The Neptune System in Voyager's Afterglow

Any time the view of a planet leaps from a fuzzy dot accompanied by two pinpoints of light to the riveting details of swirling clouds, rings, cratered moonlets, and even individual dust particles, planetary science is going to be in for some upheaval. Voyager 2's encounter with Neptune was no exception. Something as seemingly innocuous as an hour or two shift in the new length of a Neptunian day is giving meteorologists and physicists fits. And Neptune's canted, complex magnetic field found by Voyager knocks into a cocked hat most ideas about why a similar field at Uranus was unique. But there were more reassuring discoveries as well. Here are samplings of both sorts of findings.

Neptune's Fast Spin Means Trouble for All

If only Neptune were rotating a little slower, life would be simpler for some planetary scientists. But preencounter estimates of the length of a Neptunian day have been sharply reduced, complicating some explanations of the planet's behavior.

When the planet's day was estimated at 17.5 to 18 hours, planetary physicist David Stevenson of the California Institute of Technology had a nice little story explaining why Neptune radiates a considerable amount of heat drawn from its interior and Uranus does not. Neptune, he suggested, had suffered a collision late in its formation that stirred the ice and rock of its interior all the way to its center. That mixing helped break down the stratification that would otherwise have greatly inhibited the heat-driven vertical circulation that now carries heat to the surface.

Uranus' late hit, on the other hand, was off-center, as evidenced by the way it is lying on its side. That kind of collision might have failed to stir the deep interior, leaving its heat largely trapped there. Because the rotation period provides one indication of how well mixed the interior is, a Neptunian day of 17 hours or so would have implied just the difference in mixing between the two planets that Stevenson needed to explain the difference in heat leaking out.

Then the Voyager 2 planetary radio astronomy instrument put a crimp in the story. It picked up a 16-hour periodicity in the natural radio emissions from Neptune's magnetosphere. Because the magnetosphere must be tied to the deep interior of the planet, the radio group reasoned, the bulk of the planet must be rotating every 16 hours. "That makes Neptune more like Uranus," notes Stevenson. "It's becoming more difficult to put together a good story. It's harder to convince people that that's the way it is."

Meteorologist Andrew Ingersoll of Caltech finds the rotation period a bit disconcerting as well. Assuming a 16-hour rotation for the interior makes Neptune's winds blow the "wrong way" relative to the interior. They blow to the west instead of to the east, as at Jupiter and Saturn and even Uranus. "I can't say the reason for that is clear to me," says Ingersoll. If the 16-hour day is right, he and Stevenson should have plenty to commiserate about.

Two Odd Magnetic Fields Is One Too Many

When Voyager streaked through the magnetic field of Uranus in 1986, it seemed to have found the exception that proves the rule, a quirky, topsy-turvy magnetic field whose weirdness seemed only fitting for a planet like Uranus that lies on its side.

As Voyager approached Neptune last month, which is a far more conventional-looking member of the solar system, the conventional predictions about its magnetic field began appearing in the literature. Each was premised on Neptune's field resembling the well-behaved fields of Mercury, Earth, Jupiter, and Saturn. It was not to be. "Neptune looks remarkably like Uranus magnetically," observed Norman Ness of the University of Delaware and Voyager magnetic fields principal investigator. "We are quite surprised. This is the only pair of planets that has these properties." That, Ness later observed, should force theorists to rethink their ideas about how magnetic fields are generated within the interiors of planets.

Not that anyone understands in detail how even Earth's interior generates its magnetic field, but the terrestrial case seemed to serve as a good guide to how planetary interiors should work. At Earth, a flowing magnetic conductor, the molten iron of the core, generates a magnetic field that at the planet's surface is dipolar—resembling a bar magnet's two-lobed field—and inclined only 11° to the axis of rotation. That suited theorists just fine because the interaction of the magnetic field and the flows generating it should tend to align the magnetic and rotational poles, which seemed to be the case at all four of the magnetic fields known before 1986.

