42. THE MOTION OF HIDALGO AND THE MASS OF SATURN

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Abstract. The principal features of the motion of Hidalgo over the interval 1400–2900 are described. The possibility that this object is an extinct (or nearly extinct) comet nucleus is discussed. A determination of the mass of Saturn, using observations of Hidalgo during 1920–1964, is presented and compared with other recent determinations.

Unusual though the orbits of many of the minor planets may be, none is so anomalous in so many different ways as that of 944 Hidalgo. In many respects the orbit of Hidalgo represents a compromise among those of the periodic comets Tuttle, Wild, and Neujmin 1, all four objects having their aphelia near the orbit of Saturn and rather high orbital eccentricities and inclinations.

Perhaps the most significant difference between minor planets and short-period comets is that the orbits of the latter are continually being disturbed as the result of passages near Jupiter, while the orbits of the former – except for Hidalgo – are stable. That Hidalgo can pass only 0.4 AU from Jupiter (Belyaev and Chebotarev, 1968) can certainly be regarded as suggestive of its cometary nature. Actually, the orbit of Hidalgo would be relatively stable for a short-period comet, only P/Neujmin 1 and P/Arend-Rigaux having been more successful at avoiding Jupiter in recent centuries (Marsden, 1970). These two comets are unusual in that they are almost invariably asteroidal in appearance, their cometary character having been evident only when they were considerably closer to the Earth than Hidalgo ever comes. It is not unreasonable to conclude that Hidalgo is also a comet, and that the relative stability of their orbits and regular passages within 2 AU of the Sun have, in the course of centuries, caused all three comets to lose almost all their volatiles.

Figure 1 shows some of the results of a long-term integration of the motion of Hidalgo over the interval 1400–2900. Close approaches to Jupiter are indicated by arrows. The very close approaches in 1673 (0.38 AU), 2752 (0.42 AU), and 2883 (0.32 AU) are particularly to be noted. Between 1922 and 2752, when there is no approach within 1.2 AU, small periodic variations are evident, especially in the mean distance a, and these reflect the approximate 6:7 mean motion commensurability with Jupiter (although the situation is also influenced by the 7:8 commensurability); as expected, there is no secular trend in a, and the trends in eccentricity e and inclination i (to the ecliptic) are effectively canceled out in the combination $(1-e^2)^{1/2} \cos i$. Between 1400 and 2900 the longitude of the ascending node regresses from 26° to 12°, while the argument of perihelion changes from 58° to 54°.

A determination of the orbit of Hidalgo, using 94 reliable observations spanning 1920–1964 and allowing for the gravitational attractions of all nine planets, gave a mean residual of 1.″95, and there were systematic trends of 3″ and more. Suspecting that Hidalgo might be a comet and that these residuals were due to the effects of

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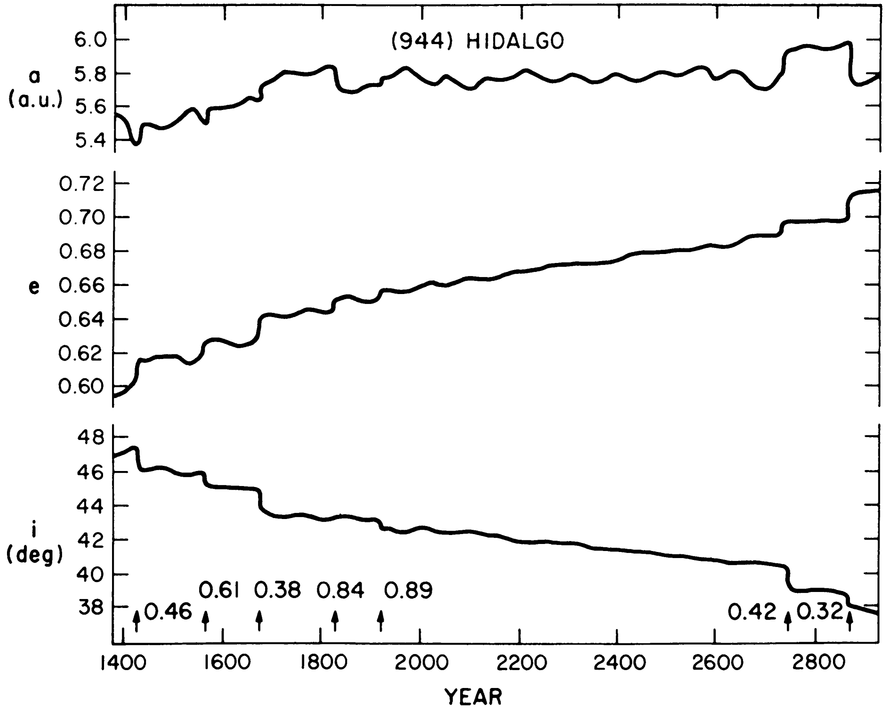

