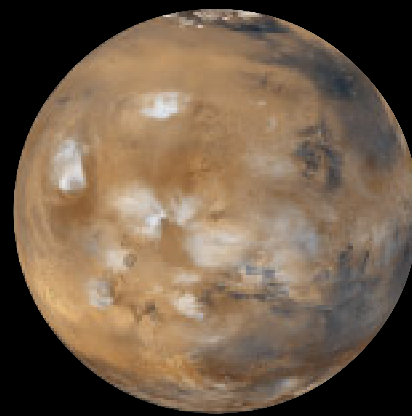

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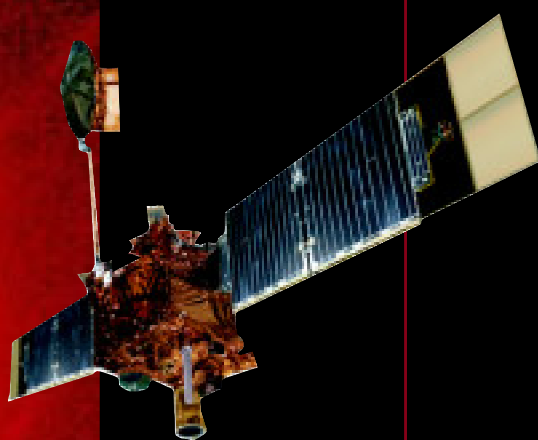
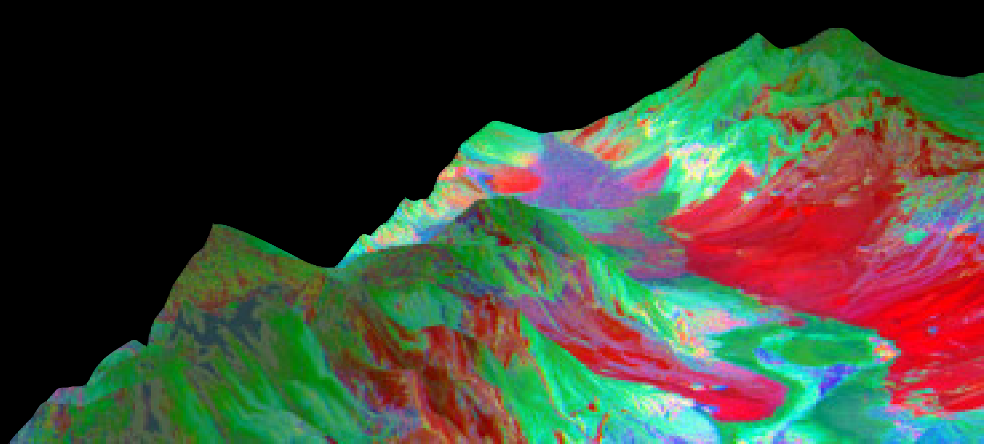


JET PROPULSION LABORATORY



2000

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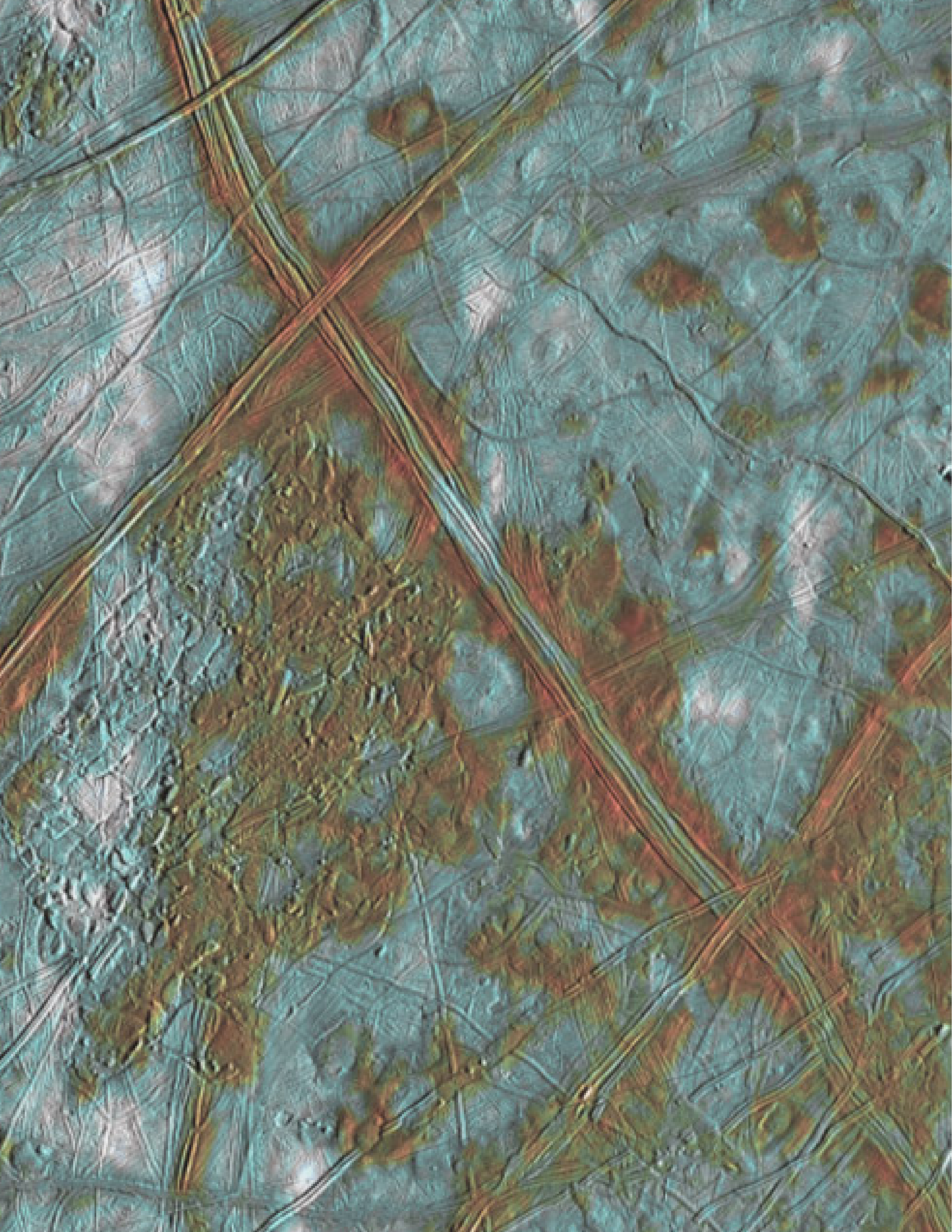
# INTRODUCTION

Year 2000 began with an intense period of self-examination for the Jet Propulsion Laboratory. Late in the previous year, two Mars-bound missions failed as they were arriving at the red planet, disappointing engineers, scientists and the public at large. After a probing series of internal and external reviews, a redesigned Mars program emerged that is intended to be more robust and more tightly coupled to the questions that scientists are attempting to answer. NASA expressed a significant vote of confidence in JPL by assigning an ambitious project to the Laboratory — to design, build and fly twin rovers to Mars in 2003.

Among other missions and research programs, the news was more gratifying. Another Mars orbiter completed its first year of mapping operations, gathering more pictures than those collected over the entire missions of the two Viking orbiters. Stalwart spacecraft such as Galileo continued to deliver scientific discoveries, while a new generation of smaller solar system exploration missions got under way.

In Earth sciences, a growing array of spaceborne instruments and satellites gave us new perspectives on the home planet, including an imaging radar mission on the Space Shuttle and two JPL instruments that began science operations after their launch on NASA's Terra orbiter in late 1999. In astronomy and physics, a JPL-built camera continued to perform flawlessly on NASA's Hubble Space Telescope, offering previously unglimpsed views of the deep universe.

