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Leonid 1999 shower clustering analysis from HDTV data

By

Juraj TÓTH*, Hajime YANO† and Vladimír PORUBČAN*

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Abstract: Recent Leonid storms provided a possibility to verify non-random grouping of particles within young meteoroid stream filaments. Analysis of possible clustering of meteoroids over a random level and results based on the High-Definition TV observation of the 1999 Leonids carried out within the scope of the Leonid MAC campaign are presented and discussed.

1. INTRODUCTION

In 1999, the Leonid meteor shower produced the first meteor storm after the perihelion passage of the parent comet 55/Tempel-Tuttle on February 28, 1998. The peak of the meteor storm appeared on November 18, 02:02 UT, with the ZHR=3700 meteors derived from visual observations (Arlt et al. 1999). The Earth crossed the filament of meteoroids which were ejected from the comet at the perihelion passage in 1899 (McNaught and Asher 1999).

Some past and recent visual (Watanabe et al. 2002a) and radar (Porubčan 1974) observations suggested that meteors appear occasionally within short time intervals in groups. Is it a result of fragmentation of meteoroids in space or is it just chance distribution? This question can be answered by statistic methods and real existence of groups of meteoroids over a random level can be explained only by a progressive fragmentation of particles in space. If this is the case, it is clear that particles of unequal size are quickly dispersed due to non-gravitational effects and any such closer groups have to originate recently.

Analyses of possible clustering of meteoroids based on visual observations refer to the major meteor showers, which only have frequencies sufficient for the statistics. But visual observations do not provide accurate time information. More reliable are results obtained from radio observations, primarily because radio data are more extensive and the time of a meteor apparition can be determined with a much higher accuracy. A common result of all these analyses

* Astronomical Institute, Faculty of Mathematics, Physics and Informatics, Comenius University, Mlynská dolina, 842 48 Bratislava, Slovak Republic.
† Planetary Science Division, The Institute of Space and Astronautical Science (ISAS), 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan.

was the absence of grouping of meteors over a random level in the permanent meteor showers (Shain and Kerr 1955; Briggs 1956; Bowden and Davies 1957; Poole 1965; Porubčan 1968). These analyses referred to the stream structures at middle and later evolutionary stages for which the result seems to be definitely negative and favour random distribution of meteoroids within streams. Therefore, it was desirable to apply similar analyses to showers or filaments of recent origin as were the Leonids 1966, 1969, 1999 and 2001. A positive grouping of meteoroids in the Leonids 1969, derived from radar observations at Springhill (Canada), was found by Porubčan 1974. The return of the Leonids in 1999 by its character was similar to the Leonids 1969 and so provided an opportunity to verify the existence of grouping of meteoroids over a random level in this young filament. The first clustering analysis of this storm was made by Gural and Jenniskens 2000 with a negative result. This paper presents a partial analysis of the HDTV (High Definition TV) observation performed by H. Yano and S. Abe (ISAS) onboard the ARIA aircraft within the NASA's 1999 Leonid Multi-instrument Aircraft Campaign (Leonid MAC) (Jenniskens et al. 2000).

2. OBSERVATION

The observations were performed as single station observations with an f/28mm intensified "Hi-Vision", or HDTV camera develpoed by NHK (Abe et al. 2000) onboard the ARIA aircraft (Leonid MAC) at a height of 11 km above the sea level during flight over the Mediterranean Sea (November 18, 1999) about the peak of the Leonid meteor storm (01:00-03:00 UT). The camera with the field of view of 60x35 degrees and the limiting stellar magnitude about +7 was directed to the north near the horizon. Fig. 1 shows a composite image of the 1999 Leonid storm obtained from the HDTV data.

