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Formation of the Leonid Meteor Stream and Storm

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Abstract

It is well known that some meteor showers display a very high level of activity at certain times, the most famous being the Leonid shower with very spectacular displays at roughly 33 year intervals. This period being also the period of the parent comet of the stream, Comet Tempel-Tuttle. An investigation of the geometry of the comet and the Earth at the time of each high activity occurrence by Yeomans (1981) suggests that most of the meteoroids are found outside the cometary orbit and lagging the comet.

In this paper we simulate the formation process of such a stream by numerically integrating the orbits of dust particles ejected from the comet and moving under the influence of gravity and radiation pressure. The intersection of these dust particles with the Earth is also considered and it is concluded that about 12% of the ejected particles may be observed and that of those observable, 63% will be outside the cometary orbit and behind the comet.

1. Introduction

The Leonid meteor shower is one of the most famous meteor showers because of its very spectacular appearance, at periodic intervals, especially in 1799 and 1833. Newton (1863,1864) and Adams (1866) suggested that the orbital period of whatever phenomenon was responsible could be about 33.25 years. Comet P/Tempel-Tuttle (or 1866 I) was discovered by both Tempel and Tuttle in 1866, and, because of its orbital similarity to the Leonids, is considered the parent comet of the stream (eg. Schiaparelli, 1867). The period of comet Tempel-Tuttle is 33.3 years. After its 1866 discovery, two returns were not seen, but on June 30, 1965, the comet was recovered by Schubart (1965). By using Whipple's model for the ejection of dust from comets (Whipple, 1951) McIntosh (1973) investigated the orbital evolution of particles in three mass intervals, at 1g, 0.1g and 0.01g. and compared the results with radar observations of the stream over a 10 year interval. Yeomans (1981) showed the empirical distribution of dust surrounding Comet P/Tempel-Tuttle by analyzing the associated Leonid meteor shower data over the interval 902-1969. He found that the majority of the particles observed were located at a position outside the comet and lagging behind it. Essentially, this information concerning the location of the meteoroids is given as Fig.1. It should be stressed that this gives information onwhere the Earth was when stream activity was detected. It says nothing about the situation where the Earth has not been.

The non-gravitational effects required to explain the deviation of comet Tempel-Tuttle from pure gravitational motion implies a preferential ejection of gas and dust in the solar direction, resulting in the particles subsequently being found inside the original orbit and ahead of the comet. Yeomans therefore concluded that radiation pressure and planetary perturbation, must play an important part in the dynamic evolution of the Leonid meteoroids and it is interesting to enquire how these effects of planetary perturbations and radiation pressure affect the orbital motion so as to place the meteoroids in locations opposite to what was expected. We will also discuss the selectivity of the observation (Babadzhanov and Obrubov, 1987).

