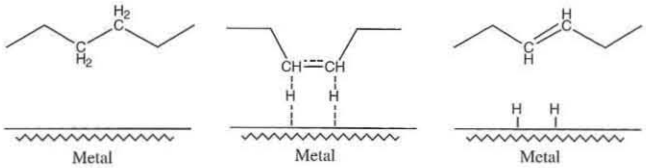
The naphtha fraction includes 265 distinct species of hydrocarbons. There are linear molecules, branched molecules, and even circular molecules. Some of these are desirable; some aren't. Highly branched molecules burn smoothly—they have a high octane rating—while linear ones make your engine knock. Molecules with double bonds have higher octane ratings than the equivalent molecules with no double bonds. And the so-called "aromatic" molecules—benzene, toluene, and the xylenes—have the highest octane ratings of all. Naphtha might have an octane rating of, say, 65, but the unleaded regular that comes out of the pump is 87 octane. And, in fact, says Patel, "We want an octane rating of 95 to 100, because some other components in gasoline tend to be very low octane. The naphtha is processed further to bring the overall octane rating up when we blend the various streams to make gasoline." And the higher the naphtha's octane rating, the more of the low-octane stuff you can blend with it, and the more gasoline you get.

The naphtha goes to the reformer, which is not a school for wayward youths but a reactor that heats the naphtha till it vaporizes. The reformer then blows the vapor through a catalyst that rearranges low-octane molecules into high-octane ones. While in the catalyst, those 265 species participate in half a dozen different families of competing reactions. Not all of the outcomes are good—a reaction that improves one molecule's octane rating may lessen another's.

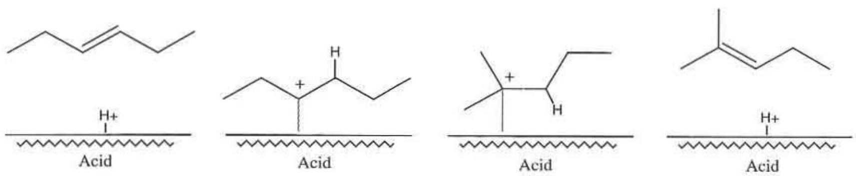
Each species undergoes each reaction at a different rate, so the operator adjusts the reformer's settings to maximize the good reactions and minimize the bad ones, based on a quick-and-dirty analysis of that batch of naphtha. Until recently, the lab gave the operator four numbers: the percentage of paraffins (linear and branched molecules with no double bonds), olefins (the same molecules, but with double bonds), naphthenes (circular molecules built around a five- or six-membered ring of carbon atoms), and aromatics; plus a boiling-point curve and a specific-gravity measurement that together provided a rough idea of the size distribution of the molecules. The operator then set the reactor's temperature, hydrogen pressure, and feed rate based on gut instinct and the accumulated wisdom of the plant, often enshrined in hand-drawn graphs taped up in the control-room window. These performance curves were worked out through trial and error, says Patel. "It was strictly an empirical model, with no chemistry behind it. If the new feed was radically different, they'd do a pilot-plant run on it first. But if it was just a little different, say maybe two percent more paraffins than the last batch, they'd say, 'Hey, I can handle this,' and just go ahead and



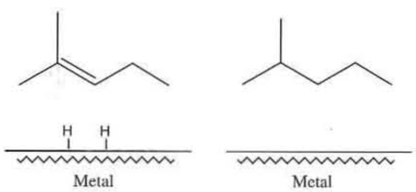
The reaction families of catalytic reforming. Reactions shown as double arrows can go either way, while single-arrowed reactions are irreversible. In this case, the series of four reactions at left lead to benzene, which is desirable, but the two reactions at right led to smaller hydrocarbons with fewer branches, which is not so desirable.



This sample paraffin isomerization reaction shows how the reforming process works. The catalyst actually uses two different components (the zigzag surface), mixed together in a heterogeneous mass. In the first step (above), a rhenium/platinum component strips a pair of hydrogen atoms off of a paraffin, converting it into an olefin, which then takes wing again.



Next, the olefin slams into the hydrogen-ion-studded surface of a second, "acid" component. The olefin's double bond picks up a proton, or hydrogen ion, converting the hydrogen into a neutral atom and leaving the now-ionized olefin stuck to the catalyst by what used to be the other end of the double bond. The ion flops around like a break dancer as other parts of the molecule try to fill the ionic hole. Eventually, a new double bond establishes itself and the rearranged olefin departs.



And finally, the newly branched olefin can have another run-in with the metallic component, emerging as a paraffin once again but with a higher octane rating.

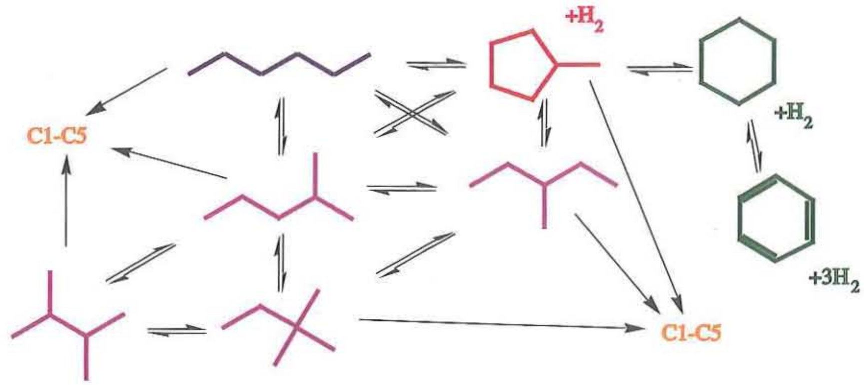
try it."

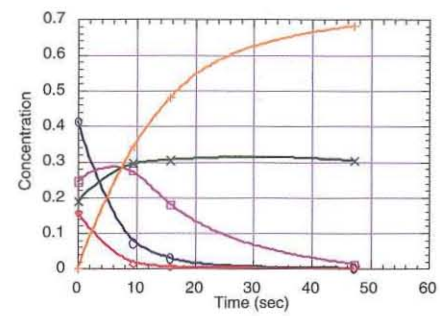
But today's instrumental methods can give you tons of data instantly—for example, that this morning's naphtha has 6.3 percent unbranched paraffins with five carbon atoms, 4.7 percent single-branched olefins with 12 carbons, 3.2 percent benzene, and so on. (The breakdown isn't so detailed above 12 carbons, but that's another story.) There aren't enough windows in the control room to post 265 graphs, and even if you had an infinite sheet of glass, there's precious little data at that level of detail to plot. Pilot-plant studies are expensive and time-consuming, so gathering process-control data hasn't kept pace with analytical advancements. Chevron estimated that it would cost several million dollars to do all the experiments needed to find just 20 different rate constants over the three reactor parameters, says Goddard, "so they decided, for a small fraction of that cost, to see if we could predict these things from theory. And I told them there's about a 50-50 chance that we could do it."

The 265 species mentioned above don't begin to reflect the full complexity of the problem. The catalyst rearranges a molecule by converting it to an ion, which you can think of as having a hole where something ought to be. Other parts of the molecule slide into the hole to try to fill it, but this just moves the hole around. Eventually, the ion spits out a hydrogen ion, becoming a stable molecule with a double bond and detaching itself from the catalyst. The original ionized site can be anywhere along the carbon backbone, so the number of different ions increases with the length of the backbone. How the molecule morphs depends on where the hole is, adding another layer of calculations. If you have up to eight carbon atoms in your feedstock, you have 540 different hydrocarbon species—including the intermediate ions and the byproducts with fewer than five carbon atoms—that you have to keep track of in your calculations. (Even though the naphtha fraction starts at five carbons, you can't neglect the smaller molecules—some of the reaction paths cause the parent molecule to break off a carbon atom. If an eight-carbon molecule becomes a seven-carbon molecule, that's fine, but if a five-carbon molecule loses a carbon, it becomes butane—a gas, not gasoline.) These 540 species can undergo 883 possible reactions. And the first set of products can hit the catalyst again downstream to undergo a second set of reactions, and so on.

So the first simplification was to limit the problem to molecules with six or fewer carbon atoms. This brought the number of species down to 85, and the number of possible reactions down to 105—much more manageable numbers.

Second, "We had to assume that the catalysts were perfect," says Goddard. "That they didn't get plugged up, and that they could hydrogenate and dehydrogenate, and protonate and deprotonate when they wanted to. Catalysis is our busi-





Above: The pared-down reaction network for six or less carbon atoms. Again, reactions with double arrows can proceed in either direction. The color coding matches the graph above right, which shows how the model evolves over time at a temperature of 950° F and a hydrogen pressure of 350 psig, or pounds per square inch (gauge)—in other words, pounds per square inch above normal atmospheric pressure.

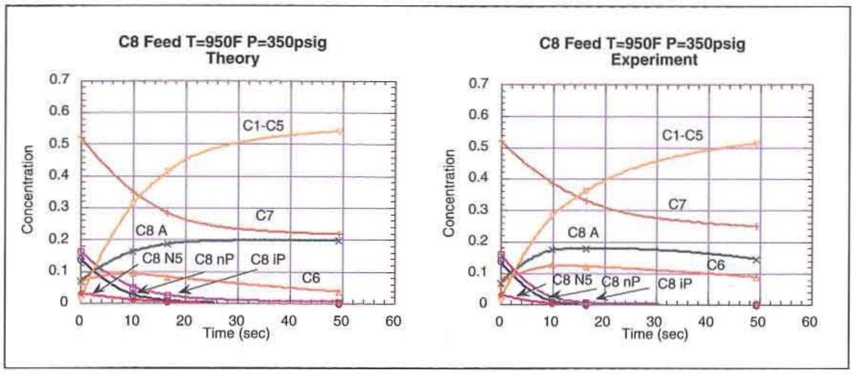
ness, and normally we would have looked in detail at what goes on on the catalytic surface, but that would not have been practical here. We could not have dealt with this unbelievably complicated set of reactions if we'd had to worry about the surface too." In the end, the catalyst was represented by seven parameters: one for each of five types of ion rearrangement—the "reaction families" mentioned earlier—that measured how much of a kick it took to get that rearrangement started, and two that reflected the catalyst's ability to ionize the hydrocarbon at two different temperatures.

