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THE ORBITAL EVOLUTION OF REAL ASTEROIDS NEAR THE 4:1 MEAN-MOTION RESONANCE WITH JUPITER

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ABSTRACT

Numerical integrations of the orbits of ten asteroids with osculating elements near the 4:1 mean-motion resonance with Jupiter have been performed over 200,000 years into the future. A variety of orbital evolutions was found, depending on the start values of the semi-major axis. The orbit of asteroid 1983 RJ_4, which lies almost exactly at the resonance centre, experiences large variations in eccentricity, evolving into an Earth-crosser on a time-scale of a few 10^4 years. This makes this region a potential source for Apollo objects and meteoritic material, although the width of the resonance region in semi-major axis seems to be very narrow.

INTRODUCTION

In this study we intend to investigate the 4:1 mean motion resonance with Jupiter as a possible source for Apollo asteroids and meteroites by following the orbital evolution of real asteroids. Yoshikawa (1989) investigated the 4:1 resonance using a semi-analytical model and numerical integrations in a simplified solar system model. Following a similar study on the 5:2 resonance (Hahn *et al.*, 1991) we examine whether the asteroids presently near the 4:1 resonance – semi-major axis $a = 2.064$ AU – experience orbital evolutions which bring them into planet-crossing trajectories.

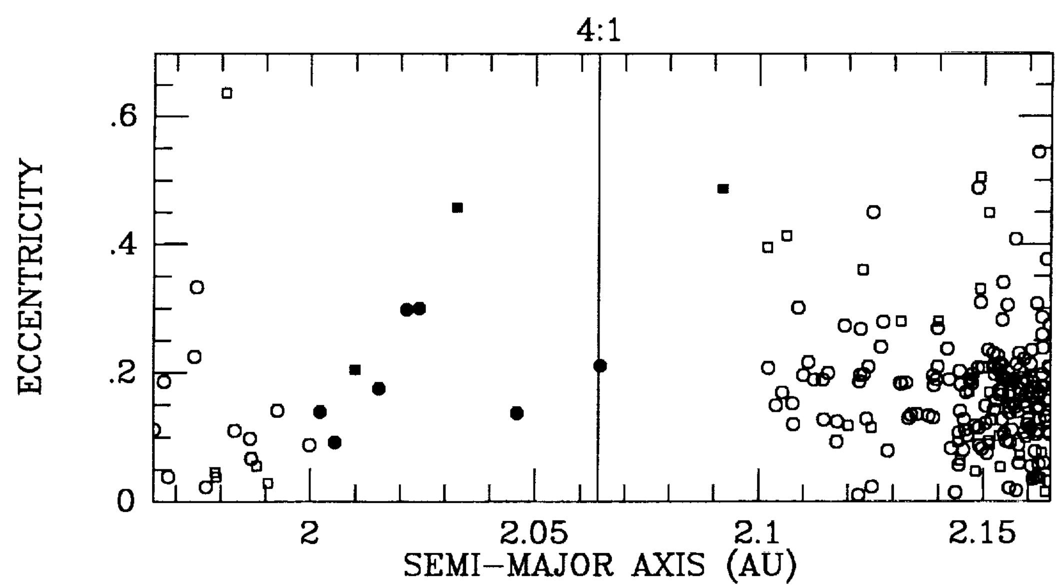

Figure 1: Distribution of asteroids near the 4:1 mean motion resonance. Circles designate unnumbered, squares numbered asteroids; the filled symbols represent the asteroids integrated in this paper.

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The 4:1 resonance is located at the inner boundary of the asteroid belt, where also the secular resonances ν_6 and ν_{16} are situated, making it a complex region. These secular resonances influence the orbital evolution on timescales of the order of some 10^6 years (see *e.g.* Froeschlé and Scholl, 1989).

We selected orbits of both numbered and unnumbered asteroids, taken from the Minor Planet Centre orbital database, in the range $2.0 < a < 2.1$ AU. (See filled symbols in Figure 1.) No variations of the elements have been considered, implying larger uncertainties for the orbital elements of the unnumbered asteroids. Nonetheless, the results should be indicative for the orbital behaviour and it is planned to continue this study with further integrations of both varied and ficticious orbits for those asteroids which showed large orbital variations.

CALCULATIONS

In our calculations we numerically integrate the equations of motion of the planets and the asteroids simultaneously, using the 15th order RADAU integrator (RA15) by Everhart (1985). As described in detail in Hahn *et al.* (1991), a solar system model which takes into account the perturbations due to all planets except Mercury and Pluto was used, and the integrations have been performed over 200,000 years into the future.

