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# Small bodies of the Sun–Jupiter system and meteor showers

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## 1. Introduction

Some small bodies come close to the Earth's orbit so that any dust ejected from them, might be seen as a meteor shower. Sporadic meteoroids cannot be associated with a single parent body [1]. Below, we consider the region of motion of a particle with negligible small mass $m_3$ in the frame of the planar circular restricted three body problem [2]. Let us, $m_1$ and $m_2$ are mass of main bodies, $r_{12}$ is a distance between these bodies, *and* $G$ is the gravitational constant. We find the region of the point motion, – distance $r_3$, ($\boldsymbol{r_3}$=$\boldsymbol{r}_3(x_3, y_3)$) *in* respect of the system center mass, – and numerically investigate the region of the particle stability motion (in closed region), using method of Runge-Kutta integrating, where $N$=50000 is the number of points in the figures.

## 2. Fundamental Equation

In accordance with works [2] we have the vector differential equation (1) of the particle $m_3$ motion in the uniformly rotating system

$$d^2\boldsymbol{r_3}/dt^2+Gm_1(\boldsymbol{r}_3-\boldsymbol{r}_1)/(|\boldsymbol{r}_3-\boldsymbol{r}_1|)^3 + Gm_2(\boldsymbol{r}_3-\boldsymbol{r}_2)/(|\boldsymbol{r}_3-\boldsymbol{r}_2|)^3)-2[d\boldsymbol{r}_3/dt, \boldsymbol{\Omega}]-\Omega^2\boldsymbol{r}_3 = 0. \quad (1)$$

Here, $\boldsymbol{r}_3$ is the radius-vector determined the position of considered point in respect of the center mass of the system. $\boldsymbol{r}_1$ and $\boldsymbol{r}_2$ are radii – vectors in respect of the center mass of the system determined the positions of the Sun with mass $m_1$ and Jupiter $m_2$ correspondingly. $\Omega$ is the angular velocity of uniformly rotation of the major bodies.

$$\boldsymbol{r}_1=-(m_2/(m_1+m_2))\boldsymbol{r}_{12},\ \boldsymbol{r}_2=(m_1/(m_1+m_2))\boldsymbol{r}_{12}, \quad (2)$$

$$\Omega=\sqrt{\frac{G(m_1+m_2)}{r_{12}^3}}\ .$$

## 3. Examples

For the numerical experiments we put $G$=6.672·10$^{-11}$ m$^3$/ (sec$^2$·kg), $m_1$=2·10$^{30}$kg (mass of the Sun), $m_2$ =$m_1$ /1048 is mass of a planet (Jupiter). In the process of the equation (1) solving we use the following units: $m_1$ is the unit of mass, $r_{12}$ is the unit of length, the unit of time $t$ is corresponded for the case $G$=1. Moreover, we put for all considered cases the following *initial* conditions: $x_1\neq0$, $dx_1/dt=0$, $y_1=0$, $dy_1/dt=0$, $x_2\neq0$, $dx_2/dt=0$, $y_2=0$, $dy_2/dt=0$, $x_3\neq0$, $dx_3/dt=0$, $y_3=0$, $dy_3/dt=0$. The results of the numerical experiments in intervals of time motion corresponded hundreds and thousands revolutions of major bodies are presented in Fig. 1 – 4.

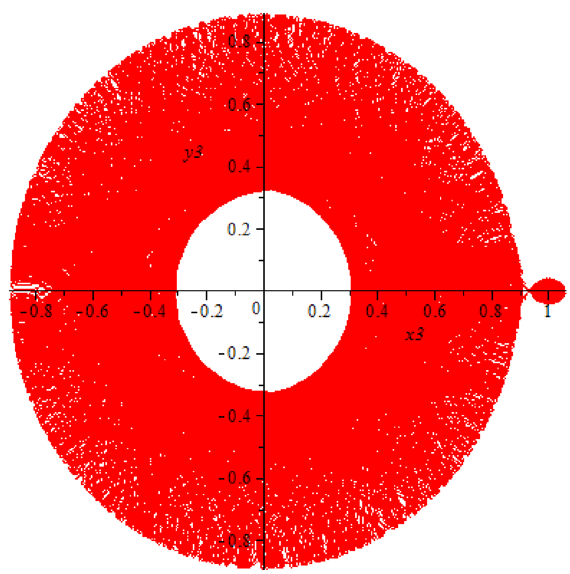


Figure 1: Migration of a meteoroid from Jupiter to Martian orbit. $x_{30}=\varepsilon$, $\varepsilon$=1.0578. t=5000 units of time.

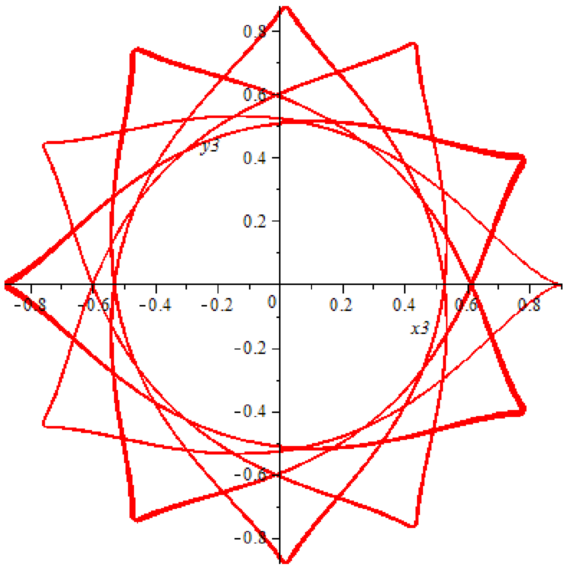


Figure 2: Migration of a meteoroid from Jupiter's orbit to the main belt of asteroids. $x_{30}=\varepsilon$, $\varepsilon=0.9$. t=5000 units of time.

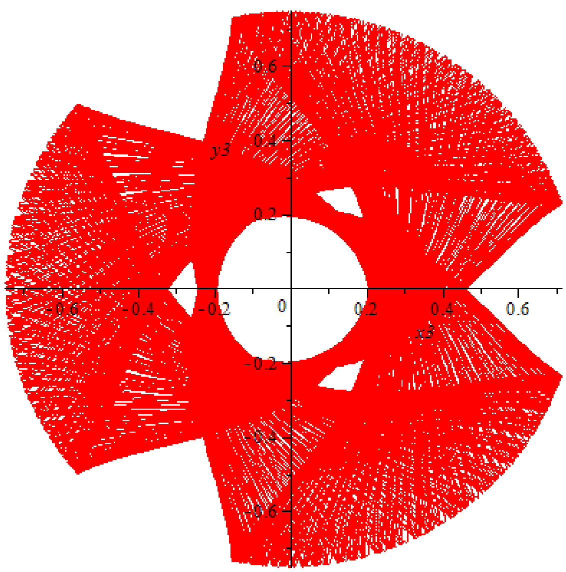


Figure 3: Migration of a meteoroid from the main belt of asteroids to the Earth. $x_{30}=-x_2+\varepsilon$, $x_2 = 1048/1049$, $\varepsilon=0.25$. $y_{30}=0$. t=2000 units of time.

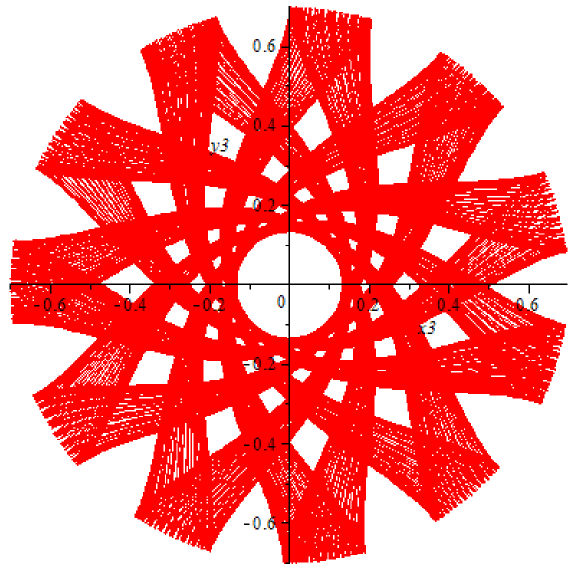


Figure 4: Migration of a meteoroid from the main belt of asteroids to the Earth. $x_{30}=-x_2+\varepsilon$, $x_2 = 1048/1049$, $\varepsilon=0.3$. t=1770 units of time.

