Outer Planets: The Ice Giants

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Exploring Uranus and Neptune satisfies NASA's objectives, "investigation of the Earth, Moon, Mars and beyond with emphasis on understanding the history of the solar system" and "conduct robotic exploration across the solar system for scientific purposes."

The giant planet story is the story of the solar system (*). Earth and the other small objects are leftovers from the feast of giant planet formation. As they formed, the giant planets may have migrated inward or outward, ejecting some objects from the solar system and swallowing others. The giant planets most likely delivered water and other volatiles, in the form of icy planetesimals, to the inner solar system from the region around Neptune.

The "gas giants" Jupiter and Saturn are mostly hydrogen and helium. These planets must have swallowed a portion of the solar nebula intact. The "ice giants" Uranus and Neptune are made primarily of heavier stuff, probably the next most abundant elements in the Sun – oxygen, carbon, nitrogen, and sulfur. For each giant planet the core is the "seed" around which it accreted nebular gas. The ice giants may be more seed than gas.

Giant planets are laboratories in which to test our theories about geophysics, plasma physics, meteorology, and even oceanography in a larger context. Their bottomless atmospheres, with 1000 mph winds and 100 year-old storms, teach us about weather on Earth. The giant planets' enormous magnetic fields and intense radiation belts test our theories of terrestrial and solar electromagnetic phenomena. The rings are puzzles, each ring system different from the others, reflecting different origins and environments.

The larger satellites of the giant planets may have liquid oceans and habitable environments beneath their icy crusts. Triton, the largest satellite of Neptune, may be a captured object from the Kuiper Belt – a part of the solar nebula that never coalesced into a planet. Triton has a young surface with active geysers erupting into the thin atmosphere.

Giant planets are our link to the cosmos. Many have been found around other stars. We know something about the orbits and masses, and we will soon know the radius, temperature, albedo, and partial composition for several of these extrasolar objects. To interpret these data, we must understand the giant planets in our own solar system.

The Galileo and Cassini orbiters, both of which carried probes, brought our understanding of the gas giants to a high level. Our understanding of the ice giants is based only on the Voyager flyby and Earth-based telescopic investigations. New questions and new opportunities abound. Thus the Solar System Exploration Decadal Survey recommended a Neptune Orbiter with Probes to follow the prime missions that were recommended for the decade 2003-2013.

It is important to explore both ice giants, but Triton tips the balance in favor of Neptune as the first target. Repeated close passes over Triton's surface may be the easiest way to study a Kuiper Belt object. Once in orbit around Neptune, the parent spacecraft could deploy a Triton lander. Studies have shown that with gravity assists from Triton, the spacecraft can go to a high inclination, low periapse orbit to explore the planet's gravity and magnetic field. These measurements reveal the secrets of the deep atmosphere and core.

As far as we know, Neptune has the only system of ring arcs in the solar system. A spacecraft in orbit for 4 years or more can observe the behavior of this system and learn how it works. In general, rings are the closest analogs in our own solar system to the solar nebula and circumstellar disks in which extrasolar planets may be forming.

Because Neptune's magnetic axis is tilted to such a large extent relative to its spin axis, the magnetosphere is "pole on" relative to the solar wind once per Neptunian day. This is a much shorter time scale than that for the magnetospheres of Earth, Jupiter, or Saturn. Studying the response to this diurnal forcing will teach us how magnetospheres operate.

Neptune's jet streams are ~10 times stronger than Earth's jet streams and are as strong as any in the solar system, which is striking when one realizes that the sunlight heating Neptune's atmosphere is 900 times less than that at Earth. Storms last for months, and oscillate in various ways without appearing to lose energy. The key to this activity may lie in the winds, temperatures, and composition of the atmosphere beneath the clouds, which is best explored with probes. Equally important, probes measure the abundances of elements and their isotopes, which reveal how the planets formed and evolved.

With a gravity assist from Jupiter, Voyager reached Neptune in ~12 years and had a successful flyby. Going into orbit requires either nuclear propulsion or aerocapture. The latter involves flying the spacecraft through the atmosphere and losing enough energy to achieve orbit insertion. Technology development includes a heat shield – a thermal protection system like that on the Galileo probe – and a radioisotope power source. RTG's were used on all previous outer planet missions, but their development is currently on hold.

A Neptune mission that uses aerocapture for orbit insertion, Jupiter for a gravity assist, and Triton as a tour engine could use a conventional launch vehicle. Exploration of Uranus and Neptune provides the opportunity to understand the history of the solar system, since the ice giants are an important part of that history and may have had a profound effect on the history of Earth.

(*) We have quoted extensively from the 2002 study, "New Frontiers in the Solar System," also known as the Solar System Exploration Decadal Survey.