Jason Perry (PhD '94) mapped the pared-down network of possible reactions and used quantum mechanics and the idealized catalyst to calculate the rate constant for each link in the network, creating a model that would predict the product distribution for any six-carbon feedstock at any combination of reactor settings. (Perry, a freelance quantum chemist—yes, there are such things!—and president of First Principles Research, was a grad student of Goddard's.) The researchers checked these predictions against real data taken at two temperatures, two pressures, and three elapsed times (the equivalent of flow rate—higher flows mean the feedstock is in contact with the catalyst for less time). Once the catalyst parameters had been adjusted to correctly predict the six-carbon products, the researchers successfully expanded the model to predict product distributions for up to eight carbon atoms.

As with the wear-inhibitor project, the researchers developed a graphic interface before giving the model to the engineers. "It's the simplest model to use they've ever had," says Perry. "Yet it gives the most detailed results. And Chevron uses lots of different catalysts, but this model could apply to all of them with the appropriate tweaking—the seven parameters all have physical meaning, so it's easy to adjust them." Patel is now using the model for process design on the pilot-plant level. "This was a real success," says Goddard. "We said we'd need three years, and it took two." "It would be cool to push the model further," says Perry. "But we've now moved on to modeling the cracking process, which is where the real action is, in collaboration with Michael Shippey [PhD '78], a senior research chemist at Chevron. Instead of doing a few hundred species going up to eight carbon atoms, we're modeling the reactions of millions of species going all the way up to 60 carbon atoms. The accounting gets a little tricky, but the principles are the same."

These projects are typical of how the group works. When an industrial partner signs on, Goddard hires a postdoc to work on the project full-time, and assigns a senior staff scientist at the MSC to direct the effort. The Caltech people and the industry people meet monthly to update each other on what's going on. Information flows in both directions, and a casual comment by one person can spark a revelation elsewhere (or dredge up a forgotten tidbit of information). "But you've got to be eyeball to eyeball," says Goddard. "If you don't have this sort of direct, continuous interaction, you don't get the right information." And sometimes the only way to get that information is to talk around the problem in a way that e-mails and phone calls just don't do. Furthermore, it's always the same industry people at each meeting—an important point for project continuity and efficient transfer of knowledge; a collaboration is only as good as the institutional memory of the collaborators.

Some face-to-face interactions go much farther than monthly meetings. The MSC issues a standing invitation to its industrial partners to come to Caltech and work in its labs for a while. Yongchun Tang, a senior research chemist at Chevron's La Habra facility and leader of their molecular modeling group, spent several months at the MSC back around the turn of the decade, when the collaboration was first getting off the ground. "We've been so successful in our model-



The model's predictions for an eight-carbon-atom feedstock matched experimental reality pretty well, tracking the rise and fall in concentration of the various hydrocarbon families. The abbreviations are as follows: C*x* is everything with *x* carbon atoms, A is aromatics, nP is unbranched paraffins, iP is one-branched paraffins, and N5 is five-carbon rings.

ing efforts because our scientists have worked at the MSC," Tang says. "It's a critical link. Being in the MSC allowed me to see how its methods could be applied to other problems we are working on, and then to bring the relevant people in. We are way ahead of the other oil companies as a result." (The projects mentioned in this article are just a sampling of the ones Chevron and the MSC have collaborated on over the years.)

Goddard's original notion was to have his theorists talking to the theorists in industry. But there aren't that many out there any more—changes in management strategies have caused most of the companies that maintained showcase research facilities as corporate crown jewels back in the '60s and '70s to abandon or severely curtail them. Like the Cold War–driven space race, they appear to have been a prestige item whose time has passed. It's become much better for the bottom line to farm your research out. "So what we do now is interact with engineers, who are interested in solutions."

Goddard is a theorist, but he's also a pragmatist. He uses these corporate contracts—which now account for about 50 percent of his budget—as a vehicle to advance his theoretical work on computational methods and verify the results. Says Goddard, "We continue to push the frontiers of the methods, but by and large the methods themselves aren't being funded. That's just part of our overhead. If you say in a grant proposal that your aim is to develop a new method, it's very easy for the reviewers to poke holes in you. Someone will say, 'Oh, the assumptions are bad,' or, 'It's not going to be practical,' or, 'You won't get the answers well enough...'" Adds Blanco, "The trouble is, when you propose method development alone, there are so many paths you can take. But our work is all based on using that method to solve a real-life problem. Then the critical issues come out naturally as you work on the problem, and we focus on solving those issues." And if those issues call for a new method, they assign a postdoc to develop it.

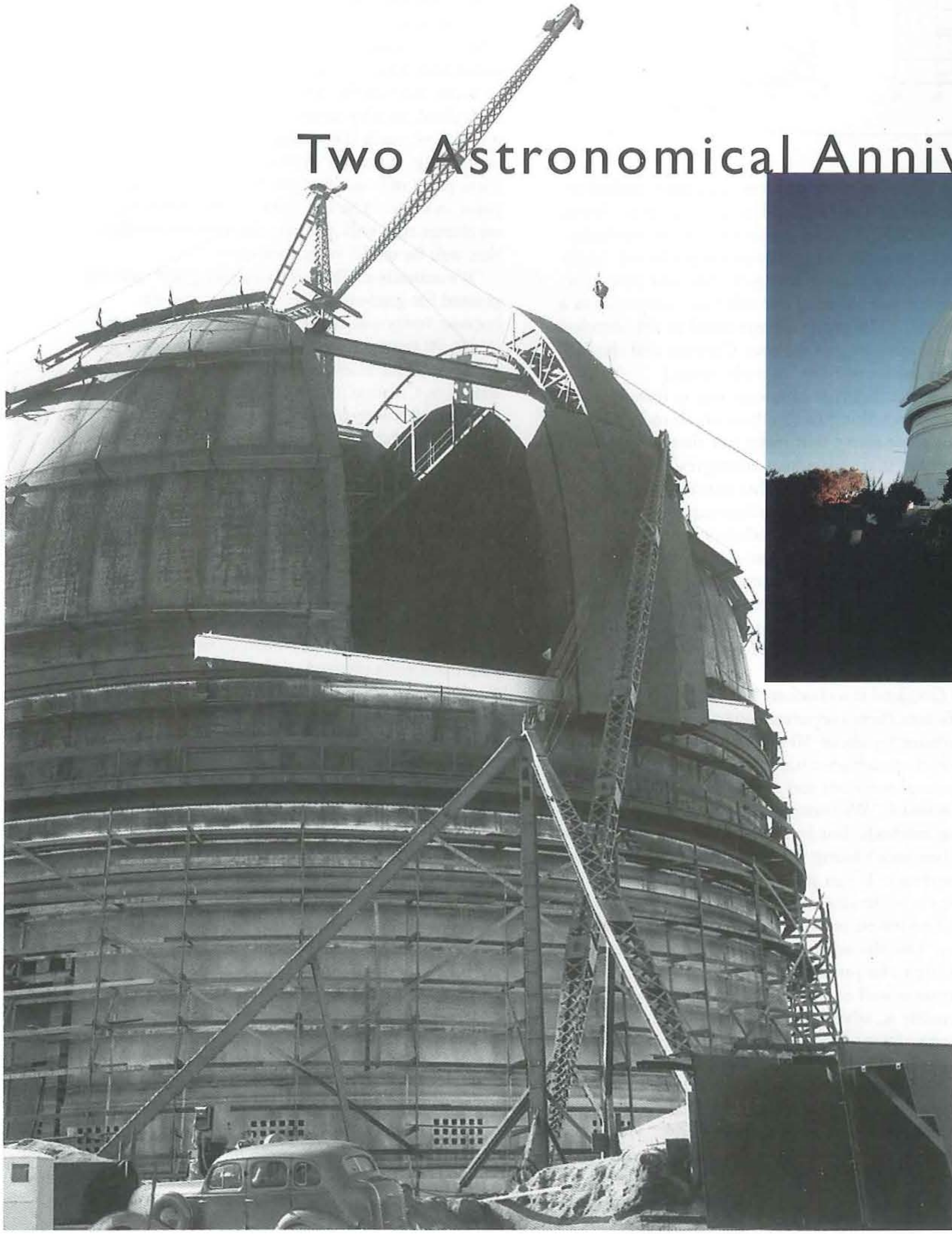
"I think it's fair to say that 20 years ago, you could have characterized what we did as 'have gun, will travel,'" Goddard resumes. "'Have method, will simulate.' We looked for whatever problems our method would be useful for. These days, it's 'what's the problem? We'll solve it.'

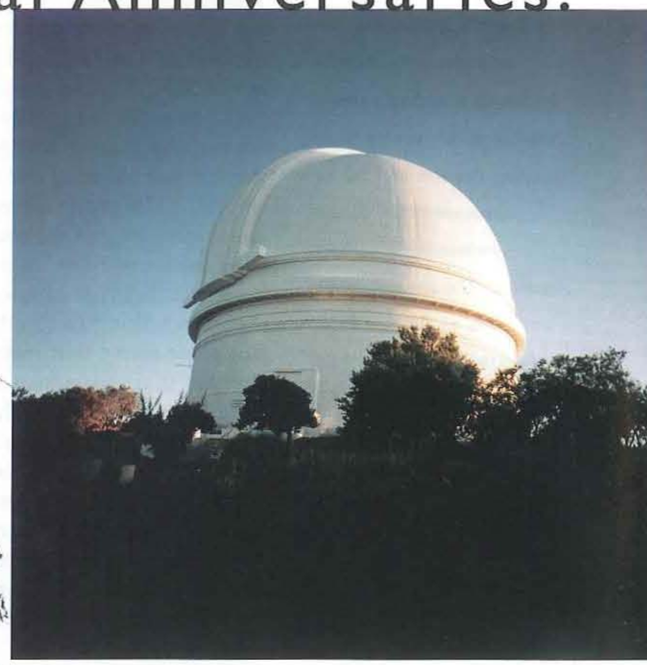
"I could spend hours just talking about applications, even though that's only about 20 to 30 percent of what we do, because that's the part that most non-theorists are going to see as interesting and important. And perhaps 25 to 30 percent of our theory work I wouldn't even tell to my closest [chemist] friends, because they wouldn't understand why we're doing it. They'd say, 'It's naive to think you can do that problem,' or, 'It's already been done, so why would you want to do it again?' or, 'You've made the wrong assumptions,' or something. Like any kind of research enterprise, some parts of it underwrite the rest of it at any point in time. You just have to keep working on things that will generate the new knowledge that will be useful years from now.

