National Aeronautics and
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2004 JET PROPULSION LABORATORY ANNUAL REPORT

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Opportunity rover looked back at its landing site, where the rover studied rocks and soils and then drove up and out of the crater for a trek to the next destination of discovery.

Cassini captured this view of the small icy moon Mimas suspended against the blue-streaked backdrop of Saturn's northern hemisphere.

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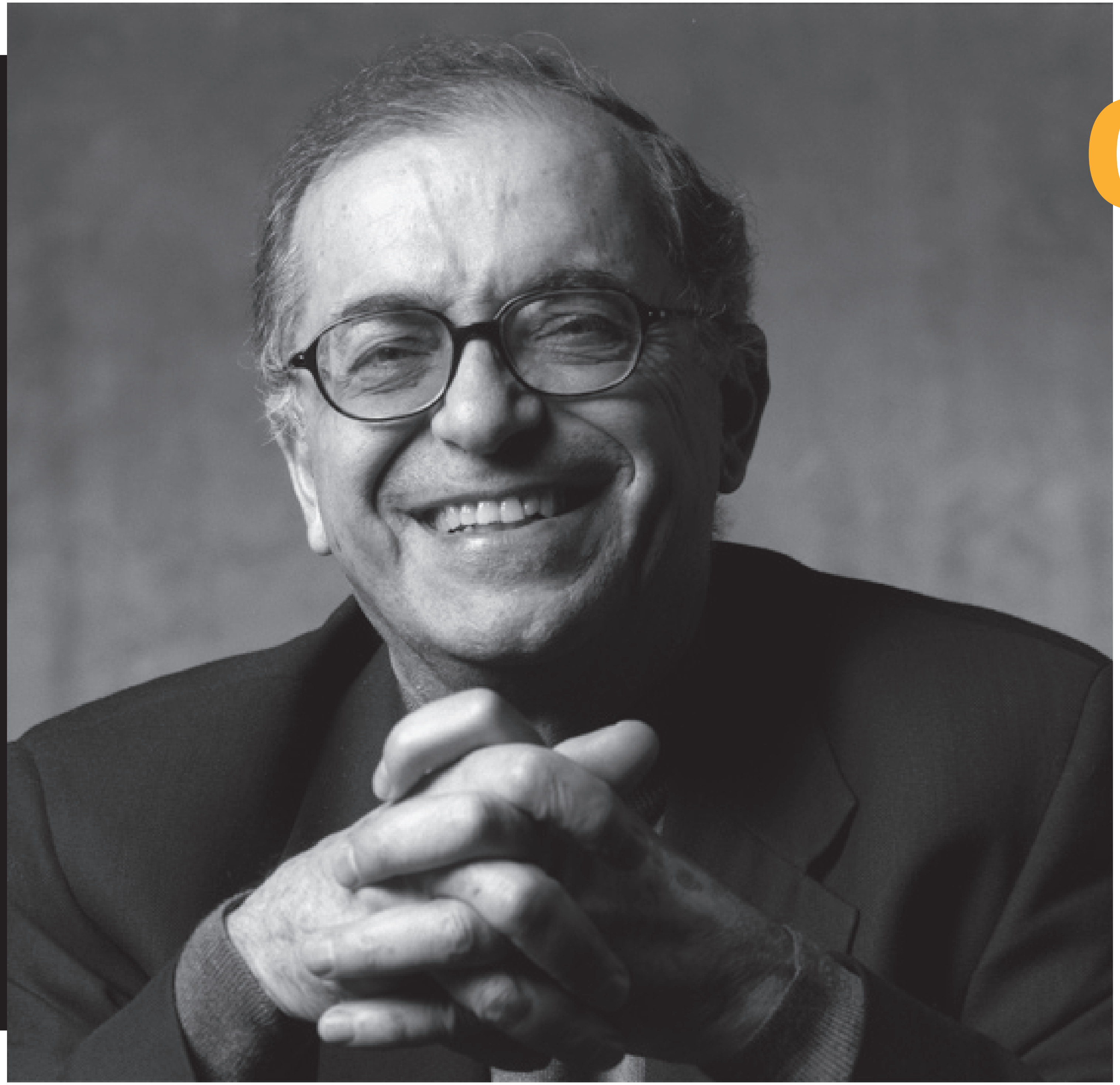
DIRECTOR'S MESSAGE



ONCE OR TWICE IN AN AGE, A YEAR COMES ALONG THAT HISTORIANS PROCLAIM AS AN ANNUS MIRABILIS — A YEAR OF WONDERS. FOR THE JET PROPULSION LABORATORY, 2004 WAS JUST THAT SORT OF TIME.

From beginning to end, it was a nonstop experience of wondrous events in space. Imagine that two robot rovers embark on cross-country rambles across Mars, scrutinizing rocks for signs of past water on the now-arid world. A flagship spacecraft brakes into orbit at Saturn to begin long-term surveillance of the ringed world, preparing to drop a sophisticated probe to the surface of its haze-shrouded largest moon. Another craft makes the closest-ever pass by the nucleus of a comet, collecting sample particles as it goes. Two new space telescopes peer into the depths of the universe far beyond our solar system, viewing stars, nebulas and galaxies in invisible light beyond the spectrum our eyes can see. A pair of instruments is lofted on a NASA Earth-orbiting satellite to monitor air quality and the protective layer of ozone blanketing our home planet. A small probe brings samples of the solar wind to Earth for in-depth study.

There is a saying that small sands make the mountain, and moments make the year. There have been so many amazing moments for us in the past 12 months that 2004 must surely rank as a Mount Everest — or a Mons Olympus, if you are on Mars — among all the years in JPL's history.

While JPL was absorbed with all of these ventures on other worlds, NASA and the White House unveiled an ambitious new plan of space exploration. The Vision for Space Exploration announced in January foresees a program of robotic and astronaut missions leading to a human return to the Moon by 2020, and eventual crewed expeditions to Mars. The vision also calls for more robotic missions to the moons of the outer planets; spaceborne observatories that will search for Earth-like planets around other stars and explore the formation and evolution of the universe; and continued study of our home planet. In order to accomplish all of this, NASA must perfect many as-yet-uninvented technologies and space transportation capabilities.

JPL has a great deal to bring to this vision. Robotic exploration of Mars will lead the way for missions that will carry women and men to the red planet. Our engineers and scientists are formulating spacecraft that could use nuclear power to enable exploration missions of the future. And even now we are designing formations of space telescopes that will capture family portraits of the planets around neighboring stars.

Those are only some of the ways that the Laboratory is contributing to NASA's broader goals. During 2004, JPL made a distinctive contribution to agencywide initiatives in areas such as safety, NASA transformation, the agency's Internet portal and NASA's Explorer Schools programs.

Technology is central to everything that NASA and JPL do, and I'm pleased that we are making excellent progress in making sure that our future here is strong. For the past three years we have been setting aside an increasing percentage of discretionary funding and devoting it to research proposals aimed at developing technologies that we need to accomplish missions of the future. A workshop on these research efforts drew a thousand attendees from JPL and our parent organization, the California Institute of Technology. This is an area, in fact, where I believe the intellectual infusion provided by our unique identity as a NASA laboratory managed by Caltech enables us to make a special contribution to our country's technical needs.

In addition to improving these technological underpinnings of JPL's missions, we spent a considerable amount of energy in 2004 working on other aspects of the Laboratory's institutional infrastructure. Three years ago, we defined 85 initiatives in a wide variety of areas that we believed would strengthen the Laboratory. I'm pleased to say that when we took stock of this effort this past fall, we had already achieved nearly all of these goals.

In tandem with this, when I became JPL's director nearly four years ago, I wanted to create a master plan that would guide the evolution of the Laboratory's physical campus across the next decade. This plan was delivered to and approved by NASA this year. We will be working on bringing it into reality over a number of years, which I am sure will have a very positive effect on the spirit of our employees and on-site contractors. Plans are currently under way for two major new facilities — a flight projects building, and an administration, education and visitor center. (Even as small a step as the purchase of new wooden benches and tables for our exterior areas this year was very well received.)

When I am asked what kind of goals to establish for the Laboratory, I always respond with the question: What legacy do we want to leave in 15 to 20 years? By 2020, there are several goals I believe we can achieve — establishing a permanent robotic presence on and around Mars; surveying niches in our own solar system and around nearby stars where life could evolve; shedding light on the origins of the universe; predicting phenomena on Earth such as hurricanes, El Niños and earthquakes; and creating an interplanetary Internet, or communication fabric linking the solar system. And, while accomplishing all of this, making our country stronger by inspiring young people to pursue careers in science and technology.

Because of the number of talented people on our team, it isn't possible to tell all their stories here. In the following pages, you will meet just a few of the people who are working to create knowledge from our exploration missions.

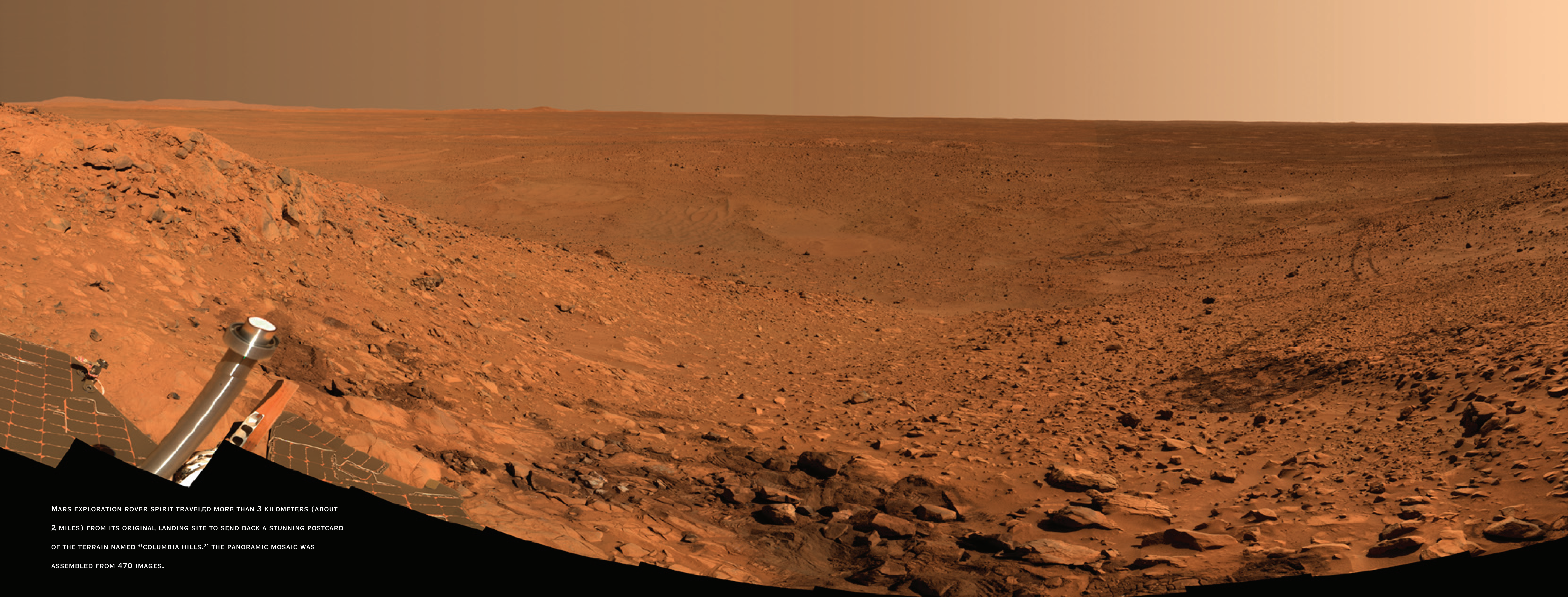
Years like 2004 pose a special challenge for us. It would be easy to say that this was a once-in-a-decade high point of mission activities, but I believe that this would miss an opportunity. We are fortunate to have many space projects in the works that have the promise of being just as exhilarating as the great mission successes that we celebrated this year. The challenge and opportunity for us now is to make every year like this one. I have no doubt that, working together, we will succeed in this.

Charles Elachi

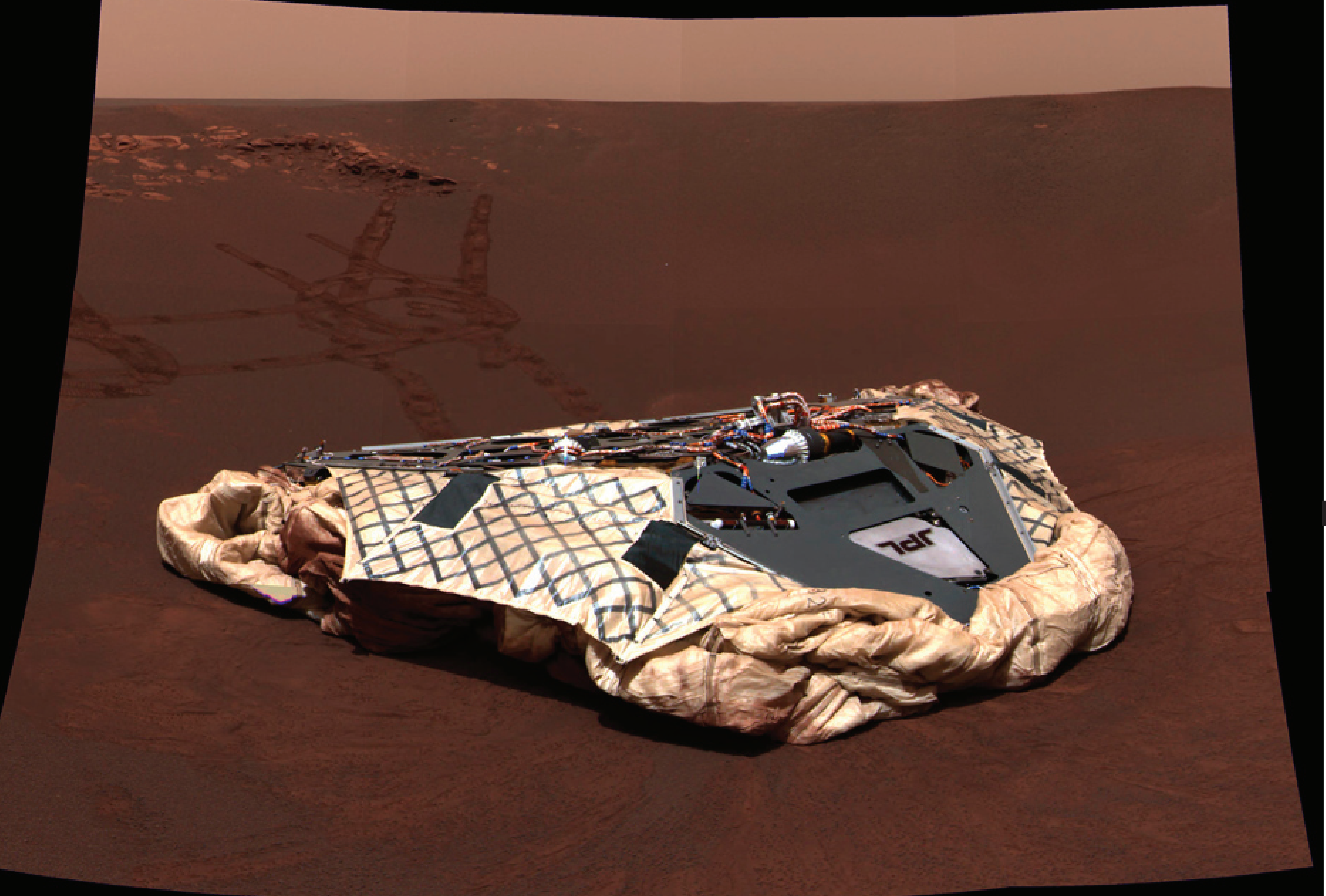
The JPL master plan envisions a future laboratory enhanced technologically and socially.

ENCOUNTERING MARS

Jubilation, pure and simple. That was the emotion that swept across JPL in early January when the first of two Mars Exploration Rovers landed, opening an interplanetary adventure that was still continuing at year's end. The experience was not without its cliff-hangers — the most significant just after the first rover's landing, when it stopped communicating with Earth for a few days, a problem solved the morning of the day the second rover landed. Yet on the whole it was an immensely gratifying team experience — for the mission, for JPL and NASA and for many beyond as the world came along for the ride.



Mars Exploration Rover Spirit traveled more than 3 kilometers (about 2 miles) from its original landing site to send back a stunning postcard of the terrain named "Columbia Hills." The panoramic mosaic was assembled from 470 images.



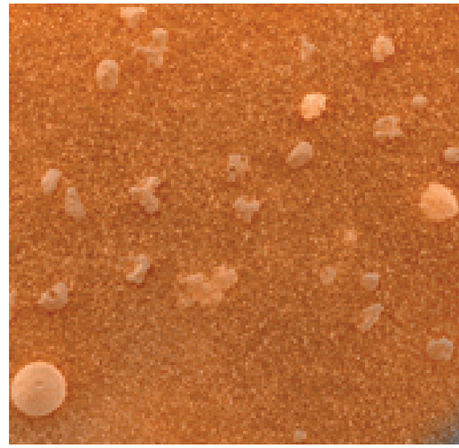
Across the year, the rovers sent home more pictures than all other Mars surface missions combined, surpassed their mission goals many times over and chalked up many billions of hits on their websites.

"The landing of the spacecraft Spirit on Mars is amazing — and inspiring," the *Los Angeles Times* wrote in an editorial in early January. "It's the most ambitious attempt ever to roam another planet." The paper called the rover's arrival "a colossal engineering feat."

"One can only marvel at the fantastic precision of the computerized technologies that allowed the robotic Spirit rover to land near the center of its target area in a vast crater," wrote the *New York Times*. Added the *Washington Post*, "The success of this mission should leave NASA's scientists with a well-deserved sense of achievement."

When Spirit hit the ground inside a Connecticut-sized crater named Gusev on January 3, the airbag-encased bundle bounced 28 times, rolled and stopped right-side up. JPL navigators expertly placed it within 10 kilometers (6 miles) of the center of its target area, an area revealed by its pictures to be a rock-strewn plain. Even before the rover rolled off its landing platform, scientists chose a stadium-sized crater about 300 meters (985 feet) to the northeast as a destination that might offer access to underlying rock layers. They eyed hills on the southeastern horizon as a tempting but probably unreachable goal for later. In what one scientist called an "interplanetary hole in one," Opportunity's bounces and rolling put it inside a 22-meter-wide (72-foot) crater with an exposure of bedrock along the crater's inner wall. "We're about to embark on what could

"ONE CAN ONLY MARVEL . . ."