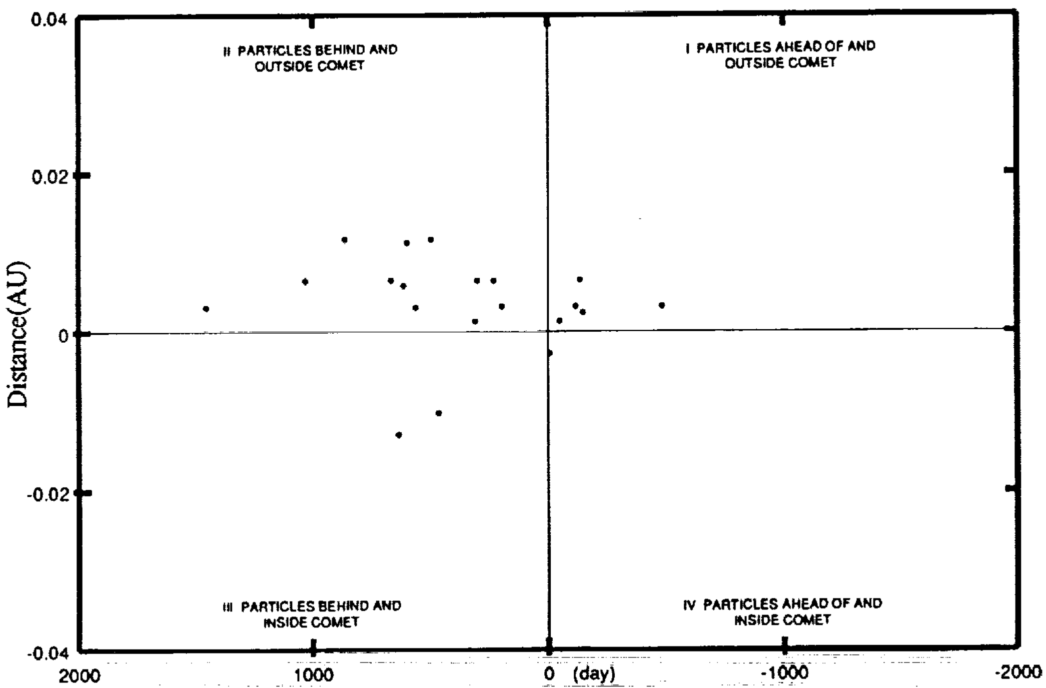

Figure 1 Meteor particles surrounding the comet

2. The Model

In our model, we assume that meteoroids are ejected from the cometary nucleus in directions which makes angles of 0°, in steps of 30° up to 330° with the direction of motion of the comet. For simplicity, all ejection is assumed to be in the orbital plane of the comet. Three different masses are taken for the meteoroids, 0.01g, 0.1g and 1g.The ejection speed is given by Whipple (1951). The meteoroids move under the gravitational field of the sun, weakened by radiation pressure.The effect of such weakening is to increase the dimensions of the meteoroid orbit as was first pointed out by Kresakova (1974). The ratio of the magnitude of the solar force due to radiation and gravity on the particle is $5.74 \times 10^{-5}/s\rho$ (in *cgs* systems). Perturbations due to Jupiter, Earth, Saturn and Uranus are included, those due to the other planets being insignificant. As the orbit of the comet in 1699 was integrated backward numerically by a single orbit generated from observations in 1965 and 1866 (Yeomans, 1981), we chose 1699 as the epoch of simulation. The initial positions of the planets are determined by empirical formula (Escobal, 1968).The equations of motion of each of the meteoroids were numerically integrated using an improved Runge-Kutta-Nystrom method (Dormand et al, 1987) and integration was performed over an interval of 266 years, or eight cycles of the Comet Tempel-Tuttle.

3. Results

3.1 Initial distribution.

The principal phenomena of interest in this paper is the distribution of meteoroids in relation to the comet, particularly when the comet is close to the the descending node, since this is when the meteors are seen, and, in order to compare with observations we require the time difference at nodal passage and the heliocentric distances at this epoch. From the model, we find for small particles with mass 0.01g, radiation pressure plays an important initial role, making the semi-major axis 2.5% larger and introduces a delay of about 490 days in the nodal passage time after one orbital period. In contrast, for the largest meteoroid size investigated, the increase in semi-major axis is only about 0.23% and results in a nodal passage delay of only about 43 days.

3.2 The final distribution

After the meteoroids are ejected, their evolution is affected by planetary perturbations. The effects of perturbations are harder to predict in a simple way and can only be determined from the numerical integration. It is also hard to disentangle the perturbational effects from that of the initial conditions, since both are present in the final distribution. However, some insight can be gained by comparing the initial and final distribution for a given meteoroid size and by comparing the final distribution for different meteoroid sizes. Fig 2 gives the final distribution in terms of the distance from the meteoroid to the comet and the time difference between particles and the comet at node for the larger meteoroids.

