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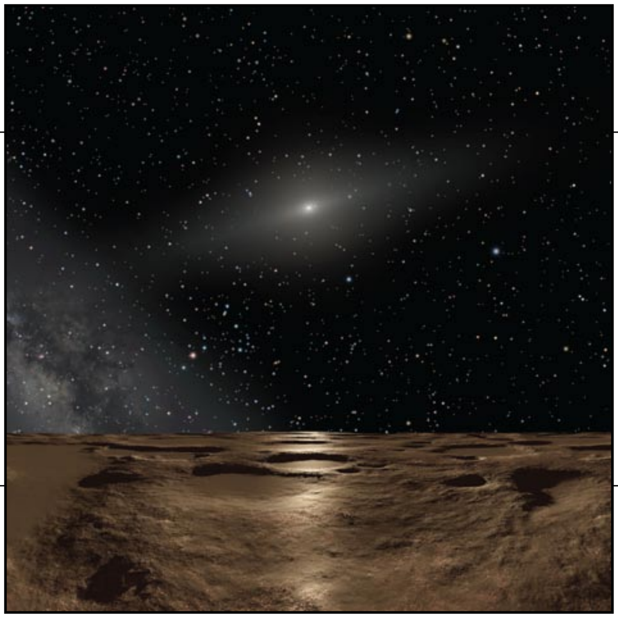

Binaries (and More) in the Kuiper Belt

Keith Noll

Taken from: Hubble 2006 Science Year in Review

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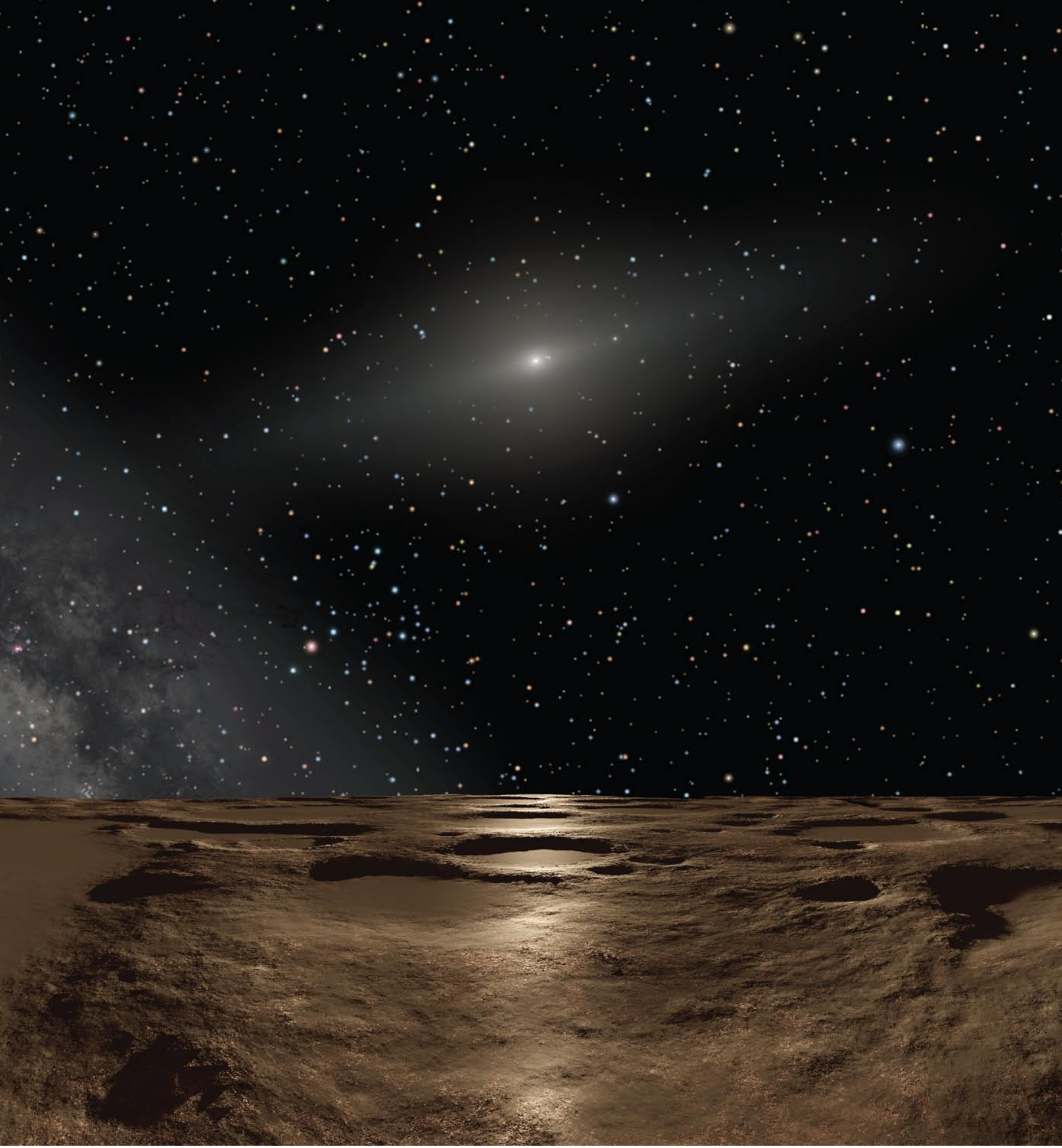


