Funeral for a Planet

JPL's Varoujan Gorjian (BS '92), who works on the Spitzer Space Telescope team, cut quite a figure as the red planet.

Their heads hung low, accompanied by black-clad mourners and a jazz band, eight planets marched in a New Orleans–style funeral procession for Pluto in the 30th annual Pasadena Doo Dah Parade. They were joined by more than 1,500 parade participants, among which were the Marching Lumberjacks, guru Yogi Ramesh, Raelian devotees, the Zorthian nymph snake sisters, and the Men of Leisure and Their Synchronized Napping Team, who stopped every now and then to recline. Marching Lumberjack Karolyn Wynek-en, who drove 700 miles from Humboldt County for the event, exclaimed, "Wow, that is awesome! That is so good, and necessary," upon seeing the open casket with its papier-mâché Pluto.

One of the mourners, Caltech Image Processing and Analysis Center staff engineer Kaly Rengarajan, saw the event as a way to educate the public. "The very idea of Pluto being demoted is so exciting. We're trying to refine what we knew before. I'm so glad people are being made aware!" she raved.

Saturn, played by JPL postdoc Angelle Tanner and accompanied by her many rings, organized the march and voiced the sentiments of most of her fellow planets when she noted, "Most astronomers don't think Pluto should be a planet, but we all miss it." Some planets, however, felt strong-armed into participation—as trumpet-playing Earth (Samantha Lawler, BS '05) noted, Saturn was "writing my recommendation letters."

Uranus (astronomy postdoc Nicholas Law) seemed to bear a grudge, sporting a T-shirt that proclaimed, "Pluto had it coming." And mourner Zane Crawford, a JPL visiting graduate student from the University of Colorado who drummed the funeral march, didn't hide his contempt. "Pluto did have it coming, seriously," he said.

Ironically, Mercury (JPL postdoc Joe Carson), winged messenger to the gods, was late. But when he showed up, he was all sympathy, perhaps because now he is the smallest planet in the solar system and fears his turn is next. After all, Mercury is only about twice the size of Pluto. "To be honest, I felt bad for Pluto," he said about the planetary excommunication. "My little cousin started crying when she found out Pluto got demoted."

Even Caltech Professor of Planetary Astronomy Mike Brown showed up, and brought along his daughter Lilah to play the fledgling Eris. "The dwarf planet was originally supposed to be named after her, so it's appropriate," said Brown. No cosmic scuffles arose, and everyone strove to maintain peace, for Pluto's sake. While some memorial services were held in Washington, D.C., days after Pluto's ejection from planetary circles on August 24, 2006, none came close to this procession. Thirty thousand onlookers gathered in the balmy weather under clear skies. And the planets were all in alignment. □—*EN*

Saturn helps a tardy Mercury with his wings.

Pass the Toothpicks, Please

When it comes to digestive ability, termites have few rivals—try noshing on a two-by-four sometime. But each termite in turn depends on the 200 or so microbial species that call its digestive tract home and are found nowhere else in nature. Despite several successful attempts, the majority of these gut bugs have never been cultivated in the laboratory, so figuring out which microbe does what remains an open question. Now a group led by Caltech researchers is untangling this complex web of relationships using sophisticated "labs on a chip" that can look at a termite's intestinal ecosystem cell by cell.

The traditional approach to this problem involves removing the gut contents of individual termites, smashing the microbial cells, extracting and pooling their DNA en masse, and analyzing the genes found in the randomized mash. Assigning relationships between any two genes or to the organisms from which they are derived is complicated at best, and often just not possible. Says Associate Professor of Environmental Microbiology Jared Leadbetter, "It was like studying the contents of several hundred books after having torn off their covers, ripped up all the pages into small pieces, and jumbled them together into a big pile. We would find sentences and paragraphs that we found extremely interesting and important, but then we were left frustrated. It was very difficult to determine what was in the rest of the book."