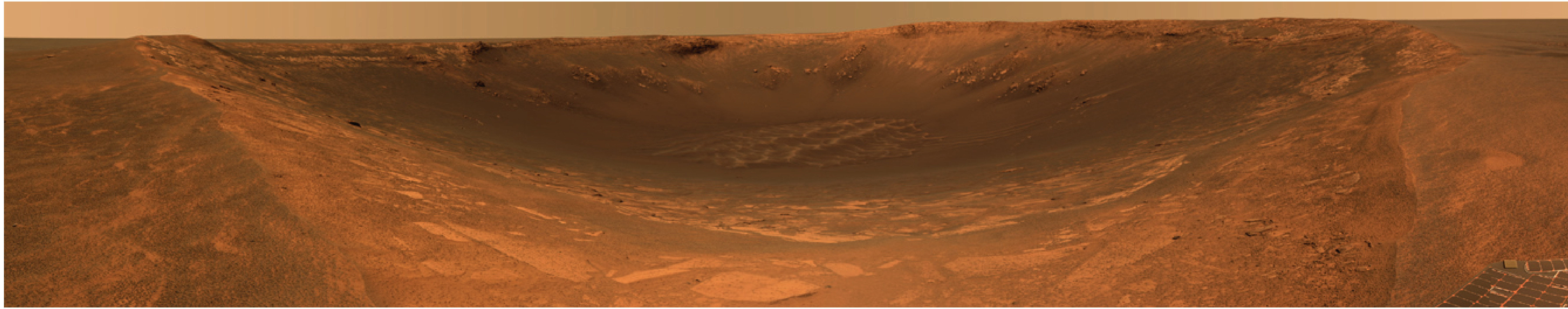
A MAGNIFIED VIEW OF MARTIAN SOIL NEAR OPPORTUNITY'S LANDING SITE FEATURES INTRIGUING SPHERICAL ROCKS.

◀ OPPORTUNITY PAUSED TO PHOTOGRAPH ITS NOW-EMPTY LANDER AND TRACKS TO A BEDROCK OUTCROP STUDIED FOR EVIDENCE OF PAST WATER.

be the coolest geological field trip in history," Dr. Steve Squyres, the mission's principal investigator, exulted after the successful landing. Opportunity spent nearly two months in this crater, informally named "Eagle Crater," collecting the evidence that told scientists a body of water had once covered the area. Then it climbed out, heading for an even deeper bowl, "Endurance Crater," to the east.

In April, both rovers successfully completed their primary three-month missions and went into bonus overtime work. During the summer, Spirit completed a 3-kilometer (nearly 2-mile) trek to the southeastern hills, to which NASA had assigned names commemorating the last crew of Space Shuttle Columbia. Opportunity descended into Endurance Crater, where it found layer upon layer of rocks bearing evidence that they had once been drenched in water. In September, NASA approved a second extension of the rovers' missions. Spirit and Opportunity were still in good health well past their intended operational lifespan, though beginning to show signs of aging.

Like extraterrestrial detectives, the rovers had specific clues to look for — any signs pointing to the existence of water in Mars' past. At least on its surface, the planet is now very dry — so any such evidence would have to be held in the rocks and minerals strewn across Mars. The landing sites were chosen for very different reasons, both, however, being related to the water question. From space, Spirit's target at Gusev resembles a now-dry channel flowing into a crater lake. In the case of Opportunity's landing site, orbiting spacecraft had revealed that it was rich in a mineral called



"THEN IT CLIMBED OUT, HEADING FOR AN EVEN DEEPER BOWL . . ."

▲ OPPORTUNITY PERCHED INCHES AWAY FROM THE EDGE OF A STADIUM-SIZED IMPACT CRATER (NICKNAMED "ENDURANCE") BEFORE DRIVING DOWN THE TREACHEROUS SLOPES. INSIDE, OPPORTUNITY FOUND MORE EVIDENCE THAT THE AREA WAS ONCE WATER-SOAKED.

hematite that usually — but not always — forms in the presence of water. Although the rovers could start their search by examining any handy rocks nearby, scientists were eager for them to get to bedrock — the underlying layers that would show the basic geological personality of each landing site. Opportunity got lucky, and found outcroppings of bedrock a quick robotic stroll away from where it bounced to a stop. There the Opportunity rover found a mineral called jarosite, a powerful smoking gun because it only forms in the presence of water. Spirit had to do more work to get to its bedrock.

AFTER A FLIGHT OF 487 MILLION KILOMETERS, SPIRIT LANDED ABOUT 10 KILOMETERS FROM THE CENTER OF THE TARGET.

▲ THE FALSE-COLOR "BLUE" TINT ON THE FLAT SURFACES BETWEEN THESE SAND DUNES INDICATES THE PRESENCE OF A MINERAL THAT USUALLY FORMS IN WATER.

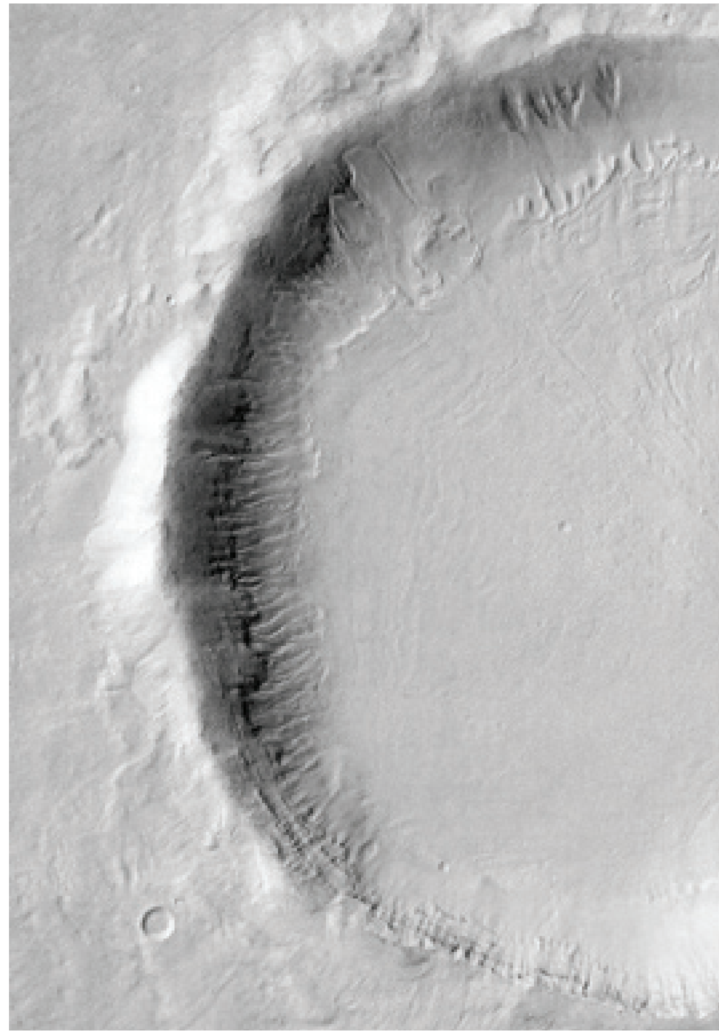
After checking first at a crater known as "Bonneville," Spirit made a long trek into the hills, where it found not only bedrock but a mineral called goethite — another rock that forms only in the presence of water.

"This is a profound discovery," NASA's associate administrator for space science, Dr. Edward Weiler, remarked at a news conference in March where scientists announced one set of water-related findings. "It has profound implications for astrobiology."

The journal *Science* bestowed the honor of Breakthrough of the Year for 2004 on the rovers for their discovery of evidence of past water on Mars. "Hearty congratulations are in order for NASA's Mars Exploration Rover team, and the whole Mars crew at the agency," said the industry magazine *Aviation Week*, "for the stunning proof they have provided that liquid water once flowed on the red planet." Added the *Houston Chronicle*, "The knowledge transmitted by this robotic mission to Mars is priceless." A *Los Angeles Times* editorial concluded with the word "Wow."

The rovers did not do all of this alone. Two NASA Mars orbiters provided crucial information for the selection of rover landing sites, and also played important communication roles once the rovers reached Mars. Nearly all of the scientific data from Spirit and Opportunity reached Earth by relay from Mars Odyssey and Mars Global Surveyor rather than using the rovers' direct-to-Earth capability. Demonstration relay sessions with the European Space Agency's Mars Express orbiter showed the success of international standards that JPL helped develop for interplanetary communications.

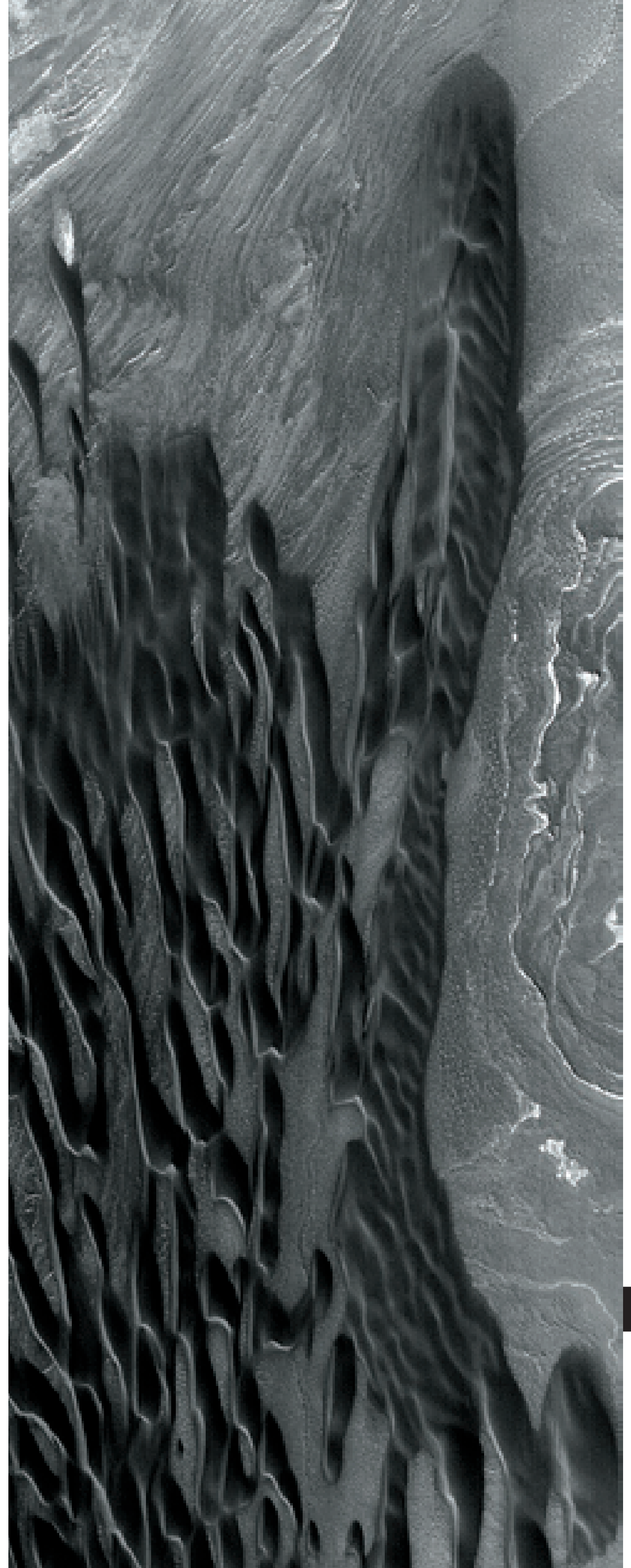
Mars Odyssey, in orbit since 2001, began its own extended mission in August after completing a prime mission that discovered vast supplies of



MARS ODYSSEY LOOKED FOR MORE EVIDENCE OF FROZEN WATER, PHOTOGRAPHING THESE GULLIES ON MARTIAN CRATER WALLS THAT MAY HAVE BEEN CARVED BY MELTING SNOW PACKS.

frozen water, ran a safety check for future astronauts and mapped surface textures and minerals all over Mars, among other feats. Odyssey findings indicate that there is too much frozen water in some relatively warm regions on Mars for it to be in equilibrium with the atmosphere, suggesting that Mars may be going through a period of climate change. The mission has tracked dramatic seasonal changes, such as the comings and goings of polar ice, clouds and dust storms. Its extension for another Mars year (through September 2006) will provide an opportunity to check for year-to-year changes at the same time of year.

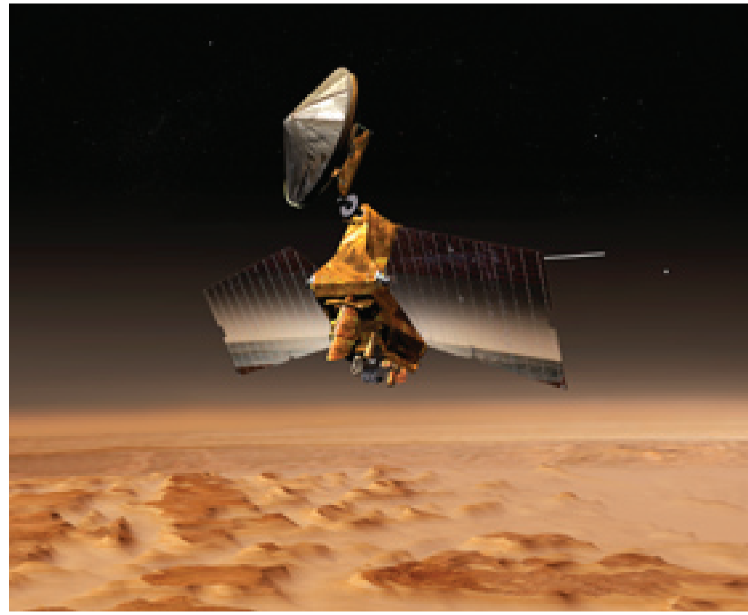
Mars Global Surveyor began its third extended mission in September after seven years of orbiting Mars. It became the longest-operating Mars spacecraft earlier in the year when it surpassed Viking Lander 1's 76-month longevity, which ended in 1982. During the past two years, operators of the orbiter and its camera developed a way to wring even sharper pictures out of what was already the highest-resolution camera ever to orbit Mars. They adjust the roll rate of the spacecraft to match the ground speed under the camera, keeping the camera pointed at the target longer. Principal goals for the orbiter's latest extended mission include continued weather monitoring and continued mapping and analysis of sedimentary-rock outcrop sites, as well as imaging of possible landing sites for future Mars missions.



MARS GLOBAL SURVEYOR IMAGED THESE DARK SAND DUNES IN THE NORTH POLAR REGION, WHERE DUST AND ICE LAYERS MAY HAVE RECORDED A HISTORY OF CLIMATE CHANGE.

While keeping the current martian fleet afloat, the team on Earth was also busy preparing their next ship. Mars Reconnaissance Orbiter will launch from Florida in August 2005 for arrival at Mars in March 2006. The orbiter's six instruments installed in 2004 include the most powerful telescopic camera ever flown to another planet, able to show martian landscape features as small as a kitchen table.

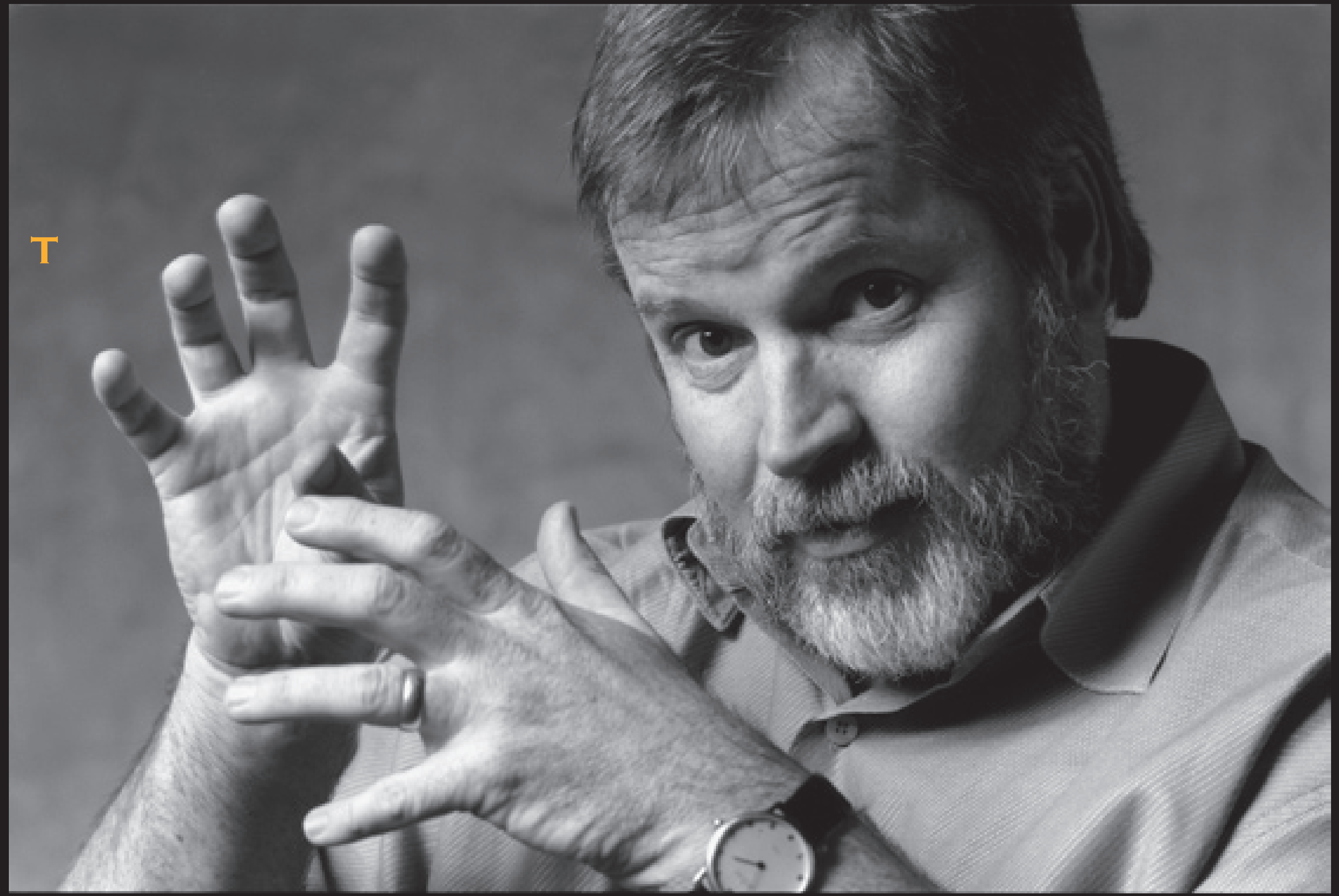
Throughout 2004, JPL also managed preparations for a Mars lander to launch in 2007 and for both a rover and orbiter to launch in 2009. The 2007 mission, Phoenix Mars Scout, will land in icy soils near the north polar ice cap of Mars. The 2009 rover, Mars Science Laboratory, will set down a large, sophisticated mobile laboratory using precision landing that will make many of Mars' most intriguing regions reachable destinations for the first time. The 2009 Mars Telecommunications Orbiter, the first spacecraft dedicated to acting as a relay station at another planet, will serve as the Mars hub for a growing interplanetary Internet. Taken together, all of these missions have established a permanent presence on Mars.