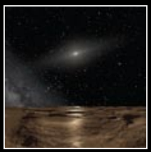
Binaries (and More) in the Kuiper Belt

Keith Noll

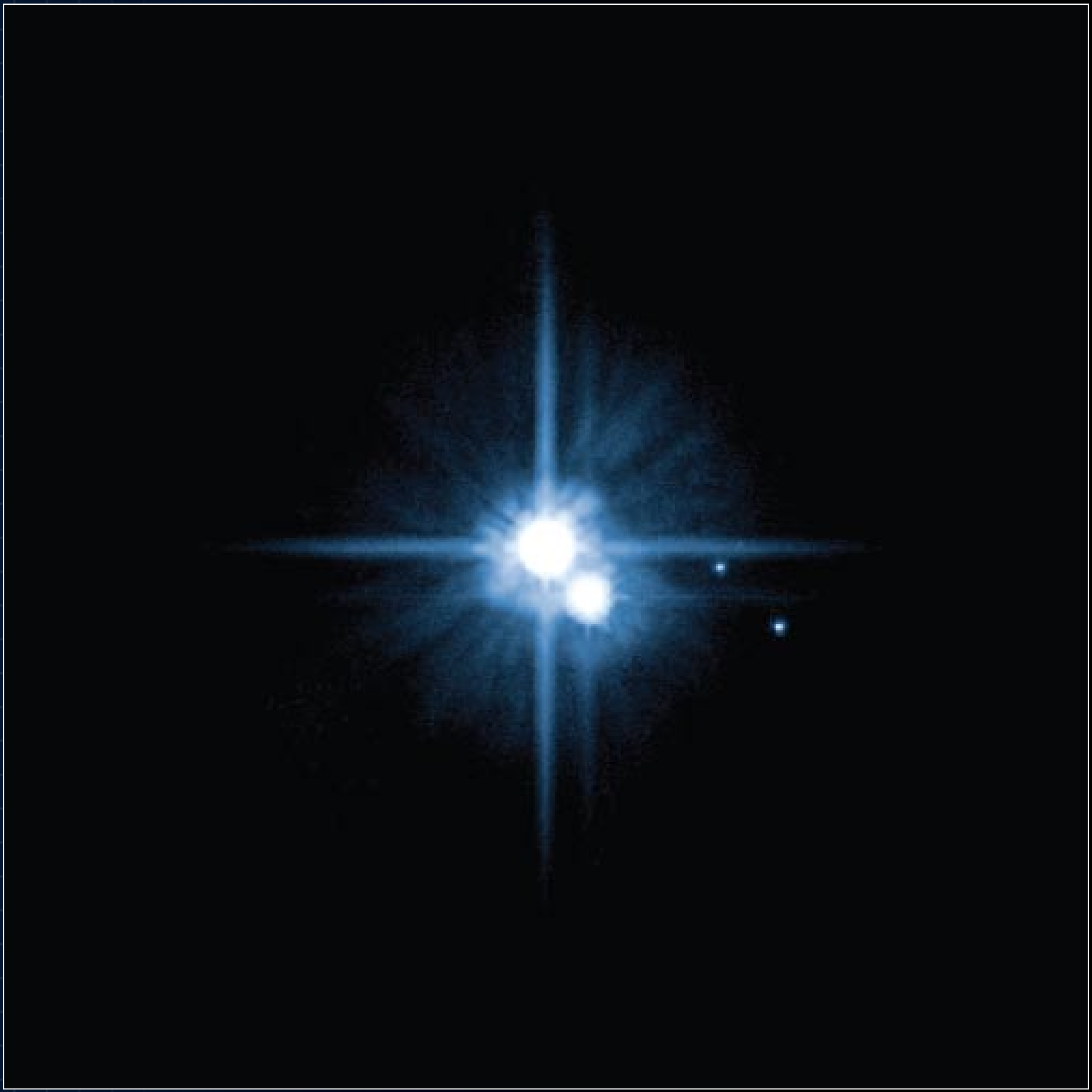
The Kuiper Belt is a broad ring of small planetary objects outside Neptune's orbit, or over 30 times Earth's distance from the Sun. Astronomers believe that the original planet-forming disk around the young Sun extended out into this region. But here, the disk would not have cleared as in the interior region, where the rubble of planet building was swept up by collisions, or cast away by gravitational perturbations as the major planets formed. For years, the Kuiper Belt was a hypothetical entity, comprising Pluto but no other known objects. Then, starting in 1992, with the advent of a new generation of sensitive digital detectors, astronomers began looking deeper and discovering many "trans-neptunian objects" (TNOs). The number is over 1000 in 2006, the same year the International Astronomical Union redefined Pluto as a "dwarf planet" and signified it the prototypical large TNO.

