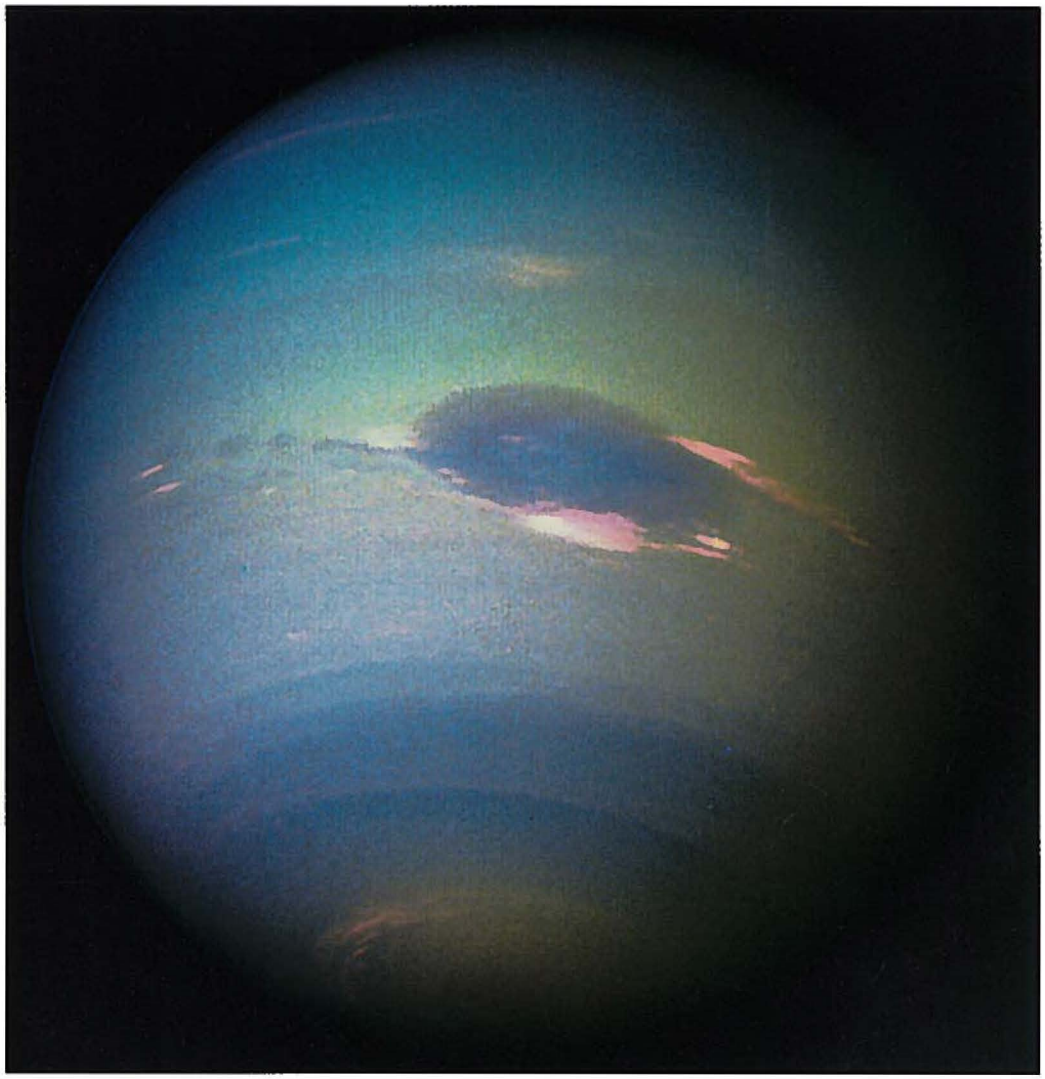
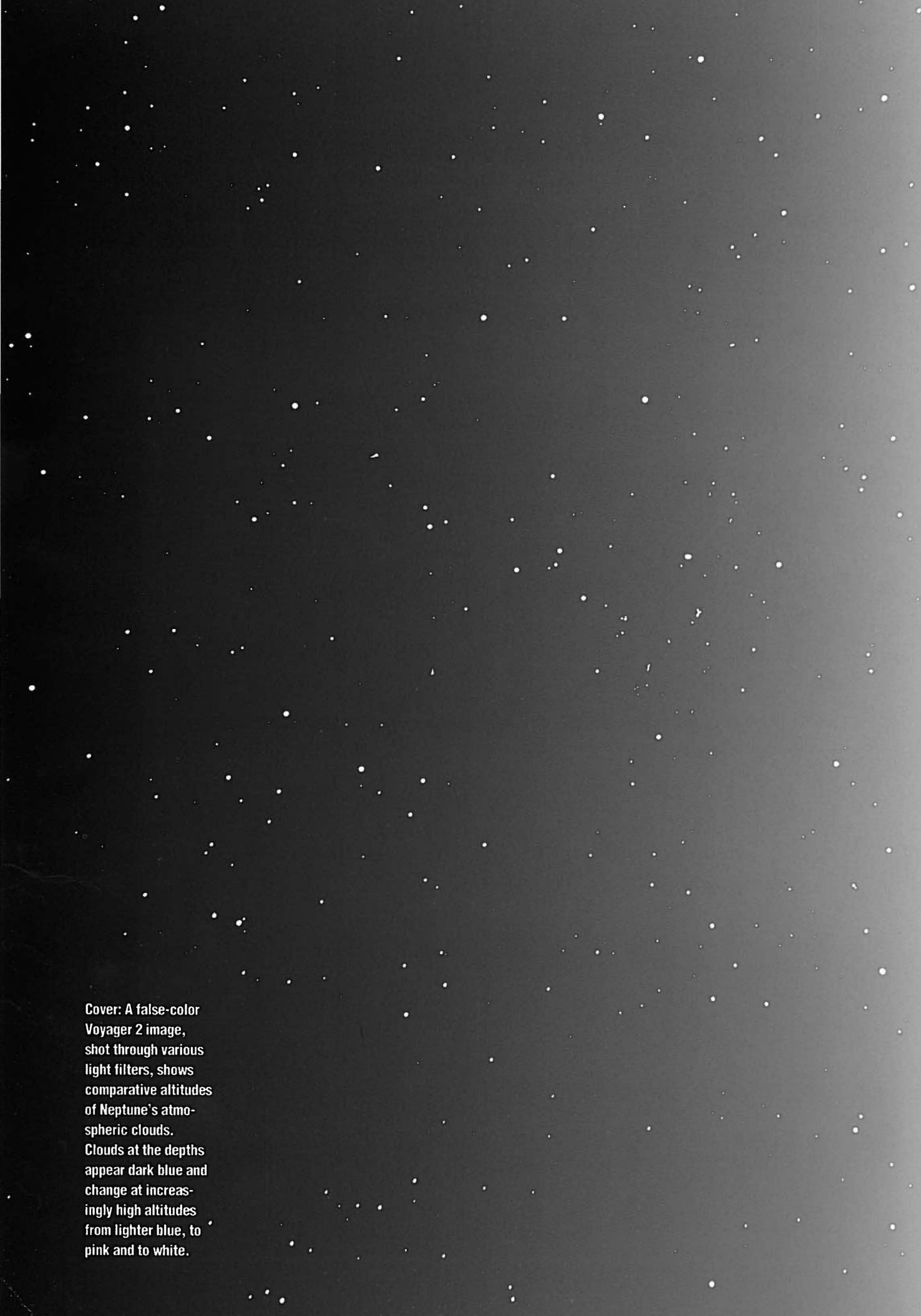
JPL

Annual Report 1989



Jet Propulsion Laboratory



Cover: A false-color Voyager 2 image, shot through various light filters, shows comparative altitudes of Neptune's atmospheric clouds. Clouds at the depths appear dark blue and change at increasingly high altitudes from lighter blue, to pink and to white.

CONTENTS

Introduction	1
Director's Message	2
Flight Projects	5
Space and Earth Science	15
Advanced Technology	22
Telecommunications Systems	31
Applications Projects	37
Institutional Activities	40

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, 1989.

JET PROPULSION LABORATORY
California Institute of Technology
Pasadena, California

INTRODUCTION

The Jet Propulsion Laboratory (JPL) of the California Institute of Technology (Caltech) is a federally funded research and development center operating under contract to the National Aeronautics and Space Administration (NASA). The people of JPL share a common objective: research and development in the national interest.

Three characteristics shape JPL's philosophy, mission and goals:

(1) As part of Caltech, JPL pursues the highest standards of scientific and engineering achievement. Excellence, objectivity and integrity are the guiding principles.

(2) As NASA's lead center for unmanned exploration of the solar system, JPL directs unmanned planetary missions for the United States.

(3) JPL helps the United States solve technological problems and performs research, development and spaceflight activities for NASA and other agencies.

JPL's mission evolved from pioneering rocket research, through guided-missile work, to space missions. Today, JPL is a preeminent national laboratory with a budget of more than $1 billion and a work force of more than 5,000 people. JPL's charter continues to emphasize exploration of the solar system.

This exploration includes participation in the observation of Earth, as well as of other stellar systems and extra-solar-system bodies. To achieve these goals, JPL scientists and engineers are developing advanced remote-sensing systems, new information and data-system architectures, multidimensional techniques for visualizing and integrating scientific data, space computer hardware (including supercomputer applications and microelectronic devices) and more. Other fields, such as machine intelligence and robotics, are being developed for both NASA and the Department of Defense.

The year reported here, 1989, witnessed renewed excitement: The Laboratory returned to space with the launches of Magellan to Venus and Galileo to Jupiter, and Voyager 2 made a stunning encounter of Neptune. The Laboratory continues to prepare two more spacecraft for flight: Ulysses and Mars Observer. These spacecraft will explore the Sun and the planet Mars, respectively. Also, JPL and France's National Center for Space Studies, Centre Nationale d'Etudes Spatiales (CNES), are developing the Ocean Topography Experiment (TOPEX)/POSEIDON mission, which will study ocean circulation.

The discovery continues.

JPL ended the decade with the most spectacular year in U.S. unmanned spaceflight history. On May 4, the Magellan spacecraft was deployed from the shuttle Atlantis, breaking NASA's 12-year hiatus in planetary launches. Upon arrival at Venus (expected in August, 1990), Magellan will map 90 percent of our sister planet's surface with a Synthetic Aperture Radar mapper developed here at JPL. The spatial resolution of 0.1 kilometer or better will give us the best pictures anyone has ever seen of this planet. The mission is expected to last one Venusian year (243 Earth days), with an additional year likely.

On August 24, Voyager 2 encountered Neptune and its satellites. As in all the previous Voyager flybys, we saw the unexpected. The fourth and final planetary giant visited by Voyager 2 captured the interest and excitement of both laypersons and experts throughout the world. Neptune has a Great Dark Spot similar to Jupiter's Great Red Spot — a turbulent storm of swirling gases. The mechanisms to explain the storms and the high wind velocities on a planet so far away from the Sun remain an unsolved mystery.

The closest approach in Voyager's entire mission was to Neptune's largest satellite, Triton. Contrary to initial expectations, the surface of the moon was visible and unique. The surface temperature of the moon was measured at 39 kelvins, making it the coldest known object in our solar system. Currently, both Voyager spacecraft are making their way to interstellar space and should be sending back data for about the next 25 years before we lose contact.

Barely had the excitement from the Neptune encounter subsided when we watched the long-awaited launch of Galileo. On October 18, Galileo lifted off aboard the shuttle Atlantis on its six-year journey to Jupiter. Because the trajectory will require one Venus and two Earth gravity assists, we will have the bonus of recording additional

Dr. Lew Allen,
Director of JPL.

scientific data and, for the first time ever, enjoy two encounters with our own home planet (in December, 1990, and December, 1991). By far our most sophisticated and complex endeavor, Galileo will reach Jupiter in 1995, deploy a probe into the Jovian atmosphere and remain in orbit taking scientific measurements of the planet and its satellites for approximately two years.

As to the future, we received approval for two new missions, Comet Rendezvous Asteroid Flyby (CRAF) and Cassini. CRAF will fly past an asteroid and rendezvous with Comet Kopff for more than two-and-one-half years. Cassini will sail by an asteroid and then pass Jupiter before going into orbit around Saturn. Both missions will use Mariner Mark II spacecraft and be built at the Laboratory.

Closer to home, a CRAY X-MP 1/8 supercomputer was installed at JPL to increase the computational abilities of JPL and Caltech researchers. Also during this year, a 128-node Hypercube parallel-processor computer was successfully integrated and tested. An eight-node Hypercube was used during the Neptune encounter for near-real-time image processing. More futuristic concepts for computing involving neural networks are being investigated; in such computing, machines will simulate the human brain by having the capacity to learn.

Two well-known and highly respected members of our staff retired from the Laboratory this year: Gene Giberson, the assistant laboratory director for the Flight Projects Office, left after 38 years of service, and John Gerpheide, the Magellan project manager, who had been at JPL since 1948, also retired. We value their contributions and dedication to the Laboratory and wish them well.

Our involvement in space exploration in the next decade and on into the next millennium will be ever expanding. Next year will see the launch of the first orbiting observatory — the Hubble Space Telescope, to which JPL has contributed the Wide-Field/Planetary Camera.

Later in the year, the Ulysses spacecraft, a joint NASA–European Space Agency project (with JPL managing the U.S. portion), will be launched. The final objective of Ulysses, which will use a Jupiter gravity assist, will be to investigate the poles of the Sun.

Still later, we will be looking at the TOPEX/POSEIDON exploration of the world's oceans. As an advance guard to the Space Exploration Initiative, the Mars Observer spacecraft will mark the return to this planet and be a precursor for future manned missions. Similar lunar missions are planned. Toward the end of the decade, we will have responsibility for another of the orbiting observatories, namely SIRTF (for Space Infrared Telescope Facility), and we will continue to support the Mission to Planet Earth.

The future of JPL looks extremely healthy, and our prime mission of space exploration will broaden significantly. With the creativity and expertise of our staff, the Laboratory will continue to be recognized as a premier institution for space-related science and engineering.

