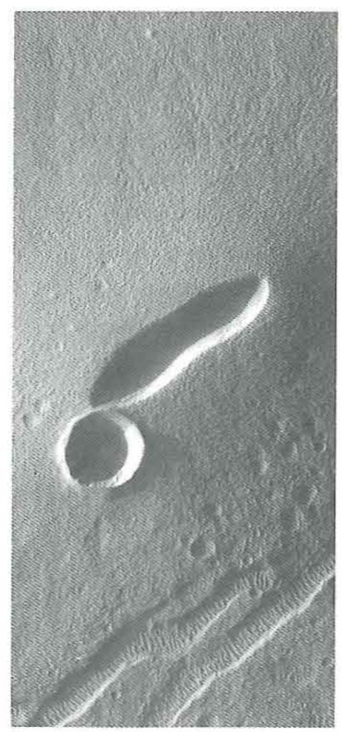
Broad Building Announced

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.

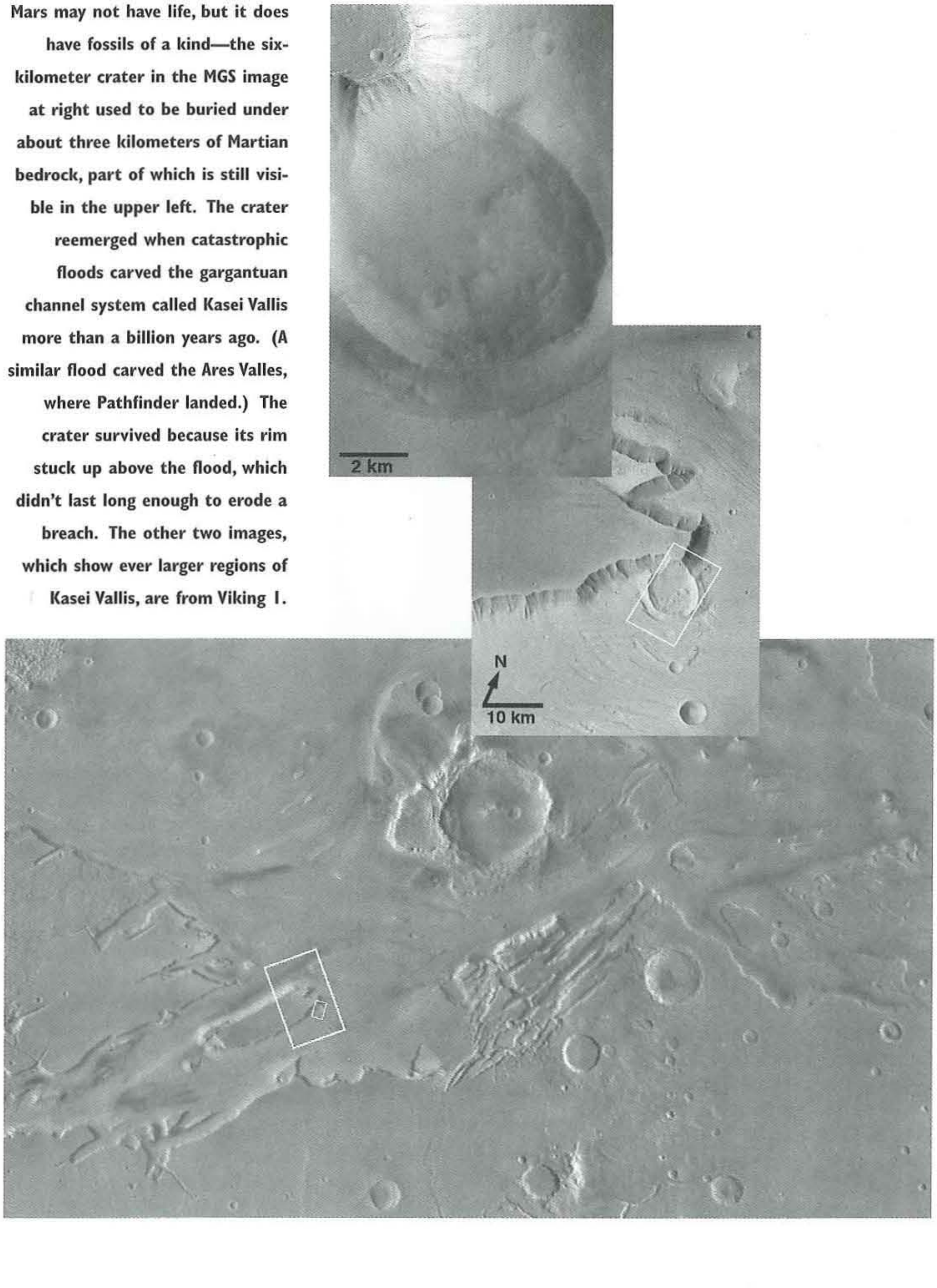
Surveying Mars

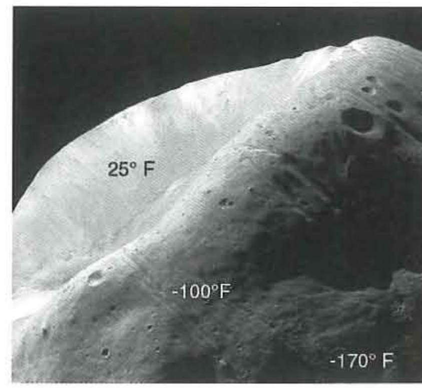


Right, top: Mars's largest volcano, Olympus Mons, is as big as Arizona and taller than three Everests. A "shield" volcano, formed by the gentle oozing of very fluid lava, Olympus Mons is very nearly as flat as a pancake—once one surmounts the cliffs ringing the volcano, typical slopes are 2–5 degrees. 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.

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.

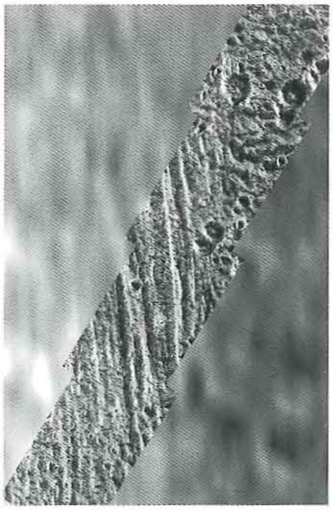
GOOD-BYE, CRUEL WORLD

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.

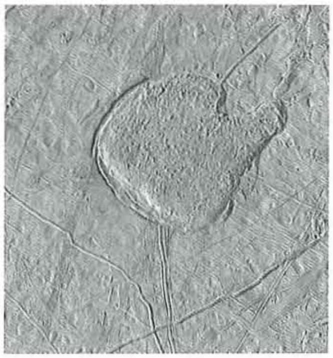