AN ARTIST'S CONCEPT OF MARS RECONNAISSANCE ORBITER OVER THE BELT OF KNOBBY TERRAIN SEPARATING MARS' CRATERED SOUTHERN HIGHLANDS FROM LOW NORTHERN PLAINS.

"... THE TEAM ON EARTH WAS ALSO BUSY PREPARING THEIR NEXT SHIP."

S P O T L I G H T



"IT WAS ONE THING AFTER ANOTHER . . ."

AS ROB MANNING REMEMBERS IT, THERE WERE SO MANY NAIL-BITERS AS THE SPIRIT AND OPPORTUNITY ROVERS CLOSED IN ON MARS AS 2004 BEGAN, IT'S AMAZING THE TEAM CAME THROUGH THE EXPERIENCE WITHOUT BECOMING NERVOUS WRECKS.

"It was one thing after another," recalls Rob, who served as manager of entry, descent and landing for the Mars Exploration Rovers. "A few months out, we were hit by a major solar flare. That actually wasn't too bad — Spirit's star tracker lost stellar reference, and we decided to reboot the spacecraft's computer. "But then, right around Christmas — about a week and a half before the first landing — a major dust storm broke out on Mars," he says. "This got us worrying. Software on the lander would open the parachute when it got to a certain dynamic pressure. If the atmosphere was too thin, it would wait too long and there wouldn't be enough time for the rover to prepare for landing. We worried a lot about this, although in the end we decided we had enough time to get the parachute open."

That wasn't all. "Then we realized we had two major hardware problems. When we did a test of the lander's battery, we discovered that it couldn't supply current fast enough when the vehicle turned away from the Sun in the hour before landing — and the entry vehicle with the rover inside would be stuck dead pointing the wrong way for entry. So all of a sudden we had to spend time 24 hours before the landing, conditioning the batteries. So then, on the Tuesday four days before landing, we found that we had deep trouble with the software and hardware designed to fire the pyros — to make the events happen to enable the entry, descent and landing. We discovered in the software testbed that the software was talking too fast to the hardware. This didn't become clear until we were 30 hours out from landing. Rather than try to fix the software, we decided just to send manual commands to enable the pyro timers."

Despite those cliff-hangers, Spirit made a flawless landing. Three weeks later it was joined on Mars by its sibling rover, Opportunity. That made Manning — who also guided entry, descent and landing of 1997's Mars Pathfinder as chief engineer of that mission's flight system — three-for-three in landing on the red planet.

Which landing made him most nervous? Perhaps surprisingly, it was the final one — Opportunity — that had him most on the edge of his seat. "With Pathfinder, my job was to prove we could do it. When we landed, I wasn't relieved, I was thrilled," Manning recalls. "With Spirit, we had been doing so many rehearsals and dry runs that the real landing itself seemed fake.

"With Opportunity, we hadn't done any rehearsals for several weeks. We were also all very nervous because Spirit had almost died" when it stopped communicating, says Manning. "So when Opportunity landed, every moment seemed very real. I was extremely aware of the fragility of these missions. When it got down safely, I was extraordinarily relieved."

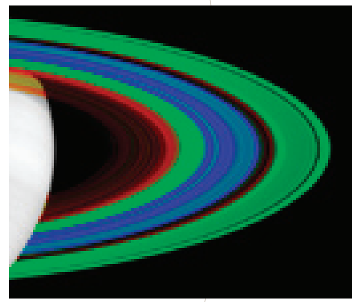
His role in the three rover missions was unique in the sense that "entry, descent and landing" wasn't a specialty taught in engineering school.

Manning originally came to JPL from Caltech as a draftsman working on diagrams of the Galileo spacecraft. He later specialized in designing spacecraft computers and ways for spacecraft like Cassini to protect themselves when faults occur.

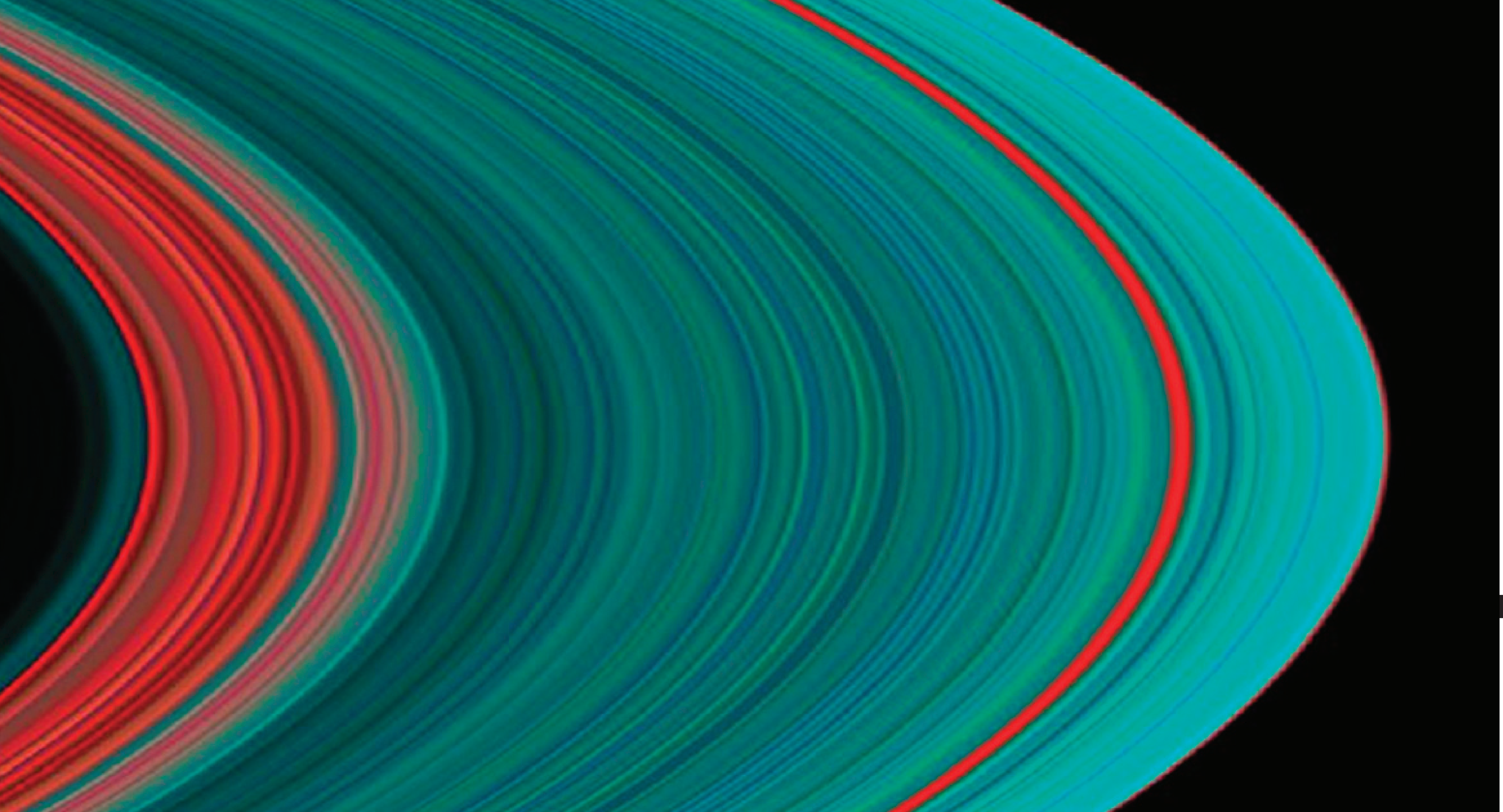
R O B   M A N N I N G

"When Pathfinder came along, they needed an overall systems engineer to look at entry, descent and landing. To do that you have to be able to work with different specialists and talk everyone's language," says Manning. "Now I'm chief engineer for JPL's Mars program — leading tiger teams and fighting fires," he adds. "It's really about the same thing — bringing our unique and talented people together."

SOLAR SYSTEM EXPLORATION

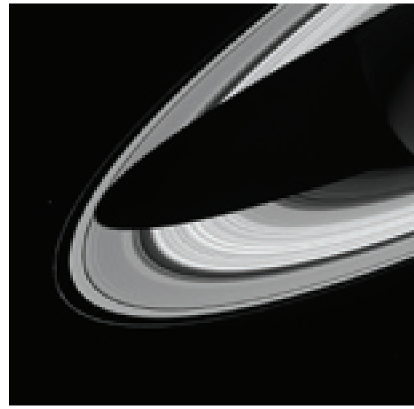


During many epochs of JPL's history, the Laboratory concentrated on a planet at a time — perhaps with a big Mars mission one year, a major Jupiter project another year. In 2004, however, the Laboratory literally had robotic explorers scattered across the solar system. The year began with a major milestone for the Stardust spacecraft, which yielded the most detailed, highest-resolution images ever taken of a comet when it flew by comet Wild 2 on January 2. The pictures revealed a much stranger world than previously believed — a rigid surface dotted with towering pinnacles, plunging craters, steep cliffs and dozens of jets spewing material into space.



Besides taking data, Stardust collected samples of comet dust that it will return to Earth in the Utah desert in January 2006.

After a seven-year journey from Earth and several flybys of other planets, the flagship Cassini spacecraft fired its main engine for an hour and a half in July to place it into a near-perfect orbit at the stately ringed planet Saturn. As it crossed the plane of Saturn's rings on its closest approach, Cassini captured dozens of stunning images showing hundreds of ringlets, waves and ripples within the rings, as well as dramatic views of storms roiling the planet's colorful atmosphere.



Saturn's outermost ring revealed delicate knot-like features in this Cassini image.

"After a seven-year journey from Earth . . ."

◀ Photographing Saturn's rings in ultraviolet light brings out differences in composition: the turquoise ringlets are icier.

"Cassini has made its way to a place where we will all begin to marvel once more," wrote the *New York Times* in an editorial following the Saturn arrival.

"The Cassini–Huygens spacecraft's successful maneuver around Saturn is an amazing feat of science," said the *Houston Chronicle.* Added the *Orlando Sentinel*, "Cassini's voyage is another example — like the pair of probes still exploring Mars — of what NASA is capable of achieving. ... Scientists are thrilled, but every American can be proud."

In October, the spacecraft made a close pass by haze-shrouded Titan, Saturn's largest moon and a prime target of the mission. "NASA at Its Best," the *Los Angeles Times* said of Cassini in a headline on its lead editorial the week of the Titan flyby. Using an imaging radar instrument and optical cameras outfitted with filters to see through the haze, Cassini sent scientists views of a geologically complex, nearly crater-free surface that may mean Titan's terrain is relatively young. "This bizarre world may be far more complex than we've even begun to imagine," said Dr. Larry Soderblom, a geophysicist with the U.S. Geological Survey and member of the Cassini science team.

At the end of December, the Cassini orbiter released an instrumented probe called Huygens.

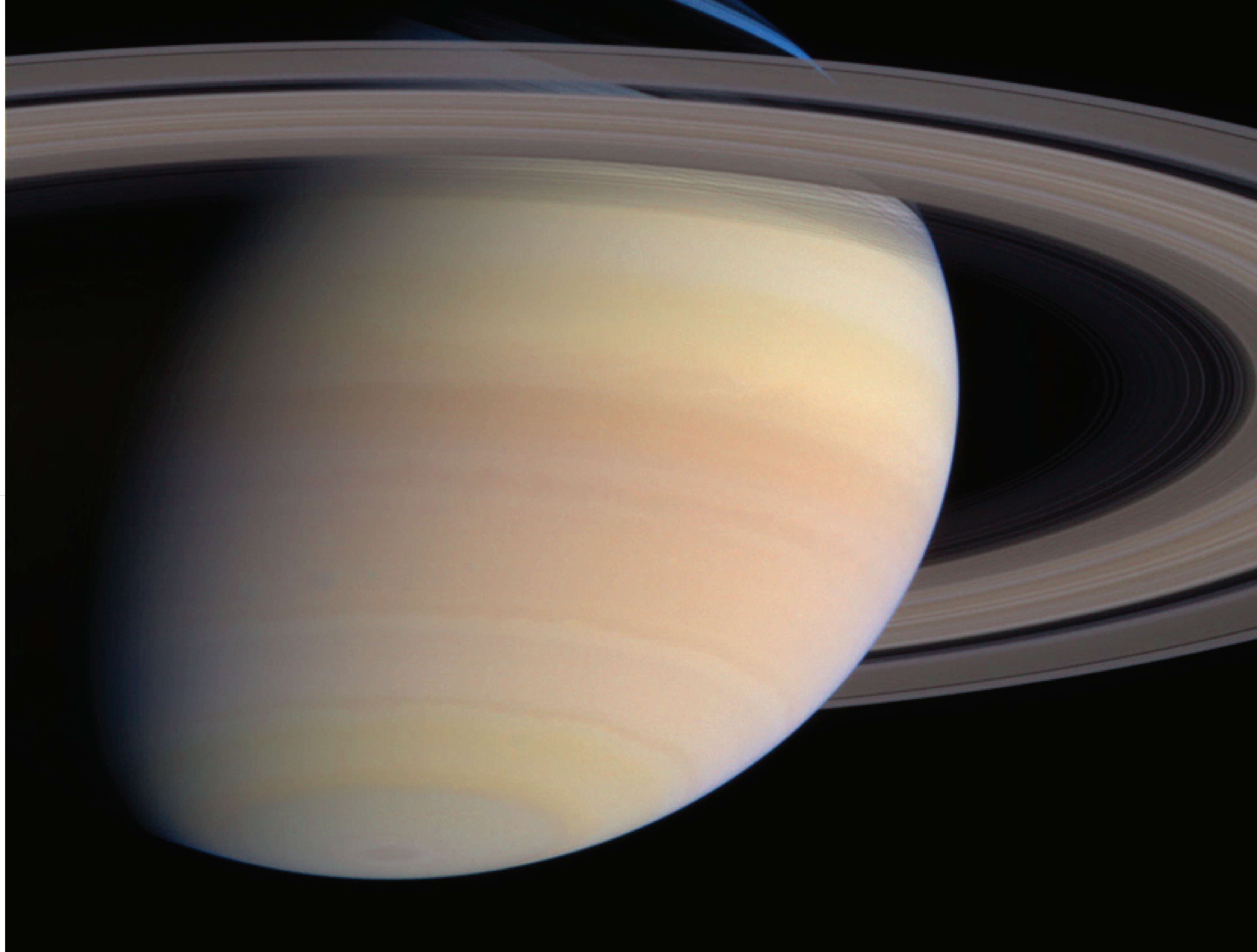
"NASA AT ITS BEST"

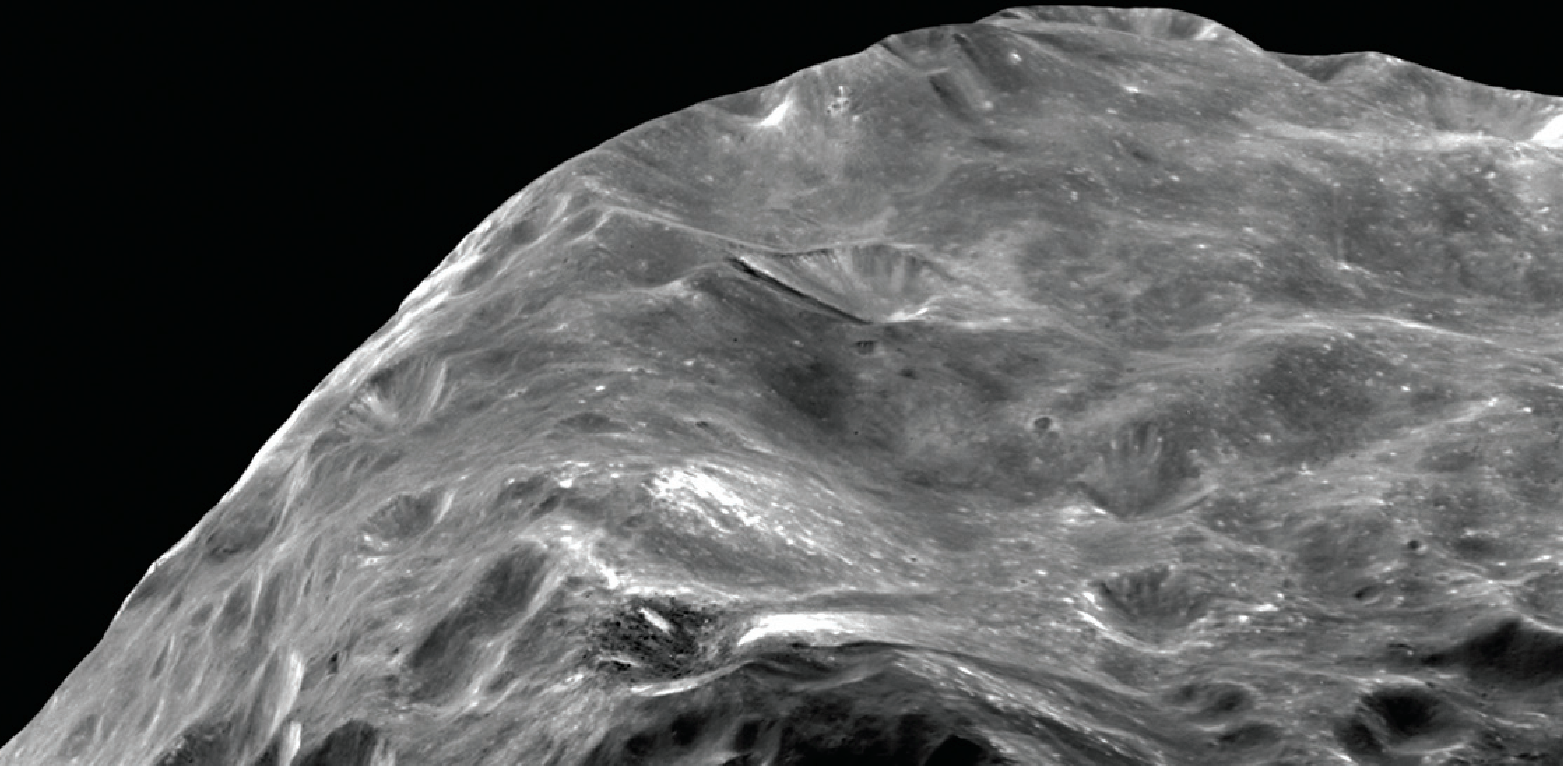
The probe, provided by the European Space Agency, was targeted to descend to the surface of Titan in mid-January 2005. Huygens will take pictures and use a mini-weather station to sample the dense atmosphere, which may hold the same organic compounds that led to the emergence of life on the early Earth.