## 4. Conclusions

a) Small bodies with zero velocity do not migrate from Jupiter to the Earth. In this case they migrate only to the Martian orbit (Fig. 1) and [2]; b) For the regions **(**Fig.1. – Fig.4.) the velocity of $m_3$ equals zero only in initial moment of time but in the work [2] the corresponding curves are plotted, mainly, only for V≡0; c) In Fig. 2. "Strange" closed trajectory of small body $m_3$ in the system "the Sun and Jupiter" is presented; d) Fig. 1 is not contradicted with the celestial mechanical model of some meteoroids origin (transfers from planet centrically to heliocentrically orbits and vise – verse).

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# Analysis of the structure of Lyrids meteor shower

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## Abstract

Lyrids' structural parameters (luminosity function parameter of r meteors distribution magnitudes, the S parameter distribution of meteoroids in the mass flow, zenithal hour number (ZHR)) are determined by visual observations made in the 1900–2007 interval. The minimal value of S is equal to 1,54 ± 0,02 and corresponds to the Sun longitude 32,19º ± 0,04º. Lyrids' activity profiles as ZHR depending on the L Sun longitude were constructed for studying the flow activity. ZHR averaging for the individual values was held according the observation in 1900–1963, 1900–2000, 2001–2007 and 1900–2007. The peak position for all groups is the same within the error and equal to 32,326º±0,107. It Two periods of lyrids activity were revealed: a period which is close to 60 years; and s period of about 10–12 years.

## 1. Introduction

The Thatcher 1861 I comet, with an orbital period of 415 years, is the parental comet of Lyrids. Lyrids are observed from 16 to 25 April, and have a low annual activity. However, in some years, the flow activity increases, and it is not associated with the comet's approach to the Sun. Four bursts of the flow activity have been reported and described in the literature in 1803, 1922, 1946 and 1982.

These reports discuss the 12-year cycle of the flow activity and its possible causes, primarily related to Jupiter's influence on the meteoroids' motion in the shower. Thus, as a rule, the main research method is the simulation of possible scenarios of Lyrids' meteoroid swarm formation and its further evolution. The study of the shower structure by visual observations, obtained over a long time interval, allows us to clarify the period of the periodic activity of the Lyrids.

Lyrids' structural parameters (luminosity function parameter of r meteors distribution magnitudes, the S parameter distribution of meteoroids in the mass flow, zenithal hour number ZHR) are determined by visual observations of lyrids, made in 1987–2007, under the aegis of the International Meteor Organization (IMO), as well as earlier observations, which were published in various sources.

## 2. Method and results

S parameter distribution of meteoroids in the mass is defined in the following form:

$$S = 1+2.5.\lg r \qquad (1)$$

when the value of function of r luminosity in visual observations is found by the distribution of meteors' magnitudes obtained by an observer for each night of observation.

The method of r and S parameters definition by visual observations is described in detail in [1]-[2].

According to the most statistically secured observations made in 1987–2007, and published on the International Meteor Society (IMS) website for each year of the observations, S individual values calculated by formula (1) were averaged over intervals of the Sun's longitude, taking into account the balance.

At the first stage, S values were averaged separately for each year and in the observation groups in 1987–1999 and in 2000–20007. The comparison of S values in each group showed that the results agree with each other within the errors. Thus, the average S curve as a function of the Sun's longitude was derived by averaging all the 1987–2007 observations.

It's considered averaged values of the parameter S Lyrids, by visual observation in 1987–1999, 2000–2007 and 1987–2007. In contrast to the start period and the end of the air flow, the interval of the Sun's longitude 31º-33º is well provided by observations, so S parameter is held by the dotted line for these areas. The minimum value of S is equal to 1,54±0,02 and corresponds to the Sun's longitude 32,19º±0.04º. Descending and ascending branches performed by the least-squares method are described by the equations.

The values of the S parameter, which were obtained by other authors on the visual and radar observations of the Lyrids, are in the range of 1.54–1.93, which agree with derived values.

Based on the 12-year period of Lyrids' activity, we can analyses the value of S parameter in 1922, 1994 and 2006, compared to the average curve, which was obtained according the observations of 1987–2007. It's showed S values for adjacent 1923, 1993, 1995 and 2005. As can be seen, only S values which were obtained by visual observations in 1922–1923 and radio-observations in 1982 are above the average line. For other years, S ranges are within average values. Thus, the study of the S parameter on the long interval observations showed that it is impossible to reveal any periodic variations of S parameter, associated with a 12-year period of the increasing stream activity. The analysis of the Lyrids' observation shows that the increase of the flow activity can be registered by radio-location method only. There was not a single significant increase in the activity of the Lyrids' stream in the last sixty years according to the visual observations. It is possible that in some years the number of flow increases owing to the small mass of meteoroids which can be recorded by radio only.

Profiles of the Lyrids' activity as ZHR, depending on the Sun's L longitude for each year separately, were constructed for studying the shower activity. ZHR averaging of ZHR individual values was conducted by 1900–1963, 1990–2000, 2001–2007 and 1900-2007 observations for the intervals of the Sun longitude 0.5º–1º. Position of the maximum, which was determined by the intersection of the ascending and descending branches conducted by least squares, is the same for all groups within a mistake and equal to 32.326º ±0.107.

ln (ZHR max) the maximum value found for each year of observation in the 1901–2007.

As can be showed, peaks of shower activity are viewed with the period which equals 10-12 years ZHRmax values for these years, are higher than average value of the activity. The Malycev period of 27 years, which is concerned with Saturn, is not confirmed, since the activity was too low in 1952. The highest values of activity in 1922, 1923 and 1982 give a period which is close to sixty years.

## 4. Summary and Conclusions

Thus, there are two periods of the stream activity which can be assumed. Most probably, the impact of resonances 1:5 (59.4-year period), and 1:1 (11.7-year period) from Jupiter is the cause of the periodic activity of the Lyrids [3]. There is the highest activity of the Lyrids when these periods coincide.

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# African meteorites falls: some statistics

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## Abstract

Since 1801, the number of meteorites falls in Africa continues to grow. 152 falls totaling a mass of 2024.24 kg were recorded, whose 80% were recovered during the period 1920-2014 with an average of 20 falls every 15 years. The average rate of falls is low in Africa with only 0.023 per million $km^2$ per year. This rate is variable in time and in space with privileged regions namely those bordered by the Sahara and southern Africa. Other factors are also involved in the spatial variation of those falls' number: the population, its density, the percentage of forest cover, and the level of awareness about meteorites. As in the worldwide falls, these meteorites are dominated by chondrites (76%).

## 1. Introduction

The scientific contribution of meteorites from Africa is undeniable, they are highly coveted by scientists and collectors worldwide. We are interested in this paper to "falls" that are meteorites seen when they fell from the sky and were subsequently collected. The African continent covers 7% of the terrestrial surface with 30,415,873 km², and 20.3% of the surface of the emerged lands [1]. This large area is supposed to host a large part of the flow of meteorites falls on the Earth.

## 2. Statistics and distribution

152 observed meteorites falls were recorded since 1800, the date when they were recognized as objects falling from the sky. They are totaling a mass of 2024.24 kg. The oldest meteorite fall (L6, 22 grams) was in 1801 in Mauritius [2]. The most recent, dated July 9, 2014, is an Eucrite fragment of more than 10 kg which has exploded in the Tighirt region in southeastern Morocco [3].

