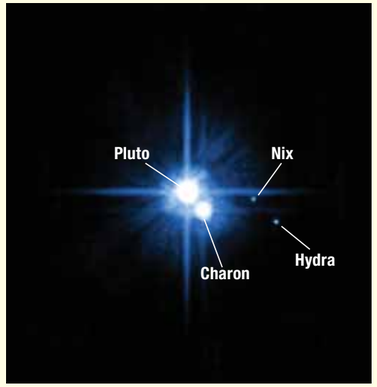
What lies beyond the planets

Everyone's heard of frigid Pluto, yet it's just the tip of the iceberg in the solar system's still-mysterious Kuiper Belt. **by S. Alan Stern**

Astronomers break down our planetary system's architecture into three distinct zones. The inner zone comprises the rocky planets and lies close to the Sun's warmth. The giant, gaseous planets dominate the middle zone. And the outer zone — called the Kuiper Belt — contains Pluto, 100,000 "ice dwarf" worlds, and several billion comets.

SEDNA'S ICY SURFACE glows dimly in the feeble light of the distant Sun. Sedna ranks among the largest objects found in the Kuiper Belt, although bigger ones likely lurk farther out. ADOLF SCHALLER/NASA/STScI



▲ **PLUTO'S FAMILY now contains at least four objects: Pluto itself, the relatively large moon Charon, and the two small moons Nix and Hydra.** HAL WEAVER (JHUAPL)/ALAN STERN (SwRI)/NASA/ESA

STATISTICS: Pluto vs. Earth

	Pluto	Earth comparison
Mass	0.0276 trillion trillion pounds	0.2% of Earth's
Diameter	1,485 miles	18.7% of Earth's
Density	1.75 grams/cc	31.7% of Earth's
Weight of 150-lb person	9 pounds	5.9% of Earth's
Distance from Sun	3,670 million miles	39 times Earth's distance
Orbital period	247.7 years	247.7 times Earth's
Length of day	153.3 hours	6 times Earth's

Mass: Total mass (1 trillion = 10^{12}); **Diameter:** Equatorial **diameter**; **Density:** Average density in grams per cubic centimeter (water = 1); **Distance from Sun:** Average distance; **Orbital period:** Sidereal period; **Length of day:** Average time between successive noons; **Earth comparison:** Ratio of Pluto's to Earth's value.

For centuries, astronomers have scrutinized the major bodies in the inner and middle zones. And, during the past 50 years, spacecraft have visited every planet in these zones. These probes have returned spectacular images and answered many of the mysteries surrounding these worlds.

Yet, the Kuiper Belt remains largely unexplored. No spacecraft has reached these far-flung objects. And even the most powerful telescopes on Earth and in space render these worlds as little more than faint points of light. Although this outer zone remains largely terra incognita, planetary scientists are starting to understand how the frigid outer solar system is put together.

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▲ **PLUTO AND CHARON posed for the Hubble Space Telescope's Faint Object Camera in 1994. This was the first image that clearly separated the closely orbiting, distant worlds.** NASA/ESA

An undiscovered continent

Formally speaking, American astronomer Clyde Tombaugh discovered the Kuiper Belt in 1930. Using a 13-inch camera at Lowell Observatory in Arizona, he found "Planet X," an object beyond Neptune that astronomers had been trying to find for the previous quarter century.

Scientists quickly dubbed this new world both Planet 9 and Pluto, the latter after the Roman god of the underworld. Observations showed it follows an unusually elliptical and inclined orbital path. Pluto takes 248 years to orbit the Sun, coming as close to our star as 29.5 astronomical units (AU; 1 AU is the average distance between the Sun and Earth, approximately 92.8 million miles [150 million kilometers]) and heading out as far as 49.5 AU.

When Tombaugh discovered Pluto, no one fully appreciated that he had revealed a third zone of the solar system. It's not a bad analogy to liken Tombaugh's discovery of Pluto to Columbus' discovery of America. Astronomers missed the conclusion that "Planet X" is the brightest member of a vast, undiscovered population that constitutes an entirely new zone of our solar system. Similarly, Columbus thought he had found India, but instead had stumbled upon a far more significant, and then unrecognized, element of Earth's geography.

For most of the 20th century, the more scientists learned about Pluto, the more it didn't seem to fit with our solar system's eight inner worlds and myriad small bodies. Suggestions about Pluto's true context did appear, however. Dutch astronomer Gerard Kuiper (1905-1973) hypothesized that Pluto might be the first known example of a vast population of bodies, including comets and "planetoids," that reside in the cold, trans-Neptunian wilderness 30 to 50 AU from the Sun.

