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ABSTRACT

This document is one of a series of publications of the National Aeronautics and Space Administration (NASA) on facts about the exploration of Jupiter and Saturn. This NASA mission consists of two unmanned Voyager spacecrafts launched in August and September of 1977, and due to arrive at Jupiter in 1979. An account of the scientific equipment aboard the spacecraft, the experiments to be carried out, and a mission profile are outlined. Two student-oriented projects, a glossary of related terms, and a suggested reading list are provided. (GA)

NASA Facts
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of the
National Aeronautics and
Space Administration
NF-87/10-77

Voyager

Mission to the Outer Planets

In the dimly lit outer reaches of our Solar System are the giant planets Jupiter and Saturn—almost unimaginably large and far away. Beyond Jupiter and Saturn are the even more remote planets Uranus, Neptune, and Pluto.

Although space exploration by the National Aeronautics and Space Administration has become a familiar achievement in the last decade, the planets that have been measured and photographed by NASA's Mariner and Viking spacecraft have been the "nearby" planets Mars, Venus, and Mercury (though "nearby" in this sense may mean millions of kilometers from Earth).

Exploring the giant outer planets, however, poses problems with a whole new set of dimensions. For this reason, a different type of spacecraft, named Voyager, has been developed to perform this formidable task.

NASA's mission to Jupiter and Saturn consists of two unmanned Voyager spacecraft scheduled to be launched in August and September of 1977 and to arrive at Jupiter in 1979. As they fly by Jupiter, their instruments look closely at the planet and its many satellites. The spacecraft instruments find out how these bodies affect the solar wind—the blizzard of protons and electrons streaming outward from the Sun. They also investigate how charged particles, such as electrons and protons, and the magnetic field of Jupiter act on each other.

The trajectories of the spacecraft past Jupiter have been chosen so that the gravity and orbital motion of the giant planet act as a slingshot to send both spacecraft to the ringed planet Saturn. Arrival at Saturn is scheduled for November 1980 and August 1981.

The first spacecraft to reach Saturn is expected to repeat the types of experiments and measurements it made as it flew by Jupiter and also to investigate the important satellite Titan and the spectacular ring system of Saturn. If these measurements have been successful, the second spacecraft to arrive might be sent to the planet Uranus, the next planet beyond Saturn. Recent discoveries have revealed that Uranus is also a ringed planet, like Saturn, which had previously been thought to be the only planet in our Solar System to have a system of rings. Thus, Voyager has the potential of exploring three of the giant planets of the outer Solar System and providing a close look of their larger satellites.

Each spacecraft's scientific instruments seek new information about the atmospheres and the environments of the planets, the surface features and atmospheres of the satellites, the nature of Saturn's rings, the magnetic fields and the flow of charged particles in the planetary systems, and the effects of the planets and satellites and rings on these particles and fields.

The Voyager Project

The Voyager project is managed by the NASA Jet Propulsion Laboratory, Pasadena, California. The Laboratory is responsible for building the two spacecraft and for conducting tracking, communications, and mission operations. NASA's Lewis Research Center, Cleveland, Ohio, has responsibility for the launch vehicles.

There are eleven science teams with a total of 85 scientists concentrating on different aspects of the scientific investigation. The leaders of the teams are shown in Table 1.

The Spacecraft

Voyager is the most far-reaching space mission to be flown by NASA, since it includes a possible flight to Uranus, which is 2.87 billion kilometers from the Sun—19 times the distance from the Sun to the Earth.

The spacecraft (Figure 1), because they have to travel so far from the Sun, differ somewhat from the earlier Mariners from which they were developed. Panels carrying solar cells to convert sunlight to electricity, needed for the instruments and the electronics of earlier Mariner spacecraft, are missing from the new

Figure 1. Artist's concept of the Voyager spacecraft showing its large precision antenna and instrument booms and antennas.

Table 1. Science Experiments and Team Leaders

Experiment	Science Team Leader
Imaging Science (2 TV cameras)	Bradford Smith, University of Arizona, Tucson, Arizona
Infrared Interferometry Spectrometer and Radiometer	Rudolf Hanel, Goddard Space Flight Center, Maryland
Ultraviolet Spectrometer	A. Lyle Bradfoot, Kitt Peak National Observatory, Arizona
Photopolarimeter	Charles Lillie, University of Colorado, Colorado
Plasma (dual plasma detectors)	Herbert Bridge, Massachusetts Institute of Technology, Massachusetts
Low-Energy Charged Particles	S. M. Krimigis, Johns Hopkins Applied Physics Laboratory, Maryland
Cosmic Rays	R. E. Vogt, California Institute of Technology, California
Magnetometer	Norman Ness, Goddard Space Flight Center, Maryland
Planetary Radio Astronomy	James Warwick, University of Colorado, Colorado
Plasma Waves	Frederick L. Scarf, TRW Systems Group, California
Radio Science	Von. R. Eshleman, Stanford University, California

spacecraft. At Jupiter, sunlight is only 1/25th as bright as it is at the Earth. At Uranus, it is a mere 1/350th as bright as Earth's sunlight. So, instead of solar cells, Voyager spacecraft rely upon radioisotope thermoelectric generators, which provide electricity through the conversion of heat from the radioactive decay of plutonium.

The generators are carried on a spar-like boom extended from the spacecraft to prevent their radiation from affecting the science instruments. They develop a total of about 400 watts at the time the spacecraft reaches Saturn. Radio communication with Earth consumes 100 watts of this available power. Science instruments consume 108 watts, and the remainder is available for the other needs of the spacecraft.

