

# Seeking answers, planetary scientists plot a return to the nearest ice giant

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Distant and obscure, the giant planets Uranus and Neptune lurk in the dark far from the Sun. Four decades ago they received one fleeting visitor from Earth, Voyager 2. No other spacecraft has ventured there since. “They are the least explored planets in our solar system,” says Heidi Hammel, a planetary scientist at the Association of Universities for Research in Astronomy in Washington, DC. “So there’s huge potential for new discovery.”

The recent decadal survey from the National Academies of Sciences, Engineering, and Medicine recommends that NASA’s next new large planetary mission take aim at Uranus (1). Unlike Voyager 2, which flew past the planet in 1986 (2), this new spacecraft would settle into orbit around Uranus and observe it for many years. At least one such orbiter has studied the five planets closest to Earth, from Mercury to Saturn. Uranus is twice as far as Saturn, yet a billion miles closer than Neptune, making Uranus the easier target. If NASA launches the mission in the early 2030s, it can reach the planet in the mid-2040s.

The impetus for the mission extends well beyond our solar system. When Voyager 2 zipped past Uranus, the only known planets were those around the Sun. Planet hunters have since found thousands of planets orbiting other stars. Many of these worlds are four times the diameter of Earth, the same size as Uranus and Neptune. A mission to Uranus would therefore scrutinize the nearest member of a planetary class that abounds throughout our galaxy. The spacecraft would investigate the planet’s structure and composition, offering clues to how these worlds originate.

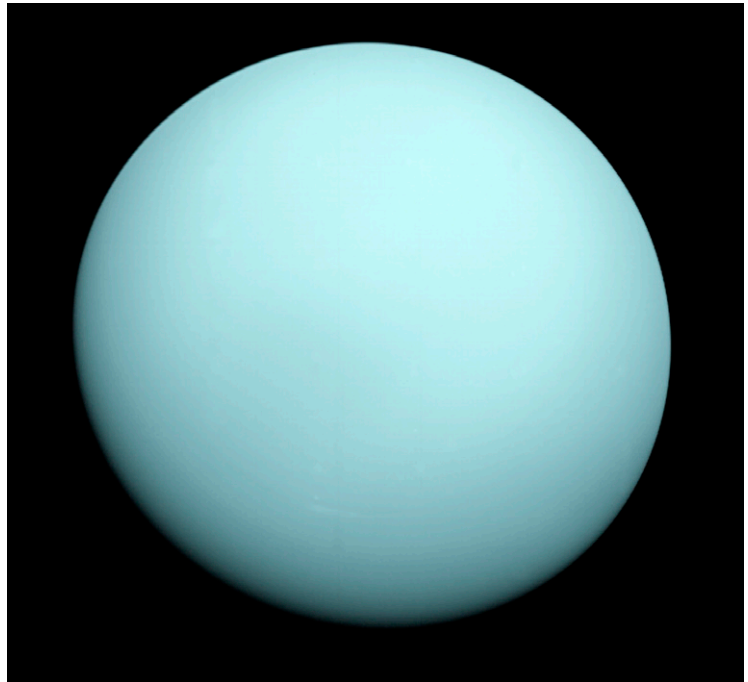
“It’s exploration,” says David Stevenson at the California Institute of Technology in Pasadena. “A major reason to go there is simply to do things you haven’t done before.”

## Ice Giants

One goal of such a mission would be to study the planet’s interior. Uranus and Neptune are twins, nearly equal in size and mass, and about 5% as massive as Jupiter, our solar system’s largest planet. Jupiter is a gas giant like Saturn, worlds made mostly of hydrogen and helium. In contrast, Uranus and Neptune are ice giants. Hydrogen and helium constitute just a fraction of their mass. Ice probably dominates instead, along with rock and iron.

But the term “ice giant” is misleading. “We’re not talking about ice cubes,” Hammel says. Their interiors are so hot that most of the “ice” is actually liquid water, methane, and ammonia. Planetary scientists call these three substances ices because they were once frozen solid in all or part of the frigid outer solar system, where the giant planets formed.