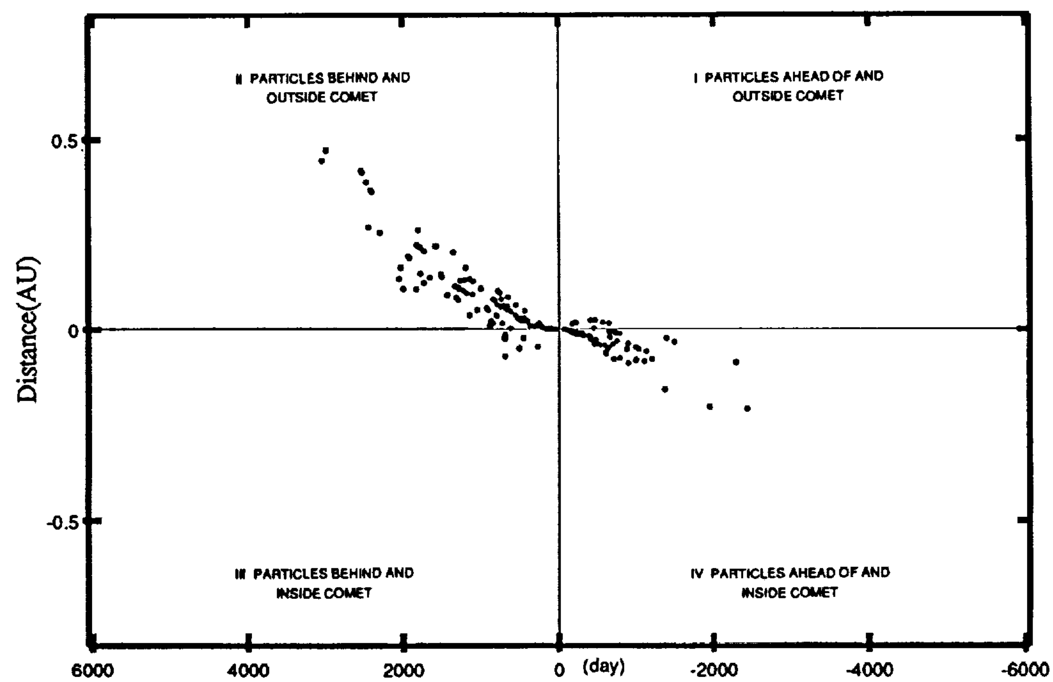

Figure 2 Final distribution of the particles surrounding the comet after the perturbation

From the computational results, which for brevity are not given here, the following general conclusions can be reached:

1° All meteoroids found in Quadrant I and III (ahead and outside or behind and inside, see Fig 2) are there because of the effects of planetary perturbations;

2° Though individual meteoroids may deviate by a largely amount from the initial configuration through the effects of planetary perturbation, the majority remain concentrated near the comet. The general shape of the stream does not appear modified;

3° At the descending node, the width of the meteor stream outside the cometary orbit is about twice that inside it ;

4° If, for an event such as the 1799 or 1833 storms, we arbitrarily assume that the distance between the particle and the Earth, D_{PE}, is less than 0.05 AU and the distance between the particle and the comet, D_{PC}, satisfies $-0.015 \leq D_{PC} \leq 0.020$ (AU), then the storm particles represent about 12% of the total particles ejected while 63% of these particles are situated in Quadrant II, a storm is more likely when the Earth is behind and outside the comet. Fig.3 is a plot of the "meteor storm" from the simulation and should be compared with the observations in Fig 1.

4 Selectivity of the Observation

In order for meteors to be seen on Earth, it is necessary that the nodal distance of the orbit is 1AU. In addition, for streams such as the Leonids, where the meteoroids are not distributed uniformly around the orbit, meteors will only be seen periodically However, for the first condition to be satisfied, it is the nodal distance of the actual meteoroid, not that of the mean stream that has to be 1AU, so that the width of the stream is an important consideration for the observation of the meteors.

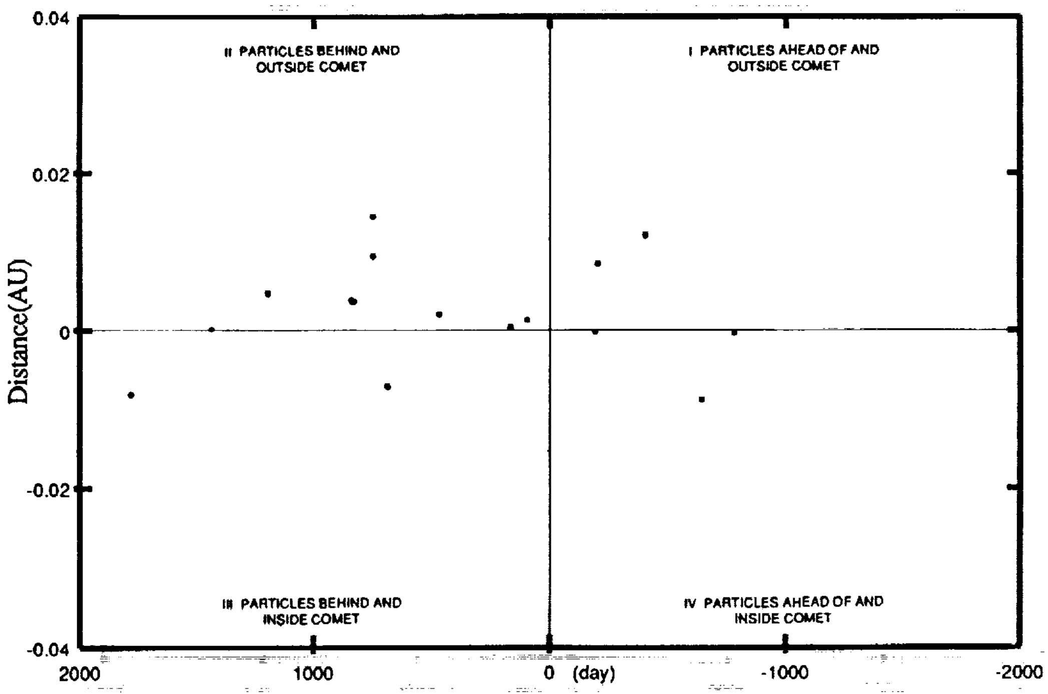

Figure 3 "Observed" model particles surrounding the comet

From our simulation, the width of the meteoroid stream outside the cometary orbit is about 0.039 AU while the inner width is only 0.016 AU.For the largest meteoroids only, where ejection speed and the effects of radiation pressure are both less, the outside width is only 0.015 AU and is illustrated in Fig 4.

