NEPTUNE RISING

ONCE A FUZZY NOBODY, NEPTUNE COMES OF AGE AS A KEY PLAYER IN THE ARRANGEMENT OF THE SOLAR SYSTEM. BESIDES, WHO CAN IGNORE A PLANET WHERE IT RAINS DIAMONDS?

FOR CENTURIES, THE PLANETARY GIANTS—Jupiter with its distinctive red spot and Saturn with its massive rings—have been the most glamorous of the planets, while the outer orbs—Uranus, Neptune, and Pluto—have been viewed, when they've been viewable at all, as dim, remote, drab, and mysterious stepsisters. Then 11 years ago *Voyager 2*, its mission to Jupiter and Saturn completed, was allowed to fly by and snap a few images of Neptune. What it eventually sent back to Earth changed everything. Neptune was literally seen in a new light, with images of a gorgeous blue orb with swirling white clouds that seemed, well, Earth-like. ¶ Three years later, the discovery of the Kuiper belt, a field of remote icy objects that includes Pluto, redefined Neptune as a major force in the arrangement of the entire solar system. Astronomers now believe Neptune's gravity not only skewed the orbits of the small, distant bodies in the Kuiper belt but also affected the position of the giant gas planets.

BY CURTIS RIST

"No one planet can tell us everything about the universe," says Heidi Hammel, a senior scientist with the Space Science Institute in Boulder, Colorado, "but Neptune seems to hold more than its share of information about the formation of our own solar system—as well as the solar systems beyond."

For decades astronomers have thought that planets remained stationary after the initial formation of the solar nebula. But something about Neptune's strange small neighbor, Pluto, tickled their curiosity. While the other planets travel in circular orbits, Pluto's orbit is a peculiarly tilted ellipse. Astronomers now know that Pluto's orbit is strange only for a planet. It is perfectly normal for some 300 known objects in the Kuiper belt. To Renu Malhotra, a staff scientist at Houston's Lunar and Planetary Institute, these elliptical orbits have explanatory power: They suggest that Neptune—a planet with the mass of more than 17 Earths—influenced the orbits of all its diminutive neighbors.

WHAT EVOLVED WAS A PLANETARY GAME OF HANDBALL INVOLVING THE GIANT PLANETS

How could this happen? The answer lies in the interactions that occurred during the solar system's early history. After the planets formed, their gravitational pull interfered with the orbits of leftover building blocks called planetesimals. "What evolved was a sort of planetary game of handball, involving Neptune, Uranus, Saturn, and Jupiter," says Malhotra. By the rules of this interaction, Neptune literally tugged planetesimals from their orbits and "handed them down" to the giant gas planets closer to the sun. As the planetesimals moved into smaller orbits, they lost orbital energy and angular momentum—and that energy was instead absorbed by the planets. "The greater the orbital energy, the bigger the orbit," explains Malhotra. Neptune, Uranus, and Saturn began to move outward—with Neptune taking a 30 percent leap that moved it to its present location of roughly 2.8 billion miles from

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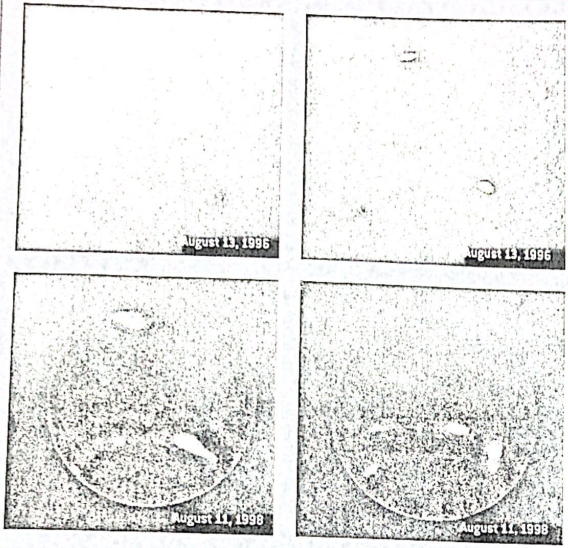


COLOR-ENHANCED IMAGES FROM THE HUBBLE SPACE TELESCOPE REVEAL NEPTUNE'S STORMY WEATHER. WINDS APPROACH 1,000 MILES AN HOUR AT THE EQUATOR, AND STORMS THE SIZE OF EARTH ITSELF CAN SWEEP ACROSS THE PLANET. METHANE IN THE UPPERMOST ATMOSPHERE ABSORBS LIGHT, MAKING THE PLANET APPEAR BLUE. THE PATCHES OF WHITE AND YELLOW INDICATE AREAS OF VERY HIGH CLOUDS.

