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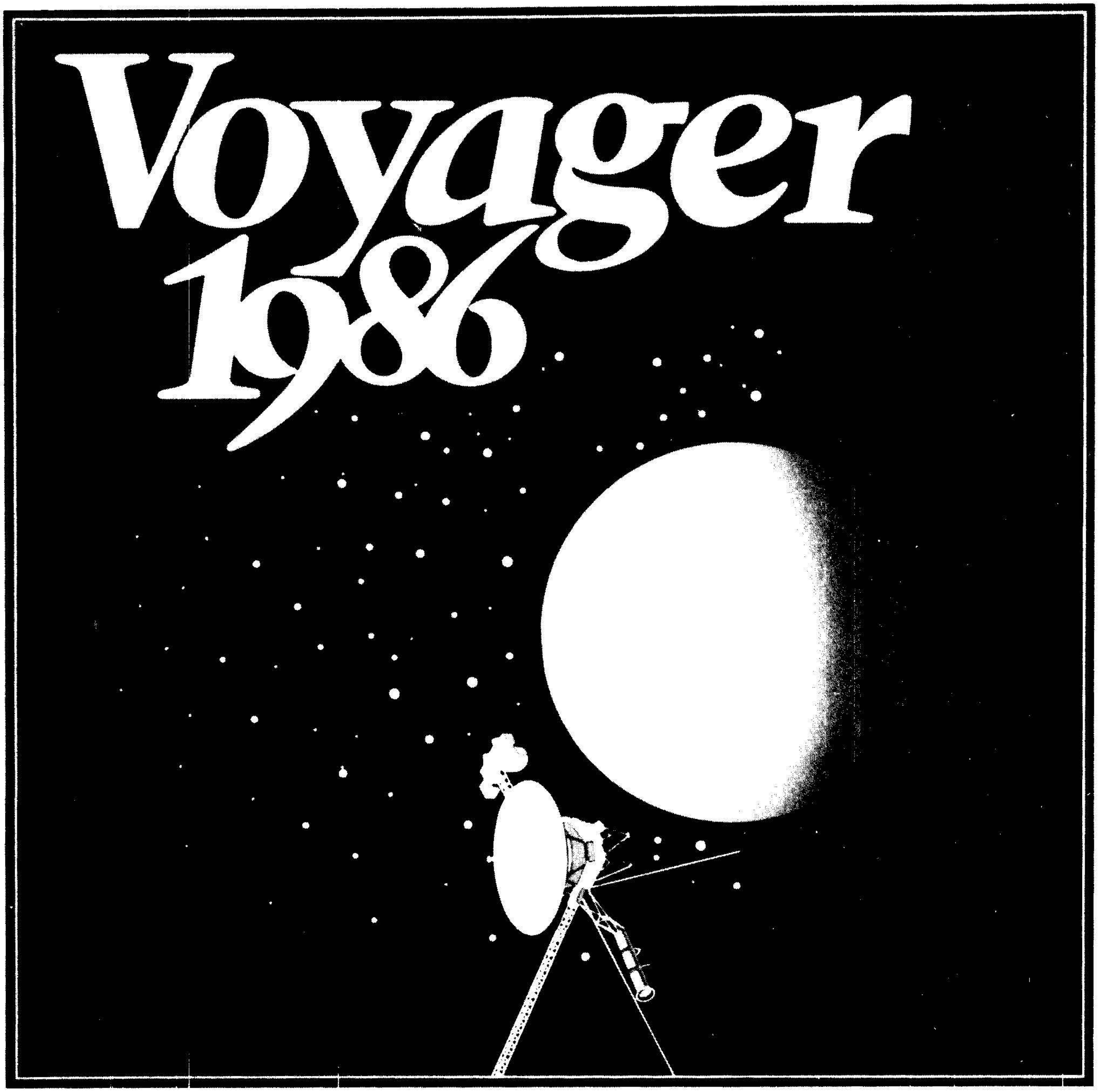

Press Kit

January 1986

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NASA News

National Aeronautics and
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VOYAGER NEARS URANUS

NASA's Voyager 2 will make its closest approach to Uranus, flying 81,500 kilometers (50,600 miles) above the cloud tops of the seventh planet, at 1 p.m. EST, Jan. 24, 1986. It will be the first spacecraft to reach the planet, providing our first close look at this system.

The Voyager 2 Uranus encounter, which began Nov. 4, 1985, continues through Feb. 25, 1986. During that period, the spacecraft's 11 instruments will perform close-range studies of the planet, its five known satellites and nine rings. The spacecraft also will search for a planetary magnetic field, new satellites and new rings.

Encounter activity peaks during a 6-hour period on Jan. 24, 1986, when the highest-priority observations will take place. In about a quarter of a day, scientists will obtain more information about Uranus, its satellites and rings, than has been learned since Sir William Herschel discovered the planet March 13, 1781. Much of the data collected during the spacecraft's closest approach, however, will be recorded on the spacecraft for playback to Earth on following days.

Uranus will be the third planet visited by Voyager 2 since the spacecraft was launched from Earth on Aug. 20, 1977. Voyager 2 flew past Jupiter on July 9, 1979, and then Saturn on Aug. 25, 1981.

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An identical spacecraft, Voyager 1, was launched Sept. 5, 1977, and flew past Jupiter on March 5, 1979, and Saturn on Nov. 12, 1980. Voyagers 1 and 2 returned to scientists an unprecedented amount of information on the two planets, their rings, moons and the interplanetary medium during the spacecraft cruise phases. More than 70,000 photos were taken of Jupiter and Saturn by Voyager 1 and 2.

Among the major discoveries at Jupiter were active volcanism on the satellite Io, thin rings of dust and ice encircling Jupiter, and three new satellites orbiting our solar system's largest planet.

The spacecraft found that Titan's (one of Saturn's moons) atmosphere is composed primarily of nitrogen, that it contains simple organic compounds, and has one and one-half times the pressure of Earth's. Several new Saturnian satellites were discovered. Most surprising, perhaps, was the discovery of unexpected phenomena in the planet's rings, including thousands of tiny wave-like features, some apparently caused by the gravitational influence of some of the satellites, and spoke-like features that may be electricially charged dust particles levitated above the main ring plane.

The Jupiter and Saturn data are still being studied by scientists.

Scientists and engineers at the Jet Propulsion Laboratory have been focusing on the Uranus encounter since Voyager 2 left Saturn behind in September 1981. All of Voyager's 11 science instruments are functioning and all will make observations of Uranus and its environment.

Because Uranus is about twice as far from Earth as Saturn, the rate at which Voyager will be able to transmit data to Earth is slower.

Normally, this would have seriously limited the number of photographic and other data that could be sent back to Earth, but engineers and scientists have programmed one of the spacecraft's computers to compress and encode the imaging data in order to return about 200 images a day. In addition, several antennas at each of NASA's Deep Space Network (DSN) sites will be electronically linked to increase their receiving power, allowing more of Voyager's faint radio signal to be captured. This technique, called arraying, greatly enhances the overall strength and quality of the signal received. Antenna arraying will be used at the Australia, Spain and California complexes.

Most of the key data obtained during the Uranus encounter and all of that during the closest approach will be received by the DSN's antenna complex in Canberra, Australia.

The Canberra complex, which also will be electronically linked with the Australian government's 64-m (210-ft) Parkes Radio Astronomy Observatory, is critical to the encounter for several reasons. The spacecraft track will be almost directly above the Australian complex during the encounter closest approach, allowing up to 12 hours of coverage of Voyager 2 daily. As a result of this geometric relationship, the spacecraft's signal quality will be enhanced because it will pass through a thinner slice of Earth's atmosphere than it will at the lower elevation at the antennas in California and Spain.

The Australian continent provides the added benefit of having large distances between antennas. The Parkes and Tidbinbilla antennas, for example, are 320 km (200 mi) apart. This reduces the risk that data at both stations might be subject to any degradation resulting from potentially simultaneous rain showers.

The Australian complex can accommodate a higher data rate than the other two DSN complexes both because of its advantageous viewing geometry in relation to the spacecraft, and because Voyager's signal quality will be improved by combining or arraying the output of several large antennas in Australia.

Antenna arraying also will be used at the California and Spain complexes.

Uranus is the third largest of the solar system's nine planets. Its polar axis lies nearly in the ecliptic plane rather than perpendicular to it, as most of the other solar system planets. Scientists do not know why Uranus is tipped 95 degrees from its vertical axis, but some speculate that early in its formation, Uranus was struck and the axis of rotation tipped by an object about the size of Earth.

Uranus orbits the sun once in 84 years, with one pole in sunlight for 42 years while the other pole is in darkness. When Voyager 2 approaches Uranus, the planet's south pole will be pointing toward the sun.

Because of the unique orientation of the Uranian system, the planet's polar region will dominate Voyager's view as the spacecraft approaches. The entire Uranian system will present a "bullseye" appearance to the spacecraft. Although Uranus will loom progressively larger in Voyager's field-of-view, the spacecraft's perspective on the planetary system essentially won't change until just hours before closest approach.

Uranus has five known satellites. They are considerably smaller than the Galilean moons of Jupiter, Saturn's Titan and Earth's moon, but they are still among the largest satellites in the solar system. Closest to the planet and smallest is Miranda, about 500 km (300 mi) in diameter. Next is Ariel, whose diameter is about 1,330 km (825 mi). Umbriel is the third satellite, with a diameter of about 1,110 km (690 mi).

Titania is fourth from Uranus and has a diameter of 1,600 km (995 mi). Outermost of the five is Oberon which, with a diameter of 1,630 km (1,010 mi), is the largest satellite of Uranus.

