Contrib. Astron. Obs. Skalnaté Pleso **41**, 15 – 22, (2011)

The orbital dispersion in the long-period meteor streams

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Received: July 19, 2010; Accepted: December 13, 2010

Abstract. The contribution of the real dispersion of the orbital elements is deduced from the long-period orbits, where an excess over the parabolic value is likely to be entirely due to measuring errors, as well as from comparing observed dispersions in different catalogues, where the observational errors should be different to each other. Shower meteor data from the IAU Meteor Data Center have been analysed with the aim of determining the orbits' distribution in the streams, based on the dispersion of their reciprocal semimajor axes. It has been shown that the major part of the observed differences in the semimajor axes within meteor streams is not due to a real dispersion of orbits but due to measuring errors.

Key words: meteors – meteoroids – meteor showers – meteor streams

1. Introduction

A thorough analysis of a large set of precisely-reduced meteor orbits enables the real dispersion of reciprocal semimajor axes within meteor streams to be estimated, even if the observational errors considerably exceed the real deviations from the parent comet's orbit. The present paper, based on a statistical analysis of photographic meteor orbits, shows the dispersion of orbital elements within the meteor streams. The contribution of the real dispersion of the orbital elements is estimated from the long-period orbits, where an excess over the parabolic value can be regarded as entirely due to measuring errors, as well as from a comparison of the observed dispersions in different lists of orbits, where the observational errors should be different. Four meteor showers, having heliocentric velocities close to the parabolic limit, were selected for this analysis.

A complete study of the real dispersion of orbital periods in meteor streams was made by Kresák (1974), which showed that the observed dispersion of the semimajor axes involves the real orbital dispersion plus errors, which are greater by a factor of 10^4 for the orbits of the meteoroids than in the case of well-determined cometary orbits. An analysis of 308 photographic orbits showed that the real dispersion of the Perseids is at least eight times smaller than indicated by observation. Porubčan (1977), in his study of the dispersion of the orbital elements of meteor orbits, analysing 295 photographic Perseids, showed that there are considerable differences in the dispersion among different catalogues, and the spread of the orbits obtained even from the most accurate catalogues is very large indeed.

For the present work, data from the photographic catalogues of the IAU Meteor Data Center (Lindblad et al. 2005) were used. The Perseids and the Orionids, associated with comets P/Swift-Tuttle (133 years) and P/Halley (75 years), are the best-represented meteor showers in the database. Among the 4 581 photographic orbits, 812 Perseids and 71 Orionids were found. To find the most probable values of semimajor axes and to compare the observed dispersion in different lists of orbits, data of these two showers were divided into two samples. The first group, of higher precision (A - catalogues) includes the orbits obtained by investigators: Whipple, Jacchia, Hawkins and Southworth, Ceplecha, Ceplecha and Spurný. All other sources of orbits of the IAU MDC database (listed in the paper Lindblad et al. 2005) create the second group (B - catalogues) for our analysis. A small number (17) of meteoroids belonging to the Lyrid meteor shower (associated with the Comet 1861 I Thatcher) and 37 Leonid meteors (the parent body is the comet P/Tempel-Tuttle with the period of 33 years) in the photographic lists do not allow us to compare the observed dispersion in different catalogues. Shower meteors were selected using the shower characteristics given by Ceplecha et al. (1998) in the same way as they were earlier when searching the MDC photographic data (Hajduková 2002). The above mentioned shower meteors have been analysed with the aim of determining the orbits' distribution in the streams, based on the dispersion of their reciprocal semimajor axes. The accuracy of the semimajor axes of meteor orbits is important because this is the orbital element, that is most directly connected with the origin of meteor particles. This has been a controversial point in polemics about the interstellar or interlpanetary origin of sporadic meteors from the beginning of the meteor astronomy, continuing to the present day. A recent detailed analysis shows that the vast majority of orbits recorded as hyperbolic with $e > 1$ are only the consequence of measurement errors and their hyperbolicity is not real (Hajduková 2008).

2. The hyperbolic orbits among the 'high speed' shower meteors

It is obvious that the occurrence of hyperbolic orbits among shower meteors are a consequence of errors in the measured parameters. A detailed analysis of photographic meteor data from the IAU MDC (Hajduková 1994, 2008) has confirmed this opinion and shown that hyperbolic orbital elements of meteors, which belong to known meteor showers, are a consequence of errors, mainly in the determination of their velocity and radiant position. The apparent hyperbolicity of these orbits is caused by a high spread in velocity determination, shifting a part of the data through the parabolic limit.