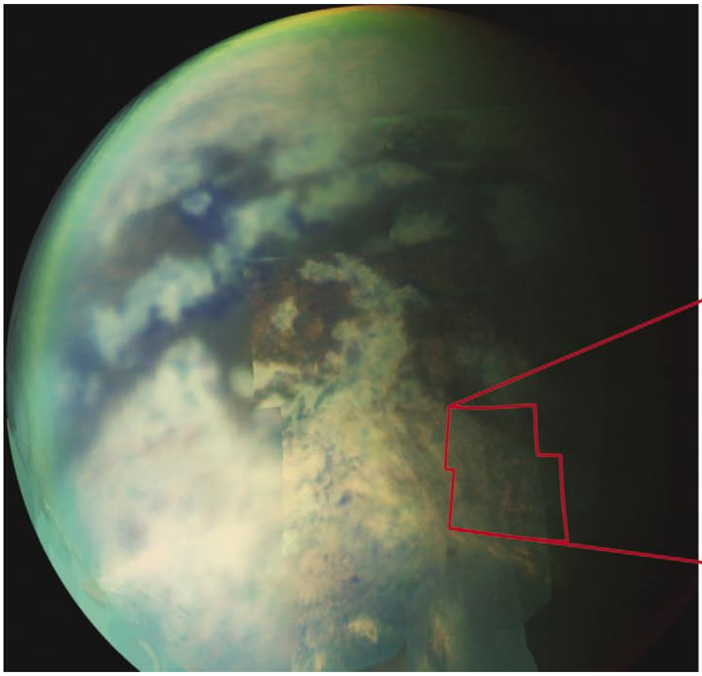
The new approach uses microfluidic devices into which more than 1,000 individual cells can be distributed into separate chambers before analysis, so that each can be studied as an individual. "With this technique, we're suddenly able to read portions of the books without having first torn off their covers," says Leadbetter. "We are still reading with a narrow penlight, but when we identify an interesting sentence, we can quickly find the title and author, and even move on to examine the other pages. This approach can lead to a better understanding of the many microbial processes that underlie the environments in which we all live."

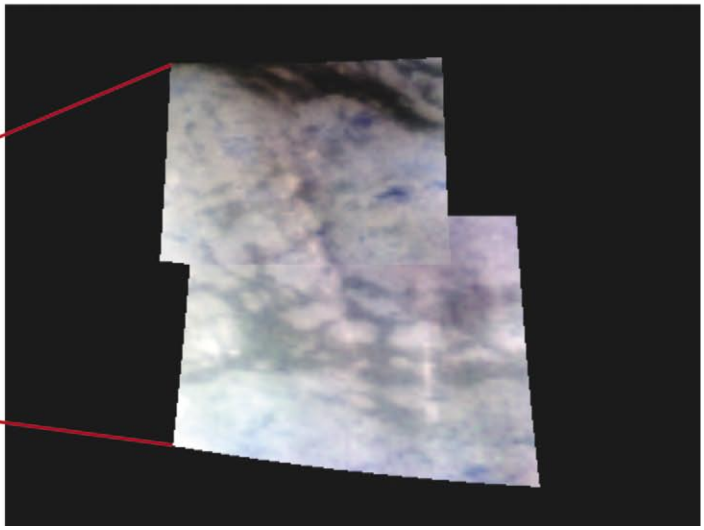
In this particular instance, the researchers found that in the California dampwood termite (*Zootermopsis nevadensis*) a family of bacteria called spirochetes are responsible for a key step in the process of digesting wood—homoacetogenesis, which makes the acetate molecules that are the termite's chief energy source. (As a side note, these acetate-producing microbes consume hydrogen gas, for which they compete with other gut bacteria that make methane—a potent greenhouse gas—thereby keeping many termite species from emitting as much methane as they otherwise would.) Termites are extremely abundant and active in many tropical ecosystems. Says Leadbetter, "There are 2,600 different species of termites, and it is estimated that there are at least a million billion individual termites on Earth. It is thought that they emit two and four percent of the global carbon dioxide and methane budget, respectively. And by extrapolation from numerous studies of a few dozen termite species, we think that there could be millions of novel microbial species found only in the hindguts of termites." The work could also illuminate ways for humans to convert plant biomass into useful products, such as transforming low-value lignocellulose (that's straw and cornstalks to you) into biofuels.