Very little is known about these moons. They could range in composition from being mostly rock to mostly ice. Scientists believe Uranus' satellites are probably similar to some of Saturn's.

They are about the same in size, but have water ice on their surfaces. They differ, however, in that they are darker. There is no evidence that they are uniformly gray -- they could display mottled dark and light surfaces like Jupiter's Callisto, or even show a surface as extreme as the black-and-white surface of Saturn's moon Iapetus.

Uranus is circled by at least nine thin rings that are among the darkest objects in the solar system -- as dark as charcoal. The outermost ring varies in size from 20 to 100 km (12 to 60 mi); two rings are about 10 km (6 mi) and two are about 3 km (2 mi). The widths of the other four are smaller, but have not been determined. Most are elliptical in shape. The rings' composition is not known, but some scientists believe that the ring particles may have contained methane which has decomposed into darker carbon materials.

Uranus is about 20 times farther from the sun than the Earth, four times farther than Jupiter and twice as far as Saturn. Uranus receives only one four-hundredth of the sunlight that Earth receives, one-sixteenth that of Jupiter and one-quarter that of Saturn.

Voyager's cameras therefore must take extremely long exposures in order to register images of the planet and its satellites.

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To cope with these constraints on Voyager's photography, a special technique called image-motion compensation will be used to prevent smearing of images at these low light levels. The technique was successfully tested at Saturn.

It involves rotating the spacecraft (which is traveling more than 45,000 mph) while the camera's shutter is open, in much the same way a photographer moves his camera while taking a picture of a speeding object.

Without image-motion compensation, the best detail visible at Miranda would be 56 km (35 mi). Using the technique, the cameras can record detail of 0.6 km (one-third mi). The technique will improve resolution of details on Oberon's surface from 48 km (30 mi) to 12.5 km (7.75 mi). Detail visible in images of Ariel will be improved from 50 km (30 mi) to 2.3 km (1.4 mi).

Voyager 2's photopolarimeter will observe two ring occultations similar to observations made at Saturn. Three of Uranus' rings will pass in front of the star Sigma Sagitarrii (Nunki) and all the rings will pass in front of Beta Persei (Algol). Based on how much starlight passes through the rings, the photopolarimeter will provide information on the width and thickness of the rings and the material they contain.

Radio science measurements will complement and extend this data using information from the spacecraft signal passing through the ring material. Radio science data on Uranus atmospheres, and ionospheres will be obtained as the spacecaft enters and exits occultation periods.

In addition to two cameras, photopolarimeter and a spacecraft radio Voyager carries an infrared interferometer/spectrometer and radiometer, an ultraviolet spectrometer, a cosmic-ray detector, a plasma instrument, a low-energy charged-particle detector, magnetometers, planetary radio astronomy receiver, and a plasma-wave instrument.

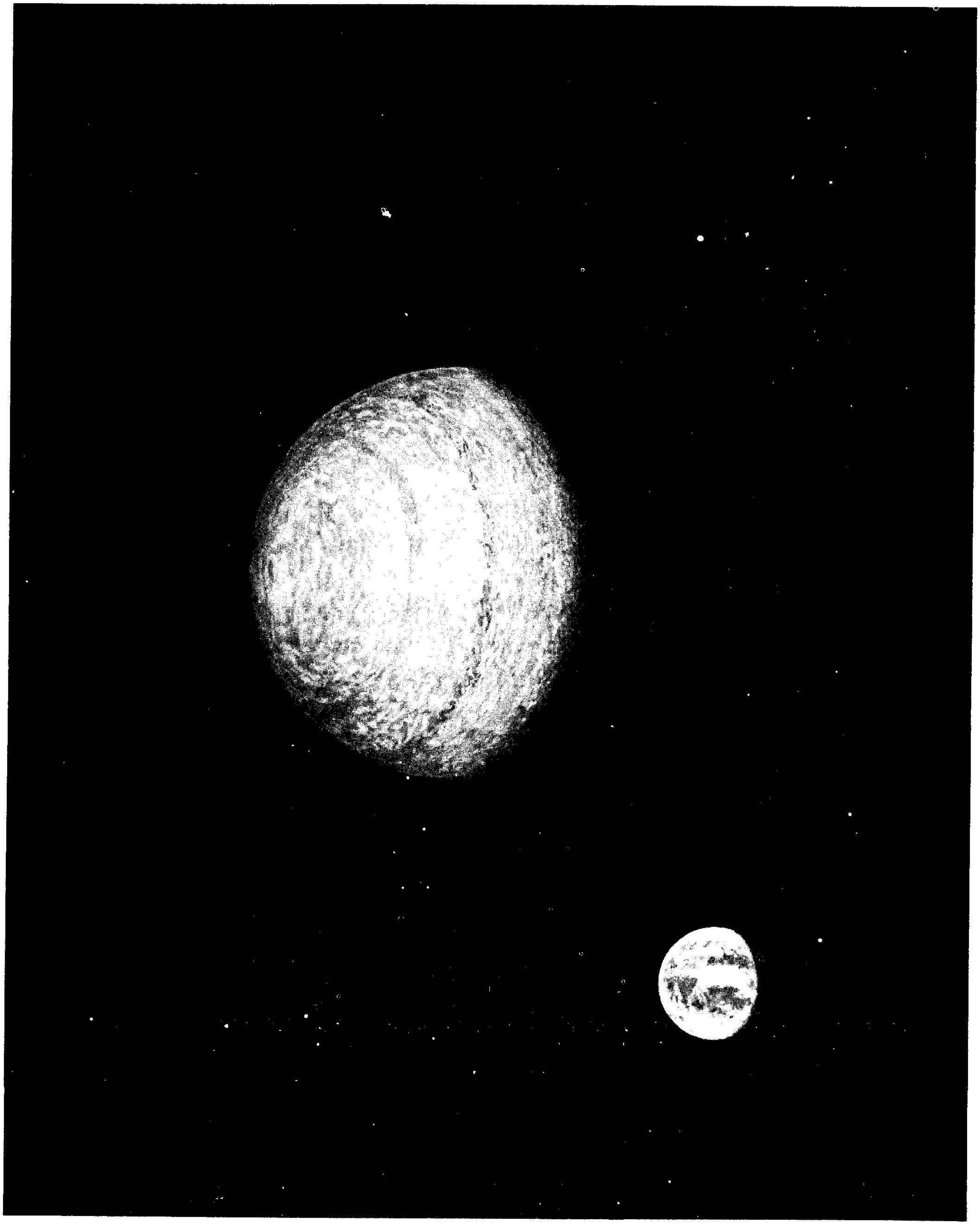
The Voyager spacecraft are based on the highly successful Mariner design. Each Voyager weighs 825 kg (1,819 lbs) and is dominated by its 3.66-m (12-ft) antenna. Electric power is provided by three radioisotope thermoelectric generators (RTGs).

This system is required because solar cells could not receive sufficient solar energy for the power needed at the great distances that the spacecraft travel from the sun.

When the Uranus encounter ends in February 1986, Voyager 2 will be on a course that will take it to Neptune, its last planetary visit on Aug. 25, 1989 (GMT).

The Jet Propulsion Laboratory in Pasadena, Calif., manages the Voyager project for NASA's Office of Space Science and Applications. Earl Montoya is Voyager Program Manager at NASA Headquarters, and Dr. William Brunk, NASA Headquarters, is Voyager Program Scientist. Richard P. Laeser of JPL is Voyager Project Manager and Dr. Edward C. Stone of the California Institute of Technology is Voyager Project Scientist.

(END OF GENERAL RELEASE; BACKGROUND INFORMATION FOLLOWS)



Uranus and Earth

URANUS

Uranus is one of the four giant gaseous planets of the solar system. It was the first planet to be discovered with a telescope, and was found by amateur astronomer Sir William Herschel on March 13, 1781. The planet has never before been encountered by a spacecraft.

The most distinctive feature of Uranus is its unusual rotational position, tipped over on its axis. Scientists theorize that early in Uranus' history, a collision with another, smaller body might have tilted the planet from a vertical or near-vertical axis to its present orientation. In the planet's 84-year-long solar orbit, one pole is in sunlight for 42 years while the other pole is in darkness. These factors are expected to give Uranus unusual weather patterns. The length of a Uranian day is uncertain, but direct measurements indicate it is either 16 or 24 hours. Theoretical models based on the rate of precession of the planet's rings set the day closer to 16 hours.

Uranus and Neptune are about the same size. Uranus is about 51,000 km (31,800 mi) in diameter; Neptune is about 49,600 km (30,500 mi). Based on their similar compositions and sizes, Uranus and Neptune can be considered as a set of twin planets (though the two are dissimilar in many ways), and Jupiter and Saturn as another set of twins.

The bulk of Jupiter and Saturn's composition is gas -- hydrogen and helium surrounding relatively small cores of mostly molten rock and various ices.

Uranus' and Neptune's cores are about the same size as Jupiter's and Saturn's. The atmospheres of Uranus and Neptune, however, are much smaller. The two may represent how Jupiter and Saturn might appear if stripped of much of their massive gas envelopes.

Uranus and Neptune's modest atmospheres consist mostly of gaseous compounds of hydrogen, carbon, nitrogen, oxygen and perhaps helium. In Uranus' case, scientists believe an ocean of melted water ice with dissolved ammonia could exist beneath its atmosphere and hazy cloud layer.

