Voyager

BULLETIN

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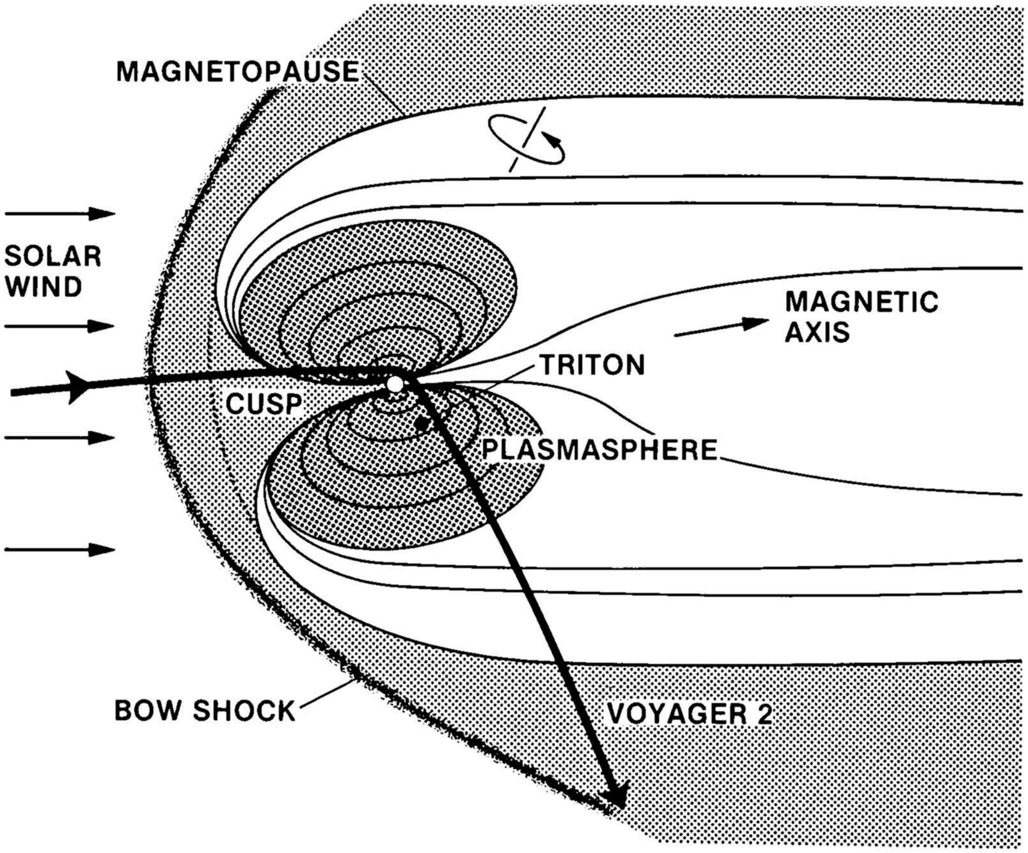


