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Press Kit

Project Voyager 2
Jupiter Encounter

RELEASE NO: 79-86

Contents

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CONTENTS (cont'd.)

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VOYAGER 2 TO TAKE JUPITER CLOSE LOOK JULY 9

Just four months after Voyager 1's startling discoveries about Jupiter, its major satellites and the complex Jovian environment, a twin NASA spacecraft, Voyager 2, is homing in for a follow-up close encounter with the giant planet on Monday, July 9.

Voyager 1 began a seven-month Jupiter surveillance on Jan. 6, ending its encounter activities on April 13. Voyager 2 opened its observatory phase on April 25 and will monitor the Jovian system until Aug. 28.

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Both spacecraft will continue on to Saturn, and Voyager 2 may be retargeted there for Uranus.

The dual-spacecraft expedition could span a decade and produce a wealth of new information on as many as 15 major bodies of the solar system.

During its surprise-packed excursion through the Jovian system, Voyager 1 discovered a wispy ring of particles around Jupiter, bolts of lightning and immense auroras in the planet's violently churning atmosphere and towering volcanic eruptions on the satellite Io.

More than 18,000 pictures of Jupiter, the Galilean satellites -- Io, Europa, Ganymede, Callisto and tiny Amalthea -- were obtained with Voyager 1's two-camera imaging system during the 98-day observation period.

Voyager 2's science sequences, partially modified by the findings of Voyager 1, are programmed for nearly 15,000 pictures. At the time of Voyager 2's closest encounter, Jupiter will be 931,360,333 kilometers (572,720,483 miles) from Earth.

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Scientists on the Voyager experiment teams found the various bodies in the Jovian system explored by Voyager 1 do not closely resemble the planets nearer the Sun, nor one another. The wide range of unexpected findings, they determined, is due to both the real differences between the outer and inner systems and to the lack of prior knowledge, the latter due in part to the great distance separating Earth and Jupiter.

Voyager 2 was launched Aug. 20, 1977, from Cape Canaveral, Fla., aboard a Titan-Centaur rocket combination. On Sept. 5, 1977, Voyager 1 was boosted onto a faster, shorter trajectory and moved ahead of Voyager 2 before the end of the year.

At Saturn encounter, the gap between the two Voyagers will be about nine months. Using Jupiter's enormous gravity, the trajectories are curved and the Voyagers accelerated for the Saturn leg of the mission. Voyager 1 will arrive at Saturn in November 1980 and Voyager 2 in August 1981. An option exists for controllers to target Voyager 2's trajectory past Saturn for a January 1986 Uranus encounter.

After completing their planetary missions, both spacecraft will search for the outer limit of the solar wind, that boundary somewhere in our part of the Milky Way where the influence of the Sun gives way to the other stars of the galaxy.

Each Voyager uses 10 instruments and the spacecraft radio system to study the planets, their principal satellites, rings of the planets, the magnetic and radiation regions surrounding the planets, and the interplanetary medium.

The Voyagers are carrying telescope-equipped slow-scan TV cameras, cosmic ray detectors, infrared spectrometer-radiometers, low-energy charged-particle detectors, magnetometers, photo-polarimeters, planetary radio astronomy receivers, plasma detectors, plasma wave instruments and ultraviolet spectrometers.

One-hundred-six scientists make up the Voyager science experiment teams.

The television investigation, probably the most interesting to most people because of the universal appeal of the visual image, will result in at least 50,000 pictures of Jupiter, Saturn, the rings of the planets, 11 of their moons and black space near the planets in a search for new Jovian and Saturnian satellites. Jupiter's thin ring was discovered in one of Voyager 1's black space pictures. Uranus, its recently discovered ring system and one or more moons, also may become targets for the Voyager 2 cameras.

The other Voyager instruments will study the planetary and satellite atmospheres and ionospheres; the magnetospheres of Jupiter and Saturn and the relationships between these regions and the solar wind that streams from the Sun through interplanetary space; and radio signals from Jupiter which, after the Sun, emits the strongest radio noise in our sky. Other objectives include all-sky surveys of interplanetary space and the measurement of cosmic rays which invade the solar system from other regions of the galaxy.

Measurements of Voyager's radio communications waves will provide information on the gravitational fields and atmospheres of the planets and their satellites, the rings of Saturn, and the solar corona.

Jupiter and Saturn are by far the largest planets and together hold in their regimes more than two-thirds of all the moons in the solar system. Jupiter's diameter is 11 times that of Earth and contains more matter than all of the other planets and moons combined. With 13 known moons, four of them the size of small planets, Jupiter is a kind of miniature solar system. Saturn has 10 satellites and a spectacular ring system which appears to be made up of tiny pieces of ice and snow.

Until recently our knowledge of Jupiter and Saturn was rudimentary.

Ground-based studies by optical, infrared and radio astronomy have defined the most basic properties of Jupiter and Saturn and their satellites and hinted at the unique scientific potential of these systems. Even less is known about Uranus and its environs.

In 1973 and 1974, Pioneer 10 and Pioneer 11 made reconnaissance flights to Jupiter. As the spacecraft sped past Jupiter, their instruments began to reveal the complexity of its atmosphere and the extent and strength of the Jovian magnetosphere. (Both spacecraft are still operating. Pioneer 11 will fly close by Saturn in September 1979.) Building on the Pioneer experience, Voyager is the next step in the exploration of the Jovian and Saturnian systems.

Voyager 2 began its observatory phase on April 25 by studying large-scale atmospheric processes on Jupiter and phenomena associated with the relationship between Jupiter's magnetosphere and the large inner moons. From 56 million km (35 million mi.), the first Jupiter pictures by Voyager 2 already exceeded the best resolution with Earth telescopes.

Just as Voyager 1 observations during the approach to Jupiter in January showed dramatic broad-scale changes in the planet from the Pioneer 11 observations four years earlier, Voyager 2 has recorded visible differences in the huge Jovian features in the much shorter term.

Voyager 2 makes its closest approach to the planet at 7:20 p.m. EDT,* July 9 at a distance of about 650,000 km (404,000 mi.) from the visible cloud tops. Activity will reach a peak during the "near encounter" phase, a 40-hour period surrounding closest approach.

In March 1979, Voyager 1's trajectory curved past the planet to a point just 278,000 km (173,000 mi.) above the cloudtops. The greater flyby distance for Voyager 2 results in less radiation exposure and a slower flight to Saturn.

The distance between Jupiter and Earth also varies greatly in the four months separating the two encounters. Voyager 1 was about 250 million km (150 million mi.) closer to Earth at the time of its Jupiter rendezvous on March 5. This is due to the planets' relative positions in their orbits around the Sun. By July 9, Earth will have traveled a distance equivalent to a third of its entire orbit around the Sun.

The trajectory for each spacecraft is unique and was designed for specific observations at both Jupiter and Saturn.

*The spacecraft actually flies closest to Jupiter at 6:29 p.m. EDT, July 9. But if one were able to watch the event from Earth, the eye would see the close encounter 51 minutes, 49 seconds, later -- the time it takes light to travel 931 million km (573 million mi.). The same velocity is true using the Voyager radio to watch the event. Hence, all times listed here are Earth-received times.

The first spacecraft flew past Jupiter just south of the equator, while Voyager 2 makes its Jupiter pass deep in the southern hemisphere.

Voyager 2 will receive a lesser radiation dose than Voyager 1. It will be closest to Europa, Ganymede and Callisto before it reaches the planet; will not have a close encounter with Io; and will remain outside Europa's orbit. First pictures of the planet-size moons will be obtained on June 25, Callisto; June 30, Ganymede; and July 3, Europa. The spacecraft is expected to cross Jupiter's bowshock about July 5 and enter the planet's magnetosphere.

By encountering the Galilean satellites during approach to Jupiter rather than on the outward passage, as done by Voyager 1, the second Voyager will obtain high-resolution photos and other measurements of their opposite sides. Closest approach to Callisto will occur at 9:13 a.m. EDT, July 8 at a range of 215,000 km (133,600 mi.); Ganymede, 4:06 a.m., July 9, 62,000 km (38,600 mi.); Europa, 2:43 p.m., July 9, 206,000 km (128,000 mi.); and Amalthea, 4:53 p.m., July 9, 559,000 km (348,000 mi.).

Some of the Voyager 2 near encounter highlights include:

• The first high-resolution pictures of Europa. Voyager 1 showed Europa to be laced with huge intersecting linear features, even from a range of nearly 2,000,000 km (1,250,000 mi.). Voyager 2 will improve upon the resolution of the March photos of Europa by about a factor of 10.