The antenna of the new spacecraft differs from that of the earlier Mariner spacecraft. To return information with a given amount of transmitter power over the immense distances to the outer planets, a much larger antenna has to be carried than for exploring planets such as Mars, Venus, and Mercury. Voyager's dish-shaped antenna is 3.7 m (12 ft) in diameter. It is constructed very accurately to beam the high-frequency radio waves without scattering them too much.

Coupled with an improved spacecraft transmitter and the large receiving antennas of the Deep Space Network on the ground, Voyager can send information to Earth at a rate of 115,000 bits per second from Jupiter, and 44,000 bits per second from Saturn. (By contrast, no matter how fast you talk, you can only send information over your telephone at a rate of 100 bits per second.) The large, high-gain antenna of Voyager is pointed toward Earth by use of electronic eyes on the spacecraft. There is also a low-gain antenna, mounted in front of the high-gain antenna, so that there can be some radio contact even if for some reason the large antenna cannot be pointed directly to Earth.

The spacecraft can transmit to Earth at two radio frequencies. During cruise between the planets the lower frequency—known as S-band—is used to send data to Earth at a relatively low rate. This is adequate for cruise science and releases the big 64-m (210-ft) diameter antennas of the Deep Space Network for other tasks. Information can be received on the smaller, 26-m (85-ft) diameter ground antennas. For encounters with the planets, when very large amounts of data must be transmitted quickly, a higher frequency (X-band) is used.

The X-band transmitter's power output is 21 or 12 watts. The S-band transmitter's power output is 28, 20, or 10 watts. Both transmitters are duplicated, in case a transmitter should fail during the long mission.

The new spacecraft is, like the earlier Mariners, built around a group of compartments that house the electronics. On top is the big antenna. In the center of the compartments is a large spherical tank containing rocket propellant. Unlike earlier spacecraft, the new Voyager does not use a single main rocket engine to correct its trajectory through space; instead, it uses its hydrazine rocket propellant in 16 small thrusters for maneuvers and attitude control. The spacecraft can be positioned by reference to the Sun and the star Canopus, or by its own internal system of gyroscopes (called an inertial reference unit) using the thrusters. For some corrections to its path through space, Voyager must fire these small rocket thrusters for as long as one hour.

To add the final velocity required at launch to escape Earth and attain a trajectory to take it to Jupiter, each spacecraft has a solid rocket system weighing about 1210 kg (2668 lb) capable of a thrust of 71,200 newtons (16,000 lb). The rocket system is dropped from the spacecraft after it has been fired.

The mission module, which is the planetary spacecraft, weighs about 810 kg (1786 lb), of which about 105 kg (231 lb) consists of science instruments.

Much of the electronics of the spacecraft is duplicated. This duplication will allow the spacecraft to switch-in alternative electronics in case of damage by high-energy, charged-particle radiation when close to the giant planets or in case of equipment failure during the long flight time required to explore the outer Solar System.