The paper appeared in the December 1 issue of *Science*, with Elizabeth Ottesen, a Caltech grad student in biology, as the lead author. The coauthors are Jong Wook Hong, an assistant professor of materials engineering at Auburn University; Stephen Quake, professor of bioengineering at Stanford; and Leadbetter. □—*RT*

There's Methane in Them Thar Hills

JPL's Cassini orbiter around Saturn got another look at its methane-clouded moon, Titan, on October 25. These closest-ever shots from the Visual and Infrared Mapping Spectrometer have a maximum resolution of 400 meters per pixel—about the size of the JPL campus, excluding parking lots—and in the image below left are overlaid on previous VIMS data. The close-up below right reveals a mountain range about 150 kilometers long and 1.5 kilometers high. This mini-Sierra Nevada has "snow"-clad summits (possibly of frozen methane) and appears to have been formed when subsurface material welled up in cracks between diverging tectonic plates, much as the mid-ocean ridges formed on Earth. "These mountains are probably hard as rock, made of icy materials, and are coated with different layers of organics," says Larry Soderblom (PhD '70), a Cassini interdisciplinary scientist with the U.S. Geological Survey in Flagstaff, Arizona. The mountain range had been seen in previous radar-mapping passes, but its signature had been difficult to interpret. In the infrared, however, the shadow it casts is clearly visible. □





Urrrp!

A giant black hole dipping into the cosmic cookie jar has been caught red-handed—the first time astronomers have seen a black hole eat a star from the first to nearly the final bites. The glutton was nailed by the ultraviolet space telescope known as the Galaxy Evolution Explorer, or GALEX—a NASA Small Explorer mission headquartered at Caltech. (See *E&S*, 2004, No. 2.) "This type of event is very rare, so we are lucky to study the entire process from beginning to end," says Caltech postdoc Suvi Gezari, the lead author of the paper in the December 10 issue of *Astrophysical Journal Letters*.

For perhaps thousands of years, the black hole rested quietly deep inside an unnamed elliptical galaxy. But then a star ventured a little too close and was torn to shreds—a black hole's gravity is so strong that even light cannot escape it. Part of the shredded star swirled around the black hole, then began to plunge into it, triggering the bright ultraviolet flare that GALEX saw. The spacecraft continues to watch as the black hole finishes the remaining crumbs of its midnight snack, observations that will ultimately provide a better understanding of how black holes evolve within their host galaxies. NASA's Chandra X-ray Observatory and the Canada France Hawaii Telescope and the Keck Observatory, both in Hawaii, have also helped chronicle the event in multiple wavelengths over two years.

In the early 1990s, three other dormant black holes were suspected of having eaten stars when the joint German-American-British Röntgen X-ray satellite picked up X-ray flares from their host galaxies. Astronomers had to wait until a decade later for Chandra and the European Space Agency's XMM-Newton X-ray observatory to confirm those findings, and show that the X rays had faded dramatically—a sign that stars were swallowed.

Active black holes are always feeding, creating glowing disks of material around themselves that are easy to see. But the black hole hiding in the heart of a typical galaxy may only snare an unsuspecting star once every 10,000 years. "Now that we know we can observe these events with ultraviolet light," says Gezari, "we've got a new tool for finding more." This black hole is thought to be tens of millions times as massive as our sun, and its host galaxy is located four billion light-years away in the constellation Boötes. □—*WC*

Sea-Urchin Genome Sequenced

A group of 240 researchers from an international consortium of more than 70 institutions has announced the sequencing of the male California purple sea urchin. The project was led by Erica Sodergren and George Weinstock, a husband-and-wife team at the Baylor College of Medicine-Human Genome Sequencing Center (BCM-HGSC), along with Richard Gibbs, director of the BCM-HGSC, and Caltech's Eric Davidson, the Chandler Professor of Cell Biology, and Andrew Cameron, a senior research associate in biology. The purple sea urchin's genome has been studied intensely for years at Caltech, and the organism is a workhorse of developmental and biomedical research. Davidson and Cameron coordinated the sequencing effort, and Caltech's Kerckhoff Marine Laboratory provided all the sea urchins required for the project.

Reported in the November 10 issue of *Science*, the high-quality "draft" sequence covers more than 90 percent of the sea-urchin genome. The genome contains more than 814 million letters, spelling out 23,300 genes, nearly 10,000 of which have already been scrutinized by the consortium. In addition to the primary results in *Science*, 41 companion manuscripts will appear in *Science* and in a special December 1 issue of *Developmental Biology*.

