Jet Propulsion Laboratory

1997

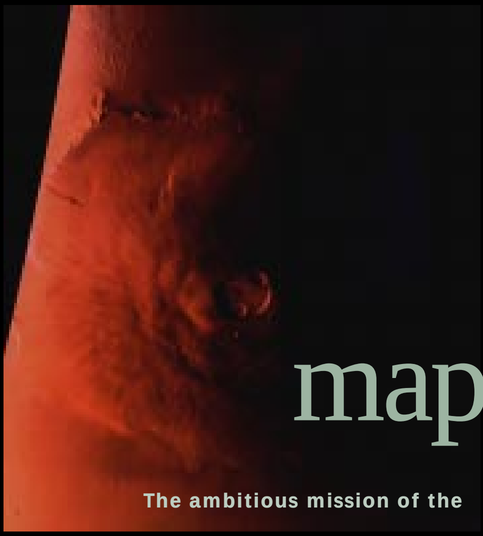
ANNUAL REPORT

A description of work accomplished under contract between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1 through December 31, 1997. Funding for this publication was provided by the California Institute of Technology.

Below: This 360-degree panorama was obtained over the course of three Martian days to ensure consistent lighting and shadow conditions.

investigating

Scientists believe that Mars in many ways resembles primordial Earth, and the series of planned investigations on the red planet may shed light on the origin and evolution of life on Earth.



mapping

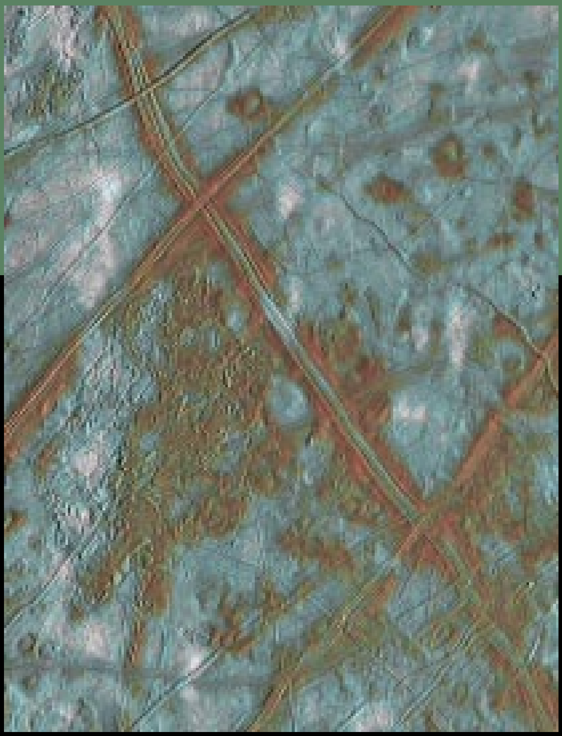
The ambitious mission of the Mars Global Surveyor is to map the planet's entire surface.

partnering

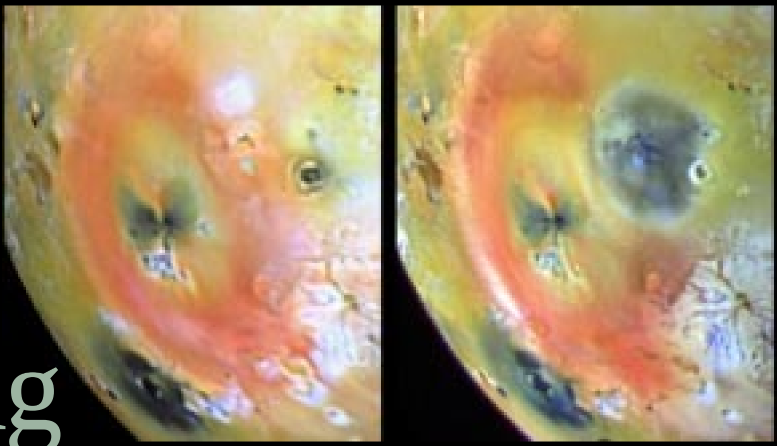
A technician inspects the heat shield of the Huygens probe after installation at Kennedy Space Center. The probe is owned by the European Space Agency — a NASA/JPL partner in the Cassini–Huygens mission.

1997

discovering



Images of Jupiter's moon Europa captured by the Galileo spacecraft led to the discovery that blocks of ice the size of cities have moved to new positions on top of what is probably soft ice or ice-crusted water.



observing

NASA's Galileo spacecraft made two observations — five months apart — which revealed a new dark spot the size of Arizona on Jupiter's moon Io. The second image indicates that dramatic volcanic activity occurred between the observations.

1997

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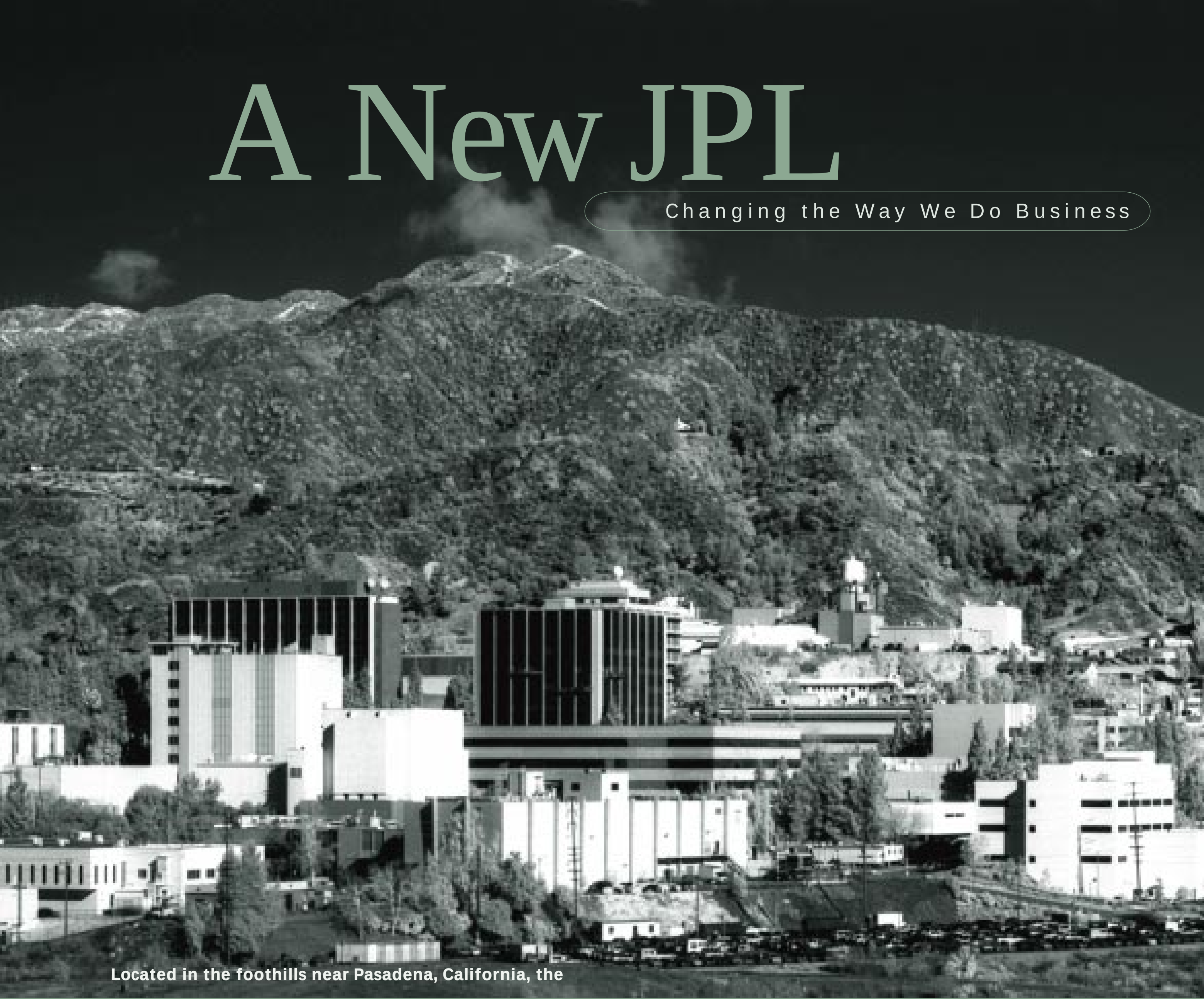
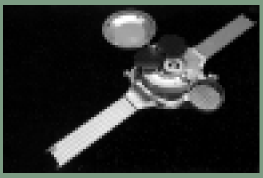


Located in the foothills near Pasadena, California, the Jet Propulsion Laboratory is the leading U.S. center for the robotic exploration of the Solar System; JPL is managed for NASA by the California Institute of Technology.

In 1997, the Jet Propulsion Laboratory (JPL), California Institute of Technology, pressed ahead with a series of internal changes designed to implement the National Aeronautics and Space Administration's (NASA's) objective of "faster, better, cheaper" in the coming millennium. Because an organization's work flows out of a complex matrix of structure, experiences, practices, beliefs and values — all taken together as "corporate culture"— the change to a new way of doing business happens neither quickly nor easily.

Business, administrative and technical processes have all been redesigned so that JPL managers and staff can carry out the more flexible, open development of missions “in parallel.” This freer exchange of people, creativity and shared technologies across the board has had a positive outcome: Missions are now being designed in a matter of a few weeks to a few months, in contrast to six months or a year or more.

Indeed, missions under design or in development during 1997 are scheduled for launch at the unprecedented rate of one per month for six months between autumn 1998 and spring 1999. And, even more gratifying, all JPL projects for NASA were within budget at the close of the fiscal year.



Genesis

JPL also has established a major initiative to engage in design, development and fabrication partnerships with other NASA centers, international space agencies, universities and the industrial community. Internally, the Laboratory continued to outsource many functions that might be done better or more economically by vendors and subcontractors, thus allowing the institution to focus its smaller staff and limited resources on tasks that no other space research organization can do.

EXCITING MISSIONS

Nineteen-ninety-seven belonged to the planet Mars and a nimble little six-wheeled rover called "Sojourner" that for three months captivated people everywhere with its slow, but purposeful movements on a rocky, reddish plain that once was a Martian seafloor.

Sojourner Rover

The Mars Pathfinder mission, carried out for NASA by JPL, was by any measure an extraordinary success. It was under budget and on time, and surpassed all expectations. It renewed the investigation of the "red planet" after a 20-year hiatus and reinvigorated the public's enthusiasm for space exploration. And, as much as anything else, it confirmed JPL's ongoing transformation into a more efficient, more innovative organization.

Pathfinder was not, however, the Laboratory's only accomplishment in 1997. Just two months after it bounced down on the Ares Vallis plain and sent Sojourner out to scout the Martian terrain, another NASA/JPL spacecraft — the Mars Global Surveyor — slipped into orbit there and began preparations for a Martian-year-long reconnaissance program. At the same time, two other Mars Surveyors were being built for a mission to begin in 1998. These Surveyors were under construction at the Denver, Colorado, plant of JPL's partner, Lockheed Martin Astronautics. And there were two more Surveyors being designed for missions in 2001.

INTRIGUING STUDIES

Nor was Mars the only planet of interest to JPL last year; Earth, Jupiter and Saturn all came under scrutiny as well.

EARTH. In its studies of our home planet, JPL dramatically expanded its research role in global climatic and weather systems and played a key role in detecting the birth of the El Niño oceanic disturbance in the winter of 1997–98. Data gathered by instruments aboard U.S.–French and Japanese satellites alerted the world that a dangerously large El Niño was looming.

It was a measure of the public's confidence in space-derived evidence that many governmental bodies — national and local, of many nations and countries — as well as individuals and firms, immediately started preparing for this disruptive event. Indeed, while the 1997–98 El Niño did devastate many areas around the globe, the precautions that were taken saved countless lives and lessened what might otherwise have been even greater damages.

JUPITER. The Galileo spacecraft has been stationed in Jupiter's orbit since the end of 1995, and in 1997 it completed its primary mission. Without skipping a beat, NASA and JPL then began an extended, focused exploration of the Jovian moon Europa, which has intriguing hints of liquid water, salts and an energy source beneath its cracked, icy crust — the ingredients of life, at least as we know it on Earth.

SATURN. Cassini, the largest, most sophisticated planetary spacecraft ever designed, was launched October 15 from Cape Canaveral on the first leg of a seven-year journey to Saturn. Unlike the Pioneer, Viking and Voyager missions of the past two decades, which carried out "first-level" inquiries, Cassini and its extensive set of scientific instruments will spend at least four years addressing deeper levels of questions about this resplendently ringed planet and, perhaps, solving some of the mysteries of the earliest phases of the Solar System.


Cassini

The 5,600-kilogram (12,346-pound), $1.3 billion Cassini and the 376-kilogram (829-pound), $196 million Mars Pathfinder, as different from one another as two spacecraft could possibly be and yet still bear the JPL stamp of origin, symbolized a major transition in both the exploration of space and the management of the Laboratory.

Cassini is the last of the so-called "flagship" missions — large, heavily equipped spacecraft with cycle times from initial design to completed mission of as much as 20 years. Pathfinder marked the debut of the "faster, better, cheaper" concept at JPL — a concept intended to accelerate the process of scientific discovery through frequent, economical missions, with start-to-end times of no more than a few years.

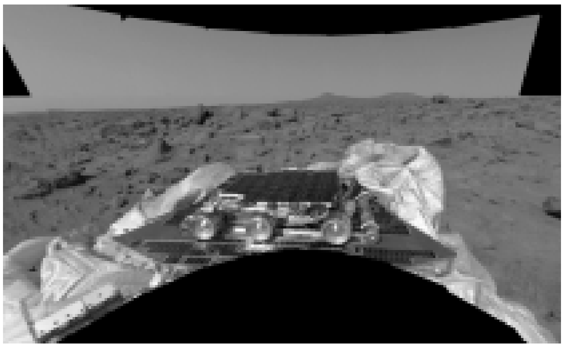
Mars

Window On Earth's Past

The two hills on the horizon are between one and two kilometers distant. Named the "Twin Peaks," they are of great interest as objects of future study.

Size aside, Mars is the only planet in the Solar System that so closely resembles Earth. It is believed to have formed out of much the same matter as Earth and at approximately the same time — 4.5 to 5 billion years ago. Its polar ice caps, towering volcanic mountains and deep chasms suggest the two planets were very much alike during their early youth.

Although Earth's features have continued to be shaped and reshaped by the elements and the movement of its tectonic plates, Mars has remained relatively unchanged for an estimated 3.5 billion years. Its surface is a record of its past, and its early history may hold answers to vital questions about Earth's evolution. Scientists believe that the planet in many ways resembles primordial Earth, and the series of planned Mars investigations may shed light on the origin and evolution of life on Earth.



Sojourner rover is shown still latched to the lander. Scientists used this image to determine the safety of deploying ramps and whether to use the right or left ramp for the rover's descent.

The scientific importance of Mars received a dramatic boost in late 1996 with the claim that a meteorite, strongly suspected of having come from that planet, possibly contained a fossil record of a strange and extremely primitive bacterial form. (That claim is being debated.)

On the Fourth of July 1997, however, Mars moved onto the world's center stage as NASA/JPL flawlessly delivered the Pathfinder lander/rover spacecraft combination onto the red planet's surface. Throughout that U.S. holiday weekend and successive weeks, the mission and its youthful, exuberant JPL project team captivated news media and people everywhere. One telling indicator of its popularity: Mars Pathfinder recorded 680 million "hits" on its Internet Web site during the course of 86 Earth days (83 Martian sols).

PATHFINDER AND SOJOURNER ROVER

Pathfinder, the second mission in NASA's Discovery Program, resoundingly showed that focused science missions can be both economical and effective. Among its innovations, Pathfinder's lander employed a direct entry technique with a parachute and air bags

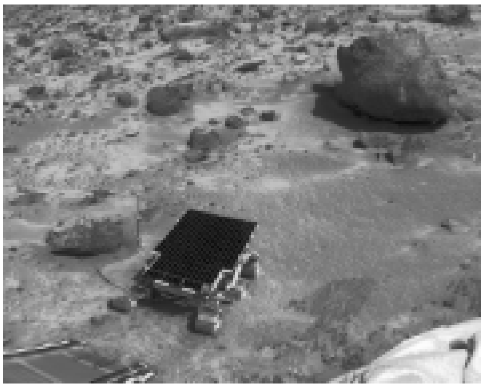
The "Mini Matterhorn" is shown at lower left in this image of the lander with its deflated airbags in the foreground.