Table 1. *Selected shower meteor data from the photographic catalogues of the IAU MDC*

Meteor stream	*No of orbits*	*No of orb. $1/a < 0$*	*Hyperbolic orbits (%)*	*Mean geoc. vel. $\bar{v}_G$ ($km\,s^{-1}$)*	*Mean helioc. vel. $\bar{v}_H$ ($km\,s^{-1}$)*	$\Delta v = \bar{v}_H - \sqrt{2}v_0$
Lyrids	17	6	35.0	47	41.92	-0.22
Perseids	812	215	26.5	59	41.70	-0.44
Orionids	71	21	29.5	67	41.52	-0.62
Leonids	37	5	13.5	71	41.43	-0.71

The meteoroid streams with long periods of several decades to centuries have heliocentric velocities v_H close to the parabolic limit $v_p = \sqrt{2}v_0$, where v_0 is the Earth's velocity. The observational errors of those meteor streams greatly exceed the real deviations from the parent comet's orbit. Selected shower meteor data are given in Table I. The mean heliocentric velocity of Lyrids ($41.92\,kms^{-1}$) differs from the parabolic limit by $0.2\,kms^{-1}$ only, in comparison with that of Perseids, which differs by $0.4\,kms^{-1}$. For Orionids and Leonids, this difference ($\Delta v = v_H - \sqrt{2}v_0$) is $0.62\,kms^{-1}$ and $0.71\,kms^{-1}$, respectively. Hence, a small error in the velocity determination may result in a designation of hyperbolicity of orbit.

The proportion of hyperbolic orbits in the database is different in different showers. Among the total of 812 photographic Perseids, there are 215 hyperbolic orbits, which represent 26.5 %. In the set of 71 Orionids, there are 21 orbits with $1/a < 0$. For the sake of comparison, it could be mentioned that among the 386 Geminids (with the mean heliocentric velocity of only $36.6\,kms^{-1}$) there is only 1 case of a hyperbolic orbit, which corresponds to 0.26 %. The high proportion of formally hyperbolic orbits in the Lyrids (35 %) is partly due to their small sample size. There is a slightly smaller number of $1/a < 0$ values within the Leonid meteors in the database (13.5 %).

It is worth mentioning that a dependence of the contribution of hyperbolic orbits among the shower meteors on the mean heliocentric velocity of a particular meteor shower was found. The proportion of hyperbolic orbits increases with the increasing heliocentric velocity ($N_{e>1}/N = f(v_H)$) of a particular shower, approaching the parabolic limit (Hajduková 2008).

3. The accuracy of semimajor axes of meteor orbits

Error in the heliocentric velocity is a significant source of uncertainty in semimajor axes determination. In the IAU MDC catalogues, the errors in velocity determination can reach the value $\delta v_H \sim 10\,kms^{-1}$. The errors differ both for individual catalogues and for individual meteor showers. The largest spread was found for the Perseids from catalogues with a lower precision, reaching values of

