Earth, Moon, and Planets (2004) 95: 69–74
DOI 10.1007/s11038-005-2875-5 

# A FINE STRUCTURE OF THE PERSEID METEOROID STREAM

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(Received 5 October 2004; Accepted 26 February 2005)

**Abstract.** A fine structure of the Perseid stream in the range of photographic magnitudes is studied using the method of indices. A new completed 2003 version of the IAU Meteor Data Center Catalogue of 4581 photographic orbits is used. The method of indices is used to acquire a basic data set for the Perseids. Subsequently, the method is applied on the chosen Perseids to study their structure. Sixty four percent of chosen Perseids taken into account are attached to one of the 17 determined filaments of orbits. The filaments are not distributed in the space accidentally, but they form a higher structure consisting of at least four well-defined and distinguished "branches".

**Keywords:** Fine structure of Perseids, meteoroids, photographic meteor orbits

## 1. Input Data and Method Used

A fine structure of the Perseid stream is studied using the method of indices – the procedure based only on mathematical statistics. A new completed 2003 version of the IAU Meteor Data Center Catalogue of 4581 precise photographic orbits (Lindblad et al., 2005) is used. Meteors with heliocentric velocities higher than 48 km/s are rejected from the analysis. Hence, the final set consists of 4526 orbits.

The method was also used in the past to identify the major meteoroid streams in the previous version of the catalogue (Svoreň et al., 2000). In that test run, all the major streams were identified, confirming the efficiency of the procedure. Besides the identification of the streams and associations, the method also enables a study of the fine structure of the streams and their filaments, a separation of which by an iterative method is complicated and hardly applicable. In this paper, the fine structure of the Perseid stream is studied applying the method of indices to the newest version of the photographic orbits database.

A detailed description of the method was published earlier (Svoreň et al., 2000).

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## 2. Groups of Similar Orbits

In the first step, the method of indices is applied to the whole IAU MDC catalogue to select a basic set of data – Perseids. As a result, in total 875 Perseid orbits are selected from the catalogue.

On the basis of previous results (Svoreň et al., 2000) the individual numbers of intervals were used in the division of each parameter. The divisions were reciprocally proportional to the relative errors of the parameters. The errors of 8 individual parameters are determined as the root-of-mean-squares deviations for the actually chosen 875 Perseids from the mean values.

Table I lists (i) the parameters considered in the method of indices (in headings), (ii) the errors of the parameters for the Perseid stream, (iii) the ranges of the parameters, i.e. the differences between highest and lowest values of selected Perseids, (iv) the ratios of a given range and the corresponding mean error, the result moreover divided by the empirical value (2.04 in our case). This value satisfies a condition that, for all the considered parameters, the sum of squares of differences between real values and the closest integers is minimal. (v) The corresponding nearest integers, serving as a basic set of numbers for the division of the parameters into the equidistant intervals, are written in the last row.

We introduce the term *association* for a group of meteors which consists of at least three similar orbits. For the investigated Perseids, the basic set of parameters (last row of Table I) and its 2-multiple give very similar numbers of associations (53 and 57). We prefer the results obtained by using 2-multiple of the basic numbers with a lower number of members (452 meteor orbits grouped into 57 associations) giving more concentrated associations. The number of orbits in the associations vary between 3 and 79.

TABLE I
The mean errors (MEs) and the numbers of intervals of basic division

| Parameter | $q$ | $e$ | $\omega$ | $\Omega$ | $i$ | $\alpha$ | $\delta$ | $v_g$ |
|---|---|---|---|---|---|---|---|---|
| ME | 0.021 | 0.14 | 6.5 | 4.7 | 2.6 | 7.1 | 1.8 | 1.8 |
| Range | 0.223 | 1.15 | 74.9 | 64.9 | 23.2 | 85.0 | 18.8 | 15.7 |
| Range/ME/2.04 | 5.20 | 4.02 | 5.65 | 6.77 | 4.37 | 5.87 | 5.12 | 4.27 |
| intervals | 5 | 4 | 6 | 7 | 4 | 6 | 5 | 4 |

Besides the five orbital elements incorporated in the Southworth–Hawkins *D*-criterion, we also include, in the procedure, the coordinates of the radiant and the geocentric velocity (Svoreň et al., 2000).