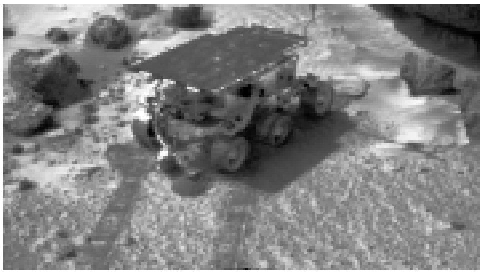
to cushion its 67-kilometer-per-hour (41.6 mile-per-hour) impact and placed the semi-autonomous 11-kilogram (24.25-pound) rover, Sojourner, on Martian soil. Aided by the rover, Pathfinder returned data on the Martian atmosphere, magnetic field and surface properties, buttressing the view that its reddish, rocky crust had once been shaped by water.

Sojourner rapidly gained friends and fame as it traveled a total of 100 meters (328 feet), albeit at the very slow speed of about 0.02 mile per hour (about 100 feet per hour), taking photos of the landscape and chemically analyzing rocks and soil with an X-ray spectrometer. Sojourner's revolutionary design included automated programs mimicking animal behavior and laser eyes allowing it to judge the size of rocks, to clamber over those its computer determined to be surmountable (up to 20 centimeters [7.8 inches]) and to sidestep those the computer said were not.

Pathfinder fulfilled all its mission objectives. The lander's specially designed camera system, capable of three-dimensional modeling, returned more than 16,500 images to Earth, including 550 taken by Sojourner and relayed through the lander back to Earth.

Top: Sojourner's descent on the right ramp was successful. Soil beneath the rover is the first target of the alpha proton X-ray spectrometer (APXS). Middle: Sojourner appears in one of the first images taken by the Imager for Mars Pathfinder (IMP) on Sol 3. Bottom: APXS is shown here placed against soil at the base of "Yogi."





MARTIAN SURPRISES

Scientists were immediately struck by the orientation of many of the rocks at the Ares Vallis site; they were all tilted toward the west-northwest, as if swept in that direction by a large, fast-moving volume of water. In fact, this interpretation became consensus the more scientists studied the images.

The rocks themselves were studied by Sojourner's alpha proton X-ray spectrometer (APXS), an instrument that fires a stream of helium nuclei (alpha particles) against a substance and records the characteristic X-rays that the now-excited compounds give off.

To their surprise, scientists found the chemical makeup of the Ares Vallis rocks to be unlike that of Martian meteorites, which are typically high in iron and magnesium, but low in silica. The APXS findings were just the opposite; the Mars rocks most closely resembled a particular kind of andesite found in Iceland and the Galapagos Islands here on Earth. Andesite, a volcanic rock with a high silica content, is found in tectonically active regions on Earth. But it isn't certain that tectonism has played a role in Mars' evolution, and so scientists speculated that Martian andesites might be formed by a mechanism that is different from that found here on Earth.

The Martian atmosphere is wispy, having only 1/100th the surface pressure of Earth's, and yet its presence and effects were clearly visible to the lander's sophisticated Atmospheric Science Instrument/Meteorology package. This suite of meteorological instruments made some 8.5 million measurements of temperatures, pressures and wind directions and speeds.

Mars proved dustier, at the time of Pathfinder's landing, than either Earth-based microwave measurements or Hubble Space Telescope observations had led scientists to expect. Dust was confirmed as the dominant absorber of solar radiation in the Martian atmosphere, a finding with important consequences for the transport of energy in the atmosphere and its circulation.

All three petals, the perimeter of the deflated airbags, the deployed Sojourner rover, the forward and backward ramps and prominent surface features are visible in this 360-degree panorama taken by the IMP on Sol 3.

"Dust devils," with unmistakable temperature, wind and pressure signatures, appeared frequently on the lander's meteorological instruments. One, seen on Sol 62, appeared to be carrying quite a bit of fine-grained material, suggesting that these gusts lift and mix the reddish dust into the atmosphere and give it a pinkish hue.

In fact, the soil characteristics measured by the Pathfinder rover's APXS were identical to those seen by the Viking landers, and scientists concluded that winds distribute the dust uniformly around the planet. Abraded rocks and dune-shaped deposits were also seen, again, suggestive of aeolian erosion. Winds blew steadily out of the south during the night, but switched to westerlies to northerlies to easterlies as the day wore on.

The weather at Ares Vallis was similar to what Viking 1 encountered at the Chryse Planitia site, some 850 kilometers (528 miles) to the southeast. There were rapid pressure and temperature variations, suggesting that atmospheric gases were warmed by the surface soon after sunup and convected upward in small eddies. The warmest it got at the landing site was –9.4 degrees Celsius (15 degrees Fahrenheit) and the coldest was –76 degrees Celsius (–105 degrees Fahrenheit) at night. One scientist said that if humans were at the Ares site at high noon, their feet would feel as if they were in pleasantly warm sand, but their heads would seem to be in a frigid, near vacuum.

Where the two Viking landers of the 1970s could not distinguish clouds from ground fog, Pathfinder did; the lander's instruments found that carbon dioxide condensed out at the extremely low temperatures some 80 kilometers (49.7 miles) up and formed thin clouds.

This image, taken on Sol 72 (September 15) from the Sojourner rover's front cameras, shows areas of Pathfinder's "rock garden."

The lander stopped sending data to Earth in September 1997, after functioning reliably for three times its design life (30 days) and gathering invaluable new data on Mars' atmosphere and surface. Most importantly, it identified the issues meriting closer study and validated design features, technology and instrumentation that will play a critical role in future missions. All of this was achieved with a fraction of the personnel and at a fraction of the cost of previous missions.

NASA underscored the increasing significance of Mars as a target of scientific study in 1994 when the agency designated JPL as the architect of its Mars Surveyor Program, charging the Laboratory to streamline the management and implementation of this large, multimission, decade-long undertaking. JPL will oversee the concept initiation, design and development of all Mars missions in cooperation with a wide range of government agency, industrial and university partners, working within tight economic budgets.

GLOBAL SURVEYOR JOINS PATHFINDER

While Pathfinder was in its second month of investigations on Mars, the planet became host to still another visitor from Earth: the NASA/JPL Mars Global Surveyor. Built as a replacement for the lost 1992 Mars Observer mission, this Surveyor was designed and fabricated in an unprecedented 26 months for $147 million in development costs (the spacecraft, science instruments, ground support computers, mission flight plan design and navigation design) — about one-fourth that of Observer.

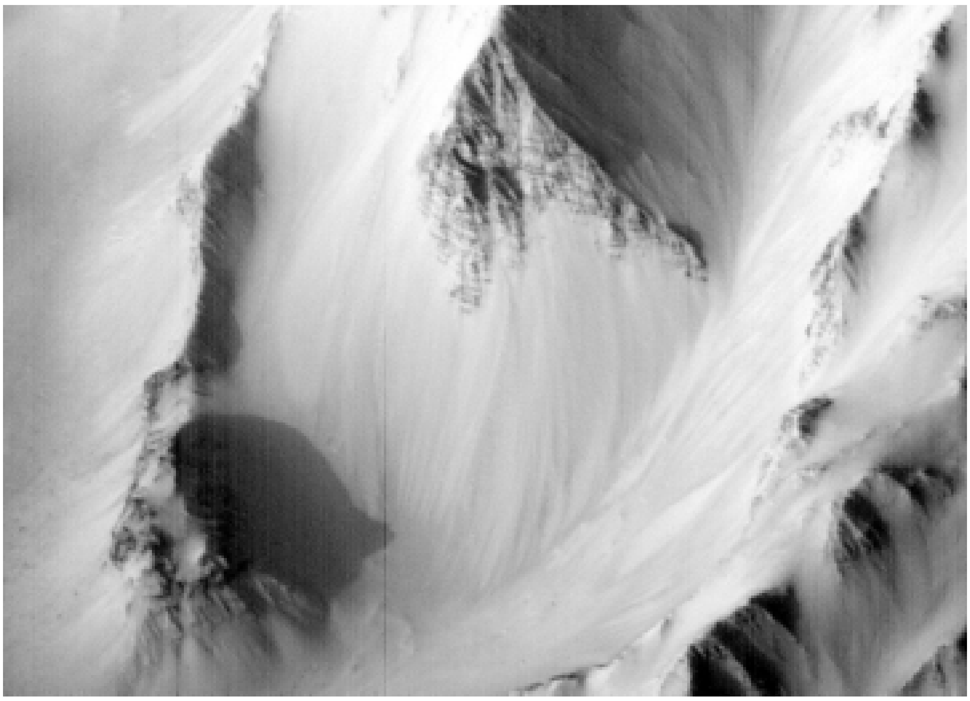
Artist's rendering of Mars Global Surveyor during aerobraking procedures.

Mars Global Surveyor entered an initial Martian orbit in September 1997 on an ambitious mission to map the planet's entire surface and study its climate, topography, mineralogy and magnetosphere. The Surveyor will use "aerobraking," an innovative method of using the planet's atmosphere to slowly reduce the spacecraft's velocity, changing its initial elliptical orbit to a circular one. This technique, which requires significantly less propulsion fuel, reduced the weight and cost of the Mars Surveyor spacecraft and permitted use of a smaller, less expensive Delta II launch vehicle. It will be used on future Mars missions.

As Mars Global Surveyor began aerobraking, a problem arose that required a prompt, innovative solution from its JPL and Lockheed Martin Astronautics team: One of Surveyor's two solar panels failed to lock into the fully deployed position and experienced excessive movement upon encountering the upper atmosphere. Rather than risk damage to the panel, engineers increased the spacecraft's altitude and redesigned the mission plan for more gradual aerobraking.

Surveyor will now enter its final orbit one year behind schedule, in early 1999. That time, however, will not be lost but will actually be used as a "bonus year" of science. Soon after arriving at Mars, for example, the spacecraft detected new evidence of a remnant, crustal magnetic field that may hold clues to the planet's evolution. It also identified a large surface area of coarse-grained hematite, a mineral which typically forms in association with hot liquids, such as at Yellowstone Park here on Earth.

This image by the Mars Orbiter Camera shows light and dark layers in rock outcroppings of canyon walls. This type of bedrock layering has never been seen before in Valles Marineris.

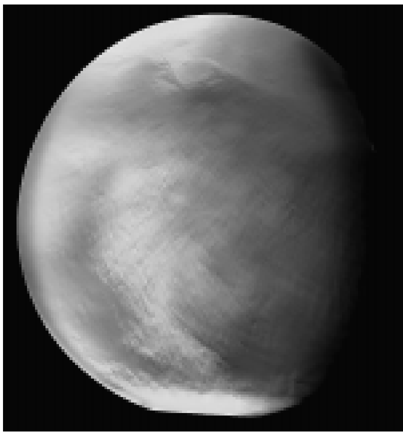


Global Surveyor will provide a general overview of Mars' past and present, identifying the scientific foci of future missions. Two additional missions in the Surveyor series are currently in development and fabrication at the Lockheed Martin Astronautics plant in Denver, and these missions will ensure that Mars remains a focus of space activity in the years immediately ahead.

The Mars Climate Orbiter is to be launched in December 1998 and will aerobrake into orbit in 1999. It will make sensitive measurements of global atmospheric temperatures and pressures, dust, water vapor and condensates. One of its two instruments is a rebuilt version of an infrared radiometer originally flown on the Mars Observer; the other is a medium-angle color camera.

The second mission, the Mars Polar Lander, is being readied for a launch early in 1999; it will also arrive at the red planet in 1999 and will be targeted to settle down on an area close to the edge of the southern polar ice cap. A special descent TV camera should provide an exciting "live" image of the touchdown.

The lander will carry a suite of sophisticated instruments provided by the University of California at Los Angeles (UCLA). Called the Mars Volatiles and Climate Surveyor, or MVACS, it includes a stereo surface imager, a robotic arm with a camera at its working end, a meteorological set of pressure, temperature, wind and water vapor sensors, and a thermal and evolved gas analyzer. The arm will scoop up soil samples and drop them into the gas analyzer to test for the presence of water, ice, hydrates and other aqueously deposited minerals — all indicators of Mars' ancient climate.



This Martian dust storm was captured by the camera aboard the Mars Orbital Surveyor.

Hitching a ride on Surveyor's lander will be the New Millennium program's Deep Space 2, a set of two small soil probes. These are to be released from the spacecraft as it descends onto Mars and will penetrate the surface at 180–200 meters per second (about 400–450 miles per hour). As each basketball-size spacecraft slams into the surface, the impact will release an instrumented probe, about the size of a soda can, to penetrate as much as 1 meter (3.28 feet) into the soil, while the aft-body remains on the surface.

Sensors are to measure the moisture and other properties of the subsurface, funneling these data through a cable up to the aft-body on the surface. The data then are to be transmitted up to Mars Global Surveyor for relay back to Earth.

A SOJOURNER OFFSPRING

Looking to the early 2000s, a Surveyor mission now in the planning and design phase at JPL will carry a new-generation rover, "Rocky 7" (since renamed "Marie Curie"), that will take photos of Mars and analyze and collect soil for later return to Earth. This Sojourner look-alike was subjected to exhaustive tests in 1997, exploring and conducting science on a 1,058-meter (0.65-mile) trip over rugged, Mars-like terrain in the California desert.

Marie Curie is designed to travel farther and to cope with more varied surfaces than Sojourner; it will have a manipulator arm fitted with a spectrometer and other instruments as well as a 1.4-meter (4.59-foot) vertical mast outfitted with two spectrometers and two stereo multispectral imagers. The imagers will allow Marie Curie to acquire three-dimensional panoramic images for navigation and science analyses.

Saturn

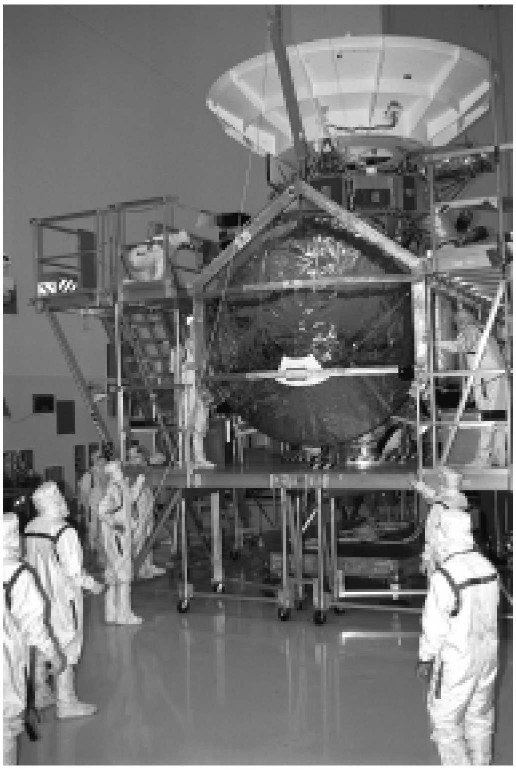
Cassini Begins Its Seven-Year Journey

A Titan IVB/Centaur rocket weighing in at 1,038 tons launched Cassini on October 15, 1997.

After months of assembly and testing at Cape Canaveral, the Cassini spacecraft began its journey to Saturn in a perfect send-off. Thus, 16 to 18 years after the Pioneer and Voyager spacecraft missions, the fabled ringed planet in 2004 will play host to Cassini, the largest robotic spacecraft ever launched.

CASSINI SPACECRAFT

The big (6.8 meters [22.3 feet] tall, 4 meters [13 feet] wide, 5,600 kilograms [12,346 pounds], fully loaded) spacecraft will make upwards of 60 orbits of the ringed planet, between 2004 and 2008, to take photos and study Saturn's chemical composition, magnetosphere, gravity and internal structure. Cassini will analyze the dust and debris circling Saturn and look at its 18 or more moons, giving particular attention to its giant moon, Titan. The Cassini project is a collaborative effort by NASA and the European and Italian space agencies, with overall management responsibility delegated to JPL.

