The Discovery of 1992 QB_1

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The solar system got a little bit bigger last year. The discovery of the distant object 1992 QB$_1$, in an orbit beyond Pluto extended the dimensions of the planetary system and provided important evidence for several hypotheses about the origin of the solar system and the source of the short-period comets.

The new object was found by David Jewitt (University of Hawaii) and Jane Luu (University of California, Berkeley) who had spent more than five years in the search. On August 30th, using the 2.2 meter University of Hawaii telescope on Mauna Kea, they detected a slow-moving 23rd magnitude object in Pisces. The initial observations suggested a distance of 41 AU (astronomical units). At that distance, if one assumed a typical comet nucleus albedo of 0.04, the object would have to be about 200 km in diameter (Jewitt and Luu, 1992).

Subsequent observations over many months have allowed a preliminary orbit for 1992 QB$_1$ to be determined (Marsden, 1992). The object has a semimajor axis of 44.38 AU, yielding an orbital period of 296 years. The orbital eccentricity is 0.1069 which means that the object ranges from a perihelion of 39.64 AU to an aphelion of 49.13 AU as it revolves around the Sun. For comparison, Neptune orbits at a mean distance of 30.07 AU with an orbital eccentricity of only 0.008, and Pluto is at 39.44 AU with an eccentricity of 0.249. Pluto's aphelion distance of 49.26 AU is actually slightly greater than that for 1992 QB$_1$. The orbital inclination is only 2.22 degrees, which means that 1992 QB$_1$ likely shares a common origin with the rest of the planetary system. However, the orbit is still somewhat uncertain and the numbers above may change as more observations become available.

Little physical information is available about 1992 QB$_1$. Jewitt and Luu determined that the object is reddish in color, suggesting it may have a hydrocarbon rich surface, similar to that seen in other primitive, outer solar system objects, and expected for icy-conglomerate cometary nuclei.

The discovery of 1992 QB$_1$ has several important implications. In a remarkable paper in 1951, Gerard Kuiper suggested that the long-period comets in the Oort cloud, the distant cloud of comets at ~10^3 to 10^5 AU from the Sun (Oort, 1950; Weissman, 1991), had been ejected from the outer planets zone. In particular, Kuiper suggested that the proto-comets had been ejected by Pluto, or if Pluto turned out to be of very low mass (as it did), by Neptune. In addition, Kuiper suggested that a remnant of this comet population would exist in a belt of objects beyond Pluto. 1992 QB$_1$ is the first object to be discovered in Kuiper's proposed comet belt, if one discounts Pluto and its satellite Charon themselves, whose primary difference with 1992 QB$_1$ is their greater size.

Several researchers (Whipple, 1964; Fernandez, 1980; Bailey, 1983) have suggested that this hypothetical ring of distant comets could be the source of the short-period comets. In contrast to the long-period comets whose orbits are randomly oriented on the celestial sphere, most of the short-period comets are in direct, low inclination orbits close to the ecliptic plane. It had been thought that the short-period comets were long-period comets thrown into the planetary system from the Oort cloud and slowly perturbed to shorter and shorter periods (Everhart, 1972; 1978). Low inclination orbits typically receive larger perturbations by Jupiter and the other giant planets, and it was thought that this process accounted for the low inclination distribution of the short-period comets. However, Fernandez (1980) showed that an initially low inclination source, already close to the planetary system, could be up to 300 times more dynamically efficient than evolution of long-period comets from the Oort cloud. Fernandez also pointed out that some larger objects, on the order of the size of Ceres (diameter -900 km) had to be circulating in the comet ring to perturb the objects into planet-crossing orbits.