• Further examination of the thin ring of particles Voyager 1 found circling Jupiter. Voyager 2 will cross the equatorial plane twice -- at 8:00 p.m. EDT on July 8 and again at 9:00 p.m. EDT on July 10. An attempt will be made to obtain a color picture of the ring.

• An Io "volcano watch." The discovery of active volcanism on the Jovian moon Io by Voyager 1 has prompted planning for intensive Io imaging operations shortly after Jupiter closest approach on July 9. Although the trajectory takes the spacecraft to a far greater Io encounter distance (1,130,000 km or 702,000 mi.) than the March encounter (less than 20,000 km or 12,000 mi.), a time-lapse imaging sequence will be executed to provide a possible history of erupting volcanos on the satellite. From 7:30 p.m. EDT, July 9 until 5:30 a.m. EDT, July 10, Voyager 2 remains within 1,215,000 km (755,000 mi.) of Io.

The Voyager 2 trajectory also carries the spacecraft behind Jupiter, relative to Earth and the Sun. As Earth disappears behind Jupiter, then emerges after two hours of occultation, the changes in the signal characteristics of the spacecraft radio link with Earth will give information about the vertical structure of the atmosphere, ionosphere and clouds. As the Sun is occulted by Jupiter, the ultraviolet spectrometer observes the Sun as it moves behind the limb of the planet observing similar scattering effects on sunlight as it penetrates the atmosphere. The Earth occultation experiment begins at 5:20 p.m. EDT, July 10 and continues until 7:08 p.m. EDT. Sun occultation extends from 8:07 p.m. EDT, until 9:30 p.m. EDT.

(At Saturn, Voyager 1 will conduct Sun and Earth occultation experiments with the planet, the moon Titan and Saturn's rings. If Voyager 2 goes on to Uranus, only occultation of the planet will be possible.)

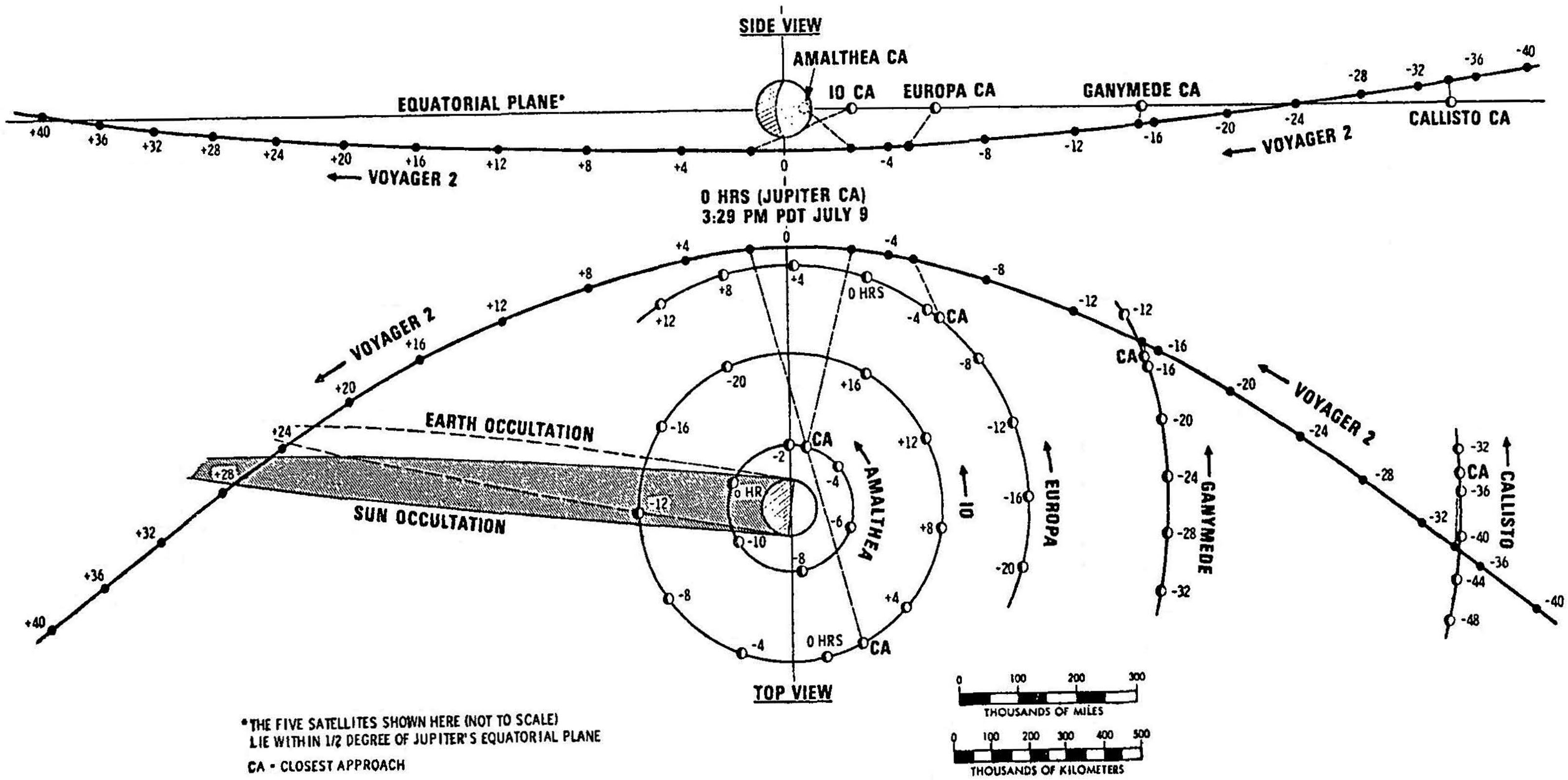
NASA's Office of Space Science has assigned project management and operation of the Voyager missions to the Jet Propulsion Laboratory (JPL), Pasadena, Calif., which is managed for NASA by the California Institute of Technology. JPL designed, assembled and tested the spacecraft, and conducts tracking, communications and mission operations. JPL operates the Deep Space Network for NASA's Office of Tracking and Data Systems.

NASA program manager is Rodney A. Mills. JPL project manager is Raymond L. Heacock. Dr. Milton A. Mitz is NASA program scientist. Dr. Edward C. Stone of Caltech is project scientist.

Estimated cost of the Voyager Project, exclusive of launch vehicles, tracking and data acquisition and flight support activities, is $343 million.

(END OF GENERAL RELEASE; BACKGROUND INFORMATION FOLLOWS.)

2 VIEWS OF VOYAGER 2 FLIGHT PAST JUPITER July 7-11, 1979



Two views of Voyager 2's flight past Jupiter between the 7th and 11th of July 1979 show relative positions of the spacecraft and five of Jupiter's moons from 40 hours before (minus) to 40 hours after (plus) closest approach to the planet. In this side view (top), the Voyager spacecraft comes in from right above the equatorial plane of Jupiter. First position is at closest approach (CA) to Jupiter, minus 40 hours. At about CA minus 34 hours, Voyager is looking at its closest approach to Callisto. The circles depicting Callisto and the other satellites show dark sides (night) and sunlit sides. Going to the overhead view (bottom), we see Voyager 2 coming in from the right and crossing Callisto's orbit as the spacecraft flies toward Jupiter. Using the scale to the right and below the planet, measurements can be made in thousands of miles or kilometers. Callisto, for example, is determined to be about 1.5 million km (900,000 mi.) away from the planet. All the Jovian satellites orbit counterclockwise in the equatorial plane of the planet. As the spacecraft continues its flight, it intersects the orbit of Ganymede at about CA minus 15 hours and looking at the side view we see it is now below Jupiter's equatorial plane at a distance of about 50,000 km (30,000 mi.).

VOYAGER MISSION SUMMARY

August 1977 - June 1979

Voyager 2, first of the two Jupiter and Saturn-bound spacecraft launched during the 1977 opportunity, lifted off Complex 14 at Cape Canaveral, Fla., aboard a Titan Centaur launch vehicle at 10:29 a.m., EDT, on Aug. 20, 1977. Liftoff occurred less than five minutes into the window on the first day of the 30-day launch period.

Sixteen days later, an identical spacecraft, Voyager 1, was boosted onto a faster, shorter trajectory which would carry it past Jupiter four months earlier and Saturn nine months earlier than its twin. The second launch was delayed four days when it was not immediately certain that Voyager 2's science boom had fully deployed and locked itself in place. Voyager 1 lifted off at 8:46 a.m., EDT, Labor Day, Sept. 5, 1977.