"It's actually evolved into a really good training ground for graduate students and postdocs, because today's world is very different from what it was 20 years ago. Typically then, a person got a PhD in basic science, and joined a company like Exxon or Chevron, and gradually learned the company's technology, gradually learned what was interesting to the company, and eventually got into a position to contribute. These days, if you're not useful on a project from Day One, they're not going to hire you. So our grad students and postdocs have to understand what the technological issues are in order to know how to use their knowledge of basic science. They have to know how to ask the right questions. There's no prescription; you have to learn how to think about problems. And you only learn to think about them by being exposed to them. It's good for them to see how we struggle with defining the problem. Mostly, in science, the important advances are in figuring out what the questions are. And the graduate students get the pleasure of seeing how interested somebody other than their advisor is in their research. Because the advisor is always interested. But to have other people who *really* think it's neat stuff, and to have students see how it's directly related to some important technology, that's good for them to see. So we think it's developed into a good model for education in addition to one for doing research."

Besides the lab's corporate clients, says Siddarth Dasgupta, "We're really a resource for the whole Caltech community. We do a lot of custom software development, and people in a lot of different fields are finding us useful. For example, if some geophysicists want to find out what happens to some kind of rock under tremendous pressure, but they don't have the software to simulate it, they can come here and work with us. They just have to give us a half-page summary of what they want to do, and we give them the resources and training to do it." □

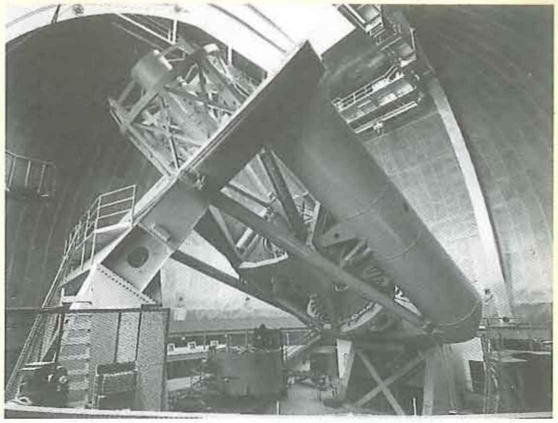
Two Astronomical Anniversaries:





Left: Progress continues on the giant dome and its shutter in December 1937. Above: The Hale Telescope dome today.

Palomar at 50



Right: **Among the dignitaries who spoke at the dedication of the Hale Telescope were President Lee DuBridge (foreground, with Mrs. Hale), and representatives of the Rockefeller Foundation, the Carnegie Institution of Washington, Caltech's Board of Trustees, and the Observatory Council.**

Left: Palomar's current director, Wallace Sargent, the Ira Bowen Professor of Astronomy (far left), talks to journalists touring the 200-inch telescope in conjunction with the 50th anniversary celebration.

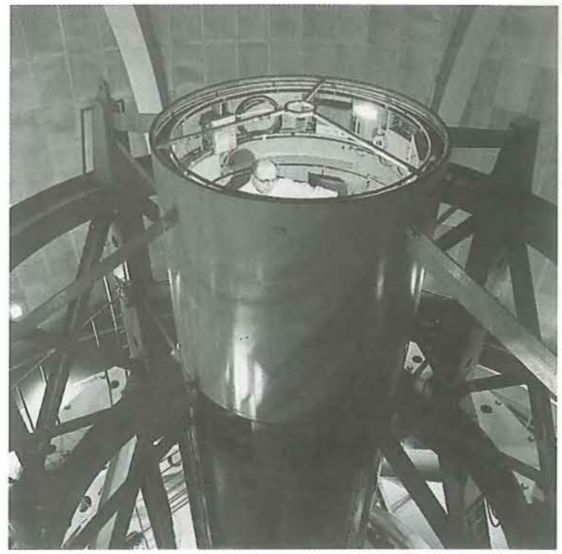
On June 3, 1948, about a thousand invited guests (and reporters) witnessed the dedication of the world's largest telescope—the 200-inch, newly christened Hale Telescope on Palomar Mountain.

On June 3, 1998, a smaller group of about 200 gathered for a dinner beneath the telescope's giant horseshoe mount to celebrate the birthday of the magnificent instrument, still healthy and working hard at 50.

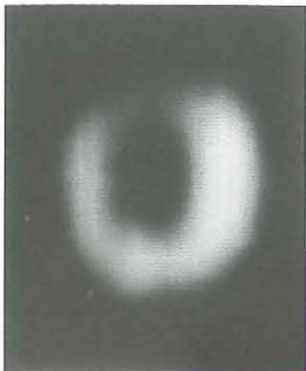
If its lifetime were to be measured from conception, however, it would be 70. It was in June 1928 that George Ellery Hale received assurance of funding from the Rockefeller Foundation's International Education Board to allow Caltech to start building the telescope. No one then dreamed that it would take 20 years (with a war intervening) to solve the engineering problems of pouring, transporting, polishing, and supporting so large a piece of glass. The mirror's progress and the telescope's construction captured the imagination of the nation and the world. Even its housing, in a dome that rivaled Rome's Pantheon in size, inspired awe. *The New York Times*, in commemorating the 50th anniversary, called it a "cathedral of science," a phrase quoted by Caltech President David Baltimore in his opening remarks at the recent dinner.

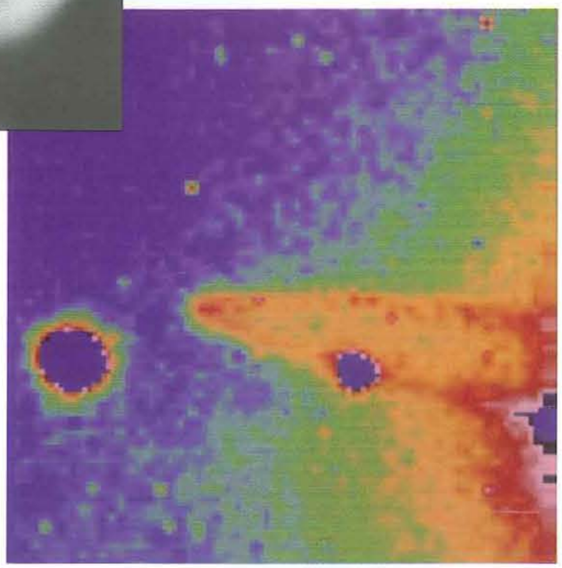
Probably the only person who attended both celebrations was Jesse Greenstein, now the DuBridge Professor of Astrophysics, Emeritus. In his talk to the 1998 audience, he noted that he had arrived at Caltech just a few weeks before the dedication of the 200-inch to take the position of "organizer" of astronomy. His only professional colleague was Fritz Zwicky, "a man of great originality," and the astronomy office in Robinson was filled with World War II debris. Within a few years of his arrival, however, Greenstein would be able to add a professorship per year for a dozen years, and Caltech's stature in astronomy grew to fit its telescope.

Greenstein began observing with the 200-inch



Jesse Greenstein at the prime focus of the Hale Telescope, his home for 30 nights a year over 40 years.





Technology marches on. The top picture dates from 1978, and is the first ever taken of the rings around Uranus. (The rings had been discovered in March 1977, when Uranus occulted a star named SAO 158687.) The planet was shot at two infrared wavelengths—one at which the planet was relatively bright, and one at which it was darker. Subtracting the two left just the rings. But the process wasn't nearly that straightforward. There were no two-dimensional CCD arrays in those days, so the Hale Telescope was repeatedly scanned across the planet and the light directed onto a pair of single-element detectors, generating two channels of analog intensity data that were recorded on magnetic tape. The tape was played through a machine that subtracted one channel from the other and output the difference as a strip chart. The strip chart was converted to digital format with a ruler and a pencil by Keith Matthews, member of the professional staff, and the digital data punched on cards that were fed into a computer. The computer interpolated the data, filling in the gaps between the points, and output the (digital) results onto another magnetic tape, which was fed into a Geology Department computer that had a video display—a rarity back then; most computers talked to their operators through teletype machines. A Polaroid photo was taken of the video screen, and that's what you see here. The entire process took months. By contrast, the recent infrared image of Jupiter's rings above took about 20 seconds to produce.

in 1952 and continued to use it for about 30 nights a year for the next 40 years. He also "fell in love with this 500-ton monster of steel and glass, still one of the great instruments of the world."

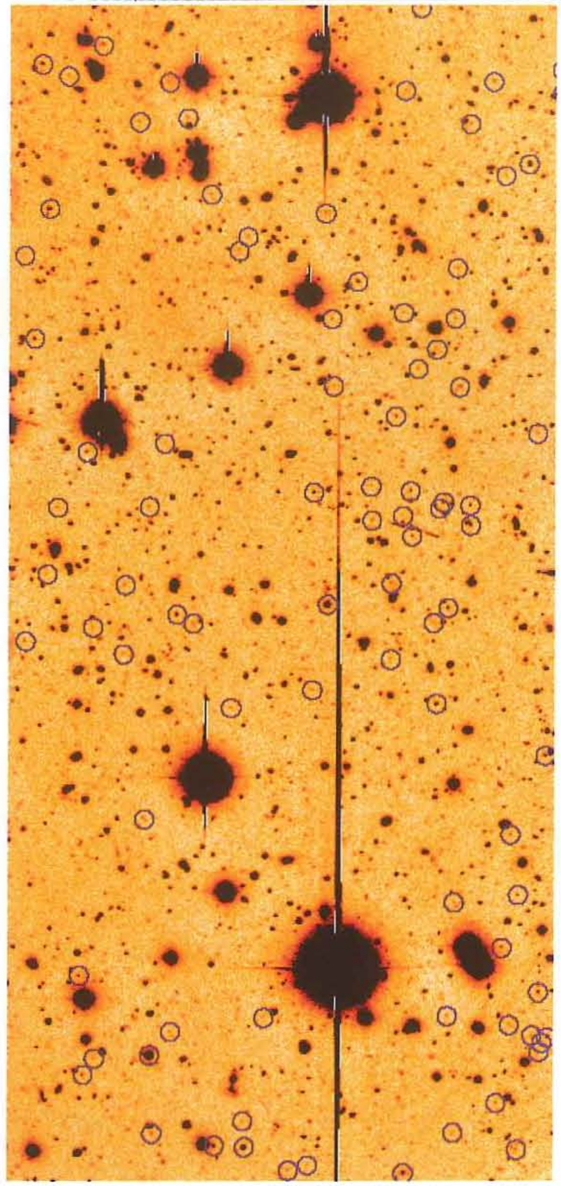
"There are hundreds of astronomers from all over the world who share my personal affection for that gray giant," Greenstein said. "It has performed miracles, observed the faintest objects possible, and seen to the edge of the expanding universe—an edge that remains ever more unreachable as larger instruments are built."

