# THE ORBITAL EVOLUTION OF THE PERSEID AND QUADRANTID METEOR STREAMS.

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## ABSTRACT

Some mathematical models of the formation of meteor streams are developed. Some of the testable predictions of these models are compared with observations.

## 1. THE PERSEID METEOR STREAM

In 1861 Daniel Kirkwood wondered; "may not our periodic meteors be the debris of ancient but now disintegrated comets, whose matter has become distributed round their orbits." ( see Brandt and Chapman (1982) ). In July of the following year a new comet was discovered, on an Earth crossing orbit, which was designated 1862 III P/Swift-Tuttle. Between 1864 and 1866 Giovanni Schiaparelli was able to compute the orbits of some of the meteoroids in the Perseid meteor stream. It soon became apparent that these particles had very similar orbits to this new comet, thus confirming the correctness of Kirkwood's conjecture.

Starting from the orbit determined from the 1862 observations, Marsden (1973) calculated the orbital evolution of Swift-Tuttle in an unsuccessful attempt to link the 1862 orbit with earlier recorded cometary apparitions. A forward integration by Yeomans (1972), which included the effects of all nine planets, predicted that the comet should return to perihelion on June 30th 1981. It has yet to be spotted despite intensive searches. Non-gravitational forces, which are observed in many comets, could be responsible for these anomalies. Whatever has happened, the parent comet should be in the vicinity of perihelion at sometime close to the present time.

The Perseid / Swift-Tuttle orbit does not evolve rapidly in time, indeed it is an incredibly stable orbit. Hughes and Emerson (1982) have estimated from observations that the ascending node of the Perseid stream is progressing by only $(38 \mp 27) \times 10^{-5}\ {}^\circ\ \mathrm{yr}^{-1}$, an order of magnitude less than any other stream. The antiquity of the Perseid shower, it was first



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observed in AD 36, confirms that the stream has remained on an Earth crossing orbit for a considerable time and hence is very stable. Celestial mechanics also predicts slow evolution. The high inclination of the stream, about 114°, means that it can only be in the vicinity of perturbing planets at its nodes, but there are no major planets near these points. Therefore it can be concluded that there is a comet with a poorly determined future on a very stable Earth crossing orbit. This might be slightly worrying as the chances of a collision between this comet and Earth must be quite high. If the Tunguska event is typical of such collisions then this must be very worrying indeed. ( see Turco et al (1982) )

Many authors have predicted that the activity of the Perseid shower should increase as its parent comet returns to perihelion surrounded by a dense swarm of recently ejected particles. By observing changes in the flux rates of the Perseid shower it might be possible to get a fix on the approximate whereabouts of the parent comet. Due to its extreme stability, the early lives of particles ejected from Swift-Tuttle into the Perseid stream can be determined ignoring planetary perturbations.

Whipple (1951) gives the following expression for the ejection speed of dust from the nucleus of a comet

$$c = \left[ \frac{1}{n\, s\, \rho\, r^{9/4}} - 0.013\, R_c \right]^{1/2} R_c^{1/2} \times 656 \text{ cms}^{-1} \quad (1)$$

where $R_c$ is the radius of the nucleus of the comet in km, $1/n$ is the fraction of solar radiation utilised for sublimation and $s$ and $\rho$ are the radius and density of the spherical dust particles in cgs units. Whipple (1978), states that a typical value for the radius of a cometary nucleus is about 1km. A value of 1 for n will be used here. Following Plavec (1955), if a particle is ejected with velocity c from a comet while it is in the vicinity of perihelion $r_o$, then the resulting overall particle velocity v can be split into components given by

$$v_r = c_r$$
$$v_u = v_o + c_u$$
$$v_b = c_b$$

where $c_r$ is in the direction of the comet's radius vector, positive away from the Sun, $c_u$ is tangential to the orbit, positive in the direction of motion and $c_b$ completes the right handed set. The orbital speed of the comet at perihelion being $v_o$, therefore