Each planet employs some mechanism to distribute the heat it absorbs and the energy it emits. Jupiter, Saturn and Neptune each have significant internal heat sources -- they emit more energy than they absorb from the sun, while Uranus, like Earth, emits very little heat of its own making. On Earth, sunlight, is absorbed mostly at the equator. From there, the oceans distribute the heat north and south to the poles to maintain global temperature equilibrium.

Uranus' southern hemisphere currently receives all the sunlight incident on the planet, so there may be significant meridional flows -- atmospheric motion that crosses the latitudes of the planet like the seams in a beachball -- carrying heat from one pole to the other.

Rings

There are nine thin, black rings known to surround Uranus. They were found in 1977 when Uranus passed in front of a bright star, affording astronomers the opportunity to detect the rings as they blocked out the light of the star. The outermost ring, called the epsilon ring, reflects only about 5 percent of the light it receives. It is about as dark as the black side of Saturn's moon Iapetus, or as dark as charcoal. The other eight rings are expected to be equally black. Inward from the epsilon ring they are: delta, gamma, eta, beta, alpha, and rings 4, 5 and 6. (The discrepancy in the nomenclature of the rings is due to their simultaneous discovery by two independent groups of observers. One group decided to call the rings by Greek letters, ordering them from the inside out. The other group numbered the rings they found and ordered them from the outside in).

Three of the rings, eta, gamma, and delta, are very nearly circular. The rest are somewhat eccentric. The epsilon ring is most unusual, being both quite eccentric and varying in width by tens of miles. It is not known if the rings formed with Uranus when the solar system originated 4.6 billion years ago, or if they are a more recent development -- perhaps the remnants of a broken-up moon, meteroids or due to a combination of these processes.

The darkness of the epsilon ring (it is the only ring whose brightness has been measured) implies that most of the particles lack bright water coatings, but they could be coated with a residue of carbon compounds leftover from methane decomposed by sunlight or by energetic particle radiation.

The Uranian rings are expected to share some of the physical characteristics unveiled in Saturn's rings by Voyagers 1 and 2. Scientists expect to find small shepherd moons, like those found at Saturn, which probably herd the rings into their unusual shapes.

Moons

Little is known of the five moons orbiting Uranus; even their sizes and masses are not well defined. They have icy surfaces but the amount of rock inside is not known.

Some scientists have suggested that some of the moons could have formed from the debris left over after a collision between Uranus and another body. In this scenario, a body one or two times the size of Earth smashed into Uranus, tipped it on its side, and splashed part of the planet's atmosphere into space. The resulting mix of rock and gases would have formed a disk around the planet, out of which the moons could have formed.

The moons are about the same size as the intermediate satellites of Saturn, such as Dione or Enceladus. The darkness of their surfaces suggests that they, like the rings, may have been darkened by the effect of radiation on methane. They could exhibit tectonic features, such as cracked surfaces or frozen flows of icy magma.

Perturbations of the Uranian rings detected from ground-based observations have been interpreted by some scientists as evidence for the possible existence of a small, sixth satellite orbiting between Miranda and the epsilon ring. If it (or other new moons) exists, it should be easily detectable by Voyager's instruments.

The Moons of Uranus

Moon	**Diameter** (km)	(mi)	**Dist. from center of Uranus** (km)	(mi)
Miranda	500±220	310±35	130,000	80,000
Ariel	1,330±130	825±80	192,000	119,000
Umbriel	1,110±100	690±60	267,000	166,000
Titania	1,600±120	995±70	438,000	272,000
Oberon	1,630±140	1,010±85	586,000	364,000

Magnetosphere

Scientists assumed that because evidence of auroral activity has been detected at Uranus, that it might possess a magnetic field. Auroras on Earth and Jupiter are caused by the interaction of their magnetic fields with the stream of atomic particles emitted by the sun, called the solar wind.

The magnetic field of Uranus, if one exists, will be unique in the solar system due to the planet's odd polar axis orientation (A planet's magnetic field is thought to be generated by fluid motion in the planet's interior, and rotates with the interior as well).

In those planets with a magnetosphere, the axis of the field is roughly aligned with the body's rotational axis. Since Uranus' rotational axis currently faces the sun, its magnetic field would meet the solar wind nearly pole-on. The magnetic field in the polar region would be funnel-shaped, dipping inward at the pole. This may allow the solar wind to penetrate closer to the planet than would otherwise be possible.

As with other planets, the solar wind would deform the other regions of the magnetic field to produce, in this case, a long tail extending directly away from the planet's northern pole. The magnetotail may also be twisted into a spiral by the rotation of the planet. In Uranus' case, the magnetosphere might extend 1 million km (620,00 mi) from the planet. Voyager's instruments could detect such a structure if it exists.

There may be energetic particles trapped within the Uranian magnetosphere (like those at Saturn). The resulting radiation effects could explain the moderately dark surfaces of the moons as well as the extremely dark rings.

Data from the planetary radio astronomy instrument on Voyager 2 are being analyzed daily for signals that would show evidence of a Uranian magnetic field. By early December 1985, however, the spacecraft already was much closer to Uranus than it was to either Jupiter or Saturn when their radio signals were first detected. No Uranian signals had yet been heard. Although the existence of a Uranian magnetic field cannot be ruled out, the presence of aurora-like emissions may not be an indication of a magnetic field, but may instead be airglow in the planet's atmosphere (Airglow is a phenomenon associated with photochemical reactions of atmospheric gases).

If Uranus has no magnetic field, the planet may interact with the solar wind in much the way Venus does. Venus has an almost nonexistent magnetic field. Thus its electrically-conductive ionosphere diverts the flow of the solar wind around the planet. The same situation could exist at Uranus, with the Uranian ionosphere meeting the solar wind in lieu of a magnetic field. The bowshock -- the area where the solar wind first responds to the presence of a planet -- would be close to Uranus on the sunward side and taper off into a tear-shaped wake behind the planet.

Uranus might also interact with the solar wind in much the same way as a comet does, resulting in a very weak bowshock and an ionized plasma tail behind the planet.

SCIENCE OBJECTIVES

Voyager 2's complement of 11 instruments will be dedicated to more than two dozen major scientific objectives during the Uranus encounter.

In January 1986, as it did at Jupiter in 1979 and Saturn in 1981, Voyager 2 will encounter a broad range of planetary phenomena. At Uranus, the spacecraft will find an atmosphere and weather system of potentially great complexity; a dark nine-banded ring system unique in orientation and composition; and a collection of at least five icy and/or rocky moons.

Scientists met in February 1984* to establish a scientific framework for the Voyager 2 encounters with Uranus and Neptune. Working groups compiled a list of high-priority Uranus science objectives, and Voyager 2 has been programmed to perform observations designed to meet these goals. Twenty-seven of these measurements will occur in the 96-hour near-encounter period of Jan. 22-26, 1986 -- most of them within 6 hours of the spacecraft's closest approach to Uranus.

Each Voyager carries 11 scientific instruments -- actually 10 plus the spacecraft radio. They can be divided into two general classes: those that require pointing (target-body sensors) and those that don't (fields and particles sensors).

There are five pointable sensors: the imaging science subsystem (consisting of wide- and narrow-angle television cameras), infrared interferometer spectrometer and radiometer, photopolarimeter subsystem, radio science subsystem, and ultraviolet spectrometer. All but the radio ride on the spacecraft's steerable scan platform.

The other six instruments measure energetic particles, radio emissions and magnetic fields, in space and near planets. They are the magnetic fields experiment (consisting of four magnetometers) plasma subsystem, low-energy charged-particle detector, cosmic-ray subsystem, plasma-wave subsystem and planetary radio astronomy experiment.

Voyager 2 observations with these instruments can be divided into four groups at Uranus: atmosphere, rings, satellites and magnetosphere.

*Proceedings published as Uranus and Neptune, NASA Conference Publication 2330, Jay T. Bergstralh, editor, National Technical Information Service, 1984.

Atmosphere

Voyager scientists hope to observe and define the global circulation and meteorology of the upper, visible clouds of Uranus, as well as the horizontal and vertical distribution of clouds and hazes.

The ultraviolet spectrometer will examine the upper atmosphere, while the infrared and radio science experiments will provide information on the composition, pressures and temperatures deeper in the atmosphere.

Various instruments, notably the infrared spectrometer, will be used to determine the heat balance at Uranus: the ratio of internal energy emitted to solar energy absorbed. Any measurable excess of energy -- as was found at Jupiter and Saturn -- would have important implications for theories on Uranus' formation and weather mechanisms.

Imaging of the sunlit southern hemisphere will help characterize wind speeds at different latitudes. Ultraviolet measurements -- building on those of the International Ultraviolet Explorer (IUE) from Earth orbit -- will search for auroral activity at the poles or find a more diffuse airglow emission.

Rings

The nine known rings of Uranus are so dark that many of the most important observations will occur after closest approach, when Voyager 2 can look at the rings as they are backlit by the sun.

Voyager's instruments will be used to determine the size, distribution and reflective properties of ring particles. Toward this end, Voyager will conduct both stellar occultation studies (measurements of starlight passing through the rings) and radio occultation studies, obtained when the spacecraft is passing behind the rings as viewed from Earth.

Photopolarimeter and radio science will pinpoint the locations of the known rings -- and perhaps reveal others -- while providing information on their structures. Voyager will search for tiny satellites embedded in the rings and for satellites that serve as "shepherds," herding material between them.

Satellites

The satellites are expected to be airless bodies, so most of what can be learned will come from imaging of their surfaces. Voyager 2's cameras will acquire images at the closest approaches to each of the five known moons; longer-range photography will produce full-disk color pictures.

