

# Voyager

## B U L L E T I N

MISSION STATUS REPORT NO. 82

MAY 9, 1988

*In the summer of 1989, Voyager 2 will once again make headlines as it adds the jewel of Neptune to its crown of accomplishments. The Neptune encounter will mark several milestones: the first spacecraft flyby of Neptune, the last planetary encounter by Voyager 2, the closest approach to any object by Voyager 2, and Voyager 2's twelfth birthday (it was launched on August 20, 1977).*

*Although Voyager 2 has been observing Neptune for more than a year, it will not be close enough to begin intensive, continuous studies until June 1989. Voyager 2's encounter of Neptune will span four months, from June 5 through October 2, 1989. On August 25, 1989 (Universal Time Coordinated)\*, Voyager 2 will sail over the north pole of Neptune, within about 4,400 kilometers (2,700 miles) of the visible cloudtops. Five hours later, the spacecraft will pass about 40,000 kilometers (24,800 miles) from Neptune's large moon Triton.*

*The Neptune encounter will be Voyager 2's closest encounter with any object in its 12-year odyssey through the outer solar system. [In 1980, Voyager 1 flew 3,915 kilometers (2,430 miles) from Saturn's haze-enshrouded moon Titan, while in 1986 Voyager 2 flew within 29,000 kilometers (18,000 miles) of the Uranian moon Miranda.]*

*The flyby distance has been chosen to provide data on magnetic fields and charged particles at Neptune, to probe deep into Neptune's atmosphere with Voyager's radio waves, and to bend Voyager 2's flight path close to Triton, while limiting the risk of damage to the spacecraft from ring particles, radiation, or atmospheric drag at Neptune.*

### Neptune, the Eighth Planet

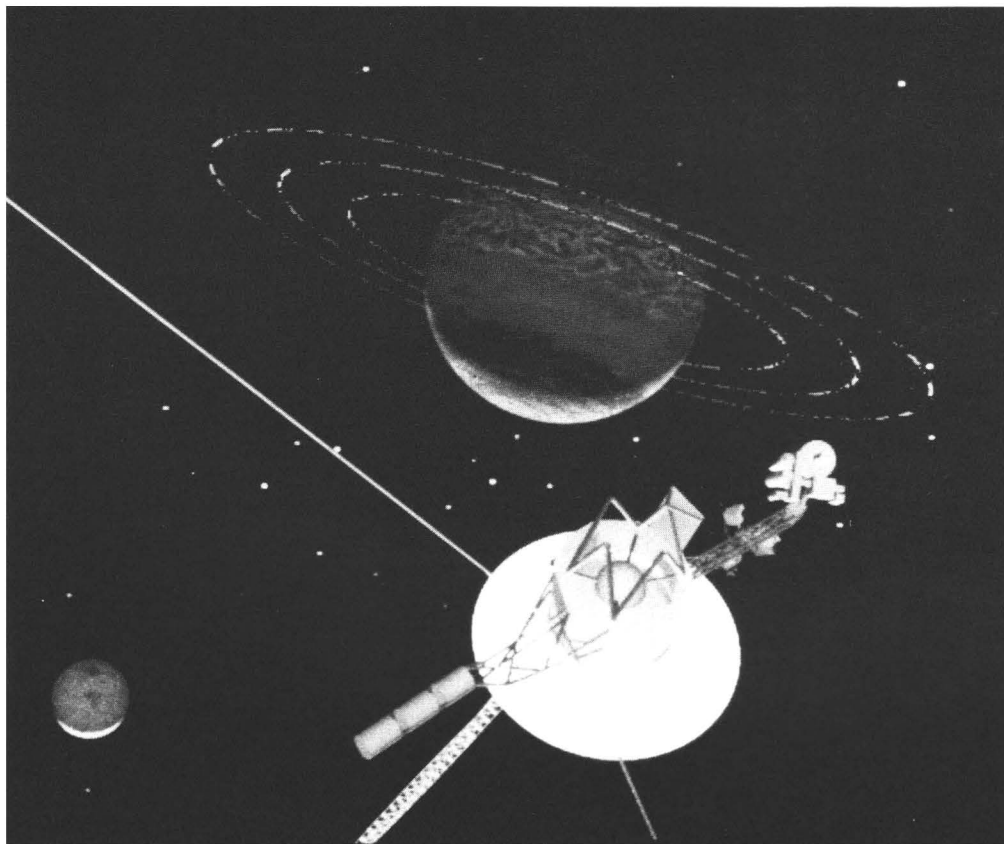
Although Neptune is the fourth largest planet, it is invisible to the naked eye because it orbits in the outer regions of the solar system, 4.5 billion kilometers (nearly 3 billion miles) from the Sun. Even our biggest and best telescopes have been able to discern only meager details about the planet since its discovery.