Fig. 1. The variations in the mean distance a, orbital eccentricity e, and orbital inclination i of Hidalgo during 1400–2900. The arrows at the foot indicate approaches to Jupiter, the least separations being stated in AU.

slight nongravitational forces, we made a solution for these effects by the method we have applied to a number of comets (Marsden, 1972). This caused the mean residual to be reduced to 1.″36 (Marsden, 1970). However, as mentioned briefly in the note in press added at the end of the paper just cited, it seems more probable that the residuals are due to the error in the IAU value for the mass of Saturn, that of Bessel (1833). In 1924 Hidalgo passed only 3.9 AU from Saturn, about the closest possible. Further, because the mean motions of the two objects are very roughly in the ratio 2:1, there was another approach, though more moderate, of 5.3 AU in 1951 (and also one of

TABLE I

Dependence of the mean residual for Hidalgo on the mass of Saturn

Reciprocal mass of Saturn	Mean residual
3500.0	1.″44
3499.0	1.26
3498.5	1.24
3498.0	1.26
3497.0	1.44

TABLE II
Residuals for 944 Hidalgo

UT	$\Delta\alpha \cos \delta$	$\Delta\delta$	UT	$\Delta\alpha \cos \delta$	$\Delta\delta$	UT	$\Delta\alpha \cos \delta$	$\Delta\delta$
1920 Oct. 31.78	0″.0	+1″.0	1934 Oct. 3.96	−0″.9	−0″.3	1937 Apr. 13.32	−0″.1	+0″.7
Nov. 19.77	+2.1	+1.2	4.97	+0.2	+1.6	14.36	+0.9	+0.4
19.82	−1.0	+1.1	7.94	−1.4	−0.2	May 12.24	+1.9	+0.8
19.85	−1.1	+0.1	8.88	−1.2	−0.7	13.28	+1.0	+0.9
Dec. 6.01	+2.0	−0.4	29.85	−1.7	−0.2	13.30	+2.7	+1.1
14.72	−1.1	−0.5	Nov. 7.20	−0.1	−0.9	June 10.20	+0.8	+0.6
1921 Jan. 15.83	+1.1	−1.4	7.21	+0.2	−1.4	10.23	+1.0	+0.7
31.79	−1.1	+1.0	12.09	−0.8	+0.3	1938 Apr. 27.34	−0.4	+0.8
Feb. 8.80	+0.5	−1.2	12.09	−0.3	+1.1	1948 Oct. 7.58	−2.8	+4.1
9.78	−0.9	+0.6	13.11	−0.5	+2.1	26.25	−0.9	0.0
12.80	+2.3	−2.2	15.30	−0.1	+0.3	26.27	−1.4	−0.1
Mar. 11.80	+0.7	+0.5	Dec. 7.12	−1.0	−0.9	Nov. 4.96	−1.4	−1.2
Nov. 9.18	+0.9	−1.5	1935 Mar. 2.09	+1.0	−1.6	4.97	−1.7	−1.2
26.13	+0.8	+0.5	Apr. 6.14	+0.7	−1.5	4.99	−0.8	−1.2
1922 Jan. 24.12	−0.1	−2.3	6.14	+0.4	−1.5	5.86	−2.8	+0.6
24.47	−0.5	−0.2	1936 Jan. 24.48	−0.1	−0.6	5.88	−2.7	−0.1
27.44	−1.0	+0.1	24.56	−0.1	−0.1	5.89	−3.1	+2.1
28.48	−0.5	−1·7	Mar. 28.30	−0.7	0.0	6.91	−0.1	+0.3
29.43	−1.4	+0.2	28.31	−0.1	−0.1	6.92	−1.9	−0.6
Feb. 5.01	+0.8	−1.0	29.33	−0.6	−0.2	6.96	−1.5	+1.2
26.42	−2.4	−0.1	Apr. 19.23	+0.4	+1.8	8.85	−0.5	+2.0
Mar. 3.43	+1.4	−1.4	26.30	+0.9	+1.2	1962 Oct. 2.42	+1.5	+0.1
4.43	−2.6	−1.2	26.31	+1.3	+1.3	2.43	+1.0	−0.5
9.46	+0.5	+2.1	27.26	+1.1	+1.5	27.26	+0.9	−0.4
22.24	−0.6	+1.2	27.27	+1.4	+1.2	27.26	+1.0	−0.6
22.26	−0.1	+1.3	May 22.17	+1.2	+0.4	Nov. 19.20	+2.3	−0.6
22.90	+0.3	−0.5	22.18	+1.7	+0.3	19.21	+2.1	−0.6
Apr. 1.01	+1.4	−1.0	23.18	+1.0	0.0	1964 Mar. 14.34	0.0	+2.2
15.14	−0.2	−1.0	23.18	+1.1	−0.2	20.33	+1.0	+0.6
15.16	−1.2	−2.7	24.18	+0.7	−0.1	20.36	+0.8	+0.4
22.20	+0.3	+0.5	24.19	+0.8	+0.2	Apr. 10.34	+1.5	+0.2
						10.37	+1.5	−0.2

