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Uranus and Neptune Should Be Top Priority, Says Report

NASA's Voyager 2 snapped this picture of a crescent Neptune on 31 August 1989 during the spacecraft's flyby of the planet. Voyager 2 is the only mission to have visited Uranus or Neptune. Credit: NASA/JPL-Caltech/Kevin M. Gill

Launching a small orbiter with an accompanying atmospheric probe to the solar system's ice giants, Uranus and Neptune, should be a top priority for NASA in the coming decade, say planetary scientists who conducted a review of potential missions to do so. Beyond being scientifically valuable, such a mission to each planet is technologically feasible, the team said. Voyager 2 visited the ice giants in the 1980s, the only craft ever to do so.

"It is important that the next mission to an ice giant study the entire system: the planet itself, the atmosphere, the rings, the satellites, and the magnetosphere," Mark Hofstadter, a planetary scientist at NASA's Jet Propulsion Laboratory in Pasadena, Calif., told *Eos*. Hofstadter is a coauthor of the June 2017 report that reviewed the mission potential for Uranus and Neptune. "Every component of an ice giant system challenges our understanding of planetary physics in a unique way," he said.

Here are five key questions the team wants to answer with dedicated missions to Uranus and Neptune. The team presented its findings and the state of ice giant science in December at AGU's Fall Meeting 2018 in Washington, D. C.

1. Why Is Neptune Too Hot and Uranus Too Cold?

Uranus and Neptune, being about the same size, should release heat leftover from planet formation at similar rates. But that's not what Voyager 2 found.

"Jupiter, Saturn, and Neptune all emit more energy than they get from the Sun," Hofstadter explained. "Uranus stands out: It's the only one that's not releasing much internal heat." It might be a result of the impact that tipped the planet onto its side, a result of differences in internal convection, or something else entirely, he speculated.

> "Every component of an ice giant system challenges our understanding of planetary physics in a unique way."

"If they're both the same type of planet… then they should be similar to each other, and why they're not makes no sense," Amy Simon, a senior scientist for planetary atmospheres research at NASA Goddard Space Flight Center in Greenbelt, Md., and a coauthor on the report, told *Eos*. "Understanding the interior structure is going to be pretty critical."

2. What Are Ice Giants Made Of?

Unlike Jupiter or Saturn, the ice giants "appear to be enriched in heavy materials, that is, elements heavier than hydrogen and helium," said Leigh Fletcher, a senior research fellow in planetary science at the University of Leicester in the United Kingdom who was not involved in the study. Past research has shown that the planets also contain significant amounts of ion-rich water. "How much is rocky and how much is icy is an open topic of debate. Why did they end up this way?" he asked.

Pinning down the planets' compositions would reveal where in the solar system they formed, Simon explained. It may also improve our understanding of planets of a similar size in other solar systems.

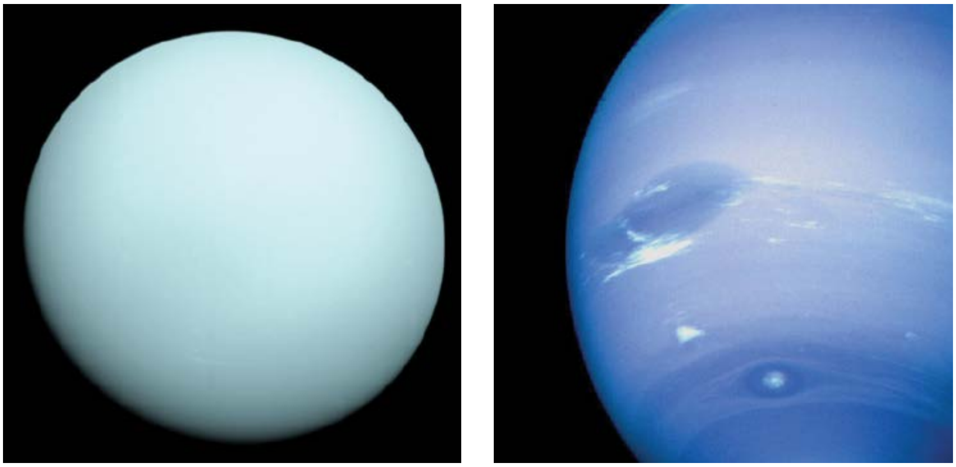
"These are the main sizes of planet that we're seeing in extrasolar planet systems," Simon said, "so the fact that we understand them so little in our own solar system is problematic for interpreting them in other solar systems."

3. Why Are the Rings of Ice Giants Narrow or Clumpy?

Uranus's 13 rings are narrow and densely packed, a formation that needs "shepherding moons" to keep it gravitationally stable, Hofstadter explained. Uranus seems to be missing the moons to do that. Moreover, he said, the particles in Uranus's μ ring look like those of Saturn's E ring, which is generated by the plumes of Enceladus. The moon associated with the μ ring, called Mab, lacks plumes, he said, so this ring's origin is yet unknown.

