What else IS out there?

Planets and other large objects could be lurking far beyond Neptune, but they'll be very difficult to find.

DAVID JEWITT

BEFORE GALILEO pointed his telescope skyward some 400 years ago, the solar system was a decidedly simple place. Apart from the Moon, the Sun, and the planets out to Saturn, only the occasional comet was seen by the unaided human eye.

Things became more interesting as telescopes and their detectors improved. Major discoveries included Uranus and Neptune as well as new classes of objects, notably the main-belt asteroids between Mars and Jupiter and the icy bodies of the Kuiper Belt beyond Neptune.

Remarkably, this phase of solar system discovery continues at an accelerated pace, as technological improvements allow us to peer ever more deeply into the abyss beyond the known planets. Steady observational progress and new speculations based on models together lead us to wonder what else might be found in the outer regions.

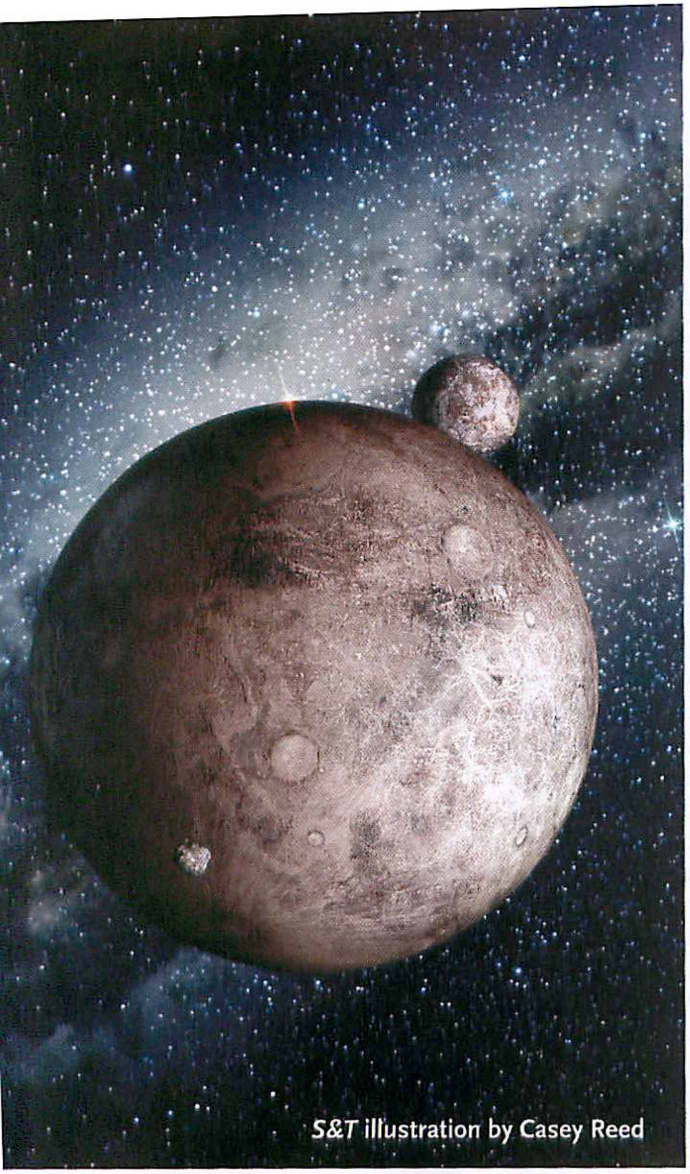
Plenty of Real Estate

The most recently discovered solar system real estate is the Kuiper Belt. The belt extends at least to 1,000 astronomical units (a.u.) and contains a rich abundance of primitive bodies that are, in part, leftovers from the planet-formation epoch. Astronomers have identified more than 1,000 Kuiper Belt objects (KBOs) since 1992, most larger than about 100 kilometers (60 miles) in diameter. A vast number of smaller objects await discovery: the Kuiper Belt holds perhaps 100 million icy bodies with diameters of 1 km or larger.

Some of these bodies escape the belt and drift toward the Sun, where they vaporize and are seen as short-period comets. At the other extreme, KBOs are known to range in size up to Pluto and Eris, both about 2,300 km across.