A key piece of evidence cam in work by Duncan et al. (1988). Using computer-based simulations, they showed that as comets evolved inward from the Oort cloud under the influence of planetary perturbations, they tended to preserve their orbital inclinations. Higher inclination orbits evolved more slowly, but eventually reached a steady-state with semimajor axes similar to the observed short-period comets. This prediction was in conflict with the observed low inclinations of most short-period comets. However, Duncan et al, showed that if the initial source of these comets was a low inclination belt of objects beyond Neptune, then the objects would preserve their low inclinations and recreate the observed distribution.

Duncan et al. estimated that the population of the Kuiper belt might be in the range 10x to 10^{10} comets, with a total mass of 0.02 to 1.0 Earth masses. Is it possible to detect this mass gravitationally? Anderson and Standish (1986) set an upper limit of 5 Earth masses in a ring of material beyond Neptune, based on tracking of the Pioneer 10 spacecraft. Hamid et al. (1968) and Yeomans (1986) set a somewhat tighter limit of 1 Earth mass based on the lack of unaccounted perturbations on the orbits of several short-period comets with large aphelia, including Comet Halley, whose aphelion distance is 35.30 AU. So, for the moment the limits that can be set are not very strict.

Duncan et al.'s work was very well received by comet dynamicists but there were also several open questions with regard to their study, Stagg and Bailey (1989) suggested that unrecognized physical processes may preferentially destroy the high inclination comets during the larger number of returns needed by them to evolve to short-period orbits. Random splitting of cometary nuclei is a well observed phenomenon but the underlying physical mechanism is not well understood, except in the few cases where comets split due to tidal stresses, i.e., passing within the Roche limit of the Sun or Jupiter, However, it is generally thought that splitting is coupled to the heating a comet receives as it approaches the Sun, Everhart (1972, 1978) showed that the most likely dynamical path for comets to evolve from the Oort cloud to short-period was to start with orbits with large perihelia, i.e., among the outer planets. But then these comets would experience relatively little heating and thus would be unlikely to split. Thus, speculations about physical processes preferentially removing the high inclination comets cannot be confirmed at this time.

Stagg and Bailey also pointed out that Duncan et al. (1988) had artificially increased the masses of the giant planets in their dynamical simulations to speed the dynamical integrations. This is a commonly used technique among celestial dynamicists, but it can lead to spurious results. In response, Quinn et al. (1991) repeated Duncan et al.'s simulations with the mass increase factor reduced from 40 to 10 and obtained similar results. In addition, Wetherill (1991) used a simpler Öpik-type integrator on the problem and obtained the same results with no mass increase.

The search for the Kuiper belt thus took on added importance. If there was an extended belt of icy planetesimals beyond Neptune, then it would mean that the long- and short-period comets came from two different, though neighboring regions of the planetary system. The long-period comets would be icy planetesimals formed in the Uranus-Neptune region and dynamically ejected to the Oort cloud. The short-period comets would have formed farther out in the Kuiper belt and could have remained in low eccentricity orbits there over the history of the solar system.

Although both the Oort cloud and the Kuiper belt can be thought of as "cold storage" for the cometary nuclei, several subtle forms of physical processing of the nucleus surfaces have been identified (Weissman and Stern, 1993). One possible consequence of the different storage locations for the long- and short-period comets is that the two groups would undergo different processing by galactic cosmic rays (Johnson et al., 1987), by impacting cometary debris (Stern, 1988), and by heating from random passing stars and supernovae (Stern and Shull, 1988). Low velocity collisions in the Kuiper belt may have led to the growth of larger bodies as compared with the cometary nuclei ejected to the Oort cloud early in the solar system's history, and/or may have resulted in a collisionally evolved size distribution, rather than an accretionary one. The heliocentric extent of the Kuiper belt, perhaps extending several hundred AU or more, almost certainly straddles the heliopause. Thus, some differences in processing may even occur within the comet belt.

In addition to Jewitt and Luu, observers at the U.S. Naval Observatory and at the University of Texas conducted searches for slow-moving, outer solar system objects. One such search by Levison and Duncan (1990) scanned 4.9 square degrees to magnitude V = 22.5 with negative results.