Augustus Oemler, director of the Observatories of the Carnegie Institution of Washington, outlined "50 Years of Research at Palomar" for the anniversary guests. Carnegie had been Caltech's partner in the Palomar Observatory until 1979, when Carnegie turned its attention to building newer telescopes. During those 50 years the Hale Telescope dominated astronomy. Already in 1952, the 200-inch had doubled the size of the visible universe, and Allan Sandage, PhD '53, of Carnegie continued to refine the Hubble constant and define the age and size of the universe. Sandage also observed on the telescope a new class of objects, dubbed quasi-stellar radio sources, or quasars, which Maarten Schmidt determined had huge red shifts and were the most distant and luminous objects in the universe. The 200-inch also was used to explain the evolution of stars, to discover large-scale structures in the universe, and to identify radio sources with optical counterparts.

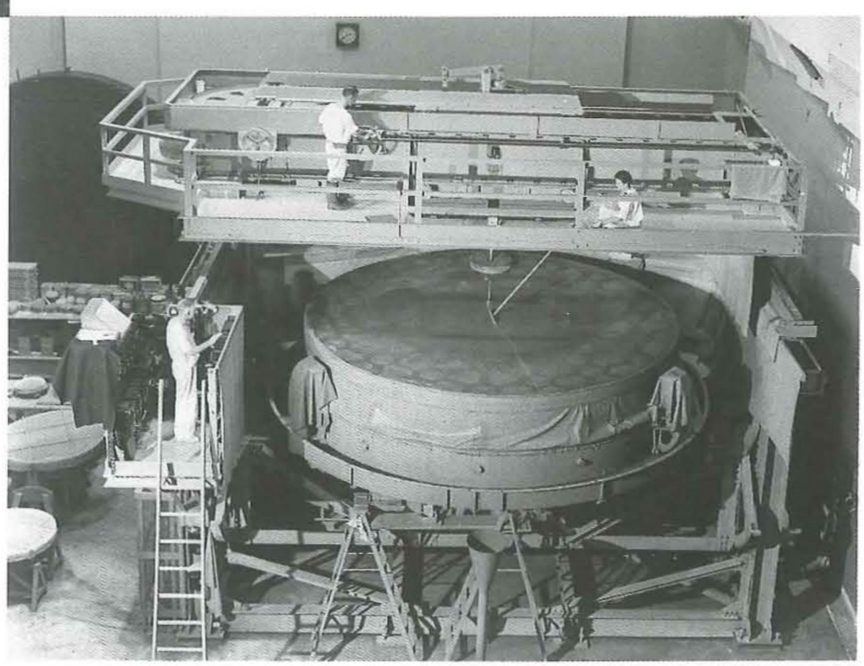
Technology has enabled the Hale Telescope to keep up with the times. In the '70s, charge-coupled devices (CCDs), which greatly improved sensitivity to light, revolutionized telescopes. The "4-shooter," a CCD camera built for the 200-inch telescope, was developed at Caltech and was one of the first adaptations of the technology to ground-based astronomy.

And the upgrading continues. "The observatory is not a museum—it is a vital facility which is

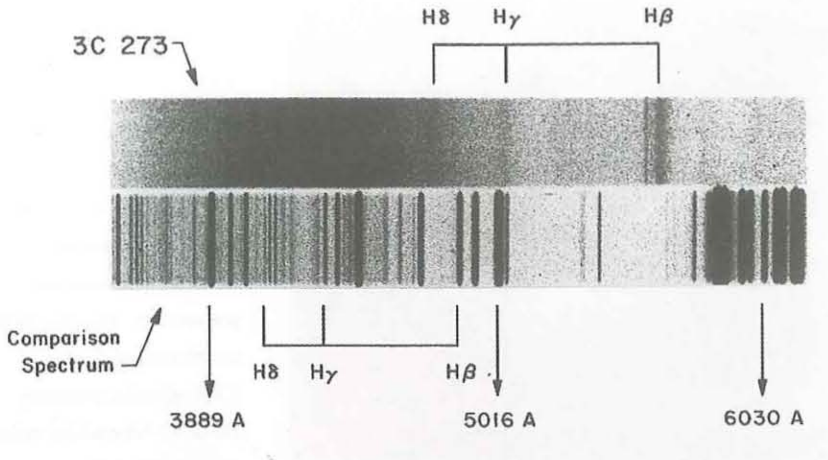
Left: The prime focus cage was so large that the Westinghouse factory door had to be enlarged and the track lowered four feet to get it out.



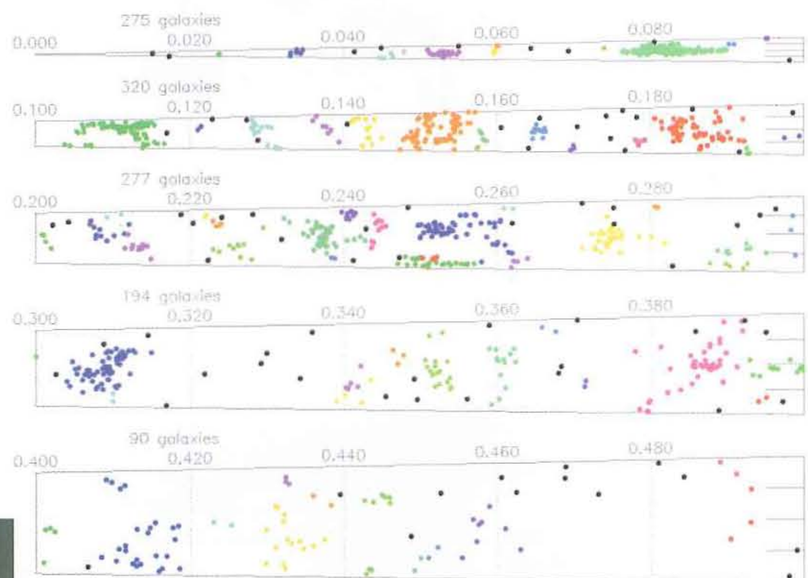
Professor of Astronomy Charles Steidel (PhD '90) is using the Hale Telescope to map the universe as it was at about one-tenth its present age. The star field at left contains some 2,000 galaxies, including about 75 "ultraviolet drop-outs" (circled) that are visible in red and green light, but not ultraviolet. Because of their age, absorption features that should lie in the far ultra-violet have been redshifted into shorter ultraviolet wavelengths that pene-trate Earth's atmosphere. Thus comparing scans of the sky through three different filters provides a quick and easy way of separating galaxies that go way back—in both senses!—from more recent ones.



Right: After it was shipped across country from Corning, New York, as crowds lined the tracks to watch, the giant mirror spent nine years (and occupied 180,000 man hours) being ground and polished in Caltech's optical shop (later reincarnated as the synchrotron building). About 30 tons of abrasives were used to grind it down from 20 tons of Pyrex to less than 15 tons.



Left: A spectrum of 3C273, the Rosetta Stone of quasars (top), and a reference spectrum (bottom). Note the relative positions of the lines labeled Hδ, Hγ, and Hβ. The key to matching objects seen through different telescopes is to have accurate location data. Early radio telescopes could only plot a source to within several arc minutes, but in 1962, the moon occulted 3C273 several times, giving its position to within an arc second. Astronomers got a second lucky break when the Hale Telescope was trained on the refined coordinates, in that the spectrum of the object they saw there was redshifted by 16 percent—unusually far for something that looked like a star (it isn't), but not so far that Maarten Schmidt (below, left) couldn't eventually identify the spectral lines.



Left: Research Fellow Don Hamilton and the Norris Spectrograph, which was built for the Hale Telescope in 1990. A robotic arm (at Hamilton's right elbow) deploys optical fibers anywhere in the instrument's field of view to carry light to a CCD detector; up to 176 spectra can be collected simultaneously, each by its own fiber.

Above: Postdoc Todd Small and Professor Wallace Sargent are using the instrument to construct detailed maps of the large-scale distribution of galaxies out to redshifts of 0.5, or about 4 billion light years. This data slice from the autumn sky starts in the upper left-hand corner, at redshift 0.0; each succeeding row picks up where the one above it left off. The colored dots are groups and clusters of galaxies, packed at least five times more densely than the field as a whole. Black dots are galaxies without nearby neighbors. The slice is about as thick as it is wide (2°), so in three dimensions it's a very tall, thin pyramid.

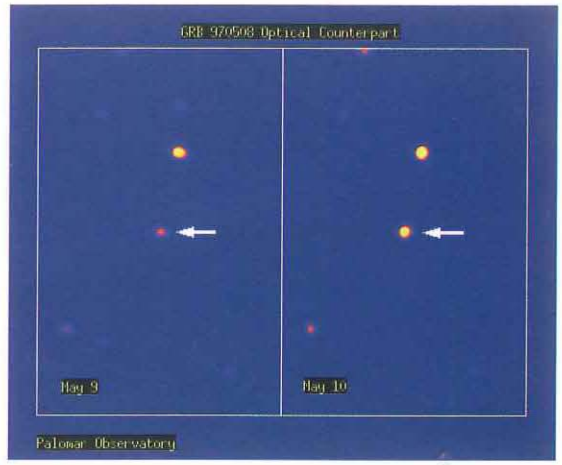
continually being upgraded and improved," said Wallace Sargent in his talk on "The Next 50 Years." Sargent is the Bowen Professor of Astronomy and current director of the Palomar Observatory. He noted the role of computers and described the adaptive optics system developed by new Palomar partners JPL and Cornell, which should provide "a dramatic improvement in image quality over small areas in the sky." Because of these efforts, "there is absolutely no doubt that the 200-inch today is a better telescope than it was 50 years ago. And how many 50-year-olds can say that?"

