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The orbital history of two periodic comets encountering Saturn

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Abstract. Two recently discovered short-period comets (P/1997 T3 (Lagerkvist-Carsenty) and P/1998 U3 (Jäger)) were found, by means of numerical integrations, to have recently encountered Saturn, leading to drastic orbital changes. In both cases the orbit was transformed from a Saturn-dominated regime (roughly tangential to Saturn's orbit) into a deep Jupiter-crossing orbit. For P/1997 T3 a close encounter to within 0.011 AU was identified in October 1954 from numerical integrations of the current orbit, taking into account the gravitational perturbations by all major planets from Mercury to Neptune and Pluto. Similarly, an approach to within 0.018 AU was found for P/1998 U3 in July 1991.

For each comet 99 variational orbits and the current orbit were integrated backwards in time well beyond the dates of the close encounters with Saturn. All orbital evolutions showed a similar change in the orbital parameters, as given above for the nominal orbit.

In order to further investigate the past orbital history, all orbits were integrated backwards in time for 10,000 years. At that time the majority of the orbits (92% and 87%, respectively) of comets P/Lagerkvist-Carsenty and P/Jäger had perihelion distances larger than 5.3 AU.

Key words: comets: individual: P/Lagerkvist-Carsenty, P/Jäger – comets: general

1. Introduction

Close encounters between major planets and small solar system bodies play an important role for the orbital evolution of these bodies. For transferring long-period comets into short-period ones Jupiter is the dominating planet (Everhart 1972) and most of the short-period comets have experienced close encounters with Jupiter (Carusi et al. 1985). The existence of the Jupiter family is well established but the existence of a Saturn family still remains to be proven. With the discovery of P/1997 T3 (Carsenty et al. 1997) it was evident after some test integrations that this comet was highly influenced by Saturn and also that it was transferred into its present orbit quite recently. It was therefore natural to look for the same behaviour among other short-period comets. With the discovery of P/1998 U3 (Meyer et al. 1998) another comet in this category was found.

Building on the work by Carusi et al. (1985), who studied the orbital evolution of 132 short-period comets and the continuation (http://www.ias.rm.cnr.it/ias-home/comet/catalog.html) of that investigation we studied the influence of Saturn on all periodic comets with well established orbits (171 comets) by integrating 400 years backward in time, and monitored close encounters with Saturn. The two comets in the present study were the only ones that during this time interval were drastically changed by Saturn and were thus studied in more detail.

The Tisserand parameter relative to a planet with semi-major axis a_s, as defined by

$$T_s = \frac{a_s}{a} + 2\sqrt{\frac{a}{a_s}(1-e^2)}\cos i,$$

can be used to characterize the orbital behaviour of a body encountering that planet. If this value is very close to 3.0 it also means that low-velocity encounters, and thereby strong orbital changes, and even (temporary) captures might be possible. As for the comets studied in this paper the pre-encounter orbital characteristics classify both orbits as typical Saturn-Family comets with Tisserand parameters T_s of 2.99 and 2.71, respectively.

2. Orbit determination

We have used all astrometric positions of P/1997 T3 and P/1998 U3 available at the Minor Planet Center (165 and 805, respectively) to determine improved orbits, and to investigate their uncertainty. This allowed us to constrain the variations for our orbital integrations to a range which is limited by the formal errors obtained from the orbit determination programme.

The code used to determine the orbit is the beta-version of OrbFit 1.1 (Karri Muinonen, priv.comm.) All available astrometric positions were initially used in the orbit determination, but for the final solution, positions which deviated more than 2.5 arcsec in a least-square fit were excluded. In Table 1 the orbital elements are given in columns two to seven. The second line for each comet gives the formal errors calculated with the orbit determination programme.