**JPL SPACECRAFT MADE NEW DISCOVERIES AT MARS AND JUPITER WHILE OUR INSTRUMENTS STUDIED EARTH AND IMAGED THE DEEP UNIVERSE.**



Without question, the workhorse of the planetary program was Galileo, which celebrated its fifth year in orbit around the giant planet Jupiter. Early in the year, Galileo executed a flyby of Jupiter's moon Europa during which the spacecraft's magnetometer detected the strongest evidence yet for a liquid ocean of salty water under Europa's icy crust. Just a few weeks later, the hardy craft made its closest-ever approach to Io, capturing images and information about that moon's intense volcanic activity and rapid surface changes.

Already extended once after its original two-year prime mission, Galileo's mission was extended for another year in early 2000. While the first extension focused on Europa and Io, the second extension, called the Galileo Millennium Mission, focused on Jupiter's largest moon, Ganymede, and on collaborative studies with Cassini as that spacecraft passed Jupiter in late 2000 en route to Saturn. Galileo flew close encounters with Ganymede in May and December, picking up magnetic evidence that Ganymede, too, may have a hidden ocean under its ice.

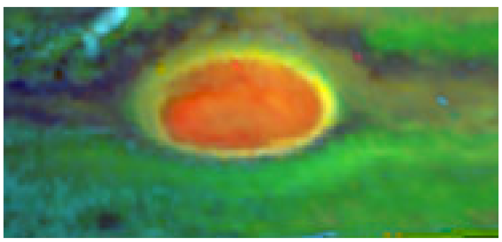
When Cassini was launched in 1997, no one knew that Galileo would still be studying the Jovian system in late 2000. With Galileo still active, NASA approved plans for Cassini and Galileo to make joint scientific observations of Jupiter as Cassini sailed past in December 2000 on its way to Saturn. Cassini began investigating Jupiter in October, returning thousands of images and measurements before the end of the year. It made its closest approach to Jupiter

**GALILEO'S MISSION WAS EXTENDED FOR A SECOND TIME AS THE SPACECRAFT CELEBRATED ITS FIFTH YEAR IN ORBIT AROUND JUPITER.**

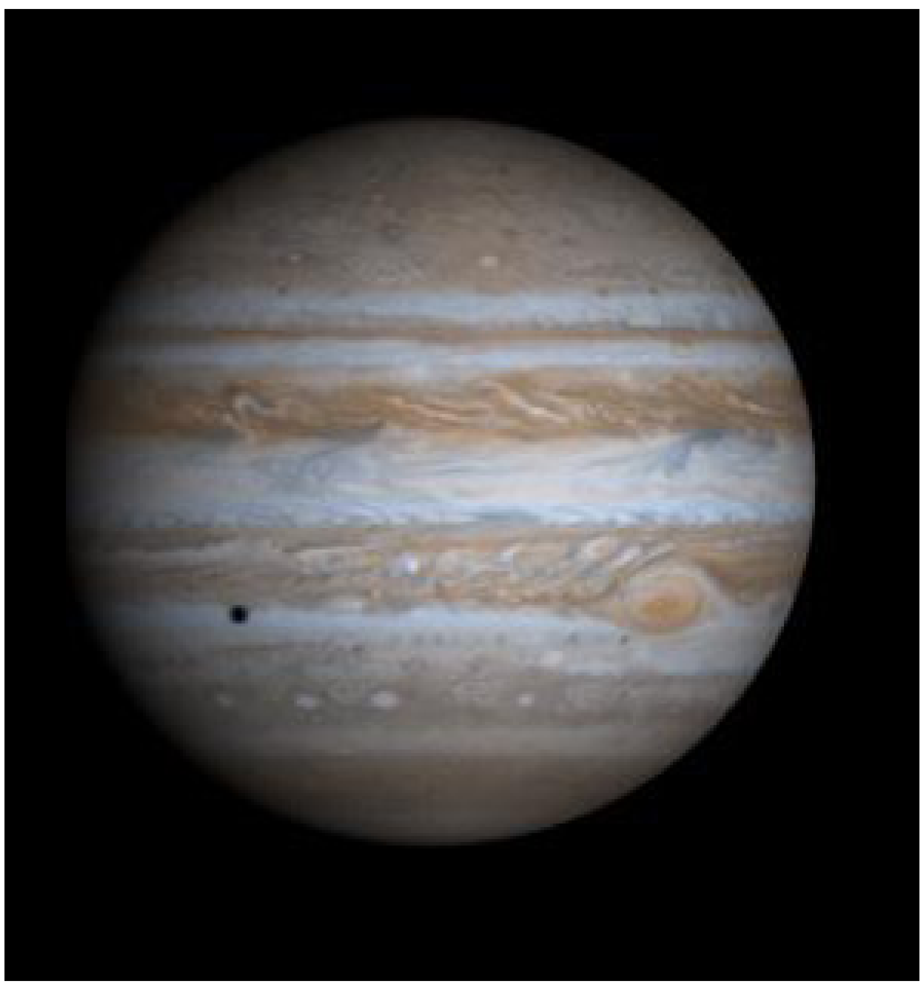
Galileo has provided evidence that Jupiter's moon Europa may have a subsurface ocean. This false-color image shows icy crustal blocks that have broken apart and rafted into new positions.

on December 30, gaining the last gravity assist needed for reaching Saturn on July 1, 2004.

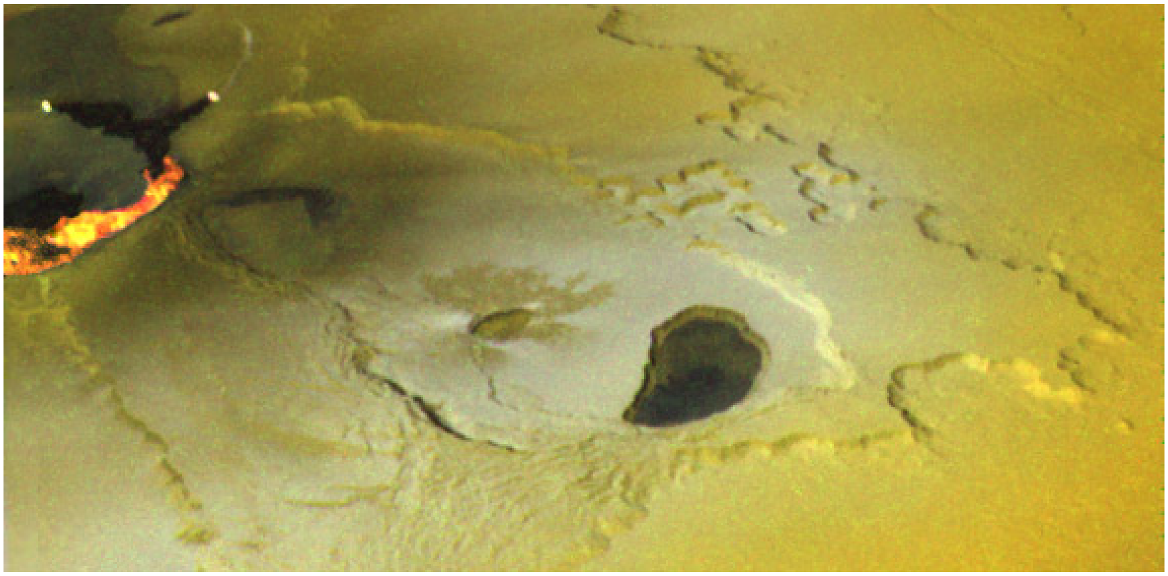
Deep Space 1 is again making a mark on the history of space exploration. After completing its primary mission to test a dozen new technologies, the mission was extended to allow observations of Comet Borrelly in September 2001. The spacecraft began the year 2000 in a crisis: it had lost its navigation system. In a spectacular rescue, mission engineers radioed software to the spacecraft to reformat its science camera to replace the lost star tracker. Since its



An ammonia ice cloud (light blue) on Jupiter imaged by Galileo. (False color)



A true-color composite of four images taken by Cassini during its pass by Jupiter. The four images were projected onto a globe to create this simulated view.