Neptune's satellite Triton is almost certainly a captured KBO (*S&T:* September 2006, page 18) and is larger still,

FAR-FLUNG PLANET *Above:* Given the solar system's tumultuous early history, objects bigger than Earth could have been gravitationally flung into the outer reaches of the solar system. Such planets would be extremely faint and difficult to detect, and so for now we have only artist conceptions such as this.



S&T illustration by Casey Reed

at 2,700 km. But Triton is only 0.3% as massive as Earth. Could truly planetary-size objects lurk in the Kuiper Belt?

The simple answer is an unqualified "yes." The Kuiper Belt is enormous, providing lots of room in which to hide bodies the size of Earth or larger.

VACUUM CLEANER Jupiter has played a major role in clearing the solar system of debris. A small object hit Jupiter in July 2009, producing the dark spot. But for every object that hits Jupiter, many more are deflected. A small percentage end up in the Oort Cloud, but most are ejected from the solar system.

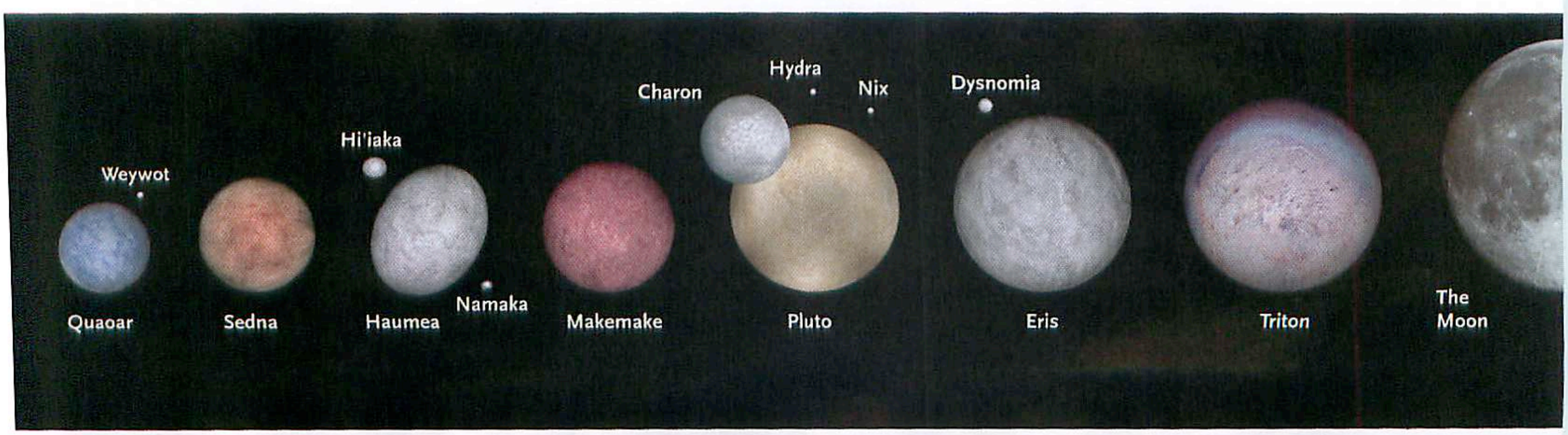
NASA / ESA / HEIDI HAMMEL (SSI) / JUPITER IMPACT TEAM

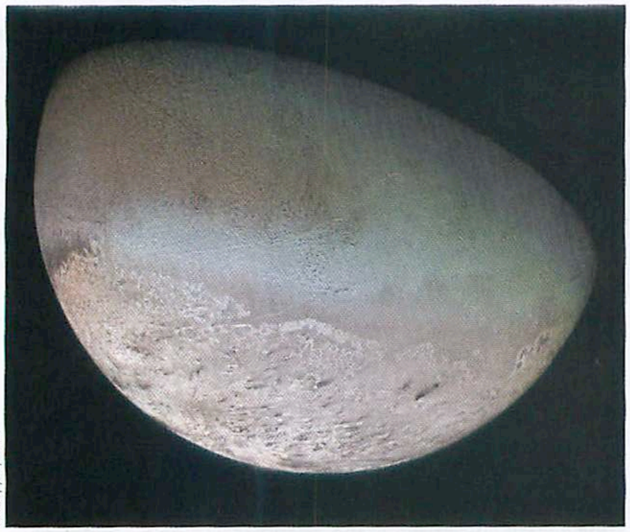
Consider a thought experiment in which an Earth twin is transported outward to ever-larger distances. At 5 a.u., the distance of Jupiter, this twin would appear at visual magnitude 2.6, comparable to one of the brighter stars in the sky. A telescope would reveal a disk 4 arcseconds across, about the same as the apparent diameter of Uranus. By 30 a.u., corresponding to Neptune's orbit, the magnitude falls to 10.8 and the diameter to 0.6 arcsecond.