In 1845, John Couch Adams of England accurately calculated the existence and location of the eighth planet, based on the motions of Uranus, but no one looked for it until 1846. Working independently, Urbain Leverrier of France also performed the calculations. Using the calculations of Adams, the English astronomer James Challis observed Neptune on August 4, 1846, but did not recognize it as a new planet. Using Leverrier's calculations, Johann Gottfried Galle, chief assistant of the Berlin Observatory, and student astronomer Heinrich Louis d'Arrest, identified the planet on September 23, 1846. Galileo may actually have observed Neptune 233 years earlier — but he did not recognize it as a planet.

At an average distance from the Sun of 30 astronomical units (AU) or 4.5 billion kilometers (2.8 billion miles), Neptune takes 165 years to travel around the Sun — nearly twice

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\*Universal Time Coordinated (UTC) is referenced to the Prime (Zero) Meridian in Greenwich, England. The actual moment of closest approach will occur on August 25 at 0400 UTC (which is August 24, 9 p.m. PDT), although many of the observations being conducted about this time will be recorded on the spacecraft's digital tape recorder for transmission to Earth later. The spacecraft's radio signals at closest approach will not reach Earth until 1:06 a.m. PDT, August 25, because radio signals (traveling at the speed of light) will take 4 hours 6 minutes to cross the vast distance from Neptune to Earth.



Seven hours after its closest approach to Neptune and two hours after its encounter with Triton, Voyager 2 will be 475,000 kilometers (295,000 miles) from the planet and headed in a direction well below the ecliptic plane.

as long as it takes Uranus, which orbits at 19 AU (2.8 billion kilometers or 1.8 billion miles) once every 84 years.

At this distance, Neptune receives about 1,000 times less sunlight than does Earth, and about 2.5 times less than Uranus, but its overall temperature is about the same as that of Uranus. Therefore, Neptune must be generating some heat of its own.

Neptune is about the same size as Uranus, with a radius of about 24,760 kilometers (15,350 miles), but it is more dense, indicating that it must contain heavier materials than Uranus does. {The mean density of a planet is an important clue to its composition and structure. To calculate a distant planet's density, scientists first calculate its volume, which is proportional to the cube of its radius [ $V = (4\pi/3)r^3$ ]. They then calculate the planet's mass based on the orbital size and period of the planet's satellites ( $M = 4\pi^2a^3/GP^2$ ) or from

perturbations in the orbits of nearby planets. The mass divided by the volume ( $M/V$ ) gives the mean density.}

Both planets rotate at about the same rate — Uranus' internal rotation rate is 17.24 hours, while Neptune's rotation rate is thought to be about 17.8 hours. Rotation rates can be measured in two ways: by tracking cloud features in the atmosphere or by monitoring the radio emissions generated by electrons spiralling in the planet's magnetic field, which originates in the planet's interior. Tracking cloud features gives the true rotation period only if wind velocities are negligible, but it is the only method available when one is too far away to detect a planet's radio waves. The radio signals give the rotation rate of the bulk of the planet.

While Uranus is unique among the planets in that its rotational axis points toward the Sun, Neptune is more con-

ventional. Its rotational axis is tilted only 29 degrees to the plane of its orbit around the Sun (Earth's axis tilts 23.5 degrees). So, as on Earth, the north pole of Neptune probably experiences midnight Sun in the summer while its south pole is cloaked in darkness. (Realize that seasons last more than 40 years on Neptune!)

Little has been learned about Neptune's atmosphere. At times, a thin atmospheric haze has been observed over half the planet. The haze comes and goes over a matter of days and weeks, and may be aerosol particles or ice crystals. The bulk of the planet is believed to be composed primarily of hydrogen, helium, and methane. If there are methane clouds on Neptune, they probably condense at a pressure level of about 2 bars (twice the mean surface pressure at sea level on Earth) and a temperature level of about 85 degrees Kelvin (-307°F). Voyager 2's radio signals can probe to a pressure

level of 3 to 5 bars, so there is a good chance of detecting methane clouds if they exist at Neptune. Although other cloud layers, including water ice clouds, are expected deeper in the atmosphere, Voyager will not be able to detect them.

Scientists expect that Neptune has a magnetic field, as do Mercury, Earth, Jupiter, Saturn, and Uranus. Penetration of the field by Voyager 2 is not likely until several hours before the spacecraft's closest approach to the planet.

### Ring Arcs

Does Neptune have rings? Maybe...and maybe not. Neptune may have a series of discontinuous ring arcs rather than rings that completely encircle it, as do Jupiter, Saturn, and Uranus.

