SMALL BODIES IN THE OUTER SOLAR SYSTEM

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This report is a continuation of three earlier reviews (Marsden 1996a, 1996b, 1998) that included a summary of our orbital knowledge of the Kuiper Belt. Presented at conferences held in the middle of 1994, 1995 and 1996, respectively, these reviews showed the steadily developing picture of a system dominated by the *plutinos*, librating in the 2:3 mean-motion resonance with Neptune, and the *cubewanos*, a somewhat more distant population of nonlibrating objects with low orbital eccentricities. The existence of a 3:4 Neptune librator and a 3:5 Neptune librator was also suspected. These librators have now been confirmed, and a possible 4:7 librator and possible second 3:5 librator have also been found. The known and suspected multiple-opposition librators are listed in Table 1. Here it is important to note that the orbital semimajor axes a (in AU), eccentricities e and inclinations i (in degrees with respect to the 2000.0 ecliptic) are mean values that eliminate the large 12-year and 30-year periodicities arising from the indirect perturbations by Jupiter and

Table 1. Librating Kuiper Belt objects.

			a	e	i	H	Nep.	Ura.
3:4	(36.41)	1995 DA$_2$	36.39	0.073	6.5	8.0	8.0	14.5
2:3	(39.39)	1993 RO	39.30	0.199	3.7	8.0	12.5	11.4
		1995 YY$_3$?	39.36	0.220	0.4	8.5	14.7	11.1
		1997 QJ$_4$	39.36	0.220	16.6	7.5	15.9	13.0
		1993 SB	39.38	0.320	1.9	8.0	20.1	7.5
		1996 TP$_{66}$	39.42	0.330	5.7	6.5	22.0	6.9
		1994 JR$_1$	39.44	0.119	3.8	7.5	11.5	15.8
		1996 TQ$_{66}$	39.47	0.123	14.7	6.5	14.2	14.8
		1995 QZ$_9$	39.52	0.148	19.6	7.5	16.5	14.3
		1996 SZ$_4$	39.55	0.253	4.7	8.0	18.2	9.9
		1994 TB	39.55	0.318	12.1	7.0	22.8	8.8
		Pluto	39.55	0.250	17.1	−1.0		
		1993 SC	39.59	0.186	5.2	7.0	14.9	12.4
		1995 HM$_5$	39.60	0.253	4.8	8.0	15.2	10.6
		1996 RR$_{20}$	39.70	0.183	5.3	7.0	11.3	13.8
		1995 QY$_9$	39.76	0.265	4.8	7.5	11.7	9.2
3:5	(42.25)	1994 JS	42.29	0.217	14.0	8.0	14.4	14.4
		1996 TR$_{66}$?	42.35	0.219	12.4	7.5	16.9	14.4
4:7	(43.65)	1997 CV$_{29}$?	43.67	0.183	8.0	7.0	11.8	16.5

Celestial Mechanics and Dynamical Astronomy **73**: 51–54, 1999.

Table 2. Nonlibrating Kuiper Belt objects.

			a	e	i	H	Nep.
5:8	(41.12)						
		1997 RX$_9$?	41.38	0.035	30.0	8.0	10.2
		1997 RT$_5$	41.71	0.082	12.7	7.0	9.2
3:5	(42.25)						
		1997 QH$_4$?	42.71	0.031	13.2	7.0	11.5
		1996 TK$_{66}$?	42.77	0.005	3.3	7.0	12.3
		1994 VK$_8$	42.81	0.030	1.5	6.5	11.2
		1994 EV$_3$	42.94	0.041	1.7	7.0	11.3
7:12	(43.05)						
		1996 TO$_{66}$	43.47	0.131	27.4	4.5	10.2
		1997 CU$_{29}$?	43.53	0.029	1.5	6.5	12.0
4:7	(43.65)						
		1993 FW	43.78	0.049	7.7	7.0	12.4
		1994 GV$_9$	43.79	0.061	0.6	7.0	11.1
		1997 CT$_{29}$?	43.84	0.025	1.0	5.0	12.5
		1996 TS$_{66}$	43.92	0.124	7.3	6.0	9.2
		1997 CS$_{29}$	43.94	0.011	2.2	5.0	13.4
		1992 QB$_1$	44.00	0.071	2.2	7.0	11.1
		1996 RQ$_{20}$	44.04	0.109	31.7	7.0	9.6
		1994 JQ$_1$	44.14	0.049	3.7	7.0	12.0
		1995 DC$_2$	44.15	0.068	2.3	7.0	11.0
5:9	(44.48)						
		1997 CQ$_{29}$?	44.71	0.081	2.9	6.5	10.9
6:11	(45.03)						
		1997 CR$_{29}$?	45.09	0.078	19.1	6.5	12.7
		1996 KV$_1$	45.27	0.110	8.1	7.5	10.1
7:13	(45.41)						
		1994 ES$_2$	45.86	0.115	1.1	7.5	10.3
		1995 WY$_2$	46.53	0.129	1.7	7.0	10.4
		1995 DB$_2$	46.62	0.140	4.1	7.5	10.1
1:2	(47.71)						