At 600 a.u., much farther than any known planet but still well within the range of distances swept by known KBOs, Earth would appear near magnitude 24 and would have an angular diameter of only 30 milliarcseconds. It would be too faint to have been recorded in any all-sky survey conducted to date, and too small to be resolved even by the largest telescopes using adaptive optics.

Neptune itself would appear at magnitude 24 if displaced to 1,200 a.u., and would go undetected in our surveys. Neither could we detect such bodies via their gravitational perturbations on the planets. Calculations show that Earth could be detected only to about 50 a.u. while Neptune's pull would be immeasurable beyond about 130 a.u. So the vastness of the Kuiper Belt provides an enormous largely unexplored space where all sorts of interesting objects might lurk.

KUIPER BELT OBJECTS Astronomers continue to find sizable objects in the Kuiper Belt. This illustration shows some of the largest known bodies, including Neptune's captured moon Triton.





NASA / JPL / USGS

KUIPER BELT INTERLOPER Neptune's large satellite Triton has a retrograde orbit, meaning it was captured from the Kuiper Belt. With a diameter of 2,700 kilometers, Triton is larger than any known Kuiper Belt object, a strong indication that sizable bodies remain undiscovered in the solar system's outer reaches.

Kuiper Belt Planets?

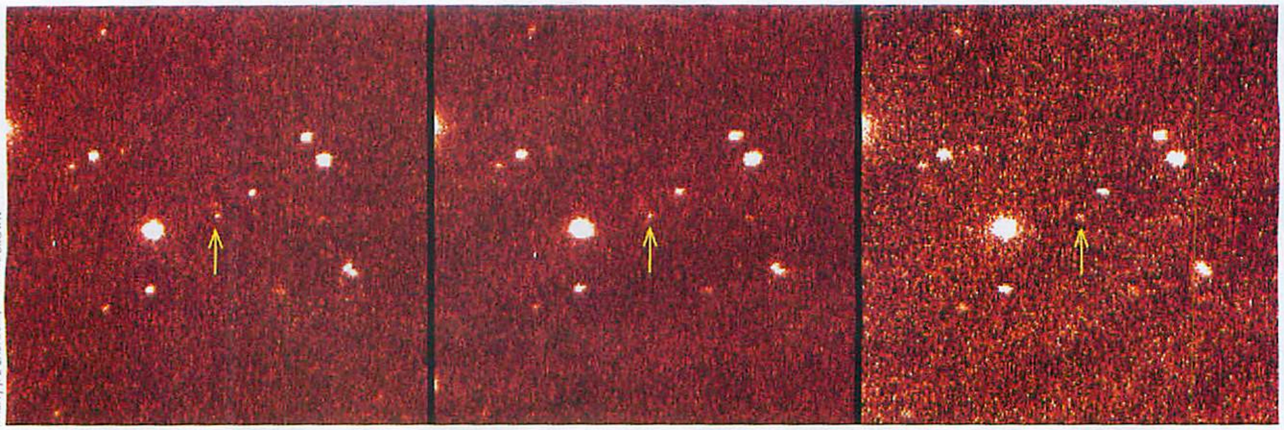
Whether large objects actually exist out there is a different matter. Our current understanding of planetary accretion indicates that it would be difficult for planets to form at Kuiper Belt distances. Smaller bodies must collide repeatedly in order to grow into larger objects and, in the rarified regions of the outer solar system, with slow orbital motions, the necessary collisions are expected to be very rare. In fact, modelers can't even account for the formation of Uranus and Neptune at their current distances of "only" 19 a.u. and 30 a.u.