A classic technique in ring searches is to monitor the brightness of a star as a

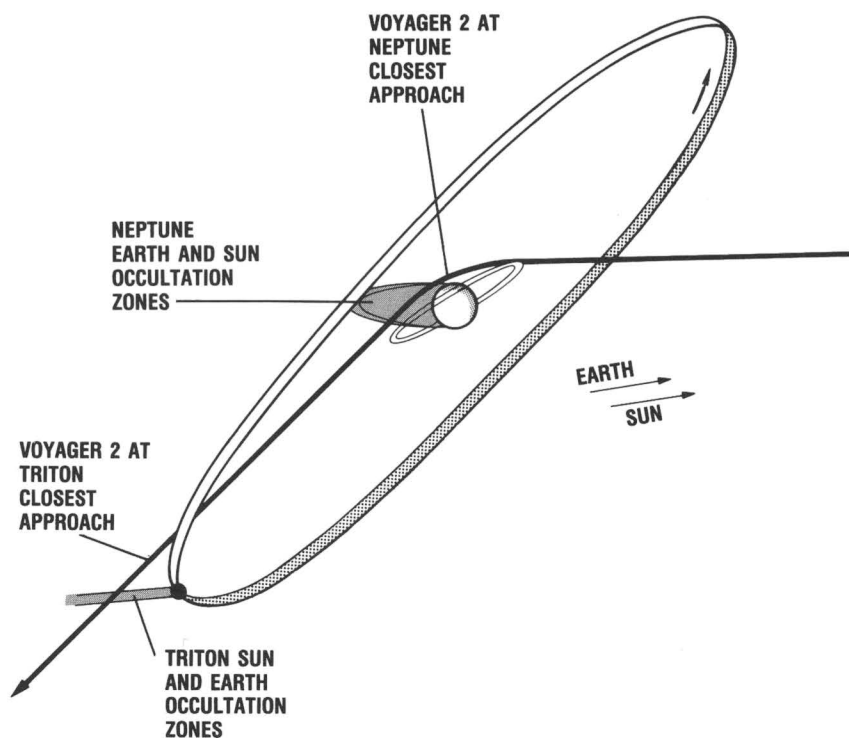
planet's ring region passes in front of (occults) the star, as seen by the observer. Rings may be deduced if the starlight blinks on and off in a regular pattern on both sides of the planet. However, effects that may be due to ring material near Neptune have been seen in only 20 percent of occultation studies, and never have they been seen to occur on both sides of the planet. Scientists have had to deduce partial ring arcs to explain this result. Currently, scientists believe there are three narrow [8- to 20-kilometer (5- to 12-mile)], near-circular, partial arcs in or near Neptune's equatorial plane at a distance that is three times the planet's radius. The size of particles comprising these rings is estimated to range from 1 micron to 1 centimeter — from dust motes to pebbles.

Since the chosen flight path carries the spacecraft close to the region of the possible ring

arcs, it is particularly worrisome to mission planners that the location of these ring arcs cannot be well defined until Voyager 2 is nearly there. Selected areas on the spacecraft are vulnerable to hits by dust-sized particles. Passage through a diffuse sheet of ring particles could result in several hits to the spacecraft, although the probability of a hit is less than one in a hundred. The current flight path will take the spacecraft outside the supposed position of the outermost ring arc, and the flight path can be adjusted as late as one week before the closest approach to Neptune if additional ring arcs are detected by then.

### Radiation

The other giant planets — Jupiter, Saturn, and Uranus — all trap high-energy particles in their magnetic fields, creating regions of trapped radiation



Voyager 2 will approach Neptune from below the ring plane, ascending above the ring plane less than one hour before closest approach, and descending below the ring plane again about 1-1/2 hours after closest approach. The Sun and Earth occultation periods will last about 50 minutes at Neptune and four minutes at Triton.

that threatens the electronics on board the spacecraft. At Jupiter, Voyager 1's photopolarimeter instrument was fatally damaged, the ultraviolet spectrometer was rendered useless for a period of time, and the spacecraft experienced enough temporary radiation damage to confuse the spacecraft's internal clock, thus throwing off the synchronization between two of the computers on board the spacecraft by eight seconds. Among other effects, some images were smeared, or blurred. The computer sequences for Neptune are being carefully written to minimize adverse radiation effects on the observations, and Voyager 2's flight path has been chosen to avoid the regions where radiation may be the worst.

### Triton and Nereid

Neptune has at least two satellites, Triton and Nereid. Neither travels in the plane of the planet's equator (Triton's orbit is inclined 160° to Neptune's equator, while Nereid's is inclined 28°).

Triton is roughly the size of Earth's moon, although its radius may be anywhere from 1,100 to 2,500 kilometers (680 to 1,550 miles). Triton is the only large moon in the solar system to be in a retrograde orbit (it travels in the opposite direction of the planet's rotation). Because of its retrograde orbit, Triton is slowly falling toward Neptune: in 10 billion years or so, Triton will be destroyed by tidal forces as it nears the planet.

Triton's surface may be covered with methane ice and shallow lakes of liquid nitrogen. Scientists believe Voyager may be able to see through Triton's atmosphere to the surface, unlike the case of Saturn's moon Titan, where the atmosphere was too thick to permit pictures of the sur-

face, although Voyager's infrared and radio studies probed to the surface.