Almost all the classes are represented in the collection of meteorites falls in Africa during the study period (Figure 1).

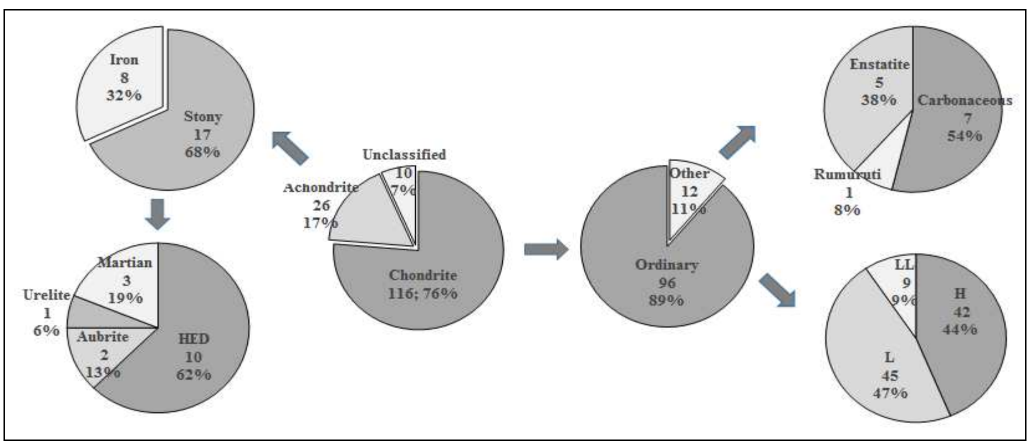


Figure 1. Types and percentages of meteorites falls in Africa.

They include 116 chondrites, 26 achondrites and 10 not classified or uncertain. However, iron meteorites are the rarest types that are seen fallen, representing only 5.9. Three Martian meteorites are present in this collection (Nakhla of Egypt, Tissint of Morocco and Zagami of Nigeria), but no lunar meteorite.

The quantitative study of meteorites falls in Africa reveals varied temporal and spatial distribution. The falls spreading rate has increased from 0.025 meteorites / $10^6$ $km^2$ every 15 years (3 falls only in the continent) during the period 1800-1860, to 0.2 falls / $10^6$ $km^2$ every 15 years (24 falls) between 1860 and 1920. This rate is timed into 3.3 (0.663 falls / $10^6$ $km^2$ / 15 years) during the period 1920-2010 which recorded 121 falls. That is, 80% of collection in the study period (Fig. 1).

The inter-sector comparison allowed to distinguish the regions which host the most meteorites falls: The West Africa has recorded 42 falls totaling mass of 666.12 kg, the third of which

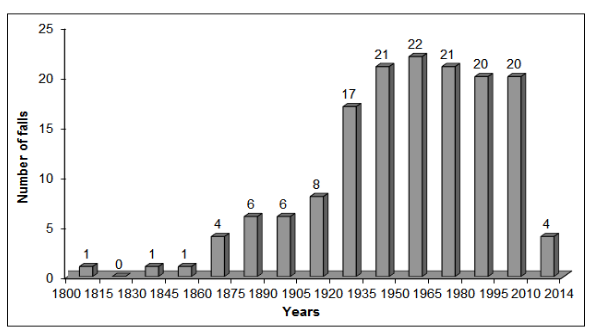


Figure 2: Evolution of meteorites falls' number in Africa between 1800 and 2014.

has fallen in Nigeria. Moreover, 36 falls totaling mass of 515.40 kg were recorded in East Africa: Tanzania presents the highest number (8 falls). The North Africa has documented 35 falls (666.77 kg), 11 of which fell in Sudan. Furthermore, the 9 falls of Morocco totalize the biggest mass recorded (376 kg) in comparison with other countries of the continent. On the other hand, other areas have recorded a low rate of falls. The southern Africa has recorded 26 falls whose 85% fell on South African territories, representing a small mass of about 165 kg. Whereas, the Central Africa has recorded only 15 falls whose mass does not exceed 18.50 kg.

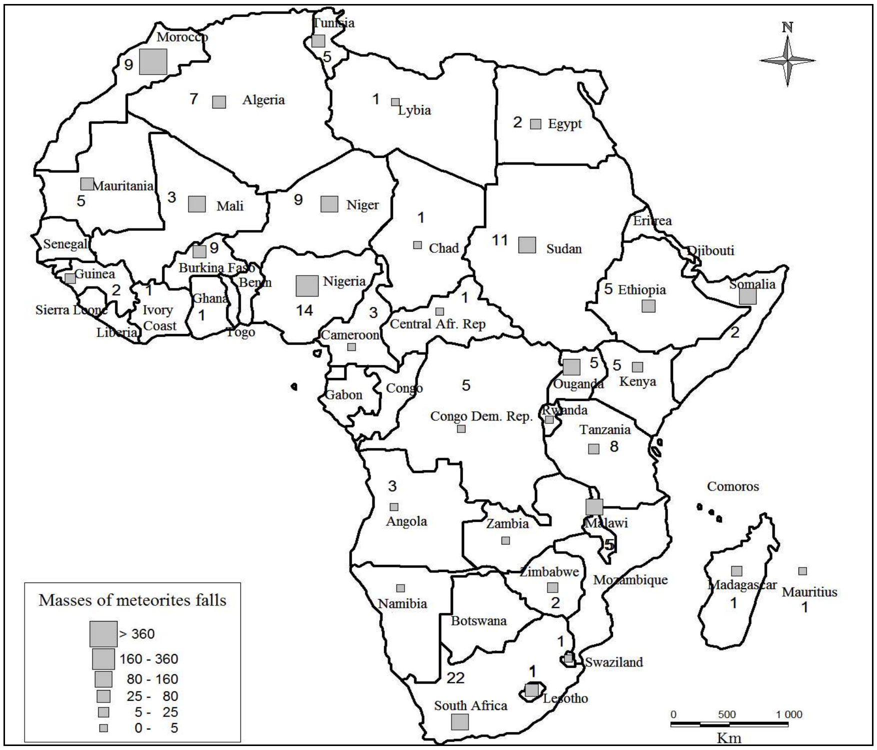


Figure 3: The distribution of numbers and masses (in kg) of meteorites' falls in Africa between 1800 and 2014.

The principal components' analysis applied on 6 variables and the 57 African countries showed that the meteorites falls number in many any of these countries, like Nigeria and South Africa, increases with population and its density. The uneven distribution of the population in other countries makes it difficult for the falls to be discovered. Their rate is low, for example in Libya and Chad and null in many African countries despite their large desert area. The spreading rate is linked to a uniformed distribution of the inhabitants [4].

## 3. Discussion and conclusion

The abundance of chondritic falls in Africa (76.3%) is similar to that observed worldwide representing 86.2% of falls [5]. Almost all the countries bordering the Sahara have a relatively large spreading rate. The discovery of meteorites falls is facilitated by the contrast between these fragments and desert sand and vegetation lack in these areas. Instead, the countries hosting dense rainforest over a large area, have seen little or no falls.

The rate of meteorites' falls in Africa ($0.023/10^6$ $km^2$/year) is twice higher than that known in Australia ($0.011/10^6$ $km^2$/year). Yet, it is still low. This is due to the lack of culture and education about meteorites.

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# A project to predict meteor showers from all potential parent comets

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## Abstract

In this project, new meteor showers associated with known periodic comets have been predicted, new parent bodies associated with known meteor showers have been suggested, and new relationships among the meteor showers that belong to the same complex have been found. Here, we present an overview of our results from the modelling of diverse meteor-shower complexes [1].