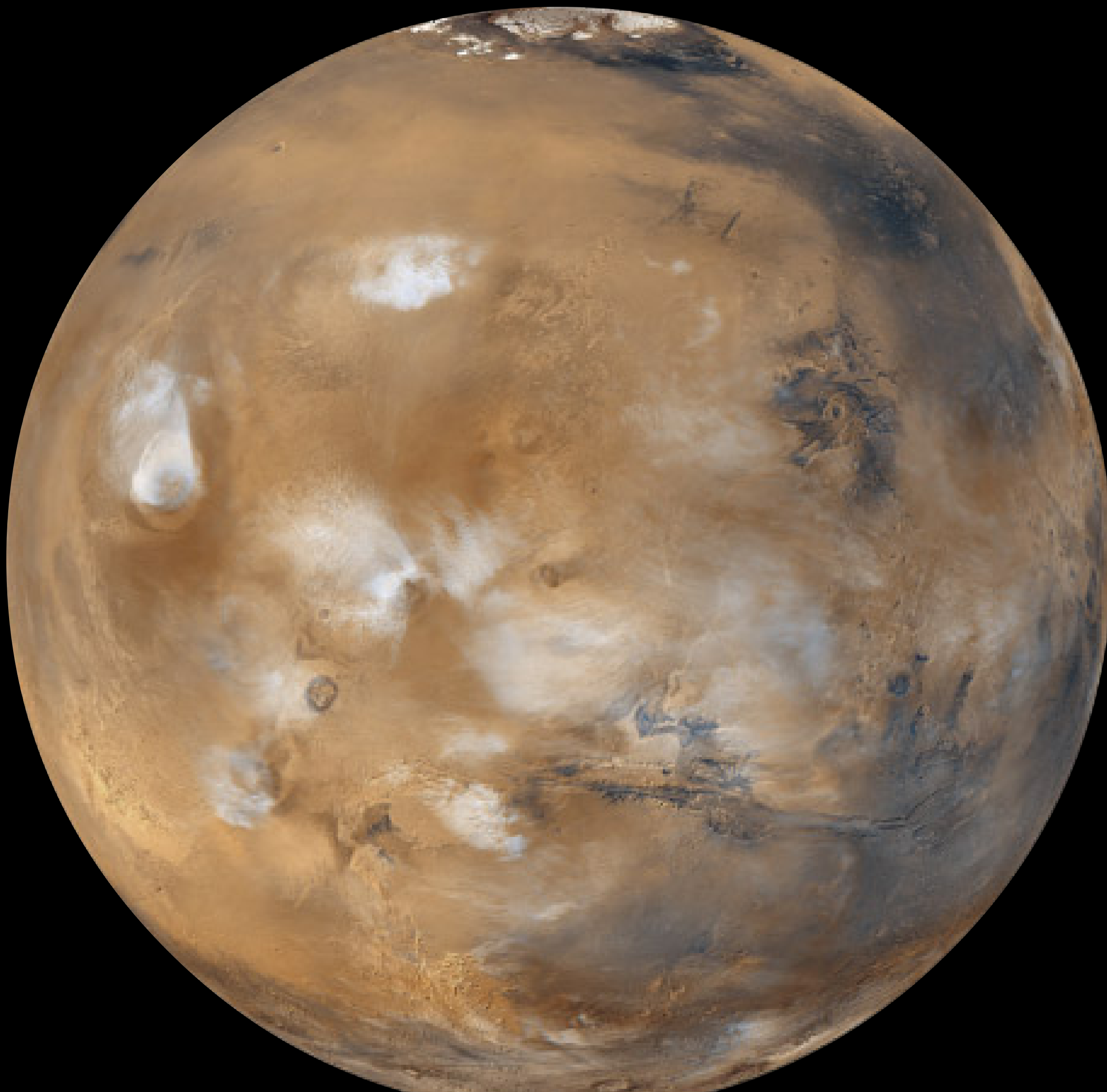


recovery in the spring, Deep Space 1 has become the longest-running ion propulsion system in space.

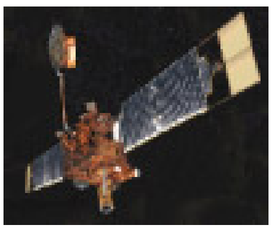
Stardust began its main mission activity of collecting interstellar dust in February for eventual delivery to Earth. At year's end, flight controllers were preparing for a flyby of Earth in January 2001.

Ulysses' most significant event in 2000 was a surprising encounter with comet Hyakutake. Flying through the comet's unexpectedly long tail, the solar-orbiting spacecraft saw wild variations in the solar wind measurements hundreds of millions of kilometers away from the comet. This led to change in ideas about comet tail structure. Ulysses began its second pass over the Sun's south pole in September. In October, the team celebrated Ulysses' 10-year anniversary in space. The twin Voyagers, now in their 23rd year, are expected to leave the Sun's sphere of magnetic influence in the next few years.

Galileo saw active volcanism on Jupiter's moon Io when Tvashtar Catena, a chain of giant calderas, erupted dramatically. The yellow and red ribbon is a lava flow more than 60 kilometers (37 miles) long. (False color)



JPL's Mars Global Surveyor spacecraft continued to return stunning images in the year 2000, including recently observed features that suggest there may be current sources of liquid water at or near the surface of the red planet. Scientists saw gullies in cliffs, usually in crater or valley walls. Compared with the rest of the Martian surface, the gullies appear to be extremely young. Another finding from Global Surveyor, though one that is causing more scientific debate, is the idea that in its early history Mars was covered by lakes or small seas. This suggestion is based upon pictures of sedimentary rocks and layers that look surprisingly like many places on Earth.



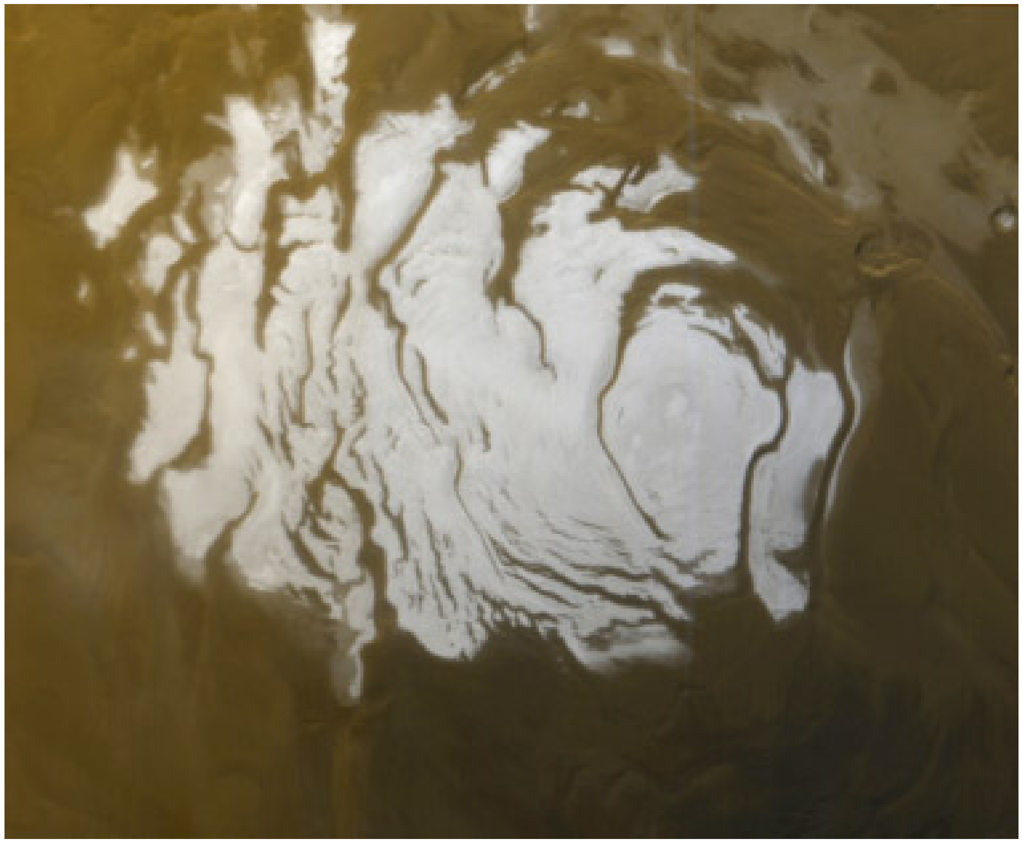
In response to the loss of Mars Climate Orbiter and Mars Polar Lander in late 1999, JPL announced the creation of new offices responsible for the management of future Mars missions and the implementation of space science flight projects. The changes were intended to provide strengthened institutional support for implementing JPL's space science missions, and to bring added focus to the Laboratory's management of exploratory missions to Mars planned for coming years.