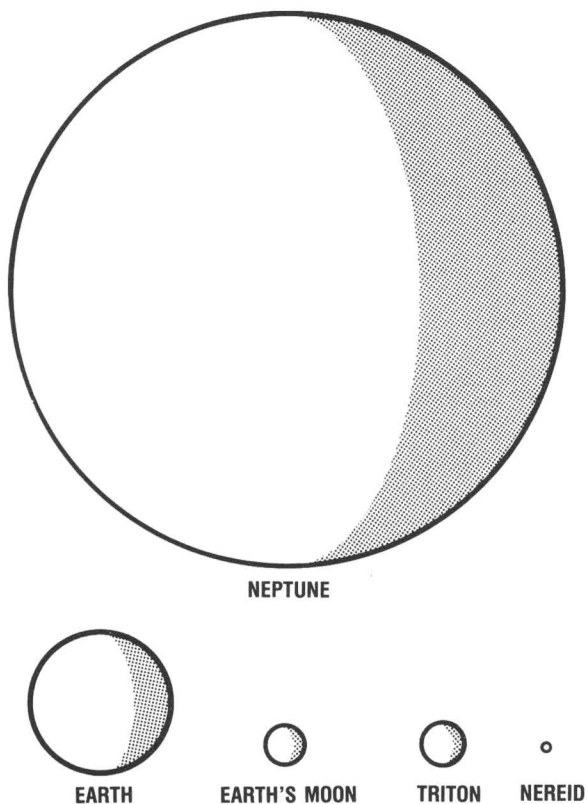
With clever programming of the spacecraft, the best Voyager images of Triton are expected to show features as small as one kilometer (0.62 mile) — or nine football fields — across from a distance of 40,000 kilometers (25,000 miles).

Triton was discovered by William Lassell of England in 1846, less than a month after the discovery of Neptune. In 1949, more than a century later, Gerard Kuiper of the U.S. photographed a second moon of Neptune, tiny Nereid.