The Hale Telescope is no longer the biggest in the world; the two 10-meter W. M. Keck Telescopes (another Caltech undertaking) in Hawaii are. In describing some recent astronomical discoveries, Sargent emphasized the collaboration between Palomar and Keck. In the discovery of the first brown dwarf, of optical counterparts to gamma-ray bursts, and of newly forming galaxies in the very early days of the universe, Palomar first identified the objects as interesting, whereupon they were followed up and confirmed spectroscopically at the Keck Observatory.

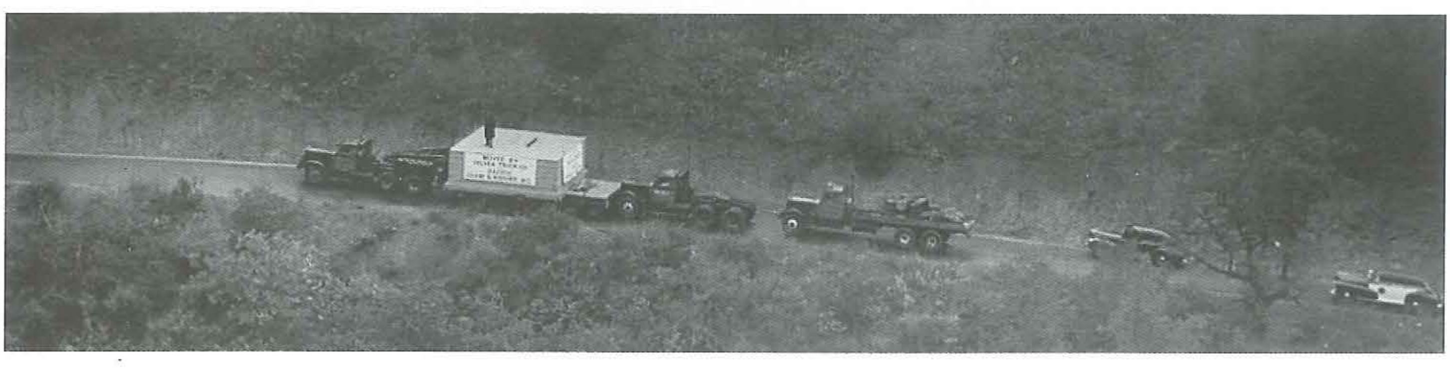
Sargent warned of the danger that the new generation of great telescopes might freeze grad students and postdocs out of hands-on experience with the instruments themselves, whereas Palomar will be able to keep alive this important astronomical tradition. He closed with the reaffirmation of a statement then-President Lee DuBridge made at the 1948 dedication:

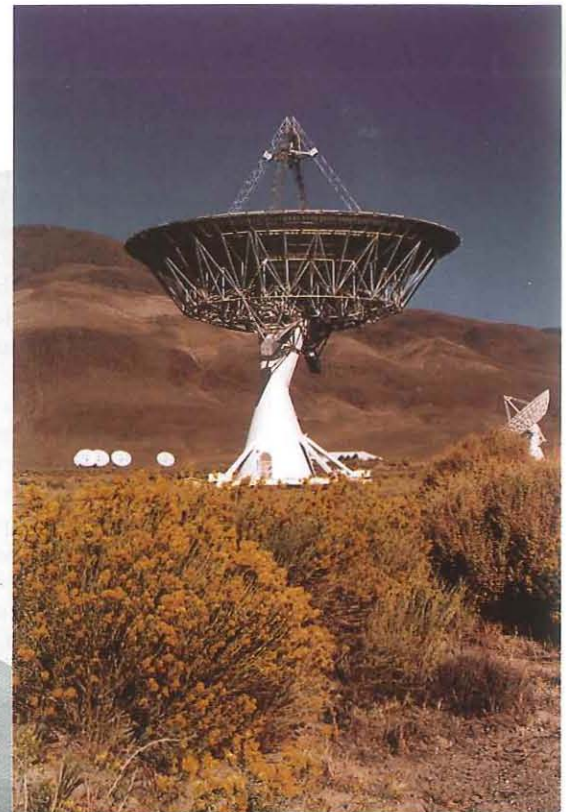
"The word 'dedicate' in the English language means to set apart by a promise. It is essentially synonymous with 'consecrate,' which means to make holy by a special act. The word has more than a formal or material significance. It also carries spiritual implications. It is in this sense actually that we do today set aside this temple of learning, and promise that it shall be devoted henceforth to deepening man's intellectual and spiritual understanding."

Below: In the media spotlights, the mirror is rolled out and prepared for its final journey to the top of Palomar Mountain. That journey (bottom), which took place on November 19, 1947, required two pushers and a puller to get up the sleet-slick road.



Above: Gamma-ray bursts suffered from the same identity crisis that quasars did, until BeppoSAX, an Italian/Dutch satellite, began providing accurate position information. On May 8, 1997, BeppoSax saw a gamma-ray burst for which the Hale telescope was able to find an optical counterpart (marked with an arrow, and still increasing in brightness two days after the burst). A spectrum taken at the Keck Observatory on May 11, by a team led by Professor of Astronomy and Planetary Science Shri Kulkarni, proved that the source is more than halfway across the observable universe from us, meaning that the burst was among the most energetic events in the universe. There's still debate as to whether all gamma-ray bursts are as distant, so it's too early to tell if this is the Rosetta Stone of gamma-ray bursts.





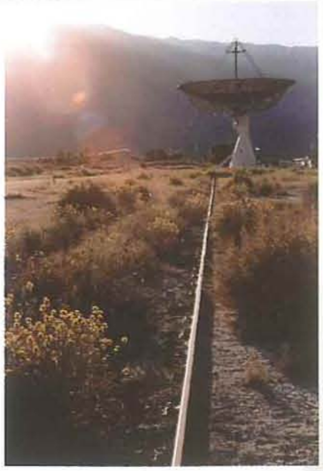
Left: One of the 90-foot dishes (foreground) is lined with reflecting steel mesh before being hoisted onto its pedestal in 1958. Above: In 1998 the same antenna has been joined by the 130-foot (right) and the millimeter-wave array (left).

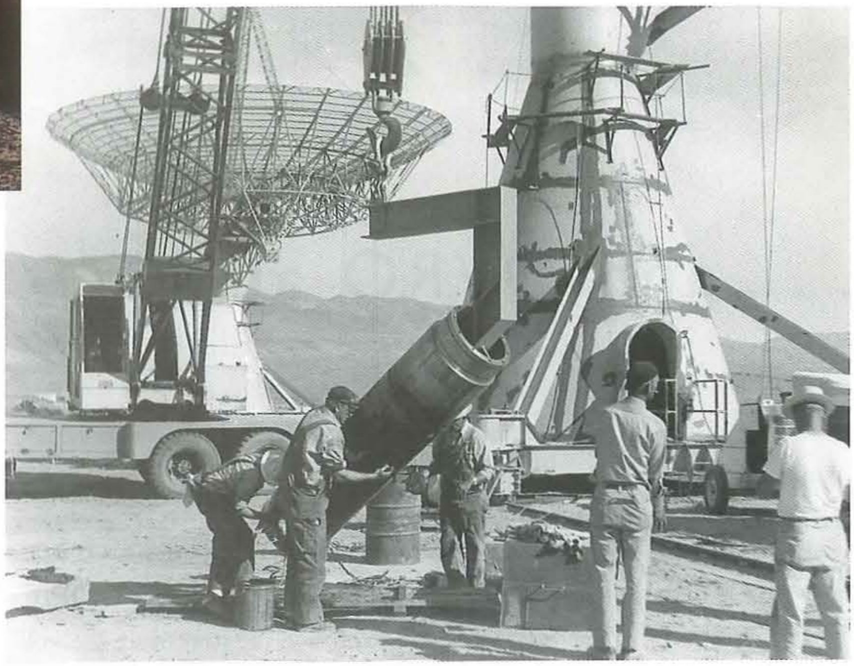
. . . and OVRO at 40

Right (top): Surveying the empty Owens Valley site; the cattle were gone but the telescopes had not yet appeared.
Center: Both 90-foot dishes and the living quarters and shop (with the White Mountains in the background) can be seen here in 1959—after the dedication but before the north arm of the L-shaped track was begun.
Bottom: OVRO's first director, Gordon Stanley, and current director, Professor of Astronomy Anneila Sargent, enjoy the desert air during a coffee break at the 40th birthday celebration.

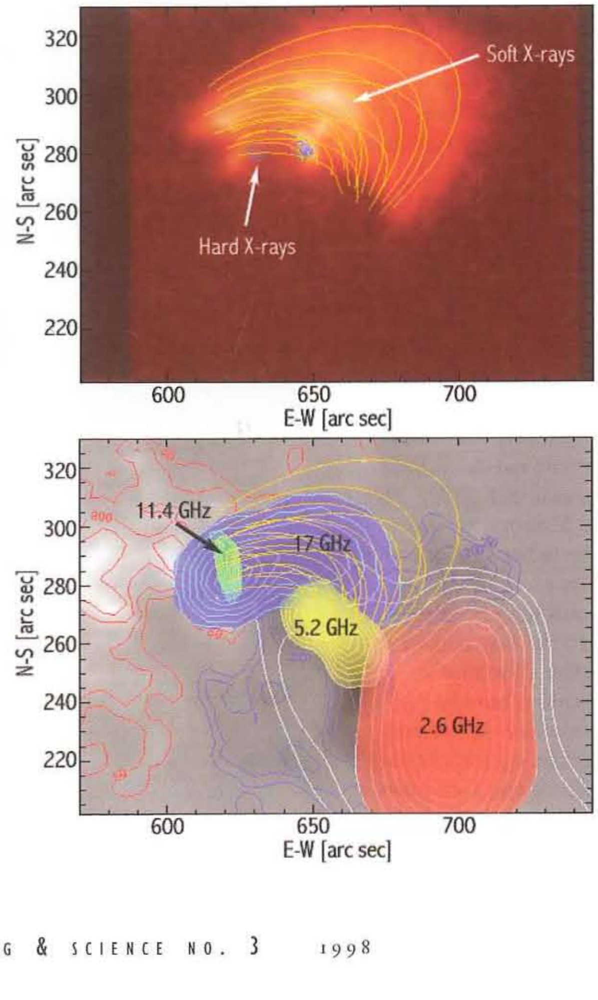
Farther down the spectrum, and a few hundred miles north of Palomar, the Owens Valley Radio Observatory marked its 40th anniversary with a day-long celebration October 3. There are actually three generations of telescopes at OVRO. The two 90-foot (27-meter) antennas were dedicated in 1958; the 130-foot (40-meter) dish was finished in 1968; and the array of six millimeter-wave antennas, each 34 feet (10.4 meters) in diameter, on a T-shaped track, was begun in 1977 and completed in 1995.