In addition, NASA Headquarters announced a new Mars exploration program for the next two decades. JPL manages the implementation of the Mars program for NASA. Under the blueprint, the Laboratory would continue with

**WAS EARLY MARS COVERED WITH SMALL SEAS? MARTIAN SEDIMENTARY ROCK RESEMBLES SOME LOCALES ON EARTH.**

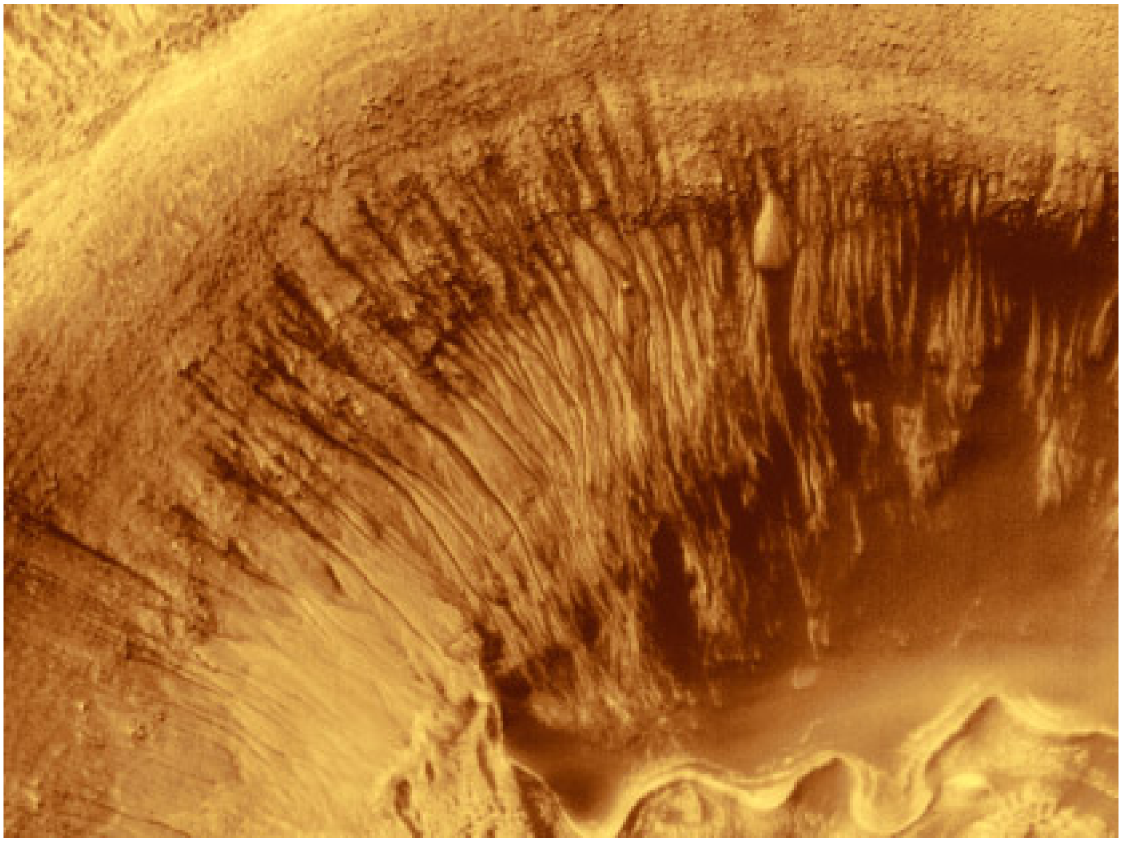
Mars Global Surveyor's 12 daily orbits provide a global snapshot of weather patterns. This image was computer-generated by wrapping a mosaicked map of Mars onto a sphere.

The south pole of Mars in summer presents a gleaming carbon dioxide frost cap at its minimum. In winter and early spring, the entire area is covered with frost.

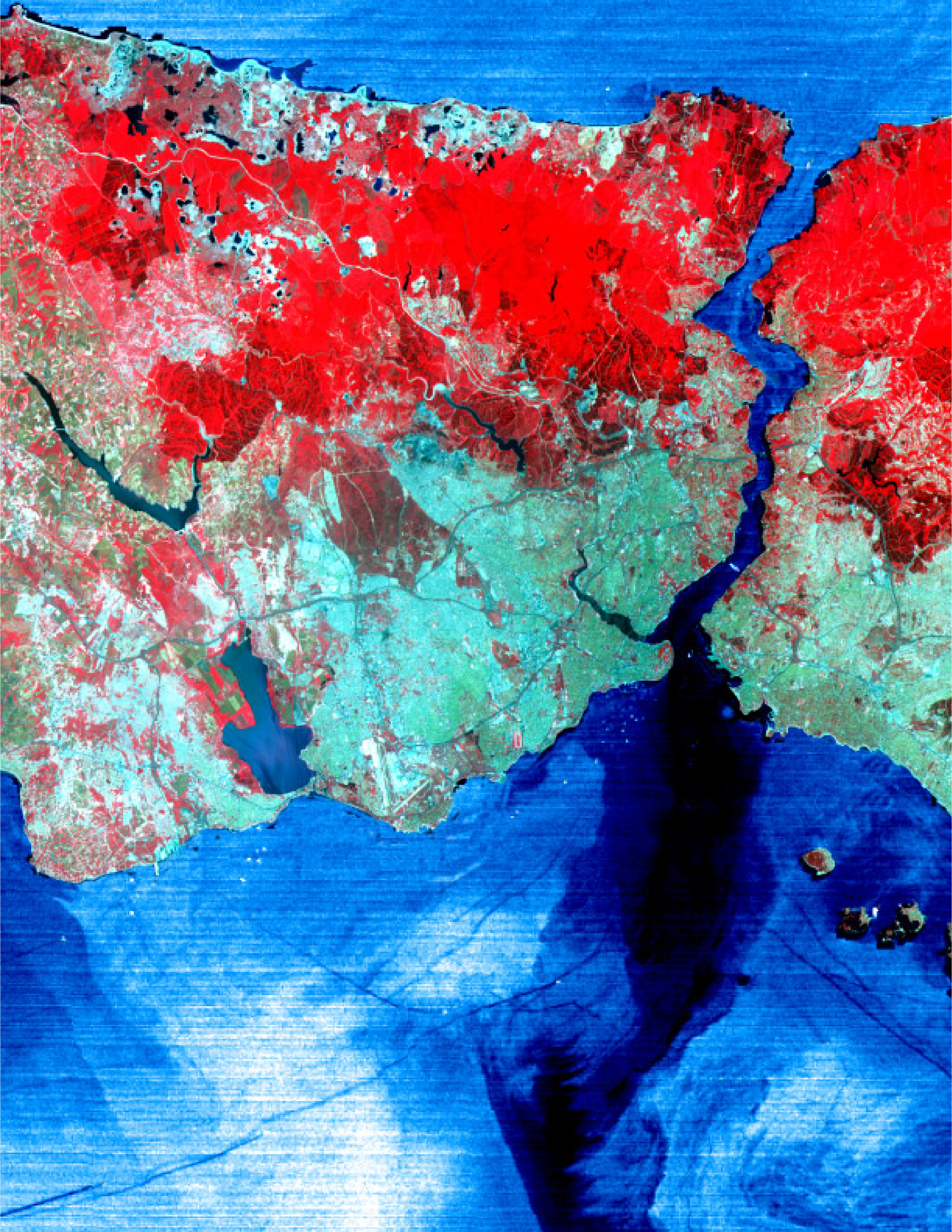


Eroded gullies in this Martian crater indicate that water once flowed on Mars. Debris transported with the water formed lobed deposits at the base of the crater.

plans to launch an orbiter, called Mars Odyssey, in April 2001. JPL would then design, build and operate a pair of long-range rovers to be launched in 2003. This would be followed by a large orbiter in 2005 built by industry, and then a rover mission in 2007 that would demonstrate so-called "smart landing," precision touchdown using autonomous radar guidance. Eventually the program would culminate in a robotic mission to return samples of Martian rock and soil to Earth, perhaps in the second decade of the century.