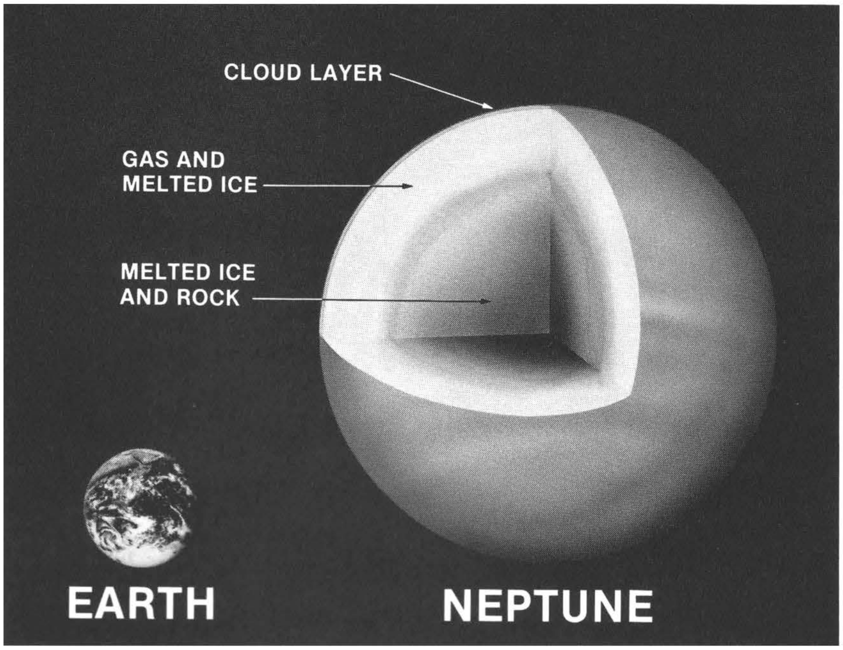
As Voyager 2 left the solar wind, the spacecraft passed through a relatively high-latitude cusp of Neptune's plasma domain before passing into a more nearly equatorial region of the tilted and offset magnetosphere. (JPL 12355AC)

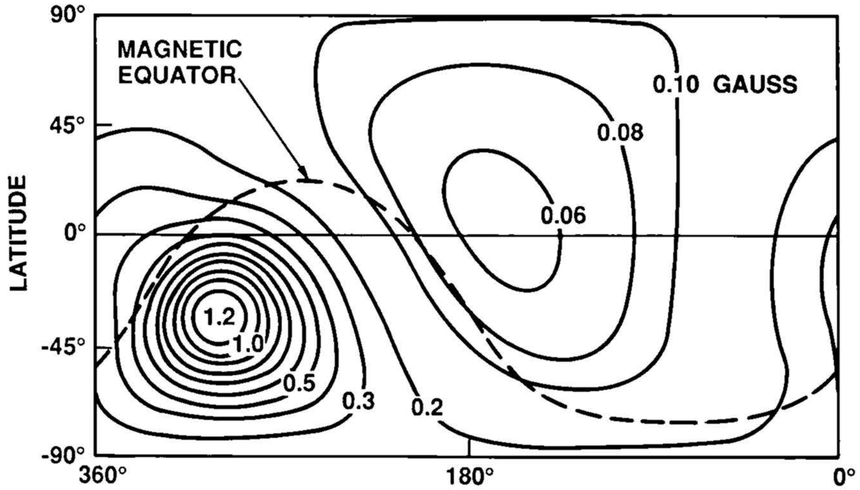
Magnetically, Neptune Is Much Like Uranus

As Voyager 2 closed on Neptune, the bets were that Neptune would have a simple magnetic dipole roughly aligned with the planet's rotational axis and centered within the planet.

Six of Voyager's instruments measure fields and particles. The first of these to sense the planet is usually the planetary radio astronomy (PRA) subsystem, which detects planetary radio emissions. These radio signals result from dynamo electrical currents generated deep in a planet's interior and carried to space along the planet's magnetic field lines. Charged particles near the planet are trapped within an imaginary "cage" formed by the magnetic field lines and are swept along as the planet rotates. All seemed quiet in the fields and particles domain until August 17 (PDT) when the PRA began to detect radio signals from Neptune. From the intervals between the signals, the PRA team deduced that the

Dynamo electrical currents are probably generated in Neptune's gas and melted ice layer as the planet rotates, producing a magnetic field that is quite near the "surface" in some regions, and ranging in strength from 1.2 to 0.06 gauss. (Top: JPL 12266BC; Below: JPL 12387AC)





rotation rate of the bulk of the planet is about 16 hours—much shorter than the 18-hour period deduced from tracking cloud features in the atmosphere.