Utah was also the destination in September for the Genesis spacecraft, which had spent more

As cassini coasted toward saturn, the planet and its dazzling rings gradually filled the camera's field of view.

▼ Purple stratospheric haze surrounds titan in this colorized image taken one day after cassini's first flyby of the giant moon.





CASSINI'S FLYBY OF PHOEBE WAS THE ONLY CHANCE TO EXAMINE THE LITTLE MOON UP CLOSE.

than three years in space collecting samples of solar wind — streams of ions that constantly flow outward from the Sun — to help scientists better understand the solar system's earliest history. The main Genesis spacecraft delivered its sample return capsule precisely as planned over the salt flats of northwest Utah, but the capsule's parachutes did not open and it impacted the ground. Even so, the capsule's samples were successfully recovered, and scientists were optimistic that they could achieve most or all of their research objectives.

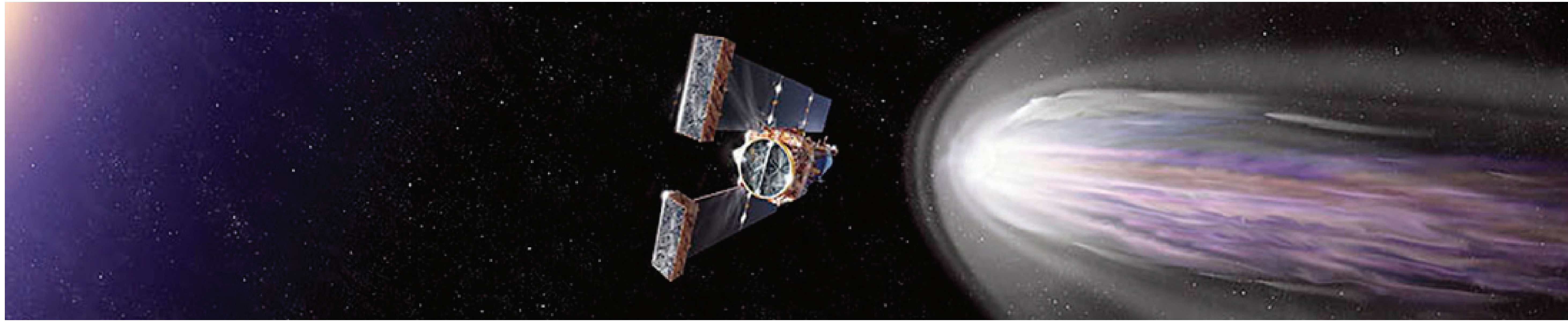
Phoebe's south pole region illustrates the moon's violent history. The brighter material is most likely ice, which streams down the crater slopes.

At the edge of the solar system, the twin spacecraft Voyager 1 and 2 journey onward 27 years after their launches. Now long past their chief mission to fly by and study the outer planets Jupiter, Saturn, Uranus and Neptune — Voyager 1 is now the most distant human-made object in space — the long-lived spacecraft are probing for the outer edge of the Sun's energy influence. In June, Voyager 1 experienced a massive solar wave that was subsequently tracked via several other planetary and Earth-orbiting spacecraft around the solar system. Later in the year, Voyager 1 and Voyager 2 detected oscillations of plasma waves that flow outward from the Sun, as well as increases in the activity of energetic particles. These may be harbingers of the spacecraft reaching a zone that scientists call the Sun's termination shock, the outer fringe of its energy influence.

In other solar system ventures, JPL engineers and scientists designed and built a microwave instrument to fly on the European Space Agency's comet-bound Rosetta spacecraft. Launched in March, Rosetta will take the next decade to journey to comet Churyumov–Gerasimenko where it will enter orbit in 2014, allowing the JPL instrument to examine the escape of gases from the comet nucleus. Other teams at JPL spent 2004 laying the groundwork for future missions. The Prometheus project is developing nuclear electric propulsion for future missions. One proposed mission, the Jupiter Icy Moons Orbiter, could use this advanced capability to allow it to hop from orbiting one moon to another around the giant gas planet Jupiter. The moons it would target — Callisto, Ganymede and Europa — may have vast oceans beneath their icy surfaces.

Progress was also made on a pair of missions that, like Stardust and Genesis, are being carried out under NASA's Discovery program of competitively selected, low-cost solar system exploration missions. Following launch in January 2005, Deep Impact will fire an impactor into comet Tempel 1 on July 4, 2005, to witness how material is ejected from the comet's interior. Scheduled for launch in 2006, the Dawn spacecraft in 2010 will reach the asteroid Vesta, where it will spend a year before departing and traveling to the solar system's largest asteroid, Ceres.

Ground-based activities in 2004 continued to build an important library of knowledge about the asteroids with orbits that bring them close to Earth. The Near-Earth Asteroid Tracking program surveyed the sky systematically from Hawaii and Southern California to find space rocks that could be on a collision course with Earth. In 1998, Congress directed NASA to find 90 percent of the estimated 1,100 near-Earth asteroids greater than 1 kilometer (about one-half mile) in diameter by the end of 2008. Scientists believe that asteroids of that size and larger have the potential of causing global consequences if they were to hit Earth, while impacts from smaller space rocks would probably be limited to regional effects. By the end of 2004, JPL's program and others have located two-thirds of the estimated total population of the larger near-Earth asteroids.



"... A RIGID SURFACE DOTTED WITH TOWERING PINNACLES, PLUNGING CRATERS, STEEP CLIFFS AND DOZENS OF JETS SPEWING MATERIAL INTO SPACE."

▲ STARDUST CAPTURED PARTICLES — BITS OF THE ANCIENT SOLAR SYSTEM — STREAMING FROM A COMET'S NUCLEUS FOR RETURN TO EARTH.

“WE’RE THE GREMLINS WHO TRY TO BREAK THE SPACECRAFT . . .”

SPOTLIGHT

LETICIA MONTAÑEZ

NOT EVERY JPL EMPLOYEE HAS HER OWN PRIVATE SPACECRAFT — AND IS PAID TO TRY TO BREAK IT.

While the real Cassini spacecraft glides from moon to moon hundreds of millions of miles away at Saturn, Leticia Montañez has an end-to-end replica of it back on Earth. Unlike the real spacecraft, however, hers is not mounted on a towering chassis robed in golden blankets; it is spread out across a table in a basement room in JPL’s mission control building. “Dissected might be a better way to put it,” she says.

But if her spacecraft has a slightly ungainly look to it, it works just like the real one. Feed in computer commands, and it does exactly the same thing. Tell it to fire a thruster, and it fires a thruster. Tell it to take a picture, and it takes a picture. Which is the point.

“We’re the gremlins who try to break the spacecraft,” said Montañez, who as lead of Cassini’s integrated test lab oversees a team of 14. “It’s our job to find every single hole.”

Every action that the real Cassini spacecraft carries out starts as a set of computer commands created at JPL. First, scientists and mission planners decide what they want the spacecraft to accomplish during a particular flyby of one of Saturn’s moons — or perhaps at another point in its orbit when it has the chance to view the planet’s stately rings or butterscotch-colored atmosphere.

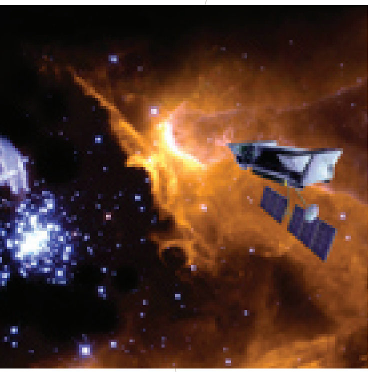
Those aspirations are turned into commands encoded in hundreds of lines of software that are periodically sent up to Cassini. But first, the commands frequently make a detour downstairs to Montañez’s lab.

“We don’t pre-test every single command that goes to Cassini,” she explains, “but we do run all of the critical maneuvers. A flyby of Titan, for example. If flight software can survive the testbed, it will be really clean when it gets to the spacecraft.”

Although her team hopes to find as few problems as possible, they do turn up the occasional glitch — or develop ideas for an improvement to make a science observation better. “We have a camera that likes the spacecraft to be nice and steady while taking pictures,” she says. “If you’re taking a series of pictures to make a mosaic of Titan and you do a few turns, you might end up with some blurred pictures. We can help fix that.”

Montañez started at JPL straight out of high school as a summer hire in the procurement office in 1982 before going off to college and earning a computer science degree from Cal State Los Angeles. She then returned to JPL and spent several years doing test work for the Galileo mission, and briefly Mars Pathfinder, before joining the Cassini team eight years ago.

“I almost ended up as an artist,” says Montañez, who took art classes at Otis College of Art and Design. But a husband-and-wife teacher team in high school whetted her interest in math. Says Montañez, “Now I can’t imagine doing anything else.”



SURVEYING THE UNIVERSE

An orchestra would offer a tame sound indeed if it were limited to notes around the middle of the scale — it achieves the richness of its sound by blending the lilting highs of violins with the throaty lows of cellos. In the same way, telescopes that behold the universe only in the middle range of visible light offer only a limited view of the rich energies reaching us from the farthest regions of space. To broaden our view, we must look higher and lower.

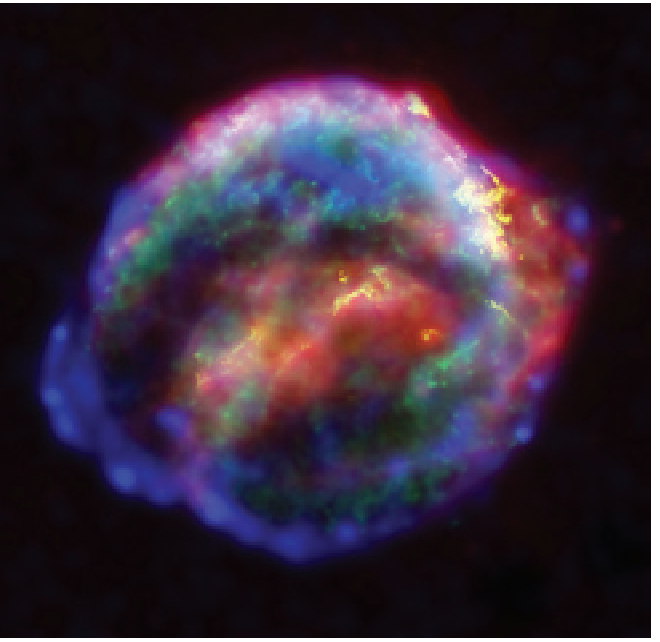
The new cello in NASA's astronomical orchestra is the Spitzer Space Telescope — formerly known as the Space Infrared Telescope Facility. After launch and in-orbit checkout late in 2003, Spitzer spent 2004 using its heat-sensing infrared eyes to pierce cosmic dust and reveal hidden objects. Just a few of those previously unglimpsed sights included a family of newborn stars whose births were triggered by the death of another star; a dying star surrounded by a mysterious donut-shaped ring; and a cannibalistic galaxy with a strange parallelogram-shaped meal at its core.

THE SPITZER SPACE TELESCOPE IMAGED A COSMIC LABORATORY WHERE SHOCK WAVES FROM AN ANCIENT SUPERNOVA EXPLOSION LED TO THE BIRTH OF MANY NEW STARS.

Spitzer also peered deep into the dustiest regions of space to capture cold and dusty planet-forming discs — planetary construction zones around stars. One of the discs was discovered to harbor what may be the youngest planet ever detected. Gazing into the distant universe, Spitzer spied one of the farthest and most ancient galaxies ever seen, and was able to measure its age and mass for the first time.

Spitzer's observations of dust surrounding other stars suggest that the process of forming planets may be more chaotic than astronomers previously believed. "It's a mess out there," said Dr. George Rieke of the University of Arizona, Tucson. "We are seeing that planets have a long, rocky road to go down before they become full-grown."

"IT'S A MESS OUT THERE."



THIS GLOWING, BUBBLE-SHAPED, EXPANDING CLOUD OF GAS AND DUST IS 14 LIGHT-YEARS WIDE. THE COMPOSITE IMAGE WAS TAKEN AT DIFFERENT WAVELENGTHS BY THE HUBBLE AND SPITZER SPACE TELESCOPES AND THE CHANDRA X-RAY OBSERVATORY.

The Spitzer telescope also joined forces this year with NASA's other Great Observatories — the Hubble Space Telescope and Chandra X-ray Observatory — to study a supernova and distant black holes. Each observatory uses different wavelengths, from high-energy X-rays with Chandra, visible light with Hubble, to infrared with Spitzer. These studies across multiple wavelengths are considered essential for putting together a complete picture of how the universe formed and evolved.

The orchestra's high notes, meanwhile, were sounded by another new spaceborne telescope launched in 2003, the Galaxy Evolution Explorer. This spacecraft uses state-of-the art detectors in the ultraviolet region beyond human vision to observe hundreds of thousands of galaxies. Its ultimate goal is to map the history of star formation over the last 10 billion years. In 2004, astronomers used the Galaxy Evolution Explorer to identify three dozen bright, seemingly young galaxies relatively nearby — a finding that implies our aging universe may still spawn newborn galaxies.

And then there are the musical duets. High atop Mauna Kea in Hawaii, a pair of 10-meter (33-foot) telescopes are specially linked by a technique called interferometry, which blends the light that they gather to create the equivalent of a much larger and more powerful telescope — in fact, eight and a half times larger in diameter than either telescope alone. The JPL-managed Keck Interferometer will eventually offer astronomers three different modes to study space objects. In 2004, scientists started using one of these modes to study discs orbiting newborn stars that are believed to be in the process of forming planetary systems. Other modes under development will help astronomers study dust discs resulting from completed planets, and also to detect Jupiter-sized planets very close to stars.

"... TO STUDY DISCS ORBITING NEWBORN STARS ..."

▲ THE TWIN KECK TELESCOPES PROBE THE DEEPEST REGIONS OF THE UNIVERSE WITH UNPRECEDENTED PRECISION.

NASA hopes to launch the technique of interferometry into space in a few years with one of the most precise telescopes ever devised, JPL's Space Interferometry Mission, recently renamed PlanetQuest. Its goal is to measure the universe by accurately determining the distances and locations of stars and nearby galaxies, and to identify Earth-like planets around nearby stars. The project has completed nearly all of the technology milestones set by NASA, paving the way for its launch in several years.

Other future planet-hunting missions under development or planning at JPL in 2004 included the Kepler mission, scheduled to launch in 2007, and the Terrestrial Planet Finder, which will consist of two space observatories: an optical coronagraph, scheduled to launch around 2014, and a formation-flying mid-infrared interferometer, to be launched sometime before 2020. In 2004 NASA approved a new JPL mission called the Wide-field Infrared Survey Explorer. This spaceborne telescope will search the sky in infrared light, looking for cool stars, planetary construction zones and the brightest galaxies in the universe. It will use infrared detectors up to 500,000 times more sensitive than previous survey missions.

The missions all explore the universe in different ways, but ultimately they all help answer the same question — Are we alone?

IN SEARCH OF NEW WORLDS, THIS ORBITING INTERFEROMETER WILL OPEN A NEW WINDOW ON THE UNIVERSE.

SPOTLIGHT

"WHAT WE WILL BE LOOKING FOR ARE PATTERNS OF LIGHT COMING FROM THE ENTIRE PLANET . . ."

ALTHOUGH IT'S NOT QUITE THE INTERPLANETARY VERSION OF A PIZZA STAND, IF YOU'RE LOOKING TO COOK UP A PLANET, VIKKI MEADOWS CAN DELIVER.

There's only one catch — the toppings aren't what's usually on the menu at the local take-out. Unless you have a taste for nitrous oxide, methane or methyl chloride.

The planets on Meadows' menu are not the true rock, ice and water kind, but rather exist only in a virtual reality. That is because they are brought to life in JPL's Virtual Planetary Laboratory, one of 16 NASA-affiliated sites at institutions around the country devoted to different pieces of astrobiology.

While colleagues at other sites pursue questions such as how life emerges, Meadows tackles one of the most immediate issues that we will face as we look at other stars with better and better telescopes: How would we recognize a life-bearing planet if we saw one?

"When we start detecting Earth-sized planets around other stars, we won't be able to see mountains and rivers," said Meadows, a native of Australia who has been with JPL for 11 years. "What we will be looking for are patterns in the colors of light coming from the entire planet that tell us what chemicals make up the planet's atmosphere and surface.

"Now, some of those planets might resemble Earth, but others might not," she added. "In fact, Earth has changed a lot since it was created, so it would look different at different periods throughout its history — in the past it looked like a different planet."

We may get our first glimpse of other Earth-sized planets in about a decade, when JPL's first Terrestrial Planet Finder mission is launched. The mission will use a large space-based telescope to search for planets like our own.

But to make that useful, scientists first have to do some homework — to refine ideas of what a life-bearing planet might look like. And that is where Meadows' planet lab comes in.

By entering parameters into their software, she and her team create planets that exist only as tables of data "that tell us the conditions of the planet — and what it would look like viewed from space," she explains.

VIKKI MEADOWS

"We can change factors like the oxygen abundance. Or what if the life there had a sulfur-dominated metabolism — what would that do to an early-type planet? And we look for biomarkers produced largely by bacteria and algae, such as nitrous oxide, methane and methyl chloride."