On Dec. 15, 1977, Voyager 1 had caught up with and passed Voyager 2 at a distance of about 170 million km (105 million mi.) from Earth. Both spacecraft had begun passage through the asteroid belt just a few days earlier -- on Dec. 10 -- Voyager 1 exiting Sept. 8, 1978, and Voyager 2 on Oct. 21. The debris-strewn asteroid belt, which circles the Sun between the orbits of Mars and Jupiter, is about 360 million km (223 million mi.) wide and, at one time, was believed to present a hazard to intruding spacecraft. The Voyagers were the third and fourth spacecraft to make such a crossing, following the early Jupiter reconnaissance flights of Pioneer 10 and 11 in 1973 and 1974.

As many as eight trajectory correction maneuvers are planned for each spacecraft to refine the flight paths and assure the precise arrival times and encounter distances required by the mission. Voyager 1 has executed five maneuvers, the last on March 16, 1979 -- 11 days after Jupiter closest approach. Voyager 2's fourth maneuver is scheduled for June 27, 1979.

Two major engineering problems -- one with each spacecraft -- arose during the long cruise phase of the mission.

During a calibration of Voyager 1's scan platform on Feb. 23, 1978, the platform's azimuth gears slowed and stalled to a standstill. During the next three months, engineers determined that a small amount of soft, pliable debris -- apparently retained in the unit during its assembly -- had found its way into the gears. By maneuvering the platform through the problem area, the bits of debris were crushed apparently by the gears, freeing the platform.

Voyager's scan platform, upon which are mounted the planet tracking instruments including the two-camera television experiment, can be rotated on two axes for precision pointing. No problems arose during the rigorous maneuvering of the platform as Voyager 1 made its Jovian system reconnaissance.

Voyager 2's primary radio receiver failed on April 5, 1978, and the spacecraft's computer command subsystem automatically switched in the backup receiver. Unlike the Voyager 1 scan platform problem which has been resolved, Voyager 2's radio emergency remains a concern. Only a single receiver is available to the spacecraft which may be expected to operate through Uranus encounter (January 1986), and it is functioning with a failed tracking-loop capacitor.

The existing receiver can no longer normally follow a changing signal frequency. Telecommunication engineers, however, have developed a technique of determining the frequency at which the Deep Space Network station must transmit commands. This procedure has worked successfully since mid-April, 1978.

Because of the loss of the redundant receiver capability, a backup mission sequence was transmitted to Voyager 2 and stored in the on-board computer. The backup sequence would assure a minimum-science encounter at Saturn in the event ground command capability is lost. The sequence will be updated periodically.

During the long cruise, numerous tests and calibrations have been conducted to allow scientists to evaluate their instruments and the acquired data.

All of the instruments on both spacecraft made measurements during the cruise -- interplanetary magnetic fields, the solar wind and sky scans by the spectral instruments (ultraviolet spectrometer, infrared interferometer and spectrometer and photopolarimeter).

The TV camera system has been exercised throughout the flight. Two weeks after launch, as part of an optical navigation and video recording and playback test, Voyager 1 captured both the Earth and the Moon in the same picture. The two crescent bodies, never before photographed together, were more than 11 1/2 million km (7 million mi.) from the spacecraft camera.

By Dec. 10, 1978, still 85 days and 85 million km (53 million mi.) from Jupiter, Voyager 1's narrow angle TV camera obtained a series of pictures of the planet revealing more detail than the very best ground-based telescopic photographs. Only a few Jovian disk images obtained by Pioneer 10 in December 1973 and Pioneer 11 in December 1974 during their final 24 hours of approach to the planet exceed the resolution in the distant Voyager pictures.

The December photos as well as others obtained during periodic camera calibrations have shown dramatic changes in the visible appearance of Jupiter during the past four years. These broad-scale differences in the huge features of the planet have been observed also by Earth-based astronomers.

Voyager 1's Jupiter observatory phase, that segment of the mission when all science activity was directed toward the planet, its satellite system and the Jovian environment within the solar system, began on Jan. 4, 1979, with the spacecraft 61 million km (38 million mi.) from Jupiter and continued through the end of the month.

Activities during the 26-day period were designed to provide scientists with a long-distance, long term look at the entire Jovian system and Jupiter's large-scale atmospheric processes in preparation for near encounter operations on March 4 and 5.

The narrow-angle television camera recorded four images, each through a different color filter, every two hours -- the time it takes Jupiter to rotate 72 degrees -- providing a "zoom" effect at five selected longitudes.

The pictures obtained at one of the five longitudes -- that which centers the Great Red Spot on the face of the planet -- were assembled into a time-lapse film which shows the complexity of the Jovian atmosphere in the region of the huge feature.

During a four-day period beginning Jan. 30, the narrow-angle camera took a picture of Jupiter every 96 seconds using three color filters. Some 3,500 images are being processed into a color film record of the planet's rapid rotation with a new color image each 3 degrees for 10 full Jupiter days. A two-rotation segment has been transferred to motion picture film.

Despite the intense radiation environment -- perhaps 100 times that which would be lethal to humans -- only two problems arose with Voyager 1's sensitive electronics. Circuitry in the photopolarimeter, which had experienced erratic analyzer wheel operation during Earth-to-Jupiter cruise, failed about six hours before closest approach to Jupiter. Even this failure may not be due to radiation. High accuracy photometry, which would have provided the best data on cloud heights and cloud particle size and shape, was lost. The instrument was turned off and it is doubtful that it will be operable at Saturn.

A brief loss of synchronization between two spacecraft computers occurred at the peak of radiation buildup and resulted in the smearing of some of the Io and Ganymede images. The timing reference between the two systems was reset when the radiation intensity diminished.

Voyager 1 recorded five crossings of the bowshock as Jupiter's magnetosphere expanded and contracted under varying pressure of the solar wind. The wind crossing occurred Feb. 28 at about 6,000,000 km (3,800,000 mi.) from the planet. The final crossing, on March 2, was at 3,600,000 km (2,100,000 mi.).

Although Voyager 1's encounters with Jupiter's inner moons occurred after the spacecraft passed the planet, long-range satellite observations began some two weeks earlier -- Callisto on Feb. 18, Ganymede on Feb. 25, Europa on March 1, Io on March 2 and tiny Amalthea, closest to Jupiter, on March 4.

On March 4, just 17 hours before closest approach, Jupiter's ring was photographed half-way between Amalthea's orbit and the planet's cloudtops. The very long exposure (11 minutes, 12 seconds) was planned for the brief period when Voyager crossed the equatorial plane of Jupiter.

Voyager 1 reached its closest point to Jupiter at 7:05 a.m., EST (spacecraft time) on March 5 at an altitude of 278,000 km (173,000 mi.) above the cloudtops. Distance from Earth at that moment was 679,675,000 km (422,330,000 mi.) or 37 43 seconds, light time. Voyager's radio signal radiated at closest approach reached the Deep Space Network station in Canberra, Australia, at 7:42 a.m., EST.

Jupiter's enormous gravity accelerated the spacecraft to 135,000 km/hr (84,000 mph). The velocity enables Voyager 1 to cross paths with Saturn at a pre-selected time and range some 20 months later.

Encounters with the Galilean satellites occurred on the outbound leg: within 19,000 km (11,800 mi.) of Io at 10:51 a.m., EST, on March 5; Ganymede, 112,000 km (69,600 mi.), at 9:53 p.m., EST, March 5; and Callisto, 124,000 km (77,000 mi.) at 12:47 p.m., EST, on March 6.

Although Voyager 1 came within 732,000 km (455,000 mi.) of Europa, final images were obtained at a far greater range -- 1,800,000 km (1,119,000 mi.) It remains for Voyager 2 to acquire the high-resolution images of Europa for determination of the nature of the intriguing pattern of linear features scarring the face of the satellite.

Voyager 1's close passage at Io was designed to send the spacecraft through the so-called Io flux tube, a magnetic link between the moon and the planet where charged particles spiral along the Jovian magnetic lines of force. Voyager's fields and particles instruments measured an electric current across the flux tube at five million amperes, some five times greater than predicted.

Voyager did not penetrate the flux tube, because the greater-than-predicted current had deflected the flux tube from its expected location.

The Voyager 1 trajectory also carried the spacecraft behind Jupiter, relative to Earth and the Sun. As Earth disappeared behind Jupiter, then emerged after two hours of "occultation," the changes in the signal characteristics of the spacecraft radio link with Earth provided information about the vertical structure of the atmosphere, ionosphere and clouds. As the Sun was occulted by Jupiter, the ultraviolet spectrometer observed the Sun as it moved behind the limb of the planet observing similar scattering effects on sunlight as it penetrated the atmosphere. The Earth occultation experiment began at 11:14 a.m., EST, March 5, and continued until 1:20 p.m., EST; Sun occultation extended from 12:07 p.m., EST, until 2:24 p.m., EST.