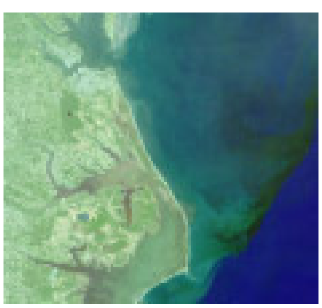


Wintertime frost burnishes the rims of Lomonosov Crater. The dark patch is a sand dune field on the crater floor. Soft winter sunlight bathes the scene in a reddish-brown hue.



A JPL-built radar instrument returned to the cargo bay of NASA's Space Shuttle for the fifth time in 2000, following earlier flights in the 1980s and 1990s. In February the Shuttle Radar Topography Mission, which used an advanced radar technique to obtain data to produce the most precise Earth map ever, was launched on Space Shuttle Endeavour. In addition to the main radar antenna that flew on the shuttle as part of JPL's previous imaging radar missions, this mission featured a secondary antenna suspended on a mast that allowed the system to collect high-precision data on Earth's topography. The mission mapped nearly 80 percent of the world's land mass, which contains about 95 percent of the planet's population.

Two JPL instruments on NASA's Terra satellite began science observations in 2000 after a launch late in the previous year. One of them, the Advanced Spaceborne Thermal Emission and Reflection Radiometer, is a general-purpose instrument that can map Earth's surface and how it changes with time and can determine the characteristics of land and water surfaces. Operated by a joint U.S.–Japan science team, the instrument has 14 spectral bands, extremely high spatial resolution and stereo imaging capabilities, leading it to be known as the Terra satellite's "zoom lens."

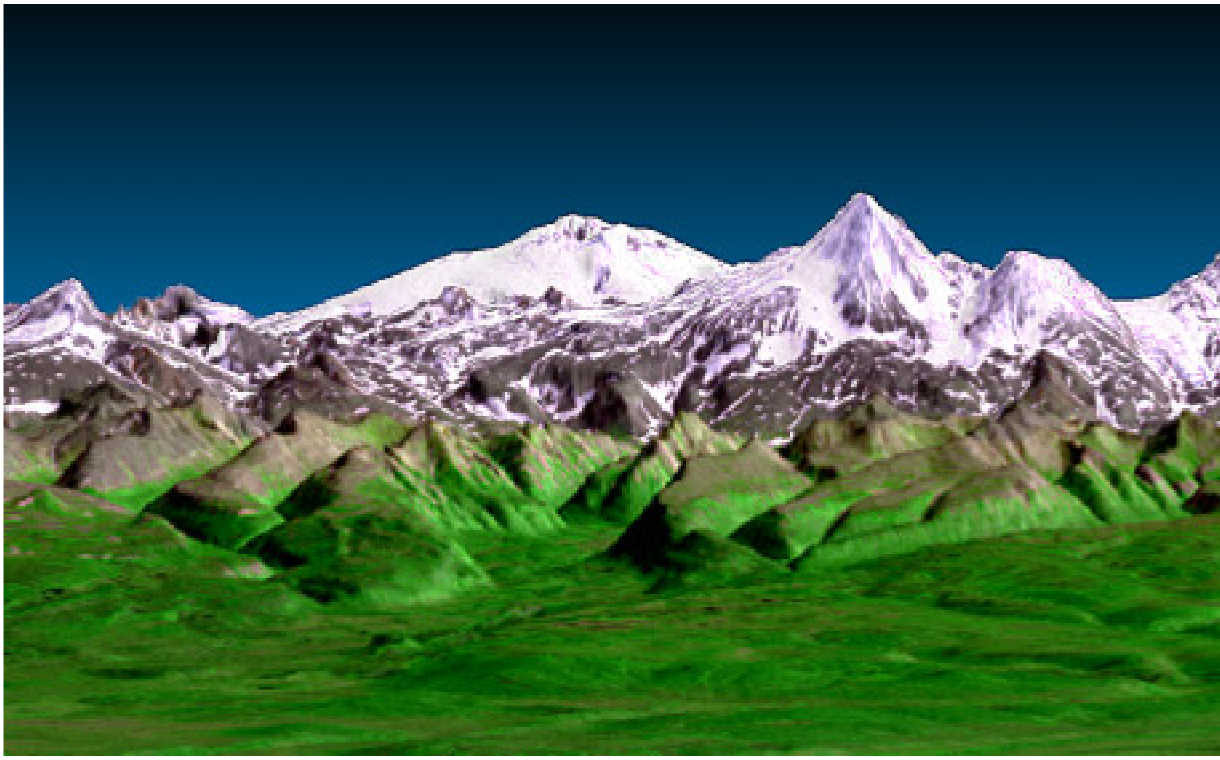


**JPL MISSIONS STUDIED OUR PLANET'S TOPOGRAPHY, ATMOSPHERE, WIND PATTERNS, LAND-SURFACE CHARACTERISTICS AND OCEANS.**

A close-up view of Istanbul, Turkey, in visible and infrared imaging channels; cold water flowing out of the Bosporus appears dark blue. Small inset: Spectroradiometer image of the North Carolina coast.

Also on Terra is JPL's Multi-angle Imaging SpectroRadiometer. This instrument captures images of Earth in four color bands at nine angles simultaneously, using nine separate cameras. The change in reflection at different view angles lets scientists distinguish different types of atmospheric particles, cloud forms and land surfaces.