Uranus became the exception to this model in 1986, when Voyager 2 found its magnetic field to be tilted 60° from the rotational axis. What was more, the center of its dipole field was offset from the center of the planet almost one-third of the way to the surface. That made for an odd map of the strength of the field at the surface as complexities of the field, which normally fade out before they reach the surface in a planet-centered field, here and there poked their way through the surface.

Given Uranus' unique magnetic field, it seemed natural enough to link it to the planet's unique orientation. Uranus is tilted 90°. Its poles are in the plane of most planets' equators and the orbits of its satellites presently form a bull's-eye as viewed from Earth. The only way a planet could get that way, researchers reasoned, was to take a tremendous off-center hit from another planet-size body late in the formation of the solar system. Perhaps such a cataclysm also profoundly and permanently disrupted the flow of hot, ionized water and minerals that generate the field, some thought. Alternatively, Voyager may have caught the field at the geologic instant of a magnetic pole reversal, when the dominant dipole field momentarily fades and reveals its inner complexities before reappearing with its north and south poles switched.

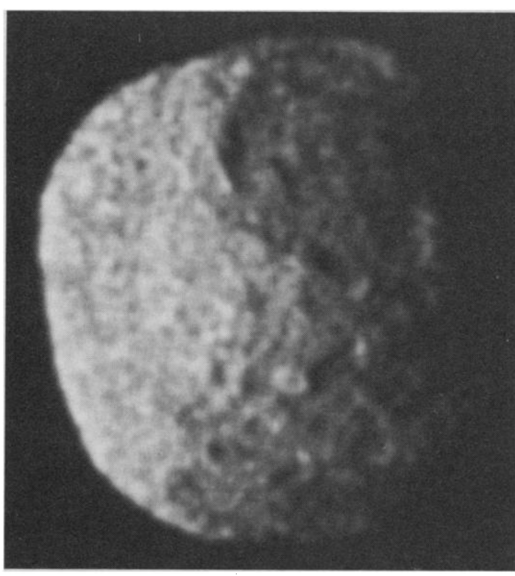
Now there is Neptune. Its magnetic field is also tilted, about 50°. Its dipole is also offset from the planet's center, more than one-third of the planet's radius. And it has the widest range of field strength at its surface of any planet, ranging from 0.06 gauss to 1.2 gauss. But there is no sign that any cataclysmic impact disrupted the young Neptune, and the odds that both planets would be reversing at the same time as Voyager happened by look ridiculously small.

"You have to pause and think that there is something about the internal circulation of these planets that is different from Jupiter, Saturn, and Earth," says planetary physicist David Stevenson of the California Institute of Technology. Ness and others had suggested that perhaps as the zone of flowing, electrically conducting fluid capable of generating a field was moved to shallower depths, as is the case with Uranus and now

Neptune, the flow might break down into smaller loops that would provide the observed complexity. After the Uranus encounter, Raymond Hide of the Meteorological Office in Bracknell, England, specifically suggested there might even be a Uranian vortex like Jupiter's Great Red Spot but deep-seated within the field-generating layer. "I thought it was a very ad hoc idea" at the time, says Stevenson, "but now I'm beginning to wonder." Neptune's magnetic field will probably have theorists wondering for a while.

Voyager Finds Rings in Need of Rejuvenation

"Rings are like perfume," says astronomer André Brahic of the Observatory of Paris, "they give me a lot of information with a little amount of material." Ring specialists sniffing around the Voyager observations of the wispy ring system of Neptune are getting a whiff of old age. Neptune's ring system is "old and decrepit," says Larry Esposito of the University of Colorado. Fear not. Even old ring systems, it now appears, can arise from their deathbeds now and again to be rejuvenated with all the vigor and beauty of the spectacular rings of Saturn. All it would take in Neptune's case is a chance catastrophe, a rare but, given time, inevitable collision of a Neptunian moon with a stray bit of solar system debris. The potential for rejuvenation that Voyager found at Neptune is a reminder that, 4.5 billion years after the solar system formed, Mother Nature can still indulge in a bit of creation.