Fig. 1: A composite image of meteors recorded by the HDTV camera onboard the ARIA airplane at the peak of the 1999 Leonid meteor storm. (Courtesy: HNK)

The data analysed are from two intervals 1:51:22 - 2:01:22 UT and 2:40:45 - 2:44:05 UT (November 18, 1999) and were divided into four sets (I - IV) of the length of 3 minutes and 20 seconds each. The first three sets (I - III) are from the period near the peak of the storm and the last one (IV) is about 40 minutes out of the peak. The HDTV data were read off from the record visually and the record was stored in a computer and replayed in 2 second movie loops. The 2 second loops were overlapping each other by 0.5 second and each loop was inspected for several minutes. By this procedure also very faint and short duration meteors could be detected on the record. The effective field of view for visual inspection was about 43x30 degrees. The time corresponding to the maximum brightness of a meteor was taken for the time of its appearance. In a total, 1863 meteors were identified on the record and 98.3 percent of them were the Leonids.

3. STATISTICAL METHODS OF ANALYSIS

We have used three statistical methods for the analysis - time distribution, Poisson distribution and correlation - applied also in the previous analyses, e.g. Porubčan 1968.

3.1 Time distribution

A random frequency distribution of the time intervals between successive echoes is described by the exponential law

$$N_{\mathrm{t}} = N\frac{\mathrm{dt}}{\mathrm{T}}\exp(-\frac{\mathrm{t}}{\mathrm{T}}) \tag{1}$$

where, N_{t} is the expected number of intervals between t and $t + dt, N$ is the total number of intervals, and T is the mean interval.

3.2 Poisson distribution

Similarly, if the occurrence of meteors is random, the distribution of rates within a sampling interval will be given by the Poisson relation

$$N_{\mathrm{i}} = N\frac{\mathrm{a}^{\mathrm{i}}}{\mathrm{i}!}\exp(-a) \tag{2}$$

where, N_{i} and N are respectively, the expected number of sampling intervals containing $i = 0, 1, 2, ...$ meteors, and the total number of intervals; a is the mean number of meteors in a unit sampling interval.

3.3 Correlation

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

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

where, t_{n} , $t_{\mathrm{n+1}}$ are successive time intervals, N and T are the total number of intervals and mean interval, respectively.

3.4 Chi-squared test

The first two methods mentioned above were statistically tested by chi-squared test whether deviations over random level are significant or not. The formula for the chi-squared test is given by

$$\chi^2 = \sum_{\mathrm{i}} \frac{(\mathrm{O_i} - \mathrm{E_i})^2}{\mathrm{E_i}} \tag{4}$$

where, O_{i} and E_{i} are the observed and expected (random distribution) values, respectively. Each O_{i} or E_{i} have to have values not less then 5 in order to avoid false test results.

4. RESULTS

4.1 Observed meteor counts

Any systematic and steep changes in meteor rates may result in spurious clustering of meteors, therefore, in order to inspect real clustering over a random level, it is necessary to study meteor data sets without long-term changes in meteor rates. Fig. 2 shows the observed counts of meteors in one minute (left plot) and 10-seconds (right plot) intervals from the analysed period, 01:51 - 02:01 UT. There is observed just a standard fluctuation about an average level (163 Leonids per minute) in raw meteor counts near the peak of the storm and no systematic change in the rate. The observed counts of meteors in the interval outside the peak, 02:41 - 02:45 UT, (58 Leonids per minute) are significantly lower, but also without any systematic change in the rate. A more pronounced fluctuation over the average level in 10-seconds intervals (Fig. 2) was observed also by Gural and Jenniskens 2000 as possible waves of meteors in a short time scale. This also suggests that meteors near the core of this young filament of the stream need not be distributed randomly.