Among the most intriguing and instructive TNOs are the gravitationally bound "trans-neptunian binaries" (TNBs), which include an astonishingly high fraction of all TNOs. (Two TNBs are multiple systems with additional members.) The unsurpassed imaging power of the *Hubble Space Telescope* is playing a key role in finding, characterizing, and ultimately understanding the enigmatic TNBs.

The first TNB was Pluto: its large satellite, Charon, was discovered in 1978. A true binary, the pair orbits a point—the center of mass—that lies outside both bodies. In 2006, *Hubble* found two smaller moons outside Charon's orbit, making this system even more fascinatingly complex. It is remarkably well ordered: the orbits are circular and lie in a common plane. As one possible way to explain this system, astronomers speculate that Pluto was originally single, but experienced a huge collision early in the history of the Solar System. Debris from the collision was incorporated into the satellites, whose orbits gradually circularized by tidal forces and evolved to their current sizes. (This is also the leading scenario for the formation of Earth's Moon.) This hypothetical origin, if correct, puts Pluto in the minority of known TNBs.



This is an artist's impression of noontime on Sedna, the farthest known planetoid from the Sun. Over 8 billion miles away, the Sun is reduced to a brilliant pinpoint of light that is 100 times brighter than the full Moon. The Sun would actually be the angular size of Saturn as seen from Earth—far too small to be resolved with the human eye. (Illustration credit: NASA, ESA , and A. Schaller.)



The Pluto system is revealed to be an unexpectedly complex multiple system in this image from *Hubble*'s Advanced Camera for Surveys. Pluto and Charon, the two brightest objects in the image orbit around a common center of mass that lies between them, a distinction that sets them apart from any previously known Solar System pair, but which they share in common with the bulk of trans-neptunian binaries. The two smaller satellites, Nix (closer to Pluto/Charon) and Hydra, were unseen in the glare of Pluto and Charon until imaged by *Hubble*. They are in co-planar and nearly circular orbits around the common center of mass.

The second TNB was 1998 WW_{31}. The primary object was found in 1998, and its companion was first detected in 2000. Observations by *Hubble* helped determine the orbit, which has maximum physical separation of 44,000 km, high orbital elongation (eccentricity = 0.82), and a period of 520 days. Using basic physics, astronomers can use the measured orbit size and period to compute the total mass of 1998 WW_{31}—one six-thousandth the mass of the Pluto/Charon system, which is too low to have circularized the orbit of the companion at the observed separation over the age of the Solar System.

In 2003, astronomers used *Hubble* for the first unbiased search for TNBs. "Unbiased" means that the sample was selected without favoring any attribute that might be related to multiplicity, in order to ensure that the findings would be a fair estimate of the occurrence of multiplicity in the general population of TNOs. The pictures from *Hubble* were scanned not only for clearly resolved companions (three were found), but also for subtle distortions of the TNO images that might be caused by an unresolved companion. (This extension beyond the normal limits of a telescope's resolution is possible because of the exceptional stability of the *Hubble* observatory.) In this way, six more TNBs were found, for a total of 9 out of a sample of 81 TNOs investigated. The best estimate—that about 11% of TNOs are multiple systems—is a *lower limit,* because the search could only have detected the subset of companions that were sufficiently bright and well separated to be found at the time of the observations. That left many beyond the range of detection, which suggests that the true fraction of multiple systems is substantially larger.