A couple of hundred guests gathered in a wind-whipped tent (no capacious dome here) to hear several sessions of talks on OVRO's history and current work. After greetings from President David Baltimore, relayed by Provost Steve Koonin, Gordon Stanley, who was the observatory's director from 1965 to 1975, spoke about the past. He described driving up past the (electronically noisy) Mojave desert, through Red Rock Canyon and into the Owens Valley in an almost unbearable combination of heat and dust, discovering the remote, and relatively noiseless, site in 1955: "By the time we arrived at Lone Pine, I was becoming excited. Here the magnificence of the Sierra Nevada reveals itself for the first time; the outside temperature was now a seemingly tolerable 115 degrees, and the lack of stations was noticeable on the car radio." Driving down a dirt road running east out of Big Pine, nestled up against the White Mountains, the Sierra Nevada rising up on the other side of the valley, he ended up in a remote piece of desert where the 130-foot antenna now stands. Providentially, the land belonged to the Los Angeles Department of Water and Power (but that's another story), and Stanley recalled how he stopped at their Independence office on his way back to Pasadena to start negotiating for a square mile of land. Stanley spoke about the early days at OVRO and about John Bolton, its founding director. He credited Bolton's vision for the





The 90-foot antennas were originally constructed to study the structure of radio galaxies in the distant reaches of the universe. Now they are being used to trace the sun's magnetic fields.

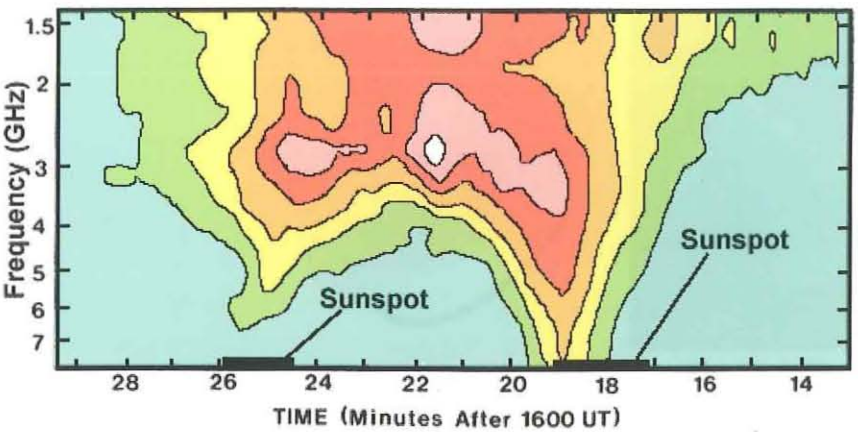


Solar flares, which erupt out of tangled magnetic fields, emit x-rays and radio waves from a layer of the sun's atmosphere called the corona. The top image, from the Yohkoh spacecraft, shows the flare's x-ray emissions, while the bottom panel plots OVRO observations at various radio frequencies, overlaid on magnetic field data for the sun's photosphere, or visible surface, a few thousand kilometers below.

observatory's later accomplishments, even though Bolton had returned to his native Australia in 1960, where he died in 1993. (His widow, Letty, traveled back for the anniversary celebration.) In conclusion, Stanley, who also calls Australia his home, quoted an Australian "bush" poet, A. B. Patterson:

"And the bush had friends to meet him and
their kindly voices greet him
In the murmur of the breezes and the river
on its bars,
And he saw the vision splendid of the
sunlight plains extended
And at night the wondrous glory of the
everlasting stars."

Anneila Sargent, OVRO's current director, thanked him and said she had been waiting for 30 years to hear that line quoted at a conference. Most of the observatory's other previous directors were also in attendance, including Robbie Vogt (acting director 1980–81), Tony Readhead (1981–1986), and Nick Scoville (1986-96). Many of the original graduate students who worked at OVRO (as well as later ones) also returned for the occasion, and several gave talks on the early work on the two 90-foot dishes, which, linked together as an interferometer, formed for a time the largest and most sensitive instrument of its kind in the world (*E&S*, Spring 1994). Its sensitivity enabled the extremely accurate measurement of the position of radio sources, making possible their identification with optical counterparts. Among the



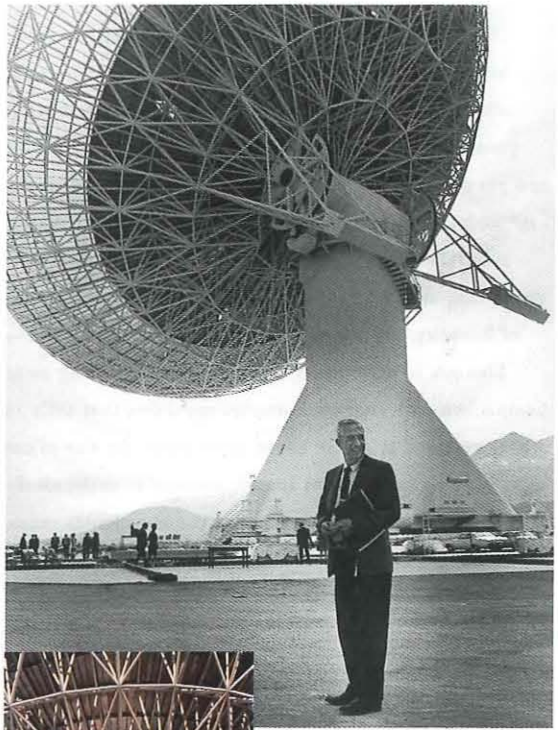
Dale Gary, visiting associate in astrophysics, has been using the 90-foot antennas to study sunspots, which are also associated with strong electromagnetic activity. This is a cross-sectional view of a magnetic loop derived from OVRO solar data, showing how its radio emissions stretch from one sunspot to the other. Although the vertical dimension here is frequency, it can be thought of as height, lower frequencies correlating with higher heights.

former grad students who spoke was Bob Wilson, PhD '62, known in his OVRO days as the Galaxy Man. Later, while at Bell Labs, Wilson co-discovered the cosmic background radiation, for which he shared the Nobel Prize in 1978.

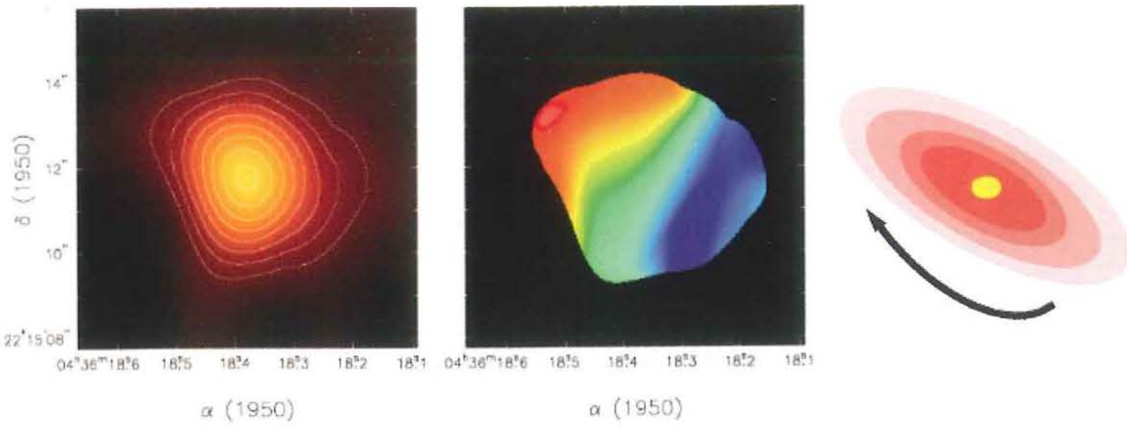
In later years, the two oldest antennas might have gone begging for something to do, according to Sargent, but with new receivers and signal processing equipment, Professor of Astrophysics, Emeritus, Hal Zirin cleverly adapted them to solar astronomy. In their current incarnation as part of a five-element array, they use the microwave spectrum to study the structure and activity of the solar atmosphere, in particular the corona's magnetic fields.

Besides the anniversary of the two original dishes, 1998 was also the 30th birthday of the 130-ft. antenna, an occasion that was pointed out by Marshall Cohen, professor of astronomy, emeritus, who had come up with the idea of the anniversary celebration. This huge antenna was built as a prototype for what was to be an array of eight large dishes, which never came to pass, having been beaten out by the Very Large Array in New Mexico. (The VLA starred with Jodie Foster in the 1997 film *Contact;* OVRO's 130-ft. dish had its own 15 minutes of fame in *The Arrival* in 1996.) The 130-ft. has served as one station in Very Long Baseline Interferometry (VLBI), an array of antennas worldwide. It was always one of the most important, said Cohen; since it was large and on the West Coast, it was used in the longest baselines, which have the weakest signals. Astronomers use VLBI to study the structure of distant quasars and radio galaxies.