The next Neptunian ring? *Although too far out to form a ring, the appearance of Neptune's newly discovered 420-kilometer moon 1989N1 is probably typical of that of the five smaller Voyager discoveries. Once destroyed by a cometary collision, the largest could form an entire ring system rivaling Saturn's.*

Voyager 2 found signs of the advancing age of Neptune's rings in the proportions of material orbiting the planet as ring particles, dust, and moons. Neptune is short on rings. As Voyager approached, it imaged two narrow, faint rings, one of which had three closely spaced bright clumps like beads on a string. It was only these clumps that Earth-based observers could readily detect when stars passing behind the rings flickered. In contrast, astronomers had nailed down nine narrow rings around Uranus long before Voyager 2 arrived. And, of course, Saturn has a massive system of rings detectable from Earth through a good pair of binoculars. Clearly, Neptune has a dearth of the millimeter- to meter-size particles that orbit a planet to make up classical rings.

Neptune's rings do have plenty of dust, a sign not so much of advanced age as rapid aging. As Voyager flew past the planet and looked back, it discovered a narrow, dusty ring that appears to be the source of a band of dust that extends inward toward Neptune's cloud tops and includes a broad dust ring. All this dust, which is on the order of a micrometer in size, lit up for the departing Voyager the same way driving a car toward the sun lights up the grime on a dirty windshield.

Neptune's dust is its rings' lifeblood trickling away. Researchers have come to appreciate in recent years that everything from radiation belts to micrometeorites chip away at the larger particles of rings, producing fine dust. Such dust is far more susceptible than larger ring particles to the subtle forces that drive particles to a fiery end in the atmosphere, such as the drag of charged particles in the planet's magnetosphere. In turn, dust particles are far less responsive to the forces, such as the gravitational nudges of nearby satellites, that confine larger particles and thus preserve rings. As a result, rings are not forever. On a geologic time scale, their mass is pulverized to be blown away forever.

Just how decrepit Neptune's ring system is might be judged in a relative fashion by comparing its mass with those of other ring systems. The smaller the mass of the ring system today, it might be assumed, the longer since a major set of rings formed around that planet. Richard Terrile of the Jet Propulsion Laboratory guesses that all the debris of the Neptunian rings would make one 5-kilometer ball. The Uranian rings might make a 10-kilometer body, while the stunning Saturnian rings weigh in at several 100-kilometer bodies. Even the lowly Jovian ring system would be younger than Neptune's system, according to its total mass.

Although Neptune's rings may by one measure be among the oldest in the solar system, rings in general appear relatively young next to the 4.5-billion-year age of the solar system itself. Are we living in a fleeting Age of Rings, a unique time when all the gas giants happen to have rings? Astronomers think not. Instead, they see each planet possessing the seeds of new rings and even whole ring systems.

The seeds of future rings are the small moons close to the planets and to their present rings. All that is needed for these seeds to flower into new rings are catastrophic impacts with the debris orbiting the sun since the solar system's creation, that is, comets. Esposito estimates that a 1-kilometer moonlet of Neptune's, which would have been too small for Voyager to see, could on average survive less than 100 million years under the comet onslaught. It must be a fragment from an earlier collision.

Once shattered itself by an impact, such a moonlet could provide the makings of a nice ring, assuming other moonlets could help confine the debris. Esposito and his colleague Joshua Colwell have proposed that Uranus' Epsilon ring could have formed in such a way no more than 600 million years ago because the planet's extended atmosphere exerts too strong a drag on it to have lasted any longer. At Saturn, the rate at which micrometeorites are eroding the broad, faint C ring suggests that it is less than 100 million years old. And the massive A ring must be no more than 20 million years old to judge by the proximity of moonlets near its outer edge.

Continuous creation of whole ring systems would work the same way. All that is needed is a larger moon and a larger comet to destroy it. Neptune, Voyager showed, may be short on ring material, but it has plenty of ring makings. Voyager discovered six new moons, five of which are close enough to Neptune to form rings.

"Around the giant planets, we have enough material to play this crapshoot," says Esposito. "It's been a long time since we've had a good hit in the Neptune system. It's old and decrepit. But if the biggest of Neptune's inner moons took a hit, you'd have a Saturn-type ring system. It's not so much a matter of young or old, but how recently the ring system has been rejuvenated." ■ Richard A. Kerr