Flight PROJECTS

Jubilant scientific and engineering teams had a rewarding year: On May 4, from the shuttle Atlantis, Magellan was launched on its 15-month voyage to Venus. There, it will map most of the planet with a Synthetic Aperture Radar (SAR), the first instrument that can produce images from orbit of Venus' surface. In August, Voyager 2 performed its final planetary encounter — with the distant giant planet Neptune. In October, Galileo began its complex trip to Jupiter.

Other teams prepared Ulysses, Mars Observer and the Ocean Topography Experiment (TOPEX)/POSEIDON mission for launch in the new decade. Ulysses will fly over the Sun's poles to explore those previously unseen regions of our star and to look out on interstellar space. Mars Observer will mark our return to the Red Planet and lead the way for President George Bush's Space Exploration Initiative, a plan to send people back to the Moon and, later, to Mars. TOPEX/POSEIDON will observe Earth's oceanic circulations to provide a basis for improved forecasting of the global environment.

Laboratory teams are looking still farther into the future, now that Congress has approved the Comet Rendezvous Asteroid Flyby (CRAF) and Cassini missions. Both use a new Mariner Mark II spacecraft. The CRAF mission will examine an asteroid and fly in formation with Comet Kopff, while Cassini will orbit Saturn, sample the atmosphere of its largest moon, Titan, and drop an independent probe on that moon's surface.

Indeed, the final decade of the twentieth century promises great excitement in deep-space exploration.

VOYAGER

"What a way to leave the solar system!" said one scientist, and, indeed, Voyager 2's last encounter was spectacular by any standards. The 12-year-old spacecraft flew just 4,950 kilometers (3,070 miles) from Neptune's swirling cloud tops and took pictures of one of its moons, Triton, which showed several geysers 8 kilometers (5 miles) high. Voyager discovered that Neptune has six small, previously unknown satellites, full rings and a magnetic field similar to that of Uranus. Astronomers had also had hints of clouds on Neptune for years, and when Voyager arrived, it found banded clouds, dark spots, bright spots and cirrus clouds.

Before the encounter, estimates of a day on Neptune had ranged from 16 to 18 hours. Voyager's planetary radio astronomy instrument fixed the planet's rotation at 16 hours, 7 minutes. The interior probably has a core of liquefied gas, melted ice and molten rock. The atmosphere consists of hydrogen, helium and methane. Neptune, the densest of the four giant outer planets (Jupiter, Saturn and Uranus are the other three), is about 64 percent heavier than it would be if it were composed of water.

Neptune receives only one nine-hundredth as much energy from the Sun as Earth, but it emits about three times that amount. Voyager's ultraviolet instrument measured temperatures in the stratosphere at about 750 kelvins. The temperature at 100 millibars is about 55 kelvins, the infrared instrument showed, and the equator and south pole are warm while the mid-latitudes are cool, just as on Uranus.

Infrared results indicate an atmosphere consisting mostly of molecular hydrogen, with less than 25 percent helium and only small amounts of methane. The instrument also found traces of acetylene.

At about 22 degrees south, a storm called the "Great Dark Spot" circles Neptune in a westerly direction in just under 18 hours, implying that it is in a zone where the wind blows more than 300 meters (1,000 feet) a second. The Great Dark Spot is as large as Earth — more than 12,500 kilometers (7,750 miles) across. Time-lapse movies show that it is not completely oval (it has spiral arms) and appears to rotate counter-clockwise. Bright, wispy cirrus clouds overlie the Great Dark Spot at its southern and northeastern boundaries. They do not appear to be moving rapidly, but the air around them surely does — a situation similar to that of lenticular clouds above mountains on Earth. Wind is deflected upward, and volatiles in that atmosphere condense at the lower temperatures to form clouds.

At about 42 degrees south, a bright cloud circles Neptune even faster than the Great Dark Spot does, scooting around once in about 16 hours. "Scooter" may be a plume rising between cloud decks. At about 55 degrees south is a small dark spot with a bright core that may be a rising, convective cloud.

Voyager also found cloud shadows in the northern and southern hemispheres (27 degrees north and 71 degrees south), the first time such features have been observed on one of the outer planets. They are cast by clouds about 50 to 100 kilometers (31 to 62 miles) above the main cloud deck.

When Voyager 2 came within 4,400 kilometers (2,728 miles) of the top of Neptune's atmosphere, data-visualization techniques were used to make video animations of Neptune and Triton from high-resolution images. These helped scientists to examine planetary features, analyze atmospheric dynamics, study satellite topography, characterize ring structure and display results. The video animations also played a role in the discovery of the anticyclonic motion of Neptune's Great Dark Spot.

MAGELLAN

On May 4, the shuttle Atlantis launched Magellan, the first JPL planetary spacecraft to leave Earth since Voyager 1 in September, 1977. An Inertial Upper Stage (IUS) boosted Magellan on its trajectory to Venus, a 15-month cruise that will take the spacecraft one-and-one-half times around the Sun.

When Magellan arrives at Venus, its SAR will scan the surface from a nearly polar, 3.15-hour orbit as Venus turns beneath it. During the 243-day primary mission, the radar is expected to map at least 70 percent of the Venusian surface and show features as small as 150 meters (492 feet) across, allowing scientists to infer processes that formed terrain features and to study similarities to, and differences from, Earth.

Magellan will use the new capabilities of the Space Flight Operations Center and Multimission Image Processing Laboratory to process a volume of imaging data greater than that of all previous planetary imaging missions combined.

GALILEO

Galileo, launched on October 18, was JPL's second flight mission to depart this year. The project has been under development since 1977. The spacecraft is more complex than any other JPL craft, and its study of Jupiter and its moons is expected to provide the richest scientific return of any project to date.

Much work was done in 1989 on mission-operations testing and training, on simulation and on ground data system integration to prepare for launch. In September, the White House Office of Science and Technology Policy approved for launch the Radioisotope Thermoelectric Generators (RTGs) that power the spacecraft. That approval later withstood litigation by antinuclear groups to delay or stop the launch.

A Venus–Earth–Earth gravity-assist trajectory supplements the boost given by the IUS and will direct Galileo past Venus in February, 1990. Venus' gravity will accelerate Galileo and send it back toward Earth. When Galileo passes Earth in December, 1990, Earth's gravitational field will then send it toward the asteroid belt. Galileo will fly by Earth once again, in December, 1991, for a final gravity assist before beginning its coast to Jupiter. It will arrive there in December, 1995.

Science targets on the way to Jupiter will include Venus, Earth, Earth's Moon and the asteroids Ida and Gaspra. However, Galileo will not sacrifice its primary goals for these secondary objectives.

Galileo consists of two parts: an orbiter built by JPL and an atmospheric probe developed by NASA's Ames Research Center. The probe will be deployed 150 days before arrival at Jupiter, and as it descends through Jupiter's atmosphere, it will send data to the orbiter for relay to Earth. The orbiter carries 11 instruments to study Jupiter and its atmosphere, as well as radiation and magnetic fields, satellites and the interplanetary medium.

Ulysses

Ulysses, the joint NASA–European Space Agency (ESA) mission to explore the polar regions of the Sun, is being prepared for a space shuttle launch in October, 1990. Ulysses will fly to Jupiter, where a gravity boost will sling it into orbit around the Sun at a high inclination.

Early this year, the spacecraft was taken from storage at the Dornier plant in Friedrichshafen, in the Federal Republic of Germany, and the process of recertification began. Instruments to be integrated with the spacecraft received microprocessor memory chips and were shipped to Europe. Integration and test are on schedule. After system tests in early 1990, Ulysses will be shipped to the Kennedy Space Center (KSC) in May.

The RTG, which provides electric power, is at a Department of Energy (DOE) facility. Analyses to obtain flight approval for the generator began in late 1989.

Tests of the Ground Data System (GDS) are under way. Integration of the mission control system (provided by ESA) with JPL's data system will begin in 1990.

In May, 1990, spacecraft upper stages and ground support team members will travel to KSC for the planned October launch.

Mars Observer

Mars Observer will be launched in September, 1992, to continue the exploration of this planet, which JPL began with the Mariner 4 spacecraft in 1964–65. A Titan III will carry this spacecraft to Earth orbit, where a Transfer Orbit Stage will boost it toward Mars.

Mars Observer will study the surface, atmosphere, interior and magnetic field of the Red Planet over all four seasons of a Martian year (687 Earth days). Experiments include

- a gamma-ray spectrometer to measure the abundance of elements on the surface
- a thermal emission spectrometer to map frosts, cloud composition and the mineral content of surface rocks
- a camera to take low-resolution images for climate studies and images at higher resolutions for studies of geology and interactions between surface and atmosphere
- a laser altimeter to determine topographic relief
- a pressure modulator infrared radiometer to measure dust, condensates, temperature profiles, water vapor and dust opacity as they vary with latitude, longitude and season

- a radio science experiment to measure temperature profiles of the atmosphere and the gravity field

- a magnetometer/electron reflectometer to determine the nature of the magnetic field and its interactions with the solar wind

Project scientists will participate from their home institutions via electronic links to JPL's Space Flight Operations Center.

Mars Observer will be used in a joint French–Russian Mars Balloon Relay Experiment. In late 1995, near the end of the mission, the Soviet Union's Mars '94 spacecraft is to arrive and deploy balloon-borne instruments into the Martian atmosphere. These will send data first to a Soviet orbiter and then, using equipment supplied by France's National Center for Space Studies, Centre Nationale d'Etudes Spatiales (CNES), to Mars Observer for formatting and transmission to Earth.

JPL is responsible for project management, mission design and mission operations and is furnishing the payload data system and instruments. General Electric Astro-Space Division is building the spacecraft.

TOPEX/POSEIDON

TOPEX/POSEIDON, a collaboration between NASA/JPL and CNES, will study the world's oceans, measuring sea levels with high accuracy, mapping basinwide variations in currents and gauging the impact of currents such as the Gulf Stream on global climate change.

It will investigate the circulation patterns of the world's oceans and map the contours of sea floors with U.S. and French radar altimeters. TOPEX/POSEIDON will carry a laser retroreflector to provide orbital tracking data. A microwave radiometer will correct for atmospheric effects.

The satellite, built by Fairchild Space Co., is to be launched in June, 1992, on an Ariane booster from ESA's space center in Kourou, French Guiana. TOPEX/POSEIDON will orbit at an altitude of 1,335 kilometers (830 miles), have a 65-degree inclination and use the Tracking and Data Relay Satellite System (TDRSS) for command and data acquisition.

NASA and the French have chosen 38 principal investigators to study data from the flight. The results of their experiments will help improve weather forecasting, plan for pollution control and evaluate offshore and coastal areas worldwide. The project team provided guidance for mission design and planning and used existing altimetry data to make interim studies of ocean currents in anticipation of the more accurate data to come from TOPEX/POSEIDON.

Mariner Mark II

NASA approved and Congress funded the first Mariner Mark II missions — Comet Rendezvous Asteroid Flyby (CRAF) and Cassini — as a new start for fiscal 1990. The major efforts this year were the design of a common spacecraft for these missions and development of major advanced technologies for flight systems.

The Federal Republic of Germany will provide a propulsion module and one science instrument for CRAF. Cassini's propulsion module will have the same design. ESA will provide an atmospheric entry probe named "Huygens" for the Cassini spacecraft.

Both spacecraft will be launched on Titan IV/Centaurs. CRAF will depart in August, 1995, fly past Earth and Asteroid Hamburga in 1997 and rendezvous with Comet Kopff in 2000. NASA chose 13 instruments, including a surface lander/penetrator, to take the first in situ measurements of a comet nucleus. At rendezvous, instruments will study the nucleus, coma, dust, tail and plasma. The primary mission will end in 2003.

NASA and ESA issued Announcements of Opportunity for Cassini science instruments on October 10. Choices are to be made next October. Cassini, to be launched in April 1996, will fly past Asteroid Maja in 1997, Earth in 1998, Jupiter in 2000 and reach Saturn in 2002. The probe will impact Titan in March, 2003. The orbiter will continue to make flybys of Titan and other satellites until the primary mission ends in 2006.

Mars Rover Sample Return

On July 20, 1989, during ceremonies commemorating the twentieth anniversary of the Apollo 11 landing on the Moon, President Bush announced his Space Exploration Initiative, a plan to send astronauts back to the Moon and also to Mars.

The Laboratory continued development of the proposed Mars Rover Sample Return missions, robotic precursors to the human voyages. NASA's Johnson Space Center has been JPL's principal partner in the planning for these important preliminary steps. The missions would advance scientific knowledge of Mars, gather environmental data (on its surface and atmosphere) necessary for subsequent human journeys and demonstrate both technology concepts and long-flight-time operations. The missions would also bring samples of Martian rocks, soil and atmospheric gases back to Earth.

Mars Rover Sample Return has several distinct elements: a surface rover with attendant delivery and landing systems; a Mars-ascent and Earth-return vehicle; a high-resolution, site-mapping orbiter and a communications relay orbiter.

In support of the President's Space Exploration Initiative, a plan was developed to integrate the Mars Rover Sample Return missions with a Mars Global Network mission and proposed enhancements to Mars Observer. These proposed changes would fulfill requirements for robotic precursors to a human outpost on the Red Planet.

To protect it from the Sun's heat, the Galileo spacecraft's science boom is covered with a gold blanket. Two of Galileo's science experiments are on the extended boom; three reside on the boom's structural base.

A false-color Landsat Thematic Mapper image shows how different colors correspond to different rock types while variations in texture indicate changes in topography. Some linear traces bounding contrasting rock types and/or landforms indicate the presence of faults.

Space and Earth

SCIENCE

The acquisition of new information and knowledge is the ultimate goal of all NASA activities at the Jet Propulsion Laboratory. This year's work brought a new understanding of Earth, Neptune, asteroids and interstellar space.

Earth Science

Earth Observing System

The Earth Observing System, part of NASA's proposed major new 1990s effort referred to as "Mission to Planet Earth," is intended to study the Earth in its entirety, as a planet, and to determine the impact of human activities on its atmosphere, hydrosphere, lithosphere and biosphere. The system consists of two sets of orbiting platforms with scientific instruments to track global changes in the environment for 10 to 15 years, beginning in 1997.