Other factors also point to the likely existence of the Kuiper belt. In 1983-84 the Infrared Astronomical Satellite (IRAS) discovered excess infrared emission around several nearby main sequence stars, e.g., Vega, Fomalhaut (Aumann et al., 1984). In one case, β Pictoris, the cloud of material was seen edge-on and was photographed with a ground-based telescope in visible light using a coronagraphic technique (Figure 1, Smith and Terrile, 1984). It was seen that the material was flattened into a very thin disk, extending up to 800 AU on either side of the central star. Several researchers (Weissman, 1984; Harper et al., 1984) suggested that this was cometary material, nascent Kuiper belts and/or Oort clouds, around these relatively young stars. Subsequent studies have shown that the β Pictoris disk displays a 10 μm silicate emission feature very similar to that seen in cometary comae (Telesco and Knacke, 1991).

Aumann and Good (1990) used IRAS data to show that G-type stars (the same spectral class as the Sun) in the solar neighborhood are typically surrounded by clouds of cold material with a typical color temperature of 20-38 K and radius of 100-150 AU. If IRAS could detect dust and debris clouds around nearby stars, could it do the same for material in our own solar system? Backman and Gillett (1987) pointed out that a distant belt of comets would be difficult to detect in the IRAS data because of confusion with the zodiacal light cloud. Aumann and Good (1990) confirmed that result but showed that excess IRAS 60 and 100 μm signal in the ecliptic plane, after subtraction of a zodiacal light model, could easily match the clouds seen around the nearby G-type stars.

An extended disk of material in the ecliptic plane in the solar nebula was suggested not only by Kuiper but also by Cameron (1962, 1978). Basically, there is no reason to expect that the solar nebula ended at the orbit of Pluto, though modelers often seemed to believe that that was all the planetary system they needed to account for. An extended disk of material would fail to form into a planet for two reasons. First, orbital periods increase with increasing solar distance and thus the mean time between possible accretionary encounters between planetesimals would increase. Second, the density of material in the solar nebula dots appear to drop off with increasing solar distance, so there would simply be fewer and/or smaller planetesimals from which to assemble a planet.

Recently, Stern (1991) has suggested that accretion among the planetesimals beyond Neptune did proceed far enough to grow small icy planets with diameters of 1000-km or more, and that as many as 10^3 bodies may have accreted in that size range. Stern argued that the unlikely existence of the satellite Triton (2700 km in diameter) in a retrograde orbit around Neptune (the retrograde orbit is interpreted as evidence of Triton being captured and not formed in orbit around Neptune), and Pluto (-2400 km diameter) with its large icy satellite, Charon (~1200 km diameter), can better be explained if many more Pluto and Charon-sized objects had formed in that region, Where are the rest of these Plutos? Many of them may have been ejected to interstellar space by the growing proto-planets, or to distant orbits in the Oort cloud where they continue to circulate. Others may yet be in distant orbits in the Kuiper belt, This raises the interesting possibility that one of these objects may some day return to the inner planets region as a giant long- or short-period comet.

But is the lone discovery of 1992 QB_1 sufficient proof of the existence of an immense belt of unseen comets? The orbit of the object, still somewhat uncertain, is well beyond the orbit of Neptune, However, Torbett (1989) and Torbett and Smoluchowski (1990) showed that the orbits of Kuiper belt comets with perihelia as large as 4S AU would be chaotic over timescales of 107 years or more, and might eventually become Neptune crossing. once under the control of Neptune, they could be gravitationally passed inward to the larger giant planets which would greatly speed their evolution to short-period orbits, or to hyperbolic ejection, which in fact is the more common end-state, Torbett and Smoluchowski also showed that planetary perturbations would tend to spread the initial belt of icy planetesimals close to Neptune's orbit, out to larger semimajor axes. This would have the effect of further lengthening the lifetimes of these objects in their distant orbits.

