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DYNAMICAL TIMESCALES IN THE JUPITER FAMILY

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ABSTRACT

Numerically integrated fictitious comets starting in orbits perihelion tangent to Jupiter have been used to estimate the duration of a typical visit to the observable Jupiter family of comets. The results show values of 3 to 6 thousand years, narrowing the previously estimated interval of 10^3 to 10^4 years.

INTRODUCTION

The time a short–period comet typically spends in the observable Jupiter family has not yet been investigated in detail. This paper presents preliminary first results from a project where dynamical simulations using a large number of fictitious orbits integrated for several tens of thousands of years, are used.

Why is the typical duration of a Jupiter family visit important to know? First, looking at the large scale dynamical evolution of the cometary population as a whole, one of the problems is how to explain the apparent steady state of the Jupiter family. Models for this must consist of balancing the dynamical infeed of comets from some source population with a combination of dynamical and physical loss (see e.g. Ip and Fernández, 1991, and Levison, 1991).

Secondly, a detailed study of the duration of Jupiter family visits appears to be of considerable interest when making models of the physical evolution of the comets over longer timescales than just a few revolutions, especially regarding the question of how the process of dust mantling of the nuclei works (e.g. Rickman et al., 1990).

METHOD

These calculations are based on the orbital evolutions derived from numerical integrations of 1000 fictitious comets for 50000 years, in a dynamical model of the Solar system consisting of the Sun, Jupiter in its present orbit and the (massless) objects. To be able to handle the close encounters with Jupiter without sacrificing accuracy, an integrator with variable stepsize (RADAU), as described by Everhart (1985), has been used.

In Quinn et al. (1990) it is concluded that the origin of the Jupiter family comets is a low–inclination distribution of Neptune crossers random–walking due to Neptune perturbations until the orbital period becomes comparable with Jupiter's, when they will evolve according to the Tisserand criterion

$$T = \frac{2a_J}{(Q+q)} + 2\sqrt{\frac{2Qq}{(Q+q)a_J}}\cos i = \text{constant}$$

where Q and q is the aphelion distance and perihelion distance respectively for the comet, i the inclination, and a_J is the semi–major axis of Jupiter's orbit.

The initial orbits in this study were thus chosen such that the comets already are on low–inclination orbits in the Jupiter—Saturn region. As is shown in figure 1 the initial perihelion distances are between 4 and 6 AU, aphelion distances between 4 and 10 AU (leading to an eccentricity interval of 0 to 0.43), and an inclination distribution between 0°and 30°. The remaining angular elements were evenly distributed between 0°and 360°.

The orbits were integrated for 50000 years, and the osculating elements were stored every 50 years. A plotted example of a perihelion distance evolution can be seen in figure

2. This example clearly shows the principal problem with how to define the time during which the comet is in the observable Jupiter family: it is not enough just to define a visit to the observable Jupiter family as when the perihelion distance is below a certain level. The "noise" around any one level gives misleading results. Rather, the definition of the duration of a visit is the time a comet spends in a "deep" capture, i. e., the time spent with perihelion distance less than 4 AU if at any time during this period the perihelion distance is less than 2 AU, while having an orbital period less than 20 years (figure 2).

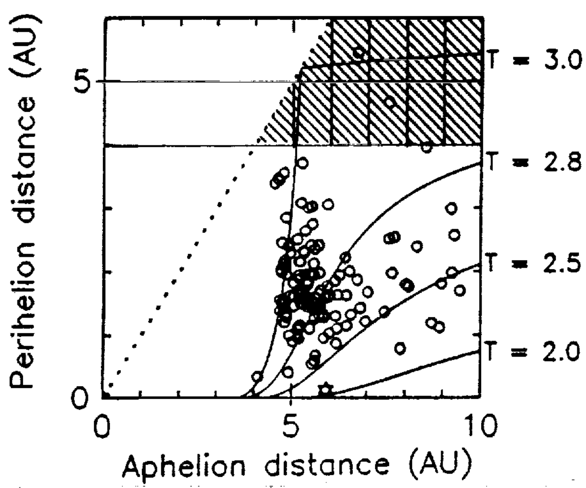

Figure 1. Shown in the figure are the initial values for perihelion- and aphelion distance (hatched area), together with the distribution of the known Jupiter family comets (rings). The labeled curves indicate the dynamical evolution according to the Tisserand criterion using inclination 0°.

