THE QUADRANTID METEOR STREAM: PAST, PRESENT AND FUTURE

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At the present time the orbit of the Quadrantid meteor stream not only intersects the orbit of Earth but also passes very close to the orbit of the planet Jupiter. This causes considerable perturbations. In a series of three papers (1,2,3) the authors replaced the myriad of meteoroids in the stream by ten test particles set at equal intervals of eccentric anomaly around the orbit. The equations of motion of these particles in the solar system were solved using a standard fourth order Runge-Kutta technique with self-adjusting step lengths. The orbits of the test particles were output at ten year intervals going back from the present to the year 300 B.C. and forward into the future to the year A.D. 3780.

The present day orbit of the Quadrantids was taken to have the following parameters:- argument of perihelion 170.4°, ascending node 282.46°, inclination 71.4°, eccentricity 0.681, perihelion distance 0.979 AU, aphelion distance 5.16 AU and period 5.38 y. These values were obtained by calculating the mean of a series of orbit measurements given in Poole et al., (4). The orbits of each of the test particles changed considerably as a function of time but it was found (1) that during a broad time interval 1100 - 1800 yr before the present, the stream had a different orbit from its present one, the approximate parameters being $\omega = 30^{\circ}$, $\Omega = 100^{\circ}$, $i = 12^{\circ}$, $e = 0.97$, $q = 0.09$ AU, $Q = 6.05$ AU, $P = 5.38$ y. The perihelion distance has increased greatly, as also has the inclination. The only parameter to remain reasonably constant during the perturbation is the semi major axis, at 3.07 AU.

A detailed investigation (2) of the short term variability of the orbital parameters indicated that their rates of change over the period A.D. 1830 - 2030 are $d\omega/dt = 0.0170^{\circ}y^{-1}$, $d\Omega/dt = 0.0049^{\circ}y^{-1}$, $di/dt = 0.0043^{\circ}y^{-1}$, $de/dt = -3.6 \times 10^{-4}y^{-1}$, $dq/dt = 0.0012$ AU y^{-1}. The reasonably constant semi major axis varied at 1.8×10^{-4} AU y^{-1} over this period. The values obtained using the modelling technique compare extremely favourably with those observed for the shower.

The minimum distance between the particle orbits and the orbit of the Earth was then calculated (3) as a function of time over the interval A.D. 1500 to A.D. 3500. The analysis indicated that the stream should

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have been first seen from Earth in the year A.D. 1870 $\pm$ 50 (it was actually first seen in January 1835). The meteoroids will have all been perturbed away from the Earth's orbit by the year A.D. 2190 $\pm$ 100.

The standard deviations of the observed orbital parameters of Quadrantid meteoroids about the mean values used for the present day orbit are quite considerable. Fig. 1 gives the distribution of the parameters of 57 accurate Quadrantid meteors obtained from observations taken by the Radio Meteor Project six station radar network at Havana, Illinois (Sekanina 5, 6). Fig. 2 illustrates the parameter distribution even more clearly. Our perturbation analysis indicates that the semi-major axis of a meteor stream particle remains relatively constant. The value the meteoroid has now is very close to the value it had immediately after release from the comet which was also very close to the value that the parent comet had at that time (7). This being so the large range of semi major axes of the Quadrantid meteoroids must be equivalent to the range of semi major axes of the comet orbit which must

