RECENT DYNAMICAL HISTORY OF THE SIX SHORT-PERIOD COMETS DISCOVERED IN 1975

Hans Rickman
Observatoire de Nice, France

In 1975 a remarkably large number of short-period comets were discovered - only the most recent number from 1977 is comparable. While the average discovery rate has been 0.8-1.0 new short-period comets per year (Kresák 1974), in 1975 there were six discoveries. In five of the cases IAU Circulars soon afterwards contained indications that close encounters with Jupiter had recently taken place (Marsden 1975, Kastel' 1975). For two of the comets, P/Kohoutek and P/Smirnova-Chernykh, also pre-encounter orbital elements were outlined, suggesting that substantial reductions of the perihelion distances had occurred.

There is at present a general consensus that, at least within the framework of the capture hypothesis, the immediate origin of the Jupiter family is a population of short- or intermediate-period comets (orbital periods $\lesssim$ 100 years) with low inclinations and perihelia near Jupiter's orbit (see e.g. Everhart 1972, Delsemme 1973, Vaghi 1973, Rickman and Vaghi 1976). Backward integrations of the motions of observed Jupiter family comets show a general agreement wich this picture (e.g. Kazimirchak-Polonskaya 1972). The present sample of six newly discovered comets offers good material for such an investigation. Long-term integrations could not be performed with any confidence for these one-apparition comets due to the uncertainties of their observationally determined "starting" orbits, but indeed a very short time interval (20 years) is sufficient in order to find major changes of the orbits in five of the six cases.

COMPUTATIONS

The bulk of the calculations to be reported were carried out by N. Carlborg and the author at the Stockholm Observatory using a Cowell N-body integration program written by Carlborg and earlier used in other investigations (e.g. Danielsson and Ip 1972). Initial data for the planetary system were adopted from Oesterwinter and Cohen (1972), and starting orbital elements for the comets were kindly communicated by B.G. Marsden. For a few comets varied orbits were treated - these include an

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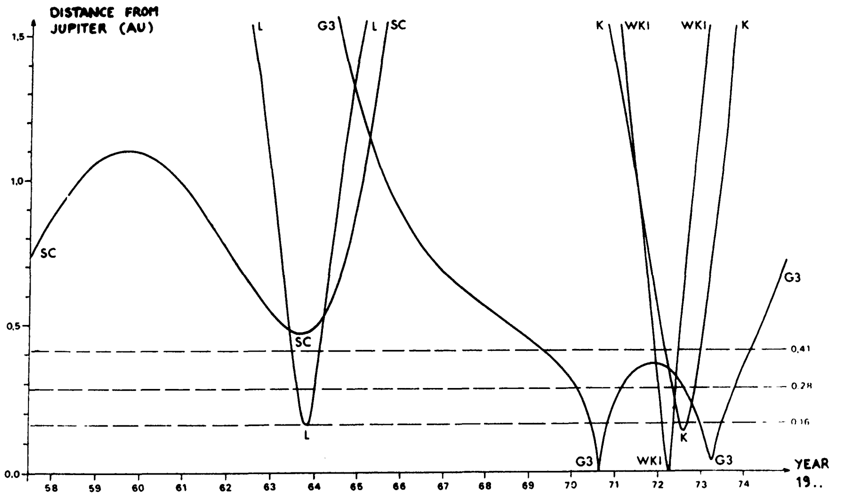

Figure 1. Distances of comets from Jupiter.

orbit computed by N.A. Belyaev for P/Smirnova-Chernykh. In the backward integration Mercury was thrown into the Sun after all the comets had been picked up at their respective osculation dates. The step-length of the integration program was automatically halved whenever necessary to keep the desired accuracy, and doubled whenever the current value was smaller than necessary. The maximum value was four days.

In Figure 1 the distances from Jupiter are represented as functions of time for the close approaches during 1957-75. The minimum extensions of three "spheres of action" around Jupiter are shown for comparison. Extremely close encounters were found in two cases. P/West-Kohoutek-Ikemura approached Jupiter to a minimum distance of 0.011 au on March 23, 1972, whereby the step-length was reduced to a minimum of $0^{d}.0625$. Comet P/Gehrels 3 is an even more extreme example. On August 15, 1970, it approached Jupiter to 0.0014 au (1.9 Jupiter radii from the planetary surface) whereby the step-length was reduced to $0^{d}.007813 \simeq 11$ minutes. Additional reversed integrations have been performed for the time intervals around the closest encounters, and the results show agreement with the original values to within a relative error of 10^{-10} in the positions and 10^{-9} in the velocities.