NASA

the sun. Jupiter, which lay on the receiving end of the planetesimals, either absorbed or ejected them. As a result, Jupiter lost orbital energy, and its circuit around the sun shrank by about 2 percent.

Malhotra had theorized that Pluto's orbit had been shaped by Neptune, but it took the discovery of the Kuiper belt in 1992 to prove it. As Neptune glided outward, only those objects beyond a certain distance would have been able to escape being captured and pushed inward. Pluto, for instance, circles the sun two times for every three orbits of Neptune. Thus Pluto is said to be in a 2:3 resonance orbit with Neptune, says Malhotra, and other Kuiper belt objects have similar orbital relationships with Neptune. Any object orbiting closer than that, she believes, would have long been ripped from its circuit by the great planet. Pluto and the other objects in the Kuiper belt are just far enough away to avoid this fate.

Such planetary rearrangements appear to be common in other solar systems. The giant gas planet that orbits star 51 Pegasi, for example, baffled astronomers when it was discovered in 1995. The planet was about the same size as Jupiter, but it orbited eight times closer to its star than Mercury does around our sun. "No gas planet could have formed that close to a star," says Malhotra, "so it had to have moved there." The theory by which Neptune and the outer planets may have moved gives one possible explanation for this—although there will inevitably be others, especially since the giant Pegasi planet must have moved inward, rather than outward like Neptune, Uranus, and Saturn.

The planetary movement of Neptune, strangely enough, may be relevant to Earth's development. One somewhat speculative theory holds that water came to Earth by way of a distant icy body—such as those found in abundance in the Kuiper belt and the more remote Oort cloud, an icy, comet-filled field. The outward movement of Neptune may have perturbed the motion of that ice-bearing body, sending it on a course that eventually caused it to crash-land on Earth.

But that's just one of Neptune's myster-

DESTINATION NEPTUNE

Because of Neptune's enduring mysteries, astronomers dream of getting firsthand information about the planet. The main problem is how to get a spacecraft to cover the more than 2.6 billion miles quickly.

Voyager 2 took just 12 years to arrive at Neptune, but it took advantage of a rare alignment of the outer planets that created something of a gravitational superhighway to the planet—a circumstance that won't repeat itself for another 200 years or so. Launched today, a similar spacecraft would have to travel the equivalent of the planetary back roads and wouldn't reach Neptune until 2030. "Nobody's interested in launching something that's so slow it won't arrive until after everybody who sent it up is either retired or dead," says John Brophy, a project manager at NASA's Jet Propulsion Laboratory in Pasadena, California. "And if it costs billions of dollars, nobody's going to want to pay for it, either."

Conventional rockets would be too slow and too cumbersome. And the thousands of pounds of fuel required would be prohibitively expensive. One speedy alternative is a spacecraft powered by ion propulsion—such as the type used on the *Deep Space I* probe launched in 1998. Instead of combustible fuel, this spacecraft uses a much smaller supply of the naturally occurring gas xenon. By running an electric current from solar panels through the gas, "you can achieve a very high exhaust velocity—much higher than you can with a conventional rocket," says Brophy. Using this fuel strategy, the trip to Neptune might take only 10 years.

An even faster and far cheaper propulsion system could be devised using a solar sail. This technology involves rigging a spacecraft after it has been launched from Earth with an ultrathin, aluminum-coated plastic sail that is less than one twentieth the thickness of a human hair. "This is basically a mirror in space," says Charles Garner, a JPL engineer. As photons from the sun hit the sail, they bounce off—imparting up to double their momentum to the spacecraft. Blown by photons, a "sailcraft," as it's called, could travel as far as Neptune in as little as three years, says Garner.