Though hundreds of images of Io had already been obtained and had already received cursory examination, active volcanism on the satellite was first identified with a photo taken March 8 not for geological study, but specifically for optical navigation purposes. A special overexposure of the Io crescent with a known pattern of stars, acquired three days after encounter, revealed a plume of gases and solid particles above the moon's limb. Further examination of earlier photos and other Io observations subsequently led to the identification of seven actively-erupting volcanos.

Other phenomena observed by Voyager 1 as it looked back at the receding planet included auroras at Jupiter's north pole and superbolts of lightning crackling in the upper atmosphere on the dark side.

Voyager 1 concluded its Jupiter observations on April 13, 40 days after closest approach. The spacecraft and its instruments will remain at a low-level of operation throughout Voyager 2's Jovian system activities and will gather and record interplanetary measurements along the billion-mile flight path to Saturn.

VOYAGER 1 SCIENCE RESULTS

Voyager 1's encounter with Jupiter and its major satellites has provided evidence of an entirely new set of phenomena in that "mini-solar system."

Scientists are now beginning to understand that very important physical, geological and atmospheric processes are going on -- in the planet, satellites and magnetosphere -- that are new to observers.

Discovery of active volcanism on Io was probably the greatest surprise -- and may turn out to have the most far-reaching effects. It is likely that activity on Io may be affecting the entire Jovian system. Io appears to be the source of matter that pervades the Jovian magnetosphere. Sulfur, oxygen and sodium, apparently erupted by the satellite's many volcanoes, were detected by Voyager 1 as far away as the outer dege of the magnetosphere. Particles of the same material were detected inside Io's orbit, where they are accelerated to greater than 10 per cent of the speed of light.

It is clear to scientists that a comparision of data from Pioneer 10 and Voyager 1 shows that something has changed in the five and one-half years since the first spacecraft reached Jupiter.

It is not clear just what the meaning is of those changes nor what has caused them. The changes may be related to Ionian activity.

It is difficult, however, to imagine that Io's volcanoes were not erupting when Pioneer 10 flew past in December 1973. Voyager scientists say it is also difficult to believe that Pioneer 10 instruments failed to see the magnetospheric concentrations of sulfur detected by Voyager 1. Pioneer 10 apparently saw no sulfur.

The following is a summary of the more important Voyager 1 science results:

Jupiter's Atmosphere

- Atmospheric features of broadly different sizes appear to move with uniform velocities. That suggests to scientists that mass motion (movement of material) and not wave motion (movement of energy through a relatively stationary mass) is being observed.

● Rapid brightening of features in the atmosphere was observed, followed by spreading of cloud material. That is probably the result of disturbances that trigger convective (up and downwelling) activity.

● A belt-zone pattern of east-west winds was seen in the polar regions, roughly similar to the pattern seen in the more temperate areas. Previous investigations led scientists to believe the polar regions are dominated by convective upwelling and downwelling. Voyager 1 indicates they are not.

● Material associated with the Great Red Spot moves in a counterclockwise (anticyclonic) direction. The material appears to have a rotation period of about six days.

● Smaller spots appear to interact with the Great Red Spot and with each other.

● Auroral emissions (similar to Earth's "northern lights") were observed in Jupiter's polar regions. They have been seen in both ultraviolet and visible light. The ultraviolet auroral emissions were not present during the Pioneer 10 encounter in 1973.

● Cloud-top lightning bolts, similar to superbolts in Earth's high atmosphere, were detected.

● The atmospheric temperature at 5 to 10 millibars (1/200th to 1/100th Earth's surface atmospheric pressure) is about 160 degrees Kelvin (-171 degrees Fahrenheit). There appears to be an inversion layer -- a warm region above a colder layer -- at the 35-millibar level. (Earth's surface pressure is approximately 1,000 millibars.)

● Voyager 1 observed an ionospheric temperature that changed with altitude, reaching about 1,100 K (1,520 F). That also was not observed by Pioneer 10, and Voyager scientists believe they are witnessing large temporal or spatial changes in the ionosphere of Jupiter.

● Helium in the upper atmosphere was measured. Its percentage compared to hydrogen is important to scientists to understand the composition and history of the atmosphere -- and indirectly, the primordial cloud out of which the Sun and planets formed. There are about 11 per cent as many helium atoms as hydrogen molecules.

● The atmospheric temperature above the Great Red Spot is substantially colder than in surrounding regions.

Satellites and Ring

• Seven currently active (erupting) volcanoes, probably driven by tidal heating, have been positively identified on Io. Many more are suspected. Plumes from the volcanoes extend up to 250 km (155 mi.) above the surface. The material is being ejected at rates up to 3,600 km/hr (2,200 mph). By comparison, ejection velocities have been measured at Mount Etna, one of Earth's most explosive volcanoes, at 180 km/hr (112 mph). The volcanism on Io is apparently associated with heating of the satellite by tidal pumping. Io's orbit is perturbed by Europa and Ganymede, and then Io is yanked back again by Jupiter. That action causes tidal bulging as great as 100 meters (330 feet), compared with typical tidal bulges on Earth of 1 m (3 ft.)

• Voyager 1 measured the temperature of a large hot spot on Io that is associated with a volcanic feature. While the surrounding terrain has a temperature of -138 C (-216 F), the hot spot's temperature is about 20 C (68 F). The hot spot may, some scientists believe, be a lava lake, although the temperature indicates that the surface of the spot is not molten; it is, at least, reminiscent of lava lakes on Earth. (A lava lake is formed by ejection of magma and is directly connected to the magma source. "Islands" in the lake are composed of blocky plastic lava called epimagma, while the lake itself is composed of thin fluid material called pyromagma.)

• Europa displays a large number of intersecting linear features in the distant, low-resolution photos from Voyager 1. The features may be caused by crustal rifting (tectonic) processes. The closer, higher-resolution photos from Voyager 2 are expected to provide additional information. There is a possibility that Europa may be internally active due to tidal heating at a level one-tenth or less than that on Io.

• Ganymede shows two distinct types of terrain -- cratered and grooved. That suggests to scientists that Ganymede's entire, ice-rich crust has been under tension from global tectonic processes.

• Callisto has an ancient, heavily cratered crust, with remnant rings of enormous impact basins. The basins themselves have been erased by the flow of the ice-laden crust -- to the degree that almost no topographical relief is apparent in Voyager 1's high-resolution images.

- Amalthea has an elliptical shape: it is 265 km (164 mi.) by 140 km (87 mi.). Amalthea is about 10 times bigger than Mars' larger satellite, Phobos.

- A ring of material was discovered around Jupiter. The ring's outer edge is 128,000 km (79,500 mi.) from the center of the planet, and is no more than 30 km (18.6 mi.) thick. Thus Jupiter joins Saturn and Uranus as one of the ringed planets. (Since the Voyager 1 encounter, the ring's existence has been verified by ground-based observations.)

Magnetosphere

- An electric current of about 5 million amperes was detected in the flux tube connecting Jupiter and Io. That was five times stronger than the current predicted before Voyager 1's arrival. The spacecraft did not fly through the flux tube, as had been planned, since the increased current had twisted the flux tube 7,000 km (4,300 mi.) from the expected location.

- Voyager 1 detected ultraviolet emissions from doubly and triply ionized sulfur and from doubly ionized oxygen. Since Pioneers 10 and 11 did not detect these same emissions, that indicates a hot plasma was not present in 1973-74 but was seen by Voyager 1. The sulfur apparently originates in Io's volcanoes.

- Plasma electron densities in some regions of the Io torus exceeded 4,500 per cubic centimeter.

- A somewhat cooler plasma, rotating with Jupiter, was discovered inside six Jupiter radii (428,000 km or 266,000 mi.) from the planet. Ions of sulfur, oxygen and perhaps sulfur dioxide were detected.

- High-energy trapped particles were also detected in the same region near Jupiter. They had significantly enhanced abundances of oxygen, sodium and sulfur.

- A hot plasma was measured near the Jovian magnetopause (the outer edge of the magnetosphere), composed mostly of protons, oxygen and sulfur.

- Kilometric radio emissions were detected coming from Jupiter. The emissions, in the frequency range from 10 kilohertz to 1 megahertz, may result from plasma oscillations in the Io torus.

- Plasma flows were detected in the dayside outer magnetosphere; they rotate with the planet at a 10-hour period.

- Voyager 1 saw evidence of the transition from closed magnetic field lines to a magnetotail of the anti-solar side of Jupiter. Although such a magnetotail was never in serious question, its existence never had been detected.

- Whistler emissions were detected that are interpreted as lightning whistlers from the Jovian atmosphere.