RESULTS

Table 1 contains a summary of initial and final (pre- and post-encounter) orbital elements for all the six comets. Detailed pre-encounter orbits will be published elsewhere (Carlborg and Rickman, in prep.). Here we turn instead to an account of particular results for the different comets.

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Comet	Perihelion distance		Aphelion distance		Orbital period		Inclination	
	1957	1975	1957	1975	1957	1975	1957	1975
P/Boethin	1.08	1.09	8.76	8.83	10.9	11.0	6.0	5.9
P/We-Ko-Ik	4.80	1.40	16.19	5.29	34.0	6.1	20.1	30.1
P/Kohoutek	2.52	1.57	5.84	5.21	8.6	6.2	4.4	5.4
P/Smi-Che	5.24	3.57	5.88	4.78	13.1	8.5	6.0	6.6
P/Longmore	3.02	2.40	4.79	4.90	7.7	7.0	26.1	24.4
P/Gehrels3	5.71	3.42	8.18	4.65	18.3	8.1	3.1	1.1

Table 1. Orbital elements in 1957 and 1975.

Comet P/Boethin, 1975a.

A remarkable fact concerning this comet is that it is the only one under consideration, which has not recently experienced any significant reduction of the perihelion distance, although it was the brightest short-period comet observed in 1975. During the interval covered by our investigation it has not penetrated to less than 2.9 au from Jupiter or to less than 6.5 au from Saturn. The 1975 apparition of comet P/Boethin did not occur at the most favourable geometric circumstances (opposition perihelion passage). The closeness of its orbital period to eleven years indicates that it may also have escaped such configurations for a long time before discovery. Our investigation has yielded an ephemeris for comet P/Boethin at its perihelion passage in 1964, and this shows that the observational circumstances were then slightly less favourable than in 1975.

Comet P/West-Kohoutek-Ikemura, 1975b.

This comet encountered Jupiter rapidly and very closely in March 1972. The Laplacean approximation of matched conic sections would have yielded a fairly accurate representation of this encounter: the heliocentric orbital elements were essentially unperturbed at distances $\Delta >$ 0.28 au from Jupiter, while the jovicentric elements were very stable at $\Delta <$ 0.28 au. The asymptotic deflection angle of the jovicentric hyperbola was 77° (mean eccentricity = 1.60). While the velocity with respect to Jupiter at the beginning of the encounter pointed less than 90° from Jupiter's heliocentric velocity, at the end of the encounter these two velocities were broadly antiparallel. As a result the heliocentric motion was severely braked, causing a decrease of the orbital period and of the perihelion distance. Comet P/West-Kohoutek-Ikemura is presently close to 2/1 resonance with Jupiter, indicating the possibility of repeated close encounters with the planet - particularly in early 1984 - in spite of the relatively high inclination of this comet's orbit.

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Comet P/Kohoutek, 1975c.

This comet is at present moving in an orbit rather similar to the one of comet P/West-Kohoutek-Ikemura. The two comets encountered Jupiter at roughly the same time (see Figure 1), but the encounters were different as well as the pre-encounter orbits. Comet P/Kohoutek approached Jupiter to a minimum distance of 0.14 au in late July 1972. As may be expected from a comet which barely enters the zone of instability of heliocentric orbits ($\Delta < 0.16$ au), the orbital elements of this comet do not exhibit any drastic changes. Nevertheless the encounter resulted in appreciable decreases of the perihelion and aphelion distances, and in particular the reduction of the perihelion distance greatly enhanced the probability of discovery of the comet. In this sense the orbital evolution of P/Kohoutek between 1957 and 1975 may be viewed as a capture into the Jupiter family, as well as the more obvious case of the evolution of P/West-Kohoutek-Ikemura.

Comet P/Smirnova-Chernykh, 1975e.

This comet has the third largest perihelion distance (3.6 au) known among short-period comets. Because of the low eccentricity (0.15) of its orbit the comet may be observable even at aphelion oppositions. Twenty years ago, however, it would not have been observable even at perihelion. Figure 1 shows that the encounter with Jupiter started before 1957 for P/Smirnova-Chernykh, and the osculating elements in Table 1 for this comet are hence insignificant. An extended integration has therefore been performed back to January 1941. The pre-encounter orbital elements found in this way are: $q = 5.7$ au, $Q = 12.3$ au, $P = 27$ years, $i = 5.7°$.

A major transformation of the cometary orbit occurred in this case without any extremely close encounter with Jupiter ($\Delta_{min} = 0.20$ au in November 1955). This is consistent with the extremely long duration of the approach ($\Delta < 1.5$ au from August 1953 to August 1965). Comet P/Smirnova-Chernykh experienced a double encounter with Jupiter, a second approach to $\Delta = 0.47$ au having occurred in September 1963. While the first approach mainly decreased the aphelion distance, the second one implied the decrease of perihelion distance which was necessary for discovery of the comet. Between the two encounters the comet's heliocentric orbit had an extremely small eccentricity ($e_{min} = 0.015$ in early 1959).