More than 30 years ago, Davidson and Roy Britten, a distingushed senior research associate at the marine lab, began to use the sea urchin as an experimental animal and decided to develop it as a model system in the then-emerging field of molecular biology. As a result, "Britten and Davidson offered a comprehensive theory of gene regulation in higher organisms, and the sea urchin has been the premier model for testing these predictions," says Gibbs. "The complete sequence is now available to further these studies."

Sea urchins are echinoderms—Greek for spiny skin—a phylum of marine animals that originated over 540 million years ago and includes starfish, brittle stars, sea lilies, and sea cucumbers. The purple sea urchin is a recent arrival, however, emerging in the North Pacific some 15–20 million years ago. Sea urchins and humans share a common ancestor that gave rise to the deuterostomes, the superphylum that includes the echinoderms and the chordates, essentially animals with a spinal cord.

The sea urchin is the first nonchordate deuterostome to be sequenced. (Insects, nematodes, and other such creatures that have been sequenced lie outside the deuterostome superphylum.) "Each genome that we sequence brings new surprises. This analysis shows that sea urchins share substantially more genes and biological pathways with humans than previously suspected," says Francis S. Collins, director of the National Human Genome Research Institute. "The sea urchin fills a large evolutionary gap in sequenced genomes," says Weinstock, codirector of Baylor's Human Genome Sequencing Center, which did the sequencing work. "It allows us to see what went on after the ancestral split that gave rise to humans and insects."

Comparing the sea-urchin to the human gene list shows which human genes are likely to be recent innovations. It also shows which human genes are evolving rapidly in response to natural selection. This will make it possible one day to know the history of every human gene—and build a picture of what the extinct ancestors that gave rise to animals ranging from worms to humans looked like.

Sea urchins sure don't look like people, but our embryonic development displays many basic similarities, an important shared property of deuterostomes. This makes the sea urchin, with its many transparent embryos and easily isolated eggs and sperm, a valuable model organism. Animal development occurs through a complex network of genes, and sea urchins provide a rapid and efficient means of manipulating that network, allowing researchers to figure out which genes turn other genes on and off. Consequently, the sea urchin is among the best understood developmental systems among animal models. Now, with the genome sequence in hand, this process can be studied exhaustively.

Because of its evolutionary position, the sea-urchin genome is a sample of unknown biological territory, the early exploration of which is already bearing fruit. The sea urchin has most of the same gene families as people, but the gene families are often larger in humans. One unexpected exception to this rule is the immune system.

Humans have innate and acquired immune systems. Innate immunity is the set of proteins that are "hard wired" to detect unique molecules within bacteria, such as their cell walls, and to signal that there is an intruder. Acquired immunity is the province of cells that "learn" to recognize specific invaders and then create customized antibodies to fight them. The sea urchin has some acquired immune system genes, but its innate immune branch is greatly expanded—10 to 20 times as many genes as in humans. This rich repertoire of sea urchin proteins could turn out to provide new reagents in the fight against infectious diseases.

And the sea urchin has no eyes and ears, at least as we know them, yet it has genes for sensory proteins that are involved in human vision and hearing. Some of the visual sensory proteins are localized within an appendage known as the tube foot, and likely function in sensory processes there. "The sea urchin reminds us of the underlying unity of all life on earth," notes Baylor's Erica Sodergren. "It is a similar set of genes and proteins being reused in different ways, in different numbers, and at different times in the life cycle to create the diversity of living forms."

The National Human Genome Research Institute of the National Institutes of Health provided most of the funding for the sequencing and annotation. □—*RT*

Red, Hot, and Gold

The ancient Greeks used finely ground gold to color glass, which paradoxically turned it a rich ruby red. They didn't know it, says Caltech staff scientist David Boyd, but they were using nanoparticles. Since then, many people have exploited the odd optical properties of nanoparticles. Now Boyd and his colleagues are taking advantage of their equally odd thermal ones in a technique called "plasmon-assisted chemical vapor deposition" that adds a powerful new tool to the methods available for making microdevices.