RESULTS

The results are summarised in Table 1, where the minimum and maximum values for the semi-major axes, eccentricities and inclinations are shown. The behaviour of the critical argument $\sigma = (4\lambda_j - \lambda - 3\varpi)$, $\varpi - \varpi_j$, the approximate resonance arguments $(\varpi - \varpi_s)$ for the ν_6 and $(\Omega - \Omega_j)$ for the ν_{16} secular resonances are also shown. The subscript j and s refer to Jupiter and Saturn respectively, no subscript refer to the asteroid, λ is the mean longitude and ϖ is the longitude of perihelion. In Figure 2 the evolution of the eccentricity for all asteroids is graphically summarized.

Asteroid		a_{max}	a_{min}	e_{max}	e_{min}	i_{max}	i_{min}	σ	$\varpi - \varpi_j$	$\varpi - \varpi_s$	$\Omega - \Omega_j$
4276	Clifford	2.011	2.009	0.26	0.14	27.7	17.2	C	C	C	C
	1986 RM_2	2.003	2.001	0.19	0.09	27.3	19.9	C	C	C	C
	1989 UK_2	2.047	2.044	0.18	0.08	19.0	9.6	C	C	C	C
	5481 T-2	2.006	2.005	0.16	0.08	25.0	18.5	C	C	C	C
	1987 UV_1	2.016	2.015	0.18	0.06	5.4	0.8	C	C	L	C
3551	1983 RD	2.094	2.069	0.50	0.20	11.1	4.7	C	C	L	C
	1987 DA_7	2.038	2.022	0.42	0.29	7.4	2.3	C	C	L	C
	1981 EJ_{30}	2.091	1.997	0.54	0.30	7.6	1.8	C/L	C	L	C
3288	Seleucus	2.102	1.973	0.61	0.44	9.8	2.7	C/L	C/L	C	C
	1983 RJ_4	2.091	1.965	0.59	0.20	12.2	4.6	C/L	C/L	C/L?	C

Table 1: Summary of the orbital evolution of the asteroids during 200,000 years. L means librating resonance argument and C a circulating one.

Below we discuss in some detail those asteroids which exhibit orbital evolutions of particular interest.

(3551) 1983 RD is at present an Amor asteroid. As can be seen from Figure 2, there is a clear secular trend of decreasing e, meaning that the orbit is evolving outwards, away from the Earth. This confirms and extends the results found by Milani *et al.*, (1989), where (3551) is classed as an "Alinda" evolving into an "Eros".

1983 RJ_4, which is the only asteroid in our sample presently almost exactly at the resonance, (see Figure 1), experiences a very rapid increase in eccentricity and becomes Earth crossing after 50,000 years. Close encounters with Earth remove the asteroids from the 4:1 resonance 5,000 years later. The eccentricity remains high and 1983 RJ_4 is an Apollo asteroid until 120,000 years. The critical argument σ is librating with a slowly moving libration centre and $\varpi - \varpi_J$ librates when 1983 RJ_4 is in the 4:1 resonance.