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Voyager imagery will provide information on sizes, shapes, surface markings and surface relief. The color images will provide information on the distribution of different materials on the surface, and about any processes that have modified the moons' surfaces. Precise radio tracking of the spacecraft -- especially during the close pass of Miranda -- could provide improved mass estimates for some or all of the moons.

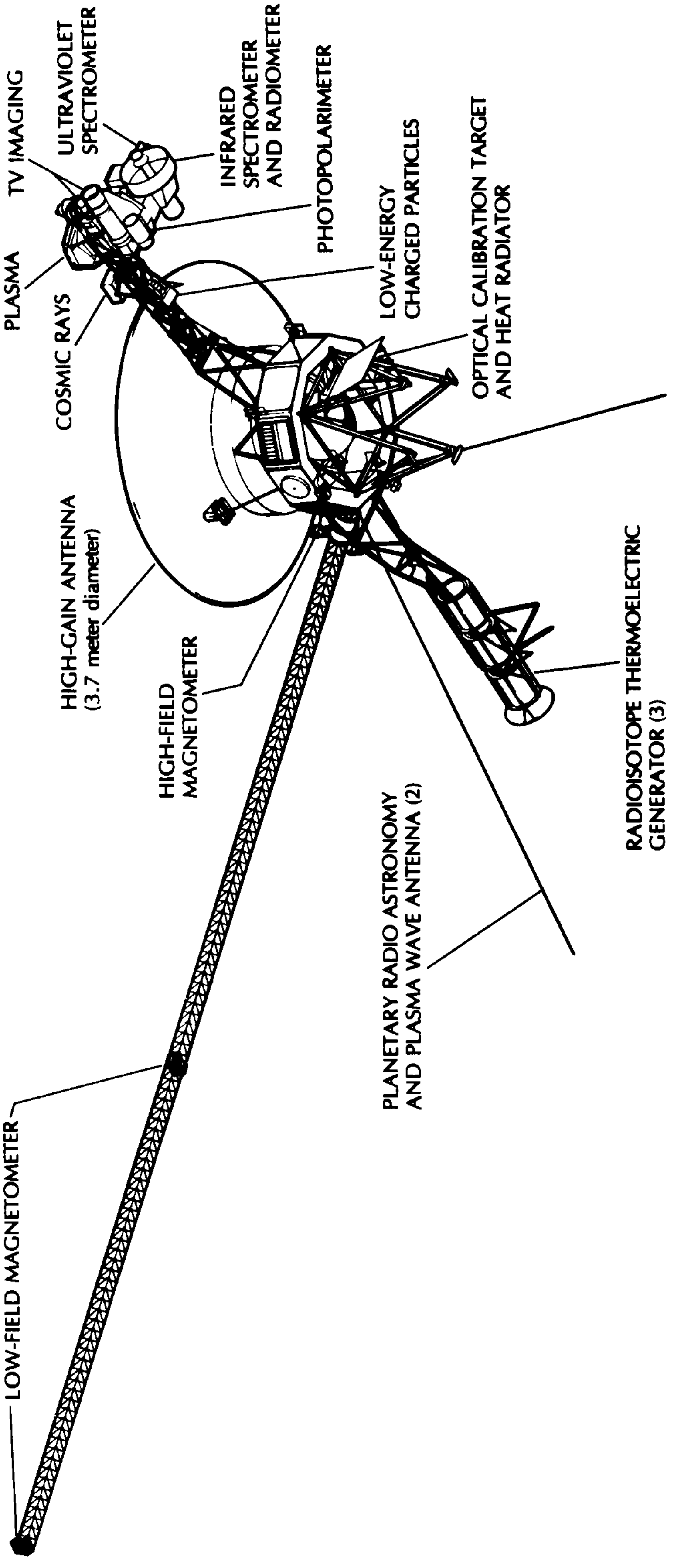
The cameras may also reveal the existence of previously unknown satellites, including ring shepherds.

Magnetosphere

The excess radiation revealed by the IUE spacecraft had been interpreted as auroral emission --an indication that Uranus may possess a magnetic field. More recently, however, the ultraviolet emissions have been interpreted as being atmospheric airglow, which would not necessarily be indicative of a planetary magnetic field. No additional evidence of a magnetic field has been observed.

If the planet does have a magnetosphere, measurements by the planetary radio astronomy experiment of the rotation of the magnetic field would, by inference, give the rotation rate of Uranus' interior.

Because of its rotational orientation, Uranus could offer the first example of a "pole-on" magnetosphere. In such a configuration, the solar wind might flow deep down into the polar regions, rather than arriving and being strongly deflected in the equatorial regions as at Earth.


LOW-FIELD MAGNETOMETER
PLANETARY RADIO ASTRONOMY AND PLASMA WAVE ANTENNA (2)
HIGH-FIELD MAGNETOMETER
RADIOISOTOPE THERMOELECTRIC GENERATOR (3)
HIGH-GAIN ANTENNA (3.7 meter diameter)
COSMIC RAYS
PLASMA
OPTICAL CALIBRATION TARGET AND HEAT RADIATOR
LOW-ENERGY CHARGED PARTICLES
PHOTOPOLARIMETER
TV IMAGING
INFRARED SPECTROMETER AND RADIOMETER
ULTRAVIOLET SPECTROMETER

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SCIENCE EXPERIMENTS

Imaging Science Subsystem

The imaging science subsystem (ISS) will observe and record the visible characteristics of Uranus, its atmosphere, satellites and rings. In addition, groups of pictures returned by the ISS wide- and narrow-angle television cameras will be used to map satellite surfaces. Images of the satellites against the background stars will help Voyager engineers navigate the spacecraft.

Specific ISS goals at Uranus are to obtain high-resolution photography of atmospheric motions, colors and unusual features (analogous to Jupiter's Great Red Spot and similar smaller spots), and to characterize the vertical structure of the atmosphere, comparative and detailed geology of the satellites, satellite size and rotation, and details of the rings.

The ISS consists of two television-type cameras mounted on the scan platform. The wide-angle camera has a focal length of 200 mm and is sensitive in the range from 4,000 to 6,200 angstroms. The narrow-angle camera has a focal length of 1,500 mm and can image in the range from 3,200 to 6,200 angstroms.

For several days before and after closest approach, Voyager will have several simultaneous imaging opportunities: high-resolution photography of Uranus as it grows larger than the field of view; a close pass by Miranda of just 29,000 km (18,000 mi); more distant photography of the other satellites; and high-resolution imaging of the rings.

To exploit such a variety of opportunities, it is necessary for the spacecraft to return large quantities of imaging data over a wide range of telemetry rates in realtime. Data also can be recorded on board the spacecraft, as during the spacecraft's occultation by Uranus (when the spacecraft will be behind Uranus and out of radio touch with Earth) and later played back to Earth.

Each camera is equipped with a filter wheel whose individual filters have a wide variety of uses. These filters permit specified types or wavelengths of light to pass through and block all other types from reaching the camera detectors.

The wide-angle camera carries one clear filter; one filter each in blue, green and orange wavelengths; a sodium-D filter, and two filters for study of the distribution of atmospheric methane. The narrow-angle camera carries two clear filters, two green filters and one filter each of violet, blue, orange and ultraviolet.

The design of the Voyager imaging system was based on those of previous Mariner spacecraft, with advances and changes dictated by the specific requirements of the Jupiter and Saturn encounters. The Uranus encounter takes the spacecraft beyond the environment and lifetime for which the cameras were designed, but no problems are anticipated.

Image-smear conditions, will be much more severe at Uranus due to lower light levels. The relatively low reflectivity of the rings and satellites, will necessitate longer exposures. (Uranus receives one-sixteenth the sunlight received at Jupiter, about one-quarter that at Saturn.) A technique called image-motion compensation (see "Customizing Voyager 2 for Uranus") will be used to prevent image smearing.

The increasingly remote distance of Voyager 2 also affects the rate at which the spacecraft can transmit pictures to Earth. Each picture consists of more than 5 million bits of information. At Jupiter, Voyager could send back as many as 75 pictures per hour. At Uranus, Voyager will be able to send back a maximum of 12-17 pictures per hour. Even this rate of return (about 200 pictures per day) can be accomplished only through special techniques of data compression and encoding, in which the 5 million bits per picture will be compressed to 2 million bits and fed into the telemetry stream at a lower rate than at Jupiter.

On the approach to Uranus, the narrow-angle camera will photograph the planet at planned regular intervals in an attempt to discern cloud motions. Resolution will improve steadily from about 1,600 km (990 mi) to a few hundred kilometers.

About one week from closest approach, the disk of Uranus will exceed the field-of-view of the narrow-angle camera. At that time, the detail visible will be about 130 km (81 mi). The wide-angle camera will begin its work, and the narrow-angle camera will shift its focus to portions of the planet that warrant special scientific interest.

The ISS weighs 38.2 kg (84.2 lbs) and uses 41.9 watts of power.

Dr. Bradford A. Smith of the University of Arizona is imaging team leader.

Infrared Interferometer Spectrometer and Radiometer

The infrared interferometer spectrometer and radiometer (IRIS) will focus primarily on Uranus' atmosphere. The instrument will gather data on:

*Uranus' heat balance -- the amount of energy the planet emits versus the amount it receives from the sun;

*The temperature, structure, dynamics and composition of the atmosphere, in particular the ratio of helium to hydrogen;and

*The characteristics of clouds and aerosols in the atmosphere.

Uranus will be especially interesting because of its unusual polar orientation. Comparison of the sunlit south pole and dark north pole is an important IRIS task.

The telescope-based IRIS system provides broad spectral coverage in the infrared from 2.5 to 50 microns and visible radiometry from 0.3 to 2 microns.