The mechanism involves three stable proteins found in nematode cells. These proteins are normally quiet, but can be readily triggered by death signals in such a way that the cell digests itself. The three proteins are known as CED-3, CED-4, and CED-9. None of these proteins alone will kill cells, the 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.

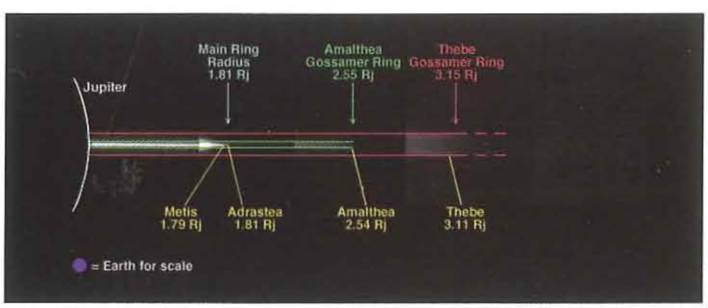


Above: This "catcher's mitt" on Jupiter's icy moon Europa is about 100 kilometers wide, as measured across the palm to the tip of the thumb. The mitt appears to be made of frozen slush and seems to bulge up from the adjacent surface, which is bent downward and cracked, most visibly along the lower left (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.

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.

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: 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 nonquantum 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. □