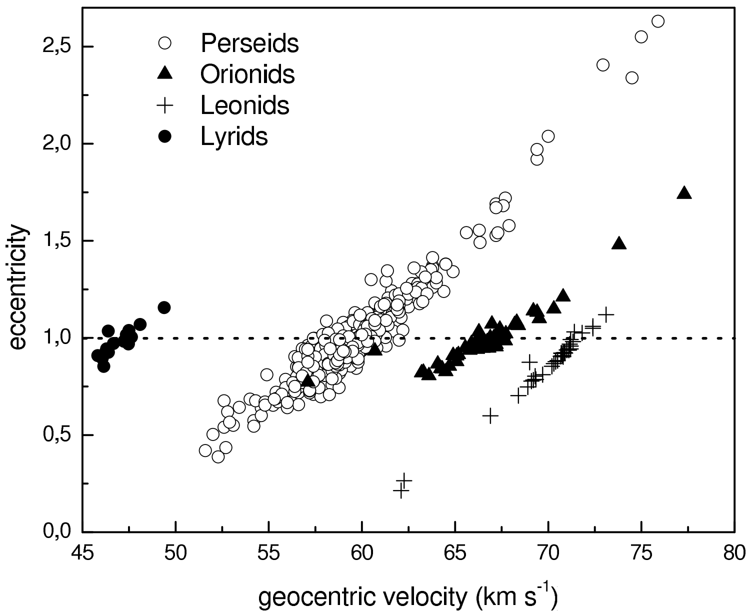

Figure 1. Eccentricities and velocities of the 4 selected meteor showers in the photographic catalogues IAU MDC show that the errors in velocity determination can reach the value $\sim 10\,kms^{-1}$. The horizontal dotted line - parabolic limit.

$10 - 15\,kms^{-1}$ (Hajduková 2008). Figure 1 shows a spread in the eccentricities and velocities of the 4 selected meteor showers. Here, it is necessary to mention that in the velocity spread and thus in the orbital spread, processes which happen in the interplanetary medium also participate. Extreme observed orbital differences between the members of a stream could be, in a few cases, a consequence of collisions, interplanetary perturbations or radiative effects. An interesting study of the meteoroid orbits perturbed by collisions with interplanetary dust was made by Trigo-Rodríguez et al. (2005). In this paper meteor orbits of a high accuracy were analysed and a presence of Leonid meteoroids with peculiar orbits (a much-lower geocentric velocity than usual and thus different orbital elements) was detected. The analysis showed that the most reasonable explanation for this orbital behaviour is collisions with micrometeoroids belonging to the zodiacal dust cloud, which could reduce the orbital speed of the meteoroid and produce shorter period meteoroid orbits.

The widely-observed orbital dispersion in all four showers, having heliocentric velocities close to the parabolic limit, is seen in distributions of the reciprocal semimajor axes in Figure 2. A relatively small spread in the values of the semimajor axes in comparison with other three showers is seen in the smallest sample of Lyrids.

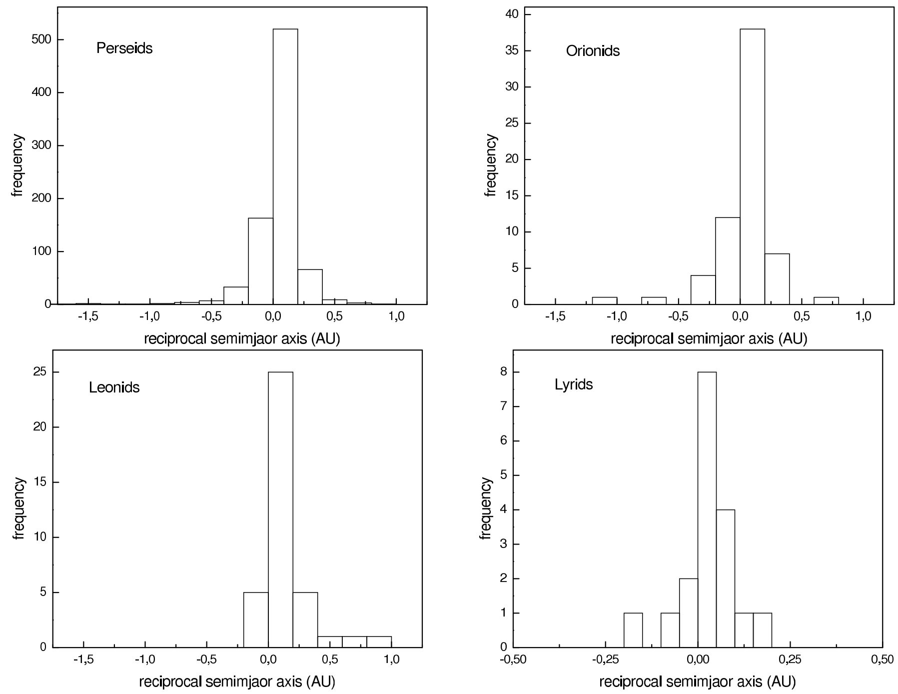

Figure 2. The distributions of the reciprocal semimajor axes show a widely-observed dispersion within all four investigated meteor streams.