$$v^2 = v_o^2 + 2\, v_o\, c_u + c^2.$$

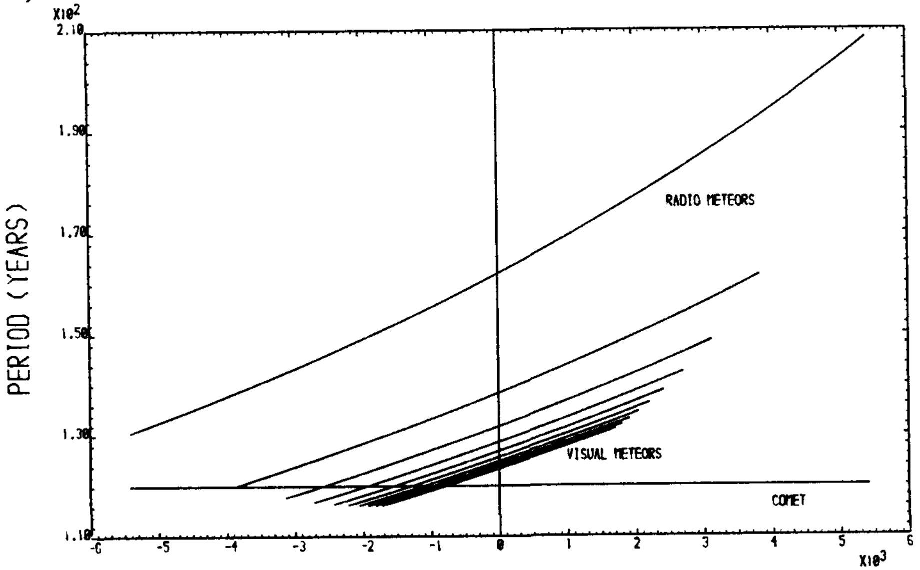
At this point Plavec, ignorant of the effects of radiation, related the semi-major axis of the parent comet's orbit to that of the new orbit taken up by the ejected particles. Therefore correcting this omission one gets

$$a = \frac{\mu'}{v^2 - 2\mu'/r_o}$$

where a is the semi-major axis of the new orbit taken up by the ejected particle and $\mu' = GM_o(1 - \beta)$ with $\beta$ given by

$$\beta = 5.74 \times 10^{-5} Q_{PR}\, s^{-1} \rho^{-1}$$

where $Q_{PR}$; the radiation pressure efficiency factor, is a number that in most cases is close to unity. However c is given for any $\beta$ by equation (1) and depending upon the direction of ejection $c_u$ can take on any value in the range (-c,+c). The period of the ejected particle is given by $P = 2\pi (a^3/\mu')^{1/2}$.




EJECTION SPEED (CM/S)
THE PERSEID METEOR STREAM

Figure 1 is a plot of ejection speed against the subsequent periods of particles ejected from comet Swift-Tuttle. The 120 year period of this comet also being indicated on this figure. The particles are taken as having ten evenly spaced $\beta$ values between those corresponding to the approximate observed spread of the small radio meteors and the larger visual meteors. The curves are asymmetrical about the parent comet's period. This is because radiation pressure, which always increases the period of the ejected particles, is competing with the ejection velocity effects which can either increase or decrease the period. If all directions of ejection are equally likely then there will always be more particles behind the comet than ahead of it. There are always some particles that have been ejected so that their period differs from that of the parent comet by at least one year. Therefore Earth will always encounter a dense swarm at least once while the comet is close to perihelion. This is substantiated by the increased flux of Perseid meteors observered the last time Swift-Tuttle was at perihelion; in 1862.

Russel (1982) reckons that the flux of Perseid meteors peaked in 1980, as his photographic observations since 1977 show double the flux of meteors in 1980 compared with the years either side of this date. This means that it is possible that Swift-Tuttle has been missed altogether this time around and will not be seen again for a further 120 years.

## 2. THE QUADRANTID METEOR STREAM

The Quadrantid meteor stream is undergoing substantial evolution due to its close proximity to Jupiter's orbit. This means that the model just used to describe early evolution of particles ejected from a comet is no longer applicable as Jovian perturbations will now considerably effect such evolution.

