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.

What lies beyond the planets.
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 the 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.

An undiscovered continent
Formally speaking, American astronomer Clyde Tombaugh discovered the Kuiper Belt in 1930. Using a 15-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 92.2 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 misused 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. Suggested by 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.

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, 2000 Chron, 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 dem- onstrated 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 Kuiper Belt remains largely unexplored. Even the most powerful telescopes on Earth... render these worlds as little more than faint points of light.

### STATISTICS: Pluto vs. Earth

<table>
<thead>
<tr>
<th></th>
<th>Pluto</th>
<th>Earth comparison</th>
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<tbody>
<tr>
<td>Mass</td>
<td>0.0275 million tons</td>
<td>0.0% of Earth’s mass</td>
</tr>
<tr>
<td>Diameter</td>
<td>1,458 miles</td>
<td>18.7% of Earth's diameter</td>
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<tr>
<td>Density</td>
<td>1.75 grams/9 pounds</td>
<td>1.75% of Earth’s density</td>
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<tr>
<td>Weight of 150-lb person</td>
<td>9 pounds</td>
<td>5.9% of Earth’s weight</td>
</tr>
<tr>
<td>Distance from Sun</td>
<td>39 times Earth’s distance</td>
<td>39 times Earth’s distance</td>
</tr>
<tr>
<td>Orbital period</td>
<td>248.7 years</td>
<td>248.7 years</td>
</tr>
<tr>
<td>Length of day</td>
<td>153.3 hours</td>
<td>6 times Earth's length of day</td>
</tr>
<tr>
<td>Mass: Total mass (1 million = 1000 metric tons)</td>
<td>3.07 million tons</td>
<td>3.07 million tons</td>
</tr>
<tr>
<td>Distance from Sun</td>
<td>3.07 million miles</td>
<td>3.07 million miles</td>
</tr>
<tr>
<td>Orbit: Spherical orbit</td>
<td>308.7 miles</td>
<td>308.7 miles</td>
</tr>
<tr>
<td>Length of orbit</td>
<td>114.2 years</td>
<td>114.2 years</td>
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### GGIANT PLUTO’s 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.

### THE KUIPER BELT REMAINS largely unexplored. ... Even the most powerful telescopes on Earth... render these worlds as little more than faint points of light.

### PLUTO’S FAMILY now contains at least four objects: Pluto itself, the relatively large moon Charon, and the two small moons Nix and Hydra.

### 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.

### THE PLUTO SYSTEM reveals 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.

### THE PLUTO SYSTEM

Over the course of 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 that show 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 surfae.

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 that usually disappears at a rate that belies it as a distinct feature of the planet.

Instead of abruptly. Nitrogen dominates the atmospheric composition as it does the surface. Because Pluto’s gravity is so weak (just 5 to 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 haze, 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...
PLUTO AND CHARON MAKE the solar system’s only true double planet — their balance point lies between them rather than inside the main body.

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. 

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 belt analogs among many stars in our galaxy, including Vega and Beta Pictoris. This scenario appears to explain the lack of a large planet in the ancient 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. Once the Kuiper Belt 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.

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.