## 1. Introduction

Our modelling of theoretical streams and studying their dynamical evolutions for a suitably long period allows us to reveal alterations in the initial orbital corridors of meteoroid streams which were formed due to gravitational action. For a potential parent comet, we model a stream at the moment of its perihelion passage in a far past, and follow its dynamical evolution until the present. Subsequently, we analyze the orbital characteristics of the parts of the stream that approach the Earth's orbit. The modelled orbits of the stream particles are compared with the orbits of actual photographic, video, and radar meteors from several catalogues. The whole procedure is repeated for several past perihelion passages of the parent comet and allows us to map the whole complex of meteoroid particles released from a parent comet.

## 2. The modelled meteor-shower complexes

We have so far investigated 13 parent bodies, the theoretical streams of which often split into several filaments, creating meteor-shower complexes.

Meteor-shower complexes of the comet 96P/Machholz (fig. 1) and of the asteroid 2003 EH1 evolved, after a significant time, into almost identical structures [2, 3, 4]. Both the comet and the asteroid could be regarded as parent bodies of four well-known meteor showers: the daytime Arietids, the southern and northern branches of the δ-Aquarids, and Quadrantids. Their possible association to α-Cetids and to the κ-Velids was suggested. Moreover, the investigation showed that a single parent body can associate showers of both kinds, ecliptical and toroidal [3, 4, 5]. The ecliptic-toroidal structure is seen transparently in these models.

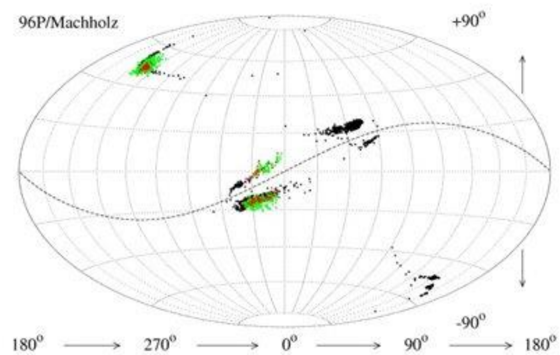


Figure 1: The meteor-shower complex of the comets 96P/Machholz. The radiants calculated from the modeled orbits (black dots) are compared with those of the real meteors from the video (green) and photographic (red) observations. The positions of the radiants in right ascension and declination are shown in the Hammer projection of equatorial coordinates.

The examination of the comet C/1917 F1 Mellish [6] confirmed the generic relationship between the comet and the December Monocerotids, suggested its possible association to the April ρ-Cygnids, and excluded its relation to the November Orionids.

We also modelled the theoretical streams of two comets in orbits situated at a relatively large distance from the orbit of Earth, 126P/1996 P1 and 161P/2004 V2. The analyses showed that parts of the streams cross the Earth's orbit and, eventually, could be observed as meteors, prevailingly on the southern hemisphere [7]. Another new meteor shower predicted in the southern sky is a result of modelling the stream of the comet 122P/de Vico [8] (fig. 2). Identification with real meteors was negative. However, there seems to be quite a high chance of discovering at least some of them in the future, with an expected increase in observations of the southern hemisphere.

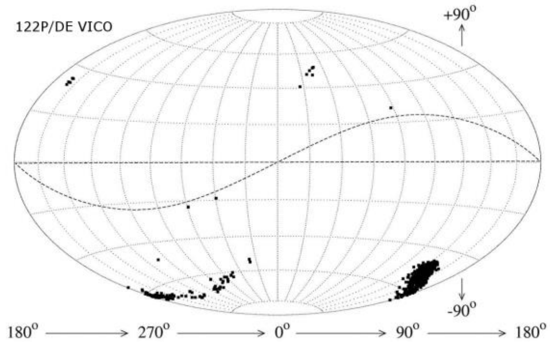


Figure 2: Radiants of a new meteor-shower, associated with the comet 122P/de Vico, which is predicted in the southern hemisphere.

Currently, we are dealing with the complex of asteroid 3200 Phaethon, which is the parent body of the well-known major shower Geminids and also of the daytime Sextantids. It appears that the particles released from the Phaethon cannot exactly evolve to the orbits of observed Geminids if we take into account only the gravitational action of the Sun and the planets. Their dynamical evolution is most probably significantly influenced also by non-gravitational effects (Poynting-Robertson drag).

## 3. Summary and Conclusions

In this project, we have investigated more than ten parent bodies. The examination is based on the modelling of a theoretical stream for several moments of the perihelion passages of a parent body in the distant past, monitoring its orbital evolution up to the present, selecting that part of the stream which approached the Earth's orbit, and comparing the characteristics of this part with the corresponding observed meteor shower. New meteor showers, mainly in the southern hemisphere, were predicted and new parent bodies of meteor showers, resp. new relationships between observed showers, were suggested.

Moreover, it was shown that a single parent body can associate multiple showers, and that a shower can be associated to multiple parent bodies. The shower radiants of all meteor-shower complexes that were examined are distributed on the sky symmetrically with respect to the Earth's apex.

## Acknowledgements

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# Latest news on the modeling of meteor showers

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## Abstract

This talk will provide a review of the techniques used for the modeling of meteoroid streams in the Solar System. New features induced by resonances will be presented. Consequences for the forecasting of the meteor showers will be presented. Similarly, the multiplication of meteor orbit determination allows for the finding of new parent bodies. Exploration of the past allows us to better know the today Earth meteoroid environment. Special focus will be provided for the Perseid stream as well as comet C/1917 Mellish. The finding of new parent bodies is an ongoing process and latest confirmed bodies will be presented.

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# The video Geminids

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## Abstract

In this study, we concentrate on the influence of errors on the distribution of meteor orbits within the stream of Geminids and on the dispersion of their radiant points. The accuracy and dispersion of the orbital elements are studied, comparing several catalogues, which enables the specific features of the Geminids, as well as the diversities of the catalogues, to be shown.

## 1. Introduction

The initial dispersion of meteoroids in a stream is influenced by a number of processes, which appear during different stages of the stream evolution. The orbits of the Geminids indicate that the gravitational forces of the other outer planets are negligible, so the stream structure is dominated by their initial spread and the non-gravitational effects. Therefore, the Geminids are rather a compact stream as it was shown in various Geminid stream models, e.g. [1, 2].
However, when studying the structure of meteoroid streams, the fact that the original orbital dispersion can be smeared by much larger observational and measurement errors also has to be considered. Kresak [3], analyzing photographic shower meteors of the IAU MDC, showed that, for the widely dispersed annual meteor showers, the measurement errors can be two or three orders of magnitude larger than the dispersion produced by planetary perturbations integrated over several revolutions. For the short-period meteor showers, the differences in the velocities are, however, less representative, and the dispersion in the semi-major axes smaller. Discovering errors is more difficult because they do not produce a spurious hyperbolicity as clear evidence of their presence, as is the case with long-period showers [4, 5].

## 2. Video meteor orbits

Meteor orbits of Geminids were selected from the European Video Meteor Network Database (EDMOND) [6], the Czech Catalogue of Video Meteor Orbits [7], the Cameras for Allsky Meteor Surveillance (CAMS) [8], and the SonotaCo Shower Catalogue [9]. The observed orbital dispersions of video Geminids, including the measurement errors, were compared with those obtained from the photographic and radar orbits of Geminids selected from the IAU Meteor Data Center [10, 11]. The semi-major axes of meteor orbits in almost all the video datasets seem to be systematically biased in comparison with the photographic and radar meteors. The observed distributions in 1/*a* are shifted towards higher values of 1/*a*. The determined velocities seem to be underestimated (fig. 1), probably as a consequence of the methods used for the measurement of the meteor positions, and/or the orbit determinations, presumably by absent or insufficient correlations for atmospheric deceleration.