JPL offered several proposals. This year, NASA selected JPL to assume the following major roles:

- Develop three key facility instruments — a High-Resolution Imaging Spectrometer, an Atmospheric Infrared Sounder and a

Synthetic Aperture Radar (SAR). Two JPL scientists will lead international teams studying issues related to global warming and global change.

- Conduct six Principal Investigator experiments with instruments to pursue key mission objectives. The experiments will call for remote-sensing technology advances in the microwave, visible and infrared portions of the spectrum.

- Participate in interdisciplinary studies in areas such as determining the role of air–sea energy exchanges and ocean circulation in climate, estimating and monitoring the surface water budget, assessing active volcanism on a global scale and studying polar surfaces.

The Earth Observing System is managed by NASA's Goddard Space Flight Center.

Instruments for the Upper Atmosphere Research Satellite

JPL developed two instruments for the Goddard Space Flight Center's Upper Atmosphere Research Satellite (UARS). The satellite will inaugurate NASA's Mission to Planet Earth by studying the ozone layer and the processes that deplete it.

JPL's Active Cavity Radiometer Irradiance Monitor, designed to measure the total solar energy reaching Earth, was delivered in July. Knowing just how much solar energy strikes the Earth is vital to understanding the photochemistry and dynamics of the upper atmosphere.

The second JPL instrument is the Microwave Limb Sounder; it will measure chemicals (notably chlorine monoxide) that are keys to the cycle by which ozone is destroyed. A smaller, more advanced version of balloon- and aircraft-launched predecessors, the sounder weighs 621 pounds and uses 163 watts of power.

The UARS will fly in late 1991 in a near-polar orbit.

Chlorine Monoxide and the Antarctic Ozone Hole

Because ozone helps to regulate ultraviolet radiation reaching Earth's surface and to control temperatures in the atmosphere, any drastic decline in this layer is a matter for concern. An ozone hole in the Antarctic develops when chlorofluorocarbons interact with stratospheric clouds containing water vapor and nitric acid. The hole returns each spring, when the ozone is depleted by a significant fraction. A study at JPL may help to explain how fast this ozone declines.

The study included the first measurements of the reaction rates of chlorine monoxide in the Antarctic stratosphere. The rate at which chlorine monoxide recombines to form another unstable molecule, called a chlorine monoxide dimer, is important in understanding how ozone is depleted.

Ozone Measurements From Table Mountain Observatory

At JPL's Table Mountain Observatory in the San Gabriel Mountains (about 60 miles northeast of Pasadena), remote-sensing devices are being tested to determine whether they can detect changes in the stratosphere, such as the Antarctic ozone hole.

In the summer, the Stratospheric Ozone Intercomparison (STOIC) demonstrated that laser remote-sensing systems can produce stratospheric ozone profiles for NASA's UARS. Thirty scientists participated in the program.

Eleven of the systems made daily measurements of ozone and provided about 250 independent ozone-profile measurements. JPL's lidar instrument, which has operated continuously since 1988, was one of two that reported every day and provided a large data base.

Balloon-Borne Laser In-Situ Sensor

JPL's Balloon-Borne Laser In-Situ Sensor made the first direct measurements of the diurnal behavior of nitrogen dioxide in the atmosphere. These measurements allow scientists to test stratospheric models that predict the role of nitrogen compounds in the destruction of ozone, assess the validity of these models and improve long-range forecasts of the effects of human activity on Earth's protective ozone layer.

The sensor uses a new approach to measure the composition of the stratosphere. At a float altitude of 30 kilometers (18.6 miles), a laser fires at a reflector dangling 500 meters (1,640 feet) below the gondola. The light is absorbed preferentially by different gases and thus allows measurements of gas concentrations accurate to one part per billion. Measurements of nighttime decay of nitrogen dioxide confirm predictions of the formation of nitrogen pentoxide, an important reservoir species in the lower stratosphere.

The instrument can measure other gases involved in the depletion of ozone as well. Hydrochloric and nitric acids, for example, which are thought to be key to the formation and chemistry of the Antarctic ozone hole, have both been sampled.

The experiments have been so successful that scientists and engineers are building a smaller version of the sensor to fly on NASA's ER-2 airplane through the Antarctic ozone hole next fall. Another is being developed for the Cassini spacecraft to sample gases, clouds and isotope ratios in Titan's atmosphere.

NASA/JPL Airborne SAR

The usefulness of the NASA/JPL Airborne SAR to a wide range of scientific disciplines — geology, hydrology, forestry and archaeology, among others — was significantly enhanced this year when its slant-range resolution was doubled from 8 meters (26 feet) to 4 meters (13 feet). This improvement resulted from an increase in the bandwidths of its receivers and transmitters, an increase in the sampling rate of its digital data system and the addition of a digital chirp generator.

The instrument's effectiveness also benefited from added automation; its operating mode can now be chosen by the master computer control system. The Airborne SAR is exceptional because it provides information as a function of both frequency and polarization.

Progress was also made when the system was installed on NASA's DC-8 aircraft along with a new flight correlator; the crew was able to obtain high-quality images of a target within minutes of data acquisition. In August and September, radar imaging data were taken at 65 sites in Scotland, Germany and the United States. About 180 high-density digital tapes were recorded, each 15 minutes long, at 10 megabytes a second — more than 9 gigabytes of data on each tape. Throughout the period, the equipment operated with no major failures and obtained three-frequency SAR data and two-frequency interferometer data. These results were obtained by using both radar polarimetry and along-track interferometry techniques — innovations developed by JPL.

Quick-look images from the new correlator gave investigators information about the progress of their experiment, allowing modifications to be made in real time. An example of the quick-look imagery produced on the DC-8 in real time shows wakes generated by ships passing through a heavily instrumented site at Loch Linnhe, Scotland.

Calibration of the radar is an important segment of its development. A large number of ground devices were deployed at various sites to calibrate the radar in both amplitude and phase of the radar echoes. One of the key measurements was determination of cross-polarization isolation. The studies and experiments provided data for algorithm development and served as technology demonstrations for the development of other spaceborne imaging-radar systems.

NASA Scatterometer

On August 31, Japan's National Space Development Agency notified JPL that its NASA Scatterometer will fly on Japan's Advanced Earth Observation Satellite. The instrument will measure wind speed and direction over the ocean in all kinds of weather.

Wind is the driving force behind ocean motion, ranging from small waves to large current systems, and it affects the exchange of heat and moisture between atmosphere and sea. Those exchanges determine regional weather patterns and global climate.

Today our only knowledge of ocean winds comes from infrequent reports by ships. Once launched into a polar orbit 500 miles above the Earth in 1995, the NASA Scatterometer will map 90 percent of the ice-free oceans every two days.

The instrument's microwave radar will use two sets of three antennas, each 10 feet long, to illuminate two 229-meter-wide (751-foot-wide) bands of ocean — one on each side of the orbital path.

Atmospheric Forcing of Sea-Surface Temperature Change

Using satellite data, the Tropical Ocean Global Atmosphere Program computed the impact of two main components of sea-surface thermal forcing on tropical oceans.

Models show that atmospheric circulation and climate are sensitive to changes in sea-surface temperatures in the tropical oceans. Because past observations proved inadequate, it was not clear just what drives temperature changes.

Observations by a microwave radiometer on the Nimbus 7 Coastal Zone Colour Scanner were used to determine evaporative cooling, and a visible–infrared radiometer on Geostationary Operational Environmental Satellite–West (GOES–W), a reference spacecraft for the International Magnetosphere Study, gave data on solar heating.

With the new model, scientists now see two regimes. Away from the equator, seasonal temperature change results largely from surface thermal forcing. For a narrow band at the equator, ocean dynamics appear to be a more important factor.

GEOMEX: Measuring Tectonic Motion in the Gulf of California

JPL has undertaken a project called GEOMEX with Oregon State University to measure the motions of the Pacific and North American crustal plates in the Gulf of California.

Earth's crust is composed of tectonic plates, which are rigid blocks separated by zones of seismic activity. The Pacific Plate, one of the largest, lies beneath the Pacific Ocean, and the North American Plate holds most of our continent. The East Pacific Rift separates them. Like other tectonic plate boundaries, the East Pacific Rift is of two alternating types: spreading ridges, where magma wells up to drive the plates apart, and transform faults, where the plates move relative to each other. The rift goes through the Gulf of California and comes ashore at the northern end — the San Andreas Fault.

Models of Earth's crust indicate that the area moves as much as 10 centimeters a year, averaged over the millions of years spanned by the geologic record. To detect such slight motion over a few years requires at least several consecutive annual measurements over baselines hundreds to thousands of kilometers long. Furthermore, those distances must be measured to an accuracy of a few centimeters by instruments set out at many sites.

GEOMEX uses Global Positioning Satellites and receivers to measure changes in distances between sites. The receivers are deployed at precisely known sites in Baja California, mainland Mexico and Southern

California. Other receivers track the satellites in turn to determine the orbits of the latter accurately.

Data from this year's campaign will be compared with data from three Mexican sites occupied in 1985; the comparison will be the first determination of plate motion by this system. The next campaign will be in the fall of 1990.

Mojave Desert Faults Found in Landsat Images

While processing images from the Earth-monitoring Landsat's Thematic Mapper, a JPL scientist found several previously unknown faults, each measuring up to 25 kilometers (15 miles) long, in the central and eastern Mojave Desert. Though the faults are not obvious in aerial photographs or radar images, field studies confirmed their presence.

The previously unknown faults form part of a fault system in the Death Valley region that connects with the San Andreas Fault. The connection indicates that the network has accommodated a significant fraction of Pacific–North American Plate motion for 10 million years and that some new faults delineate geologic blocks with differing histories. Movement also appears to have occurred at two different periods. Faults in the Bristol Mountains east of Broadwell Lake, California, lie beneath unconsolidated alluvial fan debris and are probably inactive. By contrast, most faults west and south of California's Cady Mountains cut through all deposits and may be active.

Planetary Science

Voyager Radio Science

Experiments at the time of the Voyager encounter with Neptune used the spacecraft-to-Earth radio link to detect subtle variations in the frequency and intensity of the spacecraft's signals as the planet and its big moon, Triton, affected the transmissions gravitationally. These experiments demanded more of Voyager. An intricate limb-tracking maneuver was necessary, for example, so that atmospheric refraction would bend the radio beam toward Earth. Voyager's arrival at Neptune thus had to be calculated to an accuracy of several seconds.

Better signal reception on Earth was also needed because of both the enormous distance between Earth and Neptune and the signal attenuation of Neptune's atmosphere. The DSN 70-meter antenna near the Tidbinbilla Reserve in Australia was part of a Pacific Basin array for the encounter; the array also incorporated the Australian 64-meter (210-foot) Parkes radio astronomy antenna and the Usuda 64-meter star-tracking antenna.

A first for radio science was an agreement between NASA and Japan for Neptune experiments. The Japanese supplied the Usuda antenna and a team of scientists for the encounter. NASA added a Japanese coinvestigator to its Voyager radio science team and provided recording and timing equipment at Usuda. Results from the experiments are being shared by American and Japanese scientists.

Goldstone/VLA Titan Radar

Caltech and JPL astronomers used the most sensitive radar in the world to study their most distant and difficult target yet: Titan, Saturn's largest satellite.

They combined the upgraded 70-meter (230-foot) Goldstone antenna with the Very Large Array's (VLA's) 27 antennas, recently equipped with 3.5-cm receivers for the reception of Voyager's downlink radio transmission.

On the first night, June 3, the Titan return was fairly strong: It was 38 percent of the echo strength that a metal sphere of the same radius would have returned. On the second night, the return was surprisingly different: 78 percent. On June 5, the radar return dropped to 25 percent. Titan rotated approximately 17 degrees between each observation. If a putative global ocean of

ethane existed on Titan, scientists would expect a return echo of about 2 percent; these results would appear to rule out that possibility. Instead, Titan seems more like Jupiter's large icy Galilean satellites than previously thought.

The Cassini mission to Saturn will have an intriguing object to study in Titan.

Radar Images of Asteroid 1989 PB

From the Arecibo Observatory in Puerto Rico, JPL radar astronomers studied the Earth-approaching Asteroid 1989 PB just 10 days after the asteroid was discovered by the Palomar Observatory. They captured the first two-dimensional images — with 300-meter (1,000-foot) resolution — of a kilometer-sized planetary object. The asteroid is about one mile long, elongated and irregularly shaped. The longest imaging sequence contains 64 frames and runs for 2.5 hours. The asteroid's rotation, 180 degrees in about two hours, is readily apparent.

Asteroid 1989 PB resembles two half-mile-wide objects in close contact. Almost surely the product of one or more collisions, it perhaps began as a fragment of a larger asteroid that had suffered a catastrophic event. Asteroids such as 1989 PB may constitute the largest class of irregularly shaped solid matter in nature.

The asteroid is one of more than 100 known Earth-approaching objects. Most probably came from the asteroid belt between Mars and Jupiter; some may be nuclei of extinct comets. Their orbits are unstable, and the objects will last only a few hundred million years before being either ejected from the solar system or destroyed in a collision with an inner planet. Impacts by small contact-binary asteroids such as 1989 PB may be responsible for many paired craters on the Moon.

Astrophysics

Infrared Processing and Analysis Center

NASA, JPL and Caltech established the Infrared Processing and Analysis Center in 1984 so that astronomers all over the world could obtain data from the Infrared Astronomical Satellite (IRAS) mission. Staffed by JPL employees, the center at Caltech enjoys a unique relationship with both the Campus and the Laboratory, one that has been mutually beneficial.

A NASA panel found this center to have set the standard against which future space science centers will be measured. The center provides direct aid to astronomers and produces improved products from IRAS data. About 100 astronomers visit each year, staying two to five days to consult with IRAS astronomers and pore over the data.

IRAS astronomers produced a Point Source Catalog with data on 43,866 infrared sources. By analyzing it, astronomers found a new class of quasars that emit most of their energy in the infrared. The most luminous of these IR quasars appear to emit at least as much energy as some classic quasars, which are the most powerful sources in the universe.

The center is reprocessing data from IRAS to remove solar system emissions and thus produce infrared images of the sky that are three to six times more sensitive than they would otherwise have been.