Meadows divides her time between JPL, where she hangs her hat at the virtual planet lab, and the Caltech campus, where she works at the Spitzer Science Center as a solar system observation scientist.

"I was always interested in the sciences," says Meadows, whose degrees are from the University of New South Wales and the University of Sydney. "I wanted to do biochemistry. Part of what got me into astronomy was that I went through a lot of science fiction. From Asimov to Zelazny — I read it all."

MONITORING EARTH

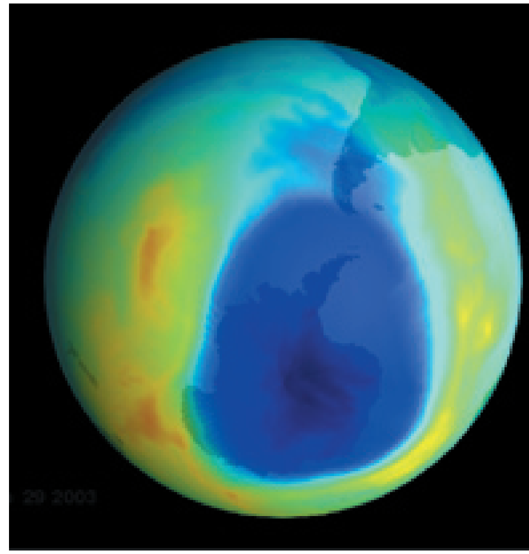
Not all of the focus at JPL in 2004 was on distant worlds. Scientists and engineers dedicated to the study of our home planet made progress on several fronts in their studies of Earth's atmosphere, oceans and land. Several of these efforts were targeted at a chemical that can be a double-edged sword — ozone. Just as there is good and bad cholesterol, there are places in Earth's atmosphere where ozone plays a positive, protective role, and others in which it can create problems.

Cape town and the cape of good hope, south africa, are in the foreground of this perspective view, generated from elevation data collected by the shuttle radar topography mission combined with a landsat satellite image.

In July, NASA launched the latest in its fleet of Earth Observing System satellites, Aura, carrying four instruments designed to survey different aspects of Earth's atmosphere. Two of the four are JPL instruments. The Tropospheric Emission Spectrometer is a first-of-its-kind infrared sensor capable of studying pollution in the troposphere — the lowest part of the atmosphere. Here, ozone from sources such as automobile and industrial emissions and the burning of plants and other agricultural waste plays a very harmful role. By contrast, ozone occurs naturally in Earth's upper atmosphere, where it shields us from the Sun's harmful ultraviolet rays. JPL's other instrument on Aura, the Microwave Limb Sounder, targets this "good" ozone layer for study. This instrument measures a comprehensive suite of the gases that regulate ozone. It has already provided unprecedented detail on the chemical evolution of this year's Antarctic ozone hole.

Aura's studies have been complemented by other efforts in 2004 that improved our understanding of the loss of "good" ozone in Earth's upper atmosphere. In one, JPL and Harvard scientists teamed to make the first-ever observations of a key molecule and gauge its role in ozone destruction. The Harvard researchers took measurements of the molecule, chlorine peroxide, from a NASA aircraft flying over the Arctic. JPL scientists used their models to better quantify the effect of chlorine peroxide on ozone loss over Earth's poles during wintertime.

"... a chemical that can be a double-edged sword — ozone."



This satellite image shows the extent of the ozone hole over Antarctica.

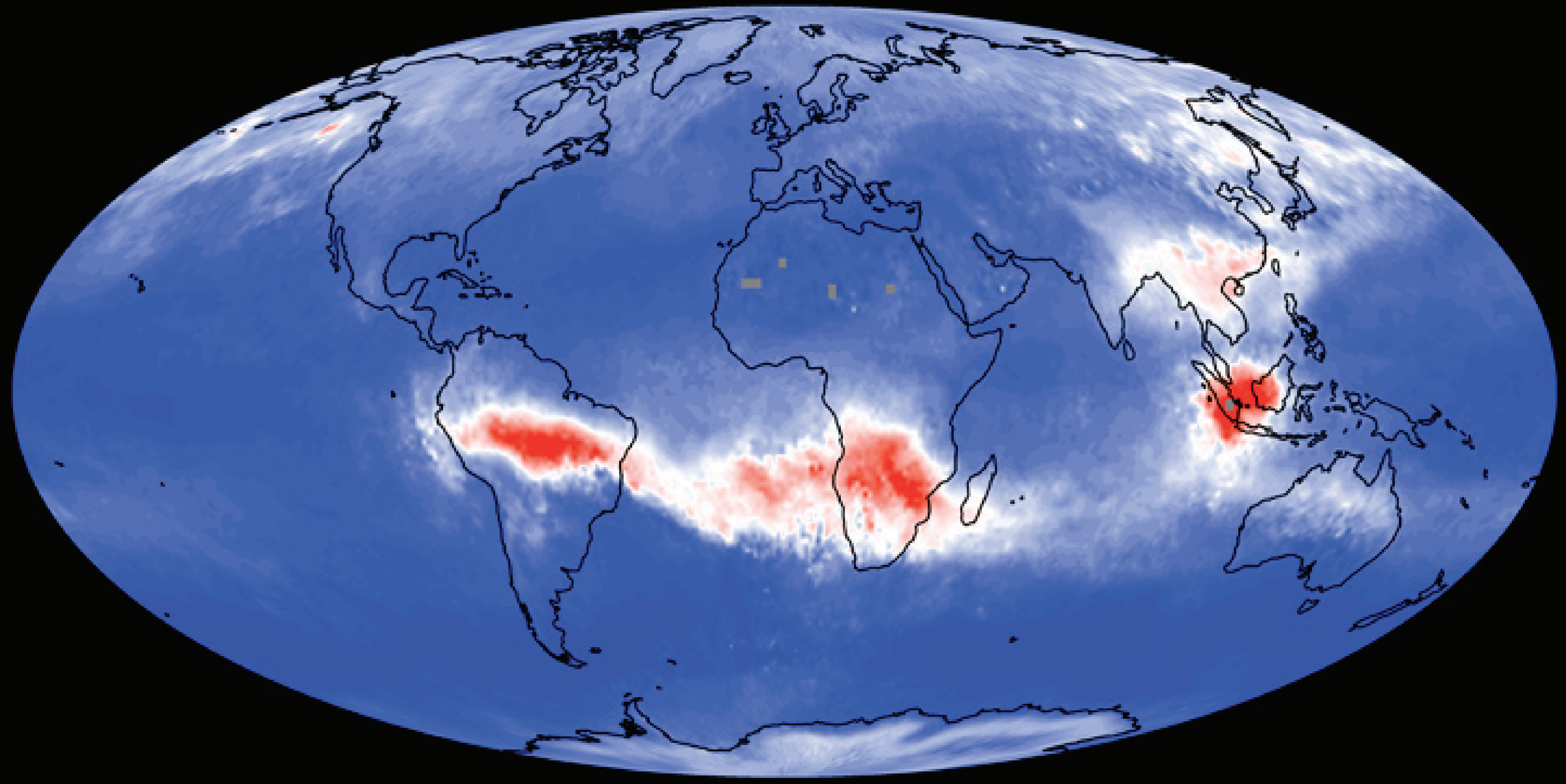
◄ Two JPL instruments are flying on board NASA's Aura satellite, monitoring different parts of Earth's atmosphere.

Another study quantified, for the first time, the relationship between ozone loss over the Arctic and changes in the temperature of Earth's stratosphere. According to this study, ozone loss due to the presence of the industrial chemicals chlorine and bromine may be sensitive to subtle changes in the climate of Earth's stratosphere — and, in fact, this sensitivity is three times greater than previously predicted. Results of the research will be used to improve computer simulations of ozone depletion.

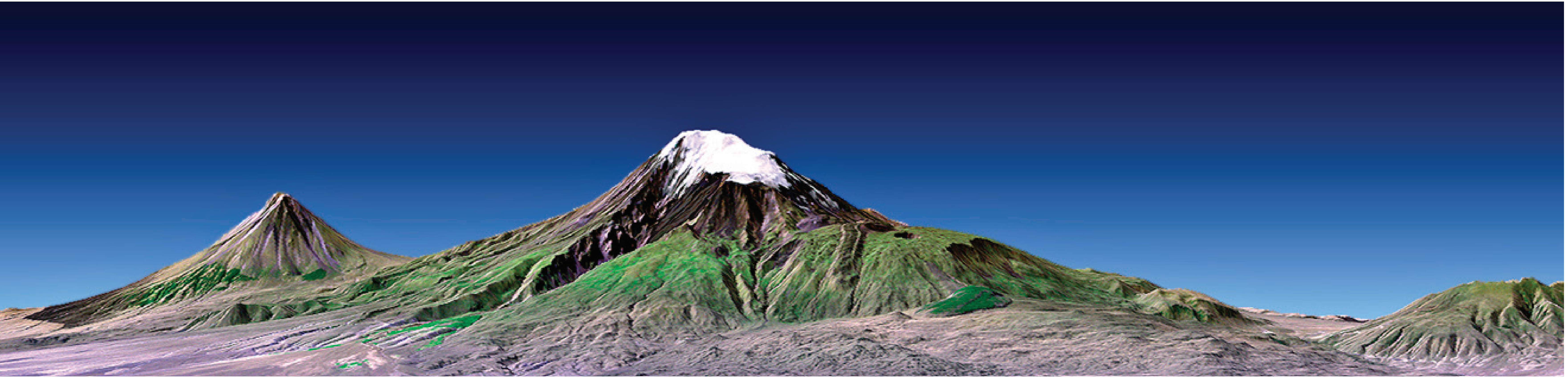
Looking down at the lower zone of the atmosphere, JPL's Atmospheric Infrared Sounder experiment aboard another NASA satellite, Aqua, produced the first-ever global map of carbon monoxide in the troposphere. This instrument can map carbon monoxide over most of the globe on a daily basis. Such daily mapping will enable scientists to track events that release carbon monoxide, such as wildfires. Carbon monoxide is a primary pollutant, as well as a precursor to "bad" ozone — and thus an indicator of the health of the lower atmosphere.

Looking lower still, JPL's Shuttle Radar Topography Mission released enormous sets of data describing the topography, or land heights, across Europe, Asia, Africa, Australia and various islands. This data release completed the world's first high-resolution, near-global elevation model, created after the radar instrument flew in 2000 aboard Space Shuttle Endeavour and mapped roughly 80 percent of Earth's landmass. For many regions around the planet, the new elevation maps are 10 times more precise than the best available

NEW TECHNOLOGY CAN CREATE A THREE-DIMENSIONAL IMAGE OF EARTH'S ATMOSPHERE — MUCH LIKE A CAT SCAN.



THE DISPERSION OF CARBON MONOXIDE FROM WILDFIRE BURNING WAS MEASURED BY A JPL INSTRUMENT ON NASA'S AQUA SATELLITE.



THE MISSION ACHIEVED ITS GOAL OF PRODUCING THE MOST COMPLETE HIGH-RESOLUTION MAP OF EARTH'S LANDFORMS.

▲ THIS PERSPECTIVE VIEW OF MOUNT ARARAT AND "LITTLE ARARAT" IN EASTERN TURKEY WAS GENERATED FROM A SATELLITE IMAGE COMBINED WITH RADAR DATA.

previously. Applications for the data range from studying earthquakes, volcanism, floods and other natural hazards, to planning development, managing precious water resources, and ensuring the safety of aircraft navigation.

A different type of radar, JPL's Airborne Synthetic Aperture Radar, flew a three-week expedition of discovery aboard a NASA DC-8 aircraft that took it and an international team of scientists from the rain forests of Central America to Antarctica. The team surveyed selected sites in Central America to help unearth archaeological secrets, and to aid preservation of resources and biological and cultural diversity. They then surveyed Antarctica and South America's Patagonia ice fields to conduct topographic ice surveys to help determine the contribution of Southern Hemisphere glaciers to sea-level rise caused by climate change.

Antarctic glaciers and climate change were the target of a pair of other studies that yielded dramatic evidence of the impact of climate warming during 2004. In one, JPL researchers used data from European and Canadian satellites to establish that ice shelves, such as the Larsen B ice shelf that broke away from the coast of the Antarctic Peninsula in 2002, act as "brakes" on the glaciers that flow into them. When these ice shelves break up, nearby glaciers can move up to eight times faster, causing the height of the glaciers to drop. The research clearly shows for the first time that the collapse of ice shelves caused by climate warming accelerates glacier flow — suggesting that climate warming can lead to rapid rises in sea level. The second study found that glaciers in West Antarctica are shrinking at a rate substantially higher than observed in the 1990s. While the rates of glacier change remain relatively small at present, the potential exists for these glaciers to increase global sea level by more than 1 meter (about 1 yard), warranting continued observations.

Meanwhile, a 10-year earthquake forecast developed by researchers from JPL and the University of California, Davis, continued to amass an impressive track record. In the two years since the Rundle–Tiampo Forecast was published in 2002, California experienced 14 earthquakes of magnitude 5 or greater — and the JPL-teamed forecast accurately predicted the locations of 13 of them. The study uses records of quakes from 1932 onward to predict locations most likely to have quakes of magnitude 5 or greater from 2000 to 2010. The information will help engineers and government decision makers prioritize areas for further testing and seismic retrofits. The scorecard is one component of a NASA project called QuakeSim, which combines high-precision space-based measurements with computer simulations and pattern recognition techniques.

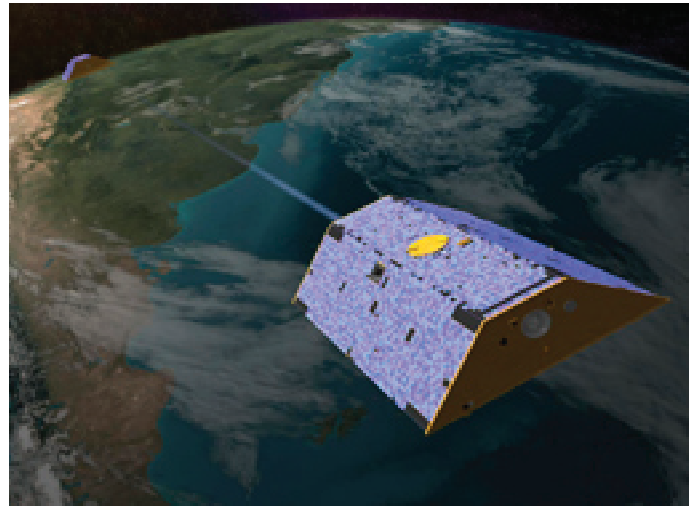
"We're nearly batting a thousand, and that's a powerful validation of the promise this forecasting technique holds," said Dr. John Rundle of UC Davis, one of JPL's collaborators on the earthquake project.

Studies of faults such as the extensive San Andreas network are a high priority. ▶

Scientists released more than a year of data from the JPL-managed Gravity Recovery and Climate Experiment, or Grace, showing for the first time that precise measurements of month-to-month changes in Earth's gravity field can track how water moves from one place to another, influencing climate and weather. Grace measured the change in gravity caused by 10 centimeters (about 4 inches) of large-scale groundwater accumulations from heavy tropical rains in places such as the Amazon basin and Southeast Asia.

Finally, a NASA study based partially on sea-level measurements from JPL's Topex/Poseidon oceanographic satellite suggests that changing winds and currents in the Indian Ocean during the 1990s contributed to warming in that ocean. The results help scientists understand how regional climates vary, ultimately impacting the marine food web.

Whether studying the atmosphere, oceans or solid Earth, the missions all have the same underlying objective — to improve life here by understanding and protecting our home planet. JPL is exploring new technologies and developing scientific tools that support this goal.

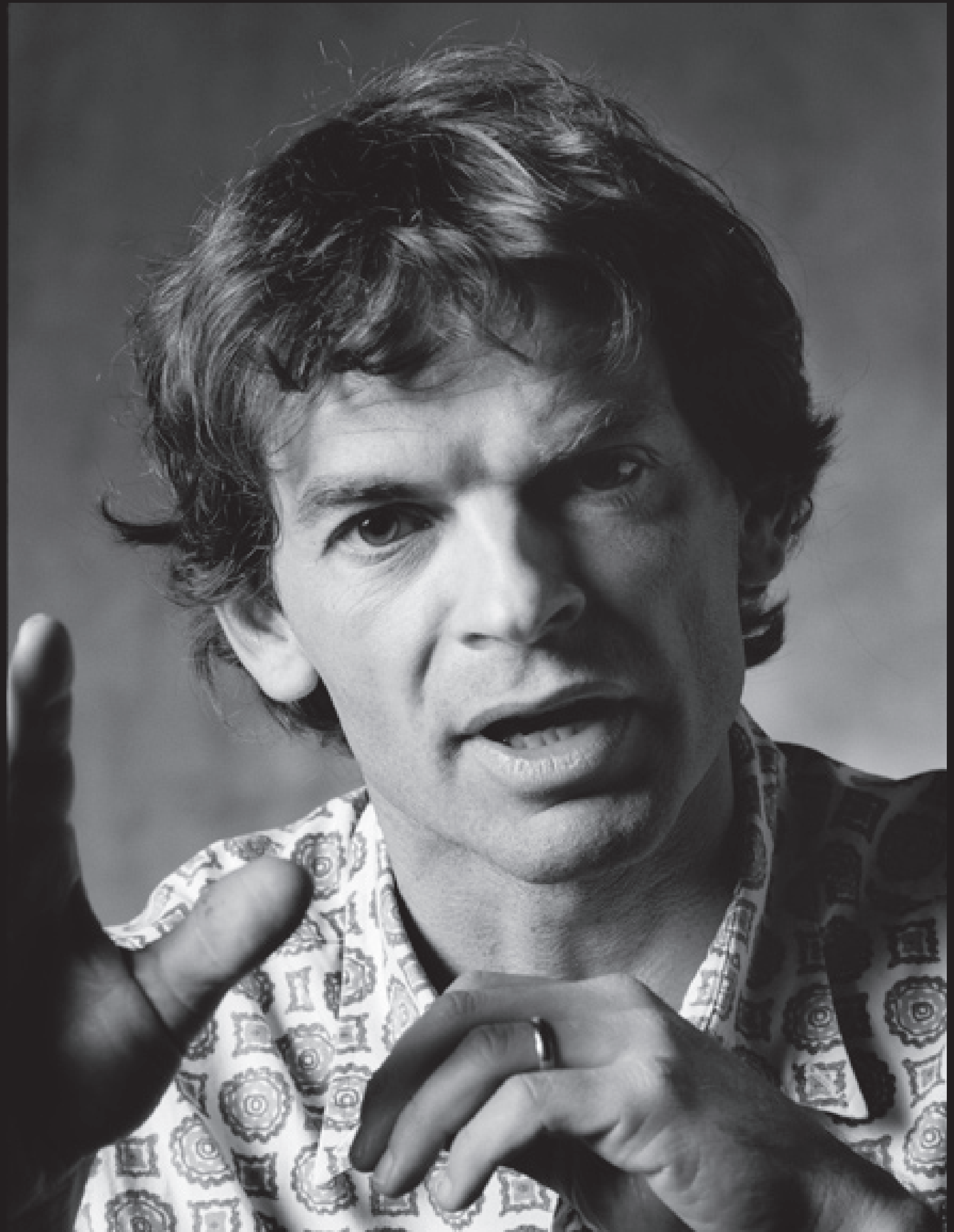


By measuring the distance between the twin Grace satellites, scientists detect tiny variations in Earth's gravity field.