- Voyager also measured radio spectral arcs (from about 1 megahertz to more than 30 megahertz) in patterns that correlate with Jovian longitude.

JUPITER SCIENCE OBJECTIVES

Voyager 1's science experiments at Jupiter fall into three broad classifications:

- Jupiter's atmosphere and its dynamics including lightning, studied by:
  - Imaging;
  - Infrared interferometer spectrometer and radiometer;
  - Ultraviolet spectrometer;
  - Photopolarimeter;
  - Radio science.
- Five of the satellites of Jupiter - Io, Europa, Ganymede, Callisto and Amalthea, studied by:
  - Imaging;
  - Infared interferometer spectrometer and radiometer;
  - Ultraviolet spectrometer;
  - Photopolarimeter.
- Jupiter's magnetic field and radiation environments and its interaction with the solar wind and the satellites, studied by:
  - Plasma;
  - Low-energy charged particles;
  - Cosmic ray;
  - Magnetometers;
  - Planetary radio astronomy;
  - Plasma wave;
  - Radio science;
  - Ultraviolet spectrometer;
  - Photopolarimeter.

Magnetic Fields Investigation

The magnetic field of a planet is an externally measureable indication of conditions deep within its interior. Four magnetometers aboard Voyager 1 gather data on the planetary magnetic fields at Jupiter, the satellites, solar wind and satellite interactions with the planetary field, and the interplanetary (solar) magnetic field.

The magnetometers reveal a great deal about the interplanetary medium -- the tenuous, ionized and magnetized gas that forms the solar wind.

The Sun constantly emits electrically charged particles -- mostly protons and electrons -- from the ionization of hydrogen. Those particles are in the fourth state of matter, called plasma (the other three states are solid, liquid and neutral gas). The plasma is of extremely low density (less than 100 particles per cubic centimeter); it fills all interplanetary space and forms the solar wind. Because it is ionized, the solar wind is an electrically conducting medium.

The solar wind is deflected by planetary magnetic fields (such as the Earth's and Jupiter's), and streams around and past the obstacle, confining the planet's magnetic field to a region called the magnetosphere.

The shape of Jupiter's magnetic field is not very well understood. Because Voyager 1 and Voyager 2 arrive four months apart, scientists can make long-term, continuous measurements of the solar wind near Jupiter and of the magnetosphere itself as it changes size and shape under changing pressure of the solar wind.

Jupiter's magnetic field is shaped much differently from Earth's. The planet's rapid rotation rate may be one explanation (the magnetic field rotates with the planet). At great distances from the planet, the magnetic field lines appear to form a spiral structure.

Interactions between the large satellites and Jupiter's magnetosphere depend on the properties of the satellite and its ionosphere, on the characteristics of the field-and-particle environment and on the properties of Jupiter's ionosphere.

A strong factor in the choice of Voyager 1's flight path was the desire to observe the region of interaction between Jupiter and the satellite Io, called the flux tube. The flux tube is defined by the magnetic lines of force from Jupiter that pass through Io. An electric current of 5 million amperes was measured in the flux tube by Voyager 1, producing dramatic effects.

Voyager 1 passed near the Io flux tube about 20,000 km (12,750 mi.) from the satellite. It was targeted to fly through the tube, but missed it because the stronger-than-expected current twisted the flux tube away from its anticipated location. (A current of 1 million amperes had been predicted.)

Jupiter emits decametric radio bursts (from 10 to 40 megahertz) that are probably connected with plasma instabilities within Jupiter's ionosphere. Io appears to have some influence on those radio emissions by way of the flux tube.

Cosmic Ray Investigation

Cosmic rays are the most energetic particles in nature and are atomic nuclei, primarily protons and electrons. They comprise all natural elements known to man. Over certain energy ranges and at certain periods of time, the content of cosmic rays is similar in proportion to that of all the matter in the solar system. Generally, however, their composition varies significantly with energy, indicating to scientists that a variety of astrophysical sources and processes contributes to their numbers.

Cosmic rays may, as we search for their origins, tell much about the solar system and its origins and processes. Cosmic rays are material samples of the galaxy and can tell us much about how stars synthesize the various elements in their interiors.

Voyager's cosmic ray instrument concentrates on the energy content, origin and acceleration process, life history and dynamics of cosmic rays, and measured the anomalous oxygen, sodium and sulfur inside the orbit of Io.

Planetary Radio Astronomy

One discovery of the planetary radio astronomy experiment (along with several other instruments) is lightning in Jupiter's atmosphere; lightning has been postulated as a catalyst for the formation of life. Together with the plasma wave experiment and several optical instruments, Voyager 1's planetary radio astronomy demonstrated the existence of lightning on Jupiter. Voyager 2 will continue those studies.

A current theory says that lightning in an atmosphere of hydrogen, methane, ammonia and water can set off reactions that eventually form complex organic molecules.

The planetary radio astronomy measures radio emissions from Jupiter in the low-frequency range from 20 kilohertz to 40.5 megahertz. (AM radio stations broadcast at frequencies between 550 and 1,600 kilohertz.) Scientists say emissions ranging in wavelength from less than one centimeter to thousands of meters can result from wave-particle-plasma interaction in the magnetosphere and ionosphere of Jupiter.

While scientists are sure Io plays an important role in the pattern of Jupiter's radio emissions, this big satellite appears not to have anything at all to do with Jupiter's 1 megahertz emissions, at least in the low-frequency ranges. Preliminary results from Voyager 1 data show no correlation between 1 megahertz bursts and Io in the low frequencies.

Infrared Interferometer Spectrometer and Radiometer

Jupiter, with its colorful and distinctive bands of clouds, has puzzled scientists for centuries: Why are the bands (light zones and dark belts) so well defined? What gives them their color? How deep is the cloud cover? What lies beneath it?

Voyager's infrared interferometer spectrometer and radiometer is designed to probe the atmosphere for answers to those questions. It also explores Jupiter's satellites.

Each chemical compound has a unique spectral character. By measuring the infrared and visible radiation given off and reflected by an object, scientists can learn a great deal about atmospheric gas composition, abundance, clouds, haze, temperatures, dynamics and heat balance.

Hydrogen, deuterium (heavy hydrogen), helium, methane, ammonia, ethane and acetylene have been identified in Jupiter's atmosphere above the upper clouds. Deeper measurements -- through holes in the clouds -- indicate the presence of water, deuterated methane, germane and phosphene.

Once the composition of an atmosphere is determined, knowledge of its absorption properties can be used to measure the temperature at various depths as it changes with pressure.

Jupiter's clouds appear to form well-defined layers in the atmosphere; above the clouds is a tenuous haze. The ease with which those structures absorb or emit infrared radiation and light permits determination of cloud depth and state (i.e., ice or aerosol).

Jupiter's bands have been observed for centuries. Why have they persisted so long? Most theories explain the bands as a result of convection -- circulation up and down -- of warm and cool air. Jupiter appears to have an internal heat source, and a relation appears to exist between cloud color and temperature in the zones and belts.

Satellite composition and temperature maps are being constructed using the distinctive spectral signatures of ices and minerals found on the surfaces. The infrared instrument also measured several hot spots on Io related to volcanic activity. Together with pictures of the satellites, the maps are used to study the geology and evolution of the bodies, and how they differ with distance from Jupiter.

<u>Photopolarimeter</u>

By studying the ways sunlight is scattered by the atmosphere of Jupiter and the surfaces of its satellites, Voyager's photopolarimeter can answer many questions about those bodies.

Eight wavelengths in the ultraviolet and visible regions of the spectrum (from 2,350 to 7,500 Angstroms) are measured in intensity to determine the physical properties of the atmosphere of Jupiter, the satellite surfaces and the sodium cloud and sulfur torus of Io.

The photopolarimeter examines both the large-scale and micro-scale structure and properties of the clouds of Jupiter. It measures the vertical distribution of cloud particles, and the particle size and shape, and provides inferences on atmospheric composition.

Similar studies define the structures of major planetary features such as the Great Red Spot, zones and belts. The photopolarimeter searches for evidence of crystalline particles in those features and will gather data on the effects of scattering and absorption of sunlight by the particles.

Jupiter's atmosphere will be compared with others that are already fairly well known -- those of Earth and Venus.

The photopolarimeter studies the density of atmospheres at the satellites (if atmospheres exist there), the texture and composition of the surfaces, the bulk reflectivity and the sodium cloud and sulfur torus of Io.

The spectral reflectivity of a body can help determine its surface composition, whether it is rock, dust, frost, ice or the remains of meteors.

In 1973 scientists first suggested that gases escaping from a satellite atmosphere might not be able to escape the gravity field of the main planet and would form donut-shaped clouds around the planet.

