72. EVOLUTION OF THE ORBITS OF SELECTED MINOR PLANETS DURING AN INTERVAL OF 1000 YEARS

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Abstract. The long-term evolution of the orbits of 944 Hidalgo, 1036 Ganymed and 1134 Kepler is investigated.

The investigations of the evolution of cometary and asteroidal orbits performed by Kazimirchak-Polonskaya (1967, 1968), Belyaev and Chebotarev (1968), and Chebotarev *et al.* (1970) are very precise, but they are limited to a 400-yr time interval (1660–2060), because precise coordinates of the outer planets are available only for this interval (Eckert *et al.*, 1951).

For our studies we have made use of approximate coordinates of the major planets computed analytically using the principal perturbation terms. It thus becomes possible, in theory, to extend the studies of orbital evolution over unlimited time intervals. One must pay attention to two points, however, which restrict the possibility of obtaining plausible results:

(1) The accumulation of error after a large number (10 000 or more) of integration steps.

(2) The approximate theory used for the calculation of the coordinates of perturbing bodies is not sufficiently accurate if the time interval elapsed from the initial osculation epoch is very long (1000 yr or more).

Consequently we have generally limited our calculations to a time interval of about 1000 yr. We make use of a variation-of-elements method, since the changes in the elements are relatively small and we can use larger integration steps. Perturbations by the planets Venus to Saturn are taken into account.

So far we have studied the evolution of the orbits of the following asteroids: 944 Hidalgo, 1036 Ganymed, and 1134 Kepler. The orbits of these asteroids all have high eccentricities and are similar to the orbits of comets.

One of the most interesting of all asteroids, 944 Hidalgo has not only one of the highest orbital eccentricities (being exceeded in this respect only by 1566 Icarus), but also one of the highest inclinations (exceeded only by 1580 Betulia) and the greatest semimajor axis. Its evolution has therefore been investigated over an interval of more than 2000 yr (from 670 to 2900) (see Table I). This minor planet is exceptional in that it can come closer to Jupiter than the other planets can (see Table II). The closest encounters of 944 with Jupiter are as follows: 0.43 AU in 1211, 0.36 in 1673 and 0.50 in 2823. Marsden (1970) has found that all the minor planets avoid encounters with Jupiter except for 944 Hidalgo. The two planets having the next closest encounters are 279 Thule and 334 Chicago, which can approach to a distance of 1.1 AU from Jupiter. According to Marsden, 944 Hidalgo is a comet.

Chebotarev et al. (eds.), The Motion, Evolution of Orbits, and Origin of Comets, 437–439.

TABLE I

Elements of 944 Hidalgo

Yr	ω	Ω	i	φ	μ	a (AU)
701	71°9	32°3	48°8	33°8	266″89	5.6120
903	69.5	30.6	47.9	34.8	260.76	5.6996
1104	64.4	29.0	47.9	35.9	272.72	5.5317
1300	61.6	27.0	46.6	37.1	265.68	5.6291
1510	59.9	25.3	45.4	38.6	266.83	5.6129
1713	59.3	23.3	43.3	40.0	254.30	5.7957
1907	56.8	21.8	43.0	40.6	255.91	5.7714
1964	57.6	21.0	42.5	41.0	252.75	5.8193
2101	55.8	20.1	42.4	41.6	260.17	5.7082
2309	55.1	18.1	41.6	42.2	253.27	5.8115
2502	54.1	16.4	41.1	42.9	258.19	5.7374
2709	53.4	14.2	40.5	43.5	258.21	5.7371
2903	51.4	12.2	39.2	44.6	258.68	5.7301

TABLE II

Minimal distances (AU)

Asteroid	Earth	Mars	Jupiter
944 Hidalgo	1.19	0.85	0.36
1036 Ganymed	0.33	0.07	1.90
1134 Kepler	0.43	0.08	1.52

The changes in the orbital elements of asteroids 1036 and 1134 are shown in Tables III and IV. In spite of the absence of close encounters with Jupiter we see that these changes have the same range as in the case of 944 Hidalgo.

TABLE III

Elements of 1036 Ganymed

Yr	ω	Ω	i	φ	μ	a (AU)
1351	115°8	232°8	22°8	35°0	816″62	2.6627
1451	118.3	229.8	23.3	34.6	815.64	2.6648
1551	121.0	227.0	23.8	34.3	816.05	2.6640
1651	124.4	223.5	24.5	33.9	816.26	2.6635
1750	126.7	221.0	25.1	33.4	815.85	2.6644
1850	128.7	218.7	25.6	33.1	816.43	2.6631
1950	131.1	216.3	26.3	32.9	818.60	2.6584
2050	133.4	214.0	27.0	32.2	817.26	2.6613
2150	135.1	212.1	27.5	31.5	815.44	2.6653
2250	136.9	210.3	28.1	31.1	815.88	2.6643
2350	139.4	208.2	28.8	30.6	817.36	2.6611
2450	141.0	206.6	29.3	30.0	816.38	2.6632

TABLE IV

Elements of 1134 Kepler

Yr	ω	Ω	i	φ	μ	a (AU)
1349	305°.7	23°.8	12°.8	28°.9	807''.92	2.6818
1450	310.7	20.1	13.2	28.6	806.01	2.6860
1551	315.4	16.6	13.6	28.8	809.59	2.6781
1648	319.1	14.0	14.0	28.3	806.89	2.6841
1749	323.6	11.1	14.4	28.3	808.19	2.6812
1850	326.3	9.0	14.6	28.0	807.23	2.6833
1951	330.5	6.7	15.0	27.8	806.87	2.6841
2048	333.1	4.9	15.3	27.6	806.55	2.6848
2149	336.9	2.8	15.6	27.5	806.34	2.6853
2250	339.5	1.3	15.8	27.3	806.19	2.6856
2351	343.0	359.5	16.0	27.2	805.44	2.6873
2448	345.3	358.0	16.2	27.3	807.96	2.6817

In conclusion we can state that there is a significant difference between the motions of comets and asteroids:

(1) Close encounters with the major planets occur less frequently for asteroids than for comets.

(2) These encounters are never as close.

Consequently, the changes in the orbital elements of asteroids are never catastrophic. Small periodic (e.g., in a) and slow secular (e.g., in ω and Ω) variations prevail in the case of asteroids. The encounters cause the evolutionary changes in the elements to be accelerated, but in general this influence is of short duration.

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