Unfortunately there is no known comet associated with this stream. This could be due to two things; either the parent comet had a close approach to Jupiter and was ejected from the solar system leaving behind just its trail of debris or the comet disintegrated entirely to leave no visible trace. This fact makes modelling the early evolution of the stream rather awkward! However, by calculating the mean behavior of the stream in the past, a suitable type of orbit for such a comet can be determined and used for such modelling. Starting from the observed mean orbit as given by Poole et al (1972), Williams et al (1979) placed ten particles at equally spaced intervals of eccentric anomaly around this orbit and from this starting configuration, then integrated the equations of motion of these particles moving through the gravitational fields of the Sun, Earth and Jupiter, over the time period from 300 BC to 3780 AD. Therefore to model the formation and subsequent evolution of the stream some time has to be chosen to place a comet on this calculated mean orbit. By considering the observed mass-segregation in the stream, Fox (1982) has deduced that the stream is about 1000 years old. However computing restraints have limited the period of integration to just 500 years. Starting from the mean orbit of 500 years ago, a theoretical comet placed at the perihelion of this orbit ejected twenty particles in random directions but with ejection speeds given by Whipple's formula; equation (1). Ten of these particles had $s= 0.22$ cm and $\rho= 0.3$ g/cm$^3$ corresponding to visual meteors, while the other ten had $s= 0.035$ cm and $\rho= 0.8$ g/cm$^3$ corresponding to radio meteors. The equations of motion of these twenty particles were integrated numerically back to the present time. Radiation pressure and drag as described by Burns et al (1979) were included in the model. The initial comet orbit is illustrated in figure 2 and the final stream orbit in figure 3.

An observer on Earth only sees a meteor when a meteoroid burns out in Earth's atmosphere. This can only happen at the appropriate node of the meteoroid's orbit as these are the only points where the meteoroid crosses the ecliptic. For the Quadrantid stream, the descending node is the one in the vicinity of Earth's orbit, so it is instructive to look at the evolution of this node with time. This evolution is shown in figure 4.

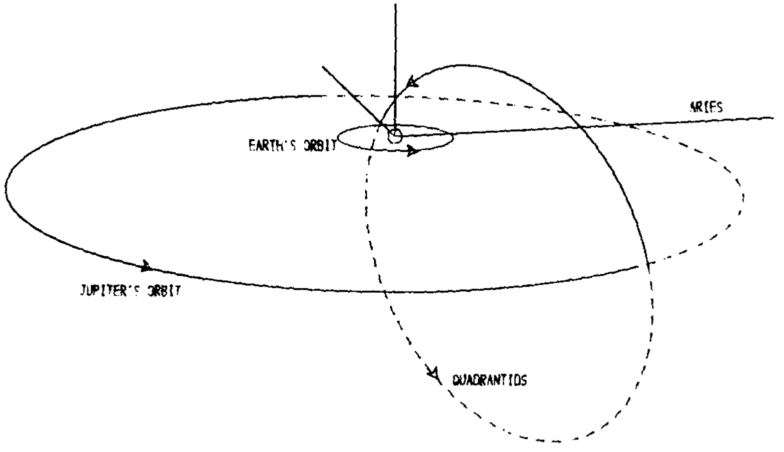



Figure 2. The initial Quadrantid orbit.

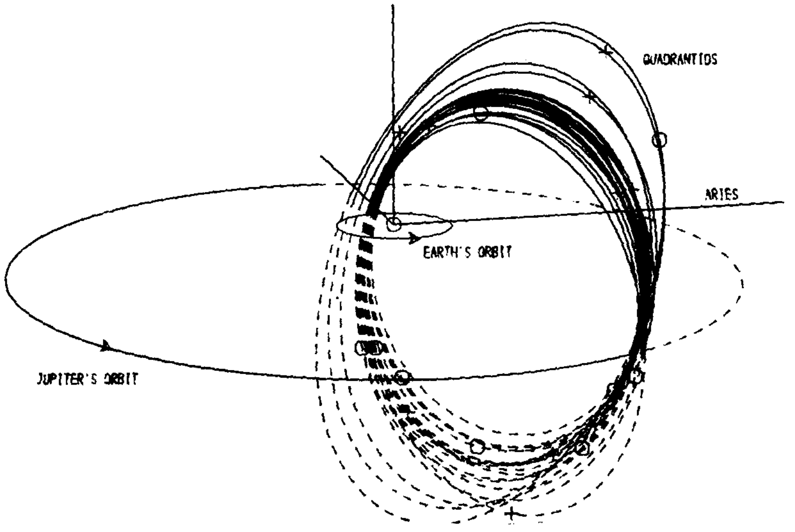



Figure 3. The final Quadrantid orbits.