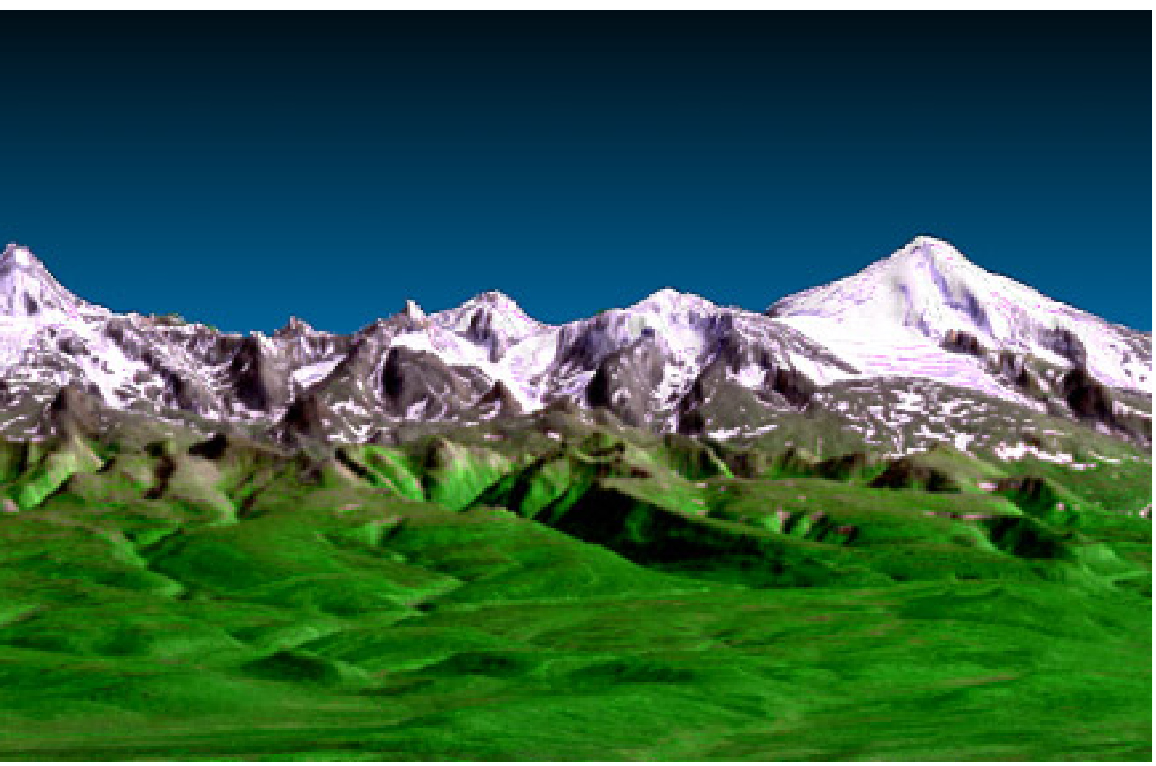
The U.S.–France Topex/Poseidon satellite continued to serve as a peerless vantage point for observing the world's oceans. By measuring sea-surface heights around the globe, the satellite can track patterns of alternately warm or cold water. Early in the year, for example, Topex/Poseidon images confirmed that a giant horseshoe pattern of higher than normal sea-surface heights that devel-



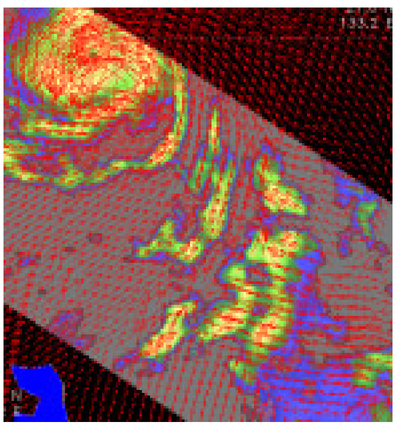
Kamchatka Peninsula, Russia: the snow-topped peaks of the volcanic range Sredinnyy Khrebet form the skyline. The image combines elevation data from the Shuttle Radar Topography Mission and Landsat imagery.

oped in 1999 was beginning to dominate the entire western Pacific and Asiatic oceans. Scientists believe that abnormally warm ocean temperatures may be part of a decade-long pattern known as the Pacific Decadal Oscillation. This pattern contrasts with El Niño and La Niña, which are smaller and shorter ocean-temperature events.

Scientists, weather forecasters and the public can now take advantage of daily wind data and animations from the ocean-wind tracker SeaWinds, a radar instrument on the QuikScat satellite. SeaWinds data show developing weather systems with unprecedented detailed information that can improve weather forecasting around the world, in addition to details about waves, currents, polar ice features and other phenomena.



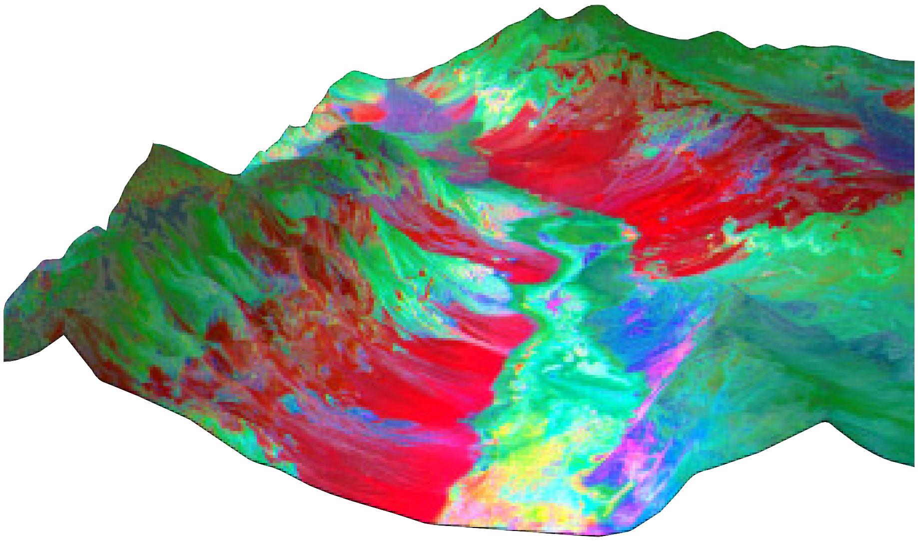
QuikScat data show surface winds (red arrows) of Typhoon Bilis. Heavy rain is indicated by green and yellow in data from another NASA satellite.

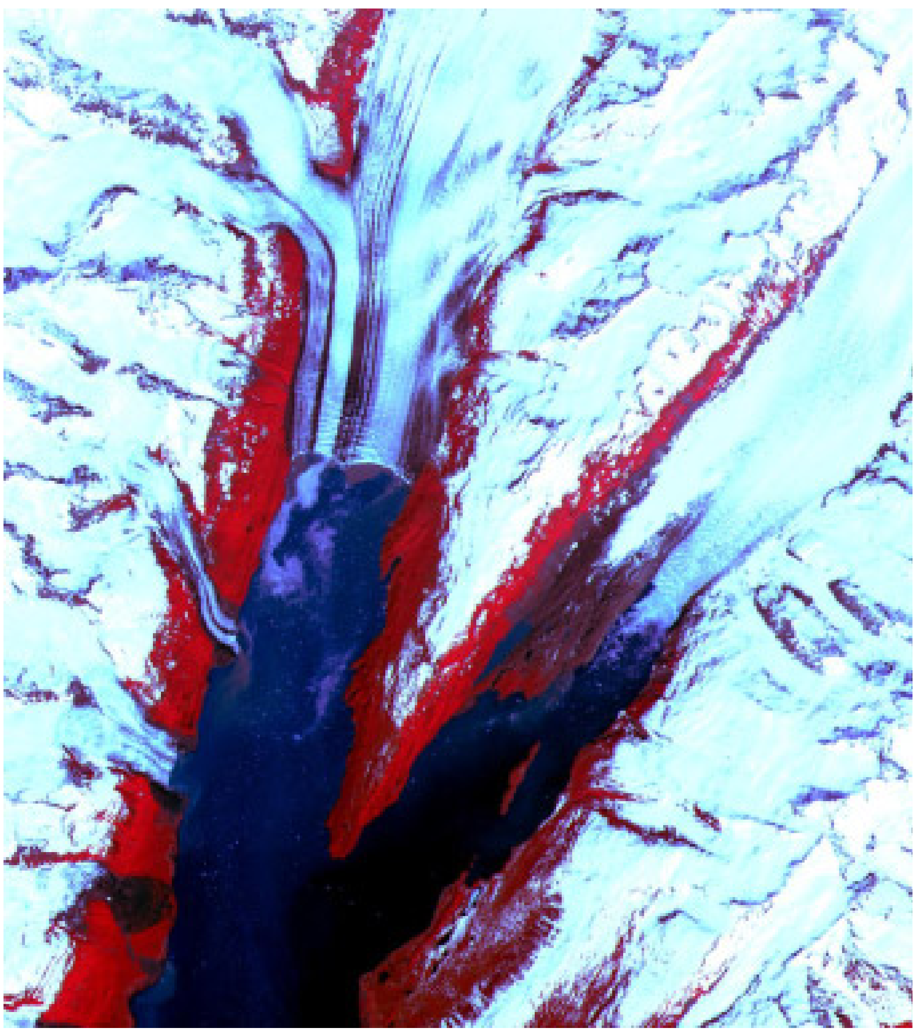


Among other Earth sciences efforts, JPL researchers conducted an investigation into the Arctic stratosphere that showed increased ozone loss during the 1999–2000 winter, one of the coldest winters on record. A JPL geophysicist was able to solve the century-old mystery of the Earth's "Chandler wobble." Named for its 1891 discoverer, the wobble is one of several motions exhibited by Earth as it rotates on its axis. The main cause is fluctuating pressure on the bottom of the ocean, caused by temperature and salinity changes and wind-driven changes in the circulation of the oceans.

