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EVOLUTION OF THE QUADRANTID METEOR STREAM

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Abstract

According to the orbital calculations of Babadzhanov and Obrubov (1987), the last close approach of the Quadrantid stream with Jupiter occurred 3200 years ago at which time the parent comet of the stream may have been captured into its present short-period orbit. If this is the case the stream may be only a few thousand years old. We have modelled the evolution of the stream to determine if such a short time scale is consistent with the observed features of the Quadrantid/ δ-Aquarid/Arietid/Ursid complex. A detailed modelling of a stream consisting of 500 test particles released 4000 yr ago and which included the effects of the gravitational perturbations of 6 planets as well as the likely spread in the initial orbital elements resulting from the ejection of the grains from the comet was carried out. Our calculations indicate that an intense shower should be seen a few days before the Quadrantid shower and that 4000 yr is too short a period for the branch corresponding to the D-Arietid branch to appear. We have considered the quasi constants of motion 1/a and J, the Tisserand quantity, and find that the Ursids and the D-Arietids are unlikely to be members of the complex and that the complex is probably be less than 4000 yr old.

Introduction

The strength and short duration of the Quadrantid meteor shower indicate a relatively young stream since shower activity decreases with age and stream width increases as the result of gravitational and other perturbations. It is generally held that since meteor streams are produced by disintegration of comets, the birth of a stream corresponds to the capture of the comet into a short-period orbit by one of the major planets. For the Quadrantid stream the most likely perturbing planet is Jupiter. According to the calculations of Babadzhanov and Obrubov (1987), the inclination of the Quadrantid orbit has varied with a period close to 3500 yr. Using their orbital elements we find the last close encounter of the stream with Jupiter took place about 3200 yr ago as shown in Figure 1 below which shows how the minimum distance between the orbit of the stream and that of Jupiter has varied over the past few thousand years. The question arises whether the parent comet was captured at the last close approach or at some previous, more distant encounter.

In one of the most important papers in recent years dealing with the evolution of meteor streams, Babadzhanov and Obrubov (1987) showed that the Quadrantid stream is likely to be part of a complex of eight meteor streams which includes the D-Arietids, the N and S δ-Aquarids and the Ursids.

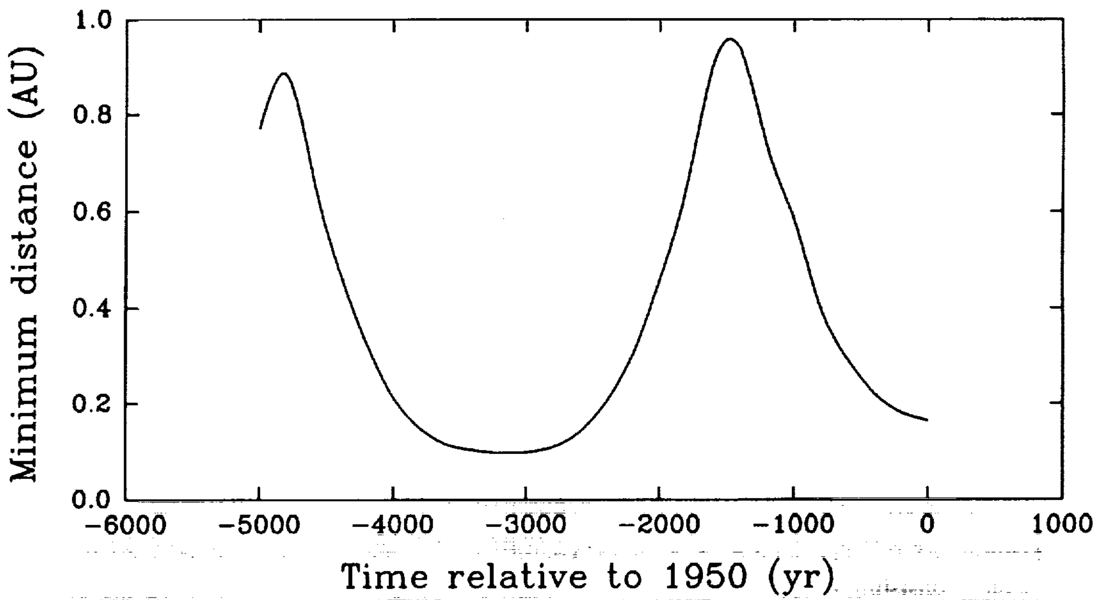

Figure 1. Closest distance between the Quadrantid stream and Jupiter's orbit in recent times based on the orbital calculations of Babadzhanov and Obrubov (1987).

The model

It is very difficult to estimate the orbit of a comet several thousand years ago if the present orbital elements are not known very precisely. We can be much more confident about the mean orbit of a meteor stream since, by definition, the small random-like perturbations resulting from the differing positions of the stream members have been averaged out and the "ring of mass" approximation for the perturbing planets should yield a good initial orbit for the stream. In the subsequent modelling of the stream the planets are treated as point masses traversing their present orbits. The motions of 500 test particles in the stream were calculated by integrating their equations of motion numerically taking into account the gravitational forces of the Sun, Venus, Earth, Jupiter, Saturn, Neptune, and Uranus. A simple fourth order Runge-Kutta integrator was used with the step length depending on the nearest perturbing body as described by Jones (1985). The starting orbital elements of the parent comet were taken as those given by Babadzhanov and Obrubov for 2050 BC. Test particles of mass 1g and density 0.8g/cm^3 were assumed to be ejected uniformly from the sunward side of the comet with velocities according to Whipple's (1951) formula. The present distributions of the nodes of these orbits are shown in Figure 2.