But it's conceivable that large objects might have formed close to the Sun and were then gravitationally scattered by planets to distant orbits in the Kuiper Belt. For example, some models suggest that Uranus and Neptune formed closer to the Sun and drifted outward due to tidal interactions with each other and with a long-gone massive precursor to the Kuiper Belt. Neptune's radial migration, from about 20 a.u. to its current location near 30 a.u., would explain why so many Kuiper Belt objects occupy Pluto-like orbits in resonance with Neptune. Other evidence that planets can be thrown around comes from the highly elongated orbits of many known extrasolar planets, perhaps produced by close encounters with other planets.

Alternatively, if the Sun formed in a dense star cluster, it might have grabbed objects formed around other stars into large, looping orbits far beyond the known planets. There are no known examples of such objects at present. Perhaps the closest analog is Sedna, whose perihelion distance of 76 a.u. lies more than twice as far from the Sun as Neptune. Sedna's inclination, though, is a modest 12 degrees, suggesting that it originated in the Sun's protoplanetary disk. Objects captured from other stars in a natal cluster would have large, even retrograde, inclinations far out of the ecliptic plane.

The theoretical possibilities are essentially unbounded and all we can do is wait for future observations to show us what lurks in the Kuiper Belt. Spacecraft will probably not be useful in this regard — they're good at making detailed observations of particular objects but not so useful for the surveys needed to explore the Kuiper Belt. The planned (but largely unfunded) Large Synoptic Survey Telescope, if built, will be more powerful (*S&T:* September 2008, page 30). With the ability to survey almost the entire sky to 24th magnitude, LSST could find planets in the Kuiper Belt's outer reaches.

DISTANT WANDERER The discovery of Sedna by Michael Brown's team was yet another indication that interesting bodies lurk in the outer realm of the Kuiper Belt. Its elongated 12,000-year orbit ranges from 76 to 975 astronomical units. These discovery images, taken over three hours on November 14, 2003 with the 48-inch telescope on Palomar Mountain, show Sedna's slow orbital motion. Sedna is visible only because it's near perihelion.



NASA / JPL-CALTECH / MICHAEL BROWN

The Outer Outer Limits

Observations prove that the Kuiper Belt is real, but there is a structure at a much larger distance whose existence can only be inferred. The Oort Cloud is a roughly spherical swarm of comets about 100,000 a.u. in scale, with all of its members in orbit around the Sun. Dutch astronomer Jan Oort (1900–1992) inferred its existence in 1950, based on the observation that the orbits of long-period comets (those with periods greater than 200 years) are large and randomly oriented in the sky. Oort reasoned that these long-period comets must be falling into the planetary region from a vast, roughly spherical and unseen cloud surrounding the Sun.

The first estimate of the number of Oort Cloud comets was 10^{12} (a trillion), while more recent work using improved measurements of the discovery rate of long-period comets suggests that the number might be 10 times smaller. The Sun's gravity is so weak at 100,000 a.u. that the gravitational tugs of passing stars and Milky Way tides together can destabilize the orbits of Oort Cloud comets. In fact, the cloud's outer radius is set by the distance beyond which comets are ripped away from the Sun.

Some Oort Cloud comets escape to interstellar space while others dip into the region of the planets and begin to vaporize in the Sun's heat. The Oort Cloud has thus been steadily depleted since its formation. In the beginning, the cloud probably contained at least a few times more comets than it does now, and perhaps 10 times as many. The erosion is slower at smaller distances, leading to the idea of an inner Oort Cloud that might persist almost unaffected at 5,000 to 10,000 a.u.

OORT CLOUD'S OUTER EDGE
The Oort Cloud's outer boundary is probably about 100,000 a.u. from the Sun. That's equivalent to about 1.5 light-years, or only about one-third of the distance to the nearest known star, Proxima Centauri.