Images were gathered during an airborne Earth-observing mission conducted during the summer around the Pacific Rim region using NASA's DC-8 Flying Laboratory. The primary observing instrument was JPL's Airborne Synthetic Aperture Radar. Also on board was JPL's Moderate Resolution Imaging Spectroradiometer, which provided detailed maps of land-surface temperature, emissions and reflectance.

This year, JPL scientists created the first comprehensive maps of Arctic sea-ice thickness using data from Canada's Radarsat satellite. This new mapping technique lets scientists study how Arctic sea ice, a sensitive indicator of climate change, grows and contorts over time.





Two images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer: a 3-D perspective view of Death Valley, color enhanced to show different surface materials; and a view of glaciers at College Fjord, Alaska, with vegetation shown in red and snow and ice in white and blue.

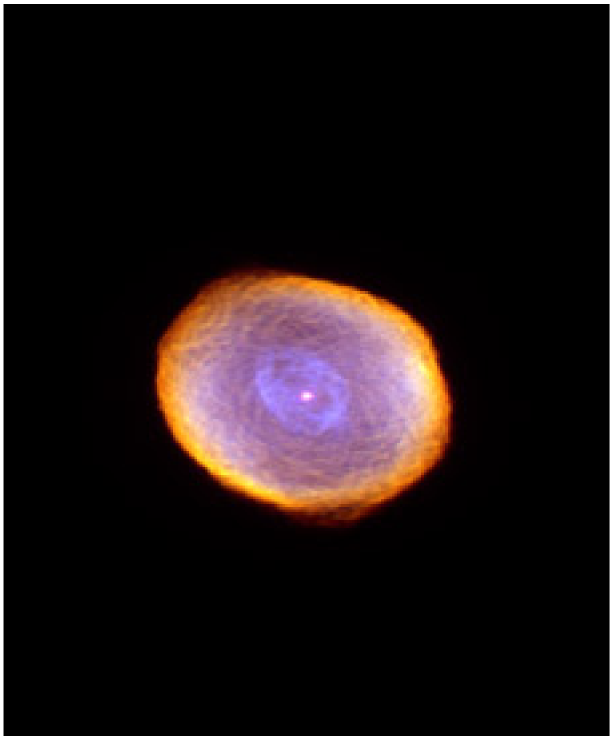
The JPL-supplied main camera on the Hubble Space Telescope, the Wide-Field and Planetary Camera 2, continued to offer the world a ringside seat on the universe — both in the depths of interstellar space and within our own solar system. The camera imaged fragments as Comet Linear broke up; observed an aurora on Jupiter, including glowing footprints of the moons Io, Ganymede and Europa; caught the motion of the nearest neutron star to Earth; witnessed the collision of galaxies in NGC 6745; and observed a mysterious astronomical object, HE2-90, that seemed to defy classification.

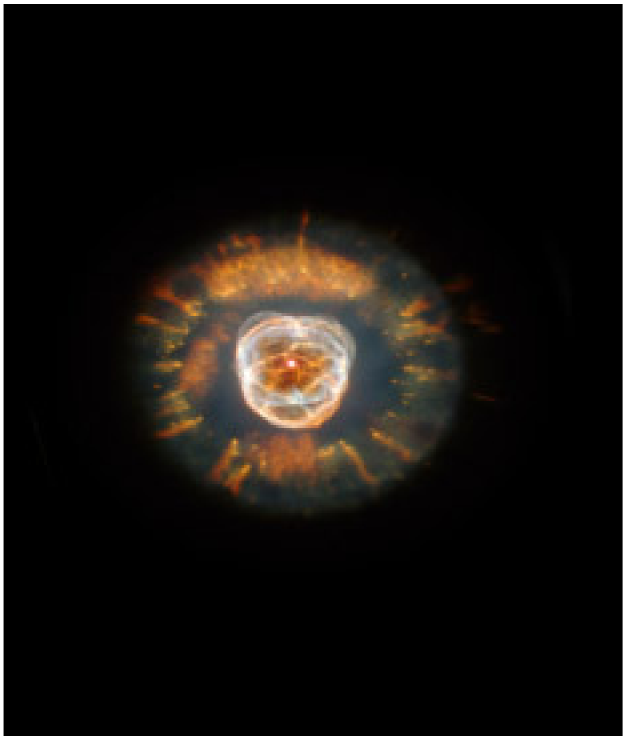
**JPL CONTINUES ITS STUDIES OF STAR AND GALAXY FORMATION AND THE QUEST FOR EXTRASOLAR PLANETS.**

The Two-Micron All-Sky Survey continued to dazzle the science community and the public with its enormous output of celestial images. The survey uses two 1.3-meter (51-inch) ground-based telescopes, one in Arizona and one in Chile. Images from the project, sponsored by NASA and the National Science Foundation, are combined and processed by the JPL/Caltech Infrared Processing and Analysis Center. The survey's website drew a large number of "hits" after the posting of images that included half a million galaxies and 162 million stars — enough data to fill 6,000 CD-ROMs.

A Two-Micron All-Sky Survey image of the Flame Nebula (NGC 2024). A dense stellar cluster in the dark area dividing the "flame" harbors accretion disks — possible sites of planet formation.

Much of JPL's other work in astronomy and physics in 2000 centered on the important business of preparing upcoming missions. Science teams were selected for two missions under NASA's Origins program. The Space Infrared Telescope Facility, the first new Origins mission and the last of NASA's Great Observatories, chose six teams of scientists to study the formation of galaxies,





JPL's Wide-Field and Planetary Camera on the Hubble Space Telescope captured these stunning images of nebulae: the Spirograph and the Eskimo. The dying star in the center of each nebula has flung off glowing material.

stars and planet-forming dust disks. After the observatory launches in 2002, the teams will use more than 3,000 hours of observing time, primarily in the first year.

Another Origins flight project, the Space Interferometry Mission, selected a team consisting of 10 principal investigators that will lead key science teams, plus five mission specialists. After launch in 2009, the innovative space system will hunt for Earth-size planets around other stars and provide new insights into the origin and evolution of our galaxy. It will also precisely measure locations and distances of stars throughout the Milky Way Galaxy.

JPL also selected teams from industry and academia to spend two years developing mission concepts for Terrestrial Planet Finder, an Origins mission scheduled for launch in 2012. It will hunt for Earth-like planets around other stars that might sustain life.

The year saw progress for the Galaxy Evolution Explorer, an ultraviolet mission that will launch in 2002. The integration of the science instrument and the spacecraft bus was initiated, and the telescope assembly and flight detector tubes were completed and delivered. The mission will study the causes and map the history of star formation in galaxies ranging over 80 percent of the age of the universe.

Five JPL scientists were among 41 researchers selected by NASA to receive grants to conduct fundamental physics research on Earth and in space. This research will seek knowledge to expand our understanding of space, time and matter.

The Hubble Space Telescope imaged the wispy tendrils of an interstellar cloud being torn apart by strong radiation from a bright star in the Pleiades.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# 2000 TECHNOLOGY

At the dawn of the 21st century, scientists and engineers are creating the technologies of the future now — lightning-speed computer chips, robotic arms, small sensors to monitor the environment, hopping robots for planetary space exploration and shoebox-size, lightweight inflatables that, once in space, can unfurl to the size of a tennis court. These developments will bring about new discoveries and lead in the search for life on other planets. Back home, they may also bring breakthrough advances in the communication, medical and commercial industries.