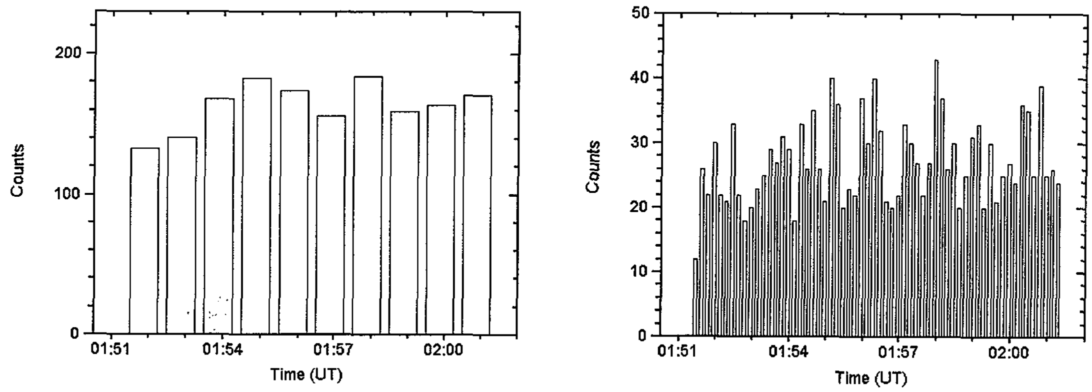

Fig. 2: The counts of Leonid meteors in one minute intervals (left plot) and ten second intervals (right plot) near the peak of the 1999 Leonid storm.

4.2 Time distribution

The time intervals between successive meteors were read off from the record with the shortest possible time resolution of 0.033 s and compared with theoretical exponential time distribution. If meteors are distributed randomly in the stream, the observed time distribution of successive meteors will follow an exponential function. The observed time distributions of all the sets of the record (histograms I-IV) are plotted in Fig. 3 and compared with the expected exponential distribution (curves). The deviations between the observed and expected distributions were tested by chi-squared test and resulting probabilities are listed in Table 1. The data in set IV are insufficient for a chi-squared test. We found that there is an enhancement of the observed over the expected distribution for the shortest time intervals between successive meteors (up to 0.033s) in set III. The set III represents the closest period from the inspected record to the peak of the storm i.e. the core of the filament 1899. The probability from chi-squared test for set III is only 4.5 percent.