## 3. Structure of the Perseid Meteoroid Stream

A clustering of orbits in the space means a clustering of their orbital parameters. Hence, we deal with the associations of orbits, it holds true for their mean parameters also. In the previous paper concerning the Perseids (Svoreň et al., 2001), the meaningful dependences of their mean parameters on each other were searched. We found that the dependences $q = q(e)$, $q = q(\omega)$, and $\omega = \omega\ (\Omega)$ (Figure 1 as an example) were sufficient to decide if particular associations are components of a given cluster.

A clustering of associations in a single parameter can occur by chance. If a given set of associations really creates a cluster, then the clustering has to be observed in each parameter. Actually, when the above mentioned dependences, with separate clusters, are graphically displayed, it is obvious that the associations tend to be in relatively isolated areas. Almost all the associations detected within a single area on a graph are also detected within single areas on the other graphs.

A filament of the Perseid stream can be characterized by a mean parameter being very close to the border between two intervals of our division. In such a case, the appropriate index corresponds with both the neighbouring intervals, i.e. it is not unique and the filament is split into two associations. Or, it can be split into several associations, if more mean parameters of the filament are close to the appropriate borders of their divisions.

The empirical limits among the filaments, obtained from the graphs (shown only for $\omega = \omega\ (\Omega)$ in Figure 1 because of the page limit), are listed in Table II.

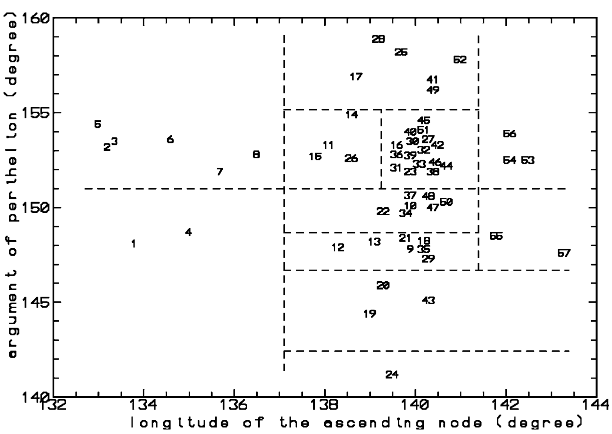


*Figure 1.* The dependence $\omega = \omega\ (\Omega)$ for the associations selected. The associations are identified by their serial numbers. The position of assigned numbers (1–57) correspond to the mean values of $\omega$ and $\Omega$ of respective association.

TABLE II
The empirical limits of parameters $q$, $e$, $\omega$, and $\Omega$ separating the groups of associations

| D.r. | Range | D.r. | Range | D.r. | Range | D.r. | Range |
|---|---|---|---|---|---|---|---|
| $q1$ | 0.916–0.926 | $e1$ | 0.712–0.864 | $\omega1$ | 140.5–142.3 | $\Omega1$ | 132.3–137.2 |
| $q2$ | 0.926–0.942 | $e2$ | 0.864–1.193 | $\omega2$ | 142.3–146.7 | $\Omega2$ | 137.2–139.2 |
| $q3$ | 0.942–0.950 | $e3$ | 1.193–1.536 | $\omega3$ | 146.7–148.8 | $\Omega3$ | 139.2–141.4 |
| $q4$ | 0.950–0.965 | | | $\omega4$ | 148.8–151.0 | $\Omega4$ | 141.4–145.4 |
| $q5$ | 0.965–0.985 | | | $\omega5$ | 151.0–155.1 | | |
| | | | | $\omega6$ | 155.1–158.6 | | |

D.r.– designation of range.