The Search for Extraterrestrial Intelligence

The Search for Extraterrestrial Intelligence (SETI) Program began as a formal project this year and has two parts: an all-sky survey at JPL and a high-sensitivity targeted search at NASA's Ames Research Center. JPL began to design and build a prototype instrument with a 2-million-channel spectrum analyzer to detect apparently artificial radio signals up to 100 light-years away. Software and algorithms are also being developed.

Measurements that characterize the local radio interference environment and help in the design of signal-detecting algorithms were taken at such sites as Goldstone, Arecibo and Ohio State University. The SETI all-sky survey is scheduled to start in October 1992, the five-hundredth anniversary of Columbus' reaching America.

Information Systems

Planetary Data System

The Planetary Data System will preserve planetary science data as a valuable national resource. It will also provide ready access to, and analysis of, the data by the planetary science community. In cooperation with the National Space Science Data Center, the system will also be used to make this data more available to the public. It is a distributed system operated jointly by JPL and other academic and federally funded institutions.

This year saw the transition from a testbed to an operational phase. An operational version will come on line in early 1990. A NASA proposal and review process will be completed, culminating in the selection of nodes for geoscience, planetary atmospheres, plasma interactions, small bodies in the solar system and planetary imaging studies.

The system has served as a pathfinder in compact-disk technology for the preservation and exchange of space-science data. For example, the system compressed on six disks all the imaging data from Voyager encounters with Uranus and Saturn and some non-imaging data as well. The work was undertaken so that the data could be distributed to the science community.

Instrument Data Analysis and Control System

With JPL managing several sophisticated instruments on the Earth Observing System's polar platforms, the Science Information Systems Program Office set out to define the significant scientific characteristics of the information system. The mission is a significant challenge because of unprecedented data rates (one terabyte a day), the 15-year mission length and complex instruments on the platforms. The Instrument Data Analysis and Control System study produced a concept both for effective operational control of the JPL instruments and the processing of scientific data. The study formed the basis of much of JPL's involvement in the early definition phase of the Data and Information System and helped contractors to understand the basis for system requirements.

Data Visualization

Combinations of remote-sensing and field data can provide insight into the evolution of Earth's crust. Recent developments in science-data visualization now make it possible to combine surface and subsurface data sets so scientists can see a three-dimensional projection of real data. It is the first time such data have been combined and displayed in a digital format.

An oblique view of the Turtle Mountains in southeastern California was created by combining a Landsat Thematic Mapper image of the area with a digital topographic model. Seismic-reflection profiles showed such subsurface properties as faults and changes in rock type to a depth of about 30 kilometers (18 miles) into the crust.

Animation Techniques for Large Data Sets

With images of Mars taken by the Viking orbiters in the 1970s, scientists simulated a flight through the Red Planet's enormous canyons and over its volcanoes. "Mars: the Movie" demonstrated improvements in JPL's computer graphics capabilities and provided planetary scientists with a more realistic, three-dimensional view of the Martian surface.

"Mars: the Movie" took 37 days of uninterrupted computer time (15 minutes for each frame) to produce; it included more than 3,500 three-dimensional frames. The viewer takes a sweeping ride down Valles Marineris, a canyon near the Martian equator that stretches farther in length than the distance from New York to Los Angeles, and over Tharsis Montes, a series of giant volcanoes.

Advanced

TECHNOLOGY

New technology constantly demands our attention — from computer chips that can assume ever more control of routine daily activities to intriguing new concepts, taken from Voyager 2 at Neptune, for manipulation of imaging data.

JPL performs a great deal of advanced technology development in anticipation of the challenges of the next decade and century. Special emphasis has been placed on space microelectronics, automation, advanced computer architectures and robotics.

The year saw many accomplishments as new technology was developed for future missions. The recently approved Comet Rendezvous Asteroid Flyby (CRAF) mission, for example, will benefit from these Laboratory efforts in, among other things, fiber optics (a rotation sensor for attitude control) and custom microcircuit fabrication (a direct memory access device for onboard computing).

The Center for Space Microelectronics Technology

Microdevices Laboratory

The new JPL Microdevices Laboratory (MDL), completed in 1989, is the primary facility of the Center for Space Microelectronics Technology (CSMT). The MDL is dedicated to research and advanced development of microelectronic and photonic devices to meet special needs of NASA and Department of Defense (DOD) space missions. The center will also significantly enhance Caltech Campus–JPL collaborative research in the fields of electrical engineering and condensed-matter physics.

The MDL is active in the development of myriad advanced space microelectronic devices, such as infrared, millimeter-wave and submillimeter-wave detectors; electronic neural network devices; lasers; and optoelectronic integrated circuits. Experimental solid-state devices based on silicon, these compound semiconductors and superconductors are fabricated and characterized by their electrical, optical and surface/interface

properties in the MDL. Technology developed at the MDL will eventually be transferred to industry.

The MDL is a 38,000-square-foot, three-story facility with clean rooms for material deposition, lithography and device processing, and conventional laboratories for characterization. The clean rooms, divided into three categories (classes 10, 100, 1,000) are arranged in conventional bays (work areas) and chases for access to mechanical pumps and utilities.

The JPL Microdevices Laboratory, now fully operational, includes a state-of-the-art electron-beam lithography system. This system makes possible the routine fabrication of devices with submicron-sized features. In materials, the laboratory's in-house capability ranges widely — from devices based on silicon and amorphous silicon, to compound semiconductors (based on gallium arsenide), to superconductors. The MDL can also characterize the surface/interface, bulk electrical and optical properties of materials and devices.

Neural Networks

JPL is particularly interested in massively parallel, highly distributed computers based on neural-network models. Unlike conventional digital computers, which use a single processor to execute a task serially, neural networks have many simple processors ("neurons") that work simultaneously and interact with one another through networks ("synapses"), much the way the brain operates. The unique computational properties of such networks make possible the solution of complex problems that involve "fuzzy" or distorted situations, for which conventional methods are time-consuming, cumbersome or simply nonexistent. This approach is attractive when a near-optimal, real-time solution is an acceptable alternative to a protracted wait for the most accurate solution.

If the promise of high speed is to be realized, massively parallel neural-network-inspired architectures must be built so that neurons and synapses can couple their operations smoothly. JPL has pioneered neural-network electronic hardware based on custom very large scale integration (VLSI) technology strategically merged with novel thin-film analog microelectronic devices. These cascading neural-network building blocks make it possible to fabricate reconfigurable high-speed neuroprocessors and thereby evaluate neural-network architectures in real applications.

JPL has developed many functional chips with typical solution times of just a few microseconds. In collaboration with Caltech, the Laboratory is studying a broad range of neural-network applications of interest to NASA and the DOD: star-field pattern recognition, multispectral data classification, robotic control, resource allocation, planetary rover path planning and multitarget tracking.

JPL's neural-network research has already demonstrated high-speed performance (equivalent to more than 1 billion floating-point operations per second) and paved the way for dedicated prototype neuroprocessors for such applications as cartographic analysis or route and mission planning. The technology of fabricating neural networks is currently being transferred to industry for engineering development.

Hypercube Project

The Caltech Campus–JPL Hypercube concurrent computer has been in development for several years. The goal is to achieve cost-effective scientific and engineering data processing at supercomputer speed. The Hypercube contains computing elements, referred to as "nodes," interconnected for communication. Nodes can be expanded by factors of two.

The Hypercube Project completed its third-generation computer in April, when the 128-node Mark IIIfp was assembled and verified. Several of the more than 100 science and engineering applications that run on smaller Hypercubes were used on the large machine, and tests proved it to be one of the world's most powerful supercomputers. For example, it computed a complicated problem in quantum chromodynamics at more than 700 million floating-point operations per second.

In the last two years, the number of useful application programs for the Hypercube has increased steadily. A major effort has been made to construct simulation models of large systems of interest to NASA and military sponsors. The Air Force Electronic Systems Division continues to fund not only such simulations, but also hardware and software development.

During the Voyager–Neptune encounter, the JPL Image Analysis Systems Group used an eight-node Mark IIIfp Hypercube to create mosaic images and rotational movies of Neptune's atmospheric dynamics in near-real time. Computational requirements included photometric correction, navigation and pointing adjustments, geometric projections (for map registration) and analysis of the motions of atmospheric features. The eight-node machine operated at 60 to 80 times the speed of the computer system usually used for such computations, a VAX 8600, so control teams could consider alternative imaging sequences as Voyager approached the planet. The concurrent operation of an image-restoration algorithm sharpened images of Triton that had been blurred by camera motion during long exposures.

One large application for the Hypercube is the analysis of electromagnetic scattering and antenna radiation patterns. Hypercube programs have been developed to design and analyze structures such as an advanced Global Positioning System (GPS) antenna. These and other programs typically run with an efficiency of 80 to 95 percent.

The Hypercube runs large distributed simulations of multiprocessor systems as a tool for the design and analysis of future machines. The Hypercube Project simulates the next-generation communications processor by using the Time Warp operating system currently under development by JPL and the University of California, Los Angeles (UCLA).

Supercomputing Project

On June 14, a CRAY X-MP 1/8 supercomputer was installed at the JPL Information Processing Center (IPC). The CRAY, a collaborative effort between Caltech and JPL, is seen as a cost-effective answer to both institutions' needs for high-performance computation; it is the first step in a phased plan to provide state-of-the-art computing for exceptionally difficult or intensive problems.

A support group helps new users of the CRAY to become proficient quickly and responds to the more complex needs of experienced users as well. The group also supported many JPL users in transferring programs from other computers to the CRAY.

MAX Flight Computer

The MAX flight-computer program is developing a fault-tolerant parallel-computer architecture for NASA spacecraft. MAX dynamically allocates resources such as processors and input–output channels to reconfigure itself automatically when faults occur.

In addition to increased performance and flexible fault tolerance, MAX takes an evolutionary step forward in spacecraft design: The hardware and software are designed as modular systems adaptable to many missions.

Six computing modules were built this year, bringing the total to 10 and allowing realistic performance and fault-tolerance tests. Each module contains two powerful 32-bit microprocessors and is designed to include 12 input–output coprocessors. The input–

output coprocessors added this year were jointly developed by the MAX and Mariner Mark II project offices. Four such coprocessors have been fabricated on a single VLSI chip and are so powerful that they can handle interprocessor communications in addition to performing many essential functions on a spacecraft.

A key part of MAX is the development of a comprehensive software environment for the sorts of fault-tolerant, real-time programs future spacecraft might need. Graphic design and debugging tools, as well as a simulator, have been demonstrated, and other capabilities are in development. MAX will be ready for possible use on flight programs in 1993.

Two-Dimensional Acousto-Optic Spectrum Analysis

Programs such as SETI require the Fourier analysis of wideband microwave and radio signals in real time and with ultrahigh resolution. Digital spectrum analyzers typically have the disadvantages of being large, heavy and power hungry. Optical spectrum analyzers, on the other hand, can be compact, transportable and flight qualifiable.

JPL's Optical Communications Group has developed a two-dimensional acousto-optic spectrum analyzer with high resolution and wide bandwidth. This laboratory tabletop analyzer, which uses a large-format charge-coupled-device array, has the potential to scan one million channels for any sign of a coded, extraterrestrial radio source.

Space Automation and Robotics

Space Robotics

JPL made significant progress this year in robotics technology. A telerobot testbed, with two manipulator arms and a third to hold a television system, became operational. It is the first such system capable of being operated either by remote control or under supervised autonomous operation; an operator can switch easily between these two modes. The system is intended to investigate problems of on-orbit repair and servicing of satellites, as well as to provide insights into the division of activities between human operator and robot.

Machine vision for robots has long been a computationally difficult area. This year, JPL worked on a real-time system that uses multiresolution image processing, an innovation originating in studies of human vision. The concept is to process images at the lowest feasible resolution for a given task. This technique directs attention to parts of images that need higher resolution so they can be analyzed in detail. General-purpose microprocessors and simple hardware are used so that the technique will be adaptable to a variety of machine-vision systems, including space telerobotic systems.

JPL engineers developed a reasoning system to calculate the geometric limits of a given situation and determine whether a proposed move is feasible. After being integrated with Robotap, a high-level task planner, and Handey, a robot-motion planner, the system showed that it could plan steps to accomplish a goal, reason about the feasibility of a move and then calculate the requisite movements while avoiding collisions with other objects.

Aspects of space robotics are being used in the Space Station Freedom's Flight Telerobotics Servicer. JPL delivered hardware and software to NASA's Goddard Space Flight Center; technical insight from the JPL research influenced specifications for the servicer.

In this, the first year of the Pathfinder Program, JPL's Planetary Rover and Sample Acquisition, Analysis and Preservation programs laid the groundwork that will enable unmanned vehicles and science payloads to explore potential sites as part of the President's Space Exploration Initiative. Such exploration must be completed before humans return to the Moon or travel to

Mars. To provide for reasonable mission returns, a considerable degree of vehicle autonomy is needed. A navigation testbed named "Robby" was built to develop and validate semiautonomous navigation techniques for rough, natural terrain.

Knowledge Systems

JPL carried out research on a knowledge systems subprogram designed to advance artificial intelligence technology and applications. Objectives here included research on leading-edge technology and knowledge-based systems and demonstration of the technology. The work includes automated mission operations, analysis of science data and data visualization.

The Spacecraft Health Automated Reasoning Prototype (SHARP) is developing techniques to monitor and diagnose spacecraft and ground systems automatically. To prove SHARP in a realistic setting, the prototype was used to analyze Voyager 2's telecommunications link in August and September, during the Neptune encounter. In its analysis, SHARP took account of real-time data from the spacecraft, the Deep Space Network (DSN) and Voyager engineering systems. Telecommunications was chosen for the first application because small, unresolved problems there can quickly escalate into serious difficulties.

Voyager personnel evaluated SHARP for about 480 hours of operational testing and helped find the cause of, and the solution for, a science-data anomaly in telemetry from Voyager. The answer was to replace a wideband interface unit in Voyager's Data Acquisition and Capture System.

The system will be used again in the Space Flight Operations Center for Magellan and Galileo. There is also interest in using SHARP to monitor science instruments on the ground and in certain applications for the DSN.