The discoveries have accumulated rapidly. As of 2006, a total of 34 TNBs are known, of which *Hubble* discovered 26. Mutual orbits have been determined for nine systems, eight based on *Hubble* observations of the separation and orientation of the components at different times. The orbits show a large diversity in diameter, eccentricity, and period. The shortest period so far is 6.4 days for the Pluto/Charon system; 2001 QT_{297} has the longest period, 825 days. For observers, the key constraint is angular separation. In the most widely separated system, 2001 QW_{322}, the components appeared to be separated by 4 arc seconds at the time of discovery; the smallest detected separation has come from *Hubble*, about 50 milliarc seconds. (At the typical distance of a TNB, about 40 times the radius of Earth's orbit, 1 arc second corresponds to 29,000 km.) Theoretical studies indicate no reason to suspect a lower limit to the physical separations of TNBs, and the large-amplitude, long-period brightness variations of one TNO—2001 QG_{298}—suggests it is one of a potentially significant population (~10–20%) of binaries so close they are nearly in contact.

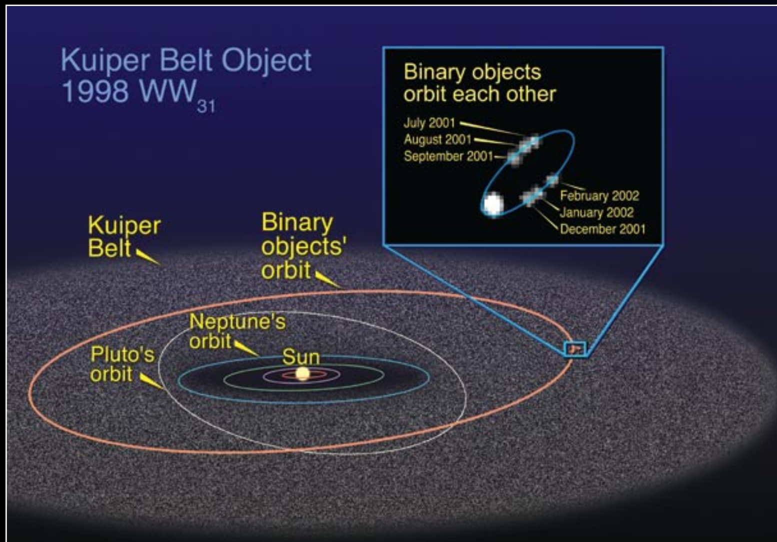
Naming the Worlds Beyond Neptune

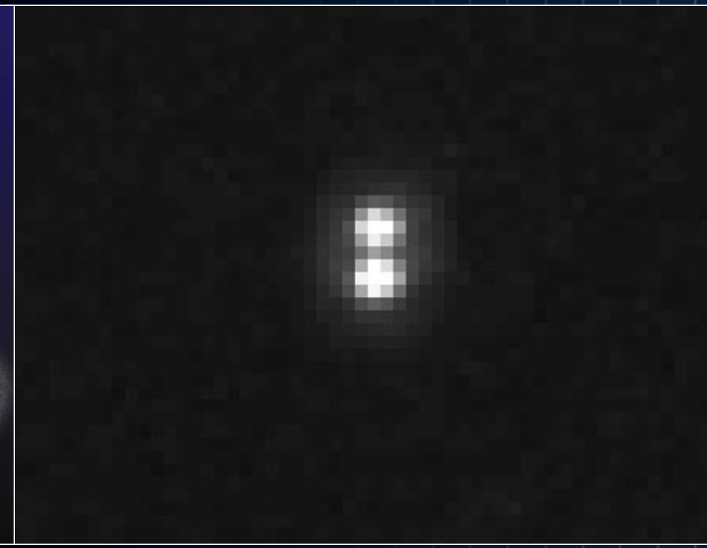
There are few issues that can spark a more spirited debate than what to name newly discovered objects in the Solar System. The naming process starts with a temporary designation by the Minor Planet Center (MPC). The MPC organizes and disseminates preliminary observational data needed to pin down the orbit, which is essential for the long-term study of newly found objects. The temporary designation comprises the year of discovery (four digits), the half-month interval within that year (one letter, skipping “I”), and a unique alphanumeric code for each object found in the two-week period. This code starts with A, runs through Z (again skipping “I”), and then repeats with an appended, subscripted number that increments each time the letter is used. For example, the temporary designation 2005 FY_9 refers to the 249^{th}—9 x 25 + 24—new object reported to the MPC in the period March 16–31, 2005.