The next fields and particles event, the bow shock crossing, occurred on August 24. During interplanetary cruise, the spacecraft is in the solar wind where particles travel at supersonic speeds near one million miles per hour. At the bow shock, the solar wind flow is slowed to subsonic speeds, heated, and deflected by interaction with the planet's magnetic field. Prior to crossing the Neptune bow shock approximately 35 Neptunian radii from the planet's center (about 865,000 kilometers or 537,000 miles), measurements by the plasma science instrument indicated that the solar wind temperature was 6,300 kelvins, but the density was only 0.0045 protons per cubic centimeter.

Within the magnetosheath, the temperature rose dramatically to about 250,000 kelvins and the density to 0.03 protons per cubic centimeter. Inbound to Neptune, Voyager 2 was in the magnetosheath for about 25 minutes before crossing the magnetopause into the planet's magnetosphere at about 22 Neptunian radii (about 500,000 kilometers or 300,000 miles) from the planet's center.

The magnetic field did not behave as expected, nor was it even *where* it was expected. Expecting a magnetic axis roughly aligned with the rotational axis, the fields and particles investigations were geared for an unusual opportunity to directly detect particles spiraling into Neptune's north polar atmosphere along magnetic field lines as Voyager 2 passed near the planet's north pole. However, Dr. John Belcher, principal investigator for Voyager's plasma science investigation, announced on August 25 that from their data, his team inferred a magnetic dipole tilted 50° from the rotational axis—surprisingly similar to the 59° tilt of Uranus' dipole. (Earth's dipole is tilted 11° from the rotational axis.)

Rather than the expected crossing near the confluence of the magnetic field lines, Voyager 2's path had carried it for the first time through a relatively high-latitude cusp of a planetary plasma domain and then into a more nearly equatorial region of the magnetosphere, allowing observations within the magnetosphere for about one-and-a-half planetary rotations.

In addition, Dr. Norm Ness, principal investigator for the magnetometry investigation, reported that Neptune's field is not a simple dipole. (An example of a simple dipole is a child's bar magnet.)

The low-energy charged particle (LECP) investigators, led by Dr. Tom Krimigis, reported sensing a tremendous number of protons, as well as helium, carbon, and hydrogen in Neptune's magnetosphere. The LECP team also reported that in the range from 28,000 to 43,000 electronvolts, they found an increased population of energetic protons inside the orbit of Triton. They measured temperatures about 700 million degrees Celsius (over 1.3 billion degrees Fahrenheit) and a density of 0.00025 per cubic centimeter. The probable source for these hot plasmas is Neptune's ionosphere.

The LECP team also reported that Voyager 2 had passed over a magnetic polar area after all, yielding the first direct detection of auroral zone particles impacting the atmosphere of a nonterrestrial planet. Their initial estimates of the auroral power was greater than one million watts (Earth's auroral power, which we see as the Northern or Southern Lights, is about 100 billion watts). Because of the tilt and offset of the magnetic field, Neptunian auroras might be expected to occur near the equator rather than at the poles, but because of the complex structure of the magnetic field near the planet, auroral activity is probably widespread.

In summary, the quick-look analysis of Voyager's pass through Neptune's magnetosphere indicates that Neptune looks very much like Uranus, magnetically. The dipole is tilted 50° from the rotational axis, and magnetic north is in the southern hemisphere. In addition, the magnetic pole is offset from the center of the planet by 2/5 (0.4) of Neptune's radius (Uranus's magnetic pole is offset by 1/3 [0.3] Uranian radius.) The magnetosphere undergoes dramatic changes as the planet rotates and the moons orbit. The dipole moment (the mean field strength at the 1-bar pressure level) is 0.13 gauss R_N3, but because of the large offset the strength of the field ranges from 1.2 to 0.06 gauss (Earth's surface field is about 0.3 Gauss). The large variation in field intensities indicates that dynamo electrical currents may be much closer to the "surface" (the 1-bar pressure level) of Neptune than was true for Jupiter or Saturn.

In terms of the density of charged particles in the planet's magnetosphere, Voyager's magnetosphere is the emptiest encountered by Voyager. The large tilt and offset apparently allow the satellites and ring particles to efficiently "sweep" charged particles out of the magnetosphere.