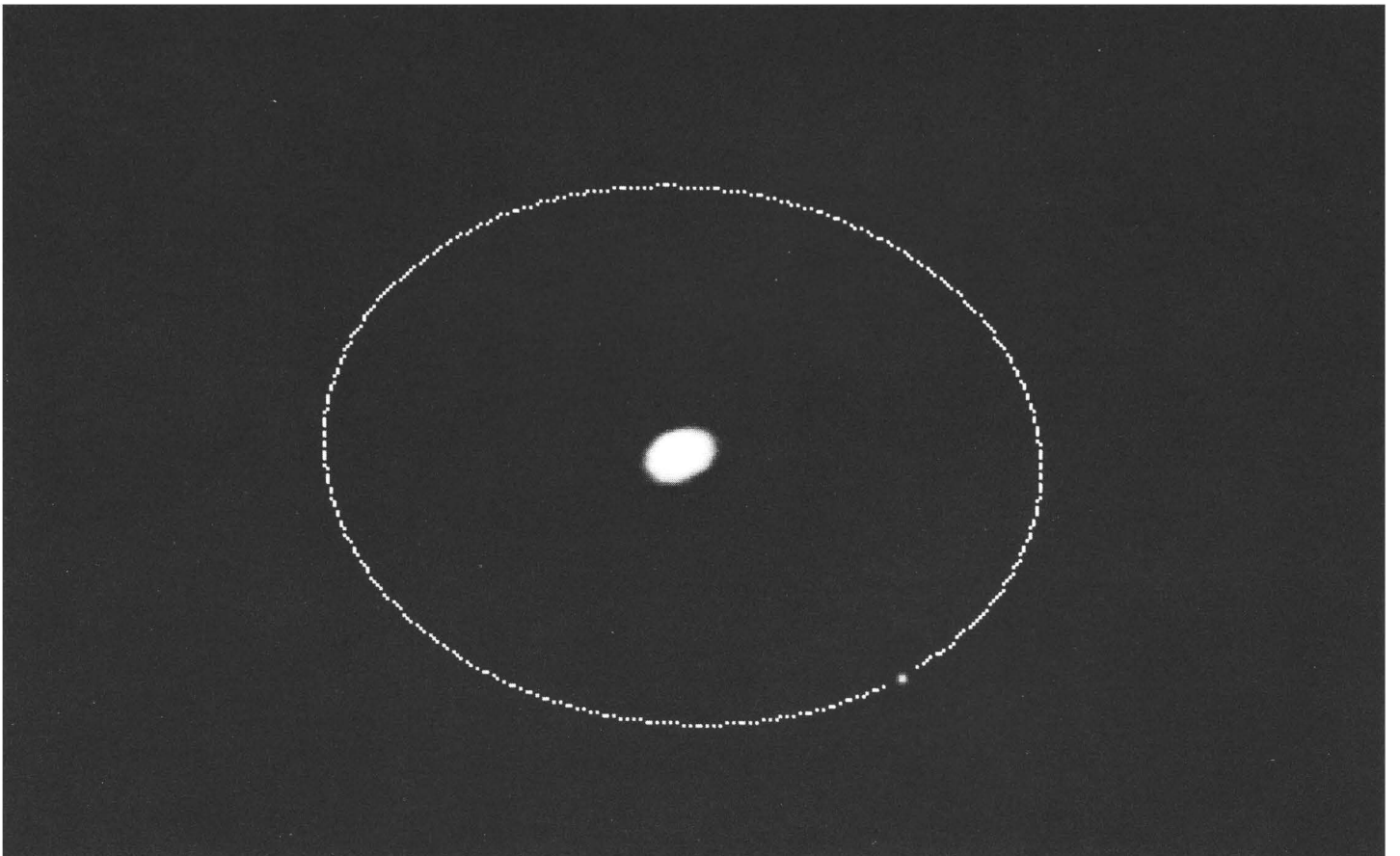
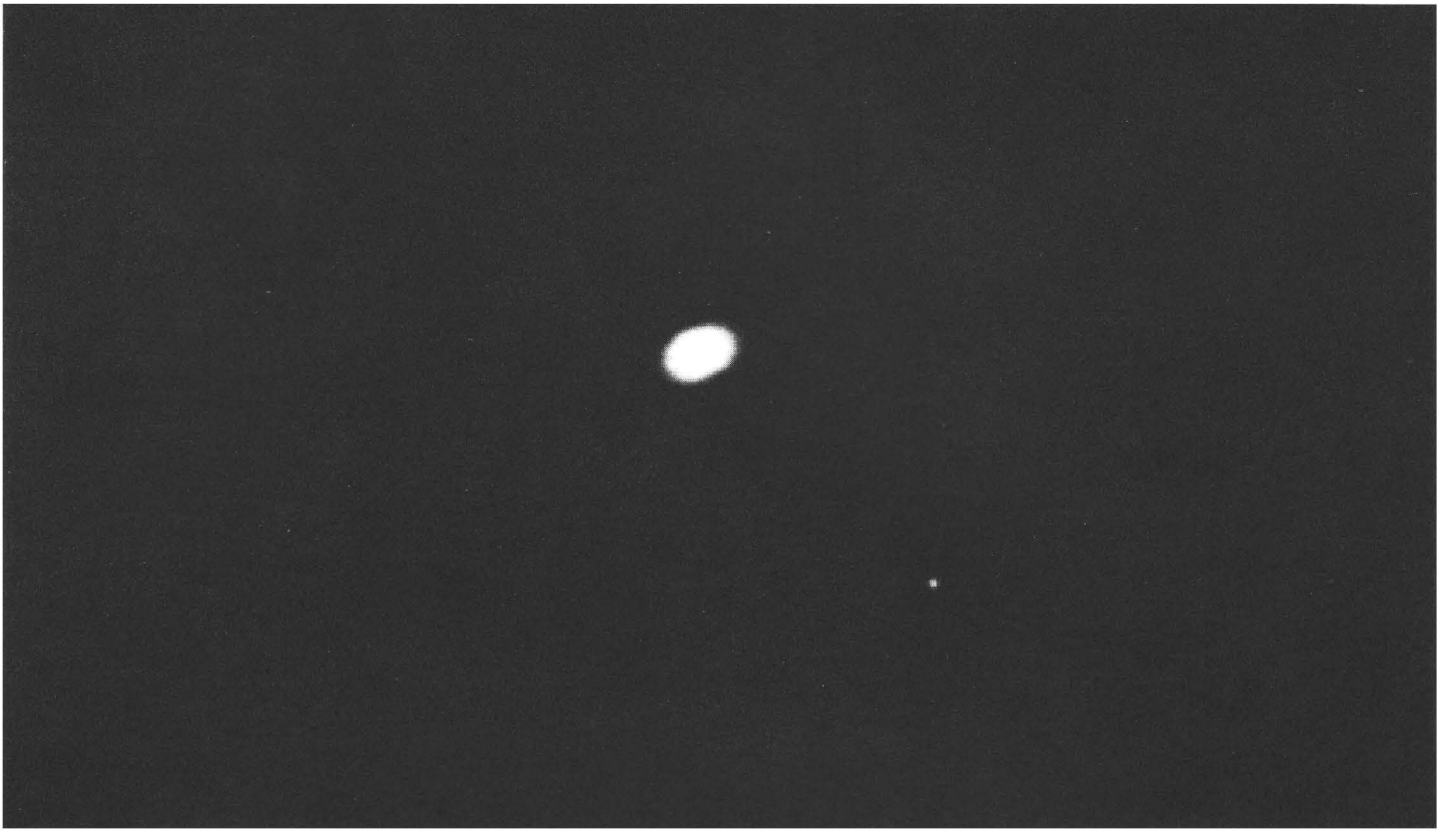
Nereid is between 300 and 1,100 kilometers (190 to 680 miles) in radius. Voyager 2 will pass 4,655,000 kilometers (2,890,000 miles) from Nereid.