Typically, observations over a couple of years improve knowledge of an orbit to the point that the future position of the object can be predicted within some acceptable limits of uncertainty. At that point, the object is ready for a permanent serial number, which by convention, is written in parentheses. The number of small Solar System bodies with such good orbits is now in the hundreds of thousands. (For example, the object 2005 FY_9 is now numbered 136472.) The permanent number is a signal to astronomers that an object is now a well-established member of the Solar System.

It is interesting to note that approximately half of the trans-neptunian objects (TNOs) given temporary designations are now “lost,” meaning that the initial estimates of their orbits were not sufficiently accurate to permit relocating them in follow-up observations, if, indeed, any such observations were ever attempted. These objects will not receive a permanent designation unless and until they are rediscovered at a future date.

Once an object is permanently numbered, it is eligible for naming. The International Astronomical Union is responsible for the naming of astronomical objects, a mandate carried out for TNOs by its Committee on Small Body Nomenclature. This group has established several naming conventions for TNOs. All must be named for mythological characters. Objects in resonances with Neptune (the ratio of orbital periods is equal to a ratio of two integers), like Pluto, are to be named for characters from underworld myths. Objects in low-inclination, low-eccentricity orbits are named for characters from creation myths. Objects orbiting between Jupiter and Neptune are named for the hybrid Centaurs. A recent extension of this convention calls for using the names of other mythological hybrid creatures for objects that cross the orbits of both Neptune and Saturn. With many of the more familiar names from Greek and Roman mythologies already in use, a rush has begun on names from the rich mythology of the wider world; (90377) Sedna, named for the Inuit goddess of the sea, is an example of this trend.





This illustration shows two different kinds of orbits on vastly different scales. The orbit around the Sun of the trans-neptunian binary 1998 WW_{31} is shown as the light-red ellipse, which extends beyond Neptune and Pluto into the swarm of more distant icy bodies known as the Kuiper Belt. The inset illustrates the mutual orbit of the two components of the 1998 WW_{31} binary (for convenience, the position of the larger, brighter member of the pair is shown as fixed). From the orbit, the mass of the binary pair can be derived using classical physics.

The image on the right of 1999 OJ_4, taken with *Hubble*'s Advanced Camera for Surveys, shows that this object is, in fact, a previously unresolved pair of nearly equal-sized objects in orbit around each other. Their small separation and faintness require *Hubble*'s unique combination of capabilities to see them.

For six of the nine systems with known orbits, the total mass has been determined with an uncertainty of 10% or better. Measured masses range from a low of six-millionths the mass of the Moon for (58534) Logos/Zoe to 0.2 lunar masses for Pluto/Charon.

As further research clarifies the occurrence rate and dynamical characteristics of trans-neptutian binaries (TNBs), and as theoretical models are developed to interpret the results, we can anticipate a profound contribution to our understanding of conditions and processes in the original protoplanetary disk. Massive collisions may have formed a few of the largest multiple systems, like Pluto and 2003 EL_{61}.

Page 48: *Hubble* performed the first direct measurement of a KBO's size by imaging the distant object known as Quaoar (presented here in an artist's concept). This icy world is approximately half the size of Pluto, making it one of the larger Kuiper Belt Objects recently discovered.

Nevertheless, the nearly equal size of components in TNBs suggests that the vast majority cannot have formed from collisions. On the other hand, the direct, collisionless capture of a single similar-mass companion by a solo TNO is impossible under the laws of orbital mechanics. Thus, most TNBs must have formed through multibody, gravitational encounters. For either collisions or capture to have produced the number of binaries being found, a much denser environment than the current Kuiper Belt is required: an environment like that thought to exist in the disk surrounding the infant Sun. In other words, the TNBs are primordial, dating back to the first few million or tens of million years after the Sun began to form. Since then, TNBs are slowly being destroyed by rare gravitational encounters, which can also change their orbits around the Sun—but no new TNBs can have formed. We can see hints of this slow depletion in the results of the 2003 survey. Comparing two subsets of TNOs—those that have or have not been scattered out of the plane of the Kuiper Belt—the occurrence rate of binarity is significantly higher for TNOs still in the plane (unperturbed orbits).

In less than 15 years, the Kuiper Belt has advanced from a hypothesis to a rich field of observational and theoretical research. It is telling us about the earliest days of the Solar System, and about events we can only hope to observe directly in analogous structures around young nearby stars. *Hubble* is at the forefront of both avenues of research.

Keith Noll is an Astronomer at the Space Telescope Science Institute in Baltimore, Maryland. He is interested in that part of the universe to which his great-grandchildren might someday travel. For the past five years, he has been studying the fascinating and complex objects that lie beyond Neptune with the *Hubble Space Telescope.*