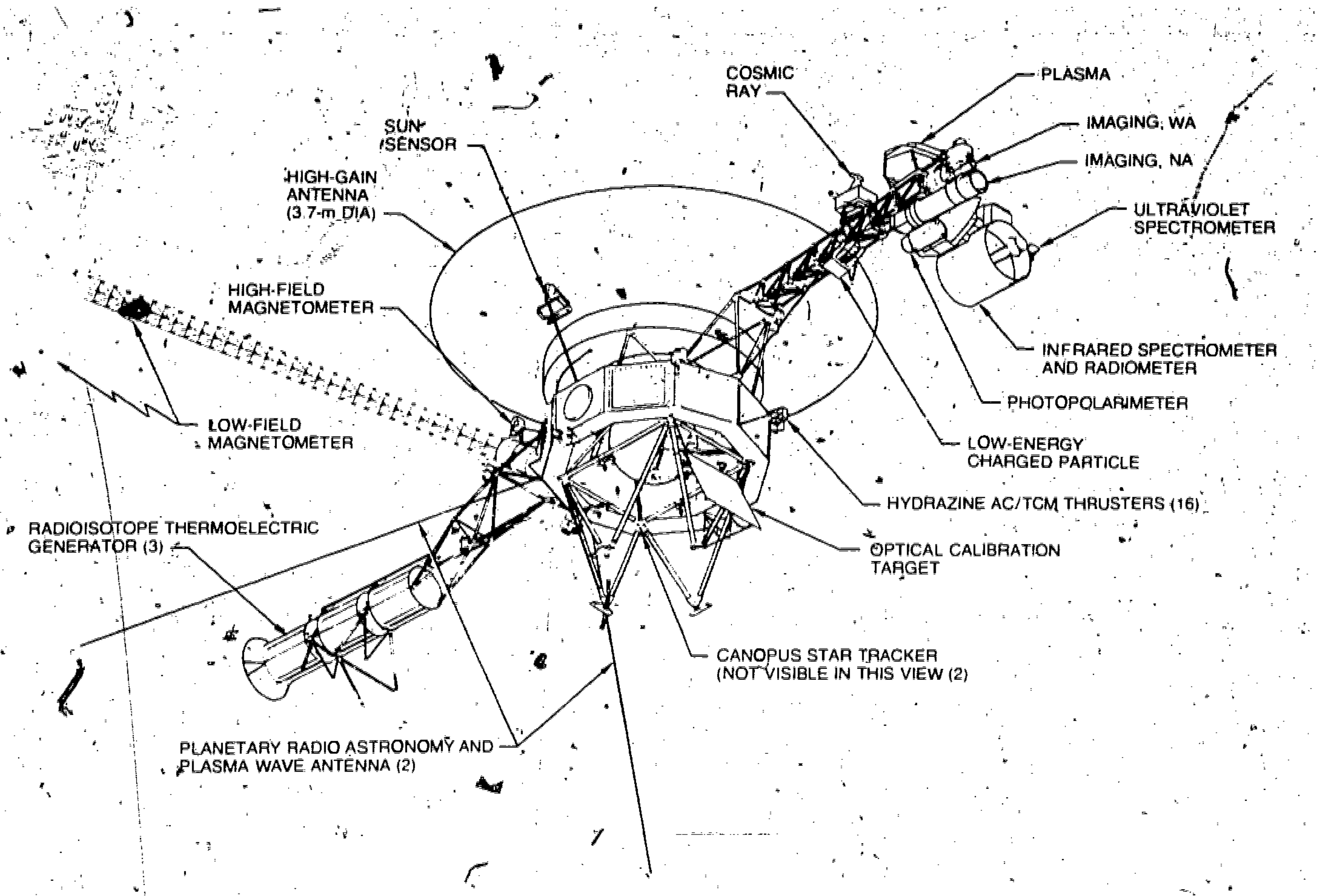

Figure 2. Drawing of the Voyager spacecraft to identify the major components and the science instruments.

The spacecraft has been designed so that the scientific measurements will not be affected greatly by the magnetic field of the spacecraft itself.

Voyager Science

Originally the mission was concerned primarily with the two giant planets Jupiter and Saturn. However, increasing interest in the satellites of these planets led to their being included in the mission's objectives. There are, indeed, five planet-sized satellites that will be inspected closely during the flight. They are all larger than Earth's Moon, and one of them, Titan, has an atmosphere whose density is comparable to that of the Earth's atmosphere.

The science instruments are quite varied. Cameras photograph the planets and satellites to a detail never possible before. Other instruments investigate the unusual environments of these large planetary systems, which are like miniature solar systems. Many of the science instruments are identified in Figure 2.

The cameras and spectrometers are mounted on a movable platform at the end of a science boom (see Figure 2) so that the instruments can look around the large high-gain antenna.

A narrow-angle camera system of 1500 mm (59 in.) focal length acts like a telephoto lens to show small areas of the planets and satellites in very great detail. A completely new wide-angle camera system was designed for the mission. It has a 200-mm (7.87-in.) focal length telescope which covers a greater area but in less detail. Both camera systems have eight filters, some of which can be used to produce color pictures of the planets and their satellites.

One spectrometer looks at the planets in ultraviolet light. There are also an infrared spectrometer, a radiometer, and a photopolarimeter. On the same boom, but not on the movable platform, there are science instruments for measuring planetary and interplanetary particles of various energies.

Another boom, extending 13 m (42.65 ft) from the spacecraft, carries devices to measure the magnetic fields of the planets.

Two long antennas project from the spacecraft to detect radio waves emitted from the planets and plasma waves in the extremely rarefied gases in the space between the planets.

The Experiments

The infrared spectrometer measures temperatures at various depths in the atmospheres and gives information about the gases in the atmospheres of the planets and their satellites.

The ultraviolet spectrometer also provides information about the gases in the atmospheres of the planets and satellites. It is particularly useful in searching for hydrogen and helium.

The photopolarimeter provides information about aerosols in planetary atmospheres and about the characteristics of the satellite surfaces.

To provide information on the types of charged particles and their direction of flow—both in interplanetary space and in the vicinity of the planets and satellites—several types of detectors are used. For example, high-energy particles expected in interplanetary space are detected by a cosmic ray telescope.

These measurements of charged particles and magnetic fields can help our understanding of the basic physics that permits electrons to be accelerated to high velocities by Jupiter. Information about the composition of the radiation belts of Jupiter and of Saturn may allow scientists to deduce how these belts are structured. Also, from the magnetic moments of the planets, the internal structure of the planets may be inferred.

The satellites of Jupiter, and probably those of Saturn also, offer obstacles to charged particles that rotate with the planet, as the inner planets of the Solar System offer obstacles to the solar wind. The way in which the satellites affect the charged particles surrounding the planets is investigated during the mission. Close approaches of the spacecraft to Io, Ganymede, and Callisto allow the instruments to search for wakes in the "ocean" of charged particles like those behind ships at sea, and for interactions of the particles with Jupiter's magnetosphere—that space around the planet where its magnetic field predominates. These science measurements can throw light on how quickly the satellites sweep up charged particles from the magnetosphere of Jupiter and how quickly the wakes of the satellites are smoothed by charged particles moving inward toward Jupiter from outer regions of the planet's magnetosphere.

The 10-m (32.8-ft) long whip antennas of the planetary radio astronomy experiment are used to detect radio waves from the planets. Radio science investigations also make use of the spacecraft's radio transmissions to Earth to observe the effects as the spacecraft passes behind the planets, the satellites, and th rings of Saturn. These observations provide information about the size of the planets and the satellites their atmospheres, the composition of the rings, an the sizes of particles making up the rings. Also, the radio signals are used to measure the gravity and the mass of each planet and satellite and to determine ver accurately their position in space and their orbita motions.

At Saturn the spacecraft should confirm the presence of a magnetic field and determine whether the planet has a magnetosphere. Some recent experiments with an Earth satellite suggested that Saturn does possess a magnetic field, but it is difficult to be sure from Earth-based observations. Voyager can look for evidence of the solar wind hitting a magnetosphere (known as a bow shock) and the way in which any such magnetosphere is affected by the rings and the satellites of Saturn. The experiments can also find out if Saturn's magnetic field is tilted relative to the spin axis of the planet, as are Jupiter's and Earth's fields relative to their axes of rotation.

The presence of Saturn's rings is expected to have major effects upon trapped charged particles if the planet does have radiation belts, especially if the magnetic field is tilted to the spin axis of the planet.