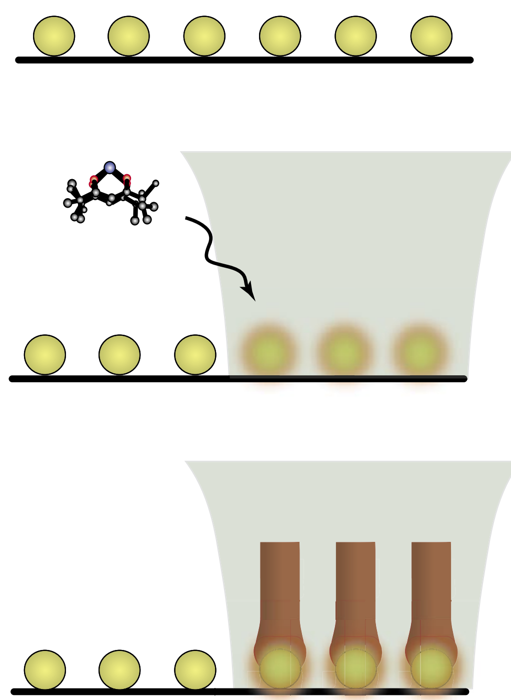
In the November issue of *Nano Letters*, Boyd and colleagues report that the process can be used to create a variety of nanostructures. The underlying material, or substrate, as it is called, is coated with gold nanoparticles and placed in a vacuum chamber that is then filled with a carrier gas containing a precursor of the material to be deposited. A low-power laser whose wavelength matches a natural resonance in the gold particles is focused onto a small spot about one micron in diameter, or less than a hundredth the diameter of a human hair, which quickly heats up by several hundred degrees—hot enough so that the particles decompose the precursor molecules in the vapor, forming microscopic deposits. Since this does not happen at nearby cool particles outside the laser spot, structures form only where the laser shines, allowing one to "draw" patterns by moving the laser across the substrate.

The key is the surprisingly low thermal conductivity at the tiny scales involved, explains Boyd. The gold nanoparticles absorb energy from the laser very efficiently, but do not conduct the heat away to their surroundings very well. They thus can be heated to much higher temperatures than one would expect.

The process requires a laser about as powerful as a green laser pointer, says David Goodwin, professor of mechanical engineering and applied physics and a coauthor of the paper. The ability to write micron-scale or smaller structures directly, without the need for conventional lithographic patterning and etching, while also keeping the substrate cool outside the laser spot, opens up new possibilities for the types of structures that could easily be fabricated.

The researchers grew lead oxide "wires" as small as a few tens of nanometers in diameter on a glass substrate, and predict that even smaller structures are possible. The team has also deposited titanium oxide and cerium oxide. "Anything that can be deposited as a film by conventional means can probably be deposited with this technique," Boyd says.

The paper's other authors are Leslie Greengard, of New York University's Courant Institute of Mathematical Sciences; Mark Brongersma of Stanford University, a former Caltech postdoc; and Mohamed Y. El-Naggar (MS '02), who has completed all the requirements for his Caltech PhD and is now a postdoc at the University of Southern California. □—*RT*



Top: Gold particles are laid down on the substrate. Middle: A pinpoint laser illuminates some of the particles, heating them, while a precursor molecule (the crablike thing) drifts by. Bottom: The hot particles break down the precursor molecule on contact, causing deposits to form on top of themselves.

Test-Tube Logic

Computers and liquids don't mix, as many a careless coffee drinker has discovered. But a breakthrough by Caltech researchers could result in logic circuits that literally work in a test tube—or even in the human body. Made of DNA, these circuits work in salt water—an environment similar to that within living cells—which could lead to a biochemical microcontroller, of sorts, for cells and other complex chemical systems. The lead author of the paper describing this work, which appeared in the December 8 issue of *Science*, is Georg Seelig, a postdoctoral scholar in Erik Winfree's lab. "Digital logic and water usually don't mix, but these circuits work in water because they are based on chemistry, not electronics," explains Winfree (PhD '98), an associate professor of computer science and computation and neural systems and recipient of a MacArthur genius grant.

Rather than encoding signals in high and low voltages, the circuits encode signals in high and low concentrations of short DNA molecules. The logic gates that process the information are carefully folded complexes of two or more additional short DNA strands. When a gate encounters the right input molecules, it releases its output molecule. This output molecule in turn can help trigger a downstream gate, so the circuit operates like a cascade of dominoes in which each falling domino topples the next one. But unlike dominoes and transistors, these components have no fixed positions and cannot simply be connected by wires. Instead, the molecules bump into each other at random, relying on the specificity of their designed interactions to ensure that only the right signals trigger the right gates.