"... to predict locations most likely to have quakes of 5 magnitude or greater ..."

SPOTLIGHT

"WE HAVE ALL BEEN ASTONISHED TO SEE HOW QUICKLY CHANGES ARE TAKING PLACE — NOT IN CENTURIES OR DECADES, BUT OVER JUST A FEW YEARS, SOMETIMES A FEW WEEKS."



ERIC RIGNOT

ERIC RIGNOT DEVELOPED A TASTE FOR SNOW, ICE AND WINTER SPORTS DURING HIS YOUTH ON THE RUGGED, VOLCANO-LACED SLOPES OF FRANCE'S IMPOSING PLATEAU, THE MASSIF CENTRAL. AS A STUDENT IN PARIS AND THEN AS A RESEARCH ASSISTANT AT USC, HIS INTELLECTUAL CURIOSITY WAS SNARED BY THE TECHNOLOGY OF IMAGE PROCESSING.

So it's not a great leap to imagine him blending those interests by spending his career using radar imagers on satellites and airplanes to track the creep of ice sheets and glaciers on the world's most desolate continent, Antarctica.

"This way of studying glaciers and ice is a technology that didn't exist 15 years ago," says Rignot, who came to JPL in 1988. At the time, the Laboratory had flown imaging radar on NASA's space shuttle in 1981 and 1984, and would do so again in 1994 and 2000. Space agencies of other countries had plans to launch imaging radar satellites. Researchers were getting a handle on how to use radar technology to study topics such as ocean winds and vegetation.

And a young program was just getting under way using radar to study ice sheets. Rignot joined a campaign that first turned its attention to the ice sheet blanketing Greenland. "We wanted to find out within the next 10 years a definite answer on whether the Greenland ice sheet was gaining or losing mass as a result of climate change. It was an exciting time, many multidisciplinary scientists pulling together." He and his colleagues spent much of the 1990s studying that island and refining techniques. "What can you learn about the motion of ice from space using imaging radars? By the end of the decade, we started applying the same successful techniques we had developed to Antarctica and other parts of the world."

Two years ago, Rignot participated in a major campaign flying an airborne radar instrument over Antarctica that was carried out jointly between NASA and scientists in Chile. This resulted in two important science papers that appeared within the past year. The news was not comforting.

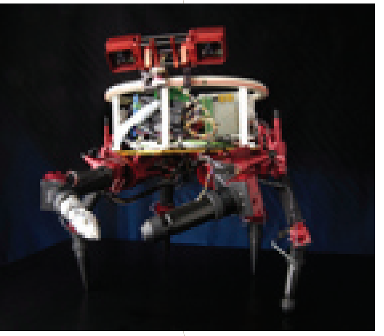
"Glaciers are changing dramatically," says Rignot. "We have all been astonished to see how quickly changes are taking place — not in centuries or decades, but over just a few years, sometimes a few weeks. Even the most alarmist of us has been taken aback by the scope and speed of what we are seeing."

In coming years, Rignot says his main focus will be to work out the mass tied up in glaciers on the Antarctic Peninsula — the large, curving finger of land protruding from the polar continent toward South America. "Glaciers there are retreating faster than anywhere else," says Rignot. This may provide us with definite clues about the future of the larger glaciers found farther south on the Antarctic continent as climate warms up.

He and his colleagues want to use a technology called radar tomography that will allow them to look at conduits and veins of melted water underneath the surface of glaciers that play an important role in controlling glacier flow. "Radar techniques will help provide breakthroughs here."

Although the technologies that Rignot is involved with have applications in the exploration of other planets — such as ice crusts on moons like Jupiter's Europa — he knows that their most important impact is at home.

"The changes in glaciers we are seeing worldwide are going to affect people directly in coming decades, slowly but surely," he says. "So I'd like to think that these techniques pioneered at JPL will continue to make a crucial contribution."



ADVANCING TECHNOLOGY

Everything that JPL does rests on technology, and keeping a sharp technological edge is one of the most important keys to the Laboratory's future. So while many teams of engineers and scientists work on flight projects, others are devoted to the pursuit of new technologies. Some of them are pursued for the sake of pure research, while others will make their way into future missions.

DATA FROM THE FINAL 30 SECONDS OF SPIRIT'S DESCENT WERE USED TO CREATE COMPUTER-GENERATED ANIMATION ILLUSTRATING HOW NEW SOFTWARE CONTROLLED THE LANDING.

When the Mars Exploration Rovers ventured forth on the red planet, the observations they made of rocks were designed by a piece of software known as the Science Activity Planner. Based on data visualization and computer simulation techniques, the software can be used in a variety of other applications in aerospace and in industrial uses such as monitoring fluid flows. The JPL package was the winner of NASA's Software of the Year award, honoring it as the "best of the best" software developed by any wing of the agency.

Getting the rovers safely onto the martian surface was the goal of another new technology called the Descent Image Motion Estimation System. This package uses machine-vision techniques to study photos taken of the ground as the rovers descended in order to understand how the spacecraft was being buffeted by wind shears. The software in turn had fully automated control over the rovers' onboard thrusters. The system successfully kept each rover well inside its safety envelope as it landed.

Yet another software initiative that was highly successful in space was a package known as the Autonomous Sciencecraft Experiment. This pack-

"... A SHARP TECHNOLOGICAL EDGE ..."

IT TAKES A PLASMA TO MEASURE A PLASMA: A NEW SYSTEM WILL HELP CREATE SENSORS TO STUDY THE REMNANT OF THE BIG BANG'S PLASMA.

age, which automates onboard science data analysis and planning of mission activities, was developed under NASA's New Millennium program under the mission name Space Technology 6. In early 2004, the software was beamed up to a satellite already in orbit, the Goddard Space Flight Center's Earth Observing 1. With no human intervention, the software detected an eruption of Mt. Erebus in Antarctica and commanded follow-up observations — providing scientists with data in hours instead of weeks. Future versions of the software might also be used to track dust storms on Mars, search for ice volcanoes on Jupiter's moon Europa or track activity on Jupiter's volcanically active moon Io.

Other efforts were targeted at shaping technologies for future missions. JPL technologists developed a novel radio that can be reconfigured by software, switching between two different radio bands to communicate with landers on other planets. Known as Electra, the system will be flown on the Mars Reconnaissance Orbiter mission in 2005.

Why roll on wheels when you can tumble? That is the premise behind a balloon-shaped robot explorer known as the tumbleweed rover, which takes advantage of wind to blow it from place to place. Equipped with a package of scientific instruments, a test version of the robot rolled across Antarctica's polar plateau analyzing air temperature, pressure, humidity and light intensity. The rover may eventually explore martian polar caps or other planets in the solar system.

In the realm of technology transfer — adapting space technologies for use on Earth — JPL initiated 36 new industry-funded collaborations in 2004. Besides placing three technologies in the Mars Exploration Rovers, five more were infused into NASA's Aura satellite via JPL's Small Business Innovative Research program. JPL engineers worked with neurosurgeons to turn an infrared camera

"WHY ROLL ON WHEELS WHEN YOU CAN TUMBLE?"

In a test of its long-term durability, the tumbleweed rover spent eight days rolling across Antarctica's polar plateau.

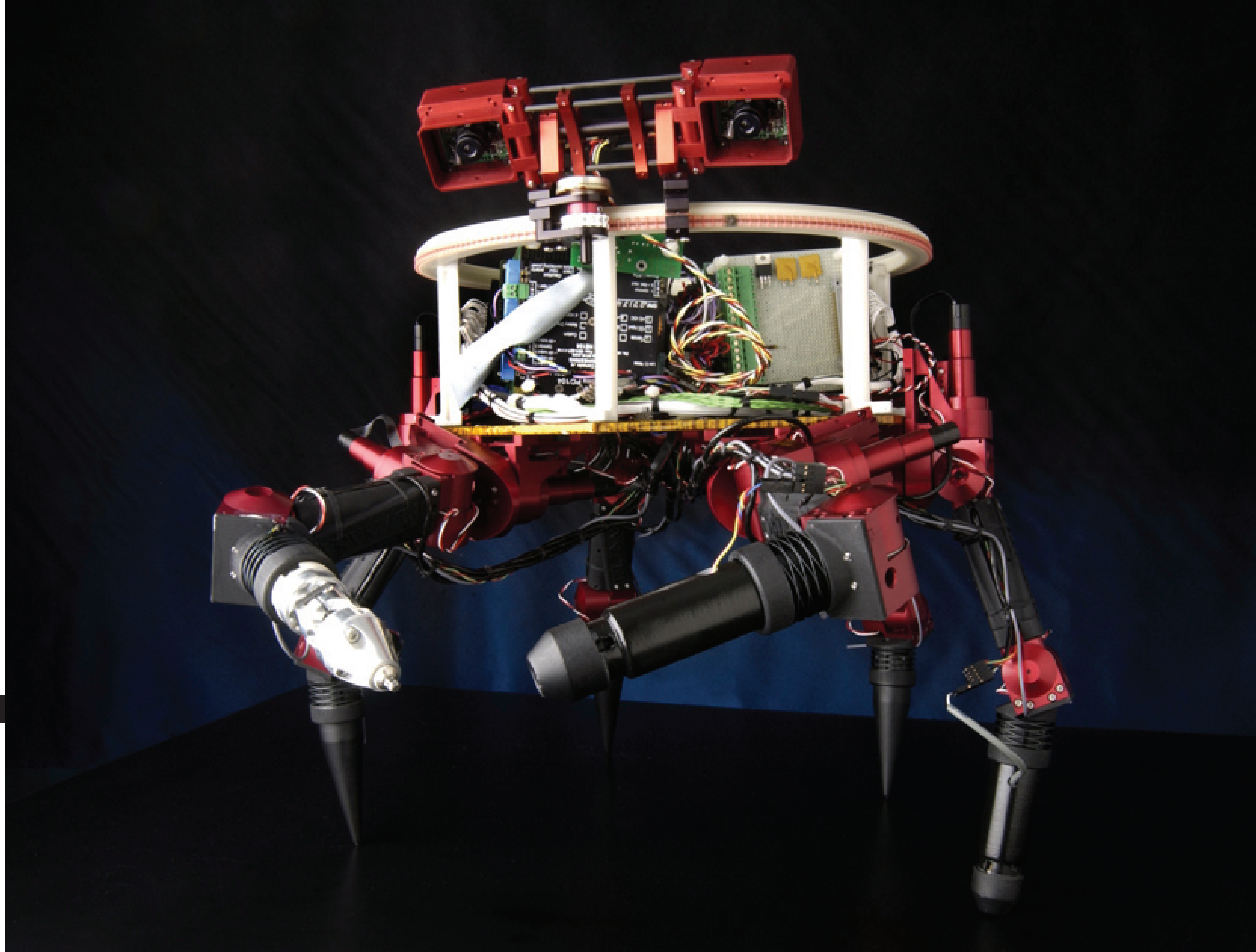
THE LEMUR WAS DESIGNED TO PERFORM SMALL-SCALE ASSEMBLY, INSPECTION AND MAINTENANCE.

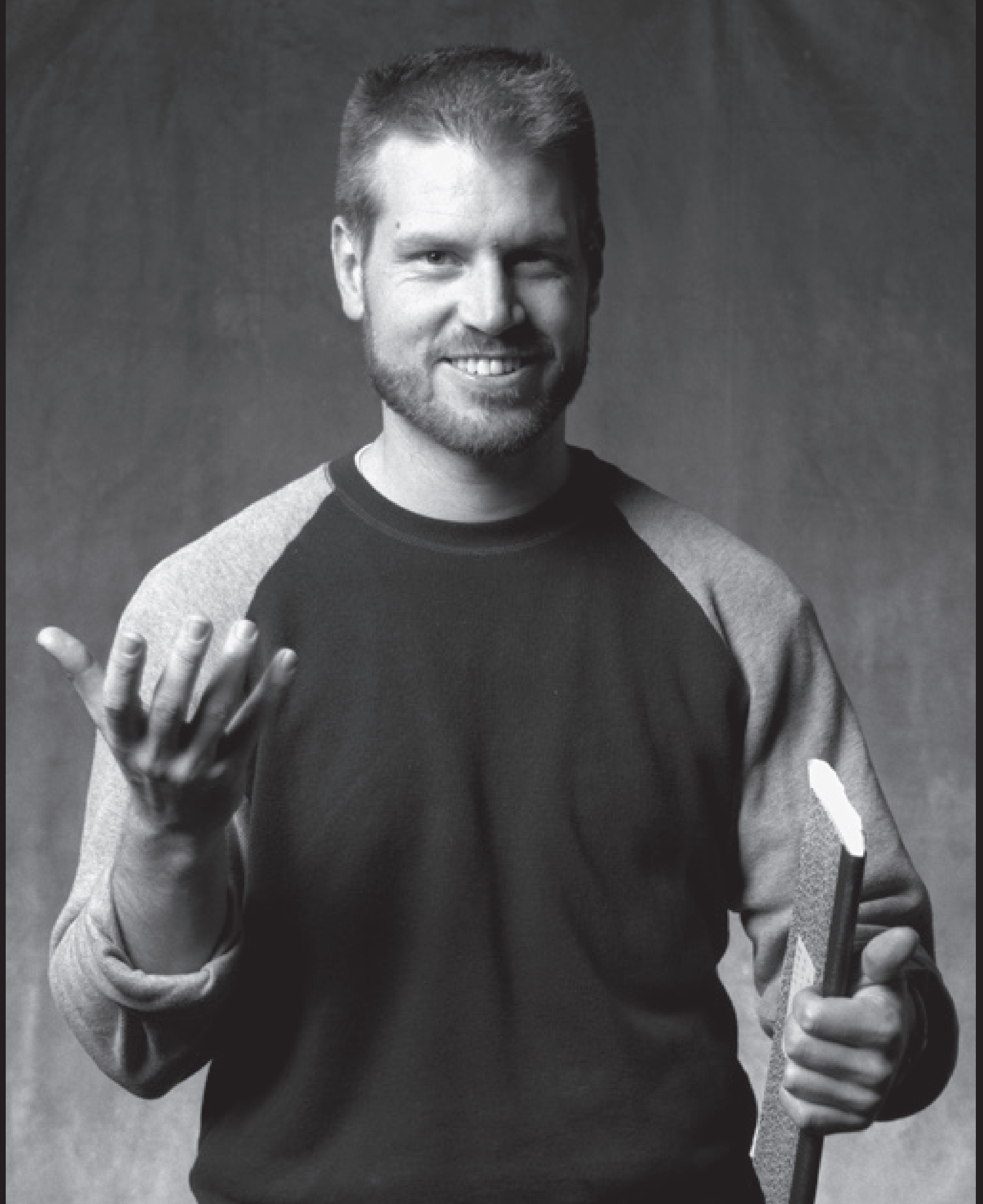
normally used in space into a brain scanner that looks for tumors, and collaborated with Children's Hospital of Los Angeles on a data system funded by the National Institutes of Health to improve the quality of medicine for children around the world.

JPL licensed two Mars Exploration Rover design patents, resulting in the sale of more than 500,000 spacecraft models. A royalty investment fund was created that reserves 50 percent of revenues from JPL software licensing to mature software for NASA and industry needs. The Laboratory also opened a licensing office to enhance communication between technologists, program managers and licensors.

JPL also undertook a number of technology projects for sponsors other than NASA. The Laboratory worked for the first time with the National Reconnaissance Office on a spaceflight demonstration vehicle that will use a technology known as nanolaminate optics. JPL began its second project with the National Geospatial-Intelligence Agency to fly a spectrometer instrument that uses gratings, a focal plane array and a telescope developed by the Laboratory. In 2004, JPL recorded about $70 million in contracts to develop new technologies for defense, intelligence and civil agencies as well as the commercial space sector.

"... A DIFFERENT KIND OF ROBOT FOR JPL."





"WHAT I WANT TO CREATE ARE WHAT YOU MIGHT CALL 'BIO-INSPIRED' ROBOTS."

SPOTLIGHT

ONE MIGHT GET THE IMPRESSION FROM ROVER MISSIONS OF THE PAST FEW YEARS THAT ROLLING ON WHEELS IS THE ONLY WAY TO EXPLORE A PLANET LIKE MARS.

But what about a robot version of a six-limbed primate, with Swiss Army knife tendencies?

That's how Brett Kennedy describes the Lemurs, robots he has developed at JPL over the past few years. Like nearly every name at the Laboratory, "Lemur" is actually an acronym — standing for Limbed Excursion Mobile Utility Robot.

Instead of wheels, Lemurs are equipped with limbs that can plug and unplug a variety of tools. They might use three-fingered grippers that enable them to cling to, say, rocks — or scale the outside of a space station or space shuttle. Or they might choose ultrasonic drills that allow them to climb by drilling into the surface of rocks.

"This was a different kind of robot for JPL," says Kennedy, who joined the Laboratory in 1997, two weeks after the Mars Pathfinder landing. "Legged or limbed robots are usually not built here. In fact, the limbed concept is new to robotics." While robots that walk on legs or use arms are not new, they have not in the past combined both functions into a single limb.

Kennedy's team created a four-limbed version of the robot to show how such a mechanical explorer might get around on a planet like Mars. This was derived from a six-legged Lemur, which was designed for in-space assembly and inspection. A robotic handyman not unlike the movie world's R2D2, it might perform maintenance on the International Space Station or put together future exploration vehicles created under NASA's vision of robotic and human exploration of the Moon and Mars.