TABLE III
The characteristics of the Perseid-stream filaments

| D.rs. | Q | N.o. | $\alpha$ | $\delta$ | $V_g$ | $q$ | $e$ | $\omega$ | $\Omega$ | $i$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $\Omega1,\omega3,q2,e2$ | *A* | 15 | 43.3 | 57.9 | 58.70 | 0.937 | 0.971 | 147.7 | 135.1 | 111.4 |
| $\Omega1,\omega5,q4,e2$ | *B* | 36 | 39.3 | 56.8 | 59.27 | 0.958 | 0.981 | 152.7 | 134.4 | 112.5 |
| $\Omega2,\omega2,q1,e2$ | *C* | 7 | 50.0 | 57.7 | 58.61 | 0.921 | 0.907 | 143.9 | 138.9 | 113.2 |
| $\Omega2,\omega2,q2,e1$ | *D* | 8 | 47.3 | 57.4 | 56.56 | 0.935 | 0.744 | 144.9 | 139.1 | 111.9 |
| $\Omega2,\omega3,q2,e2$ | *E* | 10 | 48.0 | 59.2 | 58.39 | 0.936 | 0.959 | 147.6 | 138.7 | 110.7 |
| $\Omega2,\omega5,q4,e2$ | *F* | 23 | 44.3 | 57.8 | 59.45 | 0.959 | 0.985 | 153.0 | 138.3 | 113.0 |
| $\Omega2,\omega6,q5,e2$ | *G* | 10 | 42.3 | 57.3 | 59.35 | 0.974 | 0.958 | 157.0 | 138.7 | 113.3 |
| $\Omega3,\omega1,q1,e1$ | *H* | 3 | 49.7 | 57.7 | 56.10 | 0.917 | 0.722 | 140.7 | 139.5 | 111.5 |
| $\Omega3,\omega2,q2,e1$ | *I* | 7 | 49.7 | 57.5 | 57.35 | 0.931 | 0.795 | 144.7 | 140.1 | 112.8 |
| $\Omega3,\omega3,q2,e2$ | *J* | 53 | 50.0 | 57.8 | 59.05 | 0.936 | 0.933 | 147.5 | 140.1 | 113.6 |
| $\Omega3,\omega4,q3,e2$ | *K* | 47 | 48.9 | 58.0 | 59.45 | 0.945 | 0.975 | 149.7 | 140.0 | 113.4 |
| $\Omega3,\omega4,q4,e1$ | *L* | 5 | 45.9 | 57.3 | 57.04 | 0.956 | 0.762 | 150.1 | 139.9 | 112.4 |
| $\Omega3,\omega5,q4,e2$ | *M* | 242 | 47.1 | 57.9 | 59.32 | 0.956 | 0.958 | 152.2 | 140.0 | 113.3 |
| $\Omega3,\omega5,q4,e3$ | *N* | 21 | 48.5 | 57.5 | 62.84 | 0.956 | 1.214 | 153.7 | 140.0 | 115.8 |
| $\Omega3,\omega6,q5,e2$ | *O* | 40 | 45.1 | 57.4 | 60.01 | 0.971 | 0.993 | 156.4 | 140.2 | 114.3 |
| $\Omega4,\omega3,q2,e2$ | *P* | 17 | 53.8 | 58.3 | 59.07 | 0.936 | 0.927 | 147.4 | 142.8 | 113.7 |
| $\Omega4,\omega5,q4,e2$ | *R* | 16 | 50.1 | 58.3 | 59.20 | 0.957 | 0.939 | 152.5 | 142.3 | 113.5 |

D.rs. – designation of combination of range, Q – designation of filament, N.o.– number of orbits.

In the next step, the derived limits are used to search in a whole datafile of 875 Perseids, not only among 452 orbits assigned to the 57 associations. A total of 560 (64%) of the Perseid orbits can be assigned to the 17 filaments (*A*–*R*) listed in Table III. In total, 360 combinations of $\Omega$, $\omega$, $q$, and $e$ are possible, but only 17 are actually present in the data.