There are different reasons for the error in the heliocentric velocity, such as the instrumental effects, measuring errors, irregularities in the atmospheric deceleration, errors in radiant determination and timing errors affecting the subtraction of the motion of the earth from the geocentric velocity to find the heliocentric velocity. All these different sources of errors vary widely in importance and cannot be readily separated one from another. Therefore, in analyzing the error function, it is convenient to use a median absolute deviation (Kresáková, 1974). The median a_M is the most representative value of semimajor axis a, because the arithmetic mean value a, is strongly affected by extreme deviations caused by gross errors.

The dispersion of the semimajor axis within the meteor stream is described by the median absolute deviation Δ_M in terms of $1/a$: $\Delta_M(1/a) =\mid (1/a)_{1/2} - (1/a)_M \mid$, where $(1/a)_{1/2}$ are limiting values of the interval, which includes 50 percent of all orbits. The probable range of uncertainty is determined by $\pm n^{-1/2}\Delta_M(1/a)$, where n is the number of the meteor orbits used for the median determination $(1/a)_M$. For the sake of comparison, we also derived the deviation of the median $1/a$ from the parent body: $\Delta(1/a)_C =\mid (1/a)_M - (1/a)_C \mid$, where the $(1/a)_C$ is the reciprocal semimajor axis of a parent comet.

Table 2. *Numerical data obtained for the four meteor streams. n - number of meteors; $(1/a)_M$ - the median 1/a; $\Delta_M(1/a)$ - the median absolute deviation; $\Delta_L(1/a)$ - the range of uncertainty; $\Delta(1/a)_C$ - deviation of the median $1/a$ from the parent body.*

Meteor stream/ Parent Comet	*Number of orbits*	$(1/a)_M$	$\Delta_M(1/a)$	$\Delta_L(1/a)$	$\Delta(1/a)_C$
Perseids	$n_{all} = 812$	0.043	0.049	0.002	0.0054
	$n_A = 73$	0.019	0.032	0.004	-0.0189
	$n_B = 739$	0.046	0.053	0.002	0.0074
$P/Swift-Tuttle$		0.038			
Orionids	$n_{all} = 71$	0.051	0.052	0.006	-0.0050
	$n_A = 25$	0.057	0.027	0.005	0.0012
	$n_B = 46$	0.039	0.078	0.012	-0.0167
$P/Halley$		0.056			
Leonids	$n_{all} = 37$	0.080	0.064	0.010	-0.0163
$55P/Tempel-Tuttle$		0.097			
Lyrids	$n_{all} = 17$	0.025	0.042	0.010	0.0068
$C/1861G1(Thatcher)$		0.018			

The results of our analysis are shown in Table II as well as in Figure 3. Table II summarizes the numerical results obtained for the four meteor showers. The Perseids and Orionids were also analysed separately for catalogues A and B. This table contains the median reciprocal semimajor axis $(1/a)_M$, the median absolute deviation $\Delta_M(1/a)$ in terms of $1/a$, the upper limit range of uncertainty $\Delta_L(1/a)$ and the deviation of the median $1/a$ from the parent body. We also list the reciprocal semimajor axis from parent comets. As it is seen, the absolute value of $\Delta(1/a)_C$ is considerably smaller than $\Delta_M(1/a)$ for all four meteor streams.

4. Dispersion of orbital elements in individual streams

The high proportion of hyperbolic orbits among the investigated meteor showers suggests that the measuring errors are a principal source of the observed dispersion. Figure 3 shows that the $a_{1/2}$ limits of the Perseids, Orionids and Lyrids fall clearly beyond the parabolic limit. As it is seen from Table 1, about 26.5% of the catalogued orbits of the Perseids, 29.5% of those of the Orionids, and 35% of those of Lyrids are formally hyperbolic. On the basis of this fact, we can say that the actual dispersion, at least for these three streams, is only a small part of the observed dispersion.