The instrument weighs 18.4 kg (40.6 lbs) and dissipates 14 watts average power.

Dr. Rudolf A. Hanel of NASA's Goddard Space Flight Center, is principal investigator.

Photopolarimeter Subsystem

The photopolarimeter subsystem (PPS) will study aerosol particles in Uranus' atmosphere, and the textures and compositions of the surfaces of the satellites. It also will measure the size, albedo and spatial distribution of particles in the rings, as well as the rings' optical and geometric thickness.

The PPS consists of a telescope fitted with filters and polarization analyzers. The system measures the way its targets reflect light, and hence, determines their structures, as the reflected light is polarized by chemicals and aerosols (in the case of Uranus' atmosphere) or by small particles (in the rings and on the solid satellite surfaces).

A special high-speed ultraviolet photometry mode will be used for two stellar occultations of Uranus' rings. By measuring the light from two stars -- Algol (Beta Persei) and Nunki (Sigma Sagittarii) -- seen through the rings, the PPS will help determine ring structure with high resolution.

The experiment weighs 4.41 kg (9.72 lbs) and uses 2.4 watts average power.

Dr. Arthur L. Lane of the Jet Propulsion Laboratory is principal investigator.

Radio Science Subsystem

Voyager 2's two-way radio communications link with Earth also will be used to conduct scientific investigations at Uranus. Precise measurements of the phase and amplitude of the radio signal can be analyzed to detect minute variations due to the passage near or through the planetary atmosphere and rings. At Uranus, the radio science subsystem (RSS) will:

*Study the structure of the atmosphere, including temperature, pressure, density and turbulence as the spacecraft passes behind the planet;

*Determine the optical depth, structure and particle size distribution of the Uranian rings, again during occultation passage;

*Determine the mass and gravity field of Uranus and its satellites; and

*Conduct experimental tests of Einstein's theory of relativity when the radio signal passes close to the sun to determine the influence of the sun's gravity on the radio signal.

Dr. G. Len Tyler of the Center for Radar Astronomy at Stanford University is team leader.

Ultraviolet Spectrometer

The ultraviolet spectrometer (UVS) will study Uranus' atmosphere, gathering data on its composition by means of the techniques of atomic emission and atomic absorption. UVS data will be used at Uranus to:

*Determine distributions of major constituents of the upper atmosphere as a function of altitude;

*Measure the absorption of solar ultraviolet radiation by the upper atmosphere as the sun is occulted by Uranus;

*Measure ultraviolet airglow emissions of the atmosphere from the bright disk of the planet, its bright limb (the outer edge of the disk), terminator (the dividing shadow between night and day) and dark side; and

*Determine the auroral morphology at Uranus, and the results of an orientation that places one pole toward the sun and the other in darkness for years at a time.

In addition, the UVS will continue to study the distribution and ratios of hydrogen and helium in inter-planetary and interstellar space.

The UVS employs a grating spectrometer that is sensitive to ultraviolet radiation in the range from 500 to 1,700 angstroms. The experiment weighs 4.49 kg (9.90 lbs) and uses 2 watts of power.

Dr. A. Lyle Broadfoot of the University of Arizona is principal investigator.

Cosmic-Ray Subsystem

The primary function of the cosmic-ray subsystem (CRS) is to measure the energy spectrum of electrons and cosmic-ray nuclei. The seven energetic particle telescopes in the CRS are also designed to:

*Determine the elemental and isotopic composition of cosmic-ray nuclei and solar energetic particles;

*Determine the distribution and composition of high-energy particles trapped in the Uranian magnetic field; and

*Determine the intensity and directional characteristics of energetic particles as a function of radial distance from the sun, and determine the location of the modulation boundary where the influence of the heliosphere ends and true interstellar space begins.

The CRS uses seven independent solid-state-detector telescopes. Working together, they cover the energy range from 0.5 million to 500 million electron volts.

The experiment weighs 7.52 kg (16.6 lbs) and uses 5.2 watts of power.

Dr. Edward C. Stone of the California Institute of Technology is principal investigator.

Low-Energy Charged-Particle Detector

The low-energy charged-particle detector (LECP) is designed to characterize the composition, energies and angular distributions of charged particles. In addition to studying Uranus' magnetosphere, the LECP will investigate:

*The composition of low-energy charged particles trapped in the Uranian magnetic field;

*Interactions of charged particles with the satellites and rings;

*The propagation of solar particles in the vicinity of Uranus;

*The quasi-steady interplanetary fluxes and high-energy components of the solar wind; and

*The origins and interstellar propagation of galactic cosmic rays (those originating outside the solar system).

Two solid-state particle detector systems are mounted on a rotating platform. Their sensitivity to charged particles ranges from 15,000 to more than 160 million electron volts.

The LECP weighs 7.47 kg (16.5 lbs) and draws 4.2 watts of power during encounter.

Dr. S.M. (Tom) Krimigis of the Applied Physics Laboratory at Johns Hopkins University is principal investigator.

Magnetic Fields Experiment

The magnetic fields experiment (MAG) will determine the existence and character of a Uranian magnetosphere. The four magnetometers making up the experiment will study the interaction of the magnetic field with satellites orbiting within it, and study the interplanetary-interstellar magnetic fields in the vicinity of Uranus.

Two low-field magnetometers are mounted on a 13-m (43-ft) boom away from the magnetic field of the spacecraft itself. Two high-field magnetometers are mounted on the spacecraft body. The low-field sensors can measure fields as weak as 0.002 gamma (or about one ten-millionth that of the Earth's equatorial field); the high-field sensors can measure fields more than 30 times stronger than that at Earth's surface.

Total MAG experiment weight is 5.5 kg (12 lbs). The experiment uses 3.2 watts of power.

Dr. Norman Ness of NASA's Goddard Space Flight Center is principal investigator.

Planetary Radio Astronomy Experiment

Voyager 2's planetary radio astronomy experiment (PRA) will search for and study a variety of radio signals emitted by Uranus. The PRA will determine the relationship of these emissions to the satellites, the magnetic field, atmospheric lightning and plasma environment.

The detector also measures planetary and solar radio bursts from new directions in space and relates them to measurements made from Earth.

Using two 10-m (33-ft) electric antennas as detectors, which it shares with the plasma-wave subsystem, the PRA receiver provides coverage from 20 kilohertz to 40.5 megahertz in the radio-frequency band.

The instrument weighs 7.66 kg (16.9 lbs) and uses 6.8 watts of power.

Dr. James W. Warwick of Radiophysics Inc., Boulder, Colo., is principal investigator.

Plasma Subsystem

The plasma subsystem (PLS) studies the very hot ionized gases, or plasmas, that exist in interplanetary regions and within planetary magnetospheres. About 99 percent of the matter in the universe is in the plasma state, mostly at temperatures in excess of 10,000 degrees Kelvin (17,500 degrees Fahrenheit). Among its several scientific objectives, the PLS will:

*Study the overall extent and configuration of Uranus' magnetosphere and the nature and sources of the internal plasma;

*Measure the properties of the solar wind (density, temperature and velocity) as it flows into the outer solar system and beyond;

*Study the interaction of the solar wind with Uranus and the other outer planets; and

*Determine the extent of the solar atmosphere (solar wind) and the nature of the boundary between the sun's atmosphere and the interstellar medium.

The PLS consists of two plasma detectors that are sensitive to solar and planetary plasmas -- both the positive ions and electrons -- with energies between 10 and 6,000 electron volts.

The experiment weighs 9.89 kg (21.8 lbs) and draws 8.3 watts of power.

Dr. Herbert S. Bridge of the Massachusetts Institute of Technology is principal investigator.

Plasma-Wave Subsystem

Voyager's plasma-wave subsystem (PWS) is designed to measure the electric-field components of local plasma waves. At Uranus, the PWS will measure the density and distribution of plasma, interactions of plasma waves with energetic particles, and the interactions of the Uranian satellites with the planet's magnetosphere.