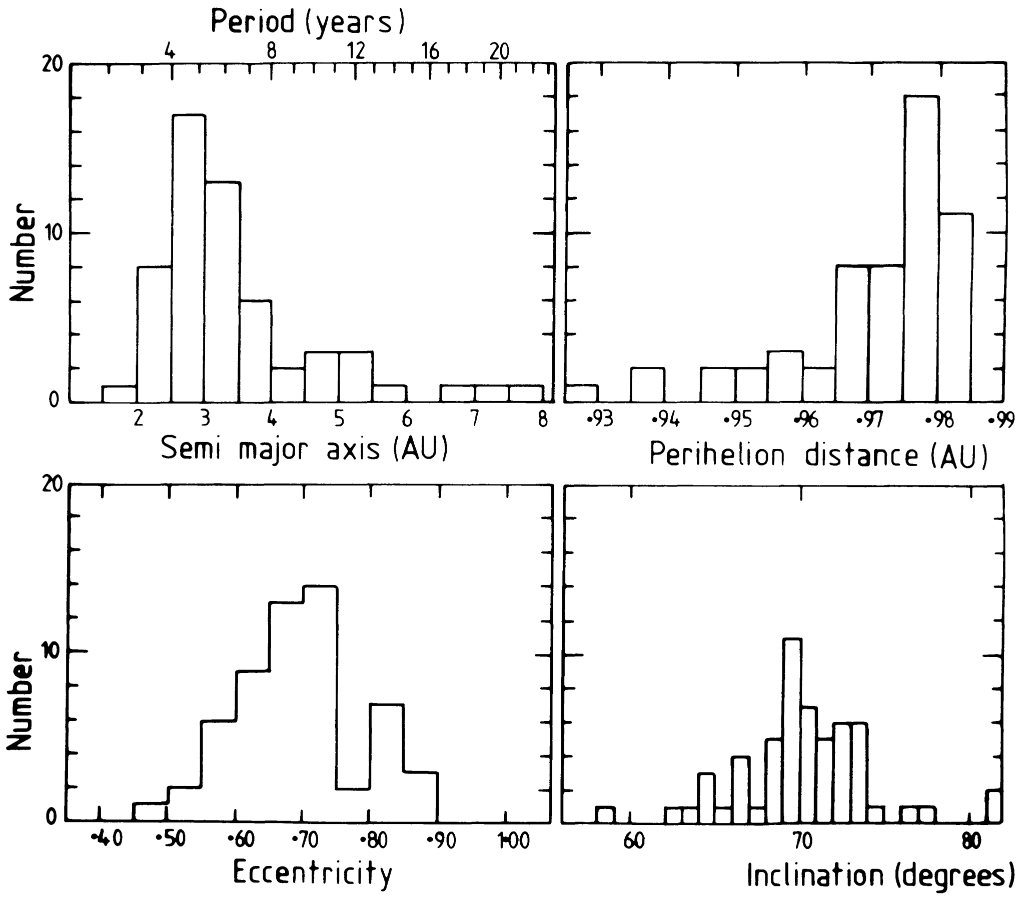

Fig. 1 The orbital parameters of 57 Quadrantid radio meteors observed in January 1962/3/4. (after Sekanina, 6).

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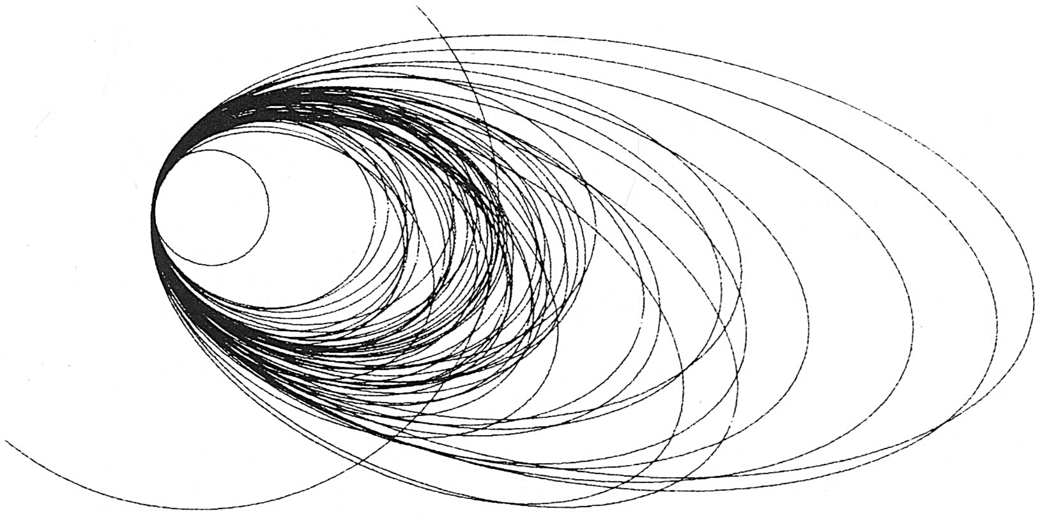

Fig. 2 The orbits of the 57 Havana radio Quadrantids. The observed values of ω, e and a have been used in plotting each orbit. The small and large circles represent the orbits of Earth and Jupiter respectively. Differences in inclination have been ignored. All the Quadrantid orbits have the same Ω.

have changed from about 7.7 to 1.9 AU or vica versa during decay and stream formation.