Although he is happy to see his concepts translated into flight hardware, Kennedy sees his focus first and foremost as being on research.

He earned mechanical engineering degrees at UC Berkeley and Stanford University; while at the latter he also worked at IBM. Since coming to JPL, he received support from the Laboratory's Research and Technology Development Fund to develop Lemur's ultrasonic drills.

BRETT KENNEDY

"I idolized Leonardo da Vinci," says Kennedy, who grew up in Claremont and who recalls being interested in Voyager's 1989 Neptune flyby when he was 15 years old. "The world forces you to specialize, but I see a value in being knowledgeable over a wide range of things. In particular, I try to approach robotics with an understanding of biology," he adds. "What I want to create are what you might call 'bio-inspired' robots."

ENGAGING THE PUBLIC

Not since the epic planetary flybys of the Voyager mission two decades ago have the eyes of the world been upon JPL as they were in 2004. With such an intense series of mission events in so short a time, public interest was keen. Thanks to five years transforming its communication, outreach and education functions, JPL was ready. The greatest challenge for JPL communicators in 2004 was to gear up for the wave of hits expected on the Laboratory's websites during key events like the Mars landings and Cassini orbit insertion.

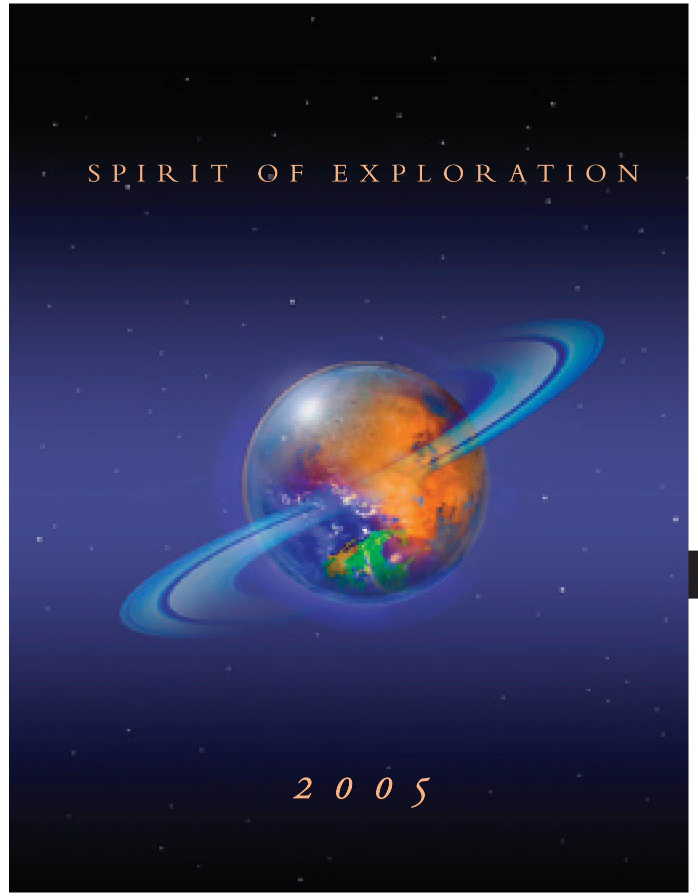
ART ACTIVITIES MINGLE WITH LEARNING ABOUT SCIENCE AND TECHNOLOGY AT THE JPL OPEN HOUSE.

To accommodate the huge groundswell of Web traffic, JPL retooled its project websites to offer many features such as near-real-time pictures as they came down from spacecraft. JPL also helped NASA reengineer the agency's overall website, enhancing it with standardized graphics and navigation and providing enough bandwidth to handle the billions of hits that eventually arrived.

As another medium of sharing space events with the public, JPL created an extensive network of relationships with museums, planetariums and science centers around the country and internationally. The Mars program's museum alliance, for example, told the rovers' and orbiters' stories to audiences of hundreds of thousands. Cassini's adventure was related in the video "Ring World," featured at 30 planetariums around the world. Via more than 9,000 DVD copies, a total audience of some 225,000 experienced the video in the United States alone.

These and other efforts earned high praise from NASA, which called JPL's Mars and Cassini outreach "the finest demonstration of the true meaning of public engagement that this agency has ever seen."

Other significant outreach initiatives included a Cassini literacy campaign, which helped students in kindergarten through fourth grade achieve sometimes immense improvements in reading and writing abilities based on content about the Saturn mission. JPL also developed new relationships with amateur astronomers through several efforts. In addition to observing campaigns supporting specific missions such as Cassini or Deep Impact, JPL in 2004 founded a "Night Sky Network" linking astronomy clubs around the country. In its first few months, the network enlisted more than 20,000 amateur astronomers and reached about 34,000 people through 350 events that highlighted astronomy and the search for planets.



THE THEME "SPIRIT OF EXPLORATION" IMBUED A NUMBER OF OUTREACH ACTIVITIES IN 2004.

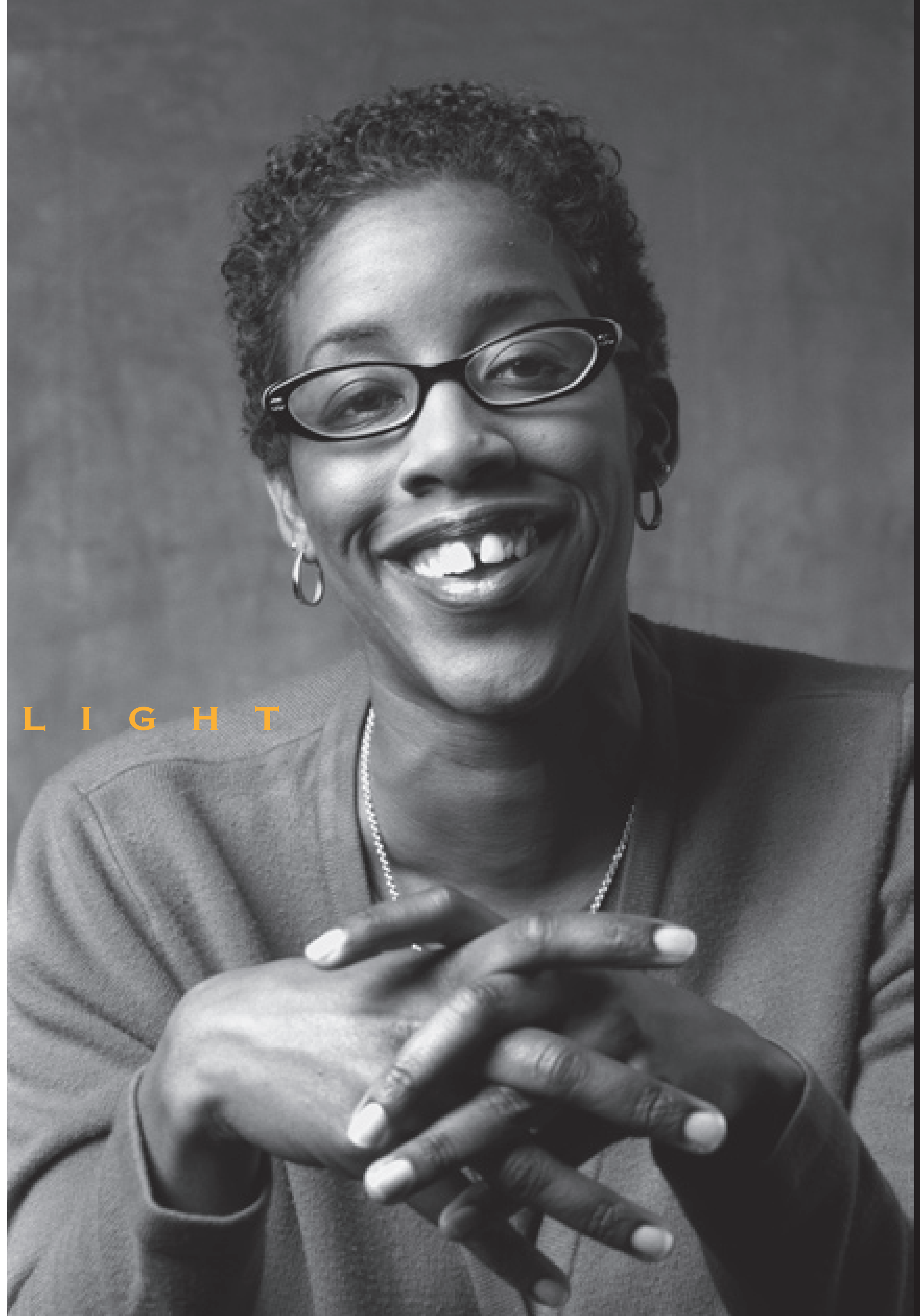
In formal education, the Laboratory brought in a great diversity of students through a number of programs. In many cases these were not one-shot events — the Laboratory was very successful in bringing students back through different programs, often going on to become employees.

Under NASA's Explorer Schools program, JPL established partnerships with nine schools around Southern California in 2004, dedicated to improving the teaching of science and technology. The program sent science and mathematics teachers "back to school" at JPL during the summer, using NASA's unique content, experts and resources to make learning science, mathematics and technology more appealing to students. During school visits, engineers who had instrumental roles in the mission to Mars encouraged young students to build even better robots and spacecraft currently exploring the solar system.

Under a strategic university research program, JPL developed and nurtured nine partnerships with key universities this year. All of these partners have a history of notable investment in, and research contributions to, critical topics in space and Earth science and space exploration.

". . . PUBLIC INTEREST WAS KEEN."

And thanks to the intense public interest in space events, JPL operated an exceptionally complex program supporting the outside news media. Throughout the year, the Laboratory mounted more news conferences than at any other time in its history. For the Mars rovers alone, JPL hosted 600 journalists and arranged more than 2,000 interviews, and also supported media operations for a visit by the Vice President of the United States.



SPOTLIGHT

"WE'RE JUST THERE TO HELP — AND WHEN WE'RE THERE, THEY ARE ALL 'A' STUDENTS AS FAR AS WE'RE CONCERNED."

SOMETIMES JPL EDUCATION AND OUTREACH EFFORTS PROPAGATE OUT TO LARGE AUDIENCES, BY WAY OF VENUES LIKE PRINTED MATERIALS, CONFERENCES AND THE WEB. BUT SOMETIMES THEY ADVANCE ON A VERY PERSONAL SCALE — ONE STUDENT, ONE JPLER AND ONE MATH PROBLEM AT A TIME.

Two afternoons a week, a dozen and a half JPL employees leave work to spend a couple of hours at two neighboring schools in Pasadena — Charles W. Eliot Middle School or John Muir High School. They tutor up to 60 students who come for help with schoolwork — covering the waterfront of topics from science to language arts.

"Some of these kids are really struggling," says Eva Graham, JPL's manager of minority education initiatives, who oversees the tutor program. "But we don't have a clue how they're doing in school. Where they are academically is the school's business. We're just there to help — and when we're there, they are all 'A' students as far as we're concerned."

Graham says she was surprised at the amount of commitment from JPL employees, given the time involved after often stressful workdays. "I'm amazed that they find the time," she says. "And I'm particularly surprised that we have such a good turnout among scientists and engineers.

"It's a release, something different to do with their schools. And you get instant feedback — the students absolutely love the tutors."

Many times students become so attached that tutors develop a loyal following. "At one point we tried to divide up different tutors by subject area — have one person work a math table, another person at a science table," says Graham. "But the kids want to stick with the tutors they particularly like working with."

JPL employees have worked in tutoring programs locally for decades, sometimes privately organized through churches or other community organizations. In the 1990s some programs became inactive, prompting Graham to start her initiative about three years ago.

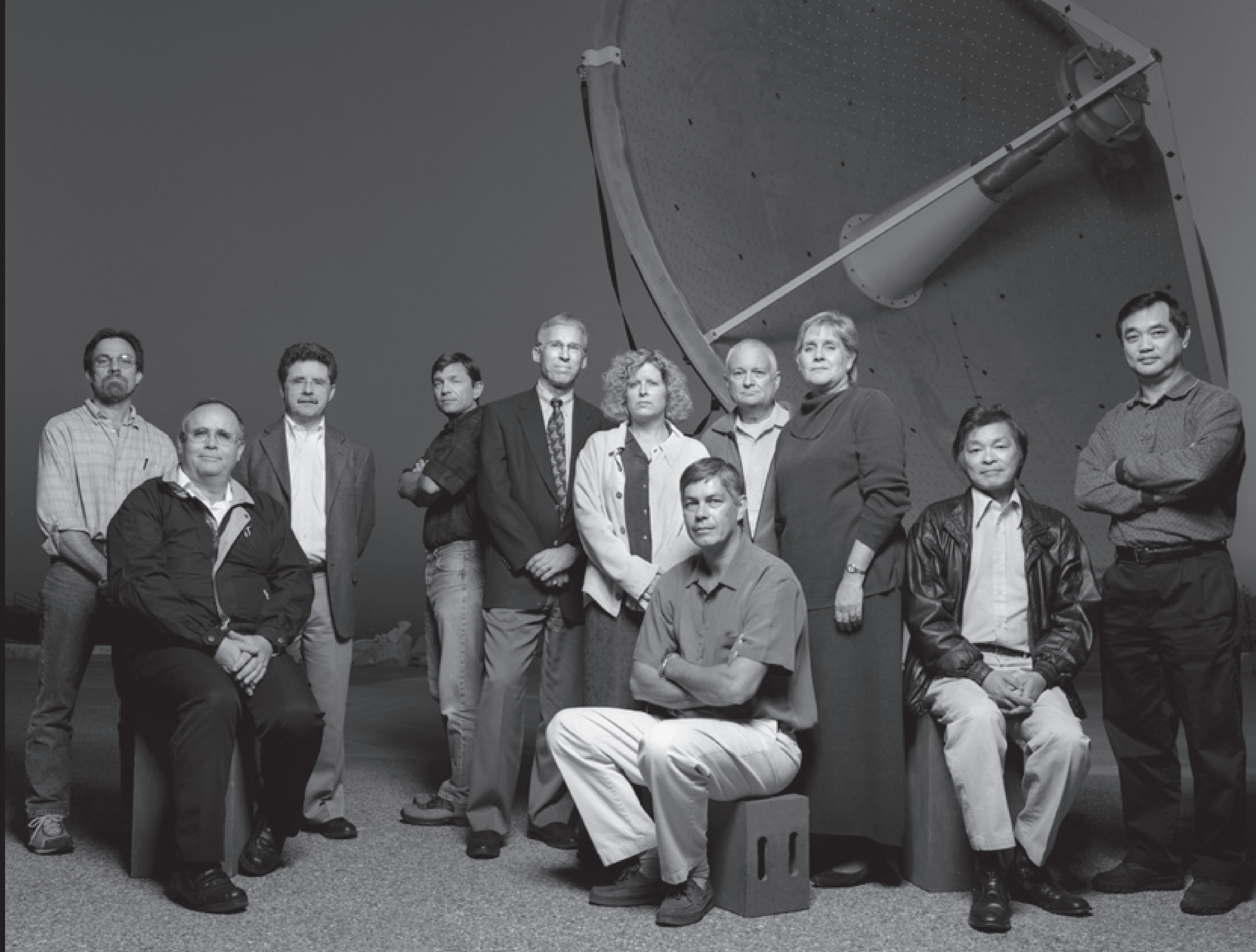
Now, the tutoring program works with students who put in about 2,000 hours per semester at the middle school, and about 1,500 student hours at the high school. Graham's colleague Rita Torres handles day-to-day coordination.

EVA GRAHAM

"It's easy as an adult to lose sight of the impact this has on kids," says Graham. "Apart from the kids' academic progress — which we don't track — it can mean a lot to them. For example, we might give out something as small as bookmarks about JPL missions. We think they're no big deal, but at the end of the semester the kids will still have them in their books."

DEEP SPACE NETWORK

If 2004 was a full year for JPL, it was the busiest year ever for the Deep Space Network. The network's giant dish antennas on three continents began the year with the most intensive support of planetary spacecraft in their history. The first event was the Stardust spacecraft's encounter of comet Wild 2, just as the Spirit and Opportunity rovers were bearing down on Mars. Throughout the year the network communicated with the Cassini spacecraft as it approached and entered orbit around Saturn, and executed a close flyby of Titan.



For the first time in Deep Space Network history, communications with spacecraft at another planet took place via orbiting spacecraft that acted as relays. The Mars Odyssey and Mars Global Surveyor orbiters provided relays for the Mars Exploration Rovers during their landings and surface operations. It was all a major success, with more than 95 percent of the data sent to Earth from the Mars rovers routed by way of these orbiting relay stations. Later in the year, the Deep Space Network successfully supported the Genesis return to Earth, a complicated communications scenario.

". . . FOUR TIMES FASTER . . ."

In all it was a significant accomplishment for the Deep Space Network, which also noted its 40th anniversary since being established in the 1960s. Over the years, the network has made enormous

THE COMPLEX IN AUSTRALIA IS ONE LINK IN THE NEVER-ENDING INTERPLANETARY COMMUNICATIONS TRAFFIC.

strides in its capabilities. Four decades ago, it could communicate with one spacecraft at a time, sending and receiving eight bits of digital data per second. Now it keeps in touch with more than three dozen spacecraft at data rates hundreds of thousands of times faster.

Even so, much of the infrastructure of the Deep Space Network has its roots in the 1960s, and so in 2004 its leadership paid particular attention to revitalizing its infrastructure to support NASA's needs over the next quarter century. Planners and engineers, for example, looked for ways to expand the network's capability to receive data by investigating new technologies. The first of these technologies being added to the network to support the Mars Reconnaissance Orbiter is the use of a new frequency band in the microwave region — Ka-band. This will allow spacecraft to send data to Earth about four times faster than now possible.

Planners, however, are setting their sights even higher. They would like to increase the communication capability not only by a factor of four, but a thousandfold. To do this, the network is investigating the use of large arrays of small antennas. The first of these new small antennas includes a 12-meter (39-foot) panel antenna and a 6-meter (20-foot) antenna installed at JPL for performance testing. The highest data rates, however, may come from laser communications. Working with NASA's Goddard Space Flight Center and the Massachusetts Institute of Technology's Lincoln Laboratory, JPL has initiated a project to test Mars-to-Earth laser communications in 2009.

In 2004, a new laboratory was installed at JPL's Table Mountain Facility to test optical communications. It will be one of the ground stations for a Mars-to-Earth laser communications link that will be tested during the Mars Telecommunications Orbiter mission to be launched in 2009.

