Physics, Chemistry, and Dynamics of Interplanetary Dust
ASP Conference Series, Vol. 104, 1996
Bo A. S. Gustafson and Martha S. Hanner (eds.)

Modelling the Orbital Evolution of the Perseid Meteoroids

J. Jones and P. Brown

Department of Physics, University of Western Ontario, London, Ontario N6A 3K7 Canada

Abstract. We have modelled the evolution in the distribution of orbits of 1.5×10^6 particles released at the 1862, 1737 and 1610 apparitions of 109P/Swift-Tuttle for a range of particle masses and for a range of ejection angles about the comet-solar line. The evolution of the stream is dominated by the influence of planetary perturbations, most notably those due to Jupiter. A periodicity of approximately 12 years in Perseid activity is noted in the material ejected during the 1862 apparition. Without Jovian perturbations, the nodes of these recently released Perseid particles would not cross the Earth's orbit. Activity from 1862 is notable in the simulations for 1991–1994 and also for the early 1980's. Ejections in 1737 and to a lesser extent in 1610 contribute material seen at the Earth in the late 1980's.

1. Introduction

The evolution of meteor streams has been investigated extensively (Williams et al, 1979; Hughes et al, 1981; Gonczi et al, 1992; Jones and Jones, 1993) using numerical modelling with varying degrees of success. Most studies have been based on Whipple's (1951) comet model. According to this model, the gas produced as the cometary material sublimes in the vicinity of the Sun carries the solid grains that were previously trapped within the cometary ices away from the nucleus. The process has been studied by many authors (Whipple, 1951, Hughes, 1977) who all obtain similar estimates for the speed to which the solid grains are accelerated as a result of the gas pressure.

The Perseid shower has been notable for its constancy and it was therefore surprising when in 1988 a second peak in the activity was observed (Roggemans, 1989) rich in bright meteors (cf. Xu, 1992). The new peak occurred about 12 hours before the traditional peak and has been seen every year since when good visual data has been obtainable (Koschack and Roggemans, 1991; Koschack et al., 1993; Rendtel, 1993). In the early 1990's, the new peak was such that for visual meteors it was several times stronger than the usual peak. The burst of activity associated with the new peak is short - it lasts for 1–2 hours so that it goes unobserved over much of the Earth. The aim of this paper is to try to use the observations of the new peak to estimate both the density of the grains as they leave the comet and the distribution of directions of the ejection velocities of the grains and to better understand the origin and nature of the current series of Perseid outbursts.

2. Method

For ejection speeds greater than a few metres per second the effect of the comets gravitational attraction can be neglected and Whipple's (1951) formula for the grain ejection speed as modified by Jones and Brown (1995) was used. The radius of 109P/Swift-Tuttle was set at 7 km.

We took the grain ejection direction distribution to be uniform over a cone whose axis was aligned with the comet–Sun radius vector. It was not clear what the cone angle should be since Whipple assumed the ejection to be uniform over the sunlit hemisphere while, as noted by Williams and Wu (1993), the Giotto images of comet Halley seem to indicate fairly narrow direction distributions - possibly as narrow as $20° - 30°$. We therefore regarded the cone angle as a variable to be determined from the fit of the observations to the theory. Meteoroids were ejected at points randomly distributed in true anomaly along 109P/Swift-Tuttle's orbit interior to 2.3 A.U. from the sun.

Having set the initial conditions for each test particle, we integrated each meteoroid forward in time taking into account the gravitational forces of 6 planets (Venus, Earth, Jupiter, Saturn, Uranus and Neptune) as well as radiation pressure and the Poynting-Robertson Effect as described by Jones (1985). For each simulated run we ejected 10^4 test particles in 50 mass categories spaced equally in Log(mass)from 1 g to 10^{-5} g for a total of 5×10^5 particles from each of the 1862, 1737 and 1610 perihelion passages.

3. Results and Discussion

We began by assuming nominal values for the grain density of $\rho = 800\mathrm{kgm}^{-3}$ and a value for the cone angle of 90°. By selecting those orbits from particles ejected in 1610, 1737 and 1862 for which the descending nodes fell within the range 1.012 – 1.015 AU, we were able to obtain a quantitative prediction of the variation of the activity over several decades and this is shown in Figure 1. Keeping in mind the statistical fluctuations associated with the relatively small numbers involved per year in the simulated data (typically 60 per year out of the initial 10^4 in any mass interval), it is clear that strong activity is predicted throughout all mass categories and particularly at larger masses beginning in 1991 and ending in 1994. This is entirely due to the ejecta from 1862 which also is responsible for activity in the early 1980's. The weaker activity seen from 1987–1989 at large mass alone is due exclusively to 1737 and 1610 ejecta with no contribution from 1862.

It is important to note that visual meteor data from the new peak included a large number of bright meteors. This matches our predictions for the early 1990's with the nominally chosen values for density and cone angle quite well. If we make the cone angle much smaller than isotropic or hemispherical ejection we find that a large number of meteoroids are encountered in 1994 – almost an order of magnitude more than in any of the years 1991–1993. Since the observations do not support such variability in the flux over these years, it is unlikely that such small cone angles can be supported by the current model. Small cone angles with meteoroid densities of 0.4 and 1.6 gcm^{-3} also produced similar results.