Then, in 1977, American astronomer Charles Kowal discovered a "miniature planet" a couple of hundred kilometers in diameter orbiting between Saturn and Neptune. Astronomers soon realized this object, 2060 Chiron, has an unstable orbit. This strongly indicates it must have come from a more distant region of the solar system. And this, in turn, suggests many more such bodies likely orbit the Sun beyond the region of the giant planets.

Later, in the 1980s, orbital simulations demonstrated that most short-period comets must originate in a disk-like reservoir beyond Neptune. This finding harkened back to the concept of a trans-Neptunian belt of primordial bodies that Kuiper had written about 4 decades earlier, spurring various searches for a trans-Neptunian "Kuiper Belt" beginning around 1988.

The clincher came in mid-1992, when David Jewitt and Jane Luu discovered a distant object orbiting on a near-circular, low-inclination orbit a billion kilometers beyond Neptune. This object, dubbed 1992 QB_1, was just the first of what have now become more than 1,000 similar discoveries in the space beyond Neptune.

Notably, however, only about 1 percent of the sky along the ecliptic has been searched so far for Kuiper Belt objects (KBOs). When such a survey is complete, astronomers expect it will reveal more than 100,000 KBOs with diameters larger than 60 miles (100 km). Pluto's context is now clear. The Kuiper Belt occupies a far greater expanse, contains a far greater mass, and embraces a far larger and more diverse suite of bodies than does the asteroid belt.

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The Pluto system

Over the course of almost 80 years, the march of technology has allowed astronomers to learn the basics of the Pluto system — despite its great distance, faintness, and small angular diameter.

Pluto is a small planet with one large and two small moons. It measures 1,485 miles (2,390 km) in diameter. The Hubble Space Telescope barely resolves Pluto. Still, these images and other data show that it apparently has polar caps and a variety of bright and dark provinces scattered about its globe. On average, Pluto reflects 55 percent of incoming sunlight, indicating fresh ices cover the surface.

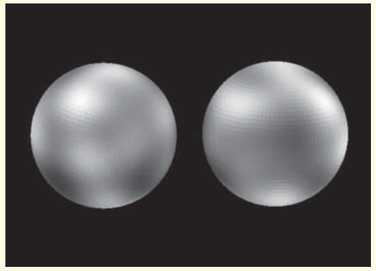
Spectroscopy shows that nitrogen ice dominates Pluto's surface composition, with small amounts of methane and carbon-monoxide ices also present. Some sort of darkening agent, with a still-undetermined composition, gives the planet a reddish color.

Pluto also has an atmosphere, which astronomers discovered by watching stars disappear behind the icy dwarf. Such occultations reveal an atmosphere when a star disappears gradually instead of abruptly. Nitrogen dominates the atmospheric composition as it does the surface.

Because Pluto's gravity is so weak (just 5 or 6 percent as strong as Earth's), the planet's atmosphere escapes at a fairly high rate. Perhaps several kilometers' worth of surface ice has been lost to space over the age of the solar system. Such "escape erosion" is not found elsewhere among the known worlds of the solar system. Pluto's atmosphere also has hazes, and observers have seen its pressure change dramatically for still poorly understood reasons.

With Pluto's great distance from Earth, it should come as no surprise how long it took observers to spot the dwarf planet's moons. U.S. Naval Observatory astronomer James Christy

▲ **GIANT PLUTO (right of center) and Charon (right of Pluto) stand watch over one of this world's recently discovered moons. The fourth moon appears as a bright dot well to Pluto's left.** NASA/ESA/G. BACON (STScI)



▲ **PLUTO'S SURFACE shows bright and dark areas largely covered in nitrogen-rich ices. These Hubble images, which reveal opposite hemispheres, also hint at Pluto's polar caps.** S. ALAN STERN (SwRI)/MARC BUIE (LOWELL OBSERVATORY)/NASA/ESA

▲ **KUIPER BELT OBJECT QUAOAR SPORTS A FINELY TEXTURED SURFACE in this artist's impression. Quaoar ranks among the largest of the estimated 100,000 KBOs.** NASA/G. BACON (STScI)

discovered the first one, Charon, in 1978. In Roman mythology, Charon is the boatman who ferries souls of the dead across the river Styx to the underworld. The moon lies about 12,160 miles (19,570 km) from Pluto and makes a circular orbit in the planet's equatorial plane.

Charon's diameter is almost precisely half that of Pluto, a ratio no planet-satellite pair of the inner or giant planets comes close to. In fact, its size (737 miles [1,186 km] across) and mass (12 percent of Pluto's) are so large relative to Pluto that the pair makes the solar system's only true double planet — their gravitational balance point lies in the space between them rather than inside the main body.

