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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.