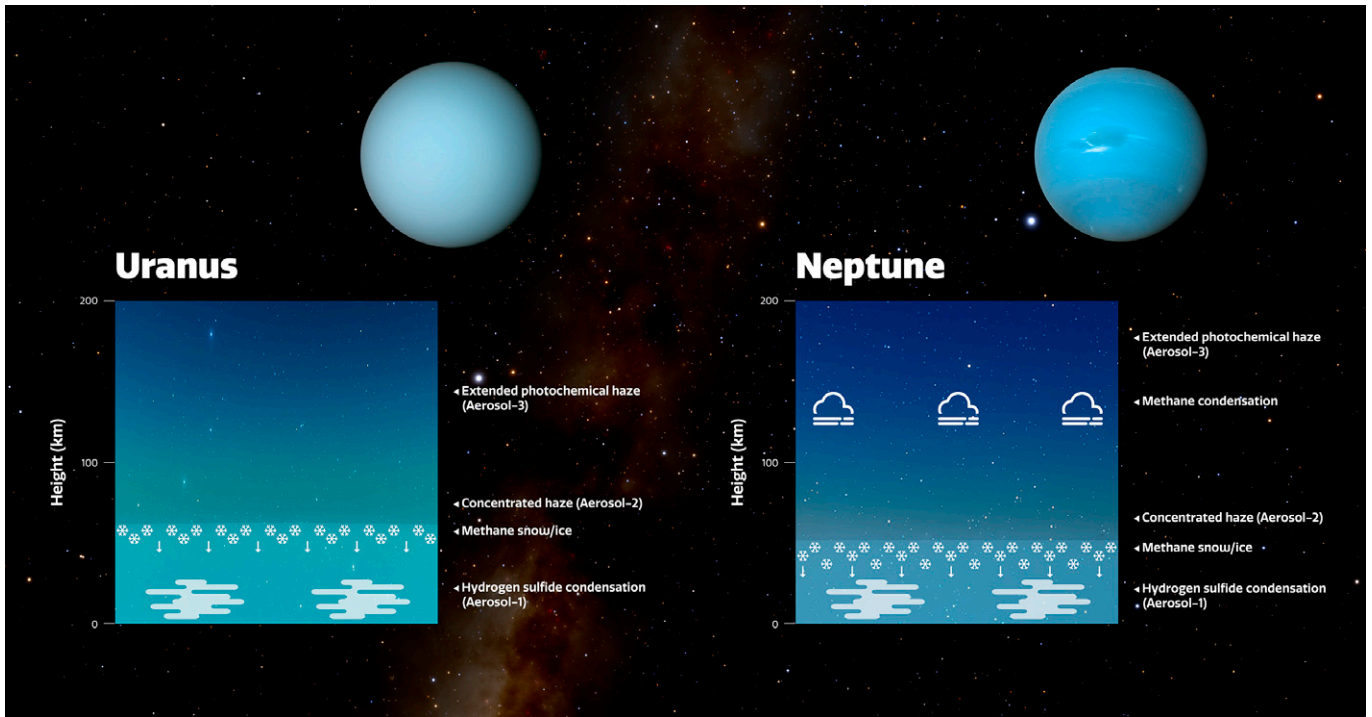
Complicating matters, researchers don’t know for sure that Uranus and Neptune are made mostly of water, methane, and ammonia, Stevenson says. Rock and gas mixed together can be as dense as this trio, hence mimicking what planetary scientists call ice. In principle, because water, methane, and ammonia consist of the abundant elements hydrogen, oxygen, carbon, and nitrogen, ice should have been more common than rock in the dust grains that built the giant planets. But if



**A mission to Uranus—seen here in an image taken by Voyager 2 in January 1986—would investigate the planet’s structure and composition, offering clues as to how ice giants originate. Image credit: NASA/JPL.**

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Neptune's more active atmosphere likely churns up more methane particles than does Uranus's atmosphere. This keeps Neptune's haze layer thinner and makes the planet appear more blue than Uranus. Image credit: International Gemini Observatory/NOIRLab/NSF/AURA, J. da Silva/NASA/JPL-Caltech/B. Jónsson.

Uranus and Neptune formed instead from the collisions of numerous rock-dominated denizens of the outer solar system like Pluto (3), the two giants could have more rock than ice. "Maybe they're actually rock giants and we've got it all wrong," says William McKinnon at Washington University in St. Louis, MO, who was on the steering committee for the decadal report.

Uranus's composition is therefore a mystery. Also, its structure may be unlike Earth's, which has a distinct core, mantle, and crust. Uranus might have a rock-iron core, a mantle of ice, and a gas envelope; or maybe not. Instead, all that material could be mixed together.

### Atmospheric Anomalies

Unlike its interior, Uranus's atmosphere is easier to observe. But it too poses questions. When Voyager flew past it, the planet's atmosphere was bland. In contrast, Jupiter and Saturn have active atmospheres, and Uranus's twin Neptune proved dynamic as well. Voyager saw storms and clouds, including a large dark spot, an enormous storm that has since vanished.

The difference between Uranus and its lively neighbors is easy to explain: All the giant planets radiate more heat than they receive from the Sun—except for Uranus. "That's a central mystery," McKinnon says. Uranus's lack of internal heat may account for its quiet atmosphere.

Uranus is unique among the planetary giants in another way, too: It lies on its side as it rotates. The rotational axes of most planets, including Earth, are approximately perpendicular to the plane of the solar system. For example, Earth's axis tilts only 23.4 degrees from the perpendicular. Uranus, however, has an axial tilt of 98 degrees. As a result, during solstice, when one of Uranus's poles leans

sunward, that pole points nearly straight at the Sun, subjecting the other hemisphere to total darkness. This was the case when Voyager flew past in 1986. Then, when equinox arrives, sunlight illuminates the entire planet from north pole to south. Because Uranus takes 84 years to orbit the Sun, equinox lights up regions that had been dark for decades.