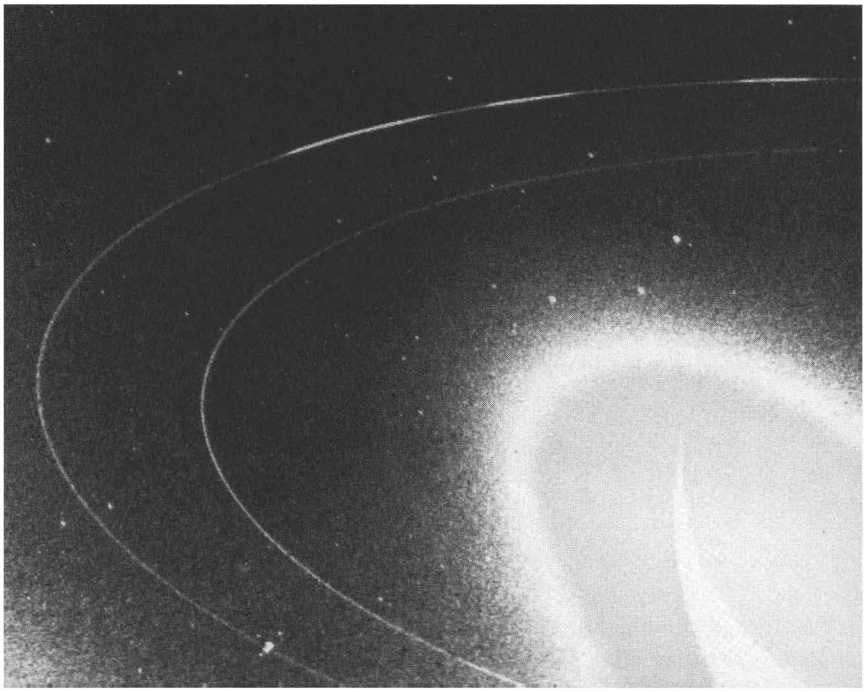
The Rings Are Complete, Not Just Arcs

Another Neptunian mystery unraveled in late August when Voyager scientists confirmed that Neptune does indeed have complete rings, not just ring arcs.

A number of ground-based observations over the last few years had produced a confusing set of data. While observing stellar occultations, in which a distant star appears to pass behind a planet, astronomers noted that, a number of times, the starlight briefly dimmed on one side of Neptune but not on the other. If these stellar occultations were caused by ring material passing in front of the star as viewed from Earth, one would expect the occultation to occur on both sides of the planet, but it never did, even in instances when two observatories recorded the same event. To account for these odd circumstances, scientists formulated a theory of partial rings, or ring arcs, that did not completely circle the planet.

Interpretation of some of the ring arc observations was difficult because Neptune's position could not be determined precisely enough. In addition, the degree of Neptune's axial tilt was not known to within 1°. For ground-based astronomers, these small uncertainties enormously complicated their understanding of the ring arc locations.

In early August, a number of excited phone calls were made in the middle of the night when a

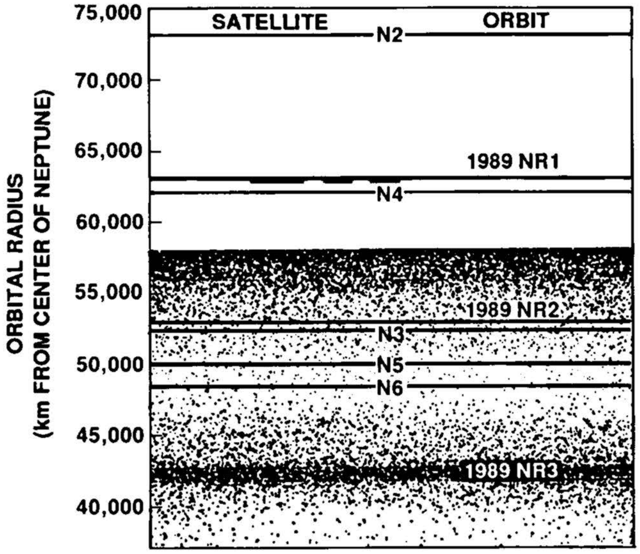


Neptune's two main rings are seen backlit by the Sun, and three bright features, each about 6 to 8° long, are seen at top in the outer ring. The image of the planet was greatly overexposed to capture detail in the rings. (P-34712)