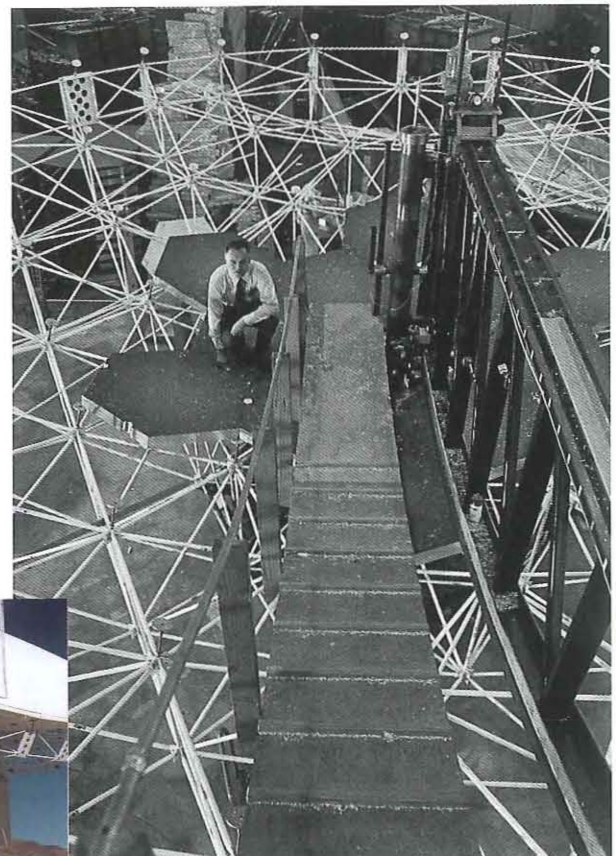
Starting in 1978, the 130-ft. antenna also carried out observations of the microwave background radiation, which has led to what Professor of Astronomy Tony Readhead described as a child of OVRO. That's the Cosmic Background Imager (see *E&S,* No. 4, 1996). On a mountaintop in Chile, far from its parent, the CBI will look for



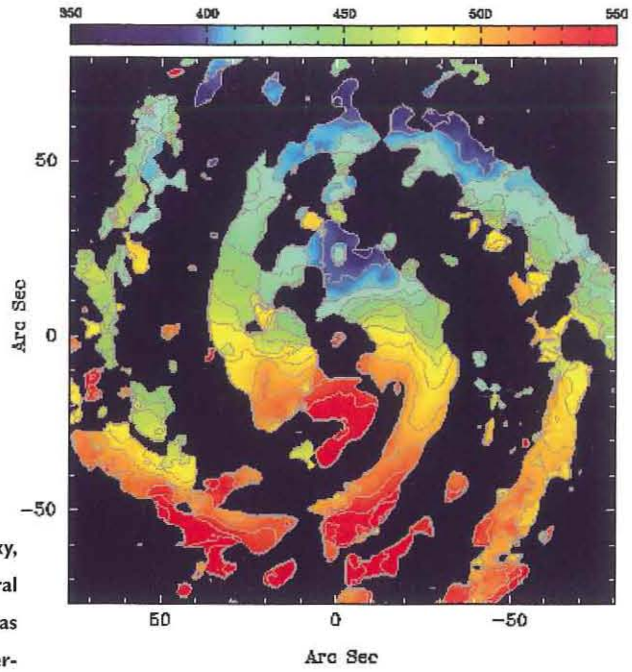
Caltech President Lee DuBridge dedicates the 130-foot antenna in October 1968 (above), and visitors get a rare opportunity to clamber around it in 1998 (left).



Professor of Astronomy Anneila Sargent and her group have been employing the millimeter array to search for other solar systems—observing stars that resemble the young sun (T Tauri stars) with surrounding disks of dust and gas out of which planetesimals, and eventually planets, might form. The image above is of a star named LkCa 15, about 500 light years away, which has a very promising protoplanetary disk. The image on the left shows contours of intensity, and the center picture represents motion—blue gas is approaching us and red gas is moving away. Comparison with computer simulations shows that LkCa 15 is surrounded by a disk about seven times the size of our solar system that contains enough material to make all the planets, and is rotating like the planets rotate around the sun.



Above: Bob Leighton works on the first dish of the millimeter array in 1974 at Caltech. His ingenious "Tinkertoy" design made it possible to take the telescope apart and reassemble it at Owens Valley. Left: In 1998 guests at the anniversary celebration tour one of Leighton's 10-meter dishes, which now number six (far left). The sixth dish, built with a gift from the Kenneth T. and Eileen L. Norris Foundation, was added in 1995.



The Whirlpool Galaxy, M51, a large nearby spiral galaxy, is shown at right as seen by the millimeter-wave interferometer's observations of the carbon monoxide (CO) molecule, which is used to trace the location of the dense molecular gas clouds that are the birthplaces of stars in galaxies and to study the association of these locations with the spiral structure. This image shows the gas's velocity (red for receding and blue for approaching), as derived from the doppler shift of the CO emission line. The overall rotation of M51's galactic disk can be seen, as well as the streaming motions associated with the spiral arms. The images on this page are the work of a team led by Nick Scoville, the Francis Moseley Professor of Astronomy.

fluctuations in the very early universe that might explain the lumpy structure that we see today, with clumps of galaxies spread unevenly about the cosmos.

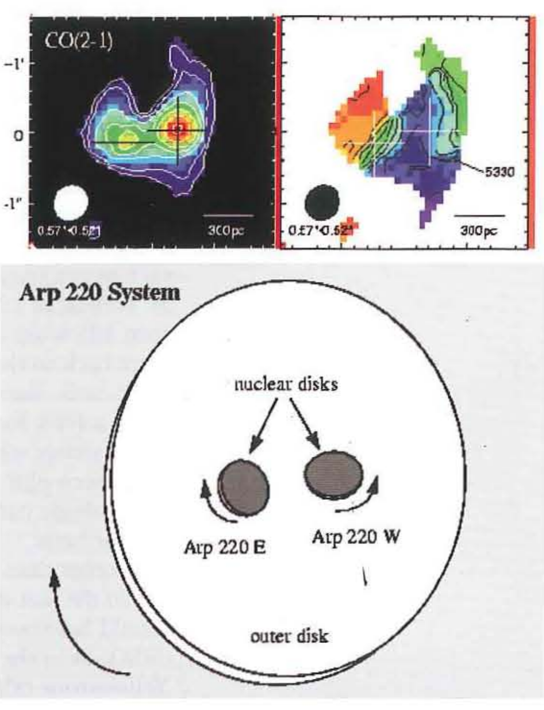
The newcomers to Owens Valley are Bob Leighton's 10.4-meter millimeter-wave antennas, a marvel of creative engineering. Leighton, the Valentine Professor of Physics, emeritus, who died in 1997 (his widow, Marge, attended the anniversary party), built the dishes out of panels machined to a particular figure and held up by a system of 1,400 struts tapped together with dowel pins—"the world's best Tinkertoy set," according to David Woody, OVRO's assistant director for site development. First constructed at Caltech (they were designed for potential assembly by astronauts in space), they were then reassembled at OVRO. The six dishes may be moved again, this time to Harkless Flats—at 9,000 feet in the Inyo Mountains, 5,000 feet above Owens Valley—for better imaging of the microwave radiation.

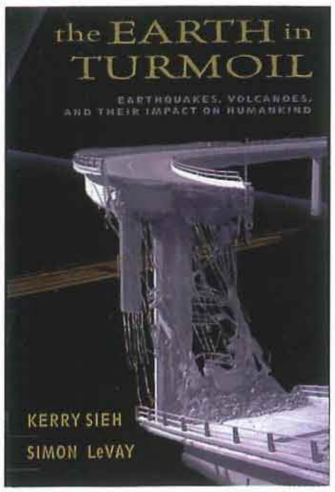
The millimeter-wave array is so sensitive that it can pick up signals 10 billion light years away. Among the closer subjects it is observing are the spiral structure of nearby galaxies, galactic nuclei, colliding galaxies, the interstellar clouds that supply the fuel for star formation, and the circumstellar disks around nearby stars that may be incubating planetary systems like our own.

In closing the talk sessions, Sargent announced that two graduate fellowships in radio astronomy, named for John Bolton and Bob Leighton, had been established, thanks to a gift from Gordon Moore, chair of Caltech's Board of Trustees.

The telescopes were open for tours, or just scrambling around on your own, following the talks, and the anniversary celebration concluded with OVRO's annual party, featuring live music and dancing and an almost-full moon. □

Carbon monoxide imaging of the extremely luminous galaxy Arp 220 was carried out in the new ultra-high resolution configuration of the OVRO millimeter array. These new observations uncovered the presence of two counter-rotating disks of gas, believed to be the remnants of two merging galaxies in Arp 220's nucleus. The upper plots show a color-coded intensity map and the gas motions. The bottom diagram illustrates a theoretical model based on the observations.





W. H. Freeman and Company, 1998, 324 pages

Our planet seems to be on a continual crash course, as the jigsaw puzzle–like plates that compose the earth's crust constantly rearrange themselves, creating and destroying ocean floors and mountain ranges, and triggering earthquakes and volcanoes.

But geologists' present knowledge of tectonic motion does not answer all the questions about earthquakes and volcanoes, as Kerry Sieh and Simon LeVay make abundantly clear in their book, *The Earth in Turmoil*. Sieh, professor of geology at Caltech, and LeVay, a well-known neuroscientist and science writer, offer a history of the earth's destructive and constructive processes for both the lay reader and the geology buff.

The book reads like a series of mysteries, setting the scene of a geologic occurrence—such as the eruption of Mount St. Helens in 1980—and then following the trail of clues back to the cause. In some cases, the mystery is never solved, for nature is a tricky writer who introduces unforeseen plot twists into the geologic narrative on a regular basis.

In other cases, the mystery lies in the fact that something should have occurred but didn't, as in the case of the Yellowstone caldera (a crater caused by the collapse of a volcano summit in the course of a major eruption). For more than 60 years, the floor of the caldera rose gradually, indicating the presence of magma pushing up from underneath. But then, without an eruption, the floor began subsiding again. The same situation is going on at present in the Long Valley caldera in Mammoth Lakes, California, where "the restless magma seems to be considering its options."

The book starts on the west coast of the United States, an area known for its seismic activity, especially on the San Andreas fault, "a seismological celebrity." Sieh has studied the San Andreas for more than 20 years, and his research, along with the findings of his peers, composes three chapters of the book, offering a glimpse of the past and present activity of the fault, as well as discussing future possibilities. From the west, the narrative travels far and fast, spreading quickly to the opposite coast like the lava that flows in the Hawaiian Islands—a turbulent region that Sieh and LeVay save for the cataclysmic end. Although the book focuses mainly on the continental U.S. and Hawaii, the authors also give snapshots of geologic activity around the world. Of course, this is entirely necessary in a world where continental collision has produced such odd occurrences as "bits of Africa that somehow ended up in Massachusetts."