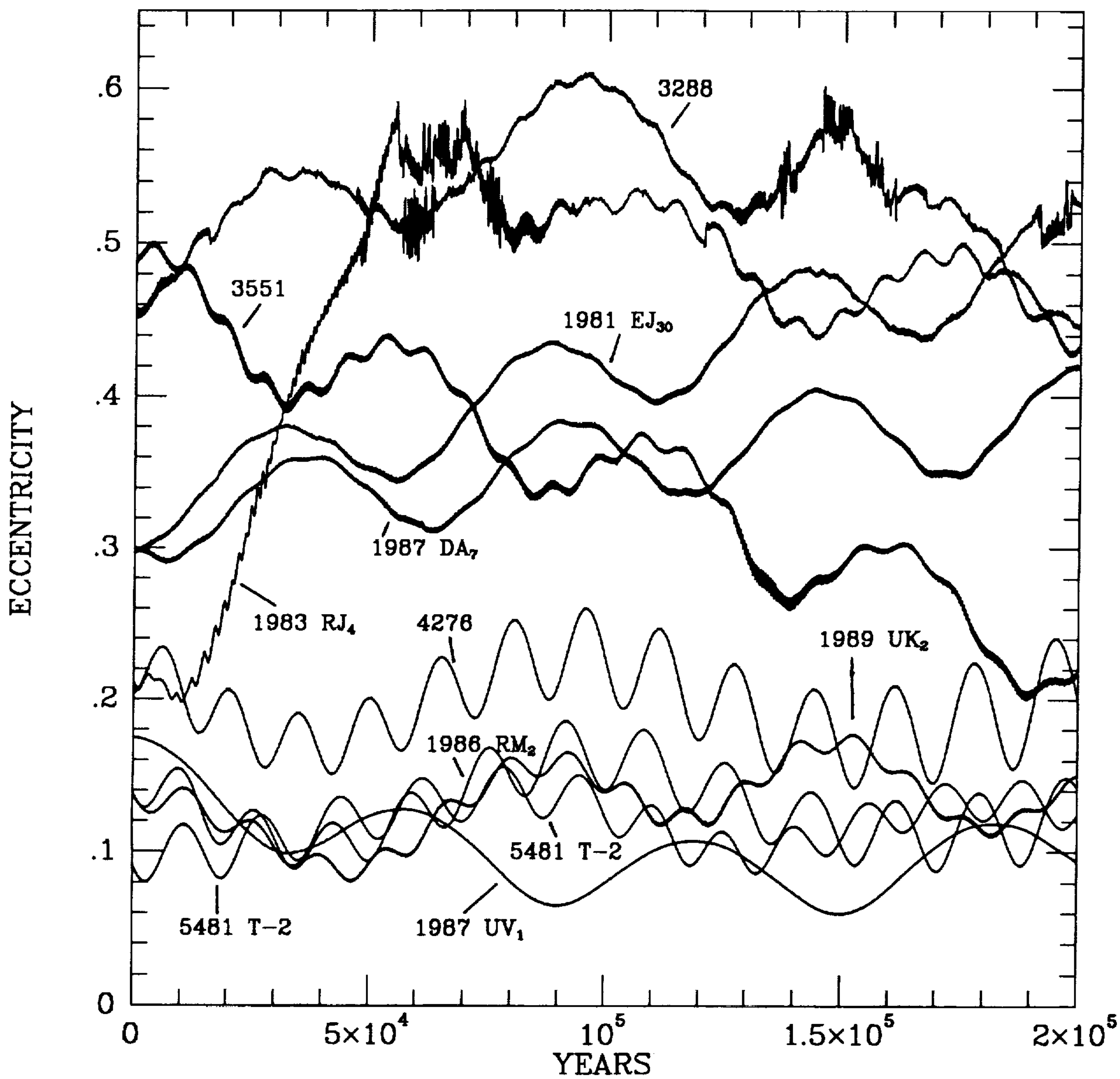

Figure 2: Evolution of the eccentricities over 200,000 years for all asteroids.

This rapid evolution into an Earth-crossing orbit may explain the lack of objects in this region. But we also conclude that the range in a, leading to such a dramatic orbital change, seems to be very narrow. In order to quantify this statement we need further studies of this orbit from an ensemble of slightly varied starting elements to determine the width of the resonant region. In the light of the results, attempts to improve the orbit of this asteroid should be made. The orbit is based on 6 observations only, from an arc of 27 days (MPC 10750) and the asteroid has not been recovered since its discovery apparition. The next favourable opposition would be in the end of 1992.

(3288) Seleucus, the second Amor asteroid in our sample, experiences two phases where σ is librating, but it also evolves into an Earth-crosser – Apollo type orbit, or as found by Milani *et al.* (1989) evolving from an "Alinda" into a "Geographos". Close encounters with the Earth are responsible for the removal from the resonance.

1981 EJ_{30} represents an example of an interrelation between mean motion- and secular resonances. The asteroid is located in the ν_6 resonance and its eccentricity shows an increasing trend, leading to Earth-crossing at the end of our integration period. This confirms earlier calculations by Shoemaker and Wolfe (priv. communication) using Williams (1969) secular perturbation theory. Close encounters with our planet move the orbit across the 4:1 resonance but only very short-lived librations of σ do occur. Also this asteroid has not yet been recovered.

DISCUSSION

We have shown – although only from one orbit – that large changes in e can occur on time-scales less than 10^5 years. This is in agreement with the semi-theoretical predictions of large variations on similar time-scales by Yoshikawa (1989). We also conclude that the range in element space, giving rise to large orbital variations, seems to be very narrow. The fact that we observe objects currently situated in this region of the asteroid belt could be an indication of their recent injection into such orbits. We also stress the necessity of improvment of the orbit of *1983* RJ_4 and encourage further search for objects around the 4:1 resonance as potential candidates for parent bodies of Near-Earth asteroids and of meteorites.

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