A Force Torque Sensor for the Shuttle's Remote Manipulator System

The space shuttle's Remote Manipulator System has already proven essential to several space missions, notably in the repair of the Solar Maximum satellite. Yet astronauts themselves have been unable to feel any of the forces that act on the arm.

A Force Torque Sensor, developed at JPL, improves the arm by providing that feedback. There are two elements: a sensor (containing strain gauges) and data-gathering electronics (attached to the manipulator's "wrist"). A computer displays information from the sensor, which lets astronauts see the forces and torques imposed on the arm in six axes. Astronaut commands affect such functions as display formatting and strain-gauge-offset compensation. Engineering data are recorded so that the arm's performance can be analyzed.

Other Technological Advances

Increased Operating Life of Xenon–Ion Engines

Ion engines impart thrust to a spacecraft when electrically charged particles created in a plasma chamber are accelerated through a nozzle at 50,000 meters per second. Such high velocities would enable ambitious exploration missions to use much less propellant than must be used with chemical engines. However, ion engines for primary propulsion must have operating lifetimes longer than 10,000 hours, and fast ions limit engine life because of their erosive effect, which is similar to the impact of sandblasting.

Xenon, normally an inert gas, can be used in an ion engine if this neutral atom is bombarded with fast electrons to create positively charged ions. The area with the highest ion concentration is in the plasma chamber, near the electron-emitting cathode, and a component, made from tantalum, called the "baffle." Experiments revealed that the baffle in 5-kilowatt xenon–ion engines erodes faster than is acceptable.

Techniques to increase ion-engine life are being studied at JPL. One technique is to add small quantities (2 percent by weight) of nitrogen to the xenon. In theory, the nitrogen and tantalum should form a metal nitride that is eroded by ions at a lower rate than is pure tantalum. Experiments this year proved the technique. A special baffle was placed in the plasma chamber and exposed to erosive ions. The baffle consisted of two squares — one of tantalum and one of graphite — placed side by side. Graphite erosion rates appeared unaffected by the addition of nitrogen to the xenon, probably because graphite does not form a sputter-resistant nitride. However, tantalum erosion rates were reduced by a factor of 15. Additional studies will focus on the physics and chemistry of the erosion mechanisms to determine the exact amount of nitrogen that should be added to the xenon.

Alkali Metal Thermoelectric Converter

JPL scientists are working on an advanced passive energy-conversion system, the Alkali Metal Thermoelectric Converter, for spacecraft and planetary rovers equipped with nuclear or solar heat sources. It converts heat in the range of 700 degrees Celsius to 1,000 degrees Celsius into electricity. The continuously operable electrochemical cell uses sodium as the working fluid. Sodium ions are conducted across a solid electrolyte from a high-temperature, high-pressure source to a low-temperature, low-pressure sink, generating electricity in the process. Research in 1989 solved the problem of decaying electrode performance through the invention of new high-power, durable electrodes made of intermetallic alloys. Long-term tests of prototype cells have begun.

Selective Oxygen Removal by Means of Novel Adsorbents

Trace oxygen removal at high temperatures (up to 800 degrees Celsius) has applications for processes (such as microgravity experiments that deal with metallic transformations) and for industry (processing materials for microdevices). While some commercial sorbents can trap oxygen at room temperature, only one can function at 250 degrees Celsius. Furthermore, industrial sorbents are not size-selective, as some applications require. To remove oxygen selectively at high temperatures, two new classes of adsorbents were developed.

The research is part of a strategy to control contamination in the sample-positioning chambers of the Drop Physics Module and the space station's Modular Containerless Processing Facility.

Closed-Loop Life-Support Systems

As part of NASA's Pathfinder Program, JPL was chosen to study life-support systems for long-duration manned missions to the Moon and Mars. A systems-engineering approach was used. A rigorous new methodology of matching mission definitions to various technologies is being applied for the first time to the design of life-support systems; the needs of a Lunar Outpost mission will be identified in this way.

A Source of Ground-State Atomic Oxygen

During the third flight of the space shuttle, in March, 1982, pictures of an experiment in the payload bay revealed an unexpected, faint orange–red glow above the shuttle's engine pods and tail. The glow was most prominent on surfaces facing the direction of flight, called the "ram direction."

Later study showed that the glow resulted when fast oxygen atoms made impact with the skin of the spacecraft, causing it to glow and erode. The energy of such ground-state neutral atoms in low Earth orbit is about 5 electronvolts. Because it is difficult to generate such atoms in the laboratory, a detailed understanding of the phenomenon was not possible. The erosion was almost certainly the result of rapid oxidation–evaporation and sputtering of the shuttle's flight surfaces. Since the glow was later seen around a variety of materials in low Earth orbit, it was thought to result from a recombination of oxygen atoms — perhaps with nitric oxide, giving rise to optical emissions from excited nitrogen dioxide molecules. However, that remained a hypothesis until the phenomenon could be reproduced in the laboratory.

Now, after four years, JPL has produced the first well-collimated beam of ground-state, low-energy atomic oxygen; the beam is free from such impurities as electrons, molecules and oxygen in its excited states. The source produces atoms in the energy range of 2 to 100 electronvolts by producing the negative O^- ion, accelerating it to the desired energy and then photodetaching it into the ground electronic state of oxygen. The experiment is performed in a high magnetic field to increase space-charge-limited currents of ions in the experiment. Flux, energy and atomic state are comparable to those that spacecraft encounter in low Earth orbit.

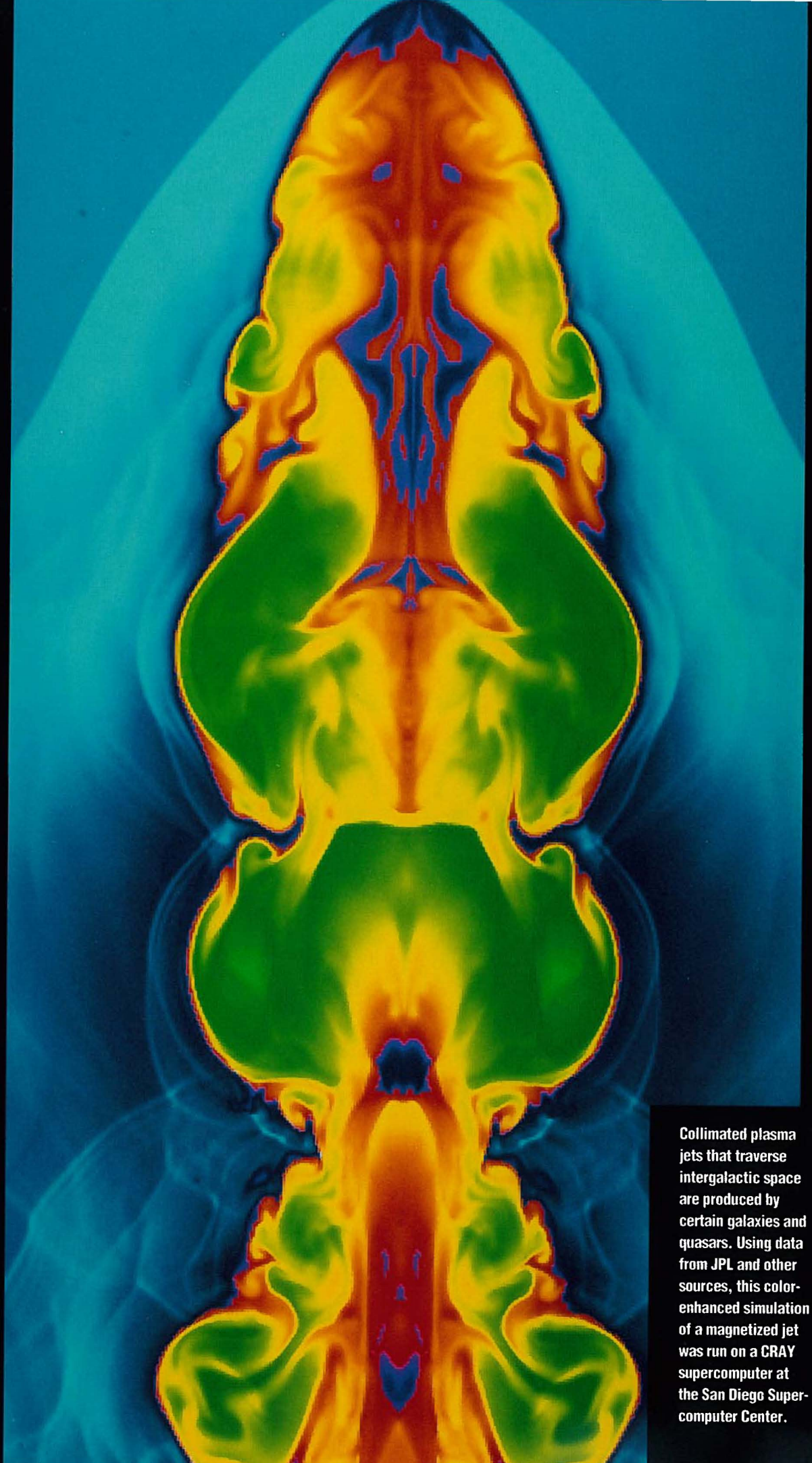
Using the source, the puzzling shuttle-glow phenomenon was simulated in the laboratory by directing the collimated beam of oxygen atoms onto magnesium fluoride. Scientists found that by bathing the target with nitric oxide, an enhanced glow could be observed; it was similar to the one measured on the shuttle. The results suggest that the glow could arise from excited nitrogen dioxide formed by surface recombination of NO + O. The excited NO_2 is ejected from the surface and then radiates in the infrared. A similar experiment with carbon monoxide directed onto the surface produced a different spectral distribution, suggesting that surface recombination was responsible for the glow.

The red–orange glow proved to be an optical effect of all surfaces facing the ram direction. Spacecraft affected by the glow include the space shuttle, the space station and the Earth Observing System. The relevant altitude range is 200 to 900 kilometers (124 to 558 miles), where atomic oxygen is the main atmospheric component.

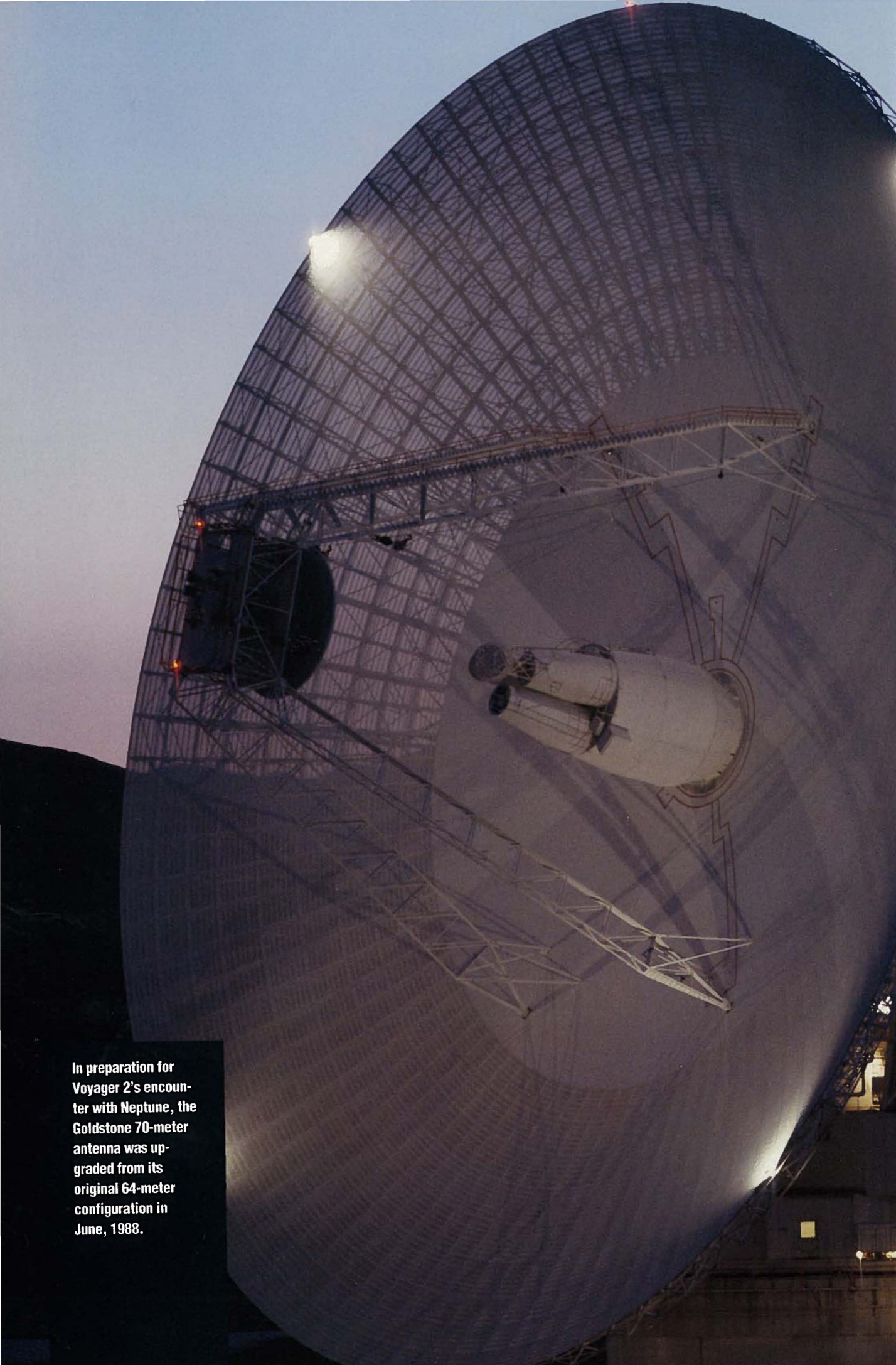
Mobile Satellite Experiment

JPL is developing technology that will allow a moving vehicle and a fixed ground station to communicate through a geostationary satellite. The Mobile Satellite Experiment (MSAT-X) will augment cellular telephones by providing voice and data service in remote areas.