What's more, he adds, the sailcraft could be deployed as reusable "slingshots." They could shuttle deep-space probes to the asteroid belt beyond Mars, hurl them into the great beyond, and then return to Earth's orbit to prepare for another mission. "When that's perfected, the cost of launching a probe would drastically fall," says Garner of the sailcraft ferry system. "It would open up a whole new era of deep-space and interstellar exploration." —C. R.

ies. When *Voyager 2* passed by the planet in 1989, it picked up images of a giant swirling storm the size of Earth that bobbed and weaved on the surface of the planet. Until then, nobody expected to find capricious storms on Neptune. Unlike the Great Red Spot on Jupiter, a turbulent region that has been observed since the days of Galileo, this storm proved unusually volatile: When the restored Hubble Space Telescope first took a look at Neptune in 1994, the dark spot had vanished. Changeable weather is no surprise to Earthlings because the sun heats up our planet's surface and sends water vapor and air rising to create clouds and wind. Farther out in the solar system, however, the sun's energy is so minimal, its effect is supposed to be reduced by the law of inverse squares. "Since Uranus is twice as distant as Saturn, it receives four times less solar energy—and should have four times less climactic activity," says Carolyn Porco, a planetary scientist at the University of Arizona.

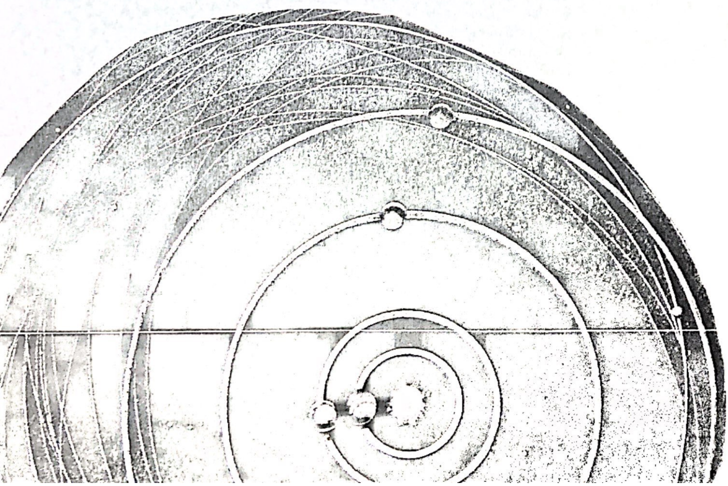
That law certainly seemed to be heeded by Uranus, which was so devoid of clouds it looked like a great cue ball hovering in space when *Voyager 2* flew by. Most astronomers predicted an equally boring Neptune—which lies 30 times beyond the distance of the Earth from the sun. Boy, were they wrong.

First, Neptune proved to be a more brilliant blue than expected. Methane in its upper atmosphere absorbs red light, creating the blue effect. And frozen methane high in its atmosphere produces wispy clouds. Within Neptune's interior, a spherical shell of water sloshes around a solid core, throwing the planet's magnetic field off 47 degrees from its axis of rotation. None of this was as surprising as the discovery of storm systems. Near-1,000-mile-per-hour winds and ever-changing clouds "went against all the models of what had been expected, and we're still trying to understand the reasons why," says Hammel. "Since the energy is not coming from the sun, that leads to the question: Where is it coming from?"

Neptune itself must harbor the answer. Planetary scientists can calculate a planet's radiation balance—the amount of energy it emits compared to the amount of sunlight

A MISBEGOTTEN MOON

Great valleys studded with bulbous masses of ice cover Triton, Neptune's largest moon. And when the weak rays of the sun vaporize frozen nitrogen below Triton's surface, giant gas geysers rise miles high. "It's a landscape unlike anything we've yet seen in the solar system," says Bill McKinnon, a planetary scientist at Washington University in St. Louis. Once a freely orbiting object about twice the diameter of Pluto, Triton became ensnared in Neptune's gravitational pull. At first, Triton's travels around the planet would have been elliptical. But over millions of years Triton's orbital interactions with Neptune nudged the satellite into a circular orbit—and the frictional heat generated by the change caused Triton's interior to melt. "What followed was an intense period of geologic activity," which appears to have ended only recently, if at all, says McKinnon. Astronomers want a closer look at Triton's unusual geology and atmosphere—which many believe to be analogous to Pluto's. "That is the only way we'll get a glimpse into this alternative kind of geology and geophysics that all of the icy worlds present," says McKinnon. —*C.R.*



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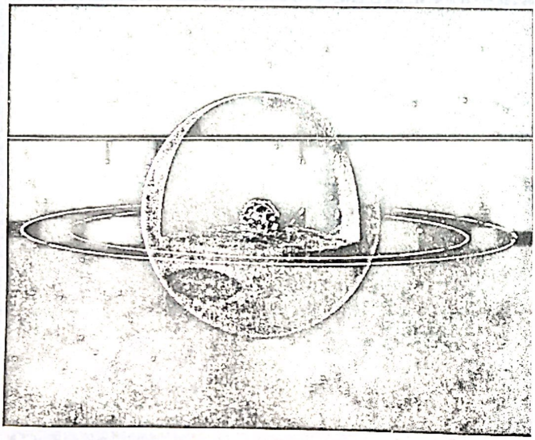
ing. "You've got great heat from the inside and very little heat from the outside, so you're not really in a stable situation at all," says Hammel.