That kind of cloud has been found in the vicinity of Io; it is composed primarily of sodium and ionized sulfur, oxygen and perhaps sulfur dioxide.

Io appears to be covered with evaporite salts, including atomic hydrogen, sodium, potassium and sulfur and perhaps, magnesium, calcium and silicon. Materials appear to be spewed out in near-continuous volcanic eruptions and may be sputtered off Io's surface by charged atomic particles trapped in Jupiter's strong magnetic field.

Radio Science

The radio that provides tracking and communication with Voyager also explores the planets and space.

Changes in frequency, phase, delay, intensity and polarization of radio signals between spacecraft and Earth provide information about the space between the two and forces that affect the spacecraft and alter its path.

When the spacecraft moves behind a body as viewed from Earth (called occultation), radio waves coming from the spacecraft pass through the ionosphere and atmosphere on their way Earthward. Changes in signal characteristics during those events give information about the vertical structure of the ionosphere, atmosphere, clouds and turbulence.

Imaging

Astronomers have photographed Jupiter since at least the late 1800s, starting first at Lick Observatory and continuing later at Lowell Observatory. Until about 1960, photography of Jupiter was conducted in a more-or-less random way: if the night was clear and some time was available at the telescope and someone was inclined, he might take a picture of Jupiter; the next opportunity might not come for weeks.

That will work for an object like the Moon or Mars, but Jupiter is all weather -- every observation ever made of the planet is of weather and weather patterns; there is nothing else to see.

Random photos of Jupiter amount to little more than taking an occasional picture of some clouds somewhere on Earth and then trying to forecast the weather. It doesn't give you much good information.

In the early 1960s, astronomers began a new routine -- an observation program in which they took pictures of Jupiter every hour all night long, on every night that was good for observing. Many of those pictures were of poor quality -- far from the textbook examples.

But they contain a wealth of information. In 10 years astronomers learned more about Jupiter than they had learned in all the time that preceded the new program.

They discovered, for example, that there is a periodic oscillation in the movement of Jupiter's Great Red Spot; the spot moves slowly around Jupiter (it isn't anchored at one longitude). But the spot does not wander smoothly; it moves, then stops, then moves again. These oscillations occur almost precisely every 90 days.

Another discovery: The Great Red Spot is not a smooth blemish, but is a giant vortex (it has been compared with a hurricane on Earth). Observers do not know if the vortex phenomenon exists all the time or only occasionally.

A third example: There appears to be a semipersistent high-velocity jet stream at a constant latitude in Jupiter's northern hemisphere. The current flows in the same direction as Jupiter rotates. Planetary observers have measured the velocity of the winds at 612 km/hr (380 mph).

But for its velocity, that jet stream resembles the same phenomenon on Earth; Earth's stream meanders north and south, carrying storms from the tropics to temperate latitudes and from the Arctic southward. But Jupiter's rapid rotation (a day is less than 10 hours long) nails the northern stream to one constant latitude.

There are many more fascinating features like these on Jupiter. But even though astronomers try to photograph the planet every hour, every night, they are at the mercy of Earth's bubbling, boiling atmosphere and the material in it. Often observers have seen "something" there, but have been unable to identify it: ground-based pictures cannot answer the flood of questions scientists ask about the planet.

That is why Voyager observations are so important.

While the two Pioneer spacecraft saw Jupiter at high-resolution for only a few days -- and thereby took a snapshot of the planet -- the two Voyagers have taken many thousands of high-resolution pictures of Jupiter for almost eight months.

That is enough to provide a significant advance in our knowledge of the planet.

The satellites, meanwhile, are another story. They are bodies the size of the Moon and the planet Mercury that cannot be clearly seen from Earth because they are too far away. One Earth-based photo of Io suggests an orange hue at the poles and a whitish appearance near the equator. A picture of Ganymede taken by one of the Pioneers suggests mottling on the surface.

But the Galilean satellites' discs are only 1/25th the apparent diameter of the planet Mars, and 1/12th the size of the planet Mercury in the eyepiece of a telescope. They are, one scientist says, too small to show anything that can be taken seriously.

So, before Voyager 1, no one knew what those big, moon-sized objects looked like. Scientists were surprised by the satellite pictures from Voyager.

Io, for example, has a surface covered with volcanoes but with no meteoritic impact craters. Europa's surface is probably covered with ice, but no one knows the depth. If the ice is a few centimeters thick, Europa may look like Earth's Moon covered with snow. However, scientists have no idea what its surface may look like if the ice is tens of meters or even kilometers thick. Europa's surface, photographed at low resolution by Voyager 1, will be seen close-up by Voyager 2.

Ganymede and Callisto are thought to be composed of almost one-half ice. But they must contain some silicates, and they surely contain some radioactive material -- therefore, there is some internal heat. How does that heat reach the surface? Uniformly? Or in convection cells as happens on Earth?

Impact craters cover the icy satellites. But ice flows, and in a relatively short time the scars fade; Ganymede's huge ring basins show very little topographic relief.

Finally there is an Earth application for the new knowledge from the Voyager images of Jupiter:

The inner planets -- Venus, Earth and Mars -- have atmospheres dominated by solar heat that arrives at the equator and flows by a variety of methods toward the poles. The equator, therefore, is hotter than the poles.

But Jupiter is not that way. Jupiter's atmospheric temperature does not appear to be dependent on latitude. There's a lot of heat moving from within Jupiter to the surface -- without any regard for where the equator is or the poles or even where the Sun is. It wells up uniformly everywhere.

On Earth one region is different from all the rest. It is a convective region called the Intertropical Convergence Zone. In that region near the equator, warm, moist air wells up to high altitudes. The moisture is condensed out of the air which then becomes very dry and cold. That dry, cold air moves outward and descends again, warming as it does. On either side of the Intertropical Convergence Zone, where the dry air reaches the surface, there is an arid, nearly useless desert. North Africa is the classic example. The zone is a region where nature's forces overwhelm man's efforts.

There is a similarity, then, between Earth and Jupiter -- one that may allow scientists studying the two planets to assist each other.

Low-Energy Charged Particles

The low-energy charged particle instrument is a strong coupling factor in Voyager's complement of fields and particles investigations, contributing to many areas of interest, including the solar wind, solar flares, particle accelerations, magnetic fields, cosmic rays and satellite surface structure.

Two detectors allow measurements during the long interplanetary cruise and the encounters. The wide dynamic range, combined with wide coverage in energy and species, allows characterization of almost all energetic particle environments that Voyager traverses.

The experiment measures particles traveling 2,400 to more than 150,000 km (1,500 to more than 90,000 mi.) a second. (High-energy particles travel at or near the speed of light -- 299,792 km a second or 186,282 mi. a second.)

Observations of particle accelerations aid in better understanding of solar flare processes, cosmic ray accelerations, and processes in Earth's magnetosphere.

Next to the Sun, Jupiter is the solar system's most powerful radio source. The reasons for that are not understood completely, but may come, in part, from the interaction between Jupiter and Io. The Io-Jupiter interaction could be of importance in understanding other astrophysical radio sources.

Plasma Experiment

When the atoms of chemical elements are broken apart into electrons and protons, the resulting gas is called a plasma. Measuring the plasma that surrounds the spacecraft is a good way to obtain information about the magnetic field through which Voyager travels and the material flowing outward from the Sun.

Traveling at supersonic speed (average 400 km or 250 mi. a second), plasma streams in all directions from the Sun, forming the solar wind. When the solar wind reacts with Earth's magnetic field, many phenomena result, such as the northern lights and geomagnetic storms. Similar events have been observed at other planets.

Voyager's plasma experiment measures plasma properties including velocity, density and temperature for a wide range of flow directions in the solar wind and planetary magnetospheres.

At Jupiter, the plasma team will study the interaction of the solar wind with Jupiter; the sources, properties, forms and structure of Jupiter's magnetospheric plasma; and the interaction of the magnetospheric plasma with the Galilean satellites.

Io, second satellite from Jupiter (tiny Amalthea is closest) is known to be a source of ionized sulfur and oxygen that form a donut-shaped ring close to Io's orbit.

It is possible, too, that Ganymede, fourth satellite out from Jupiter (Europa orbits between Io and Ganymede), has a ring of neutral particles that serve as a source for ions in the Jovian magnetosphere. If that is the case, the plasma instrument should detect some of those ions when Voyager is near Ganymede's orbit.

Jupiter's magnetosphere extends into space at least 100 times the planetary radius. Since Jupiter's radius is about 71,400 km (44,000 mi.), that places the leading edge of the magnetosphere about 7 million km (4,349,600 mi.) or farther from the planet. That distance appears typical for a quiet magnetosphere. On at least seven occasions the magnetopause -- edge of the magnetic field -- was found at varying distance, as close as 43 planetary radii, less than half the maximum distance. The magnetosphere is compressed when the solar wind's pressure increases.