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Table 1. Orbital elements of the two comets and the formal errors

Comet	a	e	i	ω	Ω	M	*Epoch*
P/1997 T3	6.6816	0.36532	4.83521	63.1985	334.269	18.049	2451200.5
	0.0002	0.00001	0.00003	0.0003	0.003	0.001	
P/1998 U3	6.0650	0.64817	19.1417	303.5425	180.8950	356.8940	2451200.5
	0.0001	0.00001	0.0001	0.0001	0.0002	0.0001	

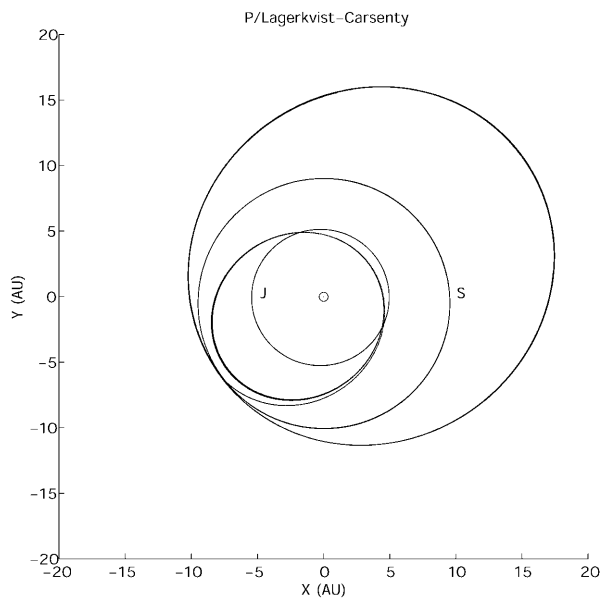

Fig. 1. The orbits of Jupiter, Saturn and P/1997 T3 (Lagerkvist-Carsenty). Axes units in astronomical units.

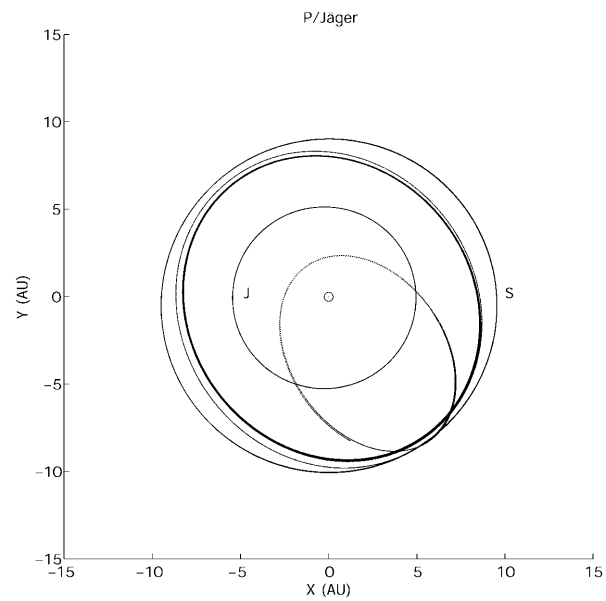

Fig. 2. The orbits of Jupiter, Saturn and P/1998 U3 (Jäger). Axes units in astronomical units.

3. Orbit integration

Based on the orbit given in Table 1, a set of 99 variational orbits were derived, of Gaussian distribution in each element, with standard deviations ten times the formal errors given in Table 1 and the original elements as mean values. These orbital elements, plus the original orbit, were used in a numerical integration to study the orbital history of the comets from an analysis of the evolutions of the whole ensemble of orbits.

The equations of motion of the planets (Mercury to Neptune, and Pluto) and the 100 comets (treated as massless bodies) were integrated backwards in time. The Swift integrator (Levinson and Duncan 1994) was used with a fixed time step of 0.02 days. The planetary coordinates were taken from the JPL DE403 ephemeris (Standish et al. 1995). Firstly, the ensemble of orbits was integrated backwards 100 years, in order to determine the time of the close encounter and gage the stability of this date (see Fig. 3 and Fig. 5). Secondly the long-term orbital evolution was investigated by running the same orbital ensemble over 10000 years, and plotting the individual evolutions of the orbital elements and distances to the planets. The choice of the integration time step of 0.02 also for the long integration was made to compensate for the performance of the integrator during close encounters.

As an additional check, the short-term (100 years) integration of the nominal orbits of both comets was also performed using the 15th order Radau integrator (RA15) by Everhart (1985), which applies variable step size. The times and minimum distances found for the two encounters with Saturn did agree perfectly, indicating that the results obtained with the Swift integrator, which performs much faster, are indeed reliable.

