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The Plutinos

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Abstract. The Plutinos are trans-Neptunian objects whose motion is controlled by the 3:2 resonance with Neptune. We briefly review the properties of the Plutino family and consider their origin and significance.

1. Overview

Prolonged ecliptic surveys have revealed a population of trans-Neptunian objects collectively known as the Kuiper Belt (Jewitt and Luu 1993, 1995 and references therein). An unexpected result of this observational work is that many of these objects reside in or near the 3:2 mean motion resonance with Neptune, as does Pluto. Accordingly, we have dubbed them "Plutinos" (little Plutos) to highlight their dynamical similarity with Pluto, and to distinguish them from other Kuiper Belt objects whose orbits are not closely controlled by nearby, massive Neptune.

A list of the currently known Plutinos and their orbital properties is given in Table 1, based on calculations by Brian Marsden (Center for Astrophysics). We sound a note of caution regarding the accuracy of the orbital parameters of some of the listed bodies, particularly those with astrometric arcs less than 1 year. Nevertheless, it is clear that a great many of the tabulated objects are in the 3:2 resonance ($a = 39.39$ AU). In fact, approximately 40% (12 out of 32) of the Kuiper Belt objects as a group are either in or close to the 3:2 resonance (Fig. 1). Other mean motion resonances may also be occupied, although less densely than the 3:2. For example, 1995 DA_2 ($a = 36.3$ AU) is probably in the 4:3 resonance with Neptune. It is well known that Pluto's orbit crosses inside that of Neptune (Pluto's perihelion distance is $q = 29.58$ AU, while Neptune's semi-major axis is $a = 30.06$ AU), but close encounters are always avoided. Several of the known Plutinos are also Neptune-crossers (e.g. 1993 SB, 1994 TB, 1995 QY9), further enhancing the dynamical similarity with Pluto. Lastly, we note that Pluto's orbital inclination ($i = 17^o$), which is often thought of as extreme, is exceeded by that of the recently found 1995 QZ_9 ($i = 19.5^o$). Whatever pumped Pluto's inclination to 17^o pumped other objects even higher. Collectively, the orbital similarities (Table 1) suggest that the Plutinos are part of a vast family of dynamically related bodies that extend in size up to Pluto itself. By extrapolating from the limited area of the ecliptic so far examined from Mauna Kea, we have estimated that the number of Plutinos larger than 100 km diameter is of order 10,000 (Jewitt and Luu 1995), and our most recent estimate (Jewitt and Luu, 1996) is larger still. Pluto is distinguished from the other objects in Table 1 primarily by its size. In our opinion, it is most meaningfully considered as the largest of the known Kuiper Belt objects, rather than as an independent (but orbitally eccentric) planet.

Table 1. Objects Near the 3:2 Mean Motion Resonance

N	Object	$a[AU]^1$	e^2	$i[deg]^3$	$q[AU]^4$	$Q[AU]^5$
1	1993 SB	39.32	0.32	1.9	26.74	51.90
2	1993 SC	39.73	0.19	5.2	32.18	47.28
3	1993 RO	39.37	0.20	3.7	31.50	47.24
4	1993 RP	39.33	0.11	2.8	35.00	43.66
5	1994 JR1	39.80	0.13	3.8	34.63	44.97
6	1994 TB	39.32	0.31	12.1	27.13	51.51
7	1995 GA7	39.46	0.12	3.5	34.72	44.13
8	1995 HM5	39.53	0.18	4.6	32.41	46.65
9	1995 KK1	39.48	0.19	9.3	38.67	46.98
10	1995 QY9	39.41	0.25	4.8	29.56	49.26
11	1995 QZ9	39.43	0.12	19.5	34.70	44.16
12	1995 YY3	39.45	0.22	1.7	30.77	48.13
13	Pluto	39.44	0.25	17.2	29.58	49.30

[1] a = semi-major axis [AU]
[2] e = orbital eccentricity
[3] i = orbital inclination [deg]
[4] $q = a(1-e)$ = perihelion distance [AU]
[5] $Q = a(1+e)$ = aphelion distance [AU].

Presumably, the 3:2 resonance stabilizes the Plutinos against gravitational perturbations by Neptune, just as it does for Pluto. Resonant objects in elliptical orbits can approach the orbit of Neptune without ever coming close to the planet itself, because their perihelia preferentially avoid Neptune. Objects in elliptical orbits that were not originally trapped in stable resonances have long since been removed by planetary perturbations (Holman and Wisdom 1993; Duncan, Levison and Budd 1995).