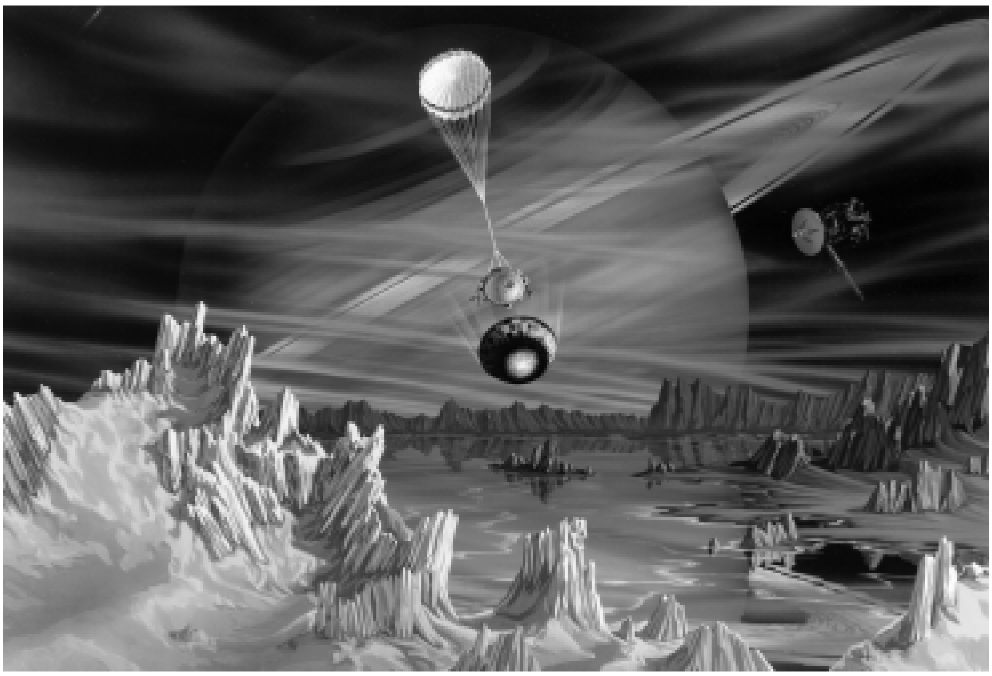


The Huygens probe is installed into the Cassini spacecraft.

HUYGENS PROBE

To more closely study Titan's thick nitrogen and methane atmosphere, Cassini will send the 350-kilogram (771.6-pound) Huygens probe, supplied by the European Space Agency, down onto the moon's surface to determine if its environment resembles the gaseous envelope believed to have surrounded primeval Earth.

This mission, the most complex and ambitious space venture yet attempted by the United States, is expected to meet all its challenging goals and to be completed under budget.



This artist's rendering shows the Huygens probe nearing the surface of Saturn's largest satellite, Titan, where there may be lakes of liquid ethane and methane over thin layers of frozen ammonia and methane.

Jupiter's Moons

Galileo's Second Year of Studies

The Galileo spacecraft provided this image of Jupiter's moon Io, the most volcanically active body in the solar system.

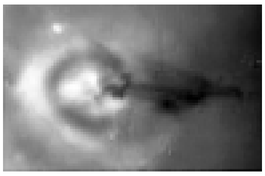
Writing another chapter in the book of space exploration, the Galileo mission began its second year of studying Jupiter, the largest of the Solar System's nine planets and the second largest radio source in the sky, with its huge magnetosphere and four major moons. Adding to many earlier discoveries, Galileo confirmed that lightning (orders of magnitude brighter in visible light than Earthly flashes) and auroral displays light up the Jovian atmosphere and that the atmosphere — largely hydrogen and helium — has both wet and dry areas.

GANYMEDE

When scientists looked closely at ever-so-slight changes in the spacecraft's trajectory and radio signals during flybys of the Galilean moon Ganymede, they deduced that this body, the largest of the Solar System's natural satellites, has both a metallic core and magnetic field.

IO

Galileo captured dramatic images of a huge outpouring of lava currently flowing on the tiny moon Io and a 193-kilometer-high (120-mile-high) eruptive plume rising above its hot surface. Io is the most active volcanic body in the Solar System, with temperatures approximating the 1,800- to 2,000-kelvin heat of Earth's volcanic eruptions of some 3 billion years ago. The moon's hot interior is the result of violent tidal friction caused by the strong gravitational tug of war between Jupiter and the other Galilean moons.

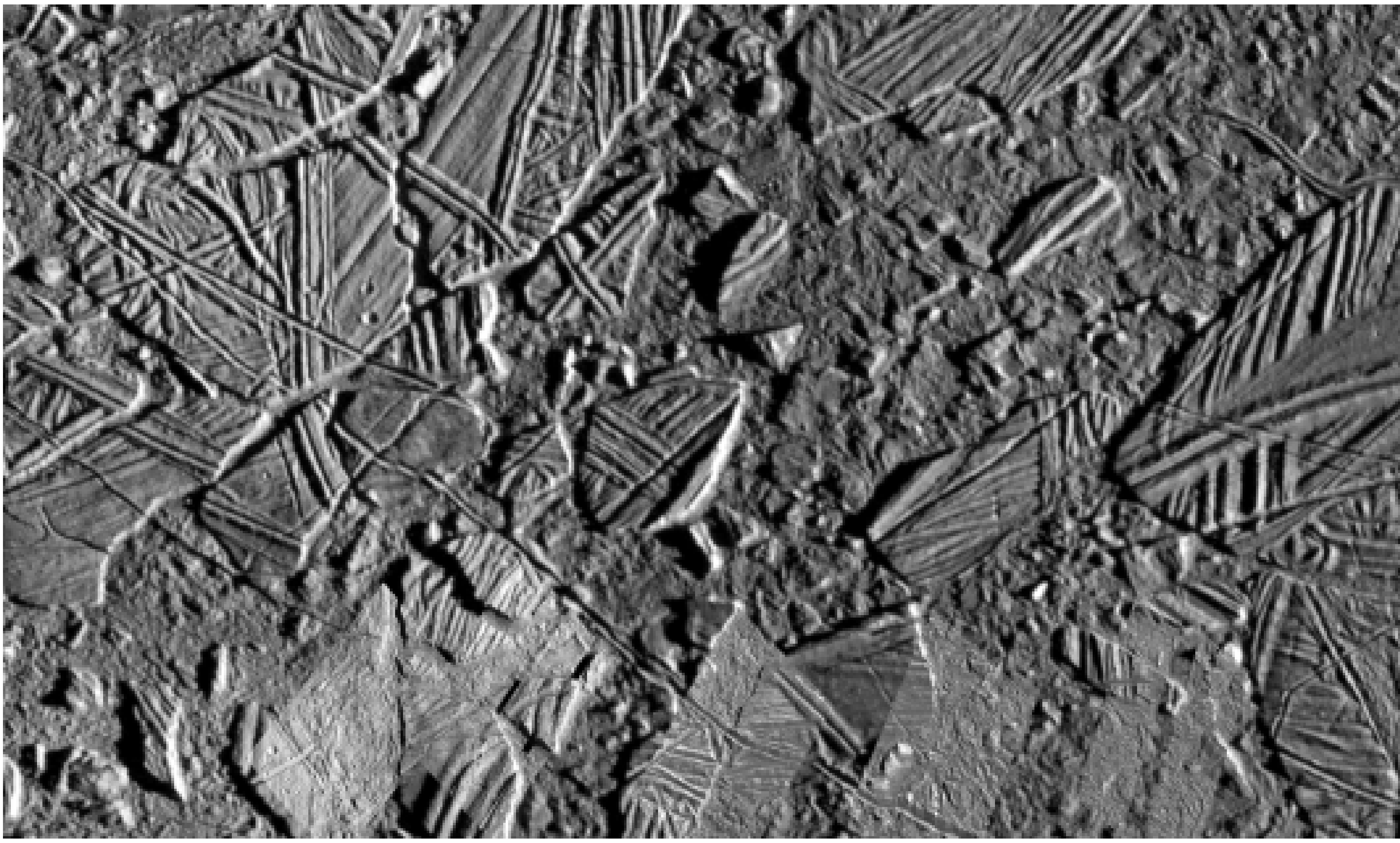


Top: This plume is near Io's boundary of day and night; this volcano has most likely been active for more than 18 years. Above: Volcanic plume erupting over a depression at the edge of Io.

EUROPA

Flybys of the moon Europa offered further evidence that it possesses a relatively young, icy surface that may conceal a slushy ocean. Investigations on Earth showing that life can be sustained in the most unlikely environments are making scientists eager to learn more about Europa. Galileo's primary mission will be extended for two years beginning in 1998. It will then be known as the Galileo Europa Mission, and it will look more closely at this moon as well as Io and Callisto. Scientists anticipate a wealth of scientific information from the extended mission.

Pieces of broken ice crust seem to have moved to new positions on top of soft ice in this image of Jupiter's moon Europa.



Earth

Our Oceans, Land and Atmosphere

A variety of missions and numerous scientific instruments are being used by JPL to study our ever changing planet.

Earth, as a planet, holds as much interest for JPL as Venus, Mars or any of the other bodies in the Solar System. Indeed, the Laboratory's role in detecting the onset of the 1997–1998 El Niño oceanic disturbance underscored the importance, and potential, JPL attaches to its Earth Sciences program.

Several important new Earth-observing programs with the promise of great benefits to people everywhere were initiated in 1997. One was “QuikSCAT,” an abbreviated name for Quick Scatterometer, a hurry-up $83 million replacement spacecraft for a similar instrument that was lost in June 1996, when the Japanese satellite of which it was a part suddenly failed.

The lost instrument—the NASA Scatterometer or “NSCAT”—had been performing superbly aboard Japan’s Advanced Earth Observing Satellite (ADEOS). Designed to reflect radar pulses off the ocean surface, NSCAT could determine if the ocean surface was choppy with white caps, gently rolling with long swells or storm-roiled by huge waves — just from the pattern of the returned signals.

Because winds affect an ocean’s surface — making it smooth or choppy — the reflected radar pulses from such winds are called “backscatter,” but they provide information about wind speeds and directions and therefore early indications of developing weather conditions.

NSCAT saw a faint, anomalous flutter in Pacific Ocean surface winds at the very end of 1996; this was the first hint of an oceanic storm that was to unleash enormous energies and batter much of the world in 1997. Scientists call this phenomenon “El Niño.”

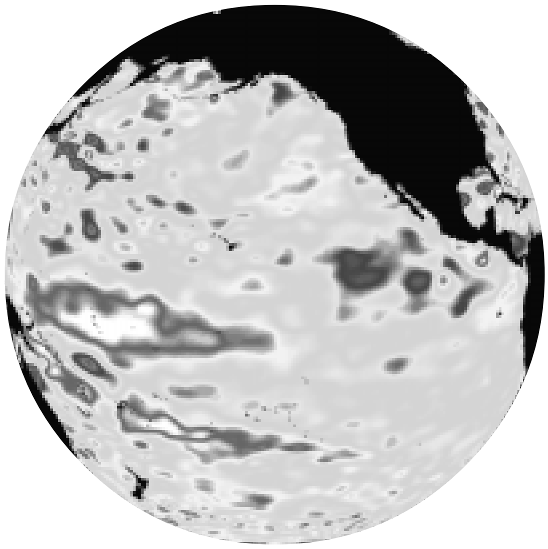
The QuikSCAT satellite carries the SeaWinds instrument — a special microwave radar that measures wind speed near the surface of Earth’s oceans. SeaWinds will continue the collection of ocean wind data begun by NSCAT.

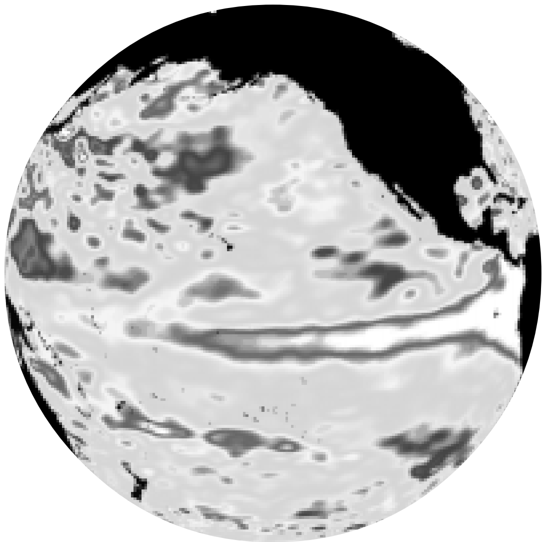
An El Niño occurs when the winds that normally push Pacific Ocean surface waters toward the Asian Continent collapse and allow an enormous quantity of warm water, packed with energy, to surge back toward South America. This typically leads to heavy rains and flooding on the west coasts of North and South America and severe droughts in Australia, Africa and Indonesia.

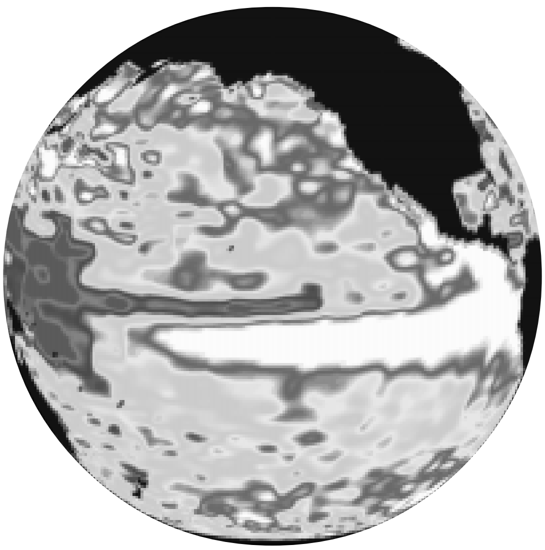
At about the same time as NSCAT was observing wind conditions indicative of an El Niño, the joint U.S.–French TOPEX/Poseidon satellite, launched in August 1992, was measuring sea-surface heights with its radar altimeters. Because a warm patch of ocean water expands, relative to the center of the Earth, it can be as much as a meter or two higher than an adjacent pool of cool water.

TOPEX, capable of picking up height variations as small as 2 or 3 centimeters (0.78 or 1.18 inches) from its orbit 1,300 kilometers (808 miles) above Earth, saw the height of a large pool of equatorial Pacific waters shifting to the east, a tip-off of El Niño.

If further corroboration was needed, JPL’s Microwave Limb Sounder instrument on the Upper Atmosphere Research Satellite soon provided it; this instrument







began detecting an increase of water vapor in the atmosphere above the tropical Pacific Ocean. When added all together, the data pointed to a large and potentially severe El Niño condition.

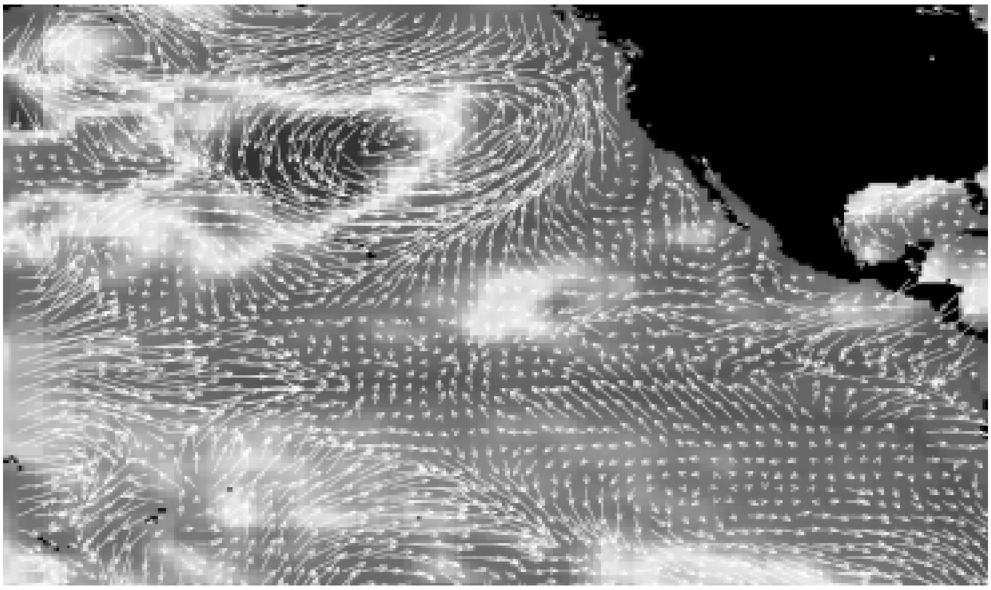
In May 1997, the National Oceanographic and Atmospheric Administration (NOAA) issued an advisory based on the data collected by JPL. By September, the sea-surface height off the coast of South America loomed nearly 4 centimeters (1.57 inches) above normal. Based upon these warnings, local, state and federal agencies began preparations for the anticipated onslaught. The 1997–1998 El Niño did not disappoint; it was a calamity worldwide.