JPL engineers tested models of ground terminals and low-cost antennas in Colorado, the Eastern Seaboard and Australia. They transmitted data and digitized voice over a 5-kilohertz channel. Techniques were developed that resist fades caused by relative motion. These tests and demonstrations are influencing the design of both American and Australian commercial networks.



Collimated plasma jets that traverse intergalactic space are produced by certain galaxies and quasars. Using data from JPL and other sources, this color-enhanced simulation of a magnetized jet was run on a CRAY supercomputer at the San Diego Supercomputer Center.



In preparation for Voyager 2's encounter with Neptune, the Goldstone 70-meter antenna was upgraded from its original 64-meter configuration in June, 1988.

Telecommunications

SYSTEMS

The Deep Space Network (DSN) is NASA's worldwide system for transmitting instructions to, and receiving data from, spacecraft beyond Earth orbit. JPL manages the network, which has sites at Goldstone Dry Lake in California's Mojave Desert; Madrid, Spain; and Canberra, Australia. The Network Control Center is at JPL. Satellite and ground communications link all locations.

Each site is equipped with four large antennas from 26 meters (85 feet) to 70 meters (230 feet) in diameter. (The 26-meter antennas support high Earth-orbiting satellites.) During encounters, antennas at different complexes can be arrayed to increase data return. They can also be coupled with those at other facilities, as was done during Voyager 2's Neptune encounter, or teamed for scientific work by means of such techniques as Very Long Baseline Interferometry (VLBI). In the latter case, simultaneous measurements made by two (or more) widely spaced antennas provide positional accuracy equivalent to that of one antenna with a diameter the size of the distance between the two antennas. This technique, originated by radio astronomers, is used for precise geodetic measurements as well as for locating spacecraft in deep space.

Overview

The DSN supported the Soviet Phobos mission, Magellan, Galileo and all shuttle missions; Earth orbiters Exos-D and GMS-4 for Japan; Tele-X for France; DFS 1 and TV-Sat 2 for Germany and the four-month Voyager 2–Neptune encounter.

The Network Consolidation Program was completed on October 2, when DSN Operations assumed responsibility for the 26-meter (85-foot) Earth-orbiter subnetwork from NASA's Goddard Space Flight Center. Under the new system, the DSN acquires all data for NASA's deep-space and high Earth-orbiting missions, supports existing near-Earth missions not tracked by the Tracking and Data Relay Satellites (TDRSs), supports launch phases of shuttle-launched and reimbursable foreign missions and provides emergency backup support for TDRS and TDRS-supported missions.

In addition to managing the DSN for NASA, the Telecommunications and Data Acquisition Office develops communications and radio science technology, manages JPL's participation in the Search for Extraterrestrial Intelligence (SETI) and performs ground-based radio and radar astronomy.

Support for the Voyager–Neptune Encounter

The network was an essential part of the Voyager–Neptune encounter. As a spacecraft travels farther from Earth, its signals become weaker. Because of the vast distance to Neptune (almost 3 billion miles), the DSN would not normally have been able to receive as many pictures from Neptune as from Uranus.

The DSN took two approaches toward improving its capability. First, the diameter of the largest antenna at each site was increased from 64 to 70 meters (210 to 230 feet). Second, antennas of other agencies were joined, or "arrayed," with DSN antennas to capture signals more effectively. The receiving capability of all 70-meter antennas, for example, was thus upgraded by a factor of 1.6 as a result of increased antenna size, the replacement of old surface panels with panels of higher precision and better focusing.

NASA contracted with the National Radio Astronomy Observatory (NRAO) and the National Science Foundation (NSF) to use the Very Large Array (VLA) radio telescope in Socorro, New Mexico, to receive data from Voyager. Australia helped with its Parkes Radio Observatory, and Japan made its 64-meter antenna at Usuda available for radio science.

The VLA's 27 radio astronomy dishes are each 25 meters (82 feet) in diameter. Signals received by those antennas were combined there, transmitted via satellite to the DSN site at Goldstone and combined with signals from two antennas — 34-meter (112-foot) and 70-meter (230-foot) — at Goldstone. On the other side of the world, signals received by the Parkes telescope, a 64-meter dish, were combined with those received by the DSN Canberra site's 70-meter antenna and two 34-meter antennas.

The VLA supported Voyager 2 for 40 days and the Parkes telescope tracked the spacecraft for 80 days. The Japanese antenna at Usuda received radio science data on the day of Voyager's closest approach.

To meet Voyager's exacting requirements, the DSN embarked on an implementation, testing and training program. Each 64-meter antenna went out of service for six to eight months for expansion to the 70-meter configuration and was tested before being returned to service.

New receivers were designed, built and tested for this mission — X-band for the VLA and Parkes stations, S-band for Usuda. Long-baseline telemetry combiners were also installed at Goldstone, to couple the signals received there with those from the VLA, and at Canberra, to couple its signals with those from Parkes. In addition, at Parkes and Usuda, special recorders for the mission's radio science experiment were installed.

Because the encounter could not be repeated, nothing was left to chance. Personnel at each DSN station and non-DSN site were carefully trained in the use of the new equipment, configurations and procedures. Crucial equipment received special maintenance, and spare parts were sent to the sites and maintenance depots.

Steps were even taken to minimize the negative effects of bad weather over the DSN stations. Rainwater on an antenna's dichroic plates and Kapton feedhorn cover can introduce noise to the spacecraft's transmissions, masking the data; a moderate shower, for example, can increase the system's temperature to more than 100 kelvins from 20 kelvins.

To counter this degrading noise, the effectiveness of commercially available hydrophobic coating and air blowers was tested by means of a wetted X-band radiometer at JPL. When these tests showed that the noise could be reduced to 5 kelvins from

an initial 30 kelvins, JPL decided to use the coating and the blowers on all antennas and feedhorns.

These measures — arraying configurations, upgraded equipment and new procedures — contributed significantly to the success of the encounter. The DSN network reliably captured data from Voyager at a maximum rate of 21,600 bits per second (bps), about what it had gathered from the spacecraft 44 months earlier during the Uranus encounter — despite the fact the distance involved was almost half again as far (4.5 billion kilometers, or 2.7 billion miles, at Neptune; 3 billion kilometers, or 1.8 billion miles, at Uranus). Without these improvements, the maximum data rate would have been less than 10,000 bps.

The Phobos Dynamics Experiment

As part of a 1987 agreement, NASA joined Russian scientists in the Soviet Union's scientific investigation of Mars and its satellite Phobos. The two Soviet spacecraft were named Phobos 1 and Phobos 2. JPL was a major partner in the Phobos Dynamics Experiment.

To satisfy the scientific goals of the venture, a C-band uplink was added to the 70-meter Goldstone antenna, and L-band downlinks were reestablished (from the Vega mission of 1986) at all three DSN complexes.

Phobos 1 was lost in September, 1988, and all DSN attention then focused on Phobos 2. (The majority of DSN support for Phobos 1 was to have occurred after the spacecraft's landing on the satellite, which was planned for March 1989.)

In January, 1989, the DSN Navigation Team provided its Soviet counterpart with trajectory information based on eight VLBI measurements. On January 29, the DSN measured the point at which Phobos 2 was inserted into Mars orbit to within 13 kilometers, an accuracy 10 times better than that available from any single-station radiometric data. The DSN provided two-way Doppler and ranging data on Phobos 2's later orbits, including the orbit it took as it approached the Martian moon.

Phobos 2 found water vapor in the Mars atmosphere, mapped the planet and took photographs of Phobos. Unfortunately, the spacecraft ceased working on March 27, about 10 days before the planned landing on Phobos.

Catalog Maintenance and Enhancement for Magellan and Galileo Navigation

Magellan and Galileo are the first interplanetary spacecraft to be tracked by VLBI. Both missions require VLBI data for accurate navigation. JPL's Very Long Baseline Interferometry Catalog of extragalactic radio sources (mostly quasars) is a background inertial reference frame against which the spacecraft are observed with two radio telescopes separated by intercontinental distances. Actual spacecraft data and catalog data are differenced to reduce common errors and locate the spacecraft in the Radio Reference Frame.

The greater the angular separation is between spacecraft and reference quasar, the smaller the error and the more precise the navigational measurement. For that reason and for maximum scheduling flexibility, the largest possible number of sources is needed near the ecliptic plane. Project engineers prefer to have a radio source within 10 degrees of a spacecraft at any particular time, implying a desired source density of at least 1 per 10 degrees on the ecliptic. The new 56-megahertz-bandwidth (Mark III) VLBI system installed in the DSN complexes has allowed rapid determination of positions of weak radio sources near the ecliptic plane and the identification of other radio sources there.

For Magellan and Galileo, the density of navigation sources within 5 degrees of the ecliptic was almost three times that of the region beyond 20 degrees of the ecliptic plane. Forty-eight usable navigation sources lie within 10 degrees of the ecliptic, and 76 are within 20 degrees. More than two-thirds of the 42 useful sources added since 1987 are within 20 degrees of the ecliptic, making VLBI radio navigation possible much more often and promising very precise trajectories for these spacecraft.

Satellite Ground Station in Alaska

JPL and the University of Alaska developed and installed a 10-meter (32.8-foot) satellite-tracking antenna on the Geophysical Institute building at the university's Fairbanks campus. The antenna will track and acquire data from polar-orbiting Earth resources satellites; the data are in the form of Synthetic Aperture Radar signals. Studying North Pole ice is the main interest, and scientists will use the data to produce images of ice, oceans and solid surfaces. The first satellites to be tracked are the European Space Agency's ERS-1, Japan's JERS-1 and Canada's Radarsat. The University of Alaska will operate the new tracking and image-processing ground station and serve as a focal point for scientists seeking a broad range of terrestrial images.

34-meter Research and Development Antenna at Goldstone

At its Goldstone DSN site, JPL is building an antenna 34 meters in diameter, with both center- and offset-fed beam waveguides, for research and development activities. The antenna, which has a design efficiency of 75 percent, is expected to have a gain of almost 68 decibels at X-band and almost 78 decibels at Ka-band.

The antenna will be used to develop new ground-based microwave components and systems for deep-space missions. With the beam waveguides, it will be able to receive multiple frequencies (X-, Ka-, S-, etc.) simultaneously. The high frequencies of Ka-band make possible wider bandwidth than other bands; this could be an important element in President Bush's Space Exploration Initiative.

Construction of the antenna's foundation (which is finished) and its pedestal started in 1988, and fabrication of its elements began in March, 1989. Most of the structural steel is being fabricated in Spain, and the dish, now complete, was assembled there. The mechanical drive components, fabricated in Italy, and the bearings are complete; they are being delivered. Construction of the pedestal and erection of the antenna should be completed in May, 1990.

Big Viterbi Decoder for Galileo and Future Missions

The three-year launch delay imposed by the Challenger tragedy on the Galileo mission had the effect of reducing the spacecraft's communications capability. Jupiter will be farther from Earth at the time of the 1995 encounter than on the originally projected 1988 encounter date. Also, the time lapse has reduced the power of Galileo's Radioisotope Thermoelectric Generators (RTGs).

Efforts are being made to increase the scientific data return in 1995. A small improvement in the capability of DSN stations to receive Galileo's signals at that time will mean a large increase in the

number of pictures the spacecraft will be able to send back from the giant planet. Such improvement is expected because of an error-correcting decoder to be installed at the stations; it effectively allows the DSN sites to capture signals 1.3 decibels weaker than they normally receive. This, in turn, will enable Galileo to send data back faster than it otherwise could and should result in 30 percent more images. The decoder will be tested in mid-1991 when Galileo's high-gain antenna is deployed.

Ultra-low-noise Performance of an 8.4-GHz Maser/Feedhorn System

Laboratory engineers are constantly seeking ways to reduce sources of noise in the DSN and thereby improve the network's ability to receive weak signals from distant spacecraft. JPL engineers reduced significantly the noise of an 8.4-GHz front-end system by cooling the maser ultra-low-noise amplifier to 1.7 kelvins (–457 degrees Fahrenheit) instead of the normal 4.5 kelvins, and by immersing the feedhorn, polarizer and other components (which normally operate at room temperature) in the liquid helium bath along with the maser.

A laboratory demonstration of this cryogenically cooled antenna front-end system measured 1.3-kelvin input noise temperature, compared with the typical 9.8 kelvins achieved by current DSN 8.4-GHz front ends. This system, if installed on a DSN beam waveguide antenna, would result in a nominal 1.9-dB (55-percent) improvement in the received signal-to-noise ratio of a spacecraft signal such as Galileo's (the actual amount of improvement is a function of antenna elevation angle, weather, etc.).

Single-Complex Interferometry

VLBI, a triangulation technique capable of measuring the angular positions of distant objects with great precision, requires two or more receiving antennas typically located thousands of miles apart. In the year reported here, JPL experimented with a small-scale form of VLBI called Connected-Element Interferometry and demonstrated accuracies comparable to those of a much larger system.

In this test, two antennas only 21 kilometers (14 miles) apart at the Goldstone DSN Complex were trained on a pair of extra-galactic quasars separated by six degrees. Because precise timing is essential to accurate interferometric measurements, the two antennas — DSS 15, a 34-meter (110-foot) dish, and DSS 13, a 26-meter (84-foot) research and development dish — were time-synchronized via a fiber-optic link. By cross-correlating the radio signals received at the two stations, engineers were able to compare the arrival times of the quasar signals and thereby calculate the relative angular positions of those two distant sources to an accuracy of 60 nanoradians.

While not as precise as the 30-nanoradian accuracy currently achievable by operational VLBI complexes on intercontinental baselines, it was nevertheless a convincing

demonstration of the technique and its potential value to future deep-space missions. A single complex with a short-baseline interferometric capability, like Goldstone, could track an interplanetary spacecraft with 50- to 100-nanoradian accuracy and so eliminate the need to relay signals from one distant VLBI site to another for comparative calculations. That would enable mission controllers to carry out tracking and navigation functions in real time and to increase the efficiency and reliability of those operations.

Centimeter-Level Accuracy for GPS Ground Measurements

VLBI is one of the most reliable ways to measure the positions of targeted objects with centimeter accuracy. However, observations by Global Positioning System (GPS) Satellites can provide key atmospheric and geophysical calibrations for deep-space tracking operations, and these can be made with small, portable antennas instead of large DSN dishes.