The mean eccentricity of the filament *N* is $\bar{e} > 1$. It is known that many of the Perseids (and equally other streams on retrograde orbits) have formally

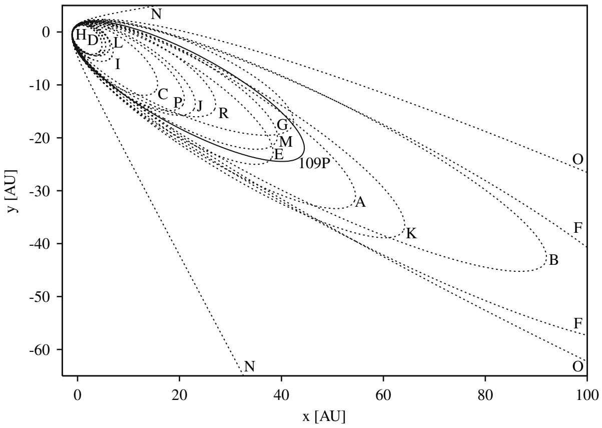


*Figure 2.* A projection the orbits of filaments into the plane of the mean orbit of 560 Perseids. The orbit of comet 109P/Swift-Tuttle is that in 1862. In the scale of figure, there is no difference between that and 1992 orbits.

hyperbolic orbits (Kresák and Porubčan, 1970). This is an effect of a large uncertainty of this element. Its range, even for mean orbits (high smoothed values), is from 0.722 to 1.214. The high determined values indicate the high real values, but the corresponding real orbits are obviously elliptic.

The selected filaments are, very probably, real structures in the space. To support their real existence we note that each of the derived filaments consists of meteors observed in different years. It also means that the filaments do not represent any clustering of meteoroids in some positions on the orbit but long-time structures of the stream.

## 4. Filaments as a Part of Complicated Structure – Branches

An analysis of the positions of the selected filaments shows that a part of them is not distributed in the space accidentally, but they form higher structures, called *branches* of the Perseid meteoroid stream.

Different approaches to the analysis can be used. The simplest method is to investigate a dependence of an occurrence of filaments on the time scale represented by a value of orbital ascending node $\Omega$. Or, we can analyze the positions of perihelia of the filaments in the celestial sphere.

Here, we present only an analysis based on a visualization of space distribution of the filaments (Figure 2). We can distinguish following four branches:

*B*1 – filaments *H*, *D*, *L*, *I*;
*B*2 – filaments (*C*), *P*, *J*, (*R*);
*B*3 – filaments (*G*), *M*, *E*;
*B*4 – filaments *A*, *K*.

Four filaments (*B*, *F*, *O*, *N*) at the "parabolic border" of the eccentricity interval seem to be individual structures without any connection with the other filaments. At branch *B*2, the filament *R* is relatively distant. Its classification as a part of this branch is questionable. It is possible that the filaments of *B*2 branch represent a transition state between the *B*1 and *B*3 branches.

We have to take into account that our conclusions are considerably influenced by the positions of aphelia closely connected with an eccentricity – parameter with the largest errors in the database. On the other hand, clustering of the aphelia could hardly be connected with a low precision of determination of meteor velocity.

In the last step, *D*-discriminants among all the pairs of selected filaments are calculated. On the basis of similarity of orbits expressed by the lowest value of *D*, a check of reality of branches found at previous section is done. The process of the check by *D*-criterion does not confirm that filament *G* belongs to the branch *B*3 and filament *R* tends more to belong to the *B*3 than *B*2 branch. Mean orbits of all the other numbers of branches are very similar to each other (in the range of the individual branch) and a similar dynamical evolution is possible.

## 5. Conclusions

We have separated and analyzed a set of 875 photographic Perseids. A total of 560 individual orbits are concentrated into 5 individual filaments and 4 branches of the stream containing 12 filaments together. The structures are dived in a cloud of 315 dispersed orbits.

## Acknowledgement

This research was supported by VEGA – the Slovak Grant Agency for Science (grants No. 2/4012/4 and 1/204/3).

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