It is immediately seen that a long, thin stream cross-section develops. The stream does not spread out much along Earth's orbit but it does spread out considerably in the solar direction. This situation is necessary in order that theory and observations should match. The

Quadrantid shower is an extremely short shower, it only lasts for about one day. This vindicates the shortness of the theoretical stream along Earth's orbit. Jovian perturbations are causing the stream to be swept across Earth's orbit at a great rate and as the shower has been observed since 1835 the observations imply that the stream should be spread out by a much greater amount in the solar direction than it is along Earth's orbit Earth would pass through this theoretical shower in a time of about 18 hours. It would reach the centre of the radio shower about four hours before it reached the centre of the visual shower. Poole et al give three values for the observed visual stream width of 8 hours, 17 hours and 24 hours, while for the radio stream they give a width of between 3 hours and 29 hours. Hughes et al (1981) give a value of fourteen hours as the time between the peaks of the visual and radio meteors.

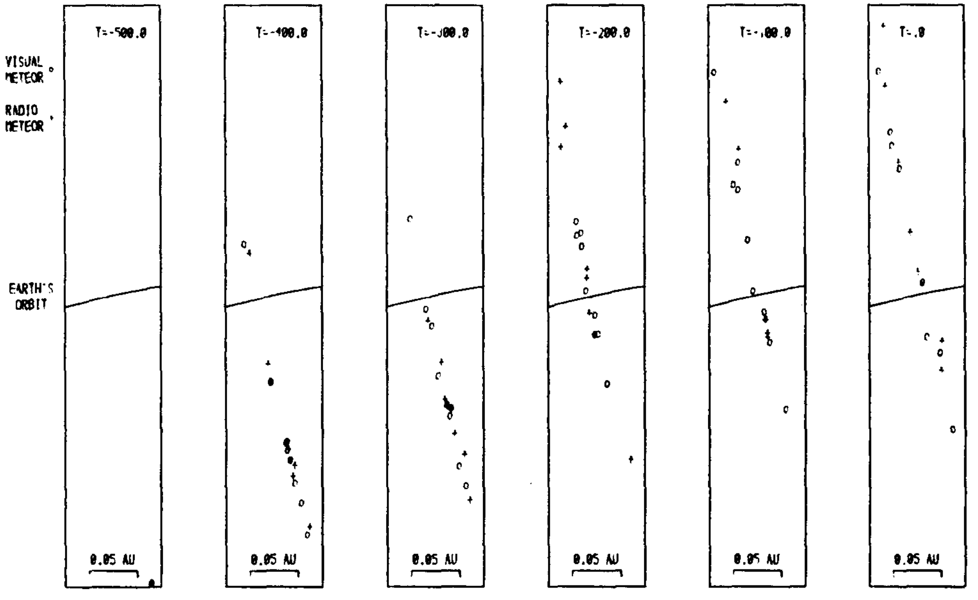



Figure 4. The evolution of the Quadrantid ascending node.

It is also noticable that in the short time that the integration has been carried out that a continuous loop of meteoroids has formed around the stream. This is in contradiction to early theories that only took into account the effects of ejection velocities and ignored radiation effects. Both radiation and Jovian perturbations are important in spreading particles around the Quadrantid stream. Thus it is no longer correct to assume that a regular meteor shower is produced by a very old stream, it can in fact be produced by a relatively young one.

REFERENCES.

Brandt, J. C. and Chapman, R. D. : 1982, Introduction to Comets, CUP.

Burns, J. A., Lamy, P. L. and Soter, S. : 1979, Icarus, 40, 1.
Fox, K. : 1982, PhD Thesis, London.
Hughes, D. W. and Emerson, B. : 1982, The Observatory, 102, 39.
Hughes, D. W., Williams, I. P. and Fox, K. : 1981, Mon. Not. R. astr. Soc., 195, 625.
Marsden, B. G. : 1973, Astron. J., 78, 654.
Plavec, M. : 1955, Bull. astr. Inst. Csl., 6, 20.
Poole, L. M. G., Hughes, D. W. and Kaiser, T. R. : 1972, Mon. Not. R. astr. Soc., 156, 223.
Russel, J. A. : 1982, Sky and Telescope, 63, 10.
Turco, R. P., Toon, O. B., Park, C.,Whitten, R. C., Pollack, J. B. and Noerdlinger, P. : 1982, Icarus, 50, 1.
Whipple, F. L. : 1951, Ap. J., 113, 464.
Whipple, F. L. : 1978, 'Comets' in 'Cosmic Dust' ed McDonnell, J. A. M., Wiley, New York.
Williams, I. P., Murray, C. D. and Hughes, D. W. : 1979, Mon. Not. R. astr. Soc., 189, 483.
Yeomans, D. L. : 1972, Computer Sciences Corporation Report, 9101-11200 -01TR.