Charon reflects less light than Pluto, returning some 35 percent of the sunlight hitting it. Unlike Pluto, water ice primarily covers Charon's surface, with trace amounts of ammonia compounds. There's no sign of nitrogen, methane, or carbon-monoxide ices.

In 2005, astronomers used the Hubble Space Telescope to search for new Pluto moons in support of the New Horizons Pluto-Kuiper Belt mission then about to be launched. They discovered two small moons. These bodies, each just 35 to 100 miles (60 to 160 km) across, orbit more than twice as far from Pluto as does Charon. Astronomers quickly named the two new moons Nix and Hydra.

In Roman mythology, Nix is the goddess of darkness and the night, and mother of Charon. Hydra is the nine-headed monster that guards the gates of the underworld. The surface colors of Charon, Nix, and Hydra are all a bland gray. Scientists do not yet have any information on the reflectivities, surface compositions, or surface appearances of Nix and Hydra.

From studies of Charon's orbit around Pluto, astronomers can determine Pluto's mass. And knowing both Pluto's mass and volume, scientists have learned that the dwarf planet's density measures close to 2 grams per cubic centimeter. This means Pluto must contain about 70-percent rock inside, in addition to its surface ices. Thus, although scientists often refer to Pluto as an icy world, it is primarily rocky.

The third zone

It has now been 16 years since the discovery of 1992 QB_1, and the subsequent realization that a vast assemblage of icy bodies rings our solar system. The objects range in size from cometary nuclei a mile or less in diameter to dwarf planets many hundreds to more than 1,550 miles (2,500 km) across. Astronomers estimate the

▲ **DWARF-PLANET ERIS, seen here with its faint moon Dysnomia (at the 8 o'clock position), currently ranks as the solar system's largest dwarf planet, besting even Pluto.** NASA/ESA/M. BROWN (CALTECH)

Kuiper Belt's total mass today at between 0.01 and 0.1 Earth-mass.

Most Kuiper Belt objects have relatively dark surfaces, typically reflecting just 3 to 15 percent of the light that falls on them. A small fraction have higher albedos, notably Pluto and Charon. In Pluto's case, the high albedo of 55 percent arises because its atmosphere regularly deposits fresh snow on its surface. The surface colors of KBOs range widely, from slightly bluish to extremely red. Astronomers also have unearthed evidence for water ice on some KBOs, like Charon, and even more-volatile substances, like nitrogen, methane, and carbon-monoxide ices, just as on Pluto.

Most of the KBOs studied so far appear to rotate on their axes in a few hours, although some take days. In 2001, researchers found the first KBO moons. Today, astronomers recognize that at least 20 percent of KBOs have moons.

Astronomers also have found that collisions play a key role in the Kuiper Belt, shaping the surfaces of KBOs and controlling the number of small bodies there. This realization led to the discovery that those short-period comets originating in the Kuiper Belt are fragments chipped off larger KBOs only millions to hundreds of millions of years ago.

Some KBOs have small moons, some have large moons, and others, like Pluto, have both. A moon allows researchers to calculate the main body's mass, and thus estimate its density. So, we've learned that while some KBOs consist primarily of rock with icy outer shells like Pluto, others are practically all ice.

How did the Kuiper Belt and KBOs form? Computer simulations show KBOs could not have formed in today's belt. Why? There is not nearly enough material in this region to accumulate into objects hundreds and thousands of kilometers across during the solar system's life.

One theory to explain this quandary suggests the primordial Kuiper Belt had to be perhaps 50 times its present mass. Numerical simulations show the largest KBOs were well on their way to growing into large planets, perhaps something the size of Mars, Earth, or even Neptune, when something suddenly interrupted their growth. A likely culprit: the growth of "nearby" Neptune.

One effect of this "dynamical excitation" would have been that collisions became erosive, rather than accretional as they had been. Once this transition took place, the growth process would have stopped. Erosion then would have ground much of the mass in the ancient Kuiper Belt into dust. The Sun's radiation pressure subsequently would have blown this dust into interstellar space.

Astronomers have witnessed similar processes taking place in what appear to be Kuiper-like belts around many stars in our galaxy, including Vega and Beta Pictoris. This scenario appears to explain the lack of a large planet in the Kuiper Belt as well as the dearth of mass found there.

Other astronomers think the mismatch between the Kuiper Belt's current mass and the much larger amount required to form the bodies in it stems from the KBOs forming elsewhere. These researchers conclude the objects we now see orbiting in the 30 to 50 AU region formed closer to the Sun, in the middle zone of the solar system, where we know a huge mass of rock and ice existed when the giant planets formed.