Unlike Earth, which has only a very thin layer of atmosphere, a thick swath of gas surrounds Neptune's small solid core. In the outer layers of Neptune's atmosphere, the pressure would be similar to that on Earth, but with temperatures of −350 degrees Fahrenheit. Deeper into the planet, however, heat and pressure probably increase, until they rise so sharply that the atmosphere—much of it hydrogen—turns into a liquid state, "probably the consistency of pudding," says Hammel. Under these conditions, electrons become stripped from molecules, and the nuclei pack together. That is not a bizarre chemical configuration—it is the definition of a metal. "But it's unusual to think about hydrogen, which we know as a gas, being found in a metallic state," Hammel says.

Last year, a team at the University of California at Berkeley came up with a hypothesis about what might be occurring in the planet's atmosphere to explain Neptune's extraordinary internal energy. Robin Benedetti, a graduate student in physics, put some a laser beam to create "pressure and heat conditions that you might find about a third of the way toward the planet's center." Methane is composed of four hydrogen atoms that surround a carbon atom. Benedetti found that under extreme pressure the bonds holding the hydrogen atoms onto the carbon dissolved, and the carbon atoms began binding to one another. Under different conditions, carbon atoms would form a coal-like substance, but under this extreme pressure, they formed diamond dust. "We're not sure how big diamond crystals might form on Neptune," she says, but they could conceivably make the Krupp diamond on Elizabeth Taylor's finger seem like a chip. If those conditions exist on Neptune, it's possible that diamonds are literally raining down through the atmosphere toward the planet's center, releasing heat as a result of friction. "This could be a really huge amount of energy," says Benedetti, and it may explain in part why Neptune radiates 2.6 times as much heat as it absorbs from the sun.

The actual answers to this and other new questions raised by Neptune will have to wait until the day an orbiter can be launched to collect more information. "We've come a long way in our understanding," says Hammel. "But until we get the sort of data that only an orbiter can provide, the best we can hope for is a blurry—but tantalizing—view of this amazing planet." ◻

A HAIL OF DIAMONDS IN NEPTUNE'S INTERIOR MAY EXPLAIN ITS INTERNAL ENERGY



GASES SURROUND NEPTUNE'S SMALL, SOLID CORE, AND THE ATMOSPHERIC PRESSURE MAY BE GREAT ENOUGH TO FORM A HAIL OF DIAMONDS. A SYSTEM OF FAINT RINGS OF DUST ENCIRCLES THE PLANET.

TOP: NASA; BOTTOM: ILLUSTRATION BY JOE ZEFF

NEPTUNE'S STRANGE SATELLITES

NASA

Neptune's eight moons are an object lesson in the puzzles of the formation of planetary satellites—and none more so than the moon Triton. In the early days of the solar system, rocky material and icy debris were flying around, glomming together to form the planets. Eventually some became so large that their gravitational pull attracted gas and interplanetary dust as well. "As they did, they became almost like mini-nebulas and started spinning disks, which formed their own satellites—just as the formation of the sun spawned the planets," says Heidi Hammel of Boulder's Space Science Institute. When spawned by the planet it orbits, a satellite revolves in the same direction as the parent planet. The moon, for example, revolves in the same direction as Earth. But Triton revolves in the opposite direction from Neptune—a clear sign it was "captured" by the planet rather than formed within Neptune's own gaseous disk.

Nor is Triton the only puzzle. All planets have an area called the Roche limit in which the gravitational pull is so strong that material can't form into a satellite. Any satellite in the Roche limit must have either been captured or, more likely, dragged there by tidal forces on the planet's surface. Neptune has four satellites in the Roche limit—the only ones in the entire solar system. "All told—from Triton's retrograde orbit and the presence of four satellites in the Roche limit—there's something peculiar about the history of Neptune's satellites," says Carolyn Porco of the University of Arizona's Lunar and Planetary Laboratory.

And the future could hold some surprises, too. "If you were able to bash up the satellites in Neptune's Roche limit today, you would have a ring system that would not look too different from Saturn's," says Porco. "So what we have here is a giant ring system waiting to happen." —C.R.