Early in the year, the war against breast cancer had a new weapon, thanks to an advanced sensor developed at JPL. The Quantum-Well Infrared Photodetector camera uses extremely sensitive infrared sensors that can be used to conduct noninvasive mammography. Locating hot spots during fires and observing volcanoes are two of the commercial applications for the sensor.

Another invention with medical applications is a drill that may eventually end up in the hands of every craftsman and orthopedic surgeon. The ultra-lightweight electric drill is miniaturized to fit in the palm of a hand and can potentially be used to extract leads from implanted pacemakers.

The environment will also benefit from space technology. A robotic device that safely strips paint from the hulls of ships without polluting the environment,

**TECHNOLOGY DEVELOPED BY JPL FOR SPACE APPLICATIONS WILL RESHAPE OUR FUTURE ON EARTH. MEDICINE, COMMUNICATIONS AND COMPUTERS WILL BENEFIT.**

This small device represents a new class of solar system exploration instruments called pods. They form a sensor web; each pod will collect and send data to others. The data will eventually be uplinked to a satellite and relayed to Earth.

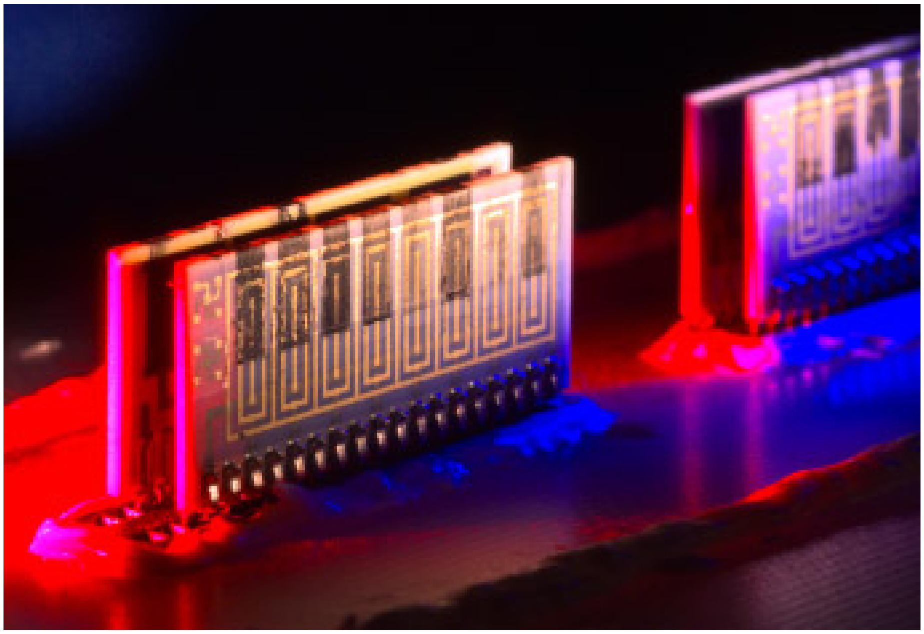
based on NASA robotics technology, can have a positive environmental impact while providing a benefit to the shipyard industry.

JPL engineers continue to miniaturize an "electronic nose" with the ability to monitor recycled air. The device, called E-Nose, may someday monitor the air for toxins in closed environments such as the Space Shuttle, the International Space Station and any future space outpost that features a closed human habitat. It also has many potential commercial uses.

It was back to the garden for JPL engineers who "planted" wireless webs of small sensors in gardens here on Earth in preparation for space missions designed to monitor biological activity on planets. Webs of sensors the size of a small sandwich box may help establish a virtual presence for exploration throughout the solar system.

This lightweight drill can penetrate hard rock while extracting samples through ultrasonic transport up the drill shaft.

Defying traditional laws of physics, researchers may have found a way to blast through imminent roadblocks on the highway to faster and smaller computers. Using modern quantum physics, researchers discovered that entangled pairs of light particles, or photons, can act as a single unit, but perform with twice the efficiency. This research potentially could enable us to continue upgrading



An electronic "sniffer," the E-Nose is an array of chemical sensors that can identify trace vapors in the air.

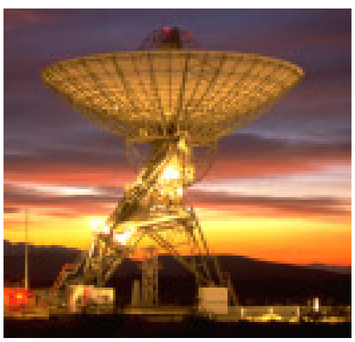
This camera, with highly sensitive infrared photo-detectors, can identify hot spots in forest fires and volcanoes.

computers even after traditional manufacturing procedures have been exhausted.

JPL engineers teamed up with and neurophysiologists to create a prototype of a robot-like device that, when complete, will be used as part of rehabilitation that might help some people now wheelchair-bound take their first steps. The device, still in the development phase, could be part of clinical trials in about three years. This same device could also someday be useful to astronauts and help them walk safely after prolonged periods in space, such as extended missions on the International Space Station.

2000

JPL's Deep Space Network provides communications between Earth and spacecraft through large antennas in California, Spain and Australia. The network supported a wide assortment of missions in 2001, such as the Earth-orbiting Quick Scatterometer (QuikScat), Mars-orbiting Mars Global Surveyor, Jupiter-orbiting Galileo and the most distant of all human-made objects, Voyager 2, now at about twice the distance to Pluto.



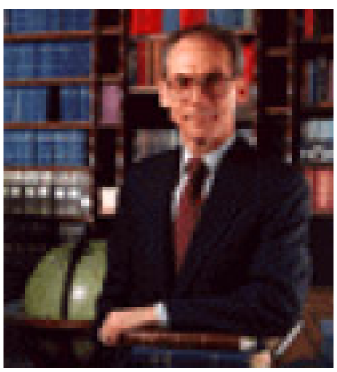
Deep Space Network antennas are also used as radio telescopes, to study natural radio emissions from sources such as star-forming regions of our galaxy and radiation belts around Jupiter. The network has partnered with the Lewis Center for Educational Research in Apple Valley, California, to make one 34-meter (112-foot) antenna available for high-school and younger students around the country to use by remote control from their classrooms. In November and December, hundreds of students at 25 middle schools and high schools in 13 states used that dish, the Goldstone–Apple Valley Radio Telescope, for measurements of Jupiter's radiation belts. The data are intended to help with interpretation of radio measurements taken near Jupiter by the Cassini spacecraft.

Deep Space Network planners and engineers are developing strategies for expanding the capabilities of the system for handling strong demand expected in 2003 and 2004, due in part to landers planned for exploring Mars.

**THE DEEP SPACE NETWORK ANTENNAS TRACK SPACECRAFT, ACT AS RADIO TELESCOPES AND PARTICIPATE IN EDUCATION.**

The electronics housing is in the center of the largest antenna at Goldstone. This view of an engineer perched at the top of the ladder gives an idea of the immense size of the dish.

Throughout most of the 1990s, JPL joined NASA centers in a gradual downsizing of its workforce, with the goal of arriving at a total of fewer than 5,000 employees and on-site contractors by the year 2000. While this was close to being realized, NASA decided to relax this requirement in view of staffing needs to support upcoming missions such as JPL's 2003 Mars Exploration Rovers. For the year 2000, JPL's workforce totaled about 5,100.



Dr. Edward C. Stone, JPL's director since 1991, announced early in the year that he intended to step down in 2001, consistent with the tradition of JPL director retirement at the age of 65. Caltech established a committee to perform a nationwide search for his successor. Stone, who also serves as project scientist for the long-lived Voyager mission as well as NASA's Advanced Composition Explorer, plans to return to the Caltech campus to teach and conduct research.

For fiscal year 2000, JPL's business base was approximately $1.233 billion.

**THE LABORATORY'S RETIRING DIRECTOR, DR. STONE, WILL RETURN TO CALTECH TO TEACH AND CONDUCT RESEARCH.**

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