As far as we know, no comets formed in the Oort Cloud, since at these vast distances the density of any matter associated with the Sun's protoplanetary disk must have been vanishingly small. Instead, we think the Oort Cloud comets were originally planetesimals formed between Jupiter and Neptune, and were then scattered outward by near-miss interactions with these growing planets.

Most of the ejected planetesimals were launched above the Sun's escape velocity and are now wandering the frigid depths of interstellar space. Perhaps 1% to 10% of the scattered objects were subsequently deflected by external forces into orbits weakly bound to the Sun. If true, Oort Cloud comets are samples of the Sun's protoplanetary disk that have been expelled to great distances and stored in deep freeze (10 Kelvins) for the age of the solar system.

The observational challenge posed in directly detecting Oort Cloud objects is daunting. At 100,000 a.u., the nucleus of Halley's Comet would appear hopelessly faint at magnitude 64. Even at only 1,000 a.u. (and magnitude

INTERSTELLAR COMETS

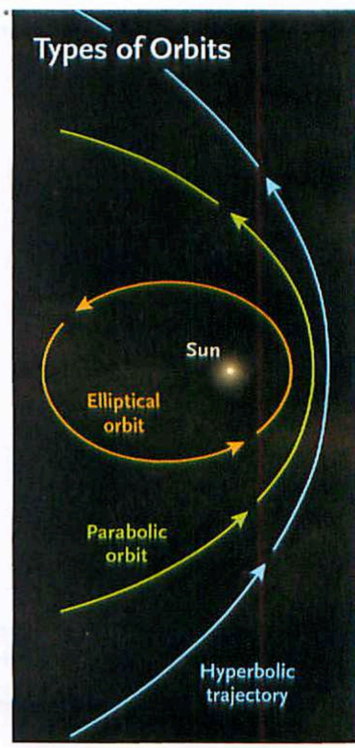
What happened to the comets that were ejected from the solar system as the Oort Cloud formed? They presumably float among the stars in interstellar space. If all stars lose 10^{12} to 10^{13} comets and there are about 10^{11} stars in our galaxy, the galaxy must hold 10^{23} or 10^{24} comets. Although numerous, the combined mass of comets is negligible compared to the mass in stars, dark matter, and interstellar clouds.

Some interstellar comets *should*, by chance, wander into the solar system. Interstellar comets would follow distinctive, strongly hyperbolic paths relative to the Sun, quite unlike any comets observed to date (the orbits of all known comets are elliptical or parabolic).

Although there have been a few claims of possible interstellar comets, none have shown hyperbolic orbits that are a prerequisite for interstellar origin. At best, the claims rely on measurements of "strange" composition, but "strange" is relative and there are other plausible explanations for such objects.

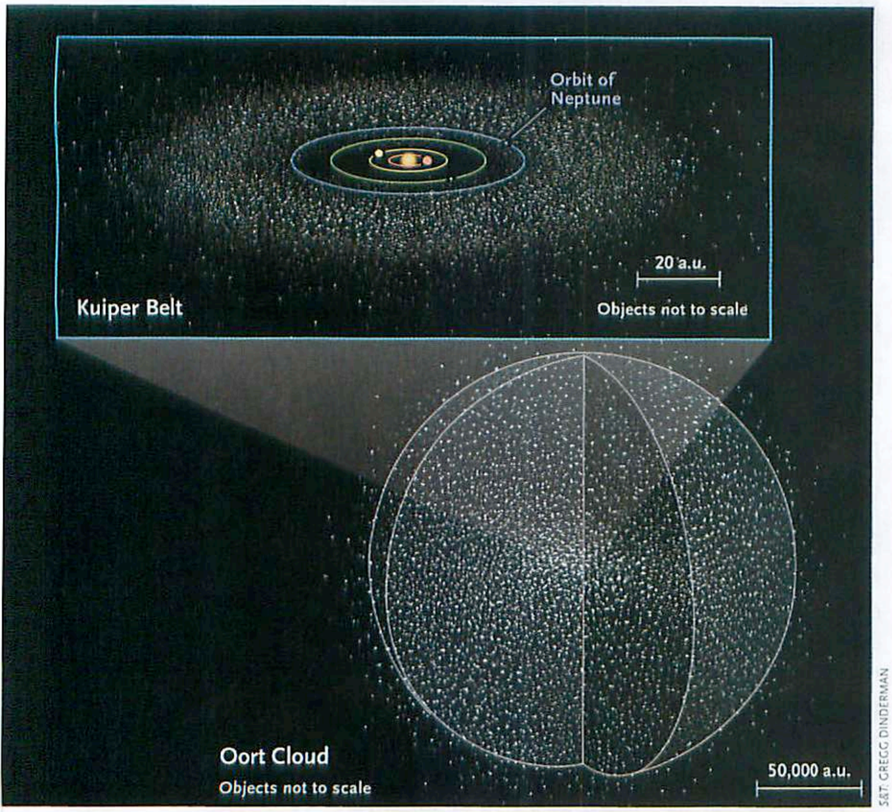
But the galaxy's huge size relative to the solar system means that we would expect visible interstellar comets to be rare, occurring at intervals from decades to centuries. No existing telescope would be expected to have found one. Interstellar planets probably exist too, but these would be roughly a trillion times less common than interstellar comets. We would never expect to see one passing through our planetary region.