4. Results

Orbital elements pre (at JDT 2433400.5) and post (at JDT 2451200.5) encounter are:

P/1997 T3:
$a = 14.2$ $e = 0.31$ $i = 9.6$ —- $a = 6.68$ $e = 0.36$ $i = 4.8$

P/1998 U3:
$a = 9.9$ $e = 0.08$ $i = 25.9$ —- $a = 6.06$ $e = 0.65$ $i = 19.1$

These values, as derived for the nominal orbits, give the changes induced by the close encounters to Saturn, and are illustrated in Fig. 1 and Fig. 2.

In Fig. 1 and Fig. 2, the orbits of both comets are projected on the ecliptic plane, the evolution before and after the close encounter with Saturn are shown. The dramatic change of the orbits after the encounters with the planet Saturn can easily be seen in both figures.

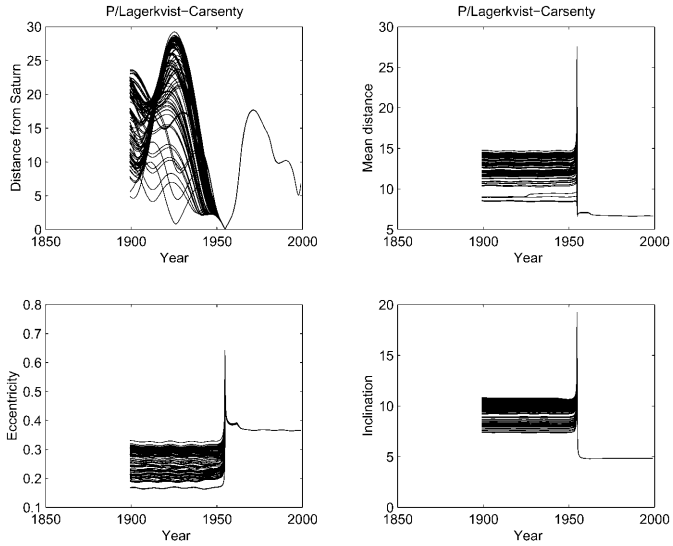

Fig. 3. The evolution of the distance to Saturn and the elements a, e and i for 100 orbits of comet P/Lagerkvist-Carsenty. The date of the close approach was determined to have occurred on October 9, 1954. The distances are in AU.

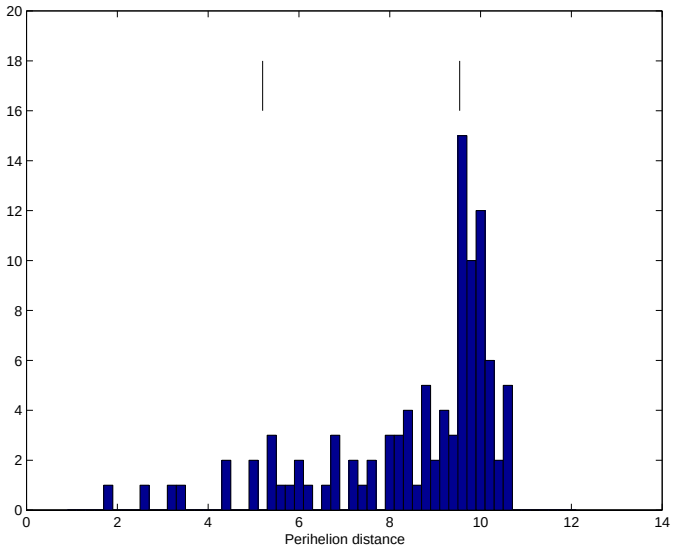

Fig. 4. The distribution of the perihelion distances (in AU) for the 100 orbits at the end of the integration 10000 years backwards in time for P/Lagerkvist-Carsenty. The mean distances of Jupiter and Saturn have been marked in the figure.