During Voyager 1's encounter with Jupiter, the pressure of the solar wind at Jupiter and the size of Jupiter's magnetosphere was predicted using data from Voyager 2 -- farther from Jupiter and closer to the Sun.

By comparing data from both spacecraft during the Voyager 1 encounter, scientists showed how the Jovian magnetosphere reacts to changes in the incoming solar wind.

Voyager 2's encounter with Jupiter's magnetosphere will be detected when the spacecraft crosses the bow shock wave, a region of demarcation between the solar wind and the Jupiter environment.

Immediately behind the bow shock is a transition region called the magnetosheath that separates the solar wind from the magnetosphere. The inner boundary of the magnetosheath, the magnetopause, separates the modified solar wind plasma in the Jovian magnetosheath from the plasma in the magnetosphere proper. Plasma in the magnetosheath slows down and is heated by passage through the bow shock. Plasma in the magnetosphere comes from several sources -- Jupiter's ionosphere, ions from satellite surfaces and atmospheres and the solar wind.

In the inner magnetosphere, plasma trapped by the magnetic field is forced to rotate with the planet. This region of corotation may extend as far as the magnetopause; the farther from the planet, the more the centrifugal force causes stretching of the magnetic field lines, more or less parallel to Jupiter's equator.

The stretched field lines form a thin disk that confines the particles within an intense, thin sheet of current flowing around the planet.

Plasma Wave Experiment

Voyager 2 is surrounded by a low-density, ionized gas called a plasma. That plasma, composed entirely of atoms that are broken apart into electrons and charged positive ions, is a good electrical conductor with properties that are strongly affected by magnetic fields.

Plasma sources include the Sun, the planets and perhaps some of their satellites. Low-density plasmas are unusual; ordinary collisions between ions are unimportant, and individual ions and electrons interact with the rest of the plasma by means of emission and absorption of waves.

Localized interactions between waves and particles strongly control the dynamics of the entire plasma medium, and Voyager's plasma wave instrument provides the first measurements of these phenomena at the outer planets.

Plasma waves are low-frequency oscillations that have their origins in instabilities within the plasma: They are of two types -- electrostatic oscillations (similar to sound waves) or electromagnetic waves of very low frequency.

The plasma wave instrument measures the electric field component between 10 and 56,000 hertz. By way of comparison, Voyager's magnetometers measure the magnetic vectors of electromagnetic plasma waves below 10 hertz, while the planetary radio astronomy instrument measures waves with frequencies above 20 kilohertz.

Plasma ions and electrons emit and absorb plasma waves. While the resulting particle-wave interactions affect the magnetospheric dynamics of the outer planets and the properties of the distant interplanetary medium, they have never been directly observed in those regions, since plasma waves cannot generally be observed far from their source and since there have been no previous wave studies at the outer planets.

Voyager is, therefore, returning the first direct observations of wave-particle interactions at great distances from the Sun. Some effects to be studied include heating of solar wind particles at the outer planet bow shocks, acceleration of solar wind particles that produce high-energy trapped radiation, and the maintenance of boundaries between the rotating inner magnetospheres and the solar wind streaming around the planets.

Another objective of the plasma wave experiment is to study the influence of wave-particle effects on the interactions between the inner satellites and the planet's rapidly rotating magnetosphere.

Control of Jupiter's decametric radio bursts through coupling of Io's ionosphere with Jupiter's magnetic field is an example.

As Io moves through Jupiter's magnetic field, it produces current flow along the magnetic field lines connecting Io to Jupiter (the flux tube).

Detection of lightning bolts in the atmosphere of Jupiter was a significant discovery of the plasma wave instrument. The instrument detects audible whistler signals that escape into the magnetosphere from lightning discharges.

The descending-scale whistle that is characteristic of lightning is caused by scattering of similar velocities when the direction of travel is along magnetic lines of force: higher frequencies arrive at the receiver sooner than lower frequencies. Using the high-rate telemetry usually reserved for transmission of imaging data, the plasma wave instrument plays to Earth the entire audio signal of space -- plasma waves, spacecraft power, thruster firing and other instruments.

Ultraviolet Spectrometer

Voyager's ultraviolet spectrometer will study the composition and structure of Jupiter's atmosphere and the material surrounding several satellites.

Two techniques have been developed to probe a planet's atmosphere without entering that atmosphere:

- Airglow observations require a large area for maximum sensitivity to the weak emissions high in the atmosphere -- where collisons between atoms and molecules are rare.

- Occultation measurements require an instrument that looks at the Sun, reading its ultraviolet radiation to measure absorption and scattering by the planet's atmosphere as the spacecraft moves into shadow.

Airglow observations measure atomic hydrogen and helium in the upper atmosphere by recording the resonance scattering of sunlight. Resonance scattering is what happens when atoms and molecules absorb solar ultraviolet at specific wavelengths and reradiate at the same wavelengths. That differs from fluorescence, in which the activating wavelength is absorbed and energy is reemitted at different wavelengths. Auroral-type emissions were also observed at Jupiter -- on both day and night sides of the planet.

As the spacecraft disappears behind Jupiter, the planet's atmosphere passes between the Sun and the ultraviolet spectrometer. Since the gases that make up an atmosphere have identifiable absorption characteristics at short wavelengths, the ultraviolet spectrometer can measure how much of each gas is present at what temperature.

The important point is not how much sunlight enters the atmosphere, but what happens to it after it enters -- how it is absorbed and scattered.

VOYAGER EXPERIMENTS

Experiment	Principal Investigator	Instruments and Functions
Imaging science	Bradford Smith, University of Arizona	Two TV cameras with 1500 mm, f/8.5 and 200 mm, f/3 optics, multiple filters, variable shutter speeds and scan rates. Wide-angle field of view, 56 x 55 millirad (about 3 deg square); on scan platform.
Infrared Interferometer Spectrometer	Rudolf Hanel, Goddard Space Flight Center	Spectrometer-radiometer measuring temperatures and molecular gas composition, with narrow, 1/4-deg field of view, producing measurements every 48 sec; on scan platform.
Ultraviolet spectrometer	A. Lyle Broadfoot, Kitt Peak National Observatory	Grating spectrometer measuring ion, atomic, and small-molecular gas abundances; spectral range 400-1600 angstroms; on scan platform.
Photopolarimeter	Charles Hord, Univ. of Colorado	200 mm telescope with variable apertures, filters, polarization analyzers, and PMT detector; on scan platform.
Plasma	Herbert Bridge, MIT	Dual plasma detectors, one aligned toward Earth/Sun and one perpendicular, with detection ranges from 4v to 6kv.

Low-energy charged Particles	S. M. Krimigis, Johns Hopkins Applied Physics Laboratory	Dual rotating solid-state detector sets, covering various ranges from 10kev to more than 30Mev/nucleon.
Cosmic Ray	R. E. Vogt, Caltech	High-energy, low-energy and electron telescope systems using arrays of solid-state detectors, several ranges from 0.15 to 500Mev/nucleon.
Magnetometer	Norman Ness, Goddard Space Flight Center	Two low-field triaxial fluxgate magnetometers located roughly 10 meters from spacecraft on boom, two highfield (~20 gauss) instruments mounted on spacecraft.
Planetary radio astronomy	James Warwick, Univ. of Colorado	Two 10-meter whip antennas and two-band receiver (20.4-1300 kHz, 2.3-40.5 MHz), detecting planetary radio emissions and bursts and solar/stellar bursts.
Plasma wave	Frederick L. Scarf TRW Space and Defense Systems	Uses 10-meter planetary radio astronomy antennas with step-frequency detector and waveform analyzer to measure plasma waves, thermal plasma density profiles at Jupiter and Saturn, satellite/magnetosphere interactions, wave particle interactions.
Radio science	Von R. Eshleman, Stanford University	Uses spacecraft S-band/X-band links in planet, satellite and Saturn ring occultations to perceive changes in refractivity and absorption; celestial mechanics information calculated from tracking data.

THE PLANET JUPITER

Everything about Jupiter is enormous: when the solar system formed, 78 per cent of the material that did not end up in the Sun went to make Jupiter.

Jupiter is the fifth planet from the Sun. It completes one orbit every 11.86 Earth years.

A day on Jupiter is complete in 9 hours, 55 minutes and 30 seconds. The extremely rapid rotation caused the planet to be flattened at the poles: equatorial radius is 71,600 km (44,490 mi.), and the polar radius is 67,000 km (41,632 mi.)