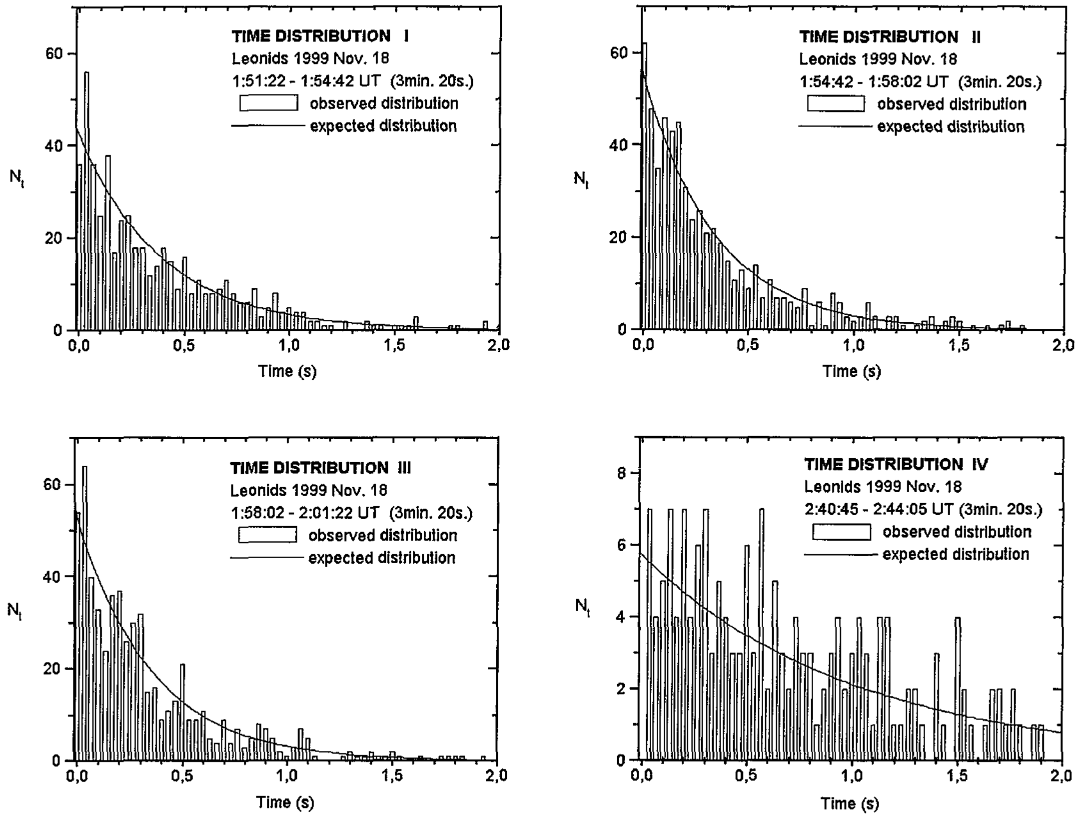

Fig. 3: The observed (histograms) and theoretical (curves) distributions of time intervals between successive meteors for three data sets close to the peak of the 1999 Leonid storm (I - 1:51:22-1:54:42 UT, II - 1:54:42-1:58:02 UT and III - 1:58:02-2:01:22 UT) and a set out of the storm peak (IV - 2:40:45-2:44:05 UT.

4.3 Poisson distribution

The inspected data sets from the peak altogether (set I-III) were divided into 1s and 0.1s sampling intervals and the numbers of meteors in these intervals were counted. Fig. 4 shows the observed distribution (dashed histograms) in a comparison with the theoretical Poisson distribution (open histograms). Similarity of the observed and expected distributions evaluated by the chi-squared test gives the probability of 9.3 percent for each distribution of both the 1s and 0.1s sampling intervals. It means that the grouping of meteors on a larger time scale (0.1s and 1s) than the limiting time resolution of the TV record (0.033s) is not very pronounced and cannot be proved by this method. Set IV does not have enough data for such an analysis.

4.4 Correlation

For the third analysis, the time intervals between successive meteors were correlated and the correlation coefficient for each inspected set (I-IV) of the HDTV record is listed in Table 1. If the correlation coefficient is zero, the observed distribution is random. The correlation coefficients for all the sets are low, however, while for the sets I, II and IV ρ are lower than the

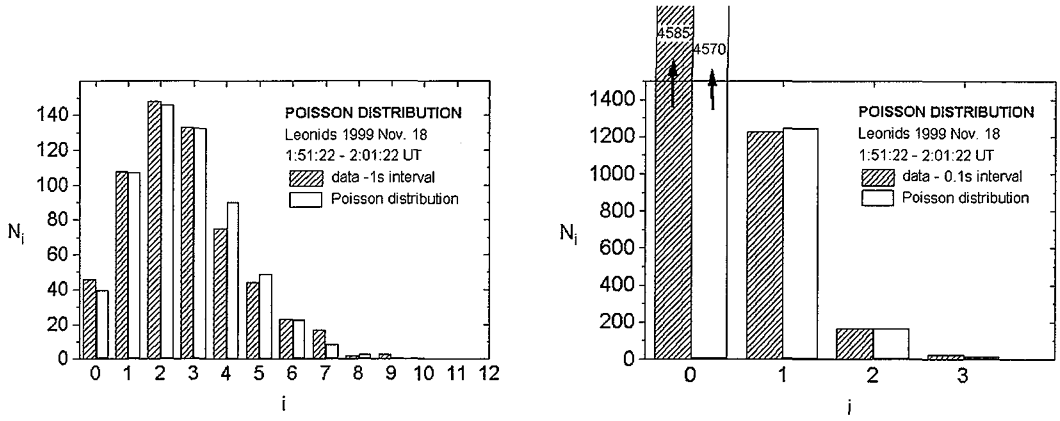

Fig. 4: The observed distribution (dashed) and theoretical Poisson distribution (open) for 1 second sampling intervals (left plot) and 0.1 second sampling intervals (right plot). i - the number of meteors in the sampling interval. $N_{\rm i}$ - the number of intervals with i meteors.

corresponding errors, for the set at the peak (III) $\rho = -0.077 \pm 0.042$ and exceeds the error by 1.8 times.