The huge satellite of Saturn, Titan, is a fascinating world. Revolving around Saturn at a mean distance of 1,222,600 km (760,000 mi), Titan is larger than Mercury, and it has a substantial atmosphere. Gases lost from Titan's atmosphere into space might be expected to form a doughnut (torus) around Saturn, which could be detected by the spacecraft's instruments. If this torus is outside Saturn's magnetosphere and in the solar wind, it may give rise to a detectable bow shock. This would provide a unique observation of the interaction of the solar wind with a gas cloud.

Even if Uranus and Neptune have substantial magnetic fields, it is unlikely that these can be detected from Earth. But Voyager should easily detect them; for even if the magnetic fields are extremely weak they are expected to give rise to very extensive magnetospheres at these planets.

The other major group of experiments beyond particles and fields is concerned with the use of the instruments on the camera platform. The atmospheres of all four planets and many of their satellites are investigated by these instruments which, together with radio science, can considerably increase our understanding of the gaseous outer planets.

Planetary atmospheres are important because they tell the story of the way in which the planets might have formed and how they evolved. Knowledge of the present states and compositions of planetary atmospheres is vital to an understanding of how the Solar

System originated and became what it is today. Any theory about the formation and evolution of the Solar System must account for the different atmospheres of the planets.

Scientists need to know such things as the temperature, pressure, density, and gaseous and particulate compositions of the atmosphere. It has been found that heat from inside Jupiter plays a major role in the circulation of that planet's atmosphere. The same may be true of Saturn and the more distant planets. Voyager's experiments are expected to tell us what is really taking place in the atmospheres of the outer planets. In addition, the mission looks at the atmospheres of satellites, which may provide important clues about how these bodies evolved.

Observations made for several weeks while approaching each of the planets provide motion pictures of the swiftly rotating atmospheres and their clouds. This is especially important for Saturn, Uranus, and Neptune, since even coarse details of cloud patterns are impossible to see from Earth with the best of telescopes.

Water ice has been detected in the rings of Saturn by radar observations from Earth, but it is believed that other substances are also present; perhaps silicates and ammonia ices. These can all be checked by Voyager's instruments during the Saturn encounters. Also, by looking at how sunlight is scattered by the rings, scientists hope to determine the sizes of particles in the rings. Radio waves passing from the spacecraft to Earth through the rings can help to determine the size of particles. Whether or not the rings are surrounded by an invisible atmosphere of gas can be checked. If one of the spacecraft is sent to Uranus, it will be able to obtain information about the recently discovered rings of that planet.

Far-encounter pictures of 12 satellites using the telephoto camera system are expected to reveal details on their surfaces only 5 to 15 km (3 to 9 mi) across. The spacecraft approaches close enough to three of the satellites to reveal details as small as 1000 m (3280 ft). The cameras look for geological details of the surfaces: craters, plains, scarps, mountains, and polar caps. The wide-angle pictures may reveal global distribution of geological areas and perhaps show why there are variations of color and albedo on the satellites. Sizes and shapes can be measured to between 0.1 and 1 percent.

Mission Profile

The trajectories used for the Voyager mission take advantage of the outer-planet alignment in the year 1977, which is most favorable for launching a spacecraft via Jupiter to Saturn with a relatively short flight time between the two giant planets. Each spacecraft is to be launched by a Titan/Centaur rocket from Kennedy Space Center, Florida, during a 30-day period beginning August 20, 1977. The first spacecraft to be launched needs more energy and takes longer to reach Jupiter. It arrives there on July 9, 1979. The second spacecraft, which is launched later in the launch period, follows a more opportune path and arrives at Jupiter before the first spacecraft, namely on March 5, 1979.

The first spacecraft to arrive at Jupiter is called Voyager 1, and it is targeted to fly by Jupiter in such a way that it can proceed to Saturn and make a close encounter with Titan. The trajectory for Voyager 1 is called JST (Jupiter, Saturn, Titan). If this first spacecraft is successful in its Titan encounter, the second spacecraft to arrive at Jupiter, Voyager 2, is targeted to fly by Saturn in a way that lets it continue on to the planet Uranus and perhaps even to Neptune. The trajectory for Voyager 2 is called JSX (Jupiter, Saturn, with option).

A spacecraft cannot be targeted to fly close to Titan in its encounter with Saturn and also fly to Uranus, because the orbits of Titan and Uranus are in different planes.

Arrival at Saturn is scheduled for November 12, 1980, for Voyager 1, and August 27, 1981, for Voyager 2. If the flight continues to Uranus, Voyager 2 arrives there on January 30, 1986. It may also be possible to reach Neptune about 1990. Thus Voyager 2 may be the nation's longest space mission: 12 years flying through interplanetary space to cover a distance of 30 astronomical units (4.5 billion km or 2.8 billion mi).

On the approach to Jupiter, the cameras start photographing the planet about 80 days in advance of the closest approach, i.e., in December 1978. The spacecraft also look for hydrogen clouds surrounding the planet and in the orbits of the satellites. The pictures show more detail than any obtained by Earth-based photographs, and at 10 days before closest approach they are better than the best obtained by the Pioneer spacecraft in 1973 and 1974. About 8 days before closest approach the entire planet is surveyed by the wide-angle camera, while the narrow-angle (telephoto) camera concentrates on detailed pictures of specific features of the turbulent atmosphere of Jupiter.