As may be expected, the massive forces that create earthquakes and volcanoes sometimes produce some interesting side effects, such as Old Faithful, a hot spot whose steamy volcanic processes are a delight rather than a fright to those who experience them. And dead forests—suffocated by the excessive amount of carbon dioxide that seeps to the surface—reveal the presence of underlying magma.

The writing itself is as cohesive as the processes it describes. Told in a visual style, the narrative also includes plenty of drawings, maps, and photographs. Sieh and LeVay augment their tale with re-creations of ancient legends and chilling first-person historical accounts. Take the case of one Mississippi Valley resident in 1812, who described his experiences during a particularly severe aftershock on the New Madrid fault.

"Carbonized wood . . . which was ejected to the height of from 10 to 15 feet, and fell in a black shower, mixed with the sand which its rapid motion had forced along; at the same time, the roaring and whistling produced by the impetuosity of the air escaping from its confinement, seemed to increase the horrible disorder of the trees which everywhere encountered each other, being blown up, cracking and splitting, and falling by thousands at a time. In the meantime, the surface was sinking, and a black liquid was rising up to the belly of my horse, who stood motionless, struck with terror."

Even though the book offers up more frightening tales of humanity's relative powerlessness against the forces of nature, in the end its purpose is not to terrify, but to educate. For besides bringing the reader up to speed on what geologists know about the earth's evolutionary processes, the authors also discuss some steps humans can take to survive in such a hostile environment.

After all, when you live on such a volatile, shifting surface as we do, putting the pieces of the geologic puzzle together is the first step toward a safer future. □

Ryan Poquette

Greenstein Lectureship Begins

Jesse Greenstein

A lectureship has been established in honor of Jesse Greenstein, DuBridge Professor of Astrophysics, Emeritus. The first annual Greenstein Lecture was given on October 28, nine days after Greenstein's 89th birthday. The speaker was Princeton University's James Gunn (PhD '66), who built the "4-shooter" CCD camera for the Hale Telescope and revolutionized ground-based optical astronomy. In his lecture, "The Sloan Digital Sky Survey: First Light and Commissioning," he affectionately referred to Greenstein as his astronomical "father." □

Honors and Awards

Giuseppe Attardi, the Steele Professor of Molecular Biology, has received a Gairdner Foundation International Award for Achievement in Medical Science for his "pioneering contribution to our understanding of the structure of the human mitochondrial genome and its role in human disease."

Lance Davis, the Harkness Professor of Social Science, has been awarded the Alice Hanson Jones Prize in Economic History. He and coauthors Robert Gallman and Karin Gleiter were honored for their book, *In Search of the Leviathan: Technology, Labor, Productivity and Profits in American Whaling, 1816–1906.*

Professor of Aeronautics Morteza Gharib (PhD '83) has been elected a fellow of the American Physical Society.

William Johnson, the Mettler Professor of Engineering and Applied Science, will receive the MRS Medal at the December meeting of the Materials Research Society. He is credited with "the development and fundamental understanding of bulk metallic glass-forming alloys," leading to a new class of structural materials for advanced engineering applications.

Thomas McGill (MS '65, PhD '69), Jones Professor of Applied Physics, has received the Defense Advanced Research Projects Agency's Best Technical Development of the Year Award for the work described in "Double Manhattan" in this issue's "Random Walk" section.

Associate Professor of Computer Science Peter Schröder is one of 24 "promising young scientific researchers" to be awarded a five-year fellowship from the David and Lucile Packard Foundation. Schröder's research involves "modeling, simulation, and visualization of large problem sizes on workstation-class computers."

John Seinfeld, Nohl Professor and professor of chemical engineering, and chair of the Division of Engineering and Applied Science, received the Fuchs Award at the International Aerosol Conference in Edinburgh, Scotland, in September.

Paul Wennberg, associate professor of atmospheric chemistry and environmental engineering science, has been selected by the National Science and Technology Council to receive the Presidential Early Career Award for Scientists and Engineers. A new award, it

Honors and Awards (Continued)

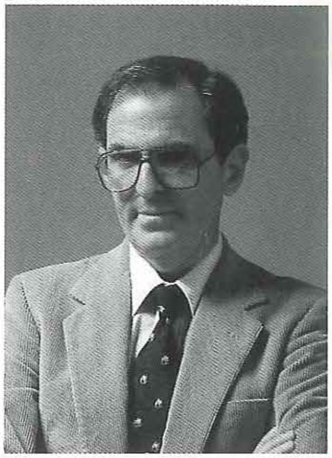
recognizes up-and-coming scientists and engineers "who show exceptional potential for leadership at the frontiers of scientific knowledge."

The 1997–98 teaching awards of the Associated Students of Caltech (ASCIT) have gone to Professor of Biology Marianne Bronner-Fraser, Professor of Applied Mathematics Donald Cohen, Professor of Physics Andrew Lange, Professor of Biology Ellen Rothenberg, and Mellon Visiting Professor of Humanities John Miles. Recipients of honorable mentions are Professor of Biology James Bower, Associate Professor of Physics Emlyn Hughes, Professor of Planetary Science and Geology Bruce Murray, Lecturer in Computer Science and Electrical Engineering Glen George, and Visiting Professor of History Timothy Breen. Named for teaching-assistant awards are Travis Williams, a senior in chemistry this year, and Alexa Harter, a graduate student in physics, and, for honorable mentions, Michael Siu, a graduate student in chemistry, and Ben Miller, who received his bachelor's degree in mathematics this past June.

Recipients of the 1997–98 Graduate Student Council Teaching and Mentoring Awards are, for classroom teaching, Professor of Aeronautics and Applied Mechanics Ares Rosakis and, for mentoring, Scott Fraser, Rosen Professor of Biology. Teaching-assistant awards have gone to Zvonimir Bandic, a graduate student in applied physics, and Ayhan Irfanoglu, a graduate student in civil engineering. □

Goodstein Gets Oersted Medal

David Goodstein, professor of physics and applied physics, Gilloon Distinguished Teaching and Service Professor, and vice provost, has been selected the 1998 Oersted Medalist by the American Association of Physics Teachers. The Oersted Medal, established in 1936, recognizes a teacher for notable contributions to the teaching of physics. This puts Goodstein in excellent company—past medalists include Carl Sagan, Exploratorium founder Frank Oppenheimer, and Nobel Laureates Hans Bethe and I. I. Rabi. Only two other Caltech faculty have ever been so honored: Robert Millikan (in 1940) and Richard Feynman (in 1972). □



David Goodstein

Steven Koonin

Ahmed Zewail

Caltech Takes Two of Six Lawrence Awards

The U.S. Department of Energy has named Steven Koonin (BS '72), vice president and provost and professor of theoretical physics, and Ahmed Zewail, the Pauling Professor of Chemical Physics and professor of physics, the recipients of this year's E. O. Lawrence Award, given for exceptional contributions to the development, use, or control of nuclear energy. The award has been given since 1959 in memory of Ernest Orlando Lawrence, the Nobel Prize–winning nuclear physicist who invented the cyclotron. Koonin and Zewail will join four other Americans at the January 15, 1999, awards ceremony in Washington, D.C.

Secretary of Energy Bill Richardson commended Caltech for Koonin's and Zewail's advancements in nuclear science, saying, "This is only the second time in the award's 38 years that one university has produced two winners."

Koonin developed a technique for modeling atomic nuclei on parallel computers that is widely used in nuclear physics and astrophysics. And his theory of quantum interference effects between emitted pions is one of the most important techniques for studying hot nuclear matter, including simulations of densities and temperatures similar to those soon after the Big Bang.

Zewail pioneered the burgeoning field of femtochemistry, in which molecular reactions are viewed in extremely short pulses of laser light. This creates stop-motion photographs, as it were, of chemical bonds in the act of breaking and forming—the so-called "transition state," which had long been hypothesized to exist but had never before been seen directly. □

Leading with Lead Trusts

Dr. Wilbur Goss, formerly assistant director of the Applied Physics Laboratory at Johns Hopkins University, has spent much of his retirement studying, investing, and putting his knowledge into practice. He says he's made more money in retirement than in his professional life.

Goss first learned about charitable lead trusts while doing research at a law library. "The more I learned, the better it looked," he says. "The concept of a lead trust intrigued me because it seemed to meet my needs and desires." As a result, Goss created the first lead trust at Caltech in 1992, and he is currently considering the establishment of another.

"This is an especially good time to think about lead trusts because the IRS discount rate (used to calculate the tax benefits of a lead trust) is at an all-time low, and that results in even greater gift and estate tax savings," he says. Unlike a charitable remainder trust, where the donor receives annual distributions for life and the remainder goes to the Institute, a lead trust works the opposite way. The Institute receives an annual distribution from the trust over a set period of time. When the trust ends, the principal goes to noncharitable beneficiaries, usually the donor's heirs. The tax advantage for the donor is that, for gift and estate tax purposes, the IRS calculates the gift to the donor's heirs at its discounted present value when the lead trust is established. Years later when the trust ends, the assets distributed to the designated heirs are likely to be worth much more, but no additional gift or estate tax is assessed.

Goss figures that the lead trust is the most tax-efficient way to transfer assets to the Institute and to heirs. "I regard Caltech as the premier technical institute in the country," says Goss, who has a PhD in physics. "The future of the country is associated with what Caltech is doing. Our leadership in the world cannot be maintained without leadership in technical fields. If I'm not willing to support Caltech with my background, who will?" The unrestricted nature of the income from this trust is particularly welcome because it allows the Institute to direct support to the area of greatest need.

It is clear that Goss and his wife Mildred, members of The Associates since 1986, are committed to excellence in education. They have put their three children through private universities and paid the tuition for their six grandchildren to attend prestigious private institutions. "We have a family tradition of trying to support private universities because we feel they have a strong role to play," he says.

"Many people my age, if they have been prudent with their finances, will have cash flow in excess of their needs," Goss says. "This is a window of opportunity to make a substantial contribution to Caltech without jeopardizing estate settlement plans. I have everything to gain and nothing to lose."

Chris Yates, JD
Susan A. Walker, CFP
Office of Gift and Estate Planning
California Institute of Technology
Mail Code 105-40
Pasadena, California 91125
(626) 395-2927
planned_gifts@caltech.edu