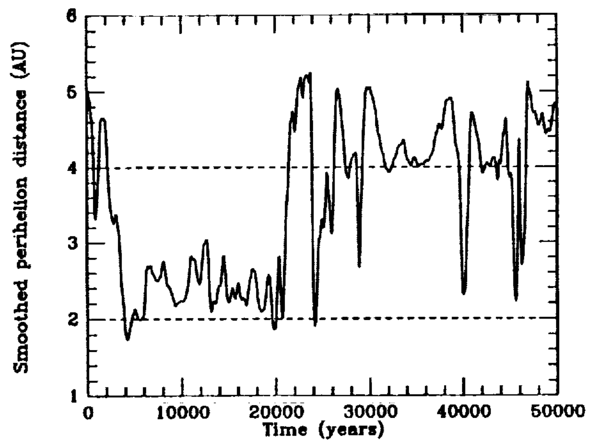

Figure 2. An example of orbital evolution for one comet. Plotted is the perihelion distance during 50000 years. The dashed lines show the chosen limits for the definition of a Jupiter family visit (see text).

Another problem with the raw data is the effect of the constant sampling interval. This means that the osculating elements sometimes are recorded at times when the comet is at a close encounter with Jupiter, which leads to a non-representative osculating orbit. To compensate for this the data has been smoothed slightly using a smoothing function covering 7 timesteps, and with the 3 central weights at 0.2, and the weights on each side at 0.1. Tests showed that without smoothing there was an overrepresentation of fictitious 50 year visits.

RESULTS AND DISCUSSION

The smoothed orbital evolutions for the 1000 comets was used to generate statistical values for the duration of the visits to the observable Jupiter family. Seven runs were made, using different subsets of initial orbits. A histogram showing the distribution of the duration of visits for all 1000 initial orbits can be seen in figure 3 and table 1. In the figure the median value is shown, as well as the quartiles and the arithmetic mean value. Results for the 6 remaining runs, with subsets of the initial orbits, can also be seen in table 1.

	Duration of visit (years)				
Initial orbits	$T_{0.25}$	$T_{0.50}$	$T_{0.75}$	<T>	n
All	2100	4375	8800	6876	348
4<q<5 AU	2300	4950	9450	7261	228
5<q<6 AU	1850	3650	7650	6153	120
0°<i<15°	1600	3525	6850	5149	158
15°<i<30°	2900	5850	11550	8422	190
0<e<0.21	2050	3950	7975	6616	182
0.21<e<0.43	2100	5000	9850	7134	166

Table 1. Results from 7 runs using different initial orbits. $T_{0.25}$, $T_{0.50}$ and $T_{0.75}$ stands for the 25% quartile, median and 75% quartile, respectively. <T> the arithmetic mean value, and n is the number of visits the T-values are based on.

Table 1 shows that the typical visit to the observed Jupiter family, as defined above, is between 3 and 6 thousand years. This number corresponds well with previously quoted values of 10^3 to 10^4 years (e.g. Fernández, 1984).