The Defense Department's GPS, scheduled to be completed in the early 1990s, consists of 21 transmitting satellites in circular 12-hour orbits. GPS equipment is portable, relatively lightweight and will ultimately offer a near-real-time measuring accuracy at least 10 times better than that of older tracking systems.

In a demonstration of GPS techniques, comparisons were made between GPS and VLBI measurements of ground baselines. When techniques developed at JPL for processing signals were used, the GPS-determined coordinates of ground stations agreed with VLBI calculations for the same facilities to better than 2.5 centimeters for baselines 2,000 kilometers long between Florida and Massachusetts and between Texas and California. These findings suggest a relative accuracy better than 15 parts per billion.

The consistency between the two techniques shows that the DSN can combine them, using the GPS to enhance and extend VLBI capabilities by determining positions of large antennas, monitoring Earth orientation and making atmospheric calibrations to support deep-space missions.

Fiber-Optic Signal Distribution

Experiments indicate that dramatic improvements in the stability, bandwidth and dynamic range of fiber-optic analog signal distribution are possible. An actively stabilized fiber-optic link has been shown to improve the stability of a hydrogen maser reference-frequency distribution system by 400 times. Fiber-optic transmitters incorporating integral optical isolators promise further improvements in stability. Fiber-optic links incorporating semiconductor-diode-pumped solid-state neodymium-yttrium-aluminum-garnet (Nd:YAG) lasers have been tested and should provide bandwidths in excess of 20 GHz, with higher dynamic range than is achievable using directly modulated semiconductor lasers. Ultrastable fiber-optic signal distribution may be used in transmitting the Doppler signature of a spacecraft in deep space, which would help support gravitational wave observations.

Applications

PROJECTS

JPL brings a strong capability in advanced systems development, along with a broad array of technological strengths, to projects of national importance not sponsored by NASA. Other sponsors range from offices within the Department of Defense (DOD) to agencies such as the Federal Aviation Administration (FAA) and the Department of Energy (DOE). The year was notable for several milestones.

Imaging System for the Delta Star Program

In March, 1988, JPL agreed to build a space-qualified ultraviolet imaging video camera for the Delta Star satellite. It was delivered to the integrating contractor, the Applied Physics Laboratory at Johns Hopkins University, on July 21, 1988, just four and one-half months after go-ahead.

The camera has an all-reflecting telescope with a 152-millimeter aperture and a focal length of 2,200 millimeters. A built-in filter wheel allows the selection of any one of five imaging wavebands from 0.21 to 0.35 micrometers. The camera has a low light level image intensifier, automatic exposure control and manual controls activated by commands issued to the spacecraft. A data stream of television images is recorded and downlinked to Earth.

Delta Star was launched from Cape Canaveral in March, 1989. The instrument exceeded all performance criteria.

ASAS/ENSCE Project

The All-Source Analysis System/Enemy Situation Correlation Element (ASAS/ENSCE) Project will field a mobile data-processing system for Army and Air Force tactical intelligence in the early 1990s. The system combines computer workstations and communications equipment in field modules. The computers receive large quantities of intelligence data, then prioritize, process and analyze the data for battlefield commanders. Several prototype workstations have been delivered to the Army and used in field exercises with considerable success. The software and hardware configuration of the overall system were developed by JPL and its subcontractors and delivered to the Army in 1989.

This system was tested and successfully used in a field exercise by the Army's III Corps at Fort Hood, Texas. In evaluating the tests, Army officers called ASAS a significant advance in tactical intelligence. The Corps supports its continuing development and eventual integration into Corps and Division Intelligence operations.

SP-100 Project

JPL manages the Space Power-100 Project (SP-100), a program to develop a nuclear-reactor-based power system for space missions for the Department of Energy, under the joint sponsorship of DOE, DOD and NASA. Potential applications include a lunar base and planetary and deep-space exploration missions.

This year the project reached a major milestone: the Nuclear Preliminary Design Review. A review board concluded that progress had been made in critical design areas and that the system contractor should proceed to the final design of subsystems and components.

The first thermoelectric cell using a sapphire insulator and niobium compliant pads was tested. The cell will produce about 25 times the power, in the same volume, as the thermoelectric couple in Galileo's Radioisotope Thermoelectric Generators.

Safety is paramount in the design philosophy of SP-100 and strongly influences its development.

Analysis and Training Systems Project

JPL designed, built and delivered the Joint Exercise Support System (JESS), a computer-based simulation system used in exercises at Army command posts to train corps, division and brigade commanders and staffs in land- and air-battle management.

Many improvements have been incorporated into the system since its initial release. These include simulated combat and combat-support functions, improved communications and networking software, and streamlined workstation software for easier controller use. The system drove exercises about 30 times this year — a dozen by the Army's Battle Command Training Program and another 18 divided among the I, III, V, VII and XVIII Corps.

Real-Time Weather Processor Project

The Real-Time Weather Processor Project completed preliminary design early in the year, finished detailed designs and, in July, conducted a formal critical design review. All hardware systems have been installed

and tested and are operational. Software has been fully coded in the Ada language and integration testing is under way.

Integration testing of the full system was scheduled for completion by the end of 1989. System integration and test will begin in January, 1990, and should be complete by April. JPL will perform Formal System Acceptance Testing for the FAA in May, 1990. A Prototype Test and Evaluation will be conducted by the FAA in July to complete the project.

Software enhancements, including an interconnect device that makes it possible to transmit radar weather data between the processors in FAA aircraft-control facilities, will be developed in 1990.

Voice Switching and Control Systems

As part of the National Aerospace Plan, industry is developing two Voice Switching and Control System prototypes for the FAA. JPL participated by developing a Traffic Simulation Unit that will provide the FAA with a means of testing the systems. This year, the unit was built, integrated, tested and delivered.

EUCOM Command Center Project

As part of its responsibility to upgrade the functional capability of the U.S. European Command Headquarters at Stuttgart, the Army selected JPL to provide certain subsystems and serve as the system integrator for its new command center. JPL has begun to develop and install elements of the system, including local area networks with secure distribution, as well as decision-support and briefing and display subsystems. A JPL field office has been established and staffed in Germany.

Technology Commercialization

JPL is helping to strengthen the nation's economy by accelerating the transfer of JPL-developed technology to industry.

Currently, four efforts make up the Technology Commercialization Program:

- The Technology Affiliates Program at JPL offers U.S. firms quick access to the technology base of the Laboratory so they can enhance their competitive positions in the international market. Once a problem has been identified by a firm and accepted by JPL as appropriate, negotiations are begun. The program is aiming for a 50-firm membership by the end of 1993.

- A Product Development Program, primarily aimed at transferring JPL technology to small businesses, has been ongoing at the Laboratory for three years.

- Under the Small Business Innovative Research program at JPL, an annual multiphase procurement, NASA invites small business firms to submit engineering and science proposals. One criterion is the potential commercial, end-product application of the concept. Approximately 40 tasks were funded in 1989.

- Working under a grant from the State of California and NASA matching funds, JPL is attempting to establish a High-Temperature Superconductivity Consortium for the benefit of U.S. industry. The member firms will pursue the commercial advantages of the technology.

Institutional

ACTIVITIES

Research and development costs for the fiscal year ending September 30 were $1.063 billion, a 2.7 percent increase over the 1988 fiscal year.

Costs for NASA-funded activities rose 6.6 percent to $744 million.

Costs for non-NASA activities amounted to $320 million, a decrease of five percent. The work force increased to 5,892 in fiscal 1988 and decreased to 5,465 in 1989.

Procurement obligations during fiscal 1989 totaled $650 million, one percent less than in fiscal 1988. These outlays included $597 million to business firms. Small businesses received $129 million of the total and minority-owned businesses received $38 million.

NASA Honor Awards

NASA honor awards, which recognize outstanding achievements by individuals and teams, are made annually by NASA. Nominations are made by JPL. The following awards were presented in a ceremony at the Laboratory on June 30.

NASA Outstanding Leadership Medal

- Raymond L. Heacock

NASA Exceptional Scientific Achievement Medal

- William J. Kaiser
- Mario J. Molina
- Douglas B. Nash

NASA Exceptional Engineering Achievement Medal

- Gary C. Bailey

NASA Equal Employment Opportunity Award Medal

- Angel C. Corral

NASA Exceptional Service Medal

- Albert G. Brejcha
- Michael M. Ebersole
- Glenn W. Garrison
- Clifford J. Heindl
- Hubert R. Henry
- Howard L. McCallon
- Harry Press
- Alex Shumka
- Robert L. White

NASA Public Service Award Medal

- Allan Bailey

NASA Group Achievement Award

- Aerospace Resistor Failure Investigation Team
- Balloon-Borne Laser In-Situ Sensor Team
- Joint Exercise Support System (JESS) Development Team
- Mark III Hypercube and Applications Project Team
- 64-Meter to 70-Meter Antenna Extension Project Team
- Space Flight Operations Center (SFOC) Development Team

NASA Public Service Group Achievement Award

- 64-Meter to 70-Meter Expansion Team

Educational Outreach

JPL's Educational Outreach program, part of the Public Education Office, works in three areas:

- teacher education and training
- the Teaching Resource Center
- materiel development

The main thrust of teacher education is a program called the Comfortable Approach to Teaching Science (CATS), which is operated by JPL in partnership with California State Polytechnic University, Pomona, and is funded by the National Science Foundation. CATS, which is designed to create high-caliber elementary-school science teachers, is in its third year, and professional evaluation is high. This year, CATS was expanded to add six Native American teachers from Window Rock, Arizona, under JPL's Native American Initiative and six teachers from the University of the District of Columbia under JPL's Initiative for Historically Black Colleges and Universities (HBCUs). The Window Rock School District modified its curriculum to place greater emphasis on science and mathematics because of the program.

A Teaching Resource Center, established as part of the Outreach program, serves national and international education communities. This year, more than 1,000 teachers visited the center and more than 200,000 others were served by mail. The center developed packages on the Magellan, Voyager and Galileo flight projects for teachers of students in kindergarten through Grade 12. As part of the center program, which is in accord with major science and mathematics textbooks used in the United States, computer-based teaching material, filmstrips and videos were distributed.

JPL Educational Outreach personnel will continue to interact with other members of the educational community, including the California Department of Education, school districts, universities and national education agencies, to develop new methods for training teachers, new teaching strategies and curriculum materials in math and science.

Initiatives in Minority Education, Hiring and Research Grant Awards

The Laboratory continued to assure equal opportunity for all employees, to increase the available pool of minority scientists and engineers and to promote research at universities and colleges with significant minority enrollment. The Initiative for Historically Black Colleges and Universities was enacted in response to an Executive Order encouraging government agencies to conduct research at predominantly Black educational institutions and to offer them educational support. A similar effort for Native Americans, also voluntary, was begun; it focuses on education in engineering and science.

The HBCU Initiative completed its first year at the close of 1989. NASA and the White House HBCU Initiative Office consider it a model of its kind. The program has two themes: The first focuses on research, the second on human interaction. Research activities include grants to HBCUs for work in areas of interest to JPL. Human interactions range from those built into programs that predate the initiative but have complementary aims, such as JPL summer employment and cooperative education programs, to the Minority Fellowship Program and Operation Pipeline.

Four research grants, funded by NASA, are in place with Central State (Wilberforce, Ohio), Jackson State (Jackson, Mississippi) and Tuskegee (Tuskegee, Alabama) Universities and the Atlanta University Center, Inc. (Atlanta, Georgia). To improve the Laboratory's flexibility, future efforts will be funded through contracts with educational institutions. New research proposals are in process; one calls for transferring special equipment and computer software to Jackson State University for a research program in scientific visualization.

The Minority Fellowship Program allows minority employees at JPL to pursue college degrees under a full-tuition, full-salary, full-time program. The program is designed to help participants to enter jobs in which minorities are underrepresented. It is the first of its kind in NASA. Three Fellows are pursuing degrees at Tuskegee, Alabama A&M University (Normal, Alabama) and Howard University (Washington, D.C.).

Operation Pipeline will increase the number of Black students in science and engineering by the early selection and development of students from primary schools. This year, six elementary-school teachers from Washington, D.C., were included in the CATS program, in cooperation with the University of the District of Columbia. In addition, a Memorandum of Understanding was signed with a JPL systems contractor, OAO Corporation, to provide undergraduate scholarships for Black students to attend HBCUs. The first two were selected from a local high school and will receive tuition and living allowances to attend Howard University.

As part of the HBCU effort, Dr. Michael Spencer of Howard University was named a Distinguished Visiting Scientist. Dr. Kofi Apenyo of JPL's Information Systems Division is on loan to Atlanta University Center to teach and do research in computer science.

The HBCU program is a cooperative effort by JPL's University Affairs Office, Office of Technical Divisions, Office of Administrative Divisions and Affirmative Action Program Office.

NASA, JPL and Northern Arizona University developed a Native American Initiative to recruit, retain and graduate greater numbers of Native Americans in engineering and science. The effort is a response to the shortage of engineering and science talent and the underrepresentation of Native Americans in those areas. Twenty students received Sacred Mountain Scholarships, sponsored by NASA, to give each strong educational and financial support, as well as professional affiliation with scientists and engineers of NASA and JPL. When they graduate in 1993, the students will increase the annual number of Native Americans graduating in engineering and science and act as role models to increase the number of Native American graduates.

As part of JPL's commitment to the outreach for Native Americans in science and engineering, the Chairman of the Navajo Nation, the Chairman of the Hopi Nation and 20 Native American students (including Sacred Mountain Scholars) took part in the Voyager–Neptune encounter. The visit was arranged with the dean and staff of Northern Arizona University's College of Engineering and Technology.

Distinguished Visiting Scientist Program

The Distinguished Visiting Scientist Program was established at JPL to promote an interchange between researchers worldwide and our own Caltech and JPL scientists and engineers. The intent of the program is to strengthen and advance areas of research that are of particular interest to JPL by providing a forum for the exchange of ideas, research methods and technical expertise.