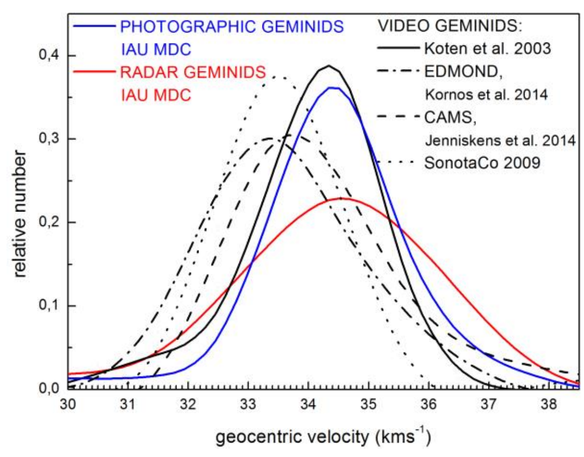


Figure 1: Normalised distributions of the geocentric velocities of the video Geminids from the different catalogues used and compared with the photographic and radar Geminids from the IAU MDC.

## 3. The observed orbital dispersion

The observed dispersions were described by the median absolute deviation in terms of 1/a, and ranges from 0.029 to 0.042 $AU^{-1}$ for the video catalogues.

Their comparison with the Geminids' dispersion from the photographic and radar data is shown in figure 2. The deviation of the median reciprocal semi-major axis from the parent, (3200) Phaethon, obtained from the photographic and radar orbits of the IAU MDC, and from the Czech Video Orbits Catalogue, is significantly larger than it was in the case of the other meteor showers investigated [4, 5]. The smaller deviations visible in the other video datasets are only a consequence of their above-mentioned shift. The actual reason for this deviation can be found when investigating the dynamical evolution of the Geminid meteoroids.

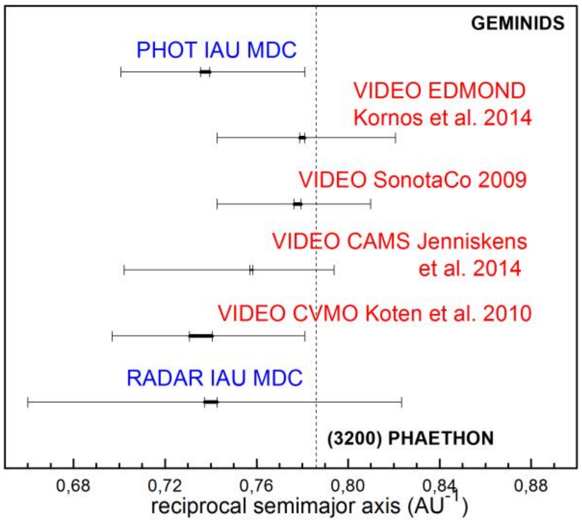


Figure 2: Observed orbital dispersion for Geminids described by absolute median deviation in terms of $1/a$: Thin line - interval between two limiting values of $(1/a)_{1/2}$, which includes 50 percent of all orbits. Bold line - interval between two limiting values of the uncertainty $(1/a)_L$ of the resulting values of median $(1/a)_M$. Dashed vertical lines - parent body.

## 4. Summary and Conclusions

The observed dispersions of Geminids is moderate and does not differ significantly between the different video sets of data. It clearly demonstrates that the Geminids are a strongly concentrated meteoroid stream. The observed dispersions in 1/a differs slightly between the datasets obtained by different observational techniques, which may be partly a consequence of different dispersions in the orbital elements for particles belonging to different mass ranges. The orbital characteristics of Geminids, including their dynamical evolution, and a further detailed error analysis concerning different catalogues will be presented.

## Acknowledgements

The work was supported, by the Slovak Grant Agency for Science VEGA, grant no. 1/0225/14, by the Slovak Research and Development Agency under the contracts no. APVV-0517-12, and by the Grant Agency of Czech Republic, grant no. 14-25251S.

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# Recent meteor showers – models and observations

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## Abstract

A number of meteor shower outbursts and storms occurred in recent years starting with several Leonid storms around 2000 [1]. The methods of modeling meteoroid streams became better and more precise. An increasing number of observing systems enabled better coverage of such events. The observers provide modelers with an important feedback on precision of their models. Here we present comparison of several observational results with the model predictions.

## 1. Introduction

The double station observations using video technique are carried out by the Ondrejov observatory team for many years [2]. Besides the regular observations of the meteor showers the campaigns are also dedicated to predicted meteor storms and outbursts. The team participated to several international campaigns during recent Leonid meteor shower return as well as on the Draconid airborne campaign in 2011. The main goal of this experiment is the determination of the meteor trajectories and orbits and the meteor shower activity is also measured and compared with predictions.

## 2. Method

To construct the meteor shower activity curve we calculate the number of shower meteors in certain time intervals – usually 10 minute long. Then the correction on the zenith distance of the radiant is performed. Finally using this corrected number we calculate the corrected hourly rate of meteors as well as its error. An example is given in Figure 1. In this case the data from different video cameras as well as the visual data were available what allows us to distinguish some interesting features of the 2011 Draconid meteor shower outburst [3].

## 3. Meteor showers

Among the most studied meteor showers is the Leonids due to recent return of their parent comet. Outbursts and storms between 1998 and 2002 and also another event in 2009 were observed and analyzed. The Draconid outbursts in 2005 and 2011 were also covered. Especially the latter was observed intensively using different instruments onboard two aircraft [4].

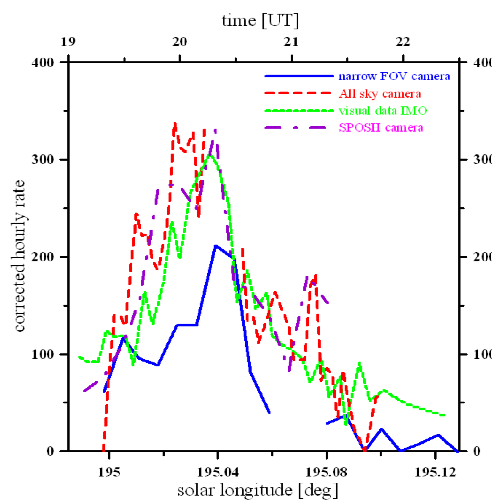


Figure 1: Comparison of activity profiles recorded by different cameras during 2011 Draconid outburst.

On the other hand there were also several unsuccessful campaigns – for example Phi Cassiopeiids on December 2012 when the prediction failed and the outburst did not occurred.

## 4. Summary

The observations show that in the case of established meteor showers (Leonids, Draconids…) the predictions are very successful in terms of the time. In many studied cases the peak of activity occurred within few minutes around predicted time. The rate of the meteors remains rather unpredictable.

On the other hand predictions are less successful in case of less known meteor showers when the data on parent comet are uncertain or even unknown.

## Acknowledgements

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# Polish Fireball Network

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## Abstract

The PFN started in March 2004. Most of its observers are amateurs, members of Comets and Meteors Workshop. The network consists of 38 continuously working stations, where nearly 70 sensitive CCTV video and digital cameras operate. We create the PyFN software for trajectory and orbit calculation.

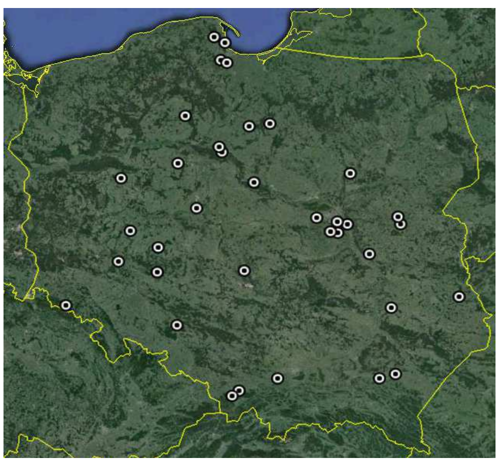

Figure 1: Positions of Polish Fireball Network video and photographic stations

## 1. Introduction

Since 2004 the Polish sky has been patrolled by cameras of Polish Fireball Network (PFN). Most of PFN observers are amateurs, members of Comets and Meteors Workshop and perform observations from their homes. Some stations are located in astronomical clubs and schools [1].