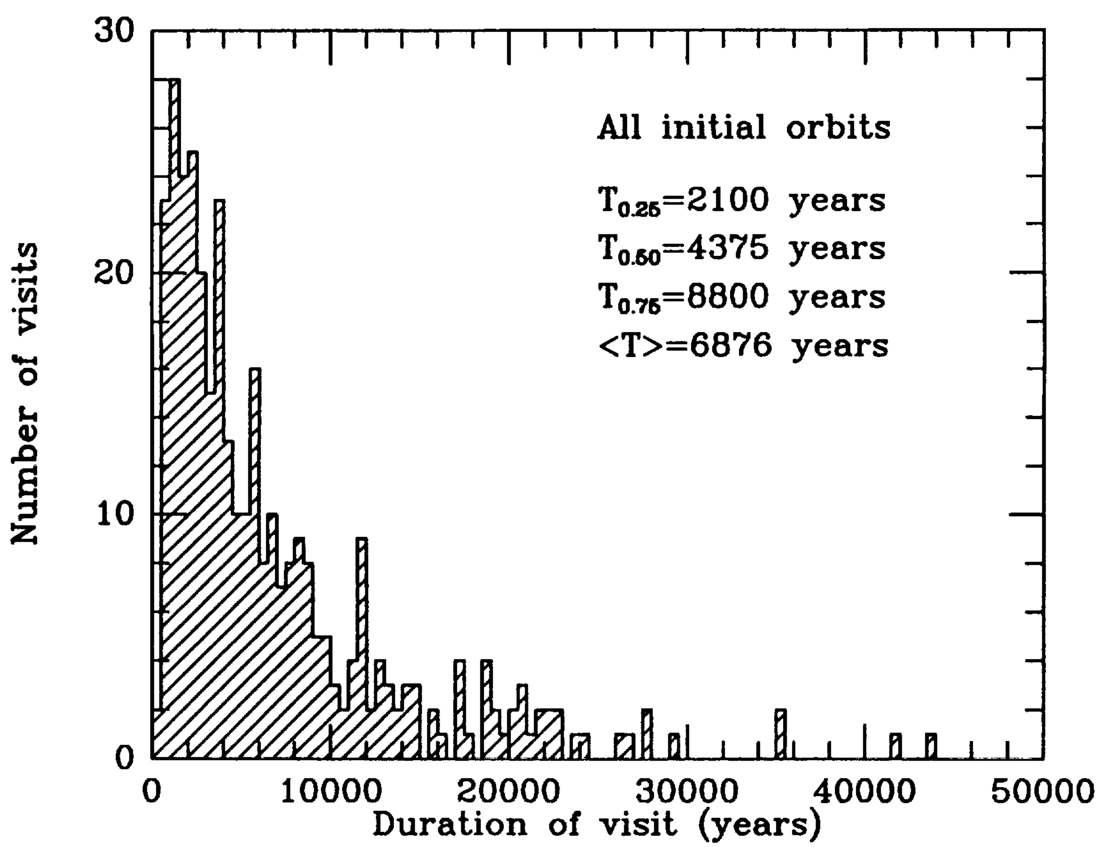

Figure 3. The distribution of duration of visits to the observable Jupiter family using all initial orbits. The width of each bin is 500 years.

No far-reaching conclusions will be made here based on this small amount of data. But looking at the results for the different subsets of initial orbits a few observations can be made. All three subset pairs (q, i and e) show a difference of more than a thousand years. This must be of significance. Perhaps surprising is the fact that both initially lower inclination and lower eccentricity orbits suffer shorter visits than higher inclination and higher eccentricity orbits. Maybe the shorter visits for the lower eccentricity orbits can be explained by the fact that comets in these orbits undergo encounters with Jupiter at relatively lower velocities, with correspondingly larger perturbations. Thus there would be a situation where the probability of a low-velocity/large-perturbation encounter with Jupiter within a short time is not too small. On the other hand comets in higher eccentricity orbits have on the average higher velocity encounters with corresponding smaller perturbations. But when a large perturbation *does* occur, the lower probability of another large perturbation within a short time is smaller than in the low-eccentricity case. In short: once a higher eccentricity comet has been captured into the Jupiter family it takes longer to leave. This should show up in the number of visits column in table 1, but only a hint of this can be seen (166 high e visits compared to 188 low e visits).

In principle, the same kind of argument could be used to explain the difference in the inclination subset pair. A comet in a high inclination orbit has a lower probability of encountering Jupiter, but when it does the equally low probability of an encounter soon after leads to a longer visit to the Jupiter family. Unfortunately this is not reflected in a smaller number of visits for higher inclination orbits, rather the opposite: 190 high i visits compared to 158 low i visits.

Regarding the perihelion distance subset pair the most striking fact is that there seems to be nearly a factor of two in difference for the number of visits in favour of the 4 to 5 AU interval (228 to 120). The fact that 4 AU has been used as the limiting perihelion distance for entry to the Jupiter family is probably the reason for this.

Obviously, what must be done in the future is to investigate how the choice of limiting perihelion distances affects the results. And maybe even more important: how does the effect of mean motion resonance locking affect the results. Especially the effects arising from a more complex dynamical model (e.g. Sun-Jupiter-Saturn-Object) must be studied.

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