The sample of 812 Perseids allowed us to determine the resulting value of median $a_M = 8.98\,AU$ with an uncertainty of only 0.002. The dispersion for Perseids, described by the median absolute deviation in terms of $1/a$, is

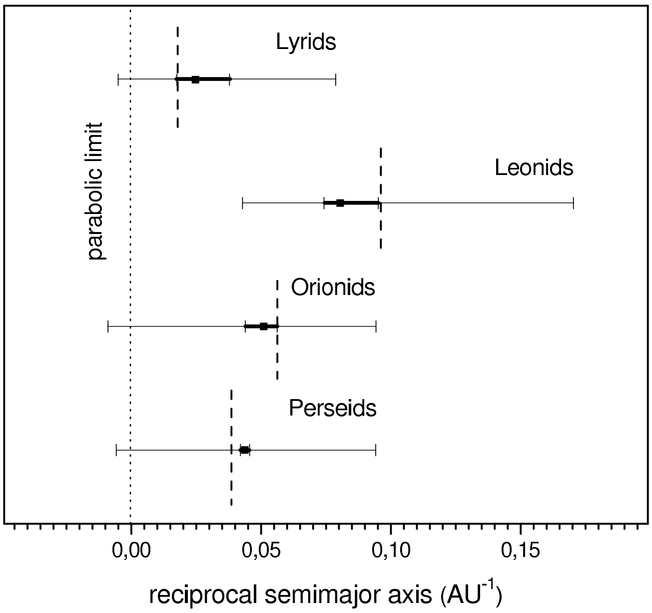

Figure 3. Observed dispersion of semimajor axes within the 4 investigated meteor showers. For each meteor stream it is plotted: Thin line - interval between two limiting values of $(1/a)_{1/2}$, which includes 50 percent of all orbits. Bold line - interval between two limiting values of the uncertainty $(1/a)_L$ of the resulting values of median a_M (square). Dotted vertical line - parabolic limit. Dashed vertical lines - parent comets.

$\pm 0.05\,AU^{-1}$. The median absolute deviation obtained from the orbits of higher precision (catalogues A) $\Delta_M(1/a)$ is 0.032 in comparison with the value of 0,053 obtained from the B catalogues of lower precision.

The median from 71 photographic Orionids is $a_M = 7.49\,AU$ and the absolute median deviation $\pm 0.052\,AU^{-1}$. For this meteor stream, a considerable influence of the dispersion on the quality of orbits is visible. The dispersion of meteor orbits obtained from B catalogues ($\Delta_M(1/a) = 0.078$) is much larger than that obtained using the catalogue A orbits with a higher accuracy ($\Delta_M(1/a) = 0.027$).

For the other two investigated meteor streams, the uncertainty resulting from the limited number of orbits (37 Leonids and 17 Lyrids) is considerably larger. The median absolute deviation Δ_M in terms of $1/a$, obtained for Lyrids from all the photographic MDC catalogues, is $0.042\,AU^{-1}$. The largest observed orbital dispersion, obtained for the Leonid meteor shower, ranges between -0.037 and $0.089\,AU^{-1}$.

Figure 3, as well as Table 2, show that there are no significant differences between the median semimajor axes of the investigated meteor streams and their parent comets. The semimajor axis of the associated comet is on the border of, or very close to, the range of uncertainty for all four meteor streams. This is in agreement with a study by Kresáková (1974), which analysed meteor orbits obtained from the most precise double-station photographic programmes.

5. Conclusions

Precisely-reduced meteor orbits from the photographic catalogues of the IAU Meteor Data Center have been analysed with the aim of determining the orbits' distribution in four chosen meteor streams with heliocentric velocities close to the parabolic limit. From the high proportion of hyperbolic orbits in the analysed catalogues, it has been shown that a major part of the observed differences in the semimajor axes within meteor streams is not due to a real dispersion of orbits but due to measuring errors. Taking into account the different observed dispersions in the different lists of orbits, as well as a large proportion of formally hyperbolic orbits in the analysed photographic observations, the upper limit of real dispersion for Perseids was estimated to be at least one third of the observed value of $0.049\,AU^{-1}$. The actual dispersion for Orionids is slightly higher than one third of that determined from the observations. The dispersion for the other two streams, described by the median absolute deviation in terms of 1/a, is $\pm 0.064\,AU^{-1}$ for Leonids and $\pm 0.042\,AU^{-1}$ for Lyrids. The absolute value of the deviation of the median 1/a from the parent comet of $\Delta(1/a)_C$ is considerably smaller than the median absolute deviation $\Delta_M(1/a)$ for all four meteor streams. The semimajor axis of the associated comet is on the border of, or very close to, the range of uncertainty for all four meteor streams.

Acknowledgements. This work was supported by the Scientific Grant Agency VEGA, grant No 0636.

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