More extensive integrations by Levison and Duncan (1993) have shown similar behavior. Levison and Duncan demonstrated that even with initial eccentricities as small as 0.01 and 0.1, comets in the Kuiper belt out to semimajor axes of about 42 AU will become Neptune crossing in less than 109 years. But at 44 AU from the Sun, the orbit of 1992 QB_1 is likely stable for at least 109 years, and possibly over the history of the solar system. The remaining question then is whether 1992 QB_1 is one of the last large survivors of a belt of Neptune approaching planetesimals that has slowly been eroded away over the past 4.5 x 109 years, or is it the first discovered member of a far more populous comet belt, extending to several hundred AU from the Sun?

At the same time, there is a problem with the latest discovery. Jewitt and Luu's search extended to 25th magnitude; 1992 QB$_1$ was 23rd magnitude at discovery. If one assumes a reasonable size distribution for the Kuiper belt comets, analogous to the asteroids or the cometary nuclei, then there should have been many more fainter, somewhat smaller objects detected by the same survey. The failure to find these smaller objects might be explained if the size of 1992 QB$_1$ is anomalous and not part of a smooth size distribution, or if the observers have overestimated the sensitivity of their surveys. Interestingly, all three of the recently discovered outer solar system objects, Chiron, Pholus (see below), and 1992 QB$_1$, are in the 200 to 300 km diameter size range.

One can draw a parallel with the discovery of the asteroid belt in the early 19th century. Ceres, the largest asteroid, was discovered in 1801, followed by three more minor planets by 1807. But the next asteroid, 5 Astraea, was not discovered until 38 years later. Today there are good orbits for -10,000 asteroids in the main belt and in planet-crossing orbits.

The first large outer solar system object, 2060 Chiron (200-340 km diameter), was found by Kowal in 1977 (Kowal et al., 1979). Chiron is in a Saturn-crossing orbit that takes it almost to the orbit of Uranus, and has recently been recognized to display cometary activity (Meech and Belton, 1989). The next object, 5145 Pholus (~200 km diameter), was found in early 1992, in an even more eccentric orbit that crosses the orbits of Saturn, Uranus, and Neptune. Now, 1992 QB$_1$ has followed that discovery by only eight months. It may be that the pace of discovery of these objects is accelerating. Based on the fact that Jewitt and Luu searched 0.7 square degrees of sky to find this one object, one can infer that as many as 104 similarly sized objects may exist at similar distances from the Sun, assuming that they are confined to orbits with inclinations less than 10°.

In fact, while this paper was undergoing review, Luu and Jewitt (1993) reported the discovery of a second distant object, 1993 FW, found on March 28, 1993. 1993 FW is similar in brightness (and hence, size) to 1992 QB$_1$ but is less red in color. Computations by Brian Marsden indicate that 1993 FW is between 38 and 56 AU from the Sun, with a most likely distance of ~42.5 AU. More observations are needed to determine the object's orbit.

For the moment, the discoveries of 1992 QB$_1$ and 1993 FW have greatly strengthened hypotheses concerning an extended solar nebula accretion disk that is the source of the short-period comets. Continuing telescopic searches in the coming years will determine if 1992 QB$_1$ and 1993 FW are indeed the first members of a new class of solar system bodies, the Kuiper belt comets, or if they are just two of a few outer solar system oddities. It is also possible that further tracking of the Pioneer and Voyager spacecraft may yield evidence of Gravitational perturbations from the integrated mass of the Kuiper belt.