The following scientists, who were appointed in 1989, have spent from 2 to 12 months at JPL, offering us their insights and expertise in the indicated fields.

Electronic Materials and Solid-state Devices

Leslie E. Cross
Pennsylvania State University,
Pennsylvania

Electron Transport in Device Structures and Electronic Properties of Materials

Craig L. Davis
University of California,
Santa Barbara, California

Climate Studies

Robert E. Dickinson
NCAR,*
Colorado

Submillimeter Astronomy

Pierre Encrenaz
Observatoire de Paris,
France

Stratospheric Spectroscopy

Crofton B. Farmer
JPL (Retired),
California

* National Center for Atmospheric Research

Charge-coupled Devices

Eric R. Fossum
Columbia University,
New York

Ecology and Climate Change

David Gates
University of Michigan,
Michigan

Optical Image Processing

Nicholas George
University of Rochester,
New York

Visible and Infrared Imaging Spectroscopy

Alexander F. H. Goetz
CIRES† and CSES‡,
Colorado

Superconductivity and Its Applications

James E. Lukens
State University of New York,
New York

Molecular Beam Epitaxy

James W. Mayer
Cornell University,
New York

Optical Interferometry

François Roddier
University of Hawaii,
Manoa, Hawaii

III-V Molecular Beam Epitaxy Growth and Characterization of High Electron Mobility Transistor (HEMT) Structures

Michael G. Spencer
Howard University,
Washington, D.C.

Geodynamics

John M. Wahr
University of Colorado,
Colorado

Senior Research Scientists and Engineers

The position of Senior Research Scientist or Engineer is a special recognition of outstanding individual achievement. Appointees are leaders in their fields, recommended to the position by peer review.

The outstanding researchers listed below are active participants in programs key to the research and institutional goals of JPL. They earned their Senior Research Scientist appointments this year.

Spectroscopy and Low-temperature Research

Daniel D. Elleman

Solid-state Physics

William J. Kaiser

Planetary Gravity Fields

William L. Sjogren

† Cooperative Institute for Research in Environmental Sciences
‡ Center for the Study of Earth from Space

Patents and Technology Utilization

During fiscal 1989, the Office of Patents and Technology Utilization prepared, evaluated and forwarded to NASA reports on 249 inventions and technical innovations resulting from JPL work. The office answered 48,912 requests from industry and the public for technical information on JPL inventions and innovations published in the NASA-sponsored monthly, *Tech Briefs*. During the year, 275 *Tech Briefs* from JPL were published, 42 percent of the NASA-wide total. The U.S. Patent Office issued 61 patents to Caltech and NASA on inventions made at JPL.

During the year, NASA made the following major monetary awards for JPL inventions described in *Tech Briefs*.

- Richard M. Goldstein, Edward R. Caro and Chialin Wu shared $4,500 equally for "Method and Apparatus for Contour Mapping Using Synthetic Aperture Radar."
- Douglas R. Clay, Bruce E. Goldstein, Raymond Goldstein and Marcia Neugebauer shared $4,000 equally for "Ion Mass Spectrometer."
- Houston D. McGinness received $3,000 for "An Improved Suspension System for a Wheel Rolling on a Flat Track."
- Robert C. Clauss and Rex B. Quinn shared $3,000 equally for "Resonance Isolator for Maser Amplifier."
- Wayne H. Kohl received $2,000 for "Distributed Multiport Memory Architecture."
- Ta Tzu Wu received $1,000 for "Demodulator for Binary-Phase Modulated Signals Having a Variable Clock Rate."
- David Trowbridge received $1,000 for "Independent Gain and Bandwidth Control of a Travelling Wave Maser."
- Fabrizio Pollara Bozolla received $1,000 for "Method and Apparatus for Implementing a Maximum-Likelihood Decoder in a Hypercube Network."

Another 466 employees received minimum ($250–$500), nominal ($250–$999), and *Tech Brief* ($150) awards totaling $98,950.

Director's Discretionary Fund

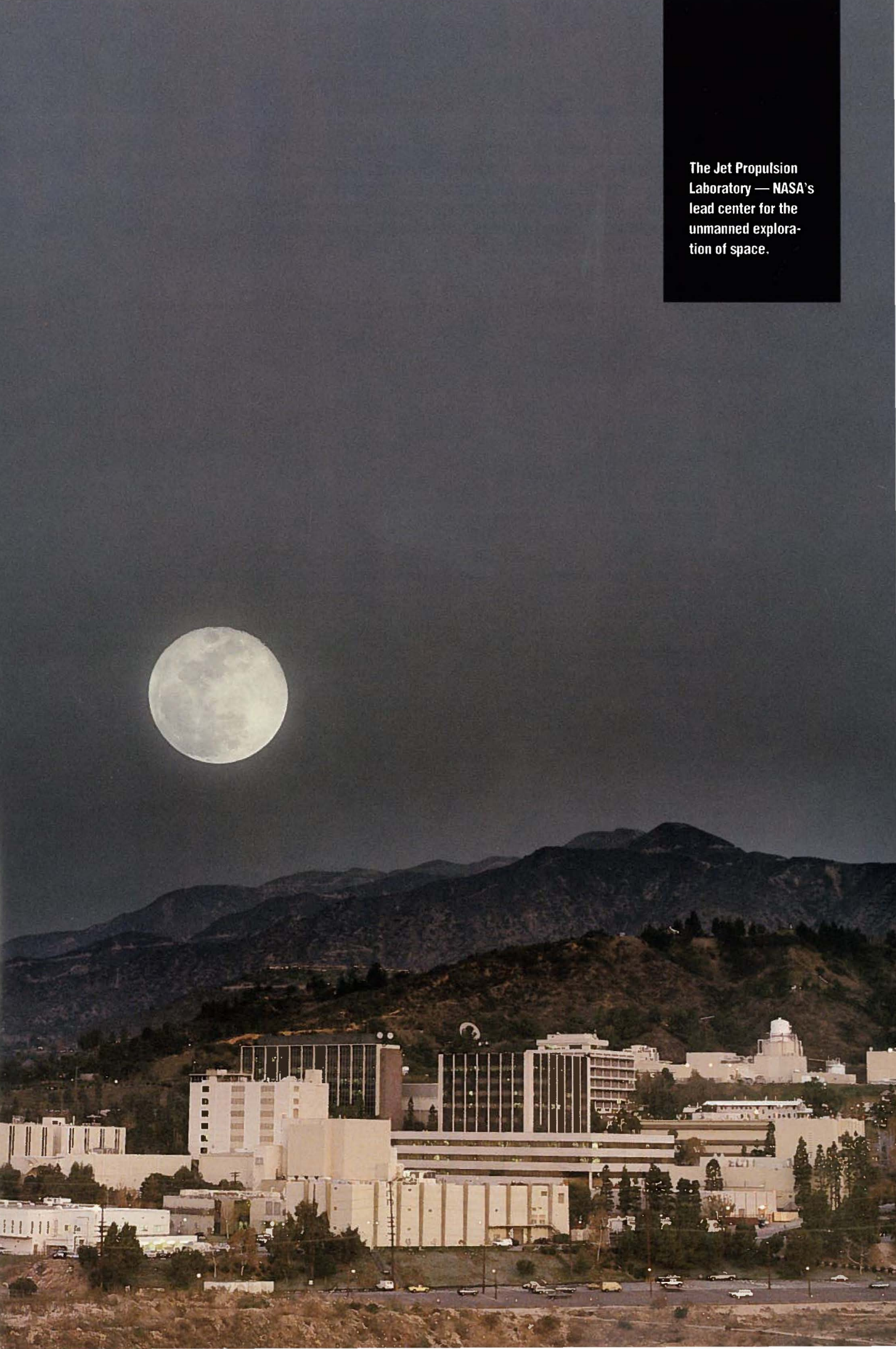
The Director's Discretionary Fund (DDF) is the major resource to support innovative and seed efforts that cannot receive conventional task-order funding. The DDF has $3 million a year.

This year, the fund initiated 13 new research tasks, extended the objectives of seven ongoing tasks and awarded more funds to them, and provided modest assistance to several other support efforts. Proposals eligible for DDF funds cover a broad range of sciences and technologies. Areas of recent emphasis include advanced microelectronics, automation and robotics, infrared- and submillimeter-wavelength technology and detection of planets beyond the solar system.

The DDF recognizes important mutual benefits from collaboration with faculty and students at Caltech and other academic institutions, so cooperation is specifically encouraged. Six principal new and extended tasks funded this year involve university faculty collaborators.

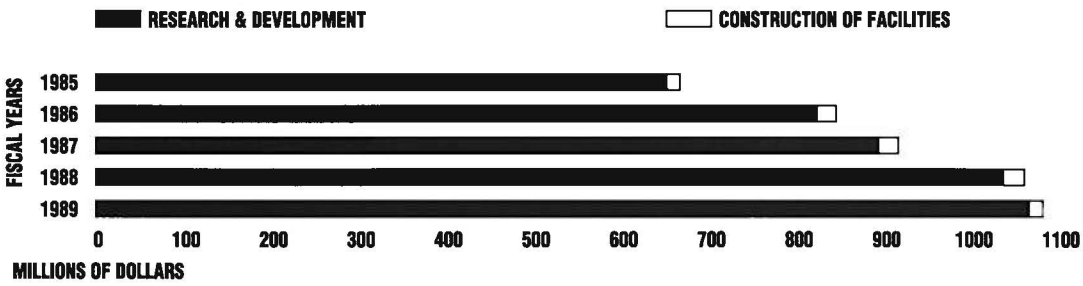
President's Fund

The Caltech President's Fund provides a second, though smaller, source of discretionary funding. Currently at a level of $1 million a year, the fund comes from Caltech and NASA resources on a dollar-for-dollar matching basis and is administered by Caltech. An explicit objective of the President's Fund is to encourage the interest and participation of university faculty and students in JPL research activities and to afford JPL staff members an opportunity for close association with research workers from the university community. The President's Fund provided resources for 11 new collaborative tasks this year.

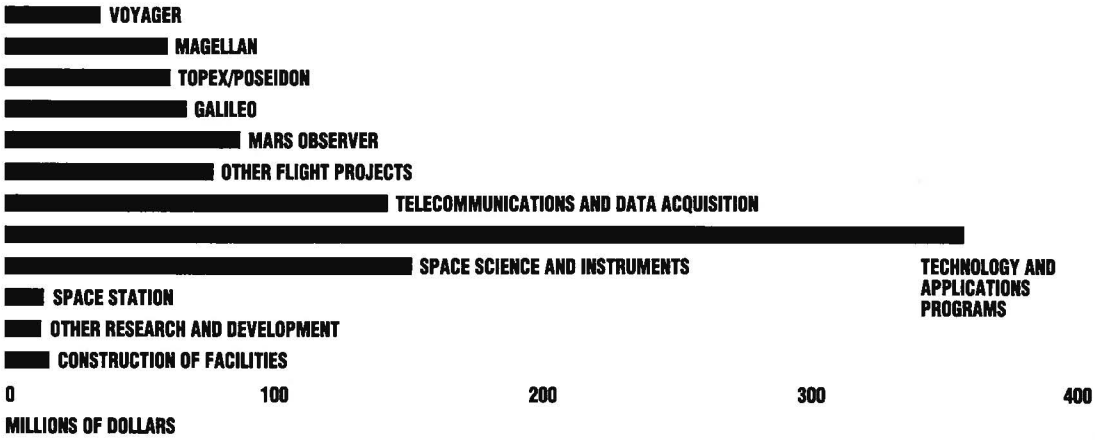


The Jet Propulsion Laboratory — NASA's lead center for the unmanned exploration of space.

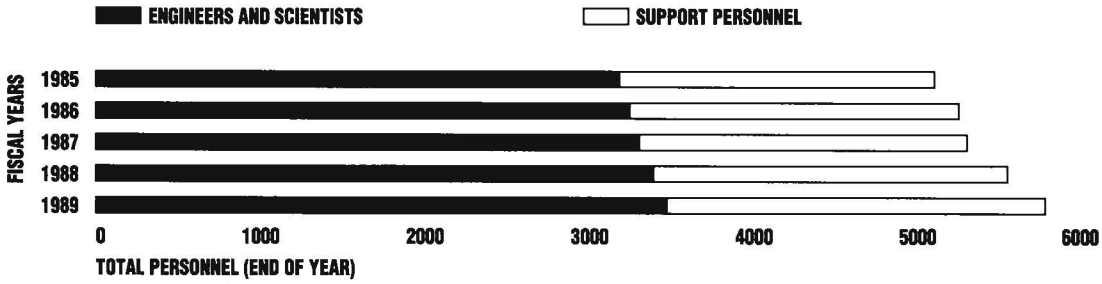
TOTAL COSTS



FISCAL 1989 COSTS



PERSONNEL



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Lew Allen
Director

Peter T. Lyman
Deputy Director

Moustafa T. Chahine
Chief Scientist

Clarence R. Gates
Associate Director

John R. Casani*
Assistant Laboratory Director,
Office of Flight Projects

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Office of Technical Divisions

Duane F. Dipprey
Assistant Laboratory Director,
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Applications Programs

Larry N. Dumas
Assistant Laboratory Director,
Office of Telecommunications
and Data Acquisition

Charles Elachi
Assistant Laboratory Director,
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Donald R. Fowler
General Counsel

W. Eugene Giberson
Assistant Laboratory Director,
Office of Flight Projects

John Heie
Assistant Laboratory Director,
Office of Administrative Divisions

Donald G. Rea
Special Assistant to the Director

William S. Shipley
Assistant Laboratory Director,
Office of Engineering and Review

* **Appointed in September, 1989, to succeed W. Eugene Giberson**

R. Stanton Avery†
Chairman Emeritus, Board of Trustees,
California Institute of Technology;
Founder Chairman,
Avery International Corporation

Harold Brown
Chairman,
Foreign Policy Institute,
The Johns Hopkins University,
School of Advanced
International Studies

Walter Burke
President,
Sherman Fairchild Foundation,
Incorporated

Lee A. DuBridge†
President Emeritus,
California Institute of Technology

Thomas E. Everhart
President,
California Institute of Technology

Charles C. Gates
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