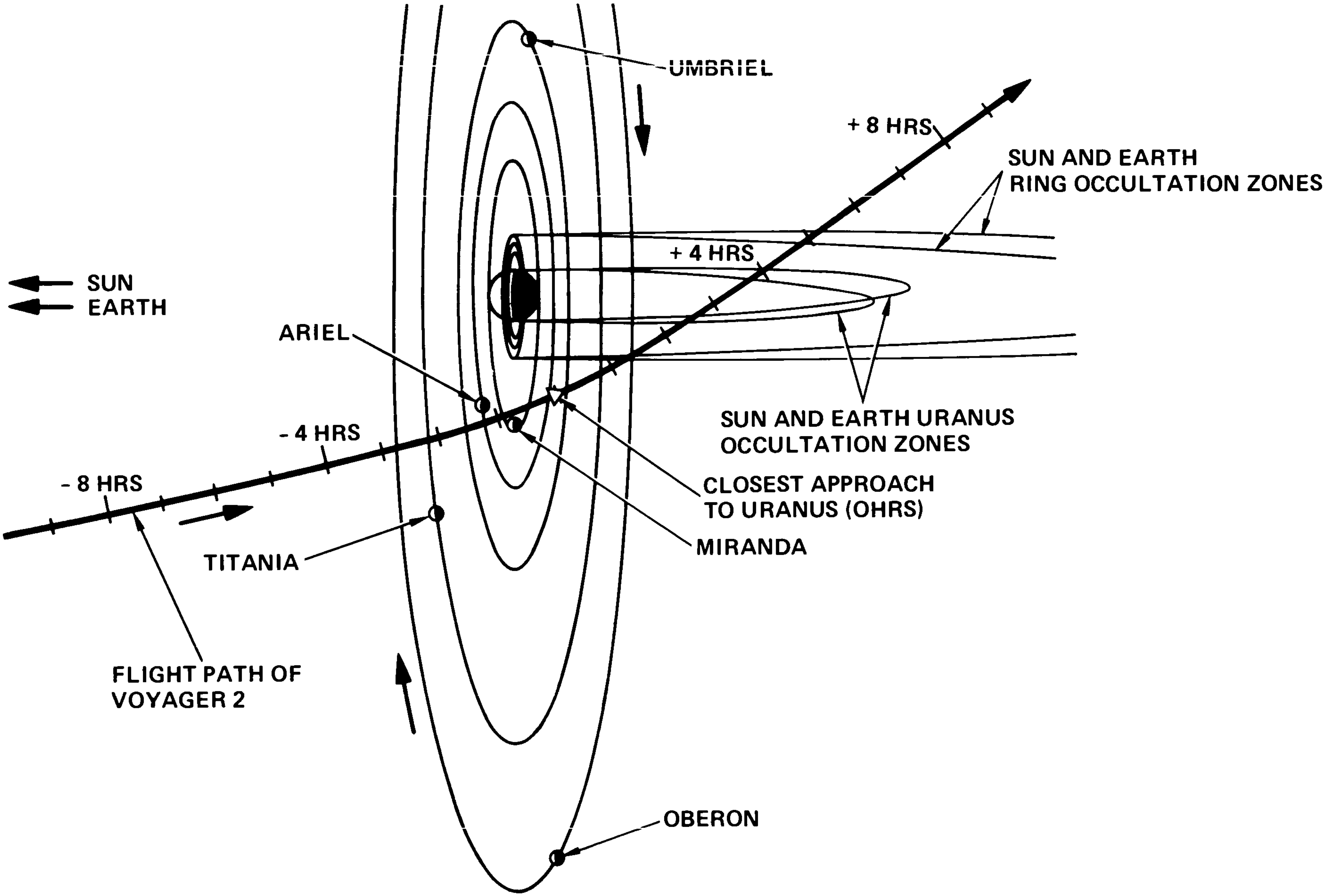
The PWS will provide key information on phenomena related to the interaction between plasma-waves and particles that control the dynamics of the magnetosphere. The satellites of Uranus may provide important localized sources of plasma and field-aligned currents, which could significantly affect the trapped-particle populations.

Two extendable electric antennas, shared with the planetary radio astronomy experiment, serve as plasma-wave detectors. The PWS system covers the frequency range of 10 hertz to 56 kilohertz. In normal mode, the PWS acts as a scanner, stepping from one frequency to another. In a second mode at selected times during encounter, the system can record electric-field waveforms across all frequencies in a broad band (50 hertz to 10 kilohertz).

The experiment weighs 1.37 kg (3.02 lbs). It uses 1.4 watts of power in normal step-frequency mode and 1.6 watts in the step-frequency-plus-waveform-analyzer mode.

Dr. Frederick L. Scarf of TRW Defense and Space Systems Group, is principal investigator.

VOYAGER 2's FLIGHT PAST URANUS
(VIEW IS VERTICAL TO PLANE OF FLIGHT PATH)



CUSTOMIZING VOYAGER 2 FOR URANUS

Voyager 2 is a relatively old spacecraft. When launched in 1977, the two Voyagers were funded to conduct Jupiter and Saturn encounters only, so the spacecraft were designed to operate at their peak performance levels for about 5 years.

Since then, Voyager engineers and science planners have designed new techniques for collecting, processing and sending data to allow Voyager 2 to carry out a full menu of experiments and observations at Uranus and Neptune. To this end, Voyager 2 has been heavily reprogrammed using earth-based commands during its flight between Saturn and Uranus. Its six on-board computers now incorporate newly-developed and more optimum methods of processing data, such as data compression. Large savings in transmitted signal power can be effected by sending only changes in the data, rather than the complete data set. The increasing distance between the spacecraft and tracking stations on Earth deceases the signal strength.

At Jupiter, data rates of 115,200 bits per second (bps) were possible; at Saturn, the rate had dropped to 44,800 bps. At Uranus, the spacecraft signal will be considerably weaker, but the same signal, received at two or more antennas (different groupings of 34-m (112 ft) and 64-m (210 ft) antennas) at each of NASA's three Deep Space Network (DSN) complexes, will be combined using a technique called arraying. This technique reinforces the strength of the signal received by electronically combining the same telemetry recorded at more than one station. Arraying will make possible a data rate of 21,600 bps at Uranus. Without arraying, fewer than half the observations planned could be performed and the data returned to Earth. The Australian government has provided NASA with use of its Parkes Radio Astronomy Observatory 64-m antenna to be specially instrumented and arrayed with the Canberra DSN complex during critical phases of the Uranus and Neptune encounters.

While the data rates will be much lower at Uranus, the data compression technique makes it possible to squeeze as many as 200 images a day using the relatively weak data stream signal strength expected during the encounter. This has been made possible inpart by reprogramming one of six computers on the spacecraft to preprocess all imaging data prior to its transmission to Earth. Instead of transmitting the full eight bits (containing 256 levels of gray) for each picture element, or pixel, only the difference between the brightness of successive pixels is transmitted. The result of this image data compression will be at least a 60 percent reduction in the number of bits needed per image.

Computer-processing of the imaging data at JPL will restore the correct brightness to each pixel to produce complete black-and-white and color images.

From Uranus, the minimum amount of time one picture will take up in Voyager's radioed data stream will be four minutes, compared to 2.4 minutes at Saturn and .8 minutes at Jupiter. Without the new image data compression technique, each picture would take up nearly 13 minutes in the data stream, severely limiting the number of images that could be returned.

Voyager 2 will be flying past Uranus and its moons at a velocity of more than 45,000 miles an hour. This poses a problem for the cameras on board: to get an unsmeared photo of an object, the camera has to track the image while the shutter is open. In addition, Uranus is twice as far from the sun as Saturn; light levels are four times lower and the targets have inherently darker surfaces, so longer exposure times will be required. All of these factors make the potential of image-smearing more of a problem.

Image-motion compensation, a technique conceived since launch, involves turning the spacecraft itself. This technique worked successfully in minimizing image-smear in close-up photography of Saturn's moons. It will be used for most of Voyager's closest approaches to the moons and rings of Uranus.

The most challenging photo opportunity exists at the innermost moon Miranda. Photographing this small, dark object at relatively close range, 29,000 km (18,000 mi), requires that the spacecraft rotate at a rate of more than 1/30th of a degree per second. This rate of rotation is in excess of that allowed by the on-board computer that maintains the spacecraft attitude. If such a roll were normally attempted, the on-board computer would direct Voyager to override the command and return to a stable position to prevent it from losing contact with Earth. Voyager engineers have designed and tested a method to override this safeguard and to safely turn the spacecraft faster in order to allow clear close-ups of Miranda.

VOYAGER 2 SPACECRAFT HEALTH

On April 5, 1978, the spacecraft's computer-command subsystem automatically switched to the back-up receiver. The back-up receiver, however, had hitherto concealed a problem of its own -- a faulty tracking-loop capacitor -- meaning that the receiver could not lock strongly on to the frequency of the transmitted signal. This meant that the ground transmitter had to send the precise frequency, which, after undergoing change (Doppler shift) while traveling the distance between the Earth and spacecraft, had to match the frequency that the receiver on the spacecraft was expecting. That frequency depends on a number of factors, including the receiver's temperature. When the prime receiver was turned back on, it failed almost immediately -- requiring that the rest of the mission be flown on the malfunctioning back-up receiver.

Voyager engineers have determined how the tuning depends on temperature, and how the operation of different subsystems onboard affects the temperature of the receiver. Even so, there is a period after any change in the spacecraft's configuration when it is impossible to know the receiver's temperature with adequate precision. As a result, commands cannot be routinely transmitted to Voyager after a change in the spacecraft configuration until the receiver temperature has had time to stabilize.

If need be, controllers can send commands to the spacecraft at different frequencies in rapid succession to ensure that one will be picked up by the receiver. This, and other techniques to work around the crippled receiver were successfully employed at Jupiter, and have been further refined in ensuing years.

There is a chance that the back-up receiver could fail or lose contact with Earth permanently. The Voyager team has planned against this possibility by programming the spacecraft computer with simplified encounter routines for execution at Uranus. The spacecraft has been instructed to send data back to Earth even in the event that it loses uplink contact.

In 1981, Voyager 2's scan platform jammed in one axis just after its Saturn encounter. The jamming prevented further pointing of the instruments for the duration of the encounter.

After 2 days, the platform was again movable. Three years of analysis and testing showed that the problem was due to a loss of lubricant and consequent damage to a bearing in the high-speed gear train of the platform. The lubricant apparently migrated back into the gear train after a short period of rest.

Voyager engineers have determined that slow-rate motion of the platform can be safely accomplished during the Uranus encounter, and a prohibition against moving the platform at a high rate will help ensure that the platform is fully usable when the spacecraft reaches Neptune.

In addition, tests designed to detect the onset of another similar failure of the scan platform have been strategically placed in the command sequences that will be executed during the encounter. In the event Voyager senses another such problem approaching, it will execute a back-up near-encounter command sequence which avoids use of critical components that could fail.

MISSION GROUND OPERATIONS

Commands for controlling all of Voyager 2's systems and operations are sent to the spacecraft in a single beam of radio signals from an antenna at one of NASA's Deep Space Network (DSN) complexes. One command load of up to 2,500 18-bit words can contain instructions for sequences of activities for the spacecraft to carry out over a period ranging from 2 days to 6 months.