Table 1: List of PFN stations

| ID | Name | Equipment 3 |
|---|---|---|
| PFN03 | Złotokłos | PAVO3 |
| PFN06 | Kraków | PAVO6, PAVO7 |
| PFN13 | Toruń | PAV14 |
| PFN17 | Gdynia | PAV20, PAV21 |
| PFN19 | Kobiernice | PAVO8 |
| PFN20 | Urzędów | PAV25, PAV26, PAV38 |
| PFN24 | Gniewowo | PAV12, PAV40 |
| PFN30 | Wrocław | PAV33, PAV34 |
| PFN31 | Szamotuły | PAV28, PAV29, PAV30, PAV31 |
| PFN32 | Chełm | PAV35, PAV36, PAV43, PAV60 |
| PFN35 | Białków | PAV39 |
| PFN37 | Nowe Miasto Lub. | PAV41 |
| PFN38 | Podgórzyn | PAV44, PAV49, PAV50 |
| PFN39 | Konin | PAV42 |
| PFN40 | Otwock | PAVO9, PAV52 |
| PFN41 | Twardogóra | PAV45, PAV53 |
| PFN42 | Błonie | PAV47, PAV48, PAV56, PAV58 |
| PFN43 | Siedlce | PAV27, PAV61, PAV67 |
| PFN45 | Łańcut | PAV55 |
| PFN46 | Grabnik | PAV57 |
| PFN47 | Jeziorko | PAV13, PAV62, PAV63, PAV65 |
| PFN48 | Rzeszów | PAV59, PAV64 |
| PFN49 | Helenów | PAV23 |
| PFN51 | Zelów | PAV22 |
| PFN52 | Stary Sielc | PAV66, PAV75 |
| PFN53 | Belęcin | PAV68 |
| PFN54 | Lęgowo | PAV69 |
| PFN55 | Ursynów | MDC01, MDC02 |
| PFN56 | Kolbudy | PAV71 |
| PFN57 | Krotoszyn | PAV70 |
| PFN58 | Opole | PAV72 |
| PFN60 | Bystra | PAV74 |
| PFN61 | Piwnice | PAV10 |
| PFN62 | Jabłonowo | MDC03 |
| PFN63 | Dobrzyń | MDC04 |
| PFN64 | Gostycyn | MDC05 |
| PFN65 | Żnin | MDC06 |

Figure 2: PF191012 Myszyniec fireball captured by all sky photographic camera at station PFN43.

The project also involved the Warsaw University Astronomical Observatory (OAUW), the Nicolaus Copernicus Astronomical Center (NCAC) and the National Centre of Nuclear Research RC POLATOM

## 2. Current status of PFN

The network consists of 38 continuously working stations, where 58 video cameras and 6 digital cameras operate. Map of PFN is presented on Figure 1. Detailed information about PFN stations is combined in Table 1.

We use sensitive CCTV video cameras (PAV). Most of cameras are equipped with CCTV lenses with a focal length f = 4 mm and F/1.2 what gives 65.6×49.2° field of view. Typical resolution of 5 minutes per pixel. Limiting magnitude of the system is +2 magnitude for meteors [1]. We use MetRec [2] software and UFOCapture[3] software for meteor detection. RecoStar and UFOAnnalyzer software are used for astrometric reduction of video recordings.

Newest "Meteor Digital Cameras" (MDC) cameras are based on sensitive digital cameras with wide or fish eye lenses.

We use also photographic equipment based on standard DSLR Canon cameras with wide angle lenses. All cameras work with shutter which produce brakes in meteor images for velocity estimation. Using this setup, on the night of Oct 18/19, 2012, at 00:23 UT, we recorded a −14.7 mag fireball – the highest Orionid meteor ever recorded [4] (see Figure 2).

Detections from all cameras are automatically transmitted via internet to central server where double station events are detected, analysed and then trajectory and obit is determined. All calculations are checked by manual inspection.

We create the PyFN software for trajectory and orbit calculation. PyFN utilize the Celpeha method described in [5].

Our Meteorite Section is the only group in Poland specialized in searching of meteorites with tested and validated methods of exploration. The main task of the Section is to find the meteorites dropped from bolides registered by Polish Fireball Network and offer them for free as the research material for the scientific institutions.

## 3. Summary and Conclusions

Combination of sensitive video cameras and photographic cameras allows us to record with good accuracy both, large number of faint meteors and unsaturated fireballs. We are preparing to setup new high resolution video and spectroscopic systems .

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# Use of the IMEX model to characterise meteor showers in the inner solar system

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## Abstract

The Interplanetary Meteoroid Environment for Exploration (IMEX) is an ESA funded project that aims to model recently produced cometary dust trails and meteoroid streams in the inner solar system. The result is a database of these trails that is relevent for studying (1) meteor showers at the Earth and other planets, (2) dust trails observed in the vicinity of comets, and (3) the impact hazard these streams pose to spacecraft and spacecraft subsystems. Here we discuss how this model can be used to understand meteoroid streams that intersect Earth, Mars, and other planets.

## 1. Introduction

Dust in the inner solar system is comprised of a static interplanetary dust cloud along with time-variant cometary and asteroidal dust streams in the vicinity of the orbits of these parent objects. The Interplanetary Meteoroid Environment for Exploration (IMEX) aims to extend ESA's Interplanetary Meteoroid Environment Model (IMEM) (which describes the interplanetary background dust cloud [1]) by characterising recently created cometary trails. The goal therefore is to understand where and when strong meteor showers of recent dust can occur anywhere in the solar system - including at the loctions of planets and spacecraft. Although designed for impact hazard assessment, the model can be applied to numerous scientific applications.

## 2. The IMEX model

Our IMEX model provides trajectories for a large number of dust particles released from $\sim$ 400 short-period comets. These are produced by emitting particles from the orbits of Halley-type, Jupiter family and Encke-type comets, and integrating their trajectories under solar and planetary gravity, radiation pressure and the Poynting-Robertson effect. These integrations are performed by the Constellation distributed computing platform (http://aerospaceresearch.net/constellation), in which the computational load of integrating millions of particle trajectories is divided between many individual computers. The dust trajectories can be retrieved from the database on a given date 1980-2080, either for all particles from one comet, or for all particles near a position in the inner solar system.

Because the model only deals with very recently emitted dust (for Halley-type comets from calender year 1700, and for Jupiter family and Encke-type comets from calender year 1850), the structures produced by the model at Earth are more analogous to meteor storms than meteor showers. Studies of individual showers can help constrain comet parameters (such as the emitted dust mass distribution and comet dust emission speeds), as well as providing information on storm events that occur at other planets or locations in the solar system. We are applying the model to understand meteor storms at various planets. Here we present initial results at Earth, Mars, and Mercury.

## Acknowledgements

This work was funded under ESA contract, and supported by Constellation, a young academics group supported by the German Society for Aeronautics and Astronautics DGLR in Stuttgart, Rechenkraft.net e.V. and Selfnet e.V. We thank all individual Constellation users for their computing time.

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# Orbit determination and analysis of meteors recently observed by Finnish Fireball Network

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## Abstract

We perform orbit determination and analysis of three fireballs recently observed by Finnish Fireball Network (FFN). Precise orbit determination was performed by using integration of differential equations of motion. This technique was implemented into free distributable software "Meteor Toolkit". Accounting of several perturbing forces are discussed. Also estimation of accuracy of orbital elements was obtained by propagation of observational error with using covariance transformation. Long-term backward integration was provided as well.

## Introduction

Currently, Finnish Fireball Network is successfully working and new observational information was obtained by its station. This is a very important to promptly process the observational data. In our work we perform an orbit determination and analysis of new observational information, obtained by FFN.

## Observational data

Orbits were determined by using observational data obtained by Finnish Fireball Network, which include 24 stations and covered about 400000 sq. km area of Finland and surrounding areas. Raw data – visual atmospheric trajectory was processed using software fb_entry [1].

