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Meteoroid orbits from video meteors. The case of the Geminid stream

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A B S T R A C T

We use the Slovak and Czech video meteor observations, as well as video meteoroid orbits collected in the CAMS, SonotaCo, EDMOND and **DMS** catalogues, for an analysis of the distribution of meteoroid orbits within the stream of the Geminids and of the dispersion of their radiants. We concentrate on the influence of the measurement errors on the precision of the orbits obtained from the video networks that are based on various meteor-detection software packages and various meteor orbital element softwares.

The Geminids radiant dispersion obtained from the large video catalogues reaches the dispersion of the radio observed Geminids, whereby the diffused marginal regions are affected mostly by meteoroids with extreme values (small or large) of the semi-major axes. Meteoroids of shorter semi-major axes concentrate at the eastern side of the radiant area and those of longer semi-major axes at the western part.

The observed orbital dispersions in the Geminid stream described by the median absolute deviation range from 0.029 to 0.042 AU^{-1} for the video catalogues. The distribution of the semi-major axes of video meteors in all the databases, except for the Ondřejov (Czech) data, seem to be systematically biased in comparison with the photographic and radio meteors. The determined velocities of the video data are underestimated, probably as a consequence of the methods used for the positional and velocity measurements. The largest shift is observed in the EDMOND and SonotaCo catalogues.

Except for the measurement errors which influence the analyses and their interpretations, we also point out the problem of the uncertainties of the numerical integration procedures that influence the simulations' results. Several experimental integrations of the Geminids parent asteroid, which we performed from the present to the past and then back to the year 2015, showed that a complete reproduction, including also the mean anomaly, is only possible for a time span of about 2700 years.

1. Introduction

The recent rapid development of video techniques is reflected in the massive increase in detected meteors. This is of high significance for minor meteor showers radiants determinations, derivations of meteoroid flux densities and other purposes. However, the production of a large number of meteor orbits often comes at the expense of their quality. This is then reflected in the meteor's characteristics and influences further analyses, models of the meteoroid streams and searches for the parent bodies. The biggest problem is the measurement and determination of velocity, as the value of the semi-major axis is very sensitive to the value of the heliocentric velocity. When studying the structure of meteoroid streams through shower meteors, the fact that the original orbital dispersion can be smeared by larger observational and measurement errors has also to be considered. The initial dispersion of meteoroids in a stream is influenced by a number of processes, which appear during different stages of the stream evolution. An overview of the underlying principles of meteor stream formation and evolution has been given by Kresák (1992), Williams (2003), and others. The effect of these processes on the structure of meteoroid streams naturally depends on the type of stream (Williams and Ryabova, 2011). However, Kresák (1992), analyzing widely dispersed annual meteor showers from the photographic catalogues of the IAU MDC, showed that the measurement errors can be two or three orders of magnitude larger than the dispersion produced by planetary perturbations integrated over several revolutions. The most significant source of uncertainty in semi-major axis determination is inaccuracy in the heliocentric velocity v_H. Errors in v_H of 1 km/s correspond to about 0.08 to 0.09 AU^{-1} in 1/a. For short-period meteoroid streams, differences in velocity are less representative and the dispersion in the semi-major axes is smaller. Thus, discovering errors is more difficult because they do not produce a spurious hyperbolicity as clear evidence of their

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presence, as is the case with long-period streams (Hajduková, 2011; Hajdukova, 2013).

The Geminids is one of the largest showers in the meteor databases, which was observed using different techniques and studied by a large number of researchers over a large time scale. A comprehensive review of observational and theoretical studies of the Geminid stream was published by Neslušan (2015). The Geminid meteor shower, observed by video technique, was reported by Ueda and Fujiwara (1993), De Lignie et al. (1983), Elliott and Bone (1993), Andreic and Segon (2008), Jenniskens et al. (2010), Jenniskens et al. (2011), Jenniskens et al. (2016a), Trigo-Rodriguez et al. (2010), Tóth et al. (2011), Tóth (2012), Rudawska et al. (2013), Madiedo et al. (2013), Molau et al. (2015), Molau et al. (2016), and others.

In this study, we concentrate on the influence of both the accuracy of various measurements and the precision of orbit determination on the distribution of meteor orbits within the stream of Geminids and on the dispersion of their radiant points. The dispersions are studied, comparing several catalogues (introduced in Section 2), which enables the specific features of the Geminids, as well as the diversities of the catalogues, to be shown. In Section 3, we describe the dispersion of the Geminids' radiant points, and in Section 4.1, the dispersion of their orbits. We also discuss the dynamics of the Geminid stream in terms of the uncertainties of the numerical integration procedures, which reflect the reliability of the results obtained (Section 5).

2. Video orbits and their precision

The necessity of high quality orbits of video meteors and precision in their velocity measurements has been discussed by Atreya et al. (2012) and Egal et al. (2014), who, to make improvements, introduced the CABERNET (*Camera for Better Resolution Network*) system. The importance of an error analysis was reported by Drolshagen et al. (2014) and Albin et al. (2015) in their analysis of the meteor velocity distribution from the CILBO (*Canary Island Long-Baseline Observatory*) double station video camera data. The accuracy of video meteor orbits was discussed by Skocic (2016), who analysed several major showers obtained by several video networks including *the Croatian Meteor Network*.