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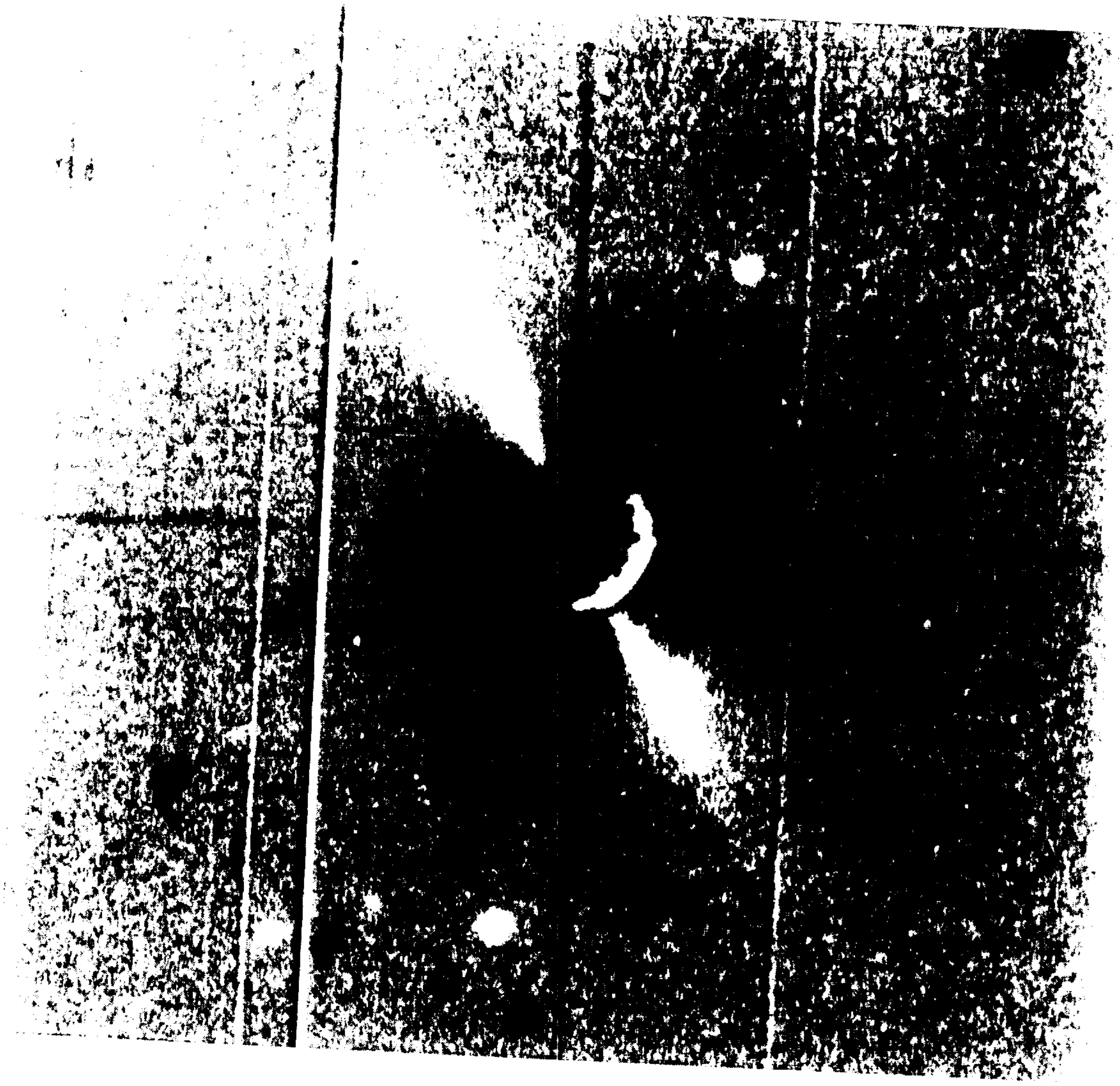

Figure 1. The disk of material, seen edge-on, around the main sequence star β Pictoris, as photographed by Smith and Terrile (1984). The thin disk extends to a distance of ~800 AU on either side of the central star, which is occulted out to a radius of about 50 AU. This remnant disk of protoplanetary material is likely similar to the accretion disk in the primordial solar nebula, that led to the formation of the Kuiper belt of comets.