Table 1. ID of considered meteoroids, and date of events.

| Fireball ID | Epoch of event, UT |
|---|---|
| FN20101226 | 2010 12 26:14:06:09.0 |
| FN20130913 | 2013 09 13:22:33:47.0 |
| FN20140925 | 2014 09 25:3:12:15.0 |

## The method of orbit determination

In our work, we use already presented [2] and successfully applied [3] approach to meteors orbit determination. This technique based at strict transformations of coordinate and velocity vectors recommended by IAU International Earth Rotation and Reference Systems Service (IERS) [4] and backward numerical integration of equations of motion. It should be noted that a similar approach was applied by [6] for the Chelyabinsk meteorite orbit reconstruction using the "mercury6" software [7]. Backward integration of equations of perturbed meteoroid motion

$$\ddot{\bar{\mathbf{r}}} = -\frac{GM_{sun}}{r^3}\bar{\mathbf{r}} + \ddot{\bar{\mathbf{r}}}_{Earth}\left(C_{nm}, S_{nm}, \bar{\mathbf{r}}, t\right)$$
$$+\ddot{\bar{\mathbf{r}}}_{Moon}\left(\bar{\mathbf{r}}, t\right) + \sum \ddot{\bar{\mathbf{r}}}_{planets}\left(\bar{\mathbf{r}}, t\right) + \ddot{\bar{\mathbf{r}}}_{atm}\left(\bar{\mathbf{r}}, t\right)$$

was performed by an implicit single-sequence numerical method [5]. The equations of perturbed meteoroid motion include central body (Sun) attraction, perturbations from Earth gravity field, Moon, other planets, and atmospheric drag. For obtaining undistorted heliocentric orbit backward integration was performed until the meteoroid intersection with the Hill sphere (i.e. about 4 days backwards in this case).

A software tool for determination of orbit of meteoroids was development. This software has a graphics user interface and uses SPICE [8] routines and kernels for coordinate transformation and computing ephemeris. One of the results of this visualization we presented at the Figure 1. Now we work towards improving the portability of our application.

## Results and discussion

After orbit determination, we produce analysis of orbital motion of meteoroids. This analysis include long-term backward integration. The interval of integration was a thousand years. During the integration, we take into account perturbations by all Solar system planets. Below we briefly discuss result obtained for meteor FN20140925. As we can see at figure 1 most strong perturbation forces are Earth and Jupiter attraction. There probably were several close approaches meteoroid to the Earth before impact (see red spike at the figure 1). Concerning the attraction of Jupiter, we can see a rather different picture. Mean values of meteoroid semi-major axis is oscillates about 2.55 a.u. which corresponds to 4 years orbital period. The ratio of meteoroid's and Jupiter's orbital periods is close to 1:3. There are two periods of change perturbation forces by Jupiter: one period is approximately 12 years and other is 120 years. Influence of this periodical perturbation we can see on the orbital elements. In this paper we perform graph only for semi-major axis (figure 2), nonetheless perturbation with the similar periodical character we can see for other orbital elements.

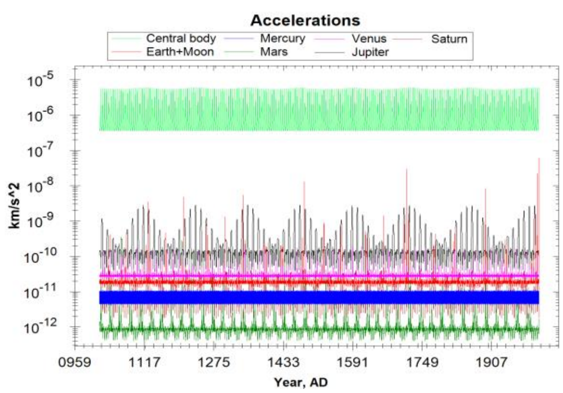


Figure **1**. Acceleration in motion FN20140925 during one thousand years backward integration.

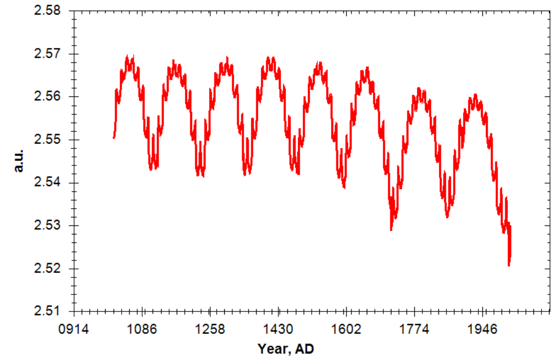


Figure **2**. Value of semi-major axis of FN20140925 during the one thousand years before impact.

## Acknowledgments

Meteor Toolkit uses freely distributed procedures and kernels of SPICE system [8] and the authors are grateful to its developers. V. Dmitriev, V. Lupovka, and M. Gritsevich carried out his work at MIIGAiK and supported by the Russian Science Foundation, project No. 14-22-00197. We would like to thank members of the Finnish Fireball Network for their observational efforts: Jarmo Moilanen, Asko Aikkila, Aki Taavitsainen, Jani Lauanne, Pekka Kokko, and Panu Lahtinen. Matti Tarvainen (Institute of Seismology, Department of Geosciences and Geography, University of Helsinki, Finland) and Peter Völger (Swedish Institute for Space Physics (IRF), Kiruna, Sweden) are kindly acknowledged for providing the seismic and atmospheric data used in fireball data analysis.

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# Meteor observations of the Perseids 2015 using the SPOSH cameras

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## Abstract

We will organize a meteor campaign in Greece focusing on the observation of the meteor activity during this year's maximum of the Perseids meteor shower. Double-station observations will be carried out from $10^{th}$ until $14^{th}$ of August using SPOSH cameras. During this period, we anticipate rates up to 100 Perseids per hour. The participation of graduate students during the observations and the data reduction will strengthen the educational aspect of the campaign.

## 1 Introduction

Perseid meteors occur every year when the Earth crosses the orbital path of the comet 109P/Swift-Tuttle on August 12-13. Near the peak, Perseids reach a Zenithal Hourly Rate of 100, with even stronger activity sometimes observed for instance during the perihelion passage of the comet in 1992 with recorded ZHRs of a few hundreds [3]. Perseids are among the few meteor showers producing such a high number of meteors every year, owing to the long lifetime of the parent body and its stable orbit.

## 2 Observations

The meteor observations will be carried out between the $10^{th}$ and the $14^{th}$ of August with the shower maximum occuring in the early hours on the $13^{th}$ of August. Two observing sites will be equipped with a *Smart Panoramic Optical Sensor Head* camera system [4]. The SPOSH cameras have been designed to image short-lived phenomena under low light conditions which makes them ideal for observing meteors. Similar to all-sky cameras, the custom-made wide angle lens system of the SPOSH offers a 120° rectangular field-of-view. The observing sites are ideally located on mountainous areas with the nearest cities being ~20 km away. This ensures a sufficiently dark sky which allows the camera to detect up to +9 magnitude stars. Meteor observations around the Perseids maximum will benefit from the new Moon on the $14^{th}$ of August.

## 3 Data Reduction

The data acquired during the observing campaign will be processed using software developed at the Technical University of Berlin (TUB) and the German Aerospace Center (DLR). The calibration software uses stars presented in the images with their positions known from star catalogs to compute the orientation of the camera in space [2]. Then a detection algorithm searches all the images for meteor-like features. Finally, the trajectories of meteors recorded from both stations are determined using standard methods [1]. The velocity of a meteor is computed with the help of a rotating shutter which is mounted in front of the camera lens for the estimation of the meteor duration. Using this additional information, the heliocentric orbit of the meteoroid is also calculated.