Discussion

The S and N δ-Aquarids are evident in the ascending and descending node plots as is the tight descending node loop close to New Year which Babadzhanov and Obrubov associate with the Quadrantid and the Ursid showers. There is no trace of the D-Arietids which should appear on the descending node plot early in June.

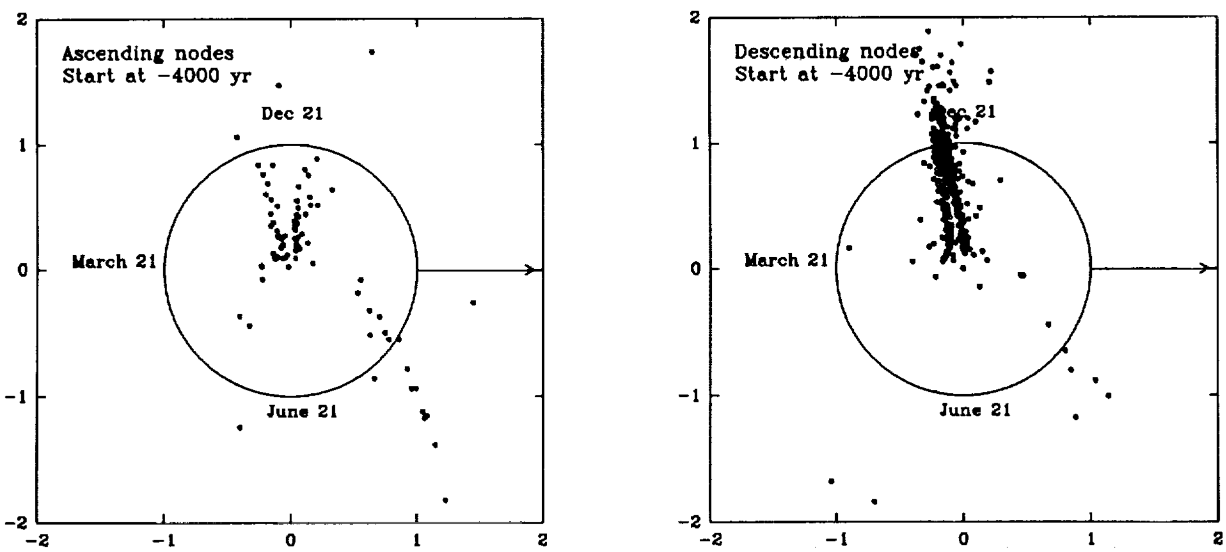

Figure 2. The present nodes for the model complex.

If the D-Arietids belong to this family of streams then the complex must be considerably older than 4000 yr. We therefore need some indicator of membership in the complex. We have chosen two well-known quasi-constants of motion: 1/a and J, the Tisserand quantity given by

$$J=\frac{a_J}{a}+2\cos(i)\sqrt{\frac{a}{a_J}(1-e^2)}$$

In Figure 3 below we have plotted the points corresponding to the various meteor showers concerned as well as the points corresponding to comets Tuttle and Machholz. Clearly the points for the δ-Aquarid and Quadrantid showers form a tight cluster as would be expected for members of the complex while the points for the Ursids and D-Arietids are well-separated from the cluster. We also note that out plot strongly supports the long-supposed association of the Ursid stream with comet Tuttle. Not only is the point for the D-Arietids far from the main cluster but its J value is >3 which implies that particles in this stream never make a close approach to Jupiter. We therefore conclude that neither the Ursids nor the D-Arietids belong to the Quadrantid complex.

McIntosh (1990) suggested both Comet 1491-I and Comet P/Machholz (1986 VIII) as possible parent comets for the Quadrantid stream. The orbital elements of comet 1491-I are uncertain and it is usually assumed to be in a parabolic orbit which would place it on the abscissa of Figure 3 and therefore far from the central cluster. However, the 1/a and J values for Comet P/Machholz are in excellent agreement with those of the cluster and therefore from this point of view it is a likely candidate for the parent comet.

Since the Ursids cannot be identified with the shower that would be active shortly before the Quadrantids, we must conclude that the complex has not yet developed to that stage and is therefore younger than 4000 yr, its birth probably corresponding to the last close approach of the stream to Jupiter 3200 yr ago.

Acknowledgments

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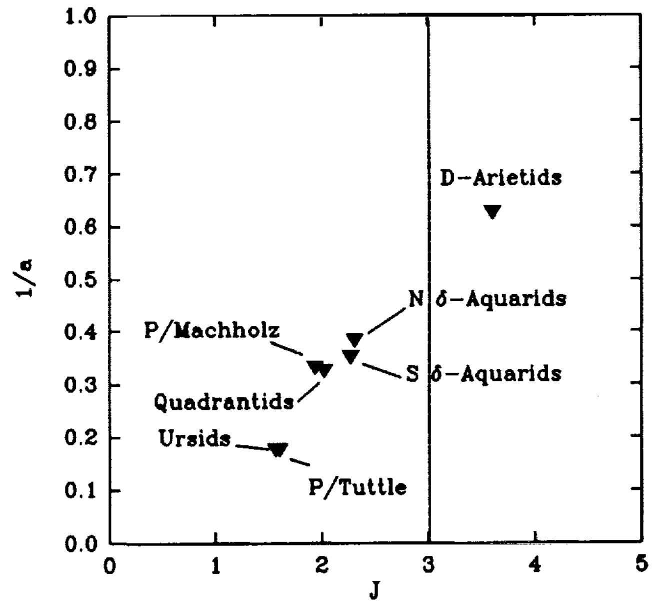

Figure 3.

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