That experience led to several important conclusions. One was that there are definite advantages to an orbiting scatterometer, and NASA moved quickly to fill the data vacuum created by the loss of NSCAT — by year-end, JPL had been awarded $83 million by NASA to develop the QuickSCAT mission, which is now scheduled for launch on a satellite in the spring of 1999. (Development also continued on another scatterometer, SeaWinds, planned for launch aboard the Japanese Advanced Earth Observing Satellite II [ADEOS II] in 2000.)

Another lesson learned concerned the value of international collaboration in oceanographic research — the teamwork between NASA, JPL and the French Centre National d'Etudes Spatiales (CNES) on the TOPEX/Poseidon mission being a perfect example.

TOPEX/Poseidon has tracked three El Niños during its five years of orbital operations and has far exceeded its original design specifications. Most importantly, it is providing scientists with a comprehensive look at global ocean circulation that is essential to a better understanding of Earth's climate. It also will lead to significant improvements in weather forecasting, with valuable benefits to agriculture, aviation and shipping — all industries that touch the daily lives of people around the world.

In March, highlighting the importance of a broad-gauged Earth-observing program, NASA assigned JPL a central role in the development of Earth System Science Pathfinders (ESSP), a new program under the auspices of Mission to Planet Earth (since renamed Earth



Arrows superimposed on this NSCAT image represent speed and direction of wind. (Length of arrow indicates relative speed.)

Science Enterprise), a long-term research effort sponsored by the space agency to study Earth as a global environmental system.

Under the ESSP umbrella, NASA assigned the Gravity and Recovery Climate Experiment (GRACE) mission to JPL. This $85.9-million mission — a partnership between the Laboratory, the University of Texas at Austin, the GeoForschungsZentrum-Potsdam (GFZ-Potsdam) and the German Aerospace Center (DLR) — is to provide precise measurements of Earth's gravity field. Employing twin orbiting satellites linked by a microwave tracking system, GRACE will measure the gravity field every 30 days and chart variations over a five-year period beginning in the spring of 2001.

Scientists expect the GRACE data, when combined with altimetry, will enable them to make more accurate measurements of ocean currents and will lead to a deeper understanding of the oceans' transport of heat from equatorial to polar regions. By monitoring time variations in Earth's gravity field, GRACE is expected to yield new scientific insights into the hydrologic cycle, ocean bottom currents and the dynamics of polar ice.

NASA also designated JPL to lead a partnership on the Chemistry and Circulation Occultation Spectroscopy Mission, a project that will seek new insight into how atmospheric circulation controls the evolution of key trace gases, aerosols and pollutants.

JPL's contribution to the Mission to Planet Earth program will include the development of critical instruments for the agency's Earth Observing System (EOS) spacecraft, set for launch in the spring of 1999. They cover a broad scientific spectrum, from the study of clouds and volcanoes to the exchange of energy, carbon and water between atmosphere, land and ocean.

One key instrument is the JPL-built Multi-Angle Imaging SpectroRadiometer (MISR). By measuring the amount of sunlight absorbed and scattered by Earth's surface and atmospheric particles, MISR will help to quantify the amount of solar energy heating Earth's surface and atmosphere and to record the changes in these systems over a nominal, six-year lifetime.

Opposite, top: This image, in late March 1997, shows the beginnings of a warm-water Kelvin wave — often the precursor of an El Niño event. Middle: Oceanographers see convincing data in this May 1997 image that suggest the return of a stronger El Niño. Bottom: White areas in this October image show warm-water sea-surface height at 6–12 inches above normal. The displacement of so much warm water alters the jet stream patterns around the world.

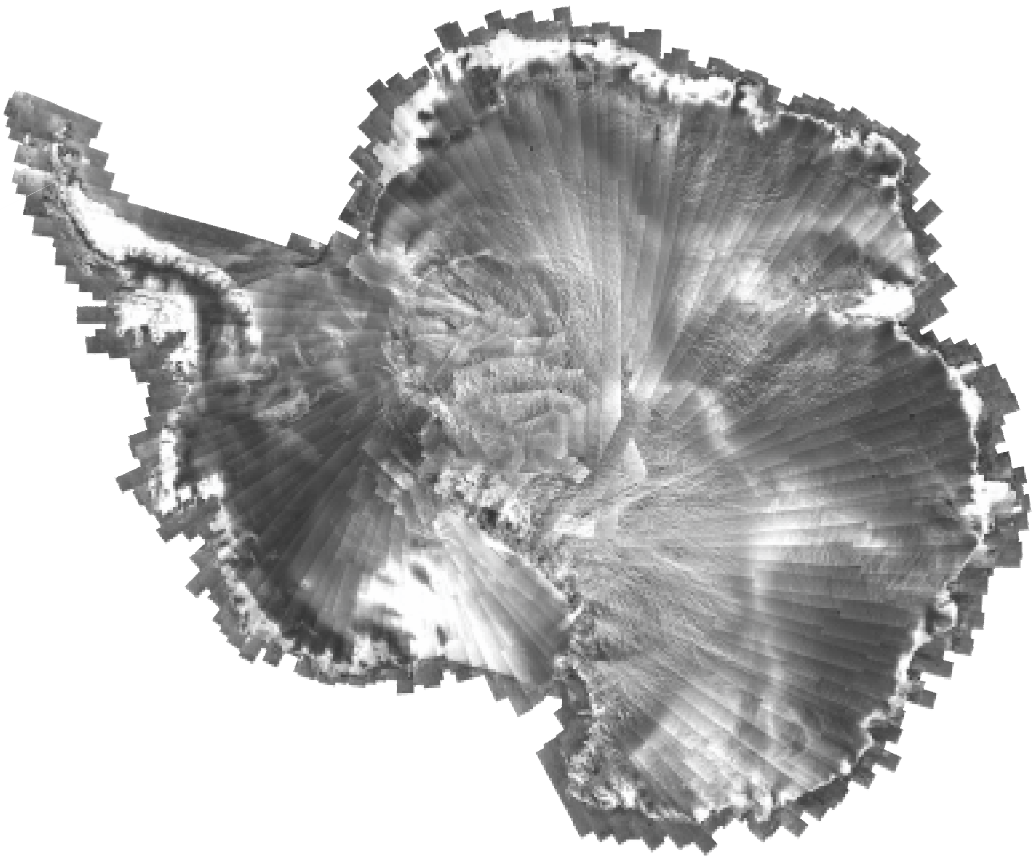
Scientists anticipate the data will reveal much about the effects of land use changes, air pollution, volcanic eruptions, the spread of deserts, deforestation and soil erosion by determining how atmospheric particles, clouds and the planet's surface itself scatter sunlight in the first place.

In a collaboration with Japan's Ministry of International Trade and Industry, the Laboratory supplied significant design support on the product generation software for the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Engineered to monitor long-term changes in Earth's surface at the local and regional levels, ASTER will facilitate closer study of land use patterns, deforestation, glacial movement and volcanic activity.

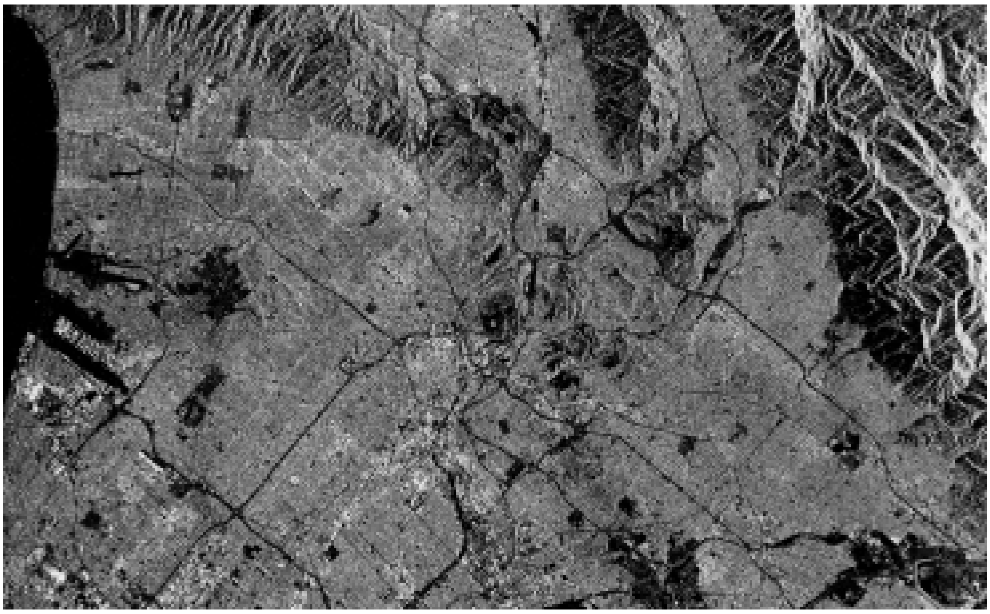
HARNESSING RADAR TECHNOLOGY

During 1997, the Laboratory once again demonstrated its ability to maximize the benefits of cutting-edge radar technology when it won approval to proceed with detailed design for the Shuttle Radar Topography Mission (SRTM). This program, using off-the-shelf commercial technology, is intended to map 80 percent of the world's topography and enable scientists to gauge changes in Earth's surface over time. SRTM is expected to be ready for a fall 1999 mission aboard a space shuttle.

JPL partnered with the Canadian Space Agency on another radar imaging project to help produce the most precise map ever made of Antarctica; the project used the Canadian imaging radar satellite, RADARSAT–1. The Laboratory planned the mission and coordinated data collection and transmission via the Alaska Synthetic Aperture Radar Facility



A mosaic of Antarctica compiled from approximately 4,000 RADARSAT-1 images acquired during the Antarctic Mapping Mission in September and October 1997.



This radar image of the greater Los Angeles area was acquired by the Spaceborne Imaging Radar-C (SIR-C) on board the Space Shuttle Endeavour.

in Fairbanks, Alaska. Some 5,000 images were processed to map the largely uncharted region and establish a benchmark for evaluating the effects of global warming on the ice sheet.

One of the more important developments in radar imaging, however, involved the Spaceborne Imaging Radar–C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR), which was flown twice in 1994 aboard Space Shuttle Endeavour. Analysis of the data from those missions, combined with additional information supplied by a European satellite, enabled scientists to provide remarkably accurate assessments of several seismic and volcanic situations around the globe.

For example, recent data from Global Positioning System satellites and other instrumentation, revealed a 15-millimeter (0.59-inch) seismic “slip” on a proposed commuter rail line near Los Angeles. The slippage was too slight to trigger an earthquake, but the information did prompt rail engineers to shift the path of the rail line to a safer route.

At Mount Rainier, the SIR-C/X-SAR images showed several sets of possible faults that had not been identified previously. These faults may generate slope failures that could lead to disastrous debris flows or even new volcanic eruptions.

The rich lode of SIR-C/X-SAR data also led to the discovery of another feature — a nearly 700-meter-wide (0.43-mile-wide) impact crater in a dry river bed in Yemen. There are many larger and more obvious craters on Earth’s moon, Mars and the Jovian and Saturnian satellites — all evidence of an era of heavy bombardment by meteorites and other debris early in the Solar System’s history; that history has been largely erased from Earth’s surface by erosion and the action of plate tectonics. Finding this Yemeni crater, absent any overt signs of rims, shatter cones or debris blankets, demonstrated that remote sensing can uncover things that the human eye wouldn’t normally detect or might overlook.

JPL managed the SIR-C/X-SAR project and developed the instrument for NASA in cooperation with the German and Italian space agencies, Deutsche Agentur für Raumfahrtangelegenheiten and Agenzia Spaziale Italiana.

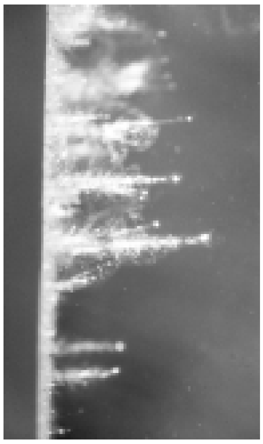
Missions of Discovery

Searching the Solar System

This extreme ultraviolet image of the edge of the solar disk shows the hot coronal magnetic loops. The first spacecraft to enter the solar corona, Solar Probe, will go within three solar radii of the Sun.

The NASA Discovery Program will be launching many smaller missions that will perform focused science with fast turnaround times. These missions will be joint efforts with industry, small business and universities.

STARDUST



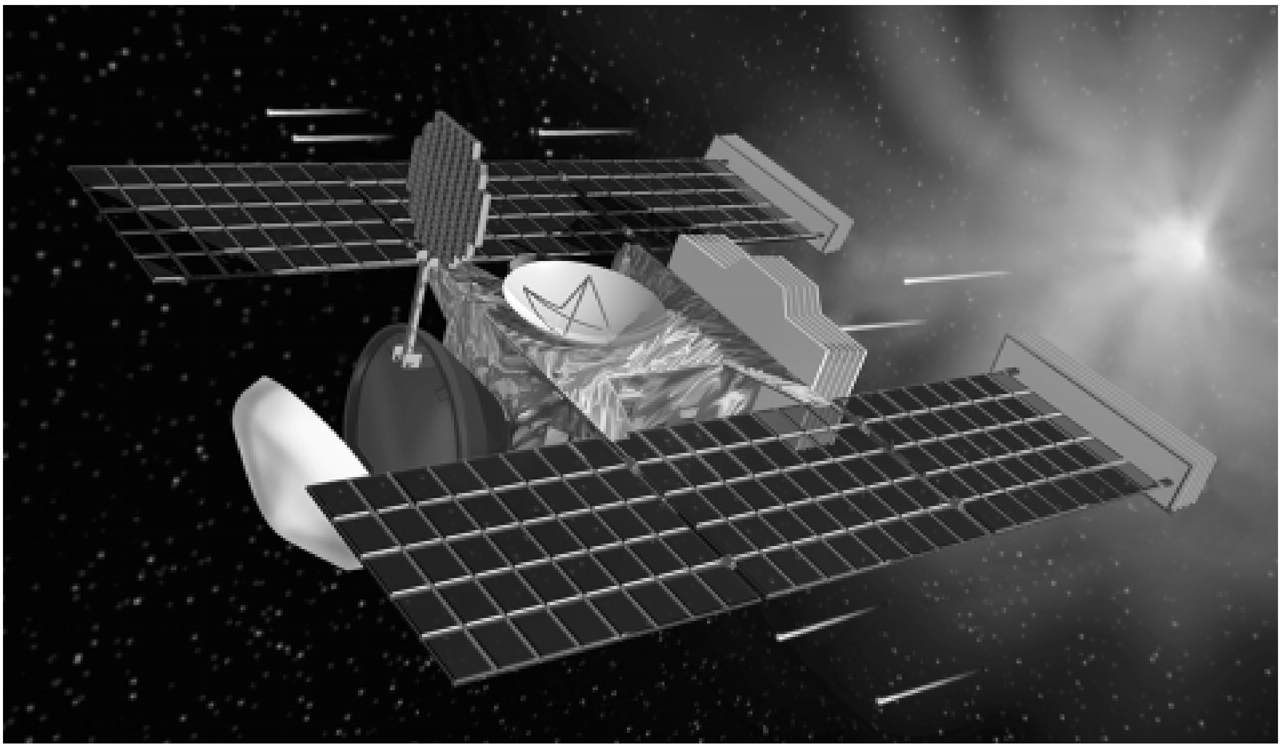
Comet dust particles, traveling at almost 10 times the speed of a bullet fired from a rifle, make carrot-shaped tracks as they become embedded in aerogel.