### Voyager's Objectives at Neptune: an Overview

NASA's plan for exploring the solar system begins with



Right: The planet Neptune and its satellite Triton were photographed by Voyager 2's television camera on January 16, 1987, from a distance of 1.4 billion kilometers (850 million miles). This picture is roughly comparable with Earth-based resolution. (The lower image is inscribed with Triton's orbit.) Triton, the bright spot at five o'clock, is about 3,500 kilometers (2,200 miles) in diameter; Neptune's diameter is 49,520 kilometers (30,700 miles). Neptune appears oblong because of smear induced by the long exposure of 5.76 seconds. Triton has been brightened artificially so that it is apparent on the photo print. This image was taken with Voyager's narrow-angle camera through a clear filter as an aid to the Voyager navigation team.





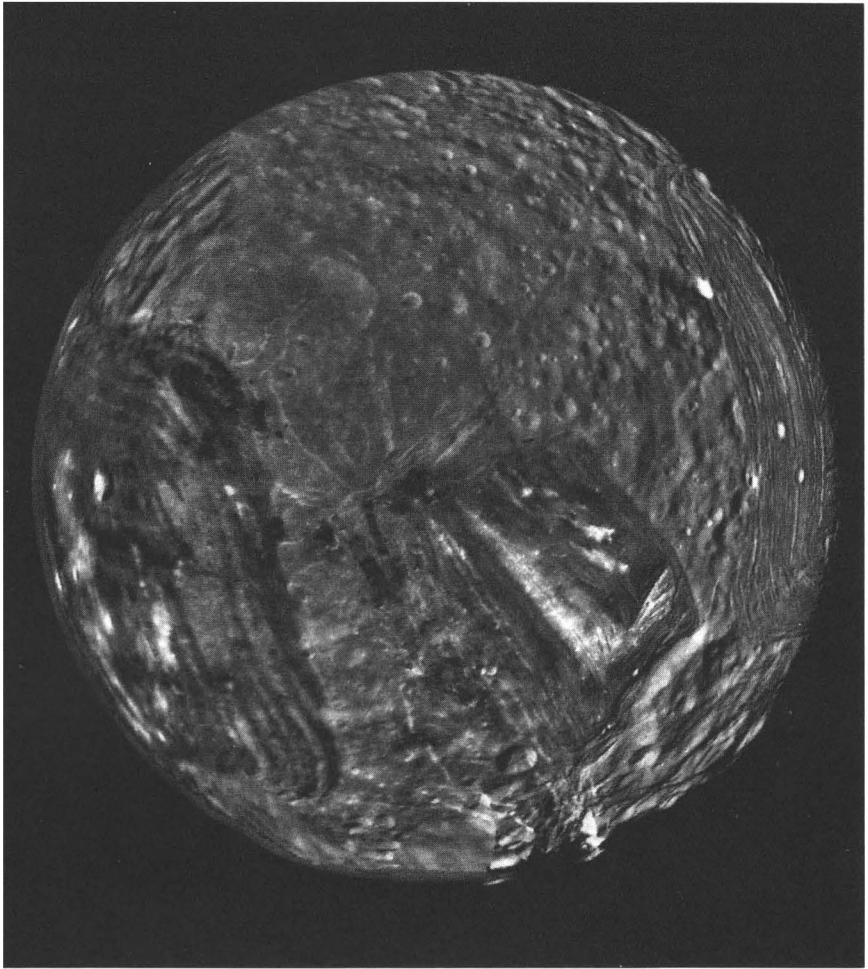
flybys of each planet, followed by more in-depth reconnaissance, and then by detailed, extended observations. With the Voyager flyby of Neptune, NASA will have completed flybys and initial reconnaissance of all planets in our solar system except Pluto. (Neither of the two Voyager spacecraft can be redirected to Pluto, and no mission to Pluto is currently planned.)

The knowledge gained so far has greatly extended comparative studies of planetary systems. At Neptune, Voyager 2 will obtain high-resolution images of the planet, its rings, and Triton, and penetrate the core of Neptune's magnetosphere. Voyager's radio waves will probe the atmospheres of both Neptune and Triton, and its imaging cameras will search for new rings and satellites.

The Voyager flight team faces several challenges at Neptune, including low light levels, longer communications distances, and an aging spacecraft.

At 30 AU, the light intensity is less than half of what was available at Uranus. Due to the low light levels, longer exposures will be required to capture images. But due to the high relative velocities between the spacecraft and its targets, long exposures result in smeared images, much the same as the blurred photos tourists shoot out of the windows of fast-moving buses.

To compensate, the flight team is further enhancing techniques employed for the Uranus encounter and adding new capabilities: Voyager 2 will use three techniques of image-motion compensation; one technique was used at Saturn and Uranus, while two new techniques have never before been used by Voyager.