Neptune's rings raise different questions. "Before the Voyager encounter," Hofstadter said, "we didn't know Neptune had complete rings. Once we got closer and got a better look, we could see that it had complete rings but that they were very clumpy."

"Certain portions of Neptune's rings are much denser than others, and the details of



Uranus (left) and Neptune's dark spot and bright streaks (right) imaged by NASA's Voyager 2 in 1986. Planets are not to scale. Credits: left, NASA/JPL-Caltech; right, NASA/JPL

how and why that happens are not clear," he said.

4. What Is the History of Ice Giants' Moons?

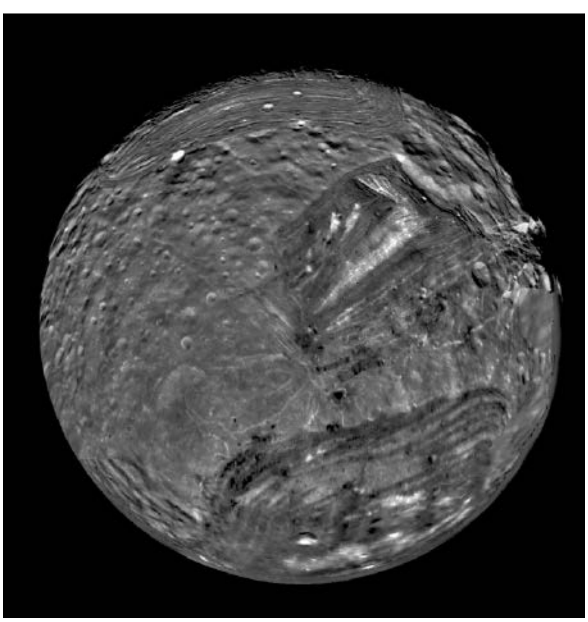
"Neptune's biggest moon, Triton, is basically a captured Pluto," Hofstadter explained. Scientists think that Triton may have formed in the Kuiper Belt beyond Neptune's orbit. Geysers and dark streaks on the moon's surface suggest that it may have a subsurface ocean similar to that of Jupiter's Europa or Saturn's Enceladus.

"We'd love to get a more careful look at Triton and see why it's active, learn about what happens when you gravitationally capture a relatively large body, and compare it to Pluto," Hofstadter said.

Regarding a possible Triton lander, Simon said that "landing on the surface of a body that we don't know much about is tough, particularly in knowing where it's safe to land." Nonetheless, "there's a lot you could learn if you could get down there."

Uranus's smallest and closest moon, Miranda, "looks like you took pieces of different puzzles and put them together," Hofstadter said. "There are blobs of very different looking regions on the surface. There's been some wild geology on this moon."

Its moon Ariel, on the other hand, might have cryovolcanism. "On these moons, water ice behaves almost like rock on the Earth, where it can be melted in the interior and flow or extrude onto the surface," he said. "There's some evidence for that kind of water volcanism on Ariel."



The south pole of Uranus's moon Miranda, imaged by NASA's Voyager 2. Credit: NASA/JPL/USGS

5. Why Are Ice Giants' Magnetic Fields So Complex?

Uranus's and Neptune's magnetic fields are relatively complex when compared with those of the gas giants, Hofstadter explained. This complexity may suggest that the deep-interior process generating the fields actually happens closer to the surface than it does on Jupiter or Saturn, he said. Sending a probe to the planets could help paint a clearer picture, he added.

"The brief Voyager flybys suggested these two planets had very irregular magnetic fields," said Fran Bagenal, a professor of astrophysical and planetary science at the Laboratory for Atmospheric and Space Physics at the University of Colorado Boulder. Bagenal, who was not involved with this study, said that a mission to these planets is critical to understanding how the planets generate magnetic dynamos in the water layers of their deep interiors and produce such irregular magnetic fields.

Moreover, "how the solar wind couples to the ice giants' magnetic fields is very different" from any other planet in the solar system, Hofstadter said, primarily because the fields themselves are so misshapen. For example, each planet's field is severely tilted from its axis of rotation and is offset from the center of the planet. Also, "the planets' magnetic fields change their orientations relative to the solar wind in a way that no other planet does," he said. Studying these fields up close could prove to be good tests for our models of planetary magnetic fields and the solar wind, Hofstadter added, which would benefit heliophysics.

> "Is one of the ice giants more important than the other to study? Uranus or Neptune?"

Uranus or Neptune?

Which planet should get a mission? For all that Uranus and Neptune are grouped together into the category of ice giants, they are remarkably different worlds, Simon explained.

An ice giant mission would need to be small enough to launch in a timely fashion but not so small that it can't answer its key science questions, she said. "It's a little bit of, Do you put your eggs in multiple baskets not knowing if you get more than one basket?" she said.

"In our study," Hofstadter said, "we asked ourselves the question, Is one of the ice giants more important than the other to study? Uranus or Neptune? And we said, no. If you want to learn about an ice giant, Uranus and Neptune are equally valuable. But while they are equally valuable, they are not the same. Each can teach us things that the other cannot."

By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer