THE PAST ORBIT OF COMET HALLEY AND ITS METEOR STREAM

A. Hajduk
Astronomical Institute of the Slovak Academy of Sciences
842 28 Bratislava
Czechoslovakia

ABSTRACT. The present paper studies the structural features of the meteor streams associated with Comet Halley deduced from the observations of its meteor showers, as check points of orbital elements in a deeper history of the comet orbit. Libration of the argument of perihelion of the comet and the corresponding displacement of the nodes, as recognized in the distribution of condensations within the stream, allows to estimate the maximum lifetime of the comet in the inner Solar System at about 2 x 10^5 years.

The present study is based on three main sources of information: The orbital elements of Comet Halley calculated by Yeomans and Kiang (1981); the libration of the argument of perihelion of the comet calculated by Kozai (1979), and the observed structural features of the associated meteor stream, as represented by the shell model of McIntosh and Hajduk (1983).

The orbital motion of P/Halley has been numerically integrated by Yeomans and Kiang back to 1404 B.C. over a total time span covering 45 revolutions. The change of orbital elements is rather small during this interval, except in the argument of perihelion (with the corresponding changes in the position of nodes) and to a lesser extent in the period (or semi-major axis). However, the changes in the period are neither periodical, nor systematic and hence attempts to use them for a reconstruction of the history of the comet's orbit (Kamienski, 1961) remained unsuccessful.

The variations of the nodal longitude and of the corresponding nodal distances are shown in Fig. 1, where the dots represent the 45 values from Yeomans and Kiang (1981) for each revolution. The solid lines represent the extrapolation of the nodal motion both backwards and forwards, within the libration limits (-18^o, $+82^o$) given by Kozai (1979). The half cycle from Ω_{min} to Ω_{max} takes 140 revolutions with a corresponding change of the nodal distance from about 0.8 AU up to 4.2 AU. Each libration cycle produces a shell of orbits. The location of the present orbit of P/Halley within the present cycle is plotted in Fig. 7 by McIntosh and Hajduk (1983).

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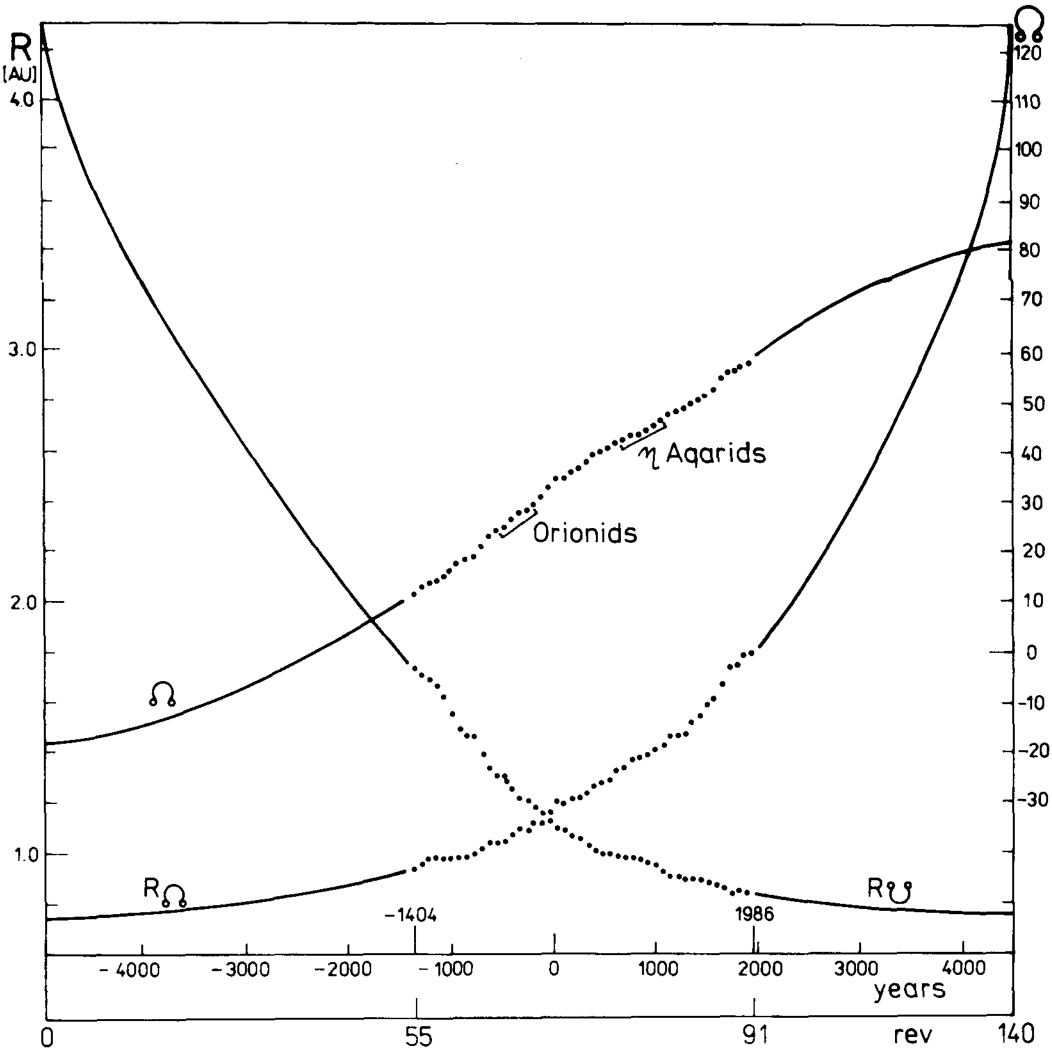

Figure 1. The nodal motion of the orbit of Comet Halley over the present libration cycle. ☊ is the heliocentric longitude of the ascending node, R☊ and R☋ are the heliocentric distances of the ascending and descending node, respectively. The dots represent values from Yeomans and Kiang (1981) for 45 revolutions.

The above data may satisfactorily serve to reconstruct the present cycle of the comet motion, but the data can give us little information about past (or future) cycles of libration, since the perturbations by Jupiter become much stronger at nodal distances near the libration limits when the orbits of Jupiter and the comet approach one another to within 0.25 AU. Kozai (1979) also lists wider changes in the other orbital elements near the libration limits.

We can use the cometary debris to reconstruct past cycles of the comet motion. According to the shell model of the cometary debris of P/Halley (McIntosh and Hajduk, 1983) the observed stable zones of increased particle density in the meteor stream correspond to the shells of particle orbits from different libration cycles of the comet. The shell is confined to a strip, the boundaries of which subtends an angle of 25^{o} with the line of apsides. The spectrum of perturbations on particles spread out along the cometary orbit (Yabushita, 1972) causes a quasi-diffusion process, connected with the thickening of the shell, forming a belt. A typical belt of particle orbits, corresponding to one complete cycle has a width of 0.44 AU perpendicular to the comet's orbital plane and a thickness of 0.044 AU within it, at r = 1 AU.

Let us identify the observed zones of higher spatial density within the two Halley meteor showers (i.e. Orionids and Eta Aquarids) with the belts corresponding to different cycles. Then the Earth's longitudes at the time of observed particle concentrations may serve as check points for the motion of the comet in the past cycles (at the nodal distance of 1 AU and with the position of nodes at the particular Earth's longitudes). The three most recent cycles are reconstructed in this way in Fig. 2. Dots represent values for the present cycle calculated by Yeomans and Kiang. They intersect the Earth's orbit ($R_{☊}$ = 1.0) at the beginning of the shower periods of Eta Aquarids and Orionids at solar longitudes of 40^{o} and 200^{o}, respectively. The position of concentrations (belts) at the Earth's distance is indicated in Fig. 2 by open circles. Most pronounced are the central double belts at 45^{o}-47^{o} and 206^{o}--208^{o}, respectively.

The three pairs of lines defined by the nodes of the belts at 1 AU and by a little different libration limits (shifted by the difference between the belts) may represent the check points for the past three cycles. Some theoretical and observational arguments support this idea. The present belt is less pronounced in observations. The comet has intersected the Earth's orbit only a couple of revolutions ago and, consequently, the belt has not yet developed enough in its width and thickness. Moreover the nodes of the present comet orbit are far from the Earth's orbit. The most pronounced central belt theoretically corresponds to the width and thickness developed in 400-500 revolutions, whereas the third belt is more diffuse with higher mass loss over 650-800 revolutions.

An analysis of the particle size distribution in the belts indicates a higher proportion of larger particles in the older belts than in the most recent one. Other structural features of

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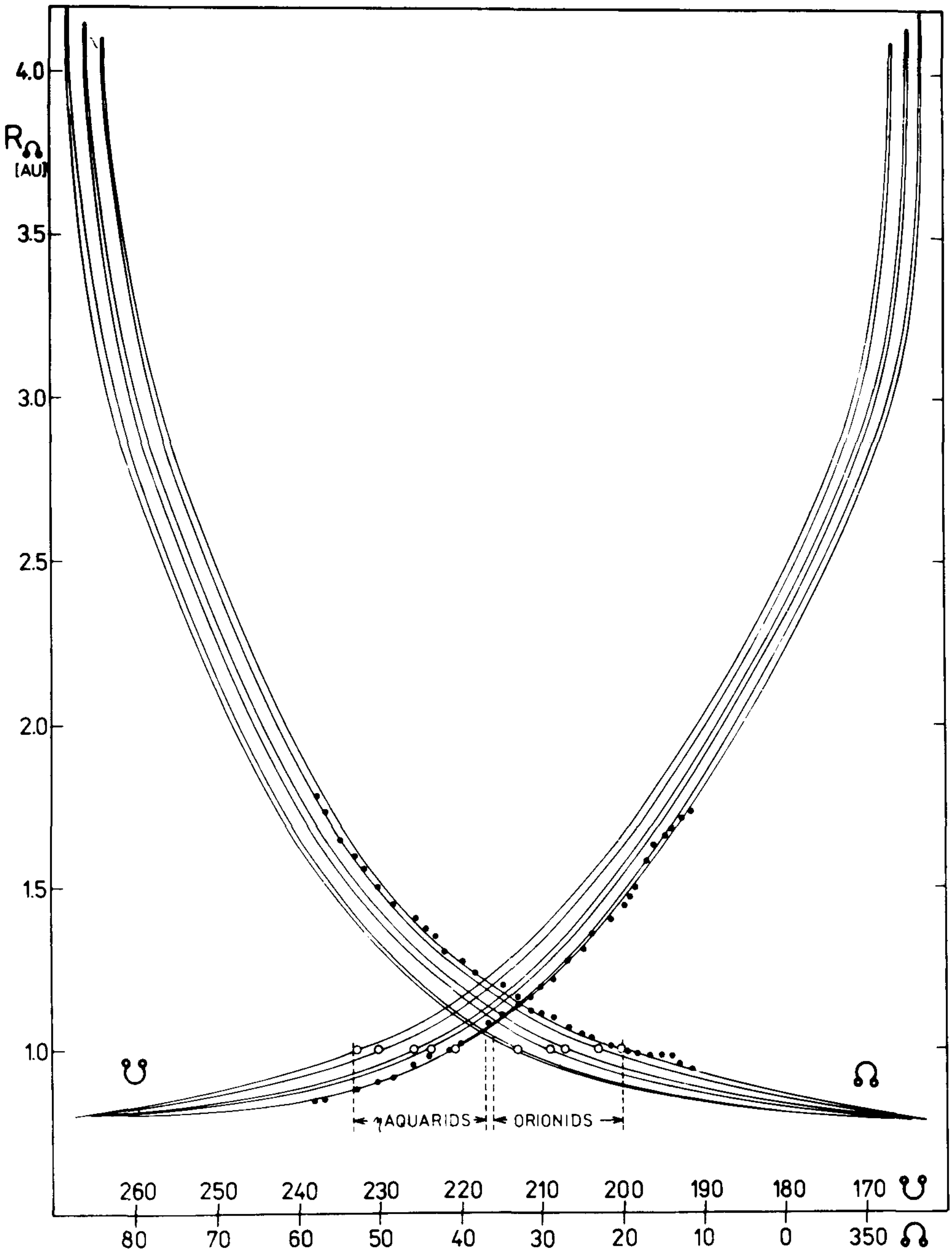

Figure 2. Three libration cycles of Comet Halley, reconstructed from meteor shower data and theoretical considerations. Circles: positions of particle concentrations at Earth's distance. Other designations as in Fig. 1.

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the stream, as stream filaments and activity changes, can also be better explained by the shell model of the stream than by a classical toroidal model. For details see McIntosh and Hajduk (1983).

It can be concluded that the structure of the observed meteor streams permits us to trace at least some characteristics of the orbit of comet Halley over a time span of about 800 revolutions. There is no observational evidence for an earlier orbital history, but the sequence of three full cycles gives some possibility to extrapolate the orbital evolution further backwards in time. If we assume that the change of Ω_{min} and Ω_{max} corresponds to the observed difference between the cycles, then the nodal distance of Ω_{max} has reached the orbit of Jupiter 8-10 cycles ago, giving a possible maximum lifetime of the comet in the inner Solar System of about 2 800 revolutions, or 200 000 years. Of course, the probability of a strong gravitational influence by Jupiter increases rapidly with the approach of nodes to the planet's orbit, which circumstance may considerably shorten the estimated maximum lifetime in the inner Solar System, starting with the capture of Comet Halley by Jupiter.

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DISCUSSION

D.K. Yeomans: Have you made an effort to include the ancient Chinese observations of the Orionid and Eta Aquarid meteor showers in your analysis ?

A. Hajduk: Yes. The ancient records collected by Imoto and Hasegawa (1958, Smithson. Contr. Astrophys., 2, 131) report conspicious meteor showers at solar longitudes (L_S) around the time of intersection of the Earth's orbit with that of the comet (between 401 and 934 A.D. for the Eta Aquarids at $L_S \sim 41^o$, with intersection between 530 and 607 A.D.; for the Orionids the intersection is too far back in time, between 836 and 763 B.C.). More details can be found in my recent paper in Asteroids, Comets, Meteors, Uppsala 1983, 425-429.

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