"We were able to construct gates to perform all the fundamental binary logic operations—AND, OR, and NOT," explains Seelig. "These are the building blocks for constructing arbitrarily complex logic circuits." The largest circuit the group has made so far processes six inputs with 12 gates in a cascade five layers deep. While this is not large by Silicon Valley standards, Winfree says that it demonstrates several important design principles. "Biochemical circuits have been built previously, both in test tubes and in cells," Winfree says. "But these circuits rely solely on the properties of DNA base-pairing. No enzymes are required to make them work."

"The idea is not to replace electronic computers for solving math problems," Winfree says. "Compared to modern electronic circuits, these are painstakingly slow and exceedingly simple. But they could be useful for the fast-growing discipline of synthetic biology, and could help enable a new generation of technologies for embedding 'intelligence' in chemical systems for biomedical applications and bionanotechnology." Such circuits could be used, for example, to detect specific cellular abnormalities.

The other authors of the paper are David Soloveichik and Dave Zhang, both grad students in computation and neural systems. □—*RT*

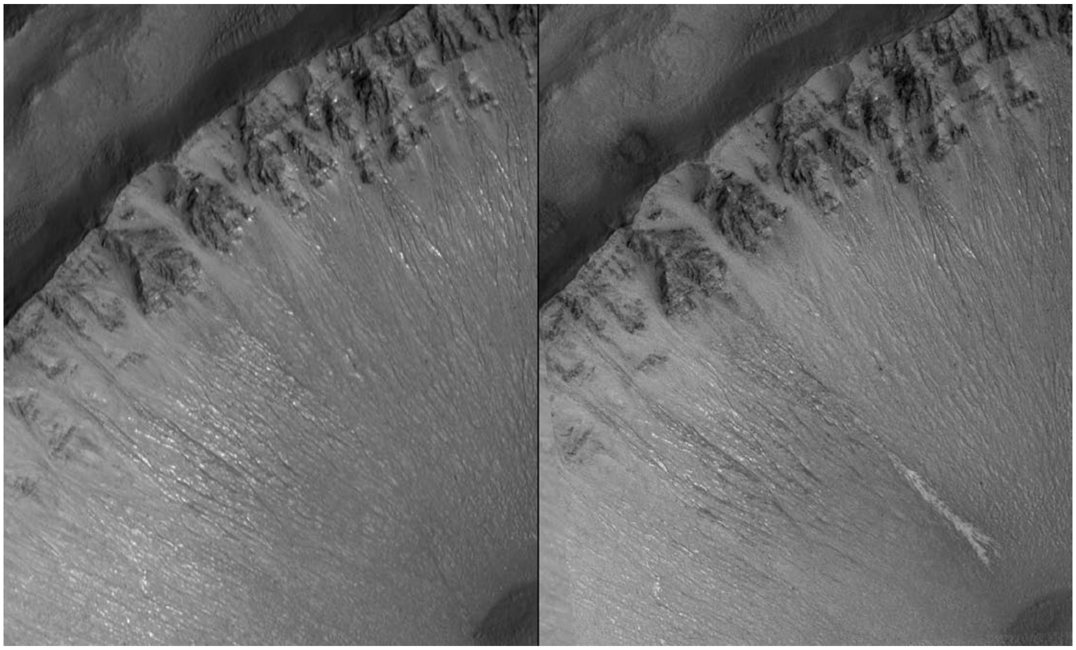
Mars Global Surveyor—Lost, But Not Forgotten

On November 21, NASA announced that Mars Global Surveyor's operating career was likely over. The news came almost three weeks after the last signal was received from the 10-year-old spacecraft, better known as MGS. One possibility is that the spacecraft lost the power to communicate because it could no longer pivot its solar panel to collect enough sunlight to recharge its batteries. Efforts are still under way to regain contact by taking photos of the spacecraft from the Mars Reconnaissance Orbiter. Knowledge of the detailed orientation of MGS may permit JPL to regain radio contact and reestablish control of the spacecraft. Arden Albee, MGS project scientist, former chief scientist at JPL, and Caltech professor of geology and planetary science, emeritus, says the odds are against recovering it, but that it will endure for many years in its orbit at 400 kilometers above the surface of Mars.