During the equinox of 2007, Uranus surprised researchers by springing to life. "We saw a lot of dynamic cloud activity on Uranus, and it actually became more Neptune-like," says Hammel, who studied the planet with the Hubble Space Telescope and the Keck Observatory atop Mauna Kea, HI. Uranus even sported a great dark spot (4, 5). The recently launched James Webb Space Telescope will soon yield still sharper views, providing more details about any clouds and storms that develop. But it's unlikely to resolve the chief mysteries surrounding the planet.

This past year, planetary scientist Patrick Irwin at the University of Oxford in England and his colleagues combined data from three observatories, including Hubble, to tackle a simple question: Why do Uranus and Neptune differ in color? Uranus is green or aqua and Neptune is blue—similar but not identical. Astronomers have long known the main source of the colors: methane gas, which absorbs red light, but not green or blue. Methane makes up about 4% of each planet's hydrogen-helium atmosphere.

To explain the difference in hue, Irwin's team studied how bright the planets look at near-ultraviolet, visible, and near-infrared wavelengths and then constructed models of atmospheric structure that best reproduced the observations. This work indicates that Uranus is greener than its twin because it has thicker haze, which reflects green light and blocks blue. Neptune's more active atmosphere wafts up fresh methane, which condenses onto particles in

the haze and causes them to sink out of sight. As a result, Neptune's haze is thinner and the planet is bluer than Uranus (6).

Because of Uranus's extreme axial tilt, however, its color varies as it orbits the Sun. At solstice, Irwin says, the haze is thicker and the planet greener. At equinox, storms break up some of the haze, making the planet bluer. The next solstice comes in 2030. "My prediction is that Uranus is going to start looking greener and greener as this haze layer builds up," he says.

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—Patrick Irwin

## Mission Possible

The following year, in June 2031, NASA will have its first chance to launch what the decadal survey simply calls the Uranus Orbiter and Probe. The spacecraft would dart past Jupiter, stealing some of that planet's angular momentum to fling itself outward. The craft would reach Uranus in 2044, 6 years before the next equinox, in 2050, when the planet should grow stormier.

The price tag: \$4.2 billion. "Science is expensive," Stevenson notes. And NASA may get help. "There's an awful lot of interest in Europe," says Oxford's Irwin, noting that Americans could build an orbiter and Europeans a probe to plunge into the planet's atmosphere, reminiscent of the collaborative Cassini mission to Saturn.

The Uranian orbiter will measure the planet's gravity field, which will give clues to how concentrated or spread out the components of its interior are. That, in turn, may provide insight into why Uranus lies on its side, especially if a massive object slammed into the planet and knocked it over, shaking up its internal structure. The atmospheric probe will measure noble gases, elements that don't normally get locked into chemical compounds and whose abundances help constrain theories of planet formation.

The orbiter will also observe close-up something Hubble has seen from afar: aurorae, which on Earth are called the northern and southern lights, because they usually

appear near the north and south poles. Aurorae arise when a planet's magnetic field funnels charged particles such as electrons and protons into the upper atmosphere, where they set atoms and molecules aglow. Voyager shocked researchers by discovering that the line connecting Uranus's magnetic north and south poles tilts 59 degrees to the planet's axis of rotation. Thus, on Uranus, aurorae can appear far from the planet's north and south poles. No one knows why the magnetic axis is so off-kilter, but Voyager later found that Neptune's magnetic field is similarly askew.

Uranus has at least 27 moons, only five of them known before Voyager, which discovered 10 new moons. Analysis of Voyager's data a decade later uncovered one more (7, 8). Astronomers using Hubble and ground-based telescopes found the rest.

Still, the five pre-Voyager satellites will likely attract the most attention, because they are the largest. Voyager passed closest to two of them, Miranda and Ariel. Although the smallest of the quintet, Miranda shows terrains that differ wildly from place to place, "kind of like a Frankenstein's monster satellite," McKinnon says.

He says Ariel resembles Pluto's largest moon, Charon, which the New Horizons spacecraft studied in 2015. Ariel and Charon are the same size—a third the diameter of Earth's Moon—and both have deep canyons, perhaps because both once had internal oceans of liquid water that froze and expanded, cracking their crusts. The three other pre-Voyager moons—Umbriel, Titania, and Oberon—also intrigue researchers, in part because the last two are the largest.

But Voyager had a problem: It saw only half of each moon. Blame the planet, not the spacecraft. The five moons lie in nearly the same plane as Uranus's equator; because the planet's rotation axis was then pointing sunward, so were theirs, which meant that half of each moon remained dark, even as it turned. In contrast, at the upcoming 2050 equinox, a spacecraft could see the five moons in their entirety. "Everybody wants to see what the other half of Miranda looks like," Hammel says.

But everybody will be waiting a while. "I hope that the human race can pull this off in my lifetime," McKinnon says.

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