Without the image-motion compensation technique devised by the Voyager flight team, the image at left, with a resolution of about 25 km (16 mi), would have been the best resolution obtained at Miranda. The mosaic above is composed of images taken from distances of 30,160 to 40,310 km (18,730 to 25,030 mi); resolution ranges from 560 to 740 meters (1,840 to 2,430 feet). This technique allows the spacecraft to drift at a controlled rate to track the target body and reduce image smear caused by high relative velocities between the spacecraft and the target.

“Classical” image-motion compensation requires that the entire spacecraft turn to track the target, and this points the communications antenna away from Earth. Data cannot be transmitted during this time and must be placed on the spacecraft’s tape recorder for later playback to Earth.

Nodding image-motion compensation will briefly “nod” the spacecraft off Earthpoint less than 0.1 degree for a matter of seconds while the exposure is made. These rates are slow: 10 times slower than the hour hand of a clock. But even a few microradians per second of uncompensated motion will result in a smeared image. Bill McLaughlin, former manager of Voyager’s Flight Engineering Office, notes “The 800-kilogram [1760-pound] Voyager spacecraft is being manipulated with a jeweller’s precision” from a distance of 3 billion miles!

Maneuverless image-motion compensation utilizes scan-platform motion during data-taking for wide-angle images and for infrared data.

Voyager 2 is also being steadied as an observing platform. Normally, the spacecraft is steadied by short (10 milliseconds) bursts of hydrazine propellant from its attitude control thrusters whenever the spacecraft senses that it has drifted off its proper orientation by a few tenths of a degree. For the Uranus encounter, flight engineers reduced the thruster bursts to five milliseconds, and for Neptune the bursts will be shortened to four milliseconds, reducing the spacecraft’s rotational rates by an additional 20 percent.

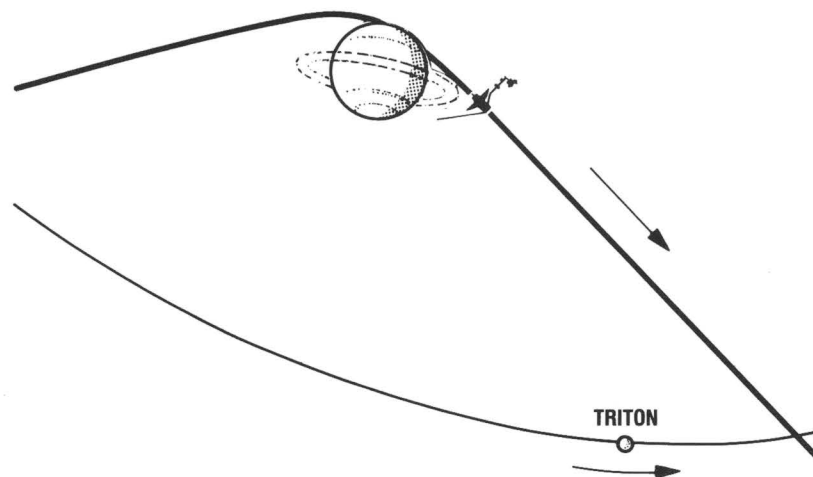
A third effort to gain the best images from Neptune involves changes in software on the ground and on the space-