At Jupiter, Voyager 1 flies by within 4.9 Jupiter radii (about 350,000 km or 217,500 mi) from the center of the planet at 12:49 GMT on March 5, 1979 (see Figure 3). The spacecraft passes within 415,000 km (258,000 mi) of Amalthea, Jupiter's small innermost satellite, and within 22,000 km (13,670 mi) of Io, the innermost of the big Galilean satellites.[*] The spacecraft flies almost along Io's orbit below the satellite for about 5 hours, thereby providing good views of the south polar regions. Shortly afterward the spacecraft is occulted by the bulk of Jupiter from the Earth and from the Sun. After emerging from behind the planet, Voyager 1 then passes within 733,000 km (455,500 mi) of Europa,

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[*] The four largest satellites of Jupiter (Io, Europa, Ganymede, and Callisto) are called Galilean satellites in honor of Galileo, who discovered them in the early 1600s.

makes a close pass by Ganymede at 115,000 km (71,500 mi), and by Callisto at about the same distance.

Afterwards, the spacecraft continues to observe Jupiter for about another month until just before the next spacecraft to arrive, Voyager 2, starts its observations of the planet.

The encounter of Voyager 2 is somewhat different, in that the spacecraft must fly by further away from Jupiter to preserve the option to fly to Uranus. Voyager 2 starts photographing Jupiter in April 1979, about 80 days ahead of the closest approach. This is at 10 Jupiter radii (714,000 km or 443,700 mi) at 11:00 p.m. July 9, 1979 (see Figure 4). Voyager 2 passes Callisto at a distance of 220,000 km (136,700 mi), then makes a very close approach of 55,000 km (34,200 mi) to Ganymede, followed by a passage within 200,000 km (124,300 mi) of Europa. Through the use of the two spacecraft, Ganymede and Callisto are seen before and after closest approach so that both hemispheres of the satellites are observed and photographed. Amalthea is passed at a distance of 550,000 km (342,000 mi), but since this satellite is so close to Jupiter as to be extremely difficult to observe from Earth, the Voyager pictures are important even though the approaches are not very close. On its way out from its closest approach to Jupiter, Voyager 2 passes through the occultation zones for both Earth and Sun.

At Saturn, Voyager 1 first makes a close approach of 7000 km (4350 mi) to Titan. Sixteen hours later it makes its closest approach to Saturn (see Figure 5). At 1:00 a.m. GMT on November 13, 1980, Voyager 1 is 3.3 Saturn radii (197,300 km or 122,600 mi) from the center of the planet and has a spectacular view of the south polar regions and the open ring system. Then the spacecraft passes within 96,000 km (60,000 mi) of Mimas, 230,000 km (143,000 mi) of Enceladus, 140,000 km (87,000 mi) of Dione, and 60,000 km (37,300 mi) of Rhea. This is the first time these satellites are seen as worlds rather than fuzzy points of light. The spacecraft passes behind the rings as viewed from Earth and through their shadow, and also passes behind the planet and through its shadow (see Figure 6). Voyager 2, if the Uranus option is chosen, first encounters Titan, but at a distance of 353,000 km (219,000 mi) below the spacecraft. An approach to within 254,000 km (158,000 mi) of Rhea is followed by one of 159,000 km (98,800 mi) of Tethys. As the spacecraft swings round the planet (see Figure 7) it passes within 94,000 km (58,400 mi) of Enceladus, 33,000 km (20,500 mi) of Mimas, and 196,000 km (121,800 mi) of Dione. Voyager 2 then passes into Earth and Sun occultations by the planet and proceeds out from Saturn, but it continues to look back and observe the planet until the end of September, 1981. It is then on its way to Uranus for a rendezvous 4½ years later (see Figure 8).

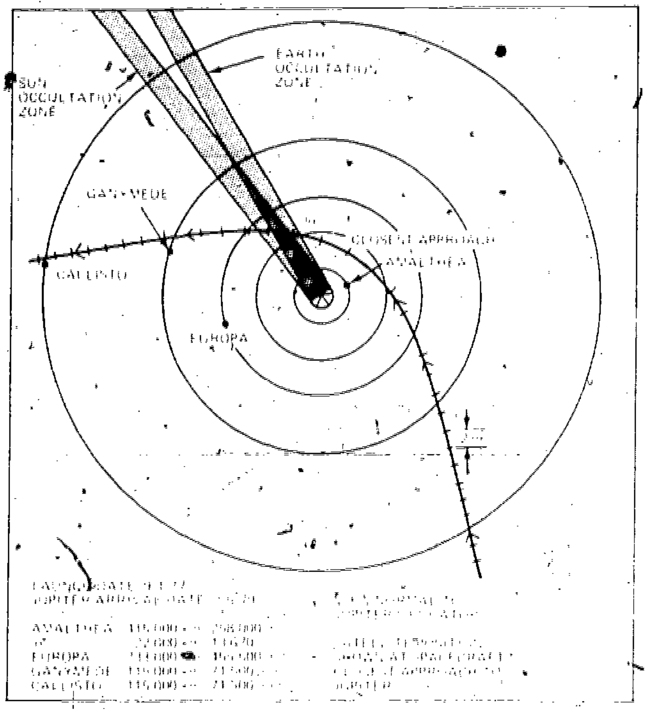


Figure 3. Diagram looking down on the north pole of Jupiter showing the path of Voyager 1 (JST trajectory) past the planet.