Comet P/Longmore, 1975g.

This comet encountered Jupiter to a minimum distance of 0.16 au in October 1963. The evolutions of the heliocentric orbital elements are similar to the ones for comet P/Kohoutek in a broad sense - no extremely rapid transformations occur, and the resulting changes of orbital elements are comparable. For comet P/Kohoutek we used the term "capture" to signify a reduction of the perihelion distance which greatly enhances the probability of discovery. In this sense one may use the word also for the calculated evolution of comet P/Longmore.

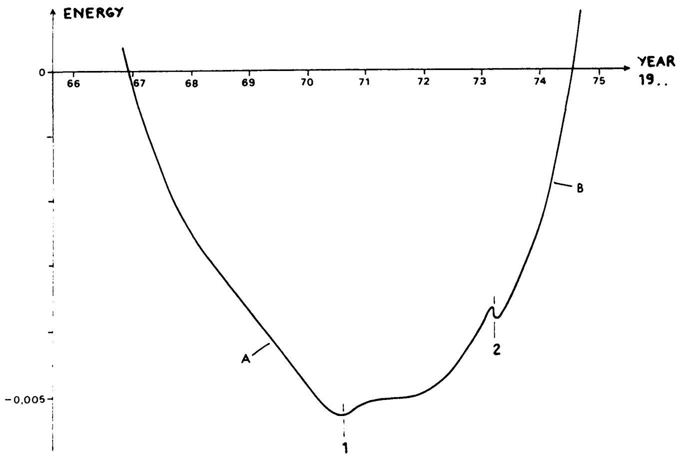

Figure 2. Jovicentric orbital energy for P/Gehrels 3. A and B denote the passages of 0.41 au jovicentric distance, 1 and 2 are the perijove passages.

Comet P/Gehrels 3, 1975o.

Like P/Smirnova-Chernykh this comet experienced a double encounter with Jupiter (see Figure 1). Both the encounters of comet P/Gehrels 3 were extremely close, however. As already mentioned, the first one implied a near-collision with the planet, and the second one took place only 2.6 years later to a minimum distance of 0.04 au on March 25, 1973. The comet remained within the stability zone of jovicentric motion ($\Delta < 0.41$ au) for the whole interval between the encounters.

Figure 2 shows the jovicentric orbital energy of comet P/Gehrels 3 as a function of time. It is evident that the jovicentric orbit was elliptic for 7.6 years, from December 1966 to July 1974, until 15 months before discovery. Together with the extended sojourn in the $\Delta < 0.41$ au sphere (April 1969 to February 1974) this makes the term "quasi-satellite' appropriate for the comet. Satellite captures by giant planets have been found before, but only concerning hypothetical "comets" (Everhart 1973, Kazimirchak-Polonskaya 1972). Numerical integration errors are of no importance in the present case. The inaccuracy of our calculation depends mainly on the fact that we took no account of Jupiter's oblateness or the perturbations by the Galilean satellites. Four different starting orbits were treated, the divergence of which throughout the whole double encounter is found to be remarkably small.

Comet P/Gehrels 3 first approached Jupiter along an extremely elongated, retrograde elliptic trajectory, the perijove distance being 0.0014 au and the apojove distance gradually decreasing to 0.36 au. After passing perijove on August 15, 1970, the comet went into its first and only apojove passage. Solar perturbations placed the actual apojove at 0.37 au from the planet, and the sense of motion was changed to prograde. The perijove distance was raised to 0.04 au while the apojove distance continued to increase beyond 0.41 au. After the second perijove passage the comet was carried away by the Sun's gravitation to enter into its present heliocentric orbit.

DISCUSSION

For comet P/Kohoutek our pre-encounter orbit is in good agreement with the preliminary estimate by Marsden (1975), while for comet P/Smirnova-Chernykh our results do not confirm those of Kastel' (1975), namely, $q = 5.7$ au, $Q = 6.7$ au before the encounter in 1963. Such a discrepancy is to be expected, since the starting orbit used by Kastel' is based upon a 38 days observational arc only and differs substantially from the ones we used.

A few general conclusions are apparent from Table 1. For all comets except P/Boethin the perihelion distances in 1957 were so large that the comets could hardly have been observed. On the other hand the orbital periods were still relatively short. Hence the above-mentioned picture of the immediate origin of the Jupiter family is supported by the present investigation. We find a high rate of transformations of cometary orbits (i.e. a high "capture rate") by Jupiter, in accordance with the recent high discovery rate of Jupiter family comets.

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