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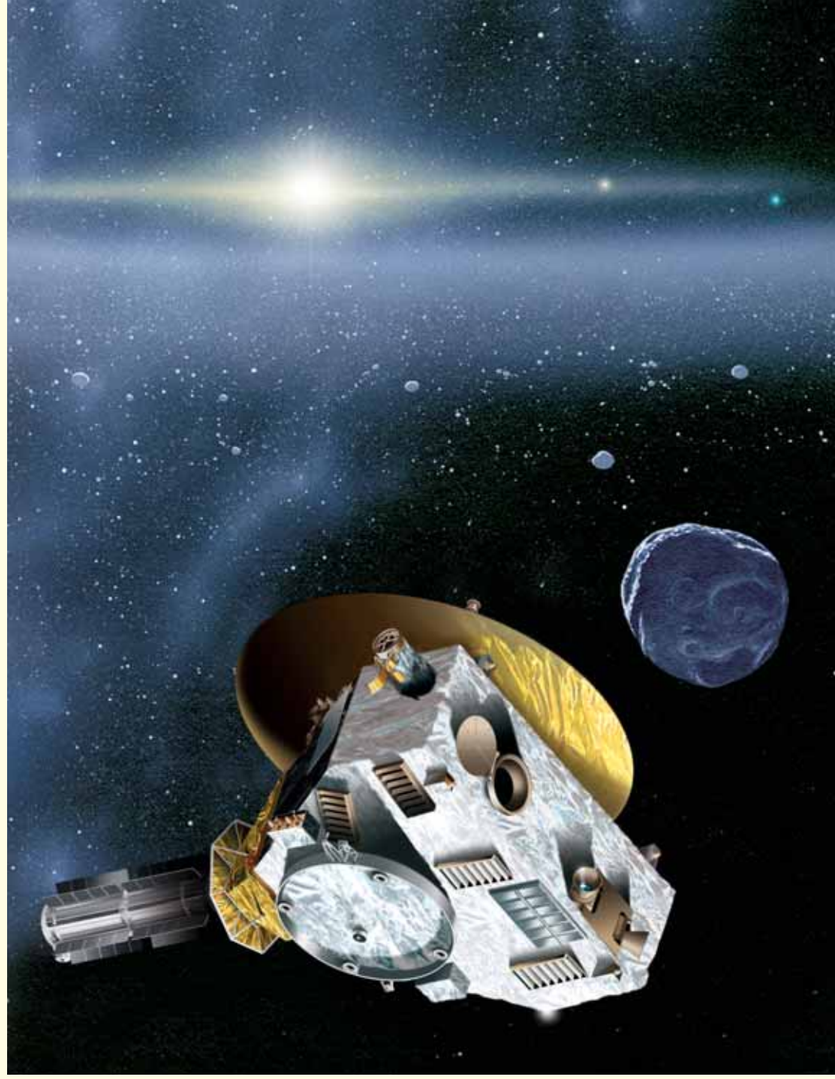
If the KBOs developed closer to the Sun, then how did they get to their present orbits? According to some models of solar system formation, the migration of the giant planets transported the KBOs. This migration would have swept many smaller bodies from the middle zone out to the Kuiper Belt and even to the Oort Cloud beyond.

What actually happened? We do not know. In fact, both scenarios may have played a role, each responsible for some aspects of the present-day Kuiper Belt.



▲ **THE NEW HORIZONS SPACECRAFT looks back on a Kuiper Belt object shortly after its flyby. From a distance of 4.1 billion miles (6.7 billion km), the faint Sun glows inside the zodiacal dust cloud.** NASA/ESA/M. BROWN (CALTECH)

A clue to the past

Overall, the Kuiper Belt is a highly varied collection of collisional shards and dwarf planets. Owing to its strongly heterogeneous population and its nature as a collection of ancient bodies left over from the formation of the outer planets, the Kuiper Belt ranks among the most scientifically significant parts of the solar system.

The Kuiper Belt's discovery has revolutionized scientists' view of our home planetary system in three important ways. First, it gave context to Pluto's existence, which, prior to 1992, appeared to be an oddity. Second, it provided strong links between our solar system and the kinds of debris disks seen around main sequence stars like Vega, Fomalhaut, and Beta Pictoris. Finally, it helped us realize that our planetary system contains a "third zone" — an ancient, icy disk of miniature worlds dotting the space beyond the giant planets.

The study of the Kuiper Belt remains in its infancy. Although we have learned much, we have much to learn. If we can count on anything, however, it's that the Kuiper Belt will continue to surprise. ◘