39. ON THE GROUPING OF METEORS IN METEOR STREAMS

V. PORUBČAN
(Astronomical Institute of the Slovak Academy of Sciences, Bratislava, Czechoslovakia)

It has been repeatedly suggested, on the basis of visual and radar observations, that meteors often appear in pairs or larger groups, within short time intervals. They usually have some similar characteristics (brightness, path, etc.) so they easily attract the observer's attention. This phenomenon could be a result of chance and only an analysis of its frequency can give an answer whether there is any *a priori* reason for it. The possible reality of this grouping has been studied by some authors. However, their observing data contained only meteors brighter than $+8^m$, and did not yield unambiguously acceptable evidence for existence of real pairs in this range and said nothing about the region of very small meteors.

The present paper is based on meteor radar observations from Ondřejov and Dušanbe. It consists of 32600 echoes, 7400 of which were obtained at Ondřejov (limiting magnitude +7) in the period of Geminids 1959 and 1961, 25200 echoes are from Dušanbe (limiting magnitude +13·5) containing Lyrids, α-β Perseids, *L*-Aurigids, Orionids and one maximum from October 28, 1966. These data enable one to discuss the problem of grouping far beyond the visual range, in the range of very small meteors and small mutual distances.

The material was selected in order to exclude large changes of frequency which may deform the observed distributions in favour of groups. It was divided into 30-min (Ondřejov) and 10-min (Dušanbe) intervals and the sets of such intervals with approximately equal frequency were combined. Their frequency distributions were compared with expected ones. Four methods of analysis were used. The departures between observed and expected distributions were checked by the χ^2-test.

For the first analysis observations were divided into 30-, 10-, 5-, and 1-sec intervals, and the number of meteors in each interval was noted. The number of intervals containing n meteors, where $n=0, 1, 2, 3, \ldots$, etc., was compared with the expected Poisson distribution, for which the expected number of echoes is

$$N_n = N \frac{a^n}{n!} e^{-a}, \tag{1}$$

where N is the total number of intervals, a is the average number of echoes in the interval.

The observations were subjected to the second analysis, in which time intervals between successive echoes were noted. The frequency distribution of such intervals

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was compared with the expected one, obtained from an exponential dependence. The expected number of such intervals between t and $t+dt$ is

$$N_t = N \frac{dt}{T} e^{-t/T}, \tag{2}$$

where N is the total number of intervals, T is the average interval.

The third analysis is based on the calculation of the correlation between successive intervals, which is expected to be zero for a random distribution of echoes. The correlation coefficient is given by formula

$$\rho = \frac{\Sigma t_n t_{n+1} - NT^2}{\Sigma t_n^2 - NT^2} \pm \frac{1}{\sqrt{N}}. \tag{3}$$

t_n, t_{n+1} are successive time intervals, N and T are the same as before.

The fourth method is based on the distribution of distances of echoes. The spacial nearness of a pair of meteors means that they appear not only in a short time interval, but also in a small interval of distances from the observer; an interval of 1 sec is equivalent to a difference of distances of only some few 10 km. To verify the grouping, the differences of distances ΔR between successive echoes have been derived from extensive material, especially for pairs of echoes which follow one after another in short time intervals (from 0 to t_1 sec), and especially for pairs which exceed the range of this interval (over t_2, $t_2 \geqslant t_1$).

Mostly the time intervals between successive echoes are not directly noted from the record; but these are obtained from the time of appearance of echoes rounded off with a certain accuracy. If we noted the time intervals with an accuracy of τ sec and the appearance times were noted with the same accuracy then for an interval n, values from $n-\tau$ to $n+\tau$ actually are recorded. If we suppose that the probability of all values inside this interval is the same, the correction is very simple. This correction for the rounding off of the time data serves as the first approximation for the distribution from the material with low frequency of meteors.

For statistics of an interval short with respect to the average interval between successive meteors (at high frequency or crude timing) the observations require attention to still another effect. As follows from an exponential dependence, the probability of the shorter intervals is higher than that of the longer ones. That is why the simple hypothesis that all intervals from $n-\tau$ to $n+\tau$ are equally probable is not sufficient. For an expected number of meteors in individual intervals the solution of this problem, instead of Equation (2), gives the relations

$$n_0 = \frac{N}{\tau} \left(\tau - T + Te^{-\tau/T}\right), \tag{4}$$

$$n_{k\tau} = \frac{NT}{\tau} \left(e^{\tau/T} - 2 + e^{-\tau/T}\right) e^{-(k\tau)/T}, \tag{5}$$

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where τ is the width of the unit interval and $k=1, 2, 3, \ldots$ are integers. For the whole material the value $\tau=1$ was used, except one record, where $\tau=0{\cdot}5$. The departure of this corrected distribution from the normal exponential can be determined by construction of the sample distributions for different combinations of N and T.

At high frequencies in all distributions another effect is present, namely the blending of the echo images on the film. Both effects mentioned above work in the same direction: they evoke an apparent increase of the number of the events near the average interval and a decrease in regions of the shortest and the longest intervals. Without taking these into account, the distributions appear to be more uniform than by chance and the real pairs can disappear in the analysis. Both effects vary with frequency, the accuracy of timing and the quality of the record. At high frequencies they influence significantly the results of the analysis (Dušanbe), at low ones they are negligible (Ondřejov). For time estimation with an accuracy of 1 sec and random material up to 5000 meteors, the limiting value of the average interval at which the first effect begins to be significant is $T\sim 2$ sec. With extension of the material the value of T grows; with higher accuracy of estimation of the time, T decreases.

From 19 Poisson distributions for 6 showers the median of the probabilities obtained by χ^2-test, is $p_M\sim 0{\cdot}53$ and the mean value is $\bar{p}\sim 0{\cdot}57$. From 15 distributions of the time intervals corrected for the first effect, $p_M\sim 0{\cdot}53$, $\bar{p}\sim 0{\cdot}54$. The results are nearly the same and very close to the value of 0·50, which we expect for a set of random distributions. The effect of blending of echoes was reconsidered on the control record and reached 3%. After removing both these effects from the record, the distributions were closer to random ones.

The results obtained from the correlation and the distance distributions confirmed the conclusions of the previous two methods. This means, that the assumption of the grouping of meteors obtained in some previous investigations was not confirmed. An analysis of the material for streams with different dispersion, in a large range of magnitudes, has indicated, that, besides the general changes of density of the streams and the changes of frequency with the position of radiant, there exists no further source of irregularities, which might be assumed to result from the successive fragmentation of the individual meteoroids in interplanetary space.

DISCUSSION

Rubcov: How did you take into account the selectivity of the equipment?

Porubčan: This was unnecessary, since it was possible to select time intervals short enough, without any systematic trend in frequency.

Rubcov: Is there any difference in the results of the analysis of grouping for meteors of different magnitudes?

Porubčan: No, a random distribution is obtained independent of the limiting magnitude of the equipment, i.e. both down to $+7^{m}$ and to $+13^{m}$.