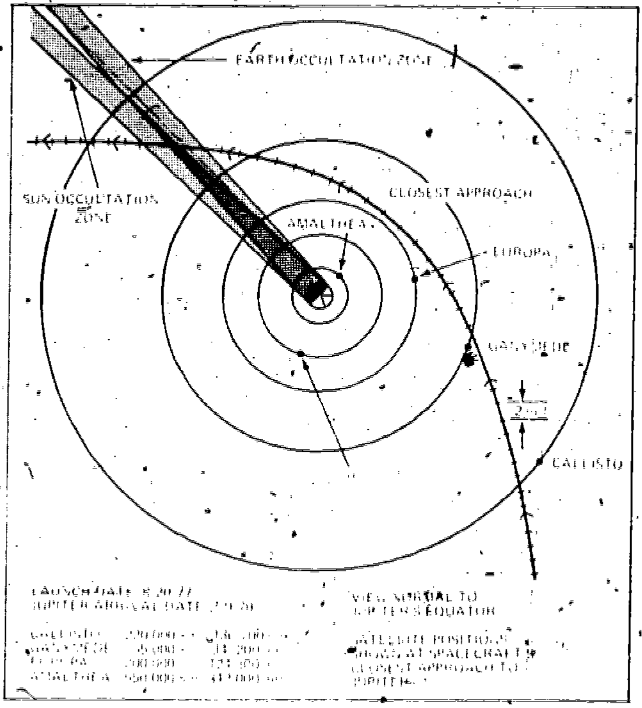


Figure 4. The path of Voyager 2 (JSX trajectory) during its encounter with Jupiter.

Both Saturn flybys are outside the ring system, but they provide good closeup views of the rings. Voyager 2 does not see the rings as well as does Voyager I. When Voyager 2 passes within 2.7 planetary radii at 1:00 p.m. GMT on August 27, 1981, it is viewing the dark side of the rings.

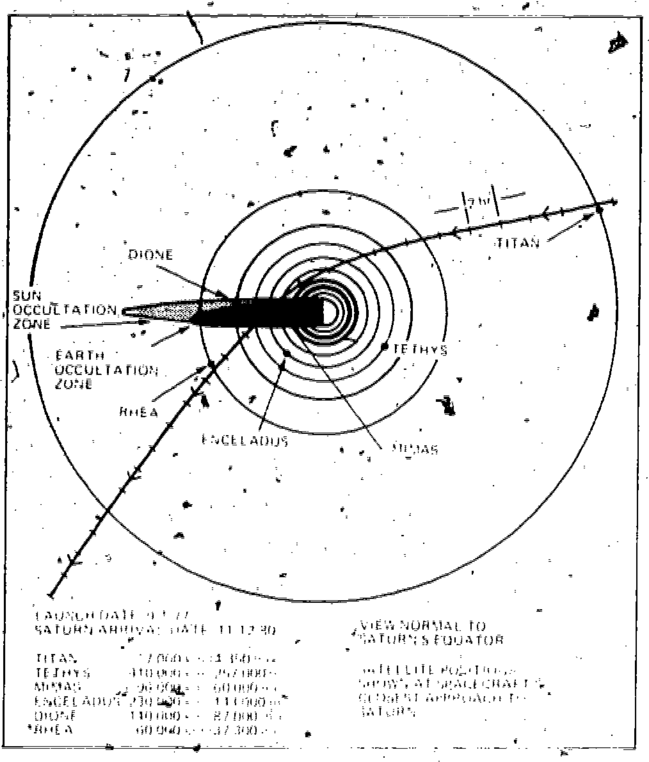


Figure 5. At Saturn, Voyager 1 makes a close approach to Titan, then flies by Saturn at a distance of only 3.3 Saturn radii from the center of the planet.

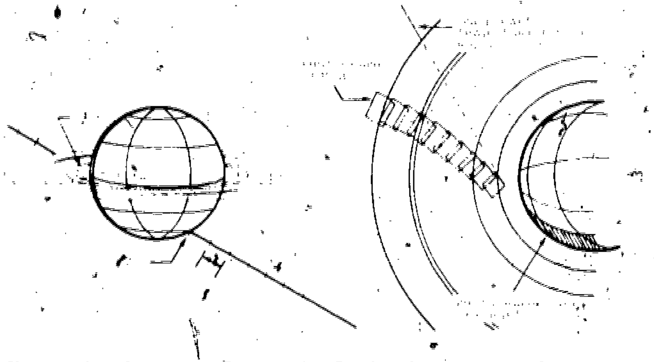


Figure 6. As seen from the Earth, the spacecraft passes behind Saturn and its rings at the times following closest approach shown in the drawing. Alongside is the view of the rings obtained 20 minutes before closest approach.

As Voyager 2 approaches Uranus, equipment within the spacecraft is prepared for the new encounter, which is quite different from the encounters with Jupiter and Saturn. This capability to change operation of equipment within the spacecraft many millions of miles from Earth is a powerful new technique for exploring several planets by one mission. This technique uses computers on board the spacecraft, the operating instructions for which can be changed by commands sent to it from Earth. Spacecraft operations can then be changed to fit the special needs of the different planetary encounters. This capability also permits controllers at the Mission Control Center to work around equipment failures that might occur because of radiation close to Jupiter and Saturn or because of the long period of operation of the spacecraft in space.

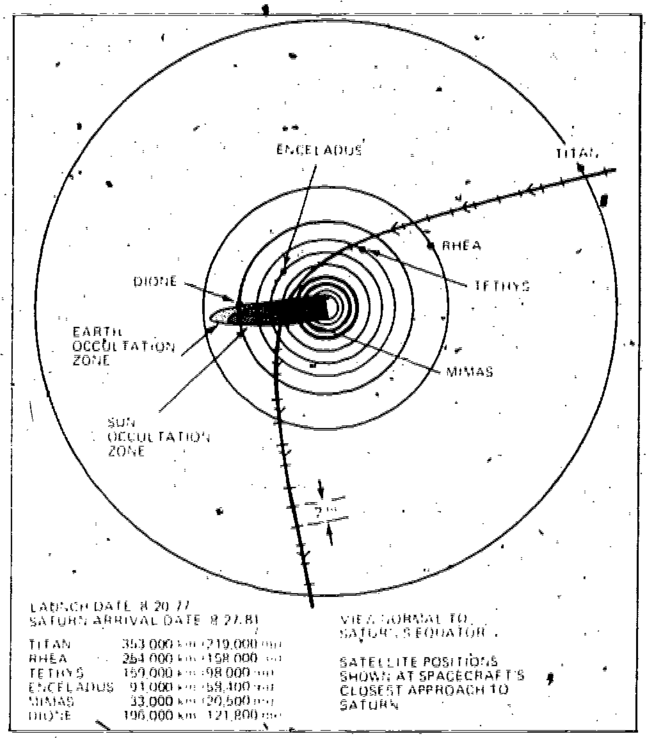


Figure 7. If the Uranus option is chosen, Voyager 2 will pass by Saturn along the JSX trajectory shown in this drawing.