Fourth in NASA's Discovery Program devoted to more focused, lower cost science, the Stardust spacecraft will be launched in February 1999 on a first-ever attempt to collect and return to Earth both cometary and interstellar dust particles. With 1- and 3-centimeter-thick (0.4- and 1.18-inch-thick) blocks of the lightweight silica foam, aerogel, mounted on both sides of an extendible, waffle iron–like collector, the spacecraft will fly slightly ahead of the comet Wild-2 (pronounced "Vilt"-2) and, at a slow speed relative to this cosmic wanderer, cut across the bow of the coma in early 2004.

The goal is to soft-capture, on one side of the collector, 1,000 or more grains and gas molecules from the cloud surrounding this comet's nucleus, as well as to obtain images of this core body itself; the spacecraft is expected to come within 150 kilometers (93.2 miles) of the nucleus. At various times in the mission, the opposite side of the collector will be deployed to gently catch 100 or more grains of interstellar material as the spacecraft flies through interstellar space. These tiny, priceless samples will be stowed inside a reentry capsule aboard Stardust. When the spacecraft returns to the vicinity of Earth, the capsule will be dropped off for a landing on a Utah desert in January 2006.

Comets, among the most primitive objects in the Universe, appear to contain a rich mix of organic compounds whose chemistry may provide answers to the origins of the planets and life. Wild-2 is a particularly interesting candidate for study because it has spent most of its existence on the fringes of the Solar System, beyond the orbit of Jupiter.

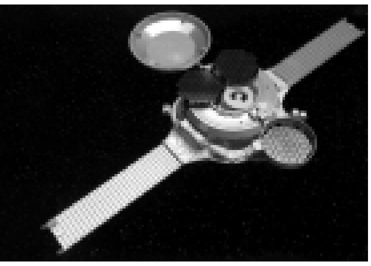
This rendering shows Stardust approaching comet Wild-2 in January 2004.



But a 1974 encounter with that planet altered Wild-2's orbit so that it now will pass through the inner reaches of the Solar System. This makes it a virtual "time capsule" from the earliest eras of the Solar System and, on its new course, a perfect target for a robotic space explorer. JPL's partners in this exciting mission are the University of Washington, Lockheed Martin Astronautics, McDonnell Douglas and the Max Planck Institute in Germany.

GENESIS

The Genesis spacecraft, equipped with ion and electron monitors and an ion concentrator, will be launched in 2001 and placed into orbit at a point between Earth and the Sun where the gravity of both is balanced. Once there, Genesis is to unfold its wing-like arrays of specially designed high-purity wafers and collect particles of the solar wind blowing past it. Then, in 2003, the sample collectors will be returned to Earth for an accurate determination of our star's average isotopic and elemental composition.

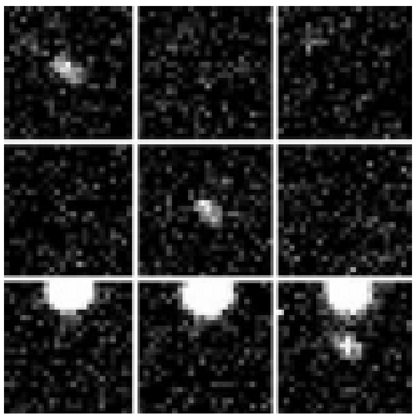


This painting depicts the Genesis spacecraft as it collects particles of solar wind during its two-year orbit between Earth and the Sun.

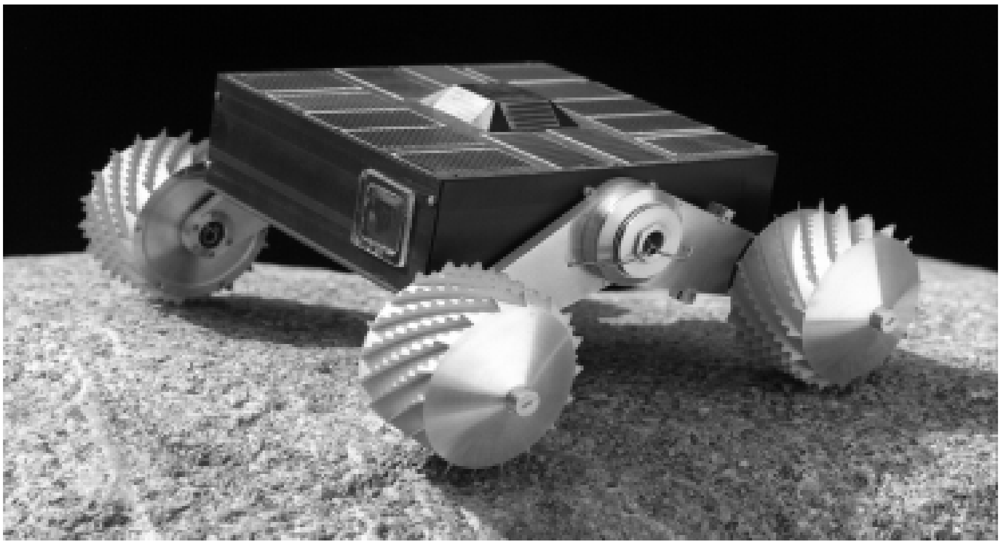
Genesis will, in effect, retrieve a sample of the heavier elements and ions present in the early Sun and thus place major constraints on the conditions, processes and events associated with the formation of planetary bodies. The Genesis mission will address some profound and mystifying questions about the Solar System. It is widely accepted that a solar nebula — a cloud of gas, dust and ice created from previous generations of stars — gravitationally collapsed about 4.6 billion years ago, and that gravity pulled 99 percent of the gas and dust together to form the Sun while the remaining 1 percent of ice grains and dust coalesced to form the planets, moons, comets and asteroids. Because all these bodies are clearly quite different in composition, the question is: How did this transition from nebula to planets take place? Scientists have proposed various evolutionary paths, but they are hampered by one major unknown: What was the original composition of the solar nebula? The answers to these and other questions will come from matter, very nearly the same as the original solar nebula, stripped from the Sun's outer layers by the solar wind and carried downstream.

NEAT

Right: The Near-Earth Asteroid Tracking system searches for moving objects by comparing sets of three images of the same part of the sky acquired during a 1-hour period.



Viewing the skies from Earth, the JPL-managed Near-Earth Asteroid Tracking (NEAT) system contributed important astronomic discoveries in 1997. Using NEAT, a totally automated 1-meter (3.28-foot) telescope with a very large charge-coupled device camera, JPL planetary scientists discovered a rare Aten asteroid and a distant comet. The Aten and the comet remain largely within Earth's orbit and are of interest because of their potential for close encounters with our planet. The new comet appears to be coming from the Oort Cloud, a region beyond the outer planets that is believed to contain trillions of comets.

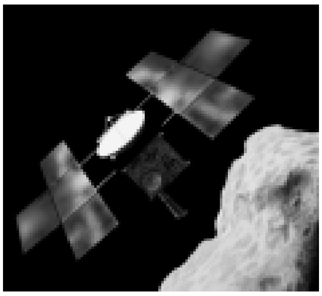


This miniaturized nanorover will fit in the palm of your hand.

MUSES–C

Collaborating with Japan's Institute of Space and Astronautical Sciences, JPL in 1997 was named to manage NASA's participation in the MUSES-C — the unusual acronym stands for "Mu" (the name of the Japanese rocket) Space Engineering Spacecraft; the "C" designates it as the third in a series — which is to be launched in 2002 toward the asteroid Nereus.

JPL's contribution will be an advanced miniature rover weighing about 0.7 kilogram (1.5 pounds) that will collect samples of the asteroid for return by the spacecraft. Like a beetle, the tiny rover will have the ability to right itself should it tip over in the extremely weak Nereus gravitational field. MUSES-C will employ solar electric propulsion and a fully autonomous guidance and navigation system and is expected to yield valuable data on the materials that formed the inner planets more than four billion years ago.

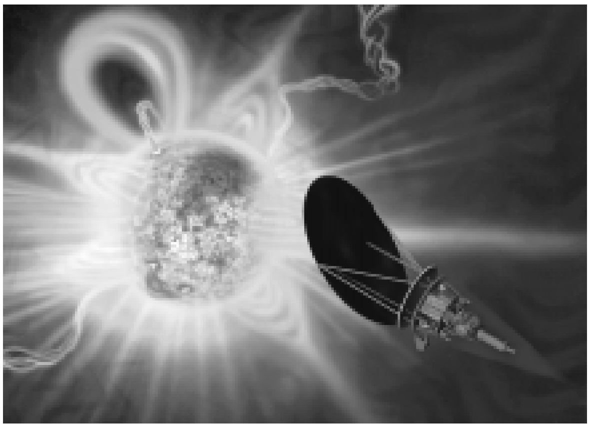


An artist's impression of the MUSES-C spacecraft approaching the near-Earth asteroid 4660 Nereus.

ICE AND FIRE

In 1997, NASA consolidated three missions tentatively scheduled for launch during the first half of the next decade because of their common, enabling technologies — lightweight, advanced hardware components and advanced software. The missions, collectively known as Ice and Fire for the environmental extremes they are to explore, include the Pluto–Kuiper Express, the Europa Orbiter and Solar Probe.

The Express is slated to visit Pluto and objects in the Kuiper disk located beyond Pluto's orbit, while the Orbiter will conduct a follow-up study of Jupiter's icy moon Europa and the Probe will focus on the Sun's corona, flying through and analyzing its polar plumes.



A painting of Solar Probe traveling through the Sun's atmosphere where it will take measurements and collect images.

Our Origins

Seeking Answers to Universal Questions

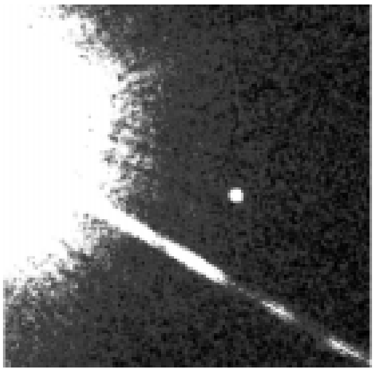
The Origins Program seeks answers to basic questions pondered by humankind: How did the galaxies form? Are there other habitable planets outside our Solar System? Is life unique to Earth?

Several astronomical missions are central to NASA's Origins Program, which is to seek extrasolar planets that perhaps harbor some form of life. What these advanced telescopes discover could answer fundamental questions about the beginnings of the Universe, as well as the formation of galaxies, stars, planets and life.

SPACE INFRARED TELESCOPE FACILITY (SIRTF)

During 1997, JPL completed preliminary planning and design of the first major Origins mission, the SIRTF, the largest infrared telescope ever to be placed in space and the fourth and last of NASA's Great Observatories. When SIRTF joins the family that includes the Hubble Space Telescope, the Advanced X-ray Astrophysics Facility and the Compton Gamma Ray Observatory, the Great Observatories will provide a comprehensive view of the sky in all wavelengths.

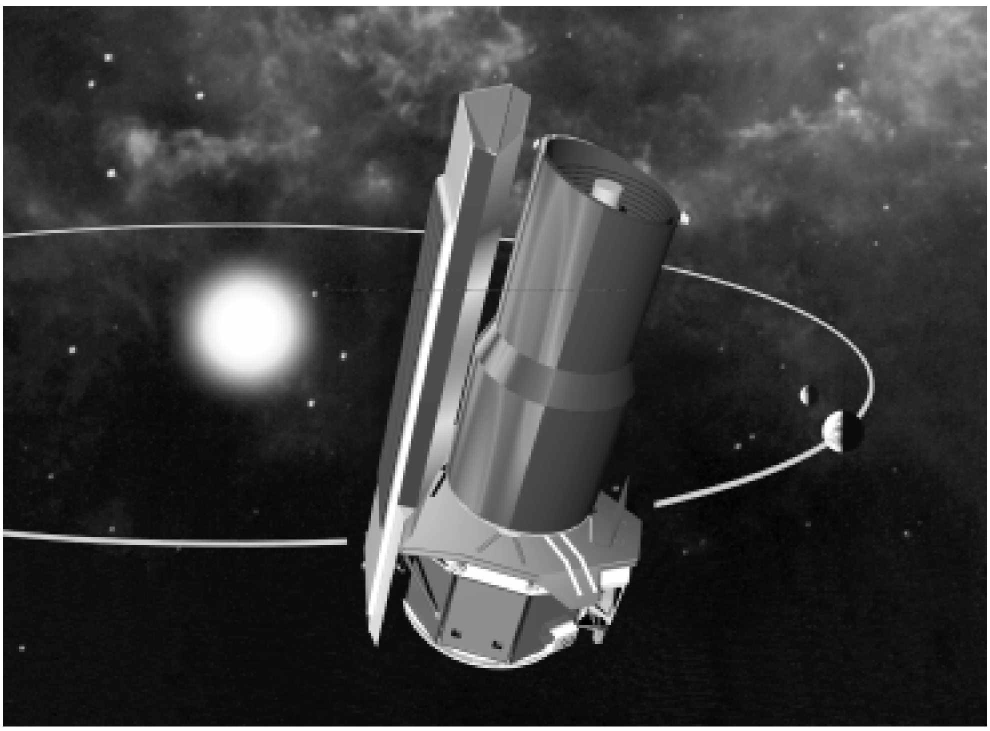
SIRTF, scheduled for a 2001 launch, will provide 24-hour viewing of deep space from a solar orbit and will be 1,000 times more sensitive than any previous infrared telescope. During its minimum operating life of two and one-half years, it will scan the skies for brown dwarf stars, which, if as numerous as some scientists believe, could account for a significant fraction of the Universe's presumed missing mass.



Hubble Telescope image of brown dwarf GL229B. (Bright dot above "spike" is caused by Hubble's optical system.) Companion star, red dwarf Gliese 229, is four billion miles away.

Interacting and colliding galaxies are extremely bright sources of infrared radiation and may represent a hitherto unknown physical process; these, too, will be targets for the 0.85-meter-diameter (2.8-foot-diameter) telescope. An additional scientific priority will be planets and protoplanetary disks and debris that may provide insights into planetary development and evolution.