In this study, we analyze Geminids from six different video catalogues. The individual samples of the Geminids were obtained using the Welch procedure (Welch, 2001, described in more detail in Section 5). All of them fulfill the Southworth–Hawkins D-criterion for orbital similarity (Southworth and Hawkins, 1963), with the condition $D_{SH} < 0.2$. The data used are summarized in Table 1. The observed orbital and radiant dispersions of video Geminids, including the measurement errors, obtained separately for each catalogue, are compared with those obtained from the photographic and radio Geminids selected from the IAU Meteor Data Center (Lindblad et al., 2003; Neslušan et al., 2014; Lindblad, 2003).

We used data from our own video observations, carried out in the Slovak and Czech Republics, that are collected in the Slovak Video Meteor Network's database (Tóth et al., 2015) and in the Czech Catalogue of Video Meteor Orbits (Koten et al., 2003). We also selected orbits of the Geminids from several video catalogues that were available: the Cameras for Allsky Meteor Surveillance (CAMS) Meteoroid Orbit Database (Jenniskens et al., 2011), Dutch Meteor Society Video Database (De Lignie, 1996), the SonotaCo Shower Catalogue (SonotaCo, 2009), and the European Video Meteor Network Database - EDMOND (Kornoš et al., 2014). The data used are based on various meteor-detection software packages and various meteor orbital element softwares. In this section, therefore, we introduce briefly all the databases of the video networks used, their instrumentation and data reduction.

Table 1
The Geminids analysed in this work. All the orbits from the video catalogues used were selected under the condition $D_{SH} < 0.2$ of the Southworth–Hawkins D-criterion for orbital similarity.

Database	No. of Geminids
The Slovak Video Meteor Network (SVMN)	143
The Czech Catalogue of Video Meteor Orbits (ONDŘEJOV)	74
The Cameras for Allsky Meteor Surveillance (CAMS)	4827
The SonotaCo Shower Catalogue (SONOTACO)	8264
The European Video Meteor Network Database (EDMOND)	2401
The **Dutch** Meteor Society Video Database (**DMS**)	104

2.1. Slovak video meteor network's (SVMN) database

The Slovak Video Meteor Network, governed by Comenius University in Bratislava, consists of four video stations situated in various locations in Slovakia, which monitor meteor activity above Central Europe. The SVMN uses the semi-automatic all sky video cameras (All-sky Meteor Orbit System, AMOS), which record meteors of +4 magnitude and brighter (Tóth et al., 2015). For meteor detection and astrometric data reduction, UFOCapture software and UFOAnalyzer (SonotaCo, 2009) are used. For meteor orbit computation, the new Meteor Trajectory software, based on the Ceplecha (1987) paper, was developed (Kornoš et al., 2015). The program computes orbital and geophysical parameters, together with their uncertainties, based on the Monte Carlo simulation. The velocity determination, giving uncertainties about 0.1 km/s, is still being worked on. So far, the achieved precision is $<3^{\circ}$ in radiant position and <10% in velocity. Data from SVMN are continuously published (Tóth et al., 2015) and contribute to the EDMOND database (see Section 2.5). However, the Slovak data from the SVMN observations are also analysed differently. For the EDMOND, velocity and radiant are calculated as average values from the stations (according to the Sonotaco), while in the SVMN, trajectory and velocity are calculated by our own software (Kornoš et al., 2015) based on Ceplecha (1987) and by fitting the observed meteor velocity.

2.2. Czech catalogue of video meteor orbits (Ondřejov data)

The Czech database of the video meteors (Koten et al., 2003) contains data obtained within the double station observational campaigns carried out in the Czech Republic. These campaigns were dedicated to several selected meteor showers. The video cameras, connected with image intensifiers, were aimed at one particular meteor shower during each campaign, so the geometry of observation was optimized for this shower. The limiting magnitude is +6. The observed data are recorded in time resolution 0.04 second. Records are searched using automatic detection software MetRec (Molau, 1999). Found meteor images are digitalized with a PC frame grabber, transformed into 768×576 pixel, 8-bit monochrome images, and stored as sequences in a non-compressed AVI format. All the recorded meteors are carefully reviewed and only records of good quality are taken into account. Raw data are measured manually and atmospheric trajectories and heliocentric orbits calculated. No automatic reduction or calculation software is applied. Only well proven methods are used for image measurement (Koten, 2002), and trajectory and orbit calculations (Borovička, 1990). The errors of the measurement are propagated through the calculation to the errors of the parameters. The achieved precision is usually a few tenths of a degree in the radiant position and up to 0.5 km/s in the velocity. The database contains only reliable data, at the expense of the total number of trajectories and orbits, which is rather small.

2.3. Dutch meteor society video (DMS) database

The double-station video observations in the Netherlands are among the first video observations of meteors, which started about 30 years