Table 1: Summary of the analysed sets from the 1999 Leonid HDTV record on November 18, with the number of Leonids in each set, the probability obtained from the time distribution by the chi-squared test and the correlation coefficient.

Part	Time interval	Leonids	Probability	Correlation
I	1:51:22 - 1:54:42 UT	502	0.241	-0.033 ±0.045
II	1:54:42 - 1:58:02 UT	570	0.695	+0.019 ±0.042
III	1:58:02 - 2:01:22 UT	558	0.045	-0.077 ±0.042
IV	2:40:45 - 2:44:05 UT	197	-	+0.066 ±0.071

5. DISCUSSION

Our analysis of the HDTV observations from the Leonid meteor storm in 1999 has shown that, in general, meteoroids in this young filament of the stream are distributed at random, which was also observed by Gural and Jenniskens 2000. This follows partially as from the time distribution (Fig. 3) so from the Poisson distribution (Fig. 4). A non-random distribution of meteoroids should appear as an excess of the observed distribution over the expected one in the wings, that is for the shortest and longest time intervals and the groups with the lowest and highest number of meteors. Though the Poisson distribution in Fig. 4 covering the whole analysed period of 10 minutes shows a positive excess of the observed distributions in favour of non-random groups, the probability of 9.3 percent from the chi-squared test is still high (considering a 5 percent level of significance) for a definitive statement of a real non-random grouping. On the other hand, there are observed deviations from a random distribution on a short time scale (about 3 minutes) in the time distribution. The most significant difference is in the set III, which is the closest set to the peak of the storm. The probability from the chi-squared test is less than 5 percent that the observed Leonids are distributed randomly, which implies they are not. On the other hand, the set II has the probability almost 70 percent that the Leonids followed a random distribution in the period 1:54:42 - 1:58:02 UT. These results from the time distribution are supported also by the correlation method, where the correlation coefficient is the largest (in the absolute value) for the set III and the smallest for the set II. The results suggest that there are groups of meteoroids within the stream, which are a small fraction from the majority of the population distributed randomly. As the Poisson distribution for the 1-second and 0.1-second sampling intervals gave more negative than positive results, the dimensions of non-random groups of meteoroids will be small (smaller than approximately one tenth of the Leonids V_g, i.e. 7 km). The result may be indicative of a real fragmentation process in the most populated central parts of the young meteoroid streams.

It is apparent from Fig. 3 (set III) that there are significant enhancements of the observed counts over the expected exponential function in the successive time intervals up to 0.033s, around 0.200 s and 0.500s. The most pronounce is the peak at 0.033s. One of possible explanation may be a periodically repeated fragmentation of particles in space. The recently fragmented particles are observed as the most pronounced groups of meteors within 0.033s time intervals between the meteors and older fragmentation may be observed as the groups at 0.2s and 0.5s intervals. An explanation mechanism for a periodical fragmentation is the thermal heating during perihelion passage of the meteoroid stream as was suggested by Watanabe et al. 2002b. They explain the observed groups of meteors (TV observation of 15 faint Leonids within 4 seconds observed by Watanabe et al. 2002a and 50 faint Leonids within 1 second observed by I. Tabe in Japan during 2001 Leonid maximum activity) as a very recent thermal fragmentation during perihelion passage just a few days before the Earth encounter. These results are indicative and supporting the inference about the existence of a non-random clustering of meteoroids in the early phases of the meteoroid streams and invoke to extend the observations to make the inference conclusive.

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