SIRTF will do all this with three major science instruments: the Infrared Array Camera (IRAC) provided by the Smithsonian Astrophysical Observatory, the Infrared Spectrograph (IRS) from Cornell University and the Multiband Imaging Photometer for SIRTF (MIPS) from the University of Arizona. Lockheed Martin/Missiles

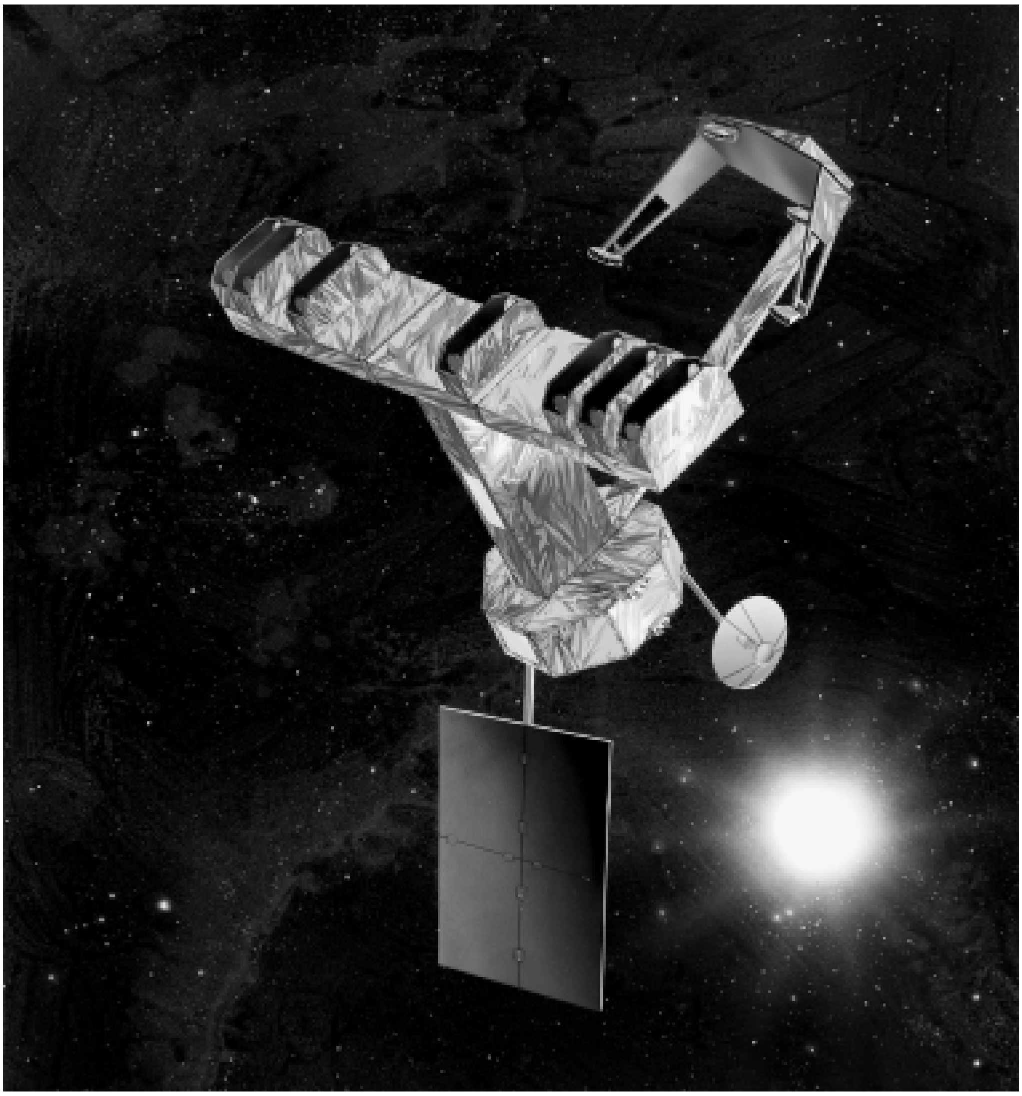


Scheduled for launch in December 2001, SIRTF represents an important scientific and technical bridge to NASA's new Origins Program.

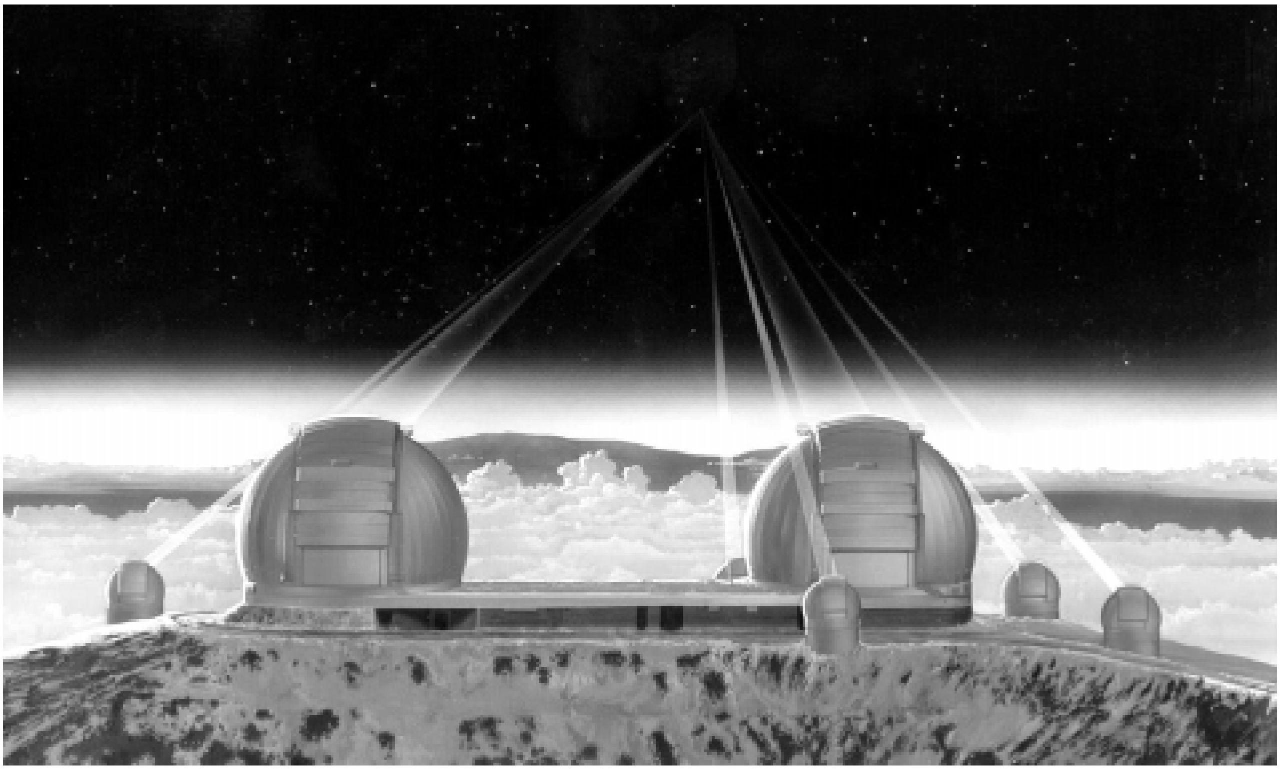
and Space Division, Sunnyvale, California, is to build the spacecraft module and will integrate it with the Cryo-Telescope Assembly module built by Ball Aerospace and Technology Corp., Boulder, Colorado. To detect the extremely faint infrared signals it is designed to capture, the SIRTF telescope within the Cryo-Telescope Assembly will be cooled by liquid helium to 5.5 kelvins (-449.77 degrees Fahrenheit).

Although NASA had pared the SIRTF budget from earlier levels prior to assigning program responsibility to JPL, the Laboratory expects to complete the project within budget. Major cost savings have been attained by designing the mission for an Earth-trailing heliocentric orbit, with the spacecraft drifting away from Earth at about 15 million kilometers (9.3 million miles) per year. This orbit puts the spacecraft and its limited reservoir of liquid helium in a far more benign thermal environment than any geocentric orbit, simplifies scheduling and operations and makes it easier to avoid interference from Sun–Earth–Moon alignments.

Substantial savings have also been realized through the innovative fabrication of telescope parts from beryllium, a very lightweight metal with the ability to "remember" its original shape and return to it after being thermally distorted. This will



The Space Interferometry Mission (SIM) will be the first to use optical interferometry in space, where it can fulfill its potential outside the distorting effects of Earth's atmosphere. SIM will combine light from two or more telescopes as if they were parts of a single gigantic telescope mirror.



Artist's concept of the Keck Interferometer atop Mauna Kea, Hawaii.

permit the first "warm launch" of an infrared space observatory and greatly reduces the amount and weight of the liquid helium and ancillary structure required for the mission.

Astronomers anticipate a rich harvest of findings from SIRTF. More than three-quarters of SIRTF's observing time will be by investigators selected competitively from the general scientific community. These "general observers" will interact with the spacecraft through the SIRTF Science Center on the Caltech Campus in Pasadena.

SPACE INTERFEROMETRY MISSION (SIM)

NASA's Origins Program gained added momentum in 1997 as JPL initiated planning for SIM. This will be the first application of long baseline optical spaceborne interferometry: a way of arraying several small telescopes so that their collected signals seem to have been gathered by a single, much larger mirror. Depending on the spacing between the individual collectors, an interferometric system can be set either for very high resolution of a particular object or sensitivity to a faint signal. A SIM spacecraft will measure precisely the locations of stars and/or search for planets orbiting close to bright stars.

Looking ahead to a 2005 launch, the Laboratory last year carried out experiments to refine and test interferometry techniques by using a computer to link the two 10-meter (32.8-foot) Keck telescopes atop Mauna Kea on Hawaii. With a baseline of 26 meters (85.3 feet) separating the two instruments, the Keck Interferometer will cast a sharp eye on nearby stars and potential planetary systems. This ground-based interferometer should be completed in 2000, after which its capabilities will be further enhanced in 2002 by the addition of four "outrigger" telescopes.

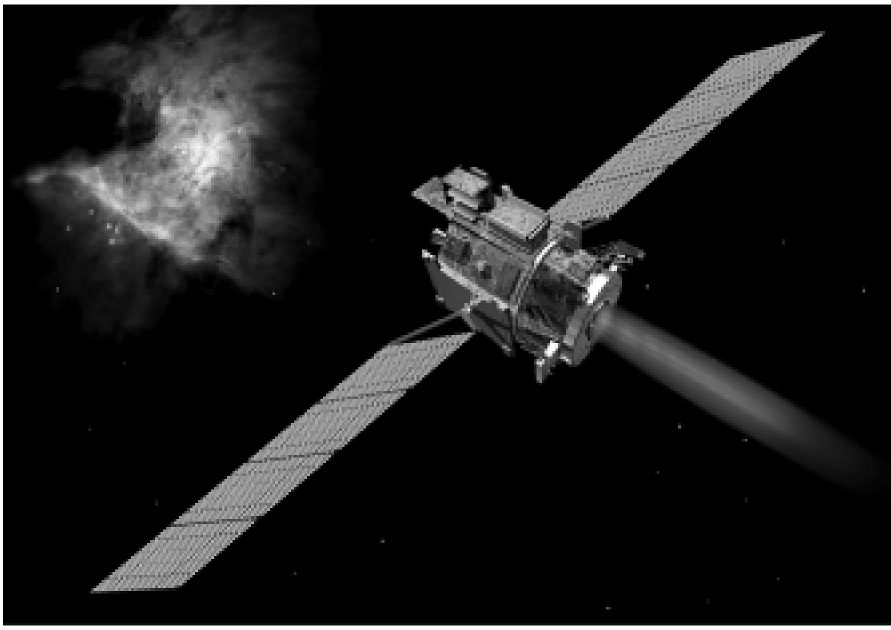
New Millennium

More Missions...More Often...at Modest Cost

In the new millennium, JPL will land a spacecraft on the surface of a comet where it will take pictures and drill for samples of the nucleus.

Approaching the 21st century, NASA and JPL review their new aims and a new model for space missions: More frequent missions, designed for more focused science, completed at a more modest budget than in the past. The new model will make it possible to develop missions with shorter development cycles that are based on fresher, innovative low-cost technologies and spacecraft that are lighter and less costly. Toward this end, NASA established the New Millennium Program in 1994.

Although elements of this model have been incorporated into a number of missions already launched or under development, a major initiative has been adopted to ensure the model's full realization in the years immediately ahead. In 1997, JPL completed much of the assembly and testing of its revolutionary Deep Space 1 mission for a launch in October 1998.



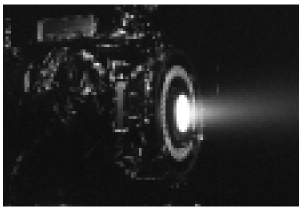
This artist's concept shows Deep Space 1 with a glow emanating from its ion thruster.

DEEP SPACE 1

The first spacecraft to use the solar electric ion propulsion of science fiction fame as its primary propulsive agent when launched in 1998 will be Deep Space 1. (It will also test a number of other advanced technologies.) In 1997, a prototype of the Deep Space 1 xenon ion propulsion engine successfully completed an 8,000-hour test at JPL. This engine's thruster and power processor were built by Hughes Electron Dynamics Division; the engine will generate a push comparable to the downward force you would feel when laying a single, ordinary sheet of paper on the palm of your hand. Nevertheless, this slight, but long-running, thrust can change the spacecraft's speed by as much as 16,000 kilometers (9,942 miles) per hour, and it would use only about one-tenth the fuel a chemical propellant system would require to achieve the same change in velocity. Although its primary goal is to validate a suite of technologies, Deep Space 1 may fly past an asteroid in 1999, as a mission bonus.

DEEP SPACE 2

Right behind Deep Space 1 is another New Millennium effort — Deep Space 2. The Deep Space 2 probes successfully ran a gauntlet of airgun, air-drop and arc-jet tests conducted by Sandia National Laboratories, the New Mexico Institute of Mining and Technology, the U.S. Air Force's Eglin Air Force Base and Phillips Laboratory and NASA's Ames Research Center. Full system tests are to be completed in 1998.



The xenon ion engine during testing in a vacuum chamber at JPL.

DEEP SPACE 3 AND DEEP SPACE 4

Initial planning and project definition began in 1997 on two other exciting New Millennium projects, Deep Space 3 and Deep Space 4/Champollion. The former will validate space interferometry technology by flying three telescopes in precise formation in solar orbit. The latter, named for Jean-Francois Champollion, the 19th-century French scholar who deciphered Egyptian hieroglyphs, is to attempt a first-time-ever rendezvous and landing of a small spacecraft on a comet nucleus. Once there, the spacecraft is to analyze the comet's composition and properties and return samples to Earth.

This artist's rendering shows Deep Space 4 (DS4)/Champollion's lander deployed for the sample return from the surface of comet Tempel 1 in early 2006.

Because a comet has very little mass and therefore a very weak gravitational field, any robot lander must be able to cling to the nucleus body long enough to carry out its scientific inquiries. During 1997, JPL constructed the Extraterrestrial Materials Laboratory for both the fabrication of friable materials — easily pulverized matter similar to what the nucleus of a comet may be like — and the testing of robot anchoring and drilling technologies.

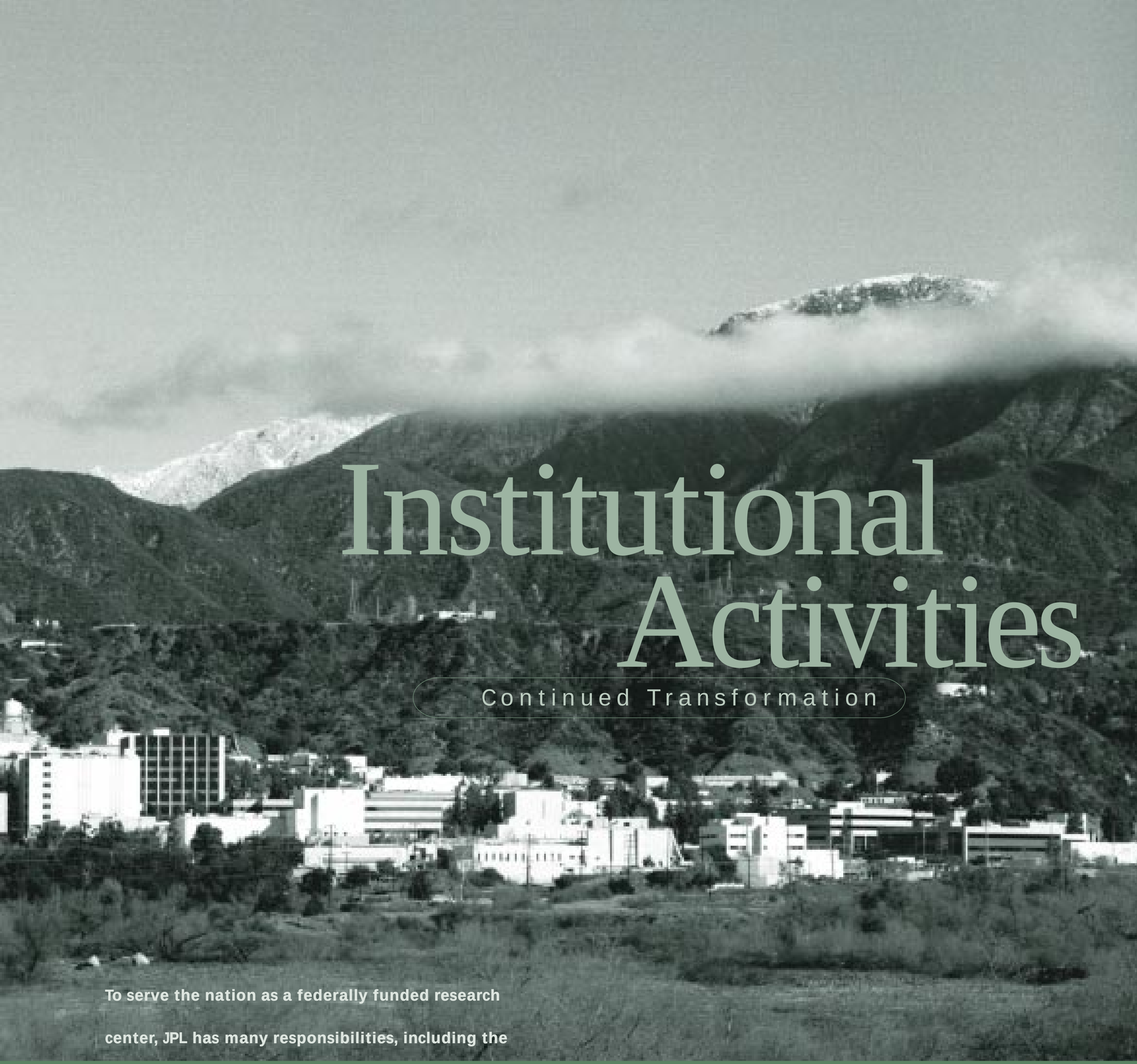
NEW COLLABORATIVE PROGRAMS

Foreshadowing the future direction of NASA's inquiries, JPL rolled out a broad, new astrobiology initiative in 1997, with JPL and other NASA centers and institutions serving as key participants. The objective will be to search for evidence of life in the Universe, to define the conditions under which life might arise and to examine planets that presently support, or once may have supported, life.