Saturn on sun-centered orbits. The numbers in parentheses are the semimajor axes (in AU) corresponding to the resonances. Following the absolute magnitude H, the entries "Nep." and "Ura." show the minimum distances (in AU) from Neptune and Uranus (the latter being of course quite small for the most eccentric 2:3 Neptune librators) within several millennia of the present time.

Table 2 lists the corresponding data (except for the minimum distances from Uranus) for the established cubewanos, which range over $41 < a < 47$ AU, with e rising to 0.14 for the most distant objects. The existence of several high-i objects is an interesting new feature that warrants the need for searches at high ecliptic latitudes. The initial columns in this table show the positions of the resonances with

Table 3. Centaurs and Scattered-Disk objects.

	a	e	i	H	Nep.	Ura.	Sat.	Jup.
(2060) Chiron	13.67	0.381	6.9	6.5	6.8	0.6	0.4	2.9
(5145) Pholus	20.30	0.572	24.7	7.0	0.3	4.9	0.6	3.5
(7066) Nessus	24.61	0.520	15.6	9.6	4.3	4.3	1.8	6.4
(8405) 1995 GO	18.05	0.620	17.6	9.0	6.4	0.8	0.2	2.1
1994 TA	16.79	0.303	5.4	11.5	7.9	1.4	5.0	6.4
1995 DW$_2$	25.06	0.247	4.1	8.0	1.0	0.2	8.6	12.8
1997 CU$_{26}$	15.78	0.170	23.4	6.5	12.7	2.8	4.4	8.1
1996 TL$_{66}$	83.82	0.582	24.0	5.0	6.4			

Neptune (out to sixth order) and possibly give a first indication of the presence of "Kirkwood gaps"—except, of course, for the high-e 3:5 and suspected 4:7 librators shown in Table 1. It is also noteworthy that the population seems to terminate *inside* the 1:2 resonance, at least for objects of the size represented by the observed H values, although this requires further investigation. Sensitivity of the detection probability to distance, and hence to a, suggests that the observed plutino-cubewano ratio, 0.65, is about twice what it would be for objects down to a given minimum size.

One of the objects discovered in late 1996 at the general distance of the Kuiper Belt was the perihelic detection (Luu *et al.* 1997) of the single known member, 1996 TL$_{66}$, of what has been termed the "scattered disk", a presumably large population of objects in orbits of rather large eccentricity and moderate inclination that at perihelion can have modest interactions with Neptune. The scattered-disk objects have an obvious dynamical symmetry with the centaurs that exist in rather unstable orbits within the realm of the giant planets and that in some cases interact with Neptune at aphelion. Table 3 gives orbital data for the seven known centaurs (three of which are intrinsically fainter than any of the entries in Tables 1 and 2) and the one known scattered-disk object. For the centaurs, columns 'Sat.' and 'Jup.' also show the minimum distances (again within just millennia of the present) from Saturn and Jupiter. The physical similarity of at least some of the centaurs to the short-period comets has been suspected (Kowal *et al.* 1979) or known (Meech and Belton 1990) for some time, and dynamical analyses (Duncan *et al.* 1995) strongly suggest that the centaurs are objects in transition between the Kuiper Belt (where they presumably originated) and the Jupiter Family of comets with their aphelia generally in the vicinity of Jupiter.

The objects tabulated in this paper have all been observed at more than one opposition. In addition, there are 26 single-opposition Kuiper Belt candidates, at least half of which are lost.

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