Jupiter has 13 known satellites; a 14th may have been seen by Charles T. Kowal of Caltech, who also found the 13th in 1974. The four largest satellites were discovered by the first man to aim a telescope at Jupiter -- Galileo Galilei in 1609-10. Galileo's discovery that Jupiter has satellites provided evidence that the Copernican theory of the solar system was correct and that Earth is not the center. The four satellites discovered by Galileo (grouped together and called the Galilean satellites) are Io, Europa, Ganymede and Callisto. All range in size from the planet Mercury to the Moon. All are being studied by the Voyagers.

Jupiter is compresed primarily of hydrogen. Indeed, it is so massive that very little of its original material could have escaped in the 4.6 billion years since it formed. The second most abundant element in Jupiter is helium. The ratio of hydrogen to helium on Jupiter is about the same as in the Sun. The solar ratio is roughly one atom of helium for 10 molecules of hydrogen.

Three other substances have been identified spectroscopically: ammonia, methane and water. The presence of hydrogen sulfide has been inferred.

The currently popular model of Jupiter's structure begins with a small molten iron-silicate core only a few thousand kilometers in diameter. The core is inferred because cosmic abundances of the elements include small amounts of iron and silicates. The temperature there is thought to be about 30,000 degrees K (53,000 degrees F).

Surrounding the suspected core is a thick layer in which hydrogen is the most abundant element. The hydrogen is separated into two layers.

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In both it is liquid, but in different states: the inner layer, about 46,000 km (28,500 mi.) radius, is liquid metallic hydrogen, which means that the hydrogen is electrically conductive like ordinary metals. That form of hydrogen has not been observed in laboratories since it requires immense heat and pressure. On Jupiter it is thought to exist at temperatures around 11,000 degrees K (19,300 degrees F) and at pressures about 3 million times Earth's sea-level atmosphere.

The next layer -- liquid hydrogen in its molecular form -- extends to about 70,000 km (43,500 mi.). Above that layer, reaching to the cloud tops for another, 1,000 km (620 mi.) is the atmosphere.

If the model is correct, Jupiter has no solid surface, but exists as a rapidly spinning ball of gas and liquid almost 779 million km (484 milliom mi.) from the Sun.

One of the puzzles about Jupiter is the fact that it radiates about two and a half times the amount of heat that it receives from the Sun. Early models postulated nuclear reactions inside the planet, or heat from gravitational contraction. These ideas are no longer believed likely.

Because Jupiter is too small and too cold to generate nuclear reactions, scientists now believe the excess heat being radiated by the planet is stored heat left over from the primordial heat generated when the planet coalesced out of the solar nebula.

The visible surface of Jupiter consists of bands of clouds, alternating dark and light. The bands appear to be convection cells that are stretched by Coriolis forces created by the planet's rapid rotation. By convention, the light features are called zones and the dark ones belts. The light zones appear to be regions of greater altitude and cooler temperatures than the dark belts. Gas warmed by the planet's internal heat rises and cools in the upper atmosphere and forms clouds of ammonia crystals suspended in gaseous hydrogen. At the top of the zones, the cooler material moves toward the equator or the poles, is deflected in an east-west direction by Coriolis forces, and then sinks back to lower altitudes. A similar but much smaller mechanism on Earth caused the Trade Winds.

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One of the most prominent features on Jupiter is the Great Red Spot. It has been observed almost constantly since its discovery 300 years ago by Giovanni Domenico Cassini. Its width is almost always about 14,000 km (8,700 mi.), but its length varies between 30,000 km (18,600 mi.) and 40,000 km (24,800 mi.)

The Great Red Spot appears to resemble an immense hurricane of Earth -- although it is much larger and has lasted much longer than any terrestrial storms. At one time scientists believed it might be a phenomenon known as Taylor Column -- a standing wave above a mountain or depression on the surface. But the current model of Jupiter has no solid surface, and the Great Red Spot has wandered in longitude several times around the planet.

Other spots have been observed in the Jovian atmosphere that are similar to but much smaller than the Great Red Spot. They, too, appear in the equatorial regions, but have relatively short lifetimes; the one most recently observed lasted just under two years.

Radio astronomers found evidence for a magnetic field around Jupiter during observations in the 1950s, when they discovered radio-frequency emissions coming from the planet. The emissions are confined to two regions of the spectrum -- with wavelengths measured in tens of meters (decametric) and in tenths of meters (decimetric). Another radio-noise contribution comes from non-thermal mechanisms that depend on the planet's magnetic field. This "synchrotron radiation" comes from electrons that move near the speed of light.

The satellite Io appears to have some link with the decametric radiation, since the bursts seem to occur when Io crosses the face of Jupiter. All radio emmissions from Jupiter are associated with rotation of the planet's magnetic field.

While the Jovian magnetic field is essentially dipolar (north and south, like Earth's), its direction is opposite Earth's (the needle of a compass on Jupiter would point south).

The axis of the field is offset about 10.8 degrees from the the rotational axis, and the center of the axis is offset from the center of the planet by about one-tenth of a Jupiter radius. At the planet's cloud tops the field ranges between 3 and 14 gauss (Earth's magnetic field at the surface averages about one-half gauss).

The shape of Jupiter's magnetic field is about the same as Earth's with some significant differences: the movement of energetic particles near the equator is intense, but at higher latitudes falls off dramatically. There is apparently an electric-current sheet along the magnetic equator that traps and holds particles there.

The five inner satellites of Jupiter affect distribution of charged particles; as the satellites orbit Jupiter they sweep particles out of their way and at the same time acquire intense radioactivity.

Jupiter's outer magnetosphere is highly variable in size, possibly due to changes in the solar-wind pressure; Voyager 1 flew in and out of the magnetosphere five times on its inbound leg.

High-energy electrons have also been observed in another unexpected place: ahead of the bow shock wave in interplanetary space. Scientists believe high-energy particles in Jupiter's magnetosphere reach such velocity that they can escape. Reexamination of records from Earth satellites turned up the fact that these electrons has been observed for many years. They were believed, however, to be of cosmic origin. Now scientists think they spin down the solar magnetic-field lines and intersect Earth, since their peaks occur every 13 months when Earth and Jupiter are connected by the spiral lines of the interplanetary magnetic field.

Jupiter's satellites fall into three groups -- the large inner bodies, then a group of four that are small, and a final group, also four in number, that are far distant and have retrograde orbits.

The five inner satellites are Amalthea -- the smallest -- about 265 km (164 mi.) by 140 km (87 mi.); Io, about the size of Earth's moon; Europa, Ganymede and Callisto.

All the outer satellites appear to be very different from the inner group. They are probably asteroids captured by Jupiter's gravity or the may be the remains of broken up satellites.

Their orbits are fairly highly inclined (25 to 28 degrees from the equatorial plane), and the outermost four pursue retrograde paths.

THE SATELLITES OF JUPITER

Name		Diameter (km, mi.)	Distance (km, mi.)	Period Distance (days, hours min. sec.)
Amalthea	(V)	240 (149)	181,500 (112,779)	$11^h57^m22.7^s$
Io	(I)	3,636 (2,259)	422,000 (262,219)	$1^d18^h27^m33.5^s$
Europa	(II)	3,066 (1,905)	671,400 (417,189)	$3^d13^h13^m42^s$
Ganymede	(III)	5,216 (3,241)	1,071,000 (665,489)	$7^d3^h42^m33^s$
Callisto	(IV)	4,890 (3,039)	1,884,000 1,170,663)	$16^d16^h32^m11.2^s$
Leda	(XIII)	7 (est.) (4)	11,094,000 (6,893,492)	238.7^d
Himalia	(VI)	170 (106)	11,487,000 (7,137,691)	250.57^d
Elara	(VII)	80 (50)	11,747,000 (7,299,247)	259.65^d
Lysithea	(X)	14 (est.) (9)	11,861,000 (7,370,084)	263.55^d
Ananke	(XII)	14 (est.)	21,250,000 (13,204,137)	631^d
Carme	(XI)	14 (est.)	22,540,000 (14,005,706)	692^d
Pasiphae	(VIII)	16 (est.) (10)	23,510,000 (14,608,436)	739^d
Sinope	(IX)	14 (est.)	23,670,000 (14,707,856)	758^d

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PLANET COMPARISON

	Earth	Jupiter	Saturn
Radius (Equatorial)	6,37^ km (3,963 mi.)	71,400 km (44,366 mi.)	59,800 km (37,158 mi.)
Satellites	1	14(?)	10 (?)
Year	1	11.86	29.46
Day	24^h	9^h 55m 33s	10h 26m (?)
Mass	1	317.9	95
Gravity	1	2.61	0.9
Mean distance from Sun	1 AU	5.203 AU	9.523 AU

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