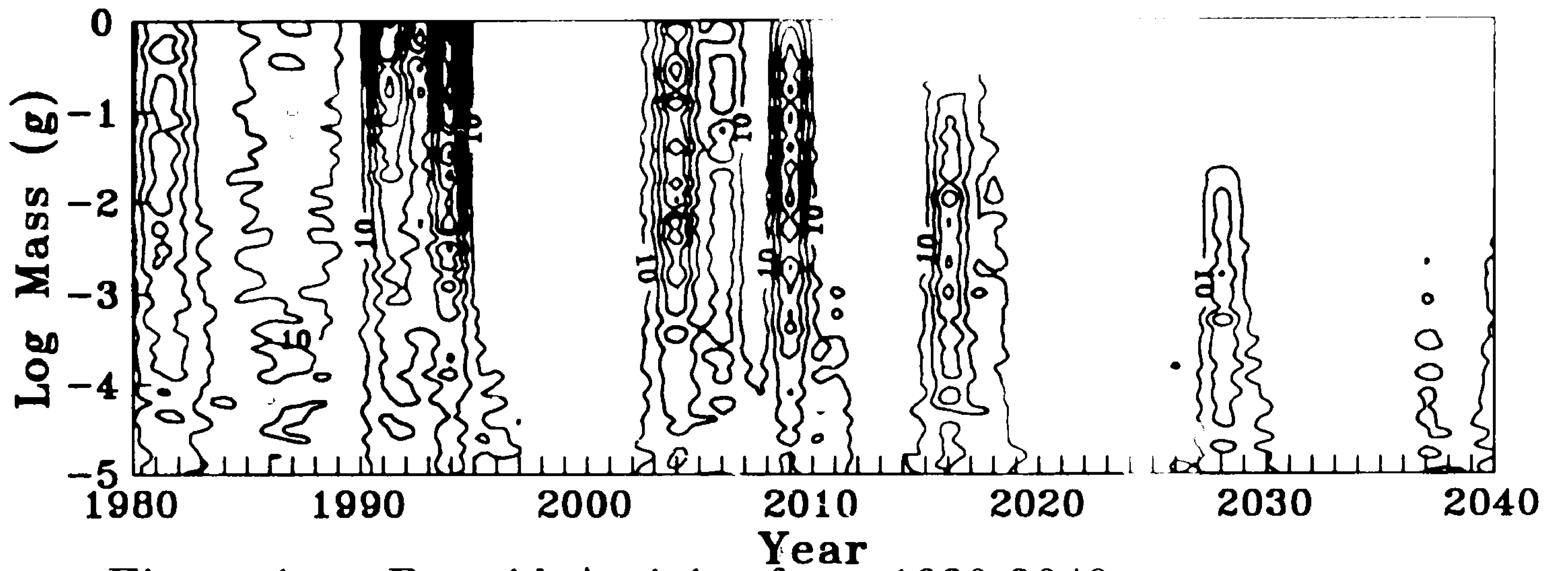

Figure 1. Perseid Activity from 1980-2040.

The final distribution, however, is less dependent on meteoroid density for a chosen cone angle. The effect of lowering density is to raise the ejection velocities in any mass category and since radiation forces are very small for Perseid meteoroids in the visual range, the net effect is to shift the distribution upward and vice versa for higher densities. Note that if the meteoroids are non-spherical the effect on the ejection velocity is equivalent to lowering the density (Gustafson, 1989). The available observations are not able to distinguish the subtle change in the final results for simulations with meteoroid densities of 0.4 or 0.8 gcm^{-3}; for 1.6 gcm^{-3} there is a probable overabundence of faint meteors predicted by the model which is not supported by TV or radar observations (Hawkes and Flemming, 1995; Watanabe, 1993).

We were also able to determine the solar longitudes of those particles which were close to the Earth's orbit and these are shown in Table 1. For the larger particles the distribution of solar longitudes was about 0.05° wide to half-maximum strength roughly corresponding to a burst of shower activity of about 1 hour as observed for the new peak. Generally, the predicted times for maximum for the outbursts are in close agreement with the observed times. For 1994 in particular, the predicted maximum is about 2 hours earlier than was observed. This is a problem which we have not been able to resolve but which may be due to such factors as the rotation of the comet and the location of the active areas on the cometary surface. This trend was also noted to a greater degree by Williams and Wu (1994) in their simulations. For the smaller secondary peak in activity from 1987–1989 resulting from 1737 and 1610 ejecta, the observed and simulated maxima times agree within the error margins, though these error limits are necessarily larger due to the smaller numbers of meteoroids involved.

4. Conclusions

We find that the current activity of the Perseid stream is well represented by an ejection model using a cone angle of 90° and a meteoroid density in the range of $0.4 - 0.8 gcm^{-3}$. The resulting activity profiles agree well with those observed from 1991–1994 and suggest that this activity is due to ejecta from 1862. Lesser levels of enhanced activity are predicted for large visual-sized particles in the interval 1986–1989 in general accord with visual observations of an early secondary maximum in Perseid activity in the 1980's. The predicted

Table 1. The theoretical solar longitude (2000.0) of maximum, λ_{th}, for the new Perseid peak compared to the corresponding observed solar longitude, λ_{obs}. The observational data are from visual observations obtained by the International Meteor Organization. No usable visual data are available for 1990 due to the presence of a full moon and few contributing observers.

Year	λ_{th}	$\pm\lambda_{th}$	λ_{obs}	$\pm\lambda_{obs}$
1988	139.67°	0.03°	139.7°	0.1°
1989	139.64°	0.04°	139.6°	0.1°
1991	139.54°	0.04°	139.58°	0.005°
1992	139.51°	0.04°	139.50°	0.04°
1993	139.44°	0.05°	139.535°	0.005°
1994	139.45°	0.04°	139.595°	0.007°

times of maxima for 1993 and 1994 are significantly different than those observed and cannot be fully explained at present.

From the model results we predict that Perseid activity associated with the new peak will decrease in 1995 and should not be present to any significant degree after 1996. A final corollory of these results is that Perseid activity should again increase due to 1862 ejecta starting in 2003 and lasting through to 2010.

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