Approaching Uranus, Voyager 2 is prepared for this strange planetary system in which the planet's axis of rotation is in the plane of its orbit around the Sun. The satellites orbit Uranus in its equatorial plane. The orbits of the satellites face the oncoming Voyager so that the Uranian system looks like a target with the planet at the bull's-eye. The flyby could take place when all the satellites are on one side of the planet, but no more than one can be close to the spacecraft if the spacecraft is to approach close to the planet. Details are worked out during the long voyage to Uranus. All the satellites are, however, photographed clearly enough to measure their sizes and to see surface detail—near impossibilities from Earth. The same condition applies to Neptune and its satellite system.

Thus, by 1990, the planets and satellites of the outer Solar System may be known in detail comparable to our current knowledge about the innermost planets—Mercury, Venus, and Mars (before Viking)—and this wealth of information will have been gathered by two spacecraft taking advantage of a unique configuration of the planets in their orbits, a configuration that will not be repeated for many human generations.

Figure 8. Following the encounter with Saturn as shown here, Voyager 2 will speed through the outer solar system to a rendezvous with Uranus 4½ years later in January 1986.

STUDENT INVOLVEMENT

Project One: Satellite Encounter

Make an enlarged sketch from Figure 3 showing Jupiter and its shadow, the path of the spacecraft from 40 hours before to 8 hours after closest approach (the tick marks on the spacecraft's path shown in Figure 3 are 2 hours apart), and the orbit of Ganymede. On the orbit of Ganymede draw the dot which represents the position of the satellite relative to the spacecraft at the time of its closest approach to the spacecraft. Place another dot on the path of the spacecraft to indicate its position at this time. This should coincide approximately with the eighth tick mark before closest approach.

Working backward and forward along the orbit of Ganymede, place tick marks to show the position of the satellite every two hours for the 24 hours before and after the closest approach to the spacecraft. Ganymede is assumed to be in a circular orbit at 1,071,000 km from the center of Jupiter. Its period in this orbit is 7.1546 days. Calculate the number of degrees it travels along its orbit in 2 hours, and use a protractor to make the tick marks.

Draw lines connecting the position of the spacecraft with the position of the satellite at each of the 2-hourly configurations. Measure the distances along these lines and convert to distances in kilometers from your knowledge of the radius of Ganymede's orbit. Make a table of distances for the 24 hours before and after closest encounter with the satellite. Plot these as a graph. What is the distance at 6 hours 40 minutes before and after encounter? If the time of closest approach for Voyager 1 is 12:49 GMT on March 5 1979, what is this in terms of your local time? Calculate in your local time the time of closest approach of Voyager 1 to Ganymede.

The diameter of Ganymede is approximately 5280 km. From the data you have in the table of distances and times, make a series of 24 drawings of the disc of Ganymede showing its relative size as seen from the spacecraft each 2 hours before and after closest approach. Scale your drawings so that the one for the closest approach is 5.28 cm in diameter. What is the relative size of the disc of Ganymede 24 hours before and 24 hours after closest approach? Calculate the angle subtended by the satellite at the spacecraft for each of these 2-hourly positions. If the high-resolution camera has a resolution of 4 seconds of arc (1 millidegree), calculate the size in meters of the smallest object that can be recognized on the satellite 24 hours before closest approach, at closest approach, and 24 hours after closest approach. Assume that the smallest object recognizable is the same as the resolution of the camera system.

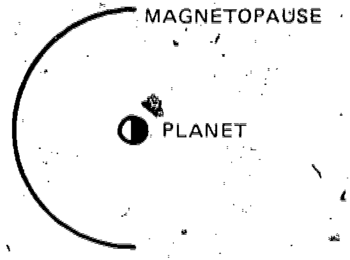
Again making use of the illustration of Figure 3, which shows the direction to the Sun, calculate the phase of Ganymede as seen from the spacecraft at each of the 2-hourly positions. Draw the position of the terminator (the boundary between day and night) on the discs of Ganymede you have already drawn, as the terminator would appear from the spacecraft. Darken the night side of the satellite.

Assume that on the first of your sketches, i.e., the disc at 24 hours before closest approach, there is a large impact basin in the exact center of the satellite as seen from the spacecraft. This basin is 300 km in diameter. Draw it on this first sketch of the satellite as seen from Voyager 1. Assuming that Ganymede rotates synchronously with its revolution about Jupiter (i.e., turns one hemisphere always towards Jupiter as the Moon does to Earth), show in your series of sketches of the disc of Ganymede the apparent movement of the big impact basin on the disc as viewed from the spacecraft. Does the basin disappear from view around the limb of the satellite? If so, when?

When would you expect to see most detail on the floor of the big basin? Remember that as the basin nears the limb the details in its floor are foreshortened by the angle of view. At the time you can see the most detail, what is the size in meters of the smallest object you can see at the 4 seconds of arc resolution of the high-resolution camera?

