ON THE RELATIONSHIP BETWEEN COMET P/MACHHOLZ AND THE QUADRANTID METEOR STREAM

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The Quadrantid meteor shower has been recognized for more than 150 years. The dynamics of the corresponding stream is peculiar due to the high orbital inclination and, for some particles, the closeness of the 2/1 mean motion resonance with Jupiter. It has been the subject of many investigations relating to the structure of the stream and its nodal retrogression as well as its long-term history and its likely cometary origin. Thus Hamid and Youssef (1963) found that the jovian secular perturbations lead to very large changes in the inclination and perihelion distance of typical stream particles with a period around 4000 yrs. From a more extensive study by Williams *et al.* (1979) it was obvious that this period is not unique but may vary considerably between different particles. Related to this behaviour is also the investigation by Froeschlé and Scholl (1982) who performed an extensive study of three-dimensional orbits at the 2/1 resonance. The orbits remain confined in the resonance zone and are stable in Hill's sense. Close encounters with Jupiter are avoided through the action of three main protection mechanisms: σ libration around 0, ω libration aroud 90°, and e–ω coupling, although most orbits exhibit large variations in inclination and eccentricity. Investigating in more detail a Quadrantid-like meteor stream, Froeschlé and Scholl (1986) also found a non-uniform nodal retrogression and an unusual progression. This behaviour causes a formation of arcs which was not found for other meteor streams in resonance with Jupiter – however, almost never having large inclinations.

Babadzhanov and Obrubov (1987, 1989) studied the long-term evolution of the mean Quadrantid orbit, calculating the secular perturbations by the Halphen-Goryachev method. Interestingly, they found that the ecliptic cross-section of the stream formed by particles in all phases of the resulting q–i oscillation has four crossings with Earth's orbit. At each of these, particles can be encountered at both the ascending and descending nodes, so eight theoretical showers exist. Six of these were identified with showers listed on the basis of observed meteor statistics. Thus the Quadrantids, along with five other showers, can be argued to form part of one and the same meteor stream complex.

The parent comet of this complex was possibly not observed until quite recently. Comet P/Machholz (1986 VIII) currently has orbital elements that differ drastically from those of the Quadrantid stream, but its long-term orbital evolution has been found to involve large-scale oscillations in inclination and perihelion distance (Rickman and Froeschlé 1988). McIntosh (1990) drew attention to the fact that firstly, these variations are similar to those found for the Quadrantids by Hamid and Youssef (1963), and secondly, that the perihelion longitude of the comet is close to those of all the streams belonging to Babadzhanov and Obrubov's complex. So, conceivably, there could have been an epoch in the past, when the Quadrantid meteors were shed by comet P/Machholz into an orbit similar to that of the comet,

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later on to diverge from the cometary orbital evolution due to differential perturbations. Green *et al.* (1990) also commented upon this possibility as well as upon the discrepancy of about 180° in the longitude of the ascending node, which may appear embarrassing. To be precise, the meteor particles have to be ejected from the comet sufficiently far back in time that by now the nodal longitudes have taken two opposite values.

We have investigated the variation of the period of q–i oscillation between different meteor particles in relation to the hypothesis that the shedding of meteors occurred nearly 4000 yrs ago, when comet P/Machholz last had a very small perihelion distance. We have shown (Gonczi *et al.* 1991) that this hypothesis is viable in view of the ejection velocities typically expected and the resulting spread in the period of q–i oscillations, using purely gravitational 3-body integrations. The most promising range of semimajor axes is just inside the 2/1 resonance, and detailed study reveals many cases of chaotic behaviour due to close encounters with Jupiter. The spatial structure of the meteoroid complex originating from comet P/Machholz is thus likely to be very complicated with a broad range of semimajor axes involved and a concentration of the ascending nodes near 100° and 280° longitude. The currently observed Quadrantids belong to the second branch only, but each branch should include a wide range of perihelion distances for which the orbits are in general unobservable; *cf.* the above-mentioned Babadzhanov and Obrubov meteor stream complex. Babadzhanov and Obrubov (1991) argued that the complex can be understood on the basis of ejection from comet P/Machholz around 4500 B.C. – an epoch partly chosen for maximum orbital similarity between the comet and the Quadrantid meteors. Our results indicate that the same goal can be achieved even for an ejection epoch 2500 years later. However, investigating the detailed structure and evolution of the complex requires a more complete dynamical model than the one used here. Over several millennia the Poynting-Robertson effect will induce important reductions of orbital eccentricity and semimajor axis, and this is bound to have an important effect on the structure of the meteoroid complex. We are continuing our work along these lines.

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Discussion

C.Keay **– Do you see any possibility of a link between comets P/Machholz and P/Encke given the very large variability of the orbital elements of P/Machholz and its related meteor streams on a time-scale of the order of 5000 years?**

H.Rickman **– The variations that we see never put P/Maccholz or the test Quadrantids into an orbit very similar to that of P/Encke. If any relation exists between these two comet-meteor complexes thus appears highly uncertain at present. Further research might well reveal some as yet unexpected links, however.**

J.Fernández **– I wonder whether the Poynting-Robertson effect can destroy the meteor stream in a time span of several thousands years, bearing in mind the very small perihelion distance you mentioned.**

H.Rickman **– Tentatively, what happens for meteor ejection $\sim$ 4000 yrs. ago is that significant evolution towards decreasing a and e is expected. Thus, if the critical interval en a, where rapid $q - i$ oscillation occurs, would be passed too rapidly, the particles might not be able to reach the Quadrantid orbit in the given time. However, in reality this does not appear to be the case. One may also conjecture that particles ejected from P/Machholz at its second last minimum of q, more than 8000 yrs. ago, would by now have been affected to the level of no longer being recognized as Quadrantids, but this remains to be verified.**