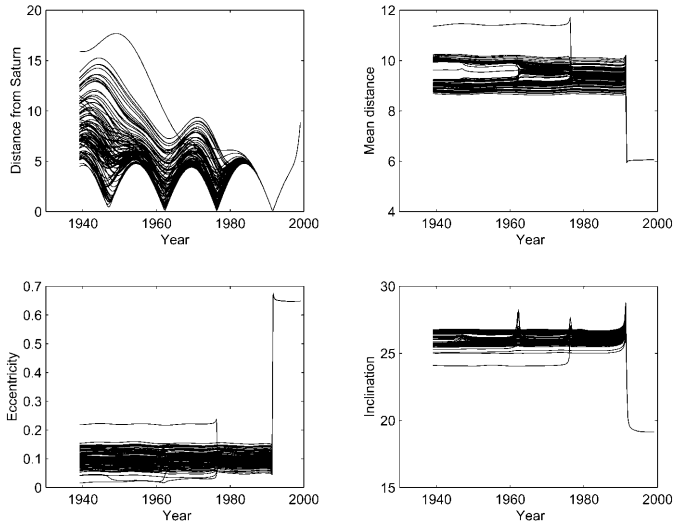

Fig. 5. The evolution of the distance to Saturn and of the elements a, e and i of the 100 orbits of comet P/Jäger. The date of the close approach was determined to have occurred on July 18, 1991. The distances are in AU.

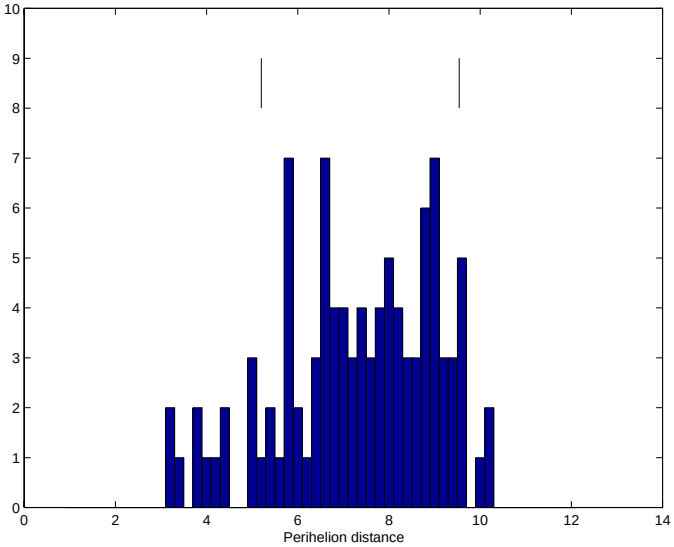

Fig. 6. The distribution of the 100 perihelion distances (in AU) at the end of the integration 10000 years backwards in time for P/Jäger. The mean distances of Jupiter and Saturn have been marked in the figure.

4.1. P/Lagerkvist-Carsenty

This comet makes the closest approach to Saturn, 0.011AU, of the two comets during the studied time interval, leading to a dramatic change of the orbit in the sense that all the 100 studied orbits were transformed into the present one by Saturn in 1954, as seen in Fig. 3. In Fig. 4 is shown the result of the integration of the same orbits 10000 years backwards in time. Here we give the perihelion distances at the end of the integration, showing that of the 100 studied orbits only 8 had perihelion distances smaller than 5.3 AU. It should be stressed that this means that during the whole time interval, only 8 orbits experienced perihelia which allowed them to interact with Jupiter.

4.2. P/Jäger

The evolution of this comet is very similar in behaviour to the one of P/Lagerkvist-Carsenty in the sense that it recently had a very close encounter (in 1991) to Saturn significantly changing the orbit into the present one (Fig. 5). To predict the real orbit before the encounter in 1991 is not possible but we integrated all orbits 10000 years backwards in time and the result is shown in Fig. 6. Of all orbits only 13 had perihelion distances smaller than 5.3 AU, during the whole timespan of the integration.

5. Discussion

Both comets were recently captured into their present orbits by Saturn, passing as close to the planet as 0.011 and 0.018 AU, respectively. No other known comet has been found to pass that close to Saturn before. It is interesting to note that both comets were discovered quite recently. Integrating 10000 years backwards in time gave the result that only a small fraction of the orbits of both comets were such that they had perihelion distances smaller than 5.3 AU, indicating their very likely recent transfer from a Saturn dominated regime into the Jupiter family.

It should be stressed that the small number (8 out of 100, and 13 out of 100) of orbits that became influenced by Jupiter means that during the whole period of integration, i.e. 10000 years, only a small fraction encountered Jupiter, thereby implying that the orbits studied have been under the control of Saturn for a long period of time, being members of the Saturn family.

Although our integration time span was probably not long enough to draw any conclusions about the transfer rate or the time scale of "handing down" of short period comets from their possible source in the Edgeworth-Kuiper belt to the inner giant planets region, it might be indicative of the time scale for transfer from Saturn dominated orbits to that of Jupiter (compare Levison & Duncan, 1994).

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