DEVELOPING ADVANCED TECHNOLOGIES

The Laboratory also established the Center for Integrated Space Microsystems (CISM) to foster the development of advanced computing and avionics technologies. This new center of excellence will help NASA achieve its vision of highly miniaturized and intelligent autonomous robotic missions for deep space exploration. CISM will concentrate on creating cutting-edge computer hardware and software technologies and on integrating miniaturized electronics packages for tomorrow's spacecraft.

The dream of using artificial intelligence software to create a thinking spacecraft is expected to make a significant leap forward when the Deep Space 1 mission flies in the fall of 1998. Designed in 1997 as a joint project of NASA's Ames Research Center and JPL, the "remote agent experiment" will validate an artificial intelligence control system designed to manage routine tasks within broad mission objectives supplied by controllers on Earth. It is one of 12 technologies to be validated during Deep Space 1's mission.



Institutional Activities

Continued Transformation

To serve the nation as a federally funded research center, JPL has many responsibilities, including the promotion and advancement of technologies that support our nation's strategic and economic interests.

The year 1997 was marked by significant changes in virtually every corner of JPL as the Laboratory forged ahead in its mission to become a process-oriented and customer-driven enterprise. Just as its engineers and scientists strove to reach new technological horizons more cost effectively, JPL as an institution sought ways to improve administrative, business and technical functions to support that effort.

REENGINEERING AN INSTITUTION

Adopting the approach called process-based management, five separate reengineering teams worked diligently to enhance the Laboratory's efficiency while fulfilling its scientific goals. The reengineering teams were identified as follows:

- New Business Solutions
- Develop New Products
- Enterprise Information System
- Growth and Assignment of People
- Define and Maintain the Institutional Environment

New Business Solutions (NBS), the broadest effort to streamline Laboratory operations, addressed such critical areas as general administration, finance, human resources and procurement. NBS last year conducted a comprehensive evaluation of JPL's core administrative and business processes and launched a major reengineering program to make JPL a more effective and efficient organization and to incorporate best business practices into administrative functions. This initiative will continue throughout 1998 and beyond.

The NBS team's most important responsibility was to spearhead the upgrading of JPL's computer capabilities. The Laboratory selected a new $3.1 million software system from Oracle Corporation to integrate business and administrative data processing into a uniform system and eliminate reliance on mainframe computers. The new software system, which is year-2000 compliant, will save time and costs in accounting, shipping and receiving, timekeeping and other areas by establishing one point of data entry, thus reducing duplicative data processing functions and improving accuracy. Plans called for the software to be installed in spring 1998. In conjunction with the new software, work also began during the year on development of a user-friendly Web site to

The Design Hub is part of a multidisciplinary computer-aided design facility that enables teams of designers, using computerized tools, to efficiently apply creativity and expertise to solve design problems.

place most of JPL's business functions on line, including personnel, property administration, procurement requisitions and timekeeping.

Under the NBS project, JPL stepped up its outsourcing of administrative support tasks to concentrate on its core competencies. For example, the Laboratory signed a 10-year, $200 million contract with OAO Corporation of Maryland for computer management services currently handled by JPL personnel. It also retained Xerox Business Services to provide duplication and document distribution services and retained outside companies to supply security and utility services.

The Project Design Center enables multi-functional teams to design the science mission, the spacecraft, and mission operations concurrently — making real-time trade-offs to remain within mission constraints and requirements.

Staff members assigned to the NBS effort worked hard at updating JPL's business practices and administrative infrastructure, and the Develop New Products (DNP) team retooled the Laboratory's design processes to meet the need for the development of smaller, less expensive and more frequent missions. The DNP team concentrated on integrating processes, tools, facilities and staff to reach JPL's financial goal of cutting product design cycle time in half and slashing costs by one third while still meeting its basic technical mission: engineering highly advanced space projects that no one has done before.

The DNP team made significant progress in adopting "art-to-part" technology that allows automatic fabrication of parts directly from computer-generated designs. It demonstrated a new centralized database for tool design, function and capabilities. In addition, DNP developed three new Discipline Centers of Excellence in 1997:

- The Project Design Center, where project engineers can conceptualize designs in real time, accomplishing in a matter of days what used to require months.
- The Design Hub, where designers, working at sophisticated workstations, can collaborate on detailed subsystem and component design.
- The Flight System Testbed, where engineers and designers can integrate virtual or physical components in spacecraft and test them.

The Enterprise Information System (EIS) team moved ahead on developing a state-of-the-art information system, implementing upgraded file distribution, electronic messaging, fiber optic network and computer services. Both the Growth and Assignment of People (GAP) and the Define and Maintain the Institutional Environment (DMIE) teams finished their assignments during 1997, and were folded into other Laboratory initiatives. GAP completed mapping processes and identifying human resource needs and was merged with NBS. After DMIE's work on process reengineering came to an end, its team members were assigned other duties in operations.

PARTNERSHIPS

Responding to NASA's call for more frequent, less costly missions, JPL intensified its effort to engage in productive partnerships with industry, universities and other NASA and governmental organizations. Among its partners during 1997 were Able Engineering Company (AEC); Allied Signal Technical Services; Ames Research Center; Ball Aerospace Corporation; the Ballistic Missile Defense Organization; Boeing Expendable Launch Systems; California State University, Northridge; Columbia University; Commonwealth Scientific and Industrial Research Organization of Australia; NASA Goddard Space Flight Center; Hughes Electron Dynamics Division; Instituto Nacional de Tecnica Aeroespacial of Spain; NASA Kennedy Space Center; NASA Lewis Research Center; Lockheed Martin Corporation; Malin Space Science Systems; Space Research Institute of the Russian Space Agency; Spectrum Astro, Inc.; University of Arizona; University of California at Los Angeles; University of Southern California; University of Washington; U.S. Air Force Research Laboratory and Utah State University.

Three of NASA's four prestigious George M. Low Awards for excellence and quality work went to aerospace companies partnering with JPL on the Mars Pathfinder and other projects: ILC Dover Inc., BST Systems Inc., and Advanced Technology Company. ILC Dover developed the Mars Pathfinder airbag landing system. BST, which specializes in high technology, won in the small-business category for its work in supplying the battery for the Sojourner rover. Advanced Technology, a metal joining firm, earned the small-business service award for producing imaging detectors and for its quality work over 26 years on a variety of other NASA and JPL projects.

JPL's annual Open House attracted a record number of visitors in 1997 — more than 37,000.

In May, JPL and California State University, Northridge (CSUN) signed an agreement to share the Laboratory's rich store of scientific and technical information with faculty and students at one of California's largest universities. The Laboratory benefits from the assistance of additional researchers and students, while CSUN gains access to the resources of a NASA national laboratory and one of the world's most advanced scientific and technical institutions.

Another important partnership was formed in August, when JPL reached a milestone two-year agreement with Columbia University to participate in Columbia's prestigious Earth

The JPL Undergraduate Scholars (JPLUS) program is dedicated to Caltech's Dr. Robert B. Leighton, shown here sculpting the first infrared telescope in the early 1960s.

Institute in New York. Working with Columbia faculty, JPL engineers and scientists will study Earth systems and their effects on society, focusing initially on climate variability, as well as natural hazards such as earthquakes, severe storms and volcanoes.

JPL celebrated the 10th anniversary of its technology transfer program. As part of its NASA mission, the Laboratory plays a major role in transferring technology and channeling it to commercial applications to help the nation maintain a globally competitive economy. JPL added 18 new companies to its Technology Affiliates Program during the fiscal year, collaborated with some 120 companies (more than half of them small businesses) on 341 tasks and received some $3 million in corporate funding. The Laboratory evaluated more than 200 new technologies, and negotiated 65 commercial software or copyright licenses and 7 patent licenses.

A typical example of this partnership approach was the licensing of a cool-process, zero-emission methanol fuel cell patented by JPL and the University of Southern California. Los Angeles-based DTI, Inc. licensed the technology for the Direct Methanol Liquid Feed Fuel Cell, and plans to use it in the development of light-duty electric vehicles.

In 1997, JPL began tests on behalf of NASA with Sony Corporation, GTE Hawaiian Tel and other companies on the satellite transmission of high-definition and high-resolution video signals and computer data over the Pacific Ocean. It is hoped that the technology will allow transcontinental editing and movies and television programs, as well as transmission of high-definition video (HDV) films directly to movie theaters.

Through the Internet, KidSat participants are involved in planning observations and using images from shuttle-based cameras to study Earth's dynamic, fragile environment.

Less sophisticated, perhaps, but certainly more fun, was the creation with Mattel Inc. of the Hot Wheels JPL Sojourner Mars Rover Action Pack Set, the toy version of Sojourner. It recreates the genuine rover's unique "rocker-bogie" suspension system.

In the waning days of 1997, JPL entered into a partnership that ventured into the frontier between the age-old fascination with balloon flight and the limits of modern technological capability. JPL personnel teamed with adventurer/entrepreneur Steve Fossett to validate instrumentation installed aboard his balloon, Solo Spirit, in his effort to become the first person to fly a balloon around the world alone. For its part, JPL gained experience that might be useful to a future "aerobot" robotic balloon studying the atmospheres of Mars and Venus.

EDUCATIONAL OUTREACH

JPL's fundamental mission to conduct advanced space science carries a deep responsibility to participate in, and contribute to, the education and training of future generations of engineers and scientists. The Laboratory met that commitment through its support of existing programs and the establishment of new educational programs and partnerships for students and teachers.

In 1997, more than 3,200 middle school students throughout the country participated in the final two flights of the highly successful KidSat program run by JPL, the University of California at San Diego and the Johns Hopkins University Institute for the Academic Advancement of Youth. Some of the youngsters operated a remote-controlled electronic still camera aboard Space Shuttle Atlantis, beaming back images of Earth to their classmates and teachers via the Internet.

In memory of the late Dr. Robert B. Leighton, a Caltech astronomer and physicist who helped develop the first digital television used by JPL in deep space, the Laboratory last year established the JPL Undergraduate Scholars (JPLUS) program. JPLUS recognizes outstanding performance and creativity among freshman community college students in the greater Los Angeles area.

JPL also sponsored a variety of other educational opportunities, including a summer teacher enhancement program and its ninth annual Planetary Science Summer School. JPL also donated a surplus 34-meter-diameter (111.55-foot-diameter) tracking antenna to the Lewis Center for Educational Research in Apple Valley, California. The radio telescope, formerly used for the Voyager missions in the 1960s and 70s, was adapted so that students anywhere in the United States may observe Jupiter and the Sun using a computer and modem to control the antenna.

Reaching out to the public, the Laboratory hosted more than 37,000 people at its annual Open House, a new record for single-weekend attendance.

THE PROMISE OF THE FUTURE

By providing clues to life's origins and practical help in so many aspects of daily life, space science has established its relevance and value to the human condition. Under the guidance of NASA and supported by JPL and others, technological advancements will surely result in discoveries that surpass our most fervent hopes.

HONORS AND AWARDS 1997

During 1997, a number of honors and awards were presented to JPL personnel — individuals and groups — by NASA, the Laboratory and a variety of organizations and professional societies in recognition of exceptional achievements or service. The annual NASA Honor Awards are presented to JPL personnel in recognition of outstanding individual or group achievements. And, through special appointments, Caltech Campus and the Laboratory recognize the accomplishments of individuals and promote the exchange of information in areas of research.

SPECIAL HONORS

Engineer's Council Distinguished Engineering Project Award

Mars Global Surveyor and Mars Pathfinder Projects

NASA Software of the Year Award

Abhinandan Jain, Guillermo Rodriguez and Guy Man for the DARTS Software Program

Asahi Shinbun Network Award

Mars Pathfinder Web Site

NASA HONOR AWARDS

Outstanding Leadership Medal

Robert J. Beale
William G. Fawcett
Matthew R. Landano
T. David Linick
James C. Marr IV
Benn D. Martin
Firouz Naderi
Donna L. Shirley
Joseph I. Statman
Paul T. Westmoreland

Exceptional Achievement Medal

Jon T. Adams
Steven Bard
N. Talbot Brady
David A. Breda
Kar-Ming Cheung
Steve A. Chien
Suzanne L. Craig
Daniel E. Erickson
Randall H. Foehner
Robert E. Freeland
Lucien Froidevaux
Robert Gershman
Dean E. Hardi
Mark Herring
Michael E. Hoenk
William Hoffman
Burton J. Jaffe
Kent H. Kellogg
Leslie L. Livesay
John J. Louie
Thomas H. May
Randy D. May
John C. McKinney
Scott C. Morgan
Gregory Neumann
Erik Nilsen
Gilles F. Peltzer
Timothy T. Pham
Carol A. Polanskey
Steven H. Pravdo
William Rafferty
J. Edmund Riedel
Chester N. Sasaki
Philip H. Stanton
Douglas S. Stetson
Paul E. Stolorz
Wu-Yang Tsai
Peter Tsou
Richard A. Volpe
Barbara A. Wilson
Elizabeth A. Wilson

Exceptional Scientific Achievement Medal

Ara Chutjian
Glenn S. Orton

Exceptional Service Medal

Luis D. Alfaro
Richard L. Ashe, Jr.
Phillip R. Barela
Patrick E. Beyer
Eva M. Bunce
Eugene S. Burke
Magdi Carlton
Dennis G. Carpenter
Tiffany Hue M. Chui
Steven L. Cornford
Gilbert W. Duke
R. Scott Dunbar
Randall R. Friedl
Lennor Gresham
Gene A. Hanover
Carol S. Hix
Allan H. Johnston
Richard P. Kemski
Tak Kiriyama
Robert C. Koukol
George O. Ladner, Jr.
Merle McKenzie
Haskell G. O'Brien
Peggy L. Panda
Theodore W. Price
Ahmed H. Salama
John F. Stocky
Curtis E. Tucker, Jr.
Carroll F. Winn

Group Achievement Award

Advanced Projects Design Team (Team X)

Airborne Laser Infrared Absorption Spectrometer (ALIAS-II) Team

Deep Space Network Antenna Upgrade Team

Galileo Orbital Operations Recovery Team

Ground-to-Orbiter Lasercomm Demonstration (GOLD) Team

High Speed Simulation Development Team

Jet Propulsion Laboratory Outreach Group

Jet Propulsion Laboratory IN-STEP Inflatable Antenna Experiment Development Support Team

Low Earth Orbiter Terminal (LEO-T) Team

Mars Global Surveyor Project Team

Mars Oxidant Experiment (MOx) Development Team

Mars Pathfinder Project Team

Multimission Image Processing System Implementation Team

NASA Scatterometer Project Team

Near-Earth Asteroid Tracking (NEAT) Team

New Millennium Program Integrated Product Development Teams

Radiation Effects Testing Group

Safety Operations Section Team

Satellite Communications Group

TOPEX/Poseidon Satellite Orbit Control Team

Upper Atmosphere Research Satellite Microwave Limb Sounder Instrument Operations Team