At the descending node, the heliocentric distance of Comet P/Tempel-Tuttle is less than 1 AU, but with heliocentric distance increasing. Consequently, for the dense part of the meteor stream the outer part is closer to the ecliptic as the comet moves from the node than the inner part (see Fig.4). For the outer part, the closest distance is only about 0.008 AU or less, while the inside portion is about 0.023 AU from the ecliptic. As the observation events will occur only when the Earth-meteoroid distance is less than some value (eg. 0.015 AU, see Yeomans 1981), the inside meteoroids have little chance of being observed This effect , together with the greater width of the outer portion, makes it much more likely that the storms are seen when the Earth is outside and behind the comet, as is observed.

5. Conclusions

By numerical integrating our model the rough shape of the stream at the descending node is obtained and the conditions under which a meteor storm will occur have been discussed. We conclude that most meteor storm will occur when the Earth is behind and outside the comet for the following reasons.

1° At the descending node, the width of the part of the stream outside the cometary orbit is about twice the inside part;

2° The distance between the Earth and the meteoroids in the outer part is less than that to the inner part.

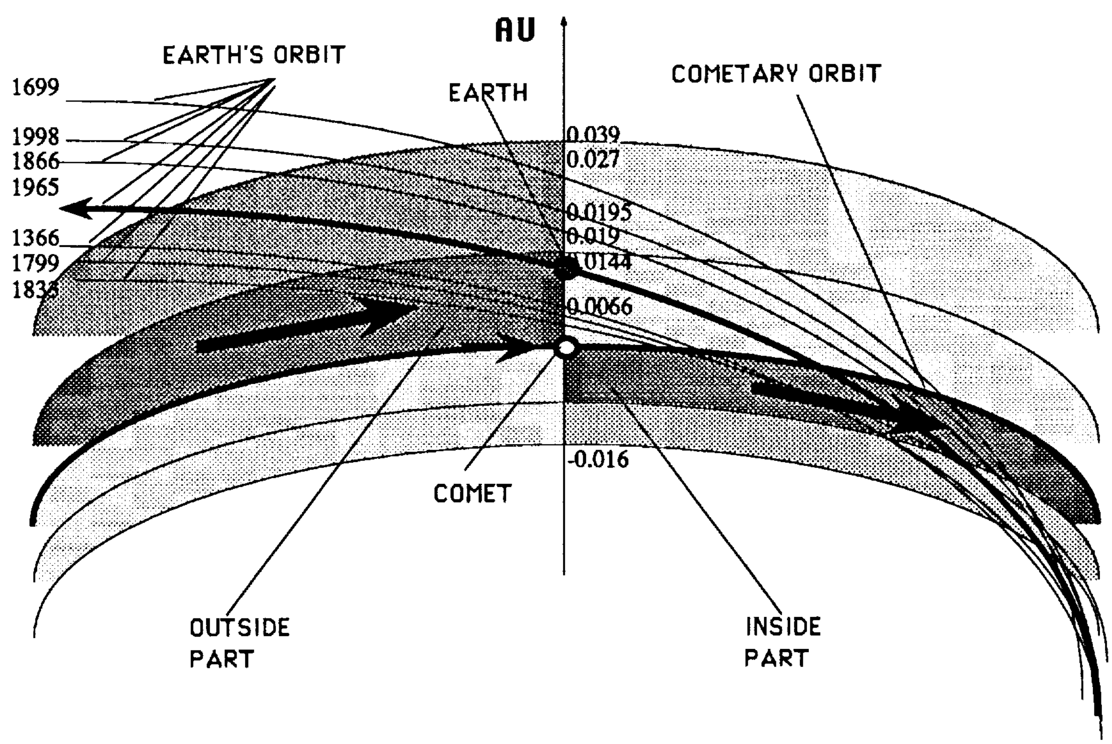

Figure 4 Position of the Earth, Comet Tempel-Tuttle & the Leonids

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