It is generally accepted that a comet will lose about 0.5 percent of its nucleus mass at each perihelion passage. The mean period of the orbits whose parameters are given in Fig. 1 is 5.36 y so the comet decay is expected to occur over a period of around 1100 y. One mechanism which is capable of introducing a large, ordered (as opposed to random walk) change in the semi-major axis of a cometary orbit is the 'jet effect'. If the cometary nucleus rotates and if there is a time lag between the absorption of the solar radiation by the dusty surface of the nucleus and the sublimation of the cometary ices the force exerted on the nucleus is non radial, lagging by up to 6°, giving a transverse force of about 10 percent of the radial force. If the nucleus has a direct rotation this transverse force increases the energy and the angular momentum of the orbit and both the perihelion distance and aphelion distance get larger. The opposite occurs for retrograde rotation.

Weissman (8) showed that for a comet with perihelion distance 0.09 AU and for non gravitational forces of 2×10^{-4}, 1×10^{-4}, 5×10^{-5} and 1×10^{-5} times the solar attraction, Δa^{-1} values of 1.8×10^{-3}, 8.9×10^{-4}, 4.6×10^{-4}, and 8.3×10^{-5} AU^{-1} per orbit are produced. The respective Δq values are 2.6×10^{-5}, 1.3×10^{-5}, 6.2×10^{-6} and 1.3×10^{-6} AU. To change the semi major axis from 7.7 to 1.9 AU with the Δa^{-1} values given above takes 220, 450, 860 and 4800 orbits respectively during which time the perihelion distance has increased by only 0.006 AU. The first of the orbit number values (220) ties in reasonably with the previous assumption that 0.5 percent mass loss occurs at each perihelion passage. Obviously a large mass loss is conducive to producing a large nongravitational force.

It may tentatively be concluded that during a broad time interval 1100 to 1800 years ago many of the Quadrantid meteoroids we see today had perihelion distances of about 0.09 AU. The Quadrantid comet decayed to form the meteoroid stream around that time. It took about 200 orbits to decay and due to a large non gravitational force acting on the nucleus the semi major axis changed from 7.7 to 1.9 AU during that time. However returning to the number versus semi-major axis plot shown in Fig. 1 it can be seen that about 68 percent of the mass loss occurs when the comet had a semi-major axis in the range $4.0 > a > 2.2$ AU.

Planetary perturbation similar to those detailed in Ref.1 have been responsible for changing parameters such as q, i and e. The spread produced in these values, as seen in Fig. 1 is due to the fact that meteoroids had differing eccentric anomalies and aphelion distances throughout their lifetimes. The differing eccentric anomalies are established extremely quickly for a meteor stream with a perihelion distance as small as 0.09 AU. It is shown in paper 1 that a complete loop of meteoroids is produced in a time between 35 and 12 y dependent on whether they have masses of 0.1 g or 2×10^{-4} g respectively.

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DISCUSSION

Reply to *Schmidt*: The equal steps in the curves for the orbital elements occur about every 59 years due to a commensurability of 5:11 between the Quadrantid meteoroids and Jupiter.

Reply to *Keller*: Because the meteoroids spent most of their life in orbits with inclinations around 70° the effects of Saturn, Venus, Mars, and even Earth are small compared with that of Jupiter.

Kresák: I think you should not attach too much weight to the convergence of the orbits 1700 years ago. Your test objects apparently have similar periods and amplitudes of long-period perturbations; under these circumstances some convergence must appear around the nearest turning points.
Hughes: I agree entirely; we are continuing to investigate this problem.