Project Two: Relative Sizes of Magnetospheres

The Earth's surface magnetic field of approximately 0.3 gauss produces a magnetopause (boundary between the magnetosphere and the solar wind) at an approximate distance from Earth's center of 10 Earth radii. Jupiter's magnetic field of 12 gauss produces a magnetopause at 53 radii from Jupiter, the distance varying with solar wind activity. Make a large drawing to scale to show the relative sizes of Earth and its magnetopause and Jupiter and its magnetopause, as shown in the sketch alongside. Scale the disc of Jupiter (diameter of 142,900 km) as 1.43 cm diameter. Alongside Jupiter, draw the Earth and its magnetopause. If Saturn has a surface magnetic field of 1 gauss, its magnetopause may be recorded by Voyager at a distance of 39 Saturn radii from the center of the planet. Draw Saturn to scale, together with its magnetopause, alongside Jupiter and Earth. (The diameter of Saturn is 119,600 km).



Then draw the Sun to the same scale. Its diameter is 1,426,000 km. Are the magnetospheres of Jupiter and Saturn comparable in size with the Sun itself? How much bigger or smaller are they?

GLOSSARY

Albedo: The ratio of the light reflected by a planet or a satellite to the sunlight falling upon it.

Boom: A slender structure or a single pole extending from a spacecraft to locate equipment or science instruments away from the body of the spacecraft.

Charged Particles: Ionized atoms (i.e., atoms that have lost one or more of their orbital electrons) and electrons moving freely in space.

Closest Approach: The position on the path of a spacecraft that is closest to the planet the spacecraft is flying by.

Cosmic Ray Telescope: A device that detects high-energy charged particles passing through a system of detectors arranged so that the direction of the particles can be determined and their energy measured.

Cruise: That part of an interplanetary flight where the spacecraft is traveling between the Earth and the planet which it is to fly by or orbit.

Data Bits: Information can be sent from one place to another in the form of a code, like the Morse code. Digital data is in a code of two bits, *zero* and *one*, equivalent to a lamp being either off or on. The rate at which these *zeros* and *ones* can be sent from a transmitter to a receiver is called the data bit rate.

Deep Space Network: A system of large antennas arranged at stations around the world so that as the Earth turns on its axis, constant communication can be maintained with a distant spacecraft. The antennas in Australia, Spain, and California pass information back and forth between spacecraft and the control center at the Jet Propulsion Laboratory, Pasadena, California. Each of the three Deep Space Network stations has a 64-m antenna and smaller antennas.

Encounter: ~~That period~~ in a space mission when a spacecraft is actively gathering scientific information about the planet it is flying by or orbiting.

Focal Length: The distance from a lens or mirror at which the image of a very distant object is focused; long focal lengths produce larger images than do shorter focal lengths, but the images are of reduced intensity. Long-focal-length telescopes are often referred to as telephoto, narrow-angle, or high-resolution systems; short focal lengths are used in wide-angle or low-resolution systems.

Ionosphere: Upper region of a planetary atmosphere, in which atoms and molecules become electrically charged by incoming radiation from the Sun.

Launch Window: A period of time during which, because of the relative positions of the planets and the Earth and the rotation of Earth on its axis, a spacecraft can be launched to reach a given planet with a certain class of launch vehicle. For Voyager, the launch window is about one hour each day during a launch period from August 20 to September 20, 1977. The beginning of the window varies between about 9:00 a.m. and 10:30 a.m., EDT.

Magnetic Moment: A measure of the magnetizing force produced by a magnetized body such as a planet.

Magnetosphere: The region surrounding a planet in which the magnetic field of the planet predominates over the magnetic field carried by the particles of the solar wind. The transition between the solar wind and the magnetosphere is a boundary known as the bow shock. The magnetosphere traps particles from the solar wind which are contained within radiation belts.

Occultation: The passage of a spacecraft behind a planet or a satellite so that the spacecraft is hidden from the observer.

Photopolarimeter: An instrument that measures the light intensity of a planet or satellite by using a polarizing device.

Radiation Belt: A region of trapped electrically charged particles, mainly protons (nuclei of hydrogen atoms) and electrons, in the magnetosphere of a planet.

Radiometer: A device to measure heat (infrared) radiation from a planet or a satellite.

S-band and X-band: Two bands or sections of the radio frequency spectrum allocated internationally for space communications. S-band is from 2290 to 2300 MHz and X-band is from 8400 to 8500 MHz.

Silicate: Rock containing large amounts of silicon, such as quartz, pyroxene, and feldspar.

Solar Wind: The flow of electrons and protons streaming outward from the Sun throughout the Solar System.

Spectrometer: A device that measures the different frequencies of radiation from a body and their relative intensities.

Spin Axis: The axis of rotation of a planet passing through the north and south poles of the planet.

Whip Antenna: A long, wire-like, flexible antenna supported at one end only.

Work Around: A way of overcoming a failure within a spacecraft so that the mission of the spacecraft can still be accomplished.

Suggested Reading

PIONEER ODYSSEY, R. O. Fimmel, W. Swindell, E. Burgess, NASA SP-396, 1977.

THE ATMOSPHERE OF TITAN, D. H. Hunten (ed.), NASA SP-340, 1974.

THE RINGS OF SATURN, F. D. Palluconi and G. H. Pettengill (eds.), NASA SP-343, 1974.

JUPITER, THE GIANT PLANET, T. Gehrels (ed.), University of Arizona Press, Tucson, 1976.

THE OUTER PLANETS, D. M. Hunten, *Scientific American*, v. 233, September 1975, pp. 130–141.

THE SMALLER BODIES OF THE SOLAR SYSTEM, W. K. Hartmann, *Scientific American*, v. 233, September 1975, pp. 143–159.

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