SPECIAL APPOINTMENTS

Distinguished Visiting Scientist

Volker Dohm
Low Temperature Physics—Institut für Theoretische Physik, Aachen, Germany

Thanasis Economou
Origins and Exobiology—Enrico Fermi Institute, Chicago, Illinois

Michael Ghil
Data Assimilation, Atmospheric–Ocean Dynamics—University of California, Los Angeles, California

Alan Gillespie
Quaternary Geology—University of Washington, Seattle, Washington

Richard G. Gordon
Geodesy, Plate Tectonics and Deformation—Rice University, Houston, Texas

Bradford H. Hager
Geophysics and Geodesy—Massachusetts Institute of Technology, Cambridge, Massachusetts

Jonathan Lunine
Origins and Exobiology—University of Arizona, Tucson, Arizona

David R. Nygren
Neutrino Astrophysics Experiment—Lawrence Livermore Laboratory, Berkeley, California

Didier Patrick Queloz
Interferometrics—Geneva University, Geneva, Switzerland

John M. Wahr
Global Geodynamics and Gravity—University of Colorado, Boulder, Colorado

Carl Wunsch
Oceanography—Massachusetts Institute of Technology, Cambridge, Massachusetts

Senior Research Scientist

Fred Y. Hadeagh
System Identification and Controls

William D. Langer
Astronomy

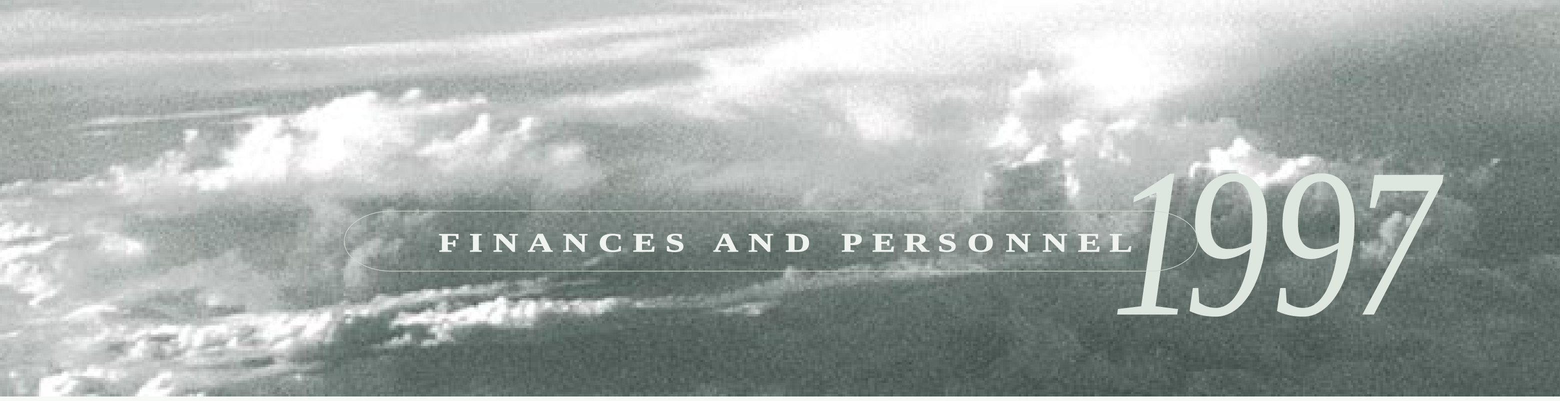
I. Stuart McDermid
Atmospheric Laser Chemistry

Kenneth H. Nealson
Exobiology

John T. Trauger
Visible and Ultraviolet Astronomy

Eugene H. Trinh
Fluid Dynamics

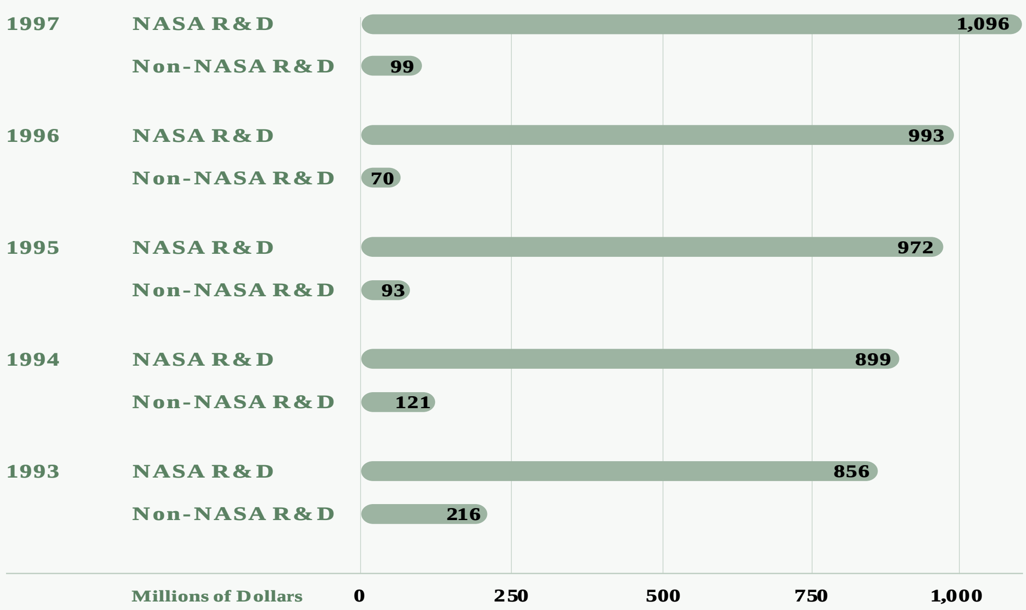
Harold W. Yorke
Protostars and Protoplanetary Disks



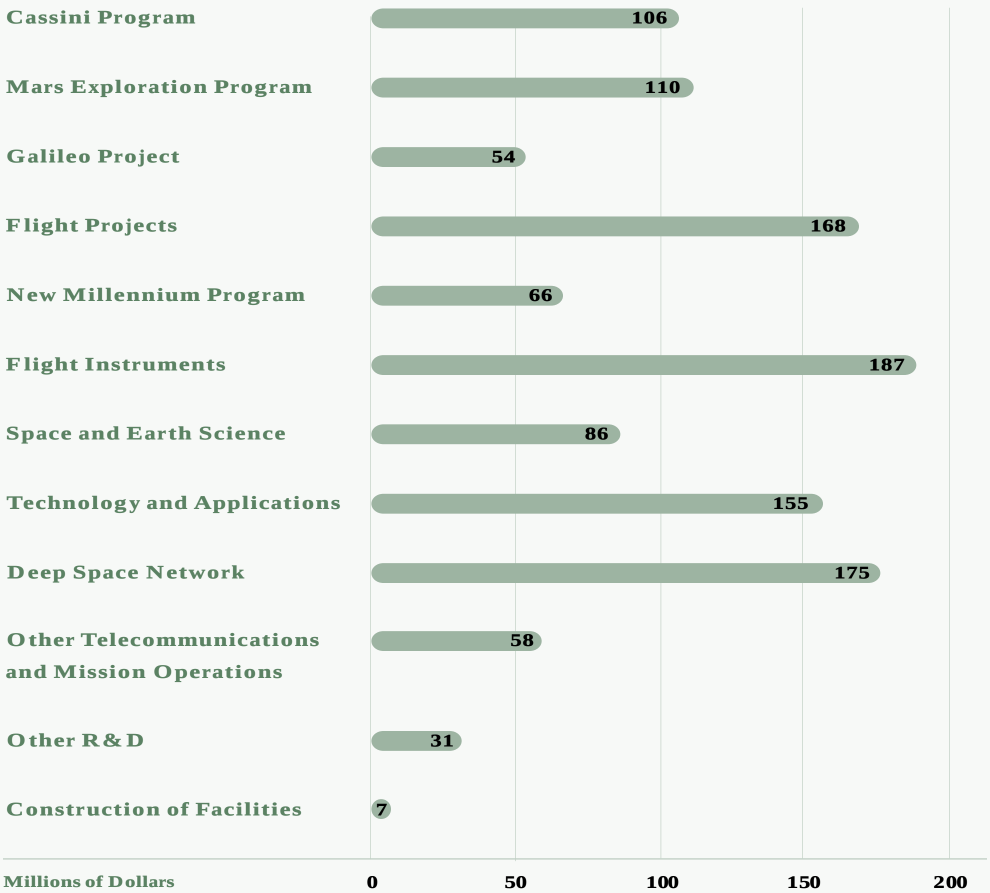
FINANCES AND PERSONNEL 1997

The annual budget for JPL's fiscal year ending in September 1997 was $1.21 billion — an increase of $0.12 billion over the 1996 budget. Research and development costs amounted to $1.19 billion; facilities construction costs accounted for the remainder. Costs for NASA-funded and non-NASA–funded activities were $1,096 million ($1.1 billion) and $70 million, respectively. The Laboratory's employee workforce decreased again during 1997, to 5,251 employees. The workforce had been 5,444 in 1996 and 5,692 in 1995. The following charts show financial and personnel statistics for the 1993–1997 period.

TOTAL COSTS



FISCAL COSTS



TOTAL PERSONNEL

	1997	1996	1995	1994	1993
Engineers and Scientists	3,438	3,522	3,643	3,746	3,850
Support Personnel	1,813	1,922	2,049	2,129	2,320

Caltech

BOARD OF TRUSTEES COMMITTEE

Consulting Members

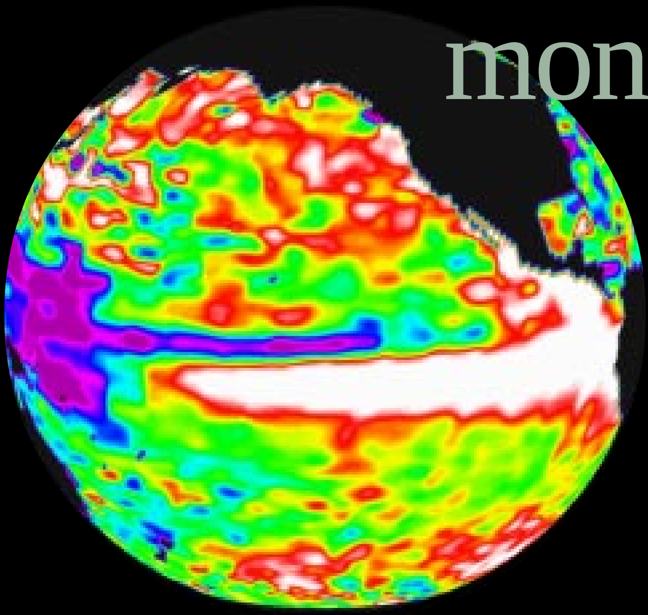
Advisory Members

JPL

EXECUTIVE COUNCIL

experimenting

During field experiments at Lavic Lake, an ancient dry lakebed in California, "Rocky 7" (a Sojourner look-alike, since renamed "Marie Curie") is commanded from JPL and other remote sites by operators and scientists via the Web Interface for Telescience.



monitoring

As the TOPEX/Poseidon satellite monitors global ocean circulations, it is providing significant improvements in weather forecasting with valuable benefits for agriculture, aviation and shipping — all areas that touch the daily lives of people around the world.

IMAGE CREDITS

Page 20, RADARSAT-1 images received by the Canada Centre for Remote Sensing and the Alaska SAR Facility (ASF). Processed by RADARSAT International and ASF. Mosaic by Byrd Polar Research Center, Ohio State University. Page 22, TRACE Mission, Alan Title, Lockheed, Principal Investigator. Page 30, Image obtained by the Halley Multicolor Camera on board the European Space Agency's (ESA's) Giotto spacecraft; provided by Dr. H. U. Keller; copyright Max-Planck Institut für Aeronomie, Lindau/Harz, FRG. Page 37, photo courtesy Marge Leighton.

measuring

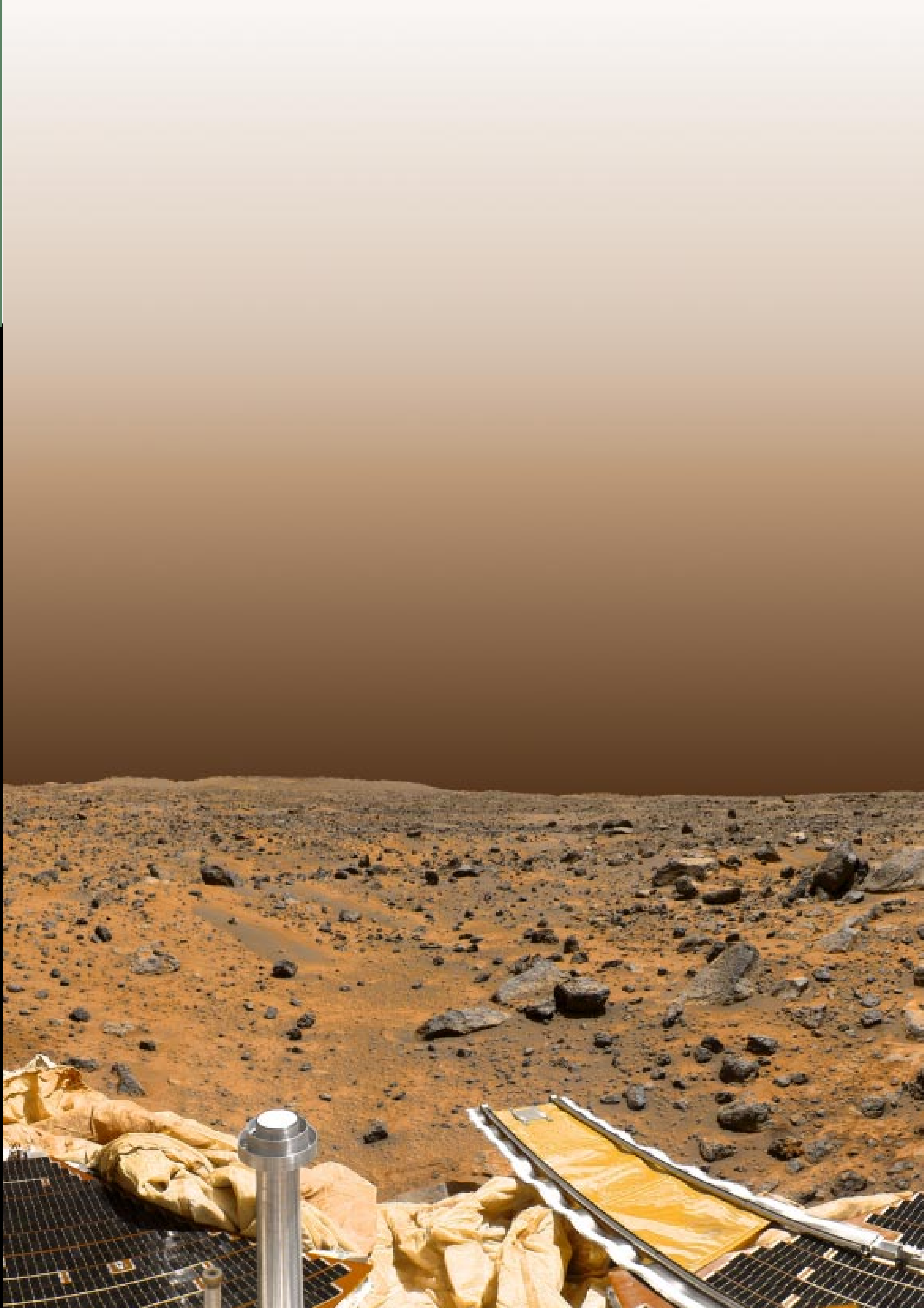
One aspect of JPL's astronomical missions, which are central to NASA's Origins Program, will be to measure the positions and thus distances and motions of celestial objects.

testing

In September 1997, JPL completed an 8,000-hour endurance test of a prototype ion engine. This test verified the engine's life expectancy.

imaging

Analysis of data from the Spaceborne Imaging Radar–C/X-Band Synthetic Aperture Radar enabled scientists to provide accurate assessments of several seismic and volcanic situations around the globe.



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