4.1 AU in 1896, before Hidalgo was discovered). Additional orbit solutions have been made using several slightly larger values for the mass of Saturn. They indicate that the Hidalgo residuals can be substantially improved if the mass is increased by about 0.1 percent, and there is thus no need to solve for any nongravitational forces. The mean residuals corresponding to the various values of Saturn's mass are shown in Table I. The best fit comes from a reciprocal mass of 3498.5, and the individual residuals from this solution are listed in Table II.

In Table III we give a selection of determinations of the mass of Saturn – particularly the more recent determinations. During the nineteenth century the determinations from Saturn's satellites were generally more reliable than those from objects external to the system. More recently, the situation has been reversed, the satellite determinations seemingly more prone to systematic errors. The agreement among

TABLE III

Determinations of the mass of Saturn

Reciprocal mass (and mean error)	Reference	Object
3501.6 ± 1.2	Bessel (1833)	Titan
3502.2 ± 0.8	Hill (1895)	Jupiter, 1750–1888
3494.8 ± 1.1	Jeffreys (1954)	Satellites
3499.9 ± 1.2	Gaillot (1913)	Jupiter, 1750–1907
3497.6 ± 0.4	Hertz (1953)	Jupiter, 1884–1948
3499.7 ± 0.6	Clemence (1960)	Jupiter
3497.6 ± 0.2	Carr and Herget (1970)	P/Schwassmann-Wachmann 1, 1927–1965[a]
3498.7 ± 0.2	Klepczynski *et al.* (1970)	Jupiter, 1913–1968[b]
3498.5 ± 0.2[c]	Shapiro (1970)	All planets, 1750–1970
3498.5 ± 0.3[d]	This investigation	Hidalgo, 1920–1964

[a] Also fits observations in 1902.
[b] Also fits observations back to 1781.
[c] The true uncertainty is estimated at ±0.5.
[d] The mean error was determined by Herget (1972).

the four very recent determinations is certainly gratifying, and we could surmise that the slight disagreement of the P/Schwassmann-Wachmann 1 result is due, either to the influence of nongravitational forces or to systematic departures between center of mass and center of light. On the other hand, nongravitational forces *might* also be affecting Hidalgo, and there are obvious difficulties in measuring the position of Jupiter (and indeed all the major planets). All things considered, we tend to agree with Shapiro's (1970) suggestion that the true value of the reciprocal mass is contained in the range 3498.5 ± 0.5, although it would perhaps be worth while to make a further independent determination from a simultaneous study of the motions of several of the minor planets of aphelion distance greater than 4.0 AU.

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Discussion

B. Yu. Levin: How will the change in Saturn's mass influence the determination of the nongravitational forces on comets?

B. G. Marsden: In the best determined cases the figures should certainly not be changed by more than 1%.