The first of the year also marked a critical milestone for Deep Space Network operations. The contract for the network's maintenance and operations passed to a new company, ITT. Network managers were pleased that the handover occurred with no problems of any kind.

ONE OF THREE OF THE NETWORK'S LARGEST DISHES IS LOCATED AT GOLDSTONE, CALIFORNIA.

A SERIES OF ENORMOUS SATELLITE DISHES ARE BUSY TALKING TO ROBOTIC EXPLORERS THROUGHOUT THE SOLAR SYSTEM.

SPOTLIGHT

"I'VE ALWAYS ENJOYED UNDERSTANDING HOW THINGS WORK . . ."

WELL BEFORE THE BEGINNING OF 2004, MANAGERS OF THE DEEP SPACE NETWORK KNEW THEY WERE GOING TO HAVE THEIR HANDS FULL IN THE FIRST FEW WEEKS OF THE YEAR.

The network, which uses complexes of giant dish antennas on three continents to communicate with spacecraft all over the solar system, already had a portfolio of 30 craft it was in touch with on a regular basis. Add to that the challenging demands of a comet flyby and not one but two Mars rover landings, and the network was going to be busier than at any other time in its history.

Fortunately, the Deep Space Network was a jump ahead. In fact, a good five years before that — before anyone knew that spacecraft events would go off the chart in early 2004 — Andrew O'Dea started working on how to streamline the aging communication network.

O'Dea and his team of 20 engineers were assigned the job of looking over the network and finding ways to simplify it. Another team attacked the "uplink" side of the house, the way that mission controllers radio commands to distant spacecraft. O'Dea's team was focused on "downlink." This means not only the process of receiving data encoded in radio signals from the spacecraft, but also analyzing the radio signal itself to ferret out whether the spacecraft is speeding up or slowing down, and pinpointing exactly where it is.

"We looked at both software and hardware," says O'Dea. "One of the goals was to reduce the amount of hardware in the network. One of the metrics we used — one of the ways we had of tracking our progress — was how many racks of equipment we removed at each of the network sites."

The team found early on that the network was divided into three distinct subsystems — receiver, telemetry and tracking — where a single one made better sense. They knitted the trio of functions together, resulting in a simpler system. "Before that time, operators used to interact with three different computers," says O'Dea. "Now they only had to deal with one."

One of the most important measures of the effort's success was the percentage of how much data were lost as the network tackled the demanding job of servicing numerous missions. In a typical month, the Deep Space Network handles 300,000 minutes — or 5,000 hours — of communication with spacecraft.

Before the modernization effort, the network might lose 2,000 minutes of data a month, or two-thirds of one percent. Although that might be an enviable rate in other industries, O'Dea's team managed to cut outages by half — whittling them down to one-third of one percent.

ANDREW O'DEA

A self-described "Army brat," O'Dea grew up in Colorado, Belgium and Portland, Oregon, before going to Caltech as an electrical engineering major. In 1985 he came to JPL as a student in Caltech's Summer Undergraduate Research Fellowship program. After graduation, several years working for JPL's Deep Space Network operations contractor and a couple of jobs in industry, he returned to the Laboratory in 1997.

Why do what he does? "I've always enjoyed understanding how things work," says O'Dea. "Tinkering with cars and that kind of thing. I used to do a lot more of it when I owned a '73 Chevy Nova. With the newer cars these days, there's a lot less you can do yourself."

ACHIEVING EXCELLENCE

Day-to-day institutional activities create the backbone to support JPL's accomplishments in space. In 2004, the Laboratory aimed at continually refining the high levels of efficiency and response required to sustain its demanding work environment. To ensure the best possible return on NASA's investment, JPL in 2004 began an ongoing business-based review of all base operations, nonscientific general operations and technical support activities.

Over the next five years, the goal is to build JPL's reputation in internal business processes and industrial partnerships to the point that it is as highly regarded as the Laboratory's technical standing.

Three major business systems were upgraded and a new project was established to improve how parts and materials are inventoried and how mechanical and electrical systems are fabricated.

". . . A TOP RATING . . ."

The annual High Technology Small Business Conference, hosted by the Laboratory for the 16th straight year, was highly successful and set a record for participation. The Small Business Conference Round Table, the Space Science Symposium and the Semi-Annual Science Forum also set attendance records for primary supplier outreach functions. NASA again recognized the Laboratory for its achievements in these areas, calling JPL extraordinarily responsive and naming it a top center in the small-business category.

Since the beginning of the space age, JPL has supported national exploration objectives.

In 2004, the third-party auditor National Quality Assurance gave JPL a top rating for ISO 9001-200 certification from the International Organization for Standardization. This certification assured that JPL's quality management system continued to meet globally accepted standards of performance. On the financial front, JPL received an unqualified audit opinion from PricewaterhouseCoopers LLP.

JPL was lauded by NASA for "high-quality, successful proposals" that continued to increase the Laboratory's opportunities for new work. JPL's business operations contributed strongly to the proposal development, providing acquisition services to assist JPL teams in selecting industrial partners, as well as costing and documentation services to deliver approximately 40 proposals to flight programs such as New Frontiers, New Millennium, Discovery, Mars Science Laboratory instruments and Lunar Reconnaissance Orbiter.

In the recruiting arena, JPL made strides to attract new talent. University recruiting was enhanced with the creation of an advisory council and establishment of relationships with strategic partnership schools, which resulted in about a third of JPL's early career hires during the year. An extensive benchmark study was conducted that resulted in increased vacation benefits to help the Laboratory compete for new college graduates and mid-career professionals.

The Laboratory continued to affirm its commitment to safeguarding the environment. NASA noted gains in JPL's management of hazardous waste and chemicals, as well as innovations in its minimizing waste and preventing pollution. JPL reduced its use of energy and significantly increased its use of compressed natural gas as an alternative vehicle fuel.

With $5.4 million in emergency funding from NASA, JPL dramatically enhanced its facility security measures, implementing physical security hardware and initiating physical access countermeasures. Expanded communications capabilities, high-security checkpoints and additional guard personnel provided increased assurance.

Finally, the Laboratory completed a plan of infrastructure improvements as part of its Facilities Master Plan, and immediately began work on the first phase. JPL finished construction of two new buildings — an environmental biology and geology laboratory, and a solar sail facility.

◀ The JPL mall creates a pleasant backdrop for both technical and public events.

"... JPL dramatically enhanced its facility security measures ..."

"WE HAVE WHAT WE CALL 'PAYROLL IN A BOX,' SO IF NEED BE WE COULD RUN PAYROLL FROM SOMEONE'S GARAGE."

SPOTLIGHT

SHARON DUNCAN

SHARON DUNCAN CAME TO WORK AT JPL IN THE MID-1980S, WHEN THE TIMECARDS THAT EMPLOYEES FILLED OUT WERE REAL CARDS — THE OLD-FASHIONED TYPE THAT EVERYONE WAS EXHORTED NOT TO "SPINDLE, FOLD OR MUTILATE" — AND PAYCHECKS WERE MADE OF PAPER, HANDED ACROSS THE COUNTER TO A TELLER AT THE BANK.

In today's world, that has all but disappeared. Employees now fill out their time on a website. Nearly everyone's pay travels magically overnight into their bank accounts, thanks to direct deposit.

All of this is a great time-saver, but it also makes the Laboratory highly dependent on its online systems — not only for payroll, but for handling contracts with suppliers and many other kinds of official business. Sitting as JPL does astride a network of earthquake faults, what would happen if, say, the Laboratory's networks were taken down by a major quake?

That's where Duncan and the team she is a part of come in. If any kind of disaster event brought computers to a standstill, the team would be dispatched to an off-site location in Southern California where nightly backups are kept. "Where we go from there depends on the nature of the event," says Duncan. "We have what we call 'payroll in a box,' so if need be we could run payroll from someone's garage."

It isn't that disaster recovery planning is a new concept for JPL — the Laboratory has maintained emergency plans for many years. "But several things came together in recent years that made us take a fresh look at this," she says. "First, there was Y2K" — meaning the concerns about whether computers would roll over from 1999 to 2000 without glitches — "and then of course 9/11."

The other issue that prompted the team to reengineer their system was cost. "Before this past year, we were using a company back east that is in the business of disaster recovery assistance," she recalls. "When their contract came up for renewal, the cost didn't work out — they were very expensive. So what we came up with is a methodology — it's more in-house."

The new approach is also more flexible. "Previously, under our contract with the outside company, if we wanted to run a practice or a test, we had to schedule it six months in advance and do it over a weekend," she says. "Now, we can do it anytime."

Duncan's 19-year career at JPL has straddled the online business system as well as acquisitions. Spending her first 10 years with the Laboratory as a contract negotiator, she then changed careers and worked as a system manager on the implementation of the online business system in 1998, eventually moving to the institutional business system.

"Basically what I do is help coordinate the work being performed by many different teams," says Duncan, whose job title is functional coordinator. "We have database administrators and system administrators to take care of the database and the servers, developers to write code and a number of functional teams who understand how the business processes work. They all have to work together smoothly to assure the integrity of the system."

MAJOR AWARDS

John Beck
NASA Videographer of the Year

Steven Chesley, Peter Day, Ian Joughin, Christopher Webster
Dr. Edward Stone Award for Outstanding Research Publication

Tom Cwik and Ron Kwok
Named Fellows, Institute of Electrical and Electronics Engineers

Jennifer Dooley, Christophe Dumas, Eui-Hyeok Yang
Lew Allen Award for Excellence

Tom Fraschetti
Distinguished Alumnus, California State University Los Angeles

John Hong
Elected Fellow, Optical Society of America

Jet Propulsion Laboratory
2004 Scientific American 50 – Research Leader in Aerospace

Rob Manning
100 Who Made a Difference, Space News

Mars Exploration Rovers
Science Breakthrough of the Year, Science Magazine

Mars Exploration Rover Team
Exploration Award, Earth and Space Foundation

Mars Exploration Rover Advanced Information Technology Infusion Team
NASA Administrator's Award

Firouz Naderi
Liberal Prize, Fondazione Liberal, Italy

Adriana Ocampo
Distinguished Alumni Award, California Community College League

Precision Global Positioning System Software System Team
Space Technology Hall of Fame, National Space Symposium

Mary Helen Ruiz
NASA Small Business Specialist of the Year

Science Activity Planner Team
NASA Software of the Year

Spitzer Space Telescope Team
Aerospace Laurel Award, Aviation Week & Space Technology

Suzanne Thompson
Gold Medal Award, 10th International Space Conference of Pacific-Basin Societies

MAJOR CONTRACTOR PARTNERS

Lockheed Martin
Genesis, Mars Global Surveyor, Mars Odyssey, Mars Reconnaissance Orbiter, Spitzer Space Telescope, Stardust

ITT Industries
Deep Space Network Operations

Orbital Sciences
Active Cavity Radiometer Irradiance Monitor Satellite, Dawn, Galaxy Evolution Explorer

Ball Aerospace
CloudSat, Deep Impact, Kepler, Quick Scatterometer, Spitzer Space Telescope

Lockheed Martin Information Technology
Desktop Computer Support

Raytheon
Science Data Systems Implementation and Operations

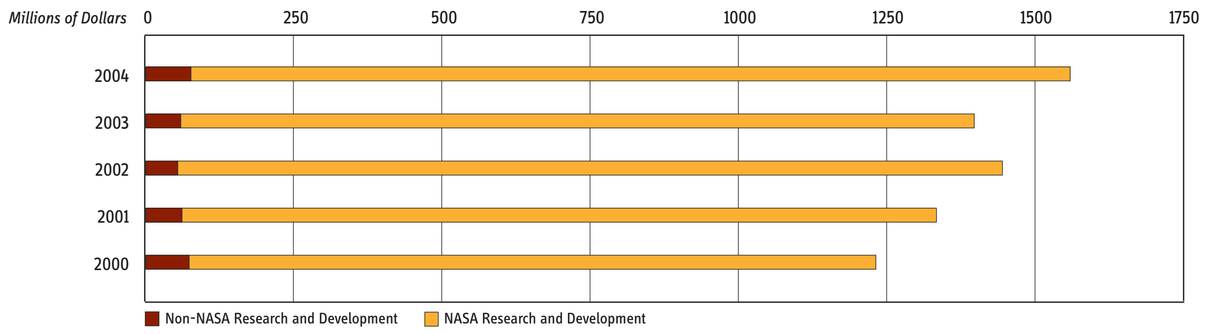
Northrop Grumman
Prometheus

Computer Sciences Corporation
Institutional Services, Information Technology Infrastructure

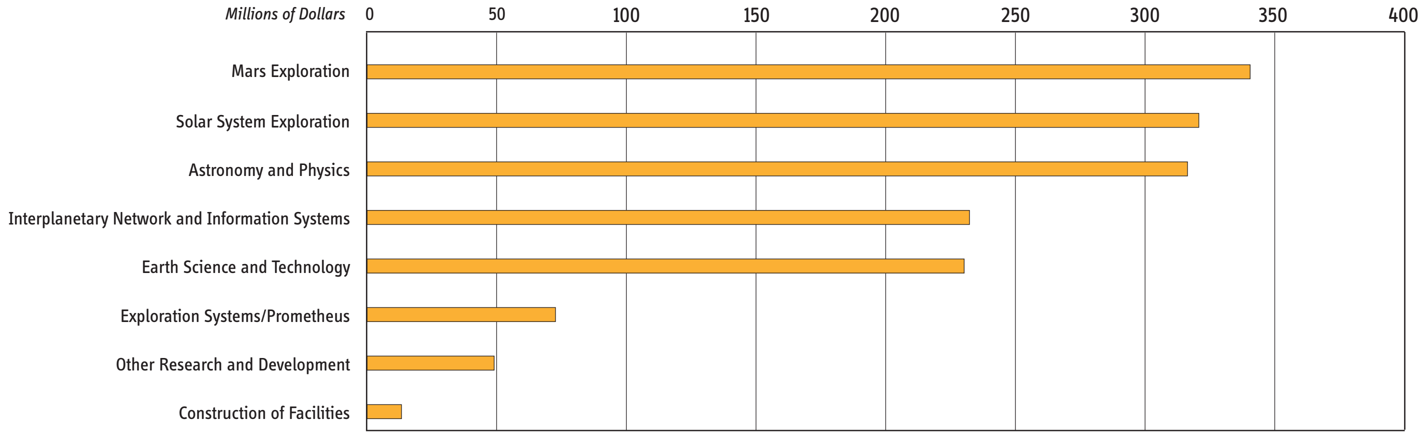
All Star Services
Facilities Maintenance

Acro Service
Secretarial and Clerical Support

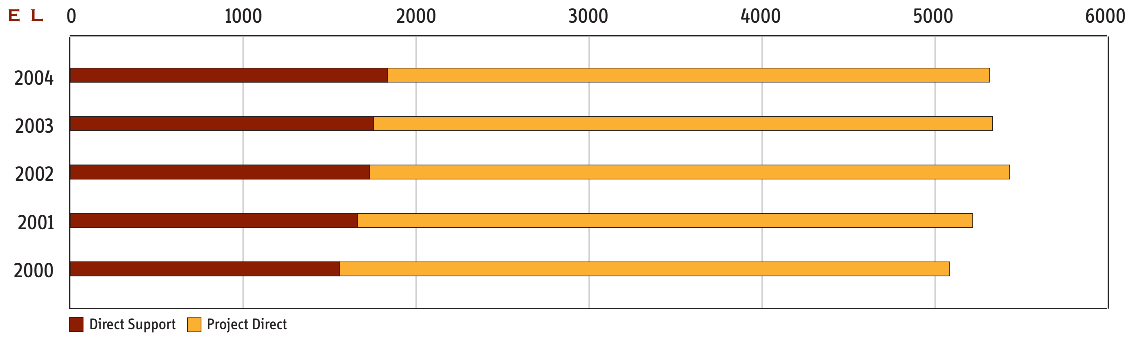
TOTAL COSTS



FISCAL COSTS 2004



TOTAL PERSONNEL



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Maria Zuber
Massachusetts Institute of Technology

TEAM PHOTOS

ENCOUNTERING MARS
(standing L to R) Tom Thorpe, Emily Eelkema, Celina Garcia, Eddie Tunstel, Jessica Brooks, Jim Erickson, Nagin Cox, Pete Theisinger, Richard Cook, Mark Adler, Bob Mase; (seated L to R) Adam Steltzner, Jessica Collison.

SOLAR SYSTEM EXPLORATION
(back row L to R) Earl Maize, Don Yeomans, Julie Webster, Ricardo Mendoza, David Seal, Nora Mainland, Kevin Grazier; (foreground L to R) Tom Duxbury, Bob Mitchell.

SURVEYING THE UNIVERSE
(standing L to R) Jennifer Dooley, Ed Massey, Larry Simmons, Mark Colavita, Jakob van Zyl, Ceci Guiar; (seated L to R) James Fanson, David Gallagher.

MONITORING EARTH
(standing L to R) Ming Luo, Debbie Higuera, Pin Chen, Johnathan Jiang, Diane Evans, Randy Friedl; (seated L to R) Deborah Vane, Bharat Chadasama, Tom Pagano.

ADVANCING TECHNOLOGY
(standing L to R) Keith Wilson, Gerry Ortiz, Melora Larson, Hamid Hemmati; (seated L to R) Heekyung Kim, Nan Yu.

ENGAGING THE PUBLIC
(standing L to R) Gregg Hanchett, Susan Watanabe, Michael Greene, Cynthie Cuno, Christine Johnson, Mark Whalen, Rich Alvidrez, Gay Yee Hill, Aimee Whalen; (kneeling/seated L to R) Henry Kline, Art Hammon.

DEEP SPACE NETWORK
(standing L to R) Neil Bucknam, William Rafferty, Asim Sehic, Bill Weber, Marjorie Raymond, Sander Weinreb, Jean Patterson, Chris Yung; (seated L to R) Joe Statman, Carlos Brinoccoli, Wallace Tai.

ACHIEVING EXCELLENCE
(standing L to R) Shruthi Aradhya, Rebecca Munoz, James Olsson, Deborah Garcia, Willis Chapman, Audrey Steffan, Toby Solarzano; (seated L to R) Lisa Ford, Myrna Snitowsky, Mary Legaspi.

DUST ENSHROUDS THIS COLORFUL STELLAR NURSERY, BUT THE SPITZER SPACE TELESCOPE'S INFRARED "EYES" LET US PEEK BEHIND THE COSMIC VEIL.