How did the 3:2 resonance come to be so full? An exciting idea first discussed by Fernandez and Ip (1984) has been explored by Malhotra (1995). Angular momentum exchange with planetesimals in the accretional phase of the solar system would lead to a radial migration of the planets with respect to the sun. Uranus and Neptune, in particular, ejected a great many comets towards the Oort Cloud and as a result of conservation of angular momentum, the sizes of their orbits changed. Malhotra concludes that coupling of the motions of the gas giant planets would lead to a net outward migration of Neptune, perhaps by 5 AU over the course of millions or tens of millions of years. As Neptune moved outwards, its mean motion resonances were pushed through the surrounding planetesimal disk, sweeping up objects from the disk along the way. Numerical simulations by Malhotra show that objects can indeed be trapped in the strongest resonances as Neptune moves, and that their eccentricities and inclinations are pumped during the process. Furthermore, the distributions of orbital parameters (e, i) of the trapped objects are determined, in part, by the rate of radial migration. Therefore, there exists the astonishing possibility that

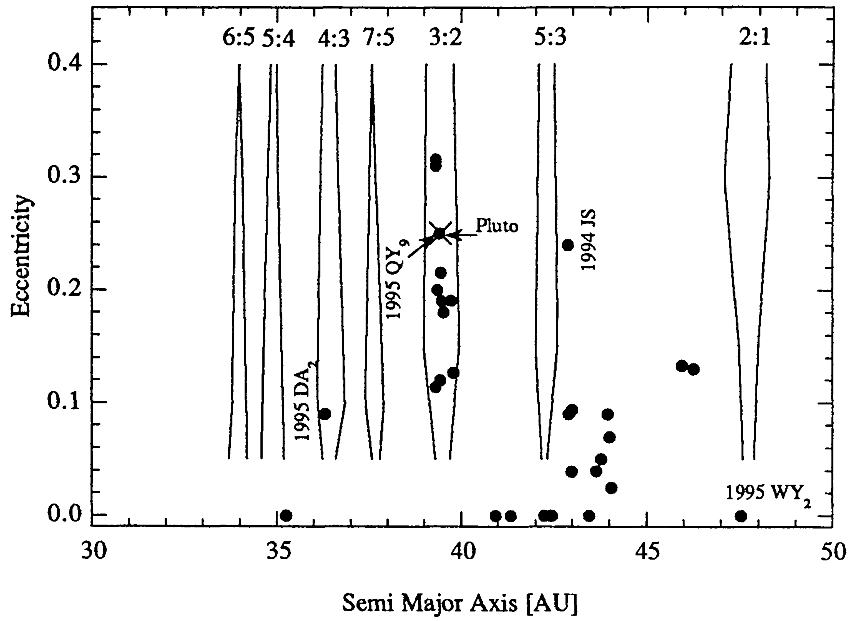

Figure 1. We plot semi-major axis against eccentricity for the known Kuiper Belt objects. The boundaries of the major mean motion resonances are drawn and labelled (from Malhotra 1996). Note the high abundance of objects in the 3:2 mean motion resonance. The location of Pluto is also marked. If it were not explicitly identified, Pluto could not be distinguished from the other Kuiper Belt objects on this Figure.

measurements of these distributions in the Plutinos might be used to determine the rate of radial migration of Neptune during its accretion phase, and so to measure the rate at which Neptune formed as well as the timescale for the ejection of the Oort Cloud comets. These quantities were previously believed to be beyond the realm of observational constraint.

This "resonance sweeping" scenario has the merit of being a natural consequence of angular momentum exchange with planetesimals in the pre-planetary disk: there is no reasonable doubt that such angular momentum exchange took place. However, there is legitimate doubt as to the magnitude of the angular momentum exchange, and even as to its sign. The inclination of Pluto is larger than typical of the objects in Malhotra's simulations (and that of 1995 QZ_9 is larger still), raising questions about the method. The exciting results above thus need to be confirmed.

Numerical work indicates that Kuiper Belt objects substantially more distant than 42 AU do not need to occupy resonances in order to survive the gravitational ravages of Neptune for 4.5 Gyr (Holman and Wisdom 1993; Duncan, Levison and Budd 1995). Indeed, the objects clustered near $a = 43-44$ AU in Fig. 1 do not occupy any mean motion resonance. Morbidelli et al. (1995) specifically find that the orbit of 1992$QB1$ ($a = 44.1$ AU) should be stable for the age of the solar system (their result is based on a somewhat heroic extrapolation of the available 3 years of astrometric data). The obvious inference is that our work to date has probed only the lightly populated inner regions of a heavily eroded disk, and that a steep wall in the volume density of Kuiper Belt objects awaits discovery as we probe deeper and fainter.

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