Our story really begins with the loss of the Mars Observer in 1993, a year after launch, as it entered Mars orbit. MGS in a sense rose from the ashes of the Observer, as it was assembled quickly from spare Observer parts. The Surveyor was half the size and mass of its forebear, but carried much of the same equipment—narrow- and wide-angle cameras, a thermal-emission spectrometer, magnetometers with an electron reflectometer, a laser altimeter, and a radio system with an ultrastable oscillator.

MGS was launched two days after the 1996 presidential election. Ten months later it pulled into an elliptical orbit around Mars. While pioneering the technique called aerobraking, in which the spacecraft would dip into and out of the Mars atmosphere repeatedly in order to slow down and reach a circular orbit, a solar-panel hinge was damaged. This incident meant the spacecraft needed to brake more slowly to reduce pressure on the panel and avoid further damage, and may have contributed to MGS's ultimate loss. MGS remained in an elliptical orbit, decelerating slowly, for one Mars year (two Earth years).

This delay yielded unexpected bonuses. It had long been thought that Mars had at best a very weak magnetic field, suggesting that, unlike Earth, Mars did not have an actively convecting nickel-iron core. The eventual circular orbit would measure such a field, if it existed. But the elliptical orbit dipped under Mars's ionosphere and revealed remnant magnetism



Far left: This Mars Global Surveyor image of an anonymous crater wall near 38.7 degrees south latitude, 263.3 degrees west longitude in the Centauri Montes region was taken on August 30, 1999. Left: Another image of the same spot taken on September 10, 2005 shows a fresh, bright deposit whose downslope end branches out like fingers of water would around obstacles. If the flow was, in fact, water, it would amount to some five to 10 swimming pools' worth, says Edgett.

in the oldest parts of the crust, suggesting that early in its history Mars had an internal dynamo resembling that of our own planet.

MGS also gathered detailed information about the Martian atmosphere during its delayed descent. The circular orbit that MGS was meant to enter was aligned so that the local surface time below the spacecraft was always 2 p.m. (2 a.m. on the night side), a compromise between the optimal lighting times for camera photography and spectral imagery. Rather than the 2 a.m./2 p.m. measurements MGS would have been restricted to in a circular orbit, the local time changed continuously in the elliptical orbit. During the prolonged aerobraking process, the Martian atmosphere was determined to vary greatly with altitude, and this information guided MGS—as well as later spacecraft—during entry into its ultimate orbiting altitude of 378 kilometers above Mars's surface.

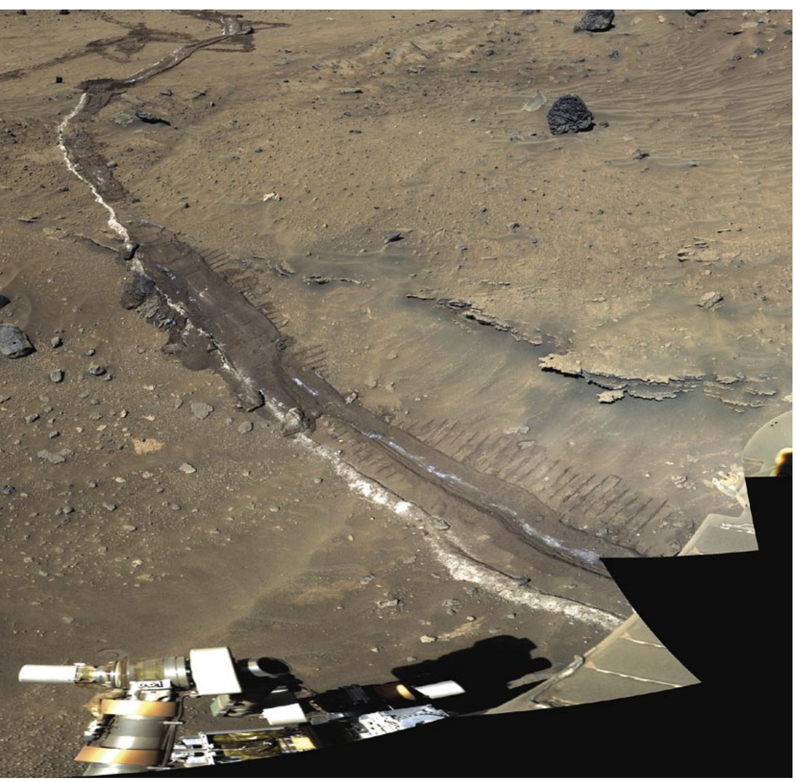
The MGS photos, which number over 240,000, have provided exciting insights into the Martian surface, suggesting a past in which water flowed through gullies and ancient river deltas. The discovery of the water-associated mineral hematite near the Martian equator guided the selection of the landing site for the Mars Exploration Rover Opportunity. Atmospheric measurements allowed MGS to report the "weather" to other incoming spacecraft. Repeated observations and measurements over five Martian years have revealed the changing surface of a planet nearly 60 million kilometers away—for a while we even had better global topographic coverage of Mars than we had of Earth. "Surveyor changed the planet into a known object," Albee says. "Second-grade kids read about Mars as if it were Earth because of the information that came from Surveyor."