The Voyager science teams determine the observations needed to be made to accomplish mission objectives. In turn, the Voyager sequence team designs blocks of time in which the spacecraft will make the science observations as it concurrently performs engineering and navigation tasks. The team tests the sequences with computer-based simulations of the spacecraft to ensure that they are consistent with the spacecraft's hardware, software and operational constraints.

The Voyager project has maintained nearly the same operating procedures that were employed during the Jupiter and Saturn encounters, but with about one-third the staff. This has resulted in fewer but longer command transmission loads during the cruise between Saturn and Uranus, and limited the number of calibrations performed.

The DSN is comprised of large antennas at three communications complexes, in Spain, Australia and California.

Commands are sent at a rate of 16 bits per second through the antenna dishes at any one of the stations. Traveling at the speed of light, they will reach the spacecraft (at Uranus) in about 2 hours and 45 minutes. With this long delay, engineers on the ground are unable to respond quickly if a spacecraft problem develops. For this reason, the spacecraft's master computer, called the computer command subsystem (CCS), has been programmed with a set of stored responses to anticipated problems.

The computer allows the spacecraft to act autonomously and quickly to protect itself from situations that could threaten spacecraft communications or operations. The CCS also contains the back-up mission load (BML), which carries basic commands that would allow Voyager 2 to conduct rudimentary investigations of Uranus if the spacecraft's radio were to fail.

Occasionally the need arises to change the state of the spacecraft or one of its instruments beyond the scope of the commands already in the spacecraft computer. Commands of this type are called realtime commands, and are usually sent for immediate execution by the spacecraft.

The telemetry received at the complexes is transmitted to JPL via wide-band and/or high-speed, telephone-quality data lines. The wideband lines are primarily used for high-bit-rate science telemetry, while high-speed lines are used for engineering telemetry and low-bit-rate science collected during the cruise phase.

Overseas lines are routed through NASA's Goddard Space Flight Center via satellite links. The Goldstone transmissions are sent directly to JPL through ground microwave stations.

Both wide-band and high-speed transmissions are received at JPL by the Network Operations Center (NOC), where they are logged on tape and also routed in realtime to the Mission Control and Computing Center for further processing.

All Voyager telemetry received and processed by the NOC is routed to the Mission Control and Computing Center (MCCC). The MCCC is responsible for display, control, decoding and routing of realtime telemetry to the Test and Telemetry System (TTS) and the JPL's Multimission Image Processing Laboratory (MIPL). The TTS displays engineering telemetry in realtime for the spacecraft team and the mission control team, and processes and displays science data for each of the science teams.

Imaging data are transferred to the MIPL for processing and analysis. Here, the imaging data are decompressed. During this process, the images can be enhanced to bring out subtle features, and in some cases, corrected for errors.

All imaging and other data are collected and processed into Experiment Data Records (EDR), which contain all available science and engineering data from a given instrument. The EDRs are the final data product forwarded to investigators for analysis. A companion record called the Supplementary Experiment Data Record (SEDR) accompanies the EDRs and contains the best estimate of the conditions under which the observations were taken.

DEEP SPACE NETWORK SUPPORT

The Uranus encounter presents an unprecedented challenge in deep-space communication. The Voyager X-band radio signal, for example, will be less than one-sixteenth as strong as it was at Jupiter in 1979. NASA's Deep Space Network (DSN) has just undergone a major upgrade adding among other capabilities: arraying and new 34-m antennas and automatic network monitor and control which will complement improvements in the Voyager flight data system program, and significantly increase the potential data return.

The DSN has carried out all tracking and communication with the Voyagers since injection onto their interplanetary trajectories after launch.

DSN stations are located around the world, in multiantenna complexes at Goldstone, in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. The three complexes are spaced at widely separated longitudes so that spacecraft can be in continuous view as the Earth rotates.

Each location is equipped with a 64-m (210-ft) antenna, 34-m (112-ft) antenna and a 26-m (85-ft) antenna. In addition, a high-efficiency 34-m antenna has been recently added at Goldstone and Canberra. A third such antenna is scheduled to begin operations at Madrid in March 1987, in anticipation of Voyager 2's 1989 encounter at Neptune.

In addition to the giant antennas, each of the complex's signal processing centers house equipment for transmission, receiving, data-handling and interstation communication. The downlink radio frequency system includes cryogenically-cooled, low-noise amplifiers.

Uplink

The uplink operates at S-band radio frequency (2,113 megahertz), carrying commands and ranging signals from ground stations to the spacecraft. The 64-m antenna stations have 400-kilowatt transmitters (normally operated at 60 kw for Voyager); transmitter power at the standard 34-m stations is 20 kw. The high-efficiency 34-m antennas at Goldstone and Canberra are presently used only for reception of spacecraft signals.

Downlink

The downlink is transmitted from the spacecraft at S-band (approximately 2,295 MHz) and X-band (approximately 8,415 MHz) frequencies. All the standard 34-m antennas and the 64-m antennas can receive the S- and X-band signals simultaneously; the high-efficiency 34-m antennas receive only X-band transmissions.

Arraying

During low telemetry rates cruise phase, a combination of 34-m or 64-m support for 16 hours per day is satisfactory. During critical mission high telemetry rate phases, Voyager requires continuous 34-m and 64-m coverage of the spacecraft and the arraying of antennas. At the Uranus encounter, all DSN antennas at each longitude will be arrayed, so that their combined collecting areas will increase the amount of signal captured and thus improve the potential for high-rate, low-error data return. In the case of Canberra, the three DSN antennas one 64-m and two 34-m will be arrayed for Voyager encounter using the 64-m Parkes Radio Astronomy Observatory which is operated by the Australian Central Science and Industry Research Organization.

At Saturn, 10 astronomical units (AU) from Earth, the signal strength supported a maximum data rate of 44,800 bits per second (bps). At Uranus, 19 AU away, the maximum supportable rate will be 21,600 bps; under special conditions, 29,900 bps may be used.

Arraying of the DSN tracking antennas will allow project engineers to approximately double the collecting area and increase the expected signal strength to only half -- instead of one-fourth the Saturn level when Voyager 2 reaches Uranus.

This is accomplished in the following manner by the new 34-m high-efficiency antennas at Goldstone and Canberra which will each effect a 25 percent increase in potential data. The 64-m Parkes antenna in Australia (arrayed with the Canberra DSN stations -- by means of a 320-km (200-mi) microwave link -- will effect at least a further 50 percent increase in collection area.

Australian activities will be critical to encounter support, because the high southern (-23 degree) declination of Voyager 2 will result in long, 12-hour spacecraft view periods at Canberra and 9-hour viewing at Parkes. (The shorter time at Parkes results from antenna pointing constraints). The quality of data received at the Australian facility is also likely to be higher than that received in California and Spain because of the large distances between antennas, which decreases the risk of data being lost due to local weather conditions.

The combined Canberra-Parkes facilities will obtain the critical closest-approach imaging and science data for Uranus and all its satellites on encounter day, in addition to data recorded on the spacecraft and played back the next day. This Canberra-Parkes array is also expected to obtain various telemetry data during closest approach, and all radio science data during the critical Uranus and ring occultation periods on encounter day. In all, the Parkes Radio Astronomy Observatory will provide 61 passes of array support, including daily array support for three weeks in January 1986.

VOYAGER MISSION SUMMARY

Voyager 2 was the first of the two Voyagers to begin the journey to the outer planets. It was launched from Cape Canaveral, Fla., aboard a Titan-Centaur launch vehicle at 10:29 a.m. EDT on Aug. 20, 1977.

Voyager 1 was launched 16 days later at 8:46 a.m. EDT Sept. 5. Flying a shorter and faster route to Jupiter, it overtook Voyager 2 on Dec. 15, 1977. At the time, they were 170 million km (105 million mi) from Earth.

Both spacecraft entered the asteroid belt, a band of rock and dust 360 million km (223 million mi) wide that circles the sun between the orbits of Mars and Jupiter. Both spacecraft left the asteroid belt without incident: Voyager 1 flew out on Sept. 8, 1978, and Voyager 2 on Oct. 21, 1978.

Voyager 1 made its closest approach to Jupiter at 7:05 a.m. EST on Mar. 5, 1979, at an altitude of 278,000 km (173,000 mi). It encountered the four Galilean satellites after passing Jupiter, and began its 20-month cruise to Saturn, boosted on its way by Jupiter's gravitational assist.