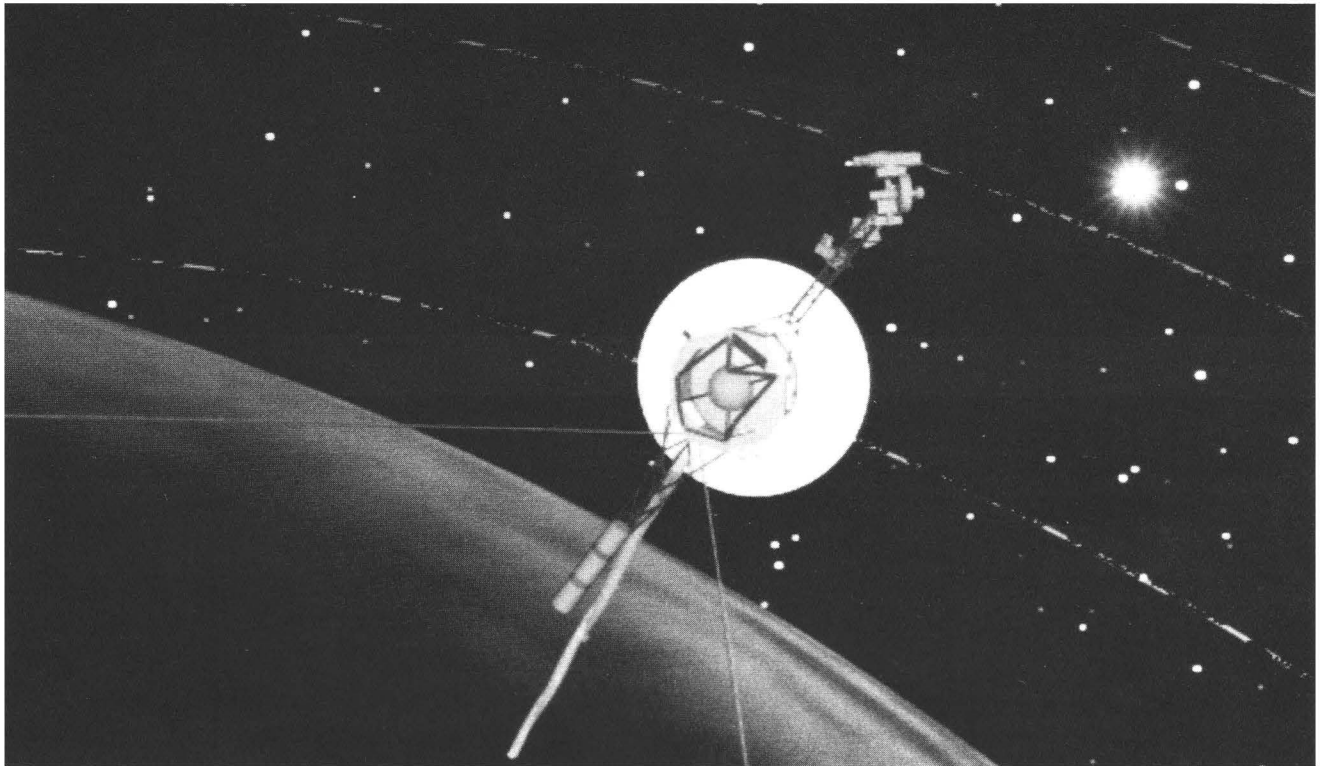
craft. Previously, exposures longer than 15 seconds had to be recorded on the spacecraft’s digital tape recorder for later playback to Earth. While typical exposures at Neptune will be as long as 15 seconds, the software changes will allow the spacecraft to obtain non-recorded images with exposures as long as 30 minutes, aiding searches for faint, diffuse ring material and small new satellites.

As Voyager speeds through the outer solar system, the radio signal from its 20-watt transmitter (the same wattage as the light bulb in a refrigerator) gets progressively fainter. Either a more sensitive receiver or larger antennae are needed to track this signal and more power is needed to transmit to the spacecraft across the vast distance. Although the spacecraft will be 1.6 billion kilometers (one billion miles) farther away, the communications rates at Neptune will be about the same as they were at Uranus due to improvements in the Deep Space Network that tracks and communicates with the spacecraft. Each of the three Deep Space Communications Complexes (located in California, Spain, and Australia) has one large antenna and several smaller ones. The

large antennas are being enlarged from 64 meters (210 feet) in diameter to 70 meters (230 feet), and a new, high-efficiency 34-meter (111-foot) antenna has been built in Spain. The 70-meter antennas have also been enhanced for higher efficiency data collection. The signal received at several antennas can be electronically combined to produce a stronger signal (this technique is called “arraying” the antennas). For the Neptune encounter, the Australian station will again array with the Australian government’s Parkes Radio Observatory, as they did for the Uranus encounter. In addition, the California stations will array with the 27 25-meter (82-foot) antennas of the Very Large Array in New Mexico. Also, Usuda Observatory in Japan will collect (simultaneously with the Australian stations) radio science data during the critical Neptune and Triton occultation periods on August 25, 1989 (UTC).

Voyager 2 will dive over the north pole of Neptune and encounter Triton as the spacecraft departs south of the ecliptic.





## Conclusion

When the Voyager mission was conceived, the design philosophy was to launch two spacecraft, a primary and a backup. If the primary spacecraft fulfilled the basic mission objectives of returning data from Jupiter and Saturn, then the second spacecraft could be used less conservatively at Saturn, and its mission could be extended to Uranus and Neptune, planets never before visited by spacecraft.

The accomplishments of the Voyager mission have far exceeded all expectations, and now we look forward to one more rush of discovery — for a

planetary encounter, especially the first, is an exhilarating, never to be forgotten experience.

As it whips past Neptune at 28 kilometers per second (more than 17 miles per second), Voyager 2's flight path will be bent to send it *below* the ecliptic plane at an angle of about 48° (Voyager 1 is headed about 35° *above* the ecliptic plane). Its voyage of discovery will continue, as it joins Voyager 1 and Pioneers 10 and 11 in their investigation of the heliosphere and ultimately enters interstellar space. Both Voyager spacecraft are expected to return useful data well into the 21st Century.

As Voyager 2 passes behind Neptune, the radio and ultraviolet spectrometer will be used to study the rings and the planet's atmosphere while looking back at the distant Sun and Earth.

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# NASA

National Aeronautics and  
Space Administration

Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California

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Status Bulletin Editor  
Anita Sohus (818) 393-0683  
Public Information Office  
(818) 354-5011  
Public Education Office  
(818) 354-8594

Technical Review  
Dr. Ellis Miner  
Design  
Audrey Steffan-Riethle

Computer Graphics  
Voyager Mission Planning Office/  
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