## Acknowledgements

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# Limitations of the current methods used to compute meteors orbits

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## Abstract

The Cameras for BEtter Resolution NETwork (CABERNET) project aims to provide the most accurate meteoroid orbits achievable working with digital recordings of night sky imagery. The level of performance obtained is governed by the technical attributes of the collection systems and having both accurate and robust data processing. The technical challenges have been met by employing three cameras, each with a field of view of 40°x26° and a spatial (angular) resolution of 0.01°/pixel. The single image snapshots of meteors achieve temporal discrimination along the track through the use of an electronic shutter coupled to the cameras, operating at a sample rate between 100Hz and 200Hz. The numerical processing of meteor trajectories has already been explored by many authors. This included an examination of the intersecting planes method developed by Ceplecha (1987), the least squares method of Borovicka (1990), and the multi-fit parameterization method published by Gural (2012). After a comparison of these three techniques, we chose to implement Gural 's method, employing several non-linear minimization techniques and trying to match the modeling as close as possible to the basic data measured, i.e. the meteor space-time positions in the sequence of images. This approach results in a more precise and reliable way to determine both the meteor trajectory and velocity through the atmosphere.

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# Could the Geminid meteoroid stream be the result of long-term thermal fracture?

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## Abstract

The previous models by Ryabova have shown that the Geminid meteoroid stream has cometary origin, so asteroid (3200) Phaethon (the Geminid's parent body) is probably a dead comet. Recently (in 2009 and 2012) some week activity was observed (see Jewitt & Li, 2010, AJ, 140), but it was not the cometary activity. Recurrent brightening of Phaethon in perihelion could be the result of thermal fracture and decomposition. In this study we model the long-term dust release from Phaethon based on this mechanism.

## 1. The reason for the study

### 1.1 First qualitative model

Some time ago the work on the *qualitative* model of the Geminid meteoroid stream was completed [1, 2]. The main discovery was that the stream has two layers, and the peculiar bimodal shape of the observed activity profile conforms to *cometary scenario* of the stream origin. To calculate orbital evolution of meteoroids the method of nested polynomials was used, which is about $10^6$ times faster than numerical integration, so it was possible to use statistically-rich models in 10 millions of meteoroid orbits.

### 1.2 Second numerical model

However the use of approximations has some shortcomings, considered in detail by Ryabova [1]. In the result the model stream turned out to be shifted in space and more compact relatively the real stream. The next step was the *quantitative* model. Numerical integration is expensive: to calculate a frugal model in 30 000 of particles a usual desktop computer has to make calculations about one month; therefore it is reasonable to begin with a preliminary model [3, 4]. It was found that the stream width increased insignificantly, so gravitational perturbations and encounters with the planets are not responsible for the mentioned discrepancy. The shower maximum in the numerical model is still shifted about one day relatively the observed one. We again come to Lebedinets [5] hypothesis that the parent body orbit underwent the drastic transformation during rapid release of the volatiles. Such transformation explains both discrepancies. Unfortunately, it is hardly possible to calculate the initial parent body orbit, if it is the case.

### 1.3 (3200) Phaethon activity

The Geminid's parent body asteroid (3200) Phaethon was discovered in 1983. Since then no activity was observed until 2009, when Jewitt & Li [6] found evidence of week activity. The same was observed in 2012 [7]. In both years the scenario was identical: about 0.5 days after perihelion passage Phaethon brightened very fast by 1 mag, and the brightness returned to its normal level within 2 days.

Jewitt & Li [6, 7] have analyzed four possible reasons for the brightening, and considered that the most plausible is the dust production by thermal fracture and decomposition. They estimated the ejected mass as $4{\times}10^8 a_{\rm mm}$ kg, where $a_{\rm mm}$ is the effective dust radius in mm. The mass of the Geminid stream according to highly uncertain estimates is $10^{12}$ to $10^{13}$ kg [8, 9]. So theoretically the stream could be produced by this periodical replenishment during several thousand years.

As it was mentioned above, the results of the Geminid modelling lead us to cometary origin of the stream. Moreover, they suggest that the dust release has happened during very short time — from one half and up to several orbital revolutions. Nevertheless, I believe that simulation the contrary scenario could clarify the situation.

## 2. Model

The method of modelling was described in details by Ryabova [1]. Taking into account that the Geminid's age is about 2 thousand years [10], and that from all ejected particles only small amount is registered on the Earth, it is not advisable to use numerical modelling. The main idea is simple: to simulate particles ejection in perihelion every several revolutions and follow their evolution till the present time.

On the moment of this abstract presenting there are no results to analyse. I could only predict that the model activity curve should be very different from the observed Geminid profile of activity.

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# Independent Identification Method applied to EDMOND and SonotaCo databases

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In recent years, networks of low-light-level video cameras have contributed many new meteoroid orbits. As a result of cooperation and data sharing among national networks and International Meteor Organization Video Meteor Database (IMO VMDB), European Video Meteor Network Database (EDMOND; [2, 3]) has been created. Its current version contains 145 830 orbits collected from 2001 to 2014. Another productive camera network has been that of the Japanese SonotaCo consortium [5], which at present made available 168 030 meteoroid orbits collected from 2007 to 2013.

In our survey we used EDMOND database with SonotaCo database together, in order to identify existing meteor showers in both databases (Figure 1 and 2). For this purpose we applied recently intoduced independed identification method [4]. In the first step of the survey we used criterion based on orbital parameters ($e$, $q$, $i$, $\omega$, and $\Omega$) to find groups around each meteor within the similarity threshold. Mean parameters of the groups were calculated using Welch method [6], and compared using a new function based on geocentric parameters ($\lambda$, $\alpha$, $\delta$, and $V_g$). Similar groups were merged into final clusters (representing meteor showers), and compared with the IAU Meteor Data Center list of meteor showers [1]. This poster presents the results obtained by the proposed methodology.

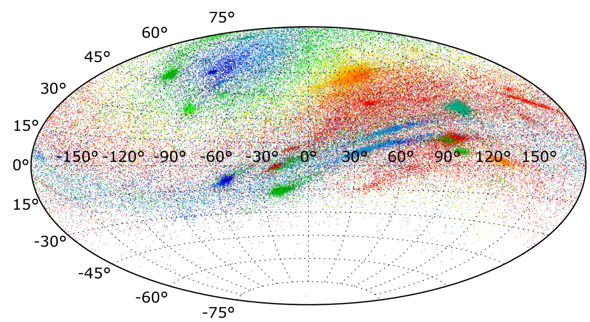


Figure 1: Radiants of all meteors in the EDMOND database.

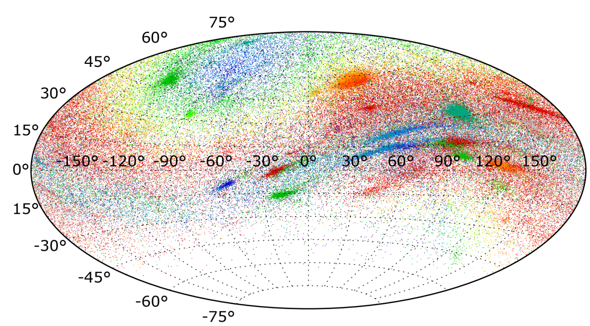


Figure 2: Radiants of all meteors in the SonotaCo database.

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# The results of the Perseid observations in 2014

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## Abstract

The results of meteor observations in 2014 are presented. For observation in the wide field of view were used television systems (the camera Watec LCL-902HS and the lense Computar 6/0.8) with fields of view of 56°x44° and a limiting magnitude (for stars) +5.5 m. Observations were carried out by a double-station method (the distance between stations is 20 km). For three year of observations in INASAN were detected above 1000 meteors. The basic parameters (radiants, geocentric velocities, heights) were calculated for double-stations meteors. The distribution of the Index Meteor Activity (IMA) of meteors to the Earth in 2014 is given. The maximum activity of the Perseids (with maximum values of IMA) was obtained in 12 August ($\lambda$ =140.0°). The distribution of the Perseid radiants was shown. The daily motion Perseid radiant was calculated by our data in 2014. Analysis of the beginning and ending heights of Perseids was presented. The distributions of meteors by absolute magnitude and the number are presented. The trajectories of the meteors and the orbits of the meteoroids were calculated from the double-station observations.

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