Still, there is a small but real chance that the next generation of all-sky survey telescopes (Pan-STARRS or LSST) might detect an interstellar interloper. How fantastic would that be?



S&T: GREGG DINDERMAN

COMET ORBITS Comets follow a wide variety of orbits. If a comet is ever found on a strongly hyperbolic trajectory, meaning it's not gravitationally bound to the Sun, this would be a dead giveaway of an interstellar origin.



COMET RESERVOIRS The Kuiper Belt mainly contains bodies left over from the Sun's protoplanetary disk; the Oort Cloud consists of objects ejected from the inner solar system. Both regions might contain large unseen bodies.

For more information about the outer solar system, visit the author's website at www2.ess.ucla.edu/~jewitt/.

43), it would be far beyond detection by any telescope yet built or imagined. Likewise, the heat radiated from comets in the cloud is too feeble to be detected against the lingering glow of the cosmic microwave background. Even stellar occultations will not cause noticeable dimming because the angular diameters of most comets at such vast distances are small compared to the angular diameters of the stars they block.

Presumably, some very large objects, perhaps even planetary in size, were launched into the Oort Cloud, but these would be so rare and so distant that we cannot expect to find them. We may have to face the fact that direct measurements at these distances can be made only by going there with a spacecraft. But it will take a long time. Traveling outward at 4 a.u. per year, NASA's New Horizons mission to Pluto is one of the fastest interplanetary craft ever flown. But it will take 25,000 years to reach 100,000 a.u. Patience, as they say, is a virtue. ✦

David Jewitt is a professor of planetary science at the University of California, Los Angeles. He is interested in the solar system's small bodies, especially comets and Kuiper Belt objects, and in planetary formation processes. With Jane Luu, he codiscovered 1992 QB_1, the first recognized Kuiper Belt object other than Pluto and its large moon Charon.

NEMESIS

In the 1980s, reports of a 26-million-year periodicity in Earth's mass extinctions led some astronomers to infer that the Sun might have a distant binary companion. The hypothetical star — fittingly named Nemesis — would stir up the Oort Cloud, sending periodic, deadly comet showers into the planetary region.

But evidence for the 26-million-year periodicity has not grown stronger with improved extinction data, and confidence in the Nemesis hypothesis has waned. A companion main-sequence star would be optically bright and it should have already been recorded in our star catalogs.

If the companion were instead a brown dwarf, it would be optically faint but bright in the infrared. NASA's WISE spacecraft will easily detect its radiated heat (*S&T:* December 2009, page 26). The real trick will be to distinguish the companion from millions of stars of similar appearance. For example, WISE might detect the radiation but offer no way to measure the companion's distinctive motion that would prove it to be gravitationally bound to the Sun.

SOLAR COMPANION? Some astronomers have suggested that the Sun might have a very distant binary companion, often referred to as Nemesis. There is no direct evidence that *such an object* exists. If it does, Nemesis is likely to be either a brown dwarf or a Jupiter-mass object.