series of Voyager images unmistakably showed arcs of ring material about 54,000 and 62,000 kilometers (about 34,000 and 39,000 miles, respectively) from the center of the planet. The inner of the two arcs spanned about 10° of arc, while the outer arc spanned about 45°, and seemed to have three or four segments. The bigger arc was whimsically nicknamed the "Arc de Triomphe."

To the team's dismay, however, the shorter arc could not be found in subsequent images, and was dubbed "the lost arc." But on August 22, a smiling Dr. Brad Smith, leader of Voyager's Imaging Science Team, announced to the press that not only had the lost arc been found, it was not an arc. "It goes all the way around," he beamed. The ring was continuous but of a very low optical thickness, too faint to have been detected from Earth. The outer ring was also seen to be continuous, but only three thicker segments could have been detected from Earth and were apparently responsible for all the reported occultation events but one. The one exception was apparently due to an incredibly unlikely occultation by 1989N2, one of Neptune's newly discovered satellites.

Voyager's computer sequences included a number of observations that could be retargetted to study new discoveries. Trajectory analysts on Voyager's Navigation Team worked feverishly to calculate the pointing positions neces-



The orbital locations of five of Neptune's newly discovered satellites, three rings, and a broad sheet of ring material are sketched here. (JPL 12383AC)

sary to image the thicker segments of the outer ring. The results were "spectacular!" and "right on the money" as in one case the image of a faint ring cut through the center reseau mark of the 800 by 800 pixel imaging frame.

Scientists knew that Voyager 2's search for tiny dust particles in the rings of Neptune would not be as sensitive as the search at Uranus because the spacecraft's flight path would be bending sharply downward to catch up to Triton, and therefore the phase angle* would not be as high as at Uranus. Nonetheless, they anxiously awaited the images to be taken in forward scattered light, when dust particles would be backlit by the Sun after the spacecraft was beyond Neptune. (As imaging scientist Dr. Carolyn Porco explained, an example of forward scattering occurs when you have a dirty windshield on your car, which does not become apparent until you drive toward the Sun, and the dust scatters the sunlight into your eyes.)

Although the highest phase-angle data was too badly smeared to yield immediate results, the much higher dust content of Neptune's rings (relative to the rings of Uranus) permitted lower phase-angle data to provide exciting results: a third ring, interior to the two narrow rings, which is diffuse and 1,000 kilometers (620 miles) wide. Like the middle ring and all but the three thicker segments of the outer ring, the third ring is too optically thin to have been detected from Earth-based occultation measurements. In addition to the third ring, images taken at a phase angle of 135° revealed a sheet of ring material that extends from inside the outer ring perhaps down to the atmosphere of the planet.

Neptune's rings appear to have much less large material than Uranus' rings do, and were not readily seen in radio science data. Some images appear to show "rocks" 10 to 20

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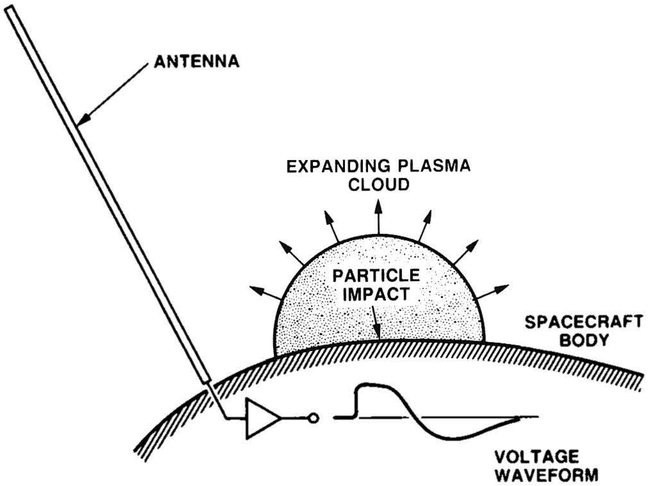
* The angle between the incoming sunlight and the light emitted or reflected from the target.