We now know that weather systems blow from west to east on Mars just as they do on Earth, and that Mars has a winter during which it snows dry ice at the poles, followed by a summer during which the ice retreats. In its final days, MGS cemented its fame as a comparison of new and old photos showed a fresh, gully-like feature in the side of a formerly smooth crater. The lack of topographic relief of the gully suggests it arose from recently flowing water rather than a landslide. According to Michael Malin (PhD '76), president of Malin Space Science Systems, the sediments deposited along the gully were diverted around obstacles and ended in finger-like branches, just as would happen to water-laid sediments on Earth. Ken Edgett, a Malin staff scientist, was quoted in the *Los Angeles Times* as saying, "You have all heard of a smoking gun; this is a squirting gun." The possibility of liquid water on Mars has boosted the hopes of many who believe life does exist on other planets.

MGS reached many milestones in its lengthy career. The first came after 28 days of data reception provided the first systematic global portrait of Mars. It satisfied all its mission objectives after one Mars year in orbit. Measured by these standards, MGS has far outlived the dreams of the space scientists who designed it and sent it on its way. And now, 10 years later, during which the spacecraft and all its instruments operated nonstop for 24 hours a day, seven days a week, MGS has finally entered a deep sleep, perhaps someday to be reawakened by a radio "kiss" from Earth. □—*EN*

Meanwhile, on the Martian surface, Spirit is on the move again as the days of spring lengthen. The rover had spent the winter strategically parked on a low ridge in order to get maximum solar power for its instruments, which performed a thorough study of its surroundings. Many mysteries remain, however, including the nature of the light material lying just beneath the surface that was exposed by the rover's wheels (below) en route to its winter quarters.

And on the opposite side of the planet, JPL controllers are looking for a route to get Opportunity, Spirit's twin, to the bottom of Victoria Crater.



BRAIN, HEAL THYSELF

Caltech neuroscientists have found a way to stimulate the growth of neural stem cells in the adult brain up to sixfold—cells that might then be used to repair it. According to Paul Patterson, the Biaggini Professor of Biological Sciences, future work may find ways to direct these stem cells—which have the ability to turn into other types of brain cells as they mature—to replace cells that die in disorders such as Parkinson's and Alzheimer's diseases and multiple sclerosis. "Basically, what my colleague Sylvian Bauer did was take a protein called leukemia inhibitory factor, or LIF, and inject it into the brains of adult mice," Patterson explains. "The results show that you can stimulate the subventricular zone to produce a much larger pool of adult neural stem cells." (Bauer, the lead author of the paper describing the work that appeared in the November 15 issue of the *Journal of Neuroscience*, was a postdoc in Patterson's lab at the time.)

"The brains of patients with neurodegenerative diseases show evidence that their neural stem cells do attempt to replace dying cells," says Patterson. "However, their contribution is very limited. Our approach may overcome this, and using one's own cells avoids the problems of the brain rejecting the transplanted cells." The next step is to see if these cells can be directed to replace cells in mice with brains that are damaged in ways similar to those of humans with Parkinson's, Alzheimer's, and multiple sclerosis.

This development in no way renders the use of embryonic stem cells obsolete, or argues against further research with embryonic stem cells, Patterson says. Embryonic stem cells have the potential to become any cell in the body, whereas this process uses adult neural stem cells for brain disorders only. □—*RT*

PICTURE CREDITS: 2, 3 — Bob Paz; 4 — NASA/JPL/U. of Arizona; 8 — NASA/JPL/MSSS; 8–9 — NASA/JPL-Caltech/Cornell