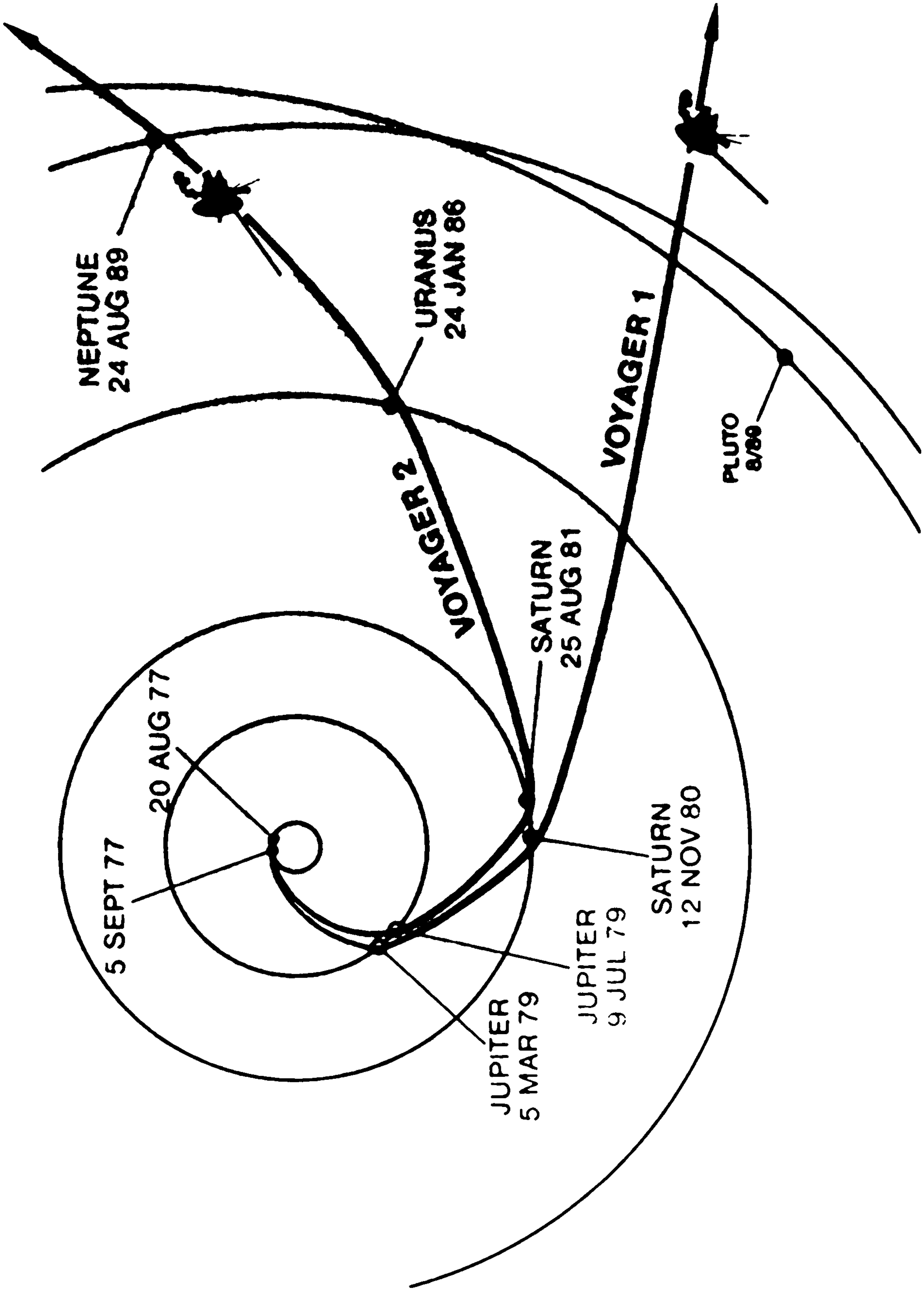
Voyager 2's closest approach to Jupiter occurred July 9, 1979. The same general encounter sequence was followed, with some important differences: Voyager 2 passed farther from Jupiter than Voyager 1 -- 650,000 km (404,000 mi) above the cloud tops, and Voyager 2 observed the Galilean satellites as it entered the Jovian system, so that between the two spacecraft, photos of both faces of the satellites were obtained.

The point of closest approach to Jupiter for both spacecraft was selected to provide the proper gravity assist to target each Voyager toward Saturn. Voyager 1 flew past the ringed planet Nov. 12, 1980, and Voyager 2 followed on Aug. 25, 1981.

Voyager 1 has completed its planetary encounters and is now climbing through unexplored space on a path upward from the ecliptic plane (the broad disk in which Earth and most of the other planets orbit the sun). It is already farther above the ecliptic plane than any other spacecraft, and is returning information on the fields and particles it encounters.

Both spacecraft are expected to cross the heliopause, the unknown boundary separating the solar system from interstellar space in the late 1990s.

Voyager 1 will travel in the direction of the star Raselhaugue (Alpha Ophiuchus); Voyager 2 toward Sirius (Alpha Canis Majoris).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PLUTO
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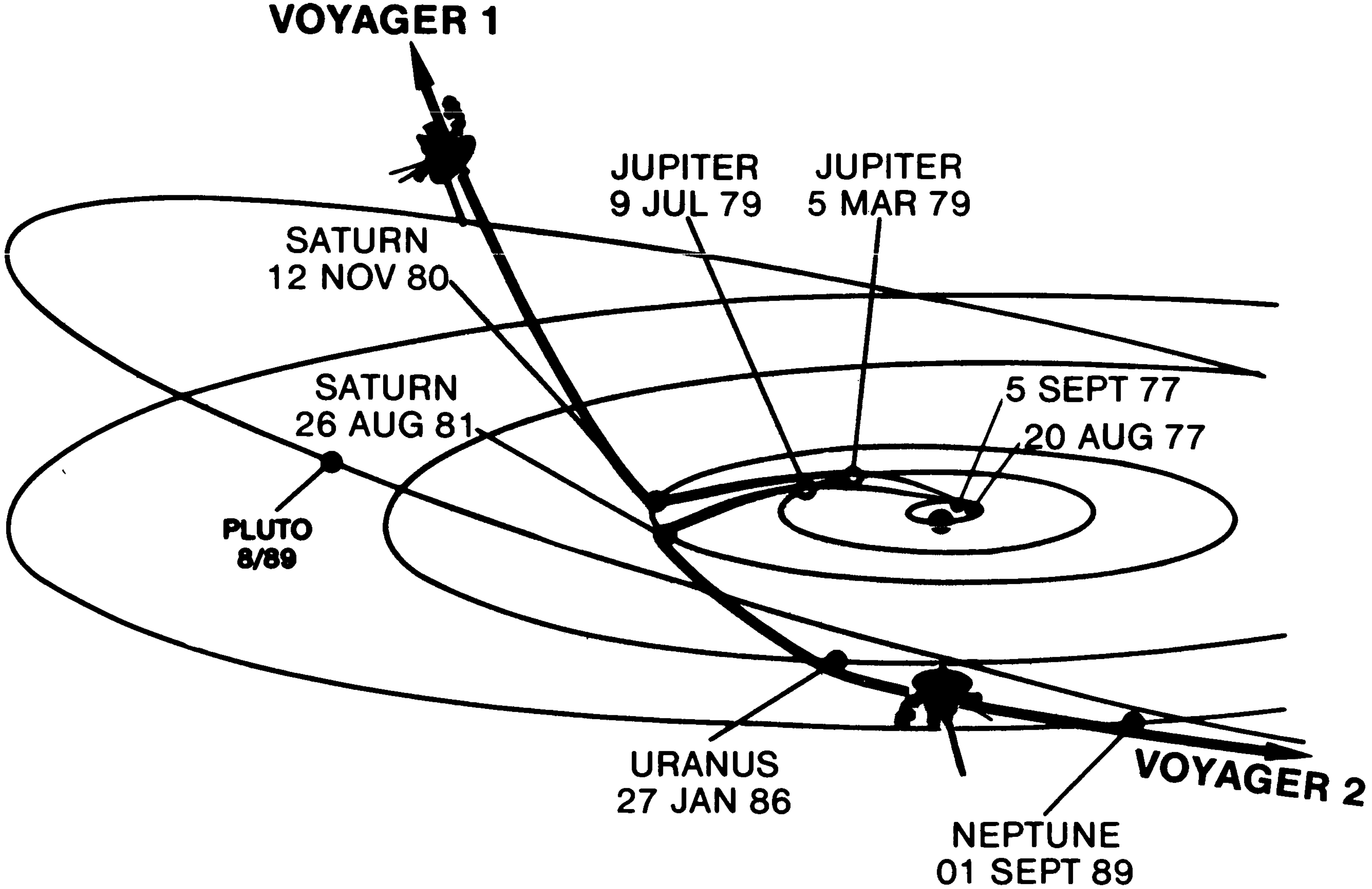
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5 SEPT 77
20 AUG 77
PLUTO
8/89
URANUS
27 JAN 86
VOYAGER 2
NEPTUNE
01 SEPT 89

QUICK-LOOK FACTS

Close approach distances and times Jan. 24, 1986 (PST/EST):

Uranus: 81,500 km (50,600 mi) (from cloud tops of Uranus)		10 a.m.	1 p.m.
Uranus: 107,000 km (64,500 mi) (from center of Uranus)			
Titania:	365,200 km (227,000 mi)	7:10 a.m.	10:10 a.m.
Oberon:	470,600 km (300,000 mi)	8:13 a.m.	11:13 a.m.
Ariel:	127,000 km (79,000 mi)	8:22 a.m.	11:22 a.m.
Miranda:	29,000 km (18,000 mi)	9:04 a.m.	12:04 p.m.
Umbriel:	325,000 km (202,000 mi)	12:53 p.m.	3:53 p.m.

One-way light time, Earth to Uranus: 2 hours, 44 minutes, 50 seconds.

Distance of Voyager 2 from Earth on Jan. 24:
2,965,400,000 km (1,842,610,000 mi)

Velocity of Voyager 2 on Jan 24:

Geocentric: 36 km/sec (80,200 mph)
Heliocentric: 22 km/sec (49,000 mph)

Launch dates:

Voyager 1	Sept. 5, 1977
Voyager 2	Aug. 20, 1977

Voyager 2 Neptune encounter: Aug. 25, 1989

Neptune close-approach distance: 32,000 km (20,000 mi)
From cloud tops of Neptune: 1300 km (800 mi)
From center of Neptune: 26,000 km (16,160 mi)

Cost of Voyager Project (excluding launch and tracking):
$600 million (through Uranus encounter)

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