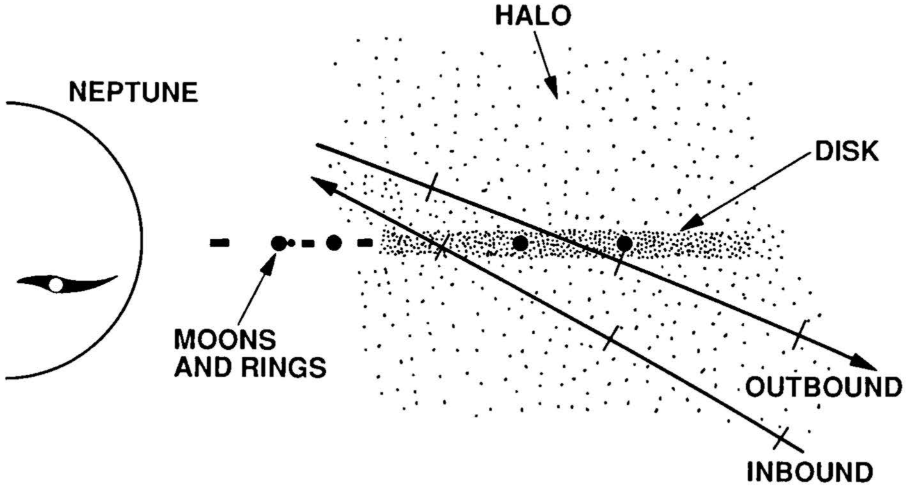
kilometers in diameter embedded in the ring arc portion of the outer ring, but these may have been aggregates of smaller particles or even artifacts of the image processing. The sizes of the ring particles were difficult to ascertain immediately, and the imaging, photopolarimetry, ultraviolet spectrometry, and radio science teams are continuing to study their data.

Yet another investigation observed the rings: the plasma wave subsystem (PWS). The PWS was not originally designed as a dust detector, noted principal investigator Dr. Don Gurnett, but at Saturn it was discovered that the instrument is a very effective detector of dust impacts. The PWS recorded dust impacts on the spacecraft on both the inbound and outbound crossings of Neptune's ring plane , just as it did at Saturn and Uranus.

As the spacecraft swept through the ring plane at a velocity of about 12 meters per second, particles impacted the spacecraft in microexplosions, completely vaporizing and producing temperatures up to 100,000 degrees and ionized gases. These created voltage pulses that the PWS could record.

“We started detecting dust impacts about two hours before [inbound] ring plane crossing,” said Dr. Gurnett. “Watching our data display in real time, we found it very scary as the impact rate went up, and continued for about 10 minutes.”





Dust particles vaporize as they impact the spacecraft; the ionized gases create voltage pulses that are recorded by Voyager 2's plasma wave subsystem. Voyager 2 recorded impacts continuously for about one hour before and after ring plane crossing both inbound to and outbound from Neptune. (Top: JPL 12273BC; Bottom: JPL 12333BC)

Impacts were also seen for about two hours after the outbound ring plane crossing.

Dr. Gurnett said that there appears to be an intense disk with a dense concentration of particles. The maximum impact rate was 300 per second, corresponding to about three particles in each 1,000 cubic meters of space. The particles are probably about the size of those in smoke or clouds, and may be created by meteoritic impacts on larger ring particles and the moons.

Analysis of the Neptune data continues, and the conclusions of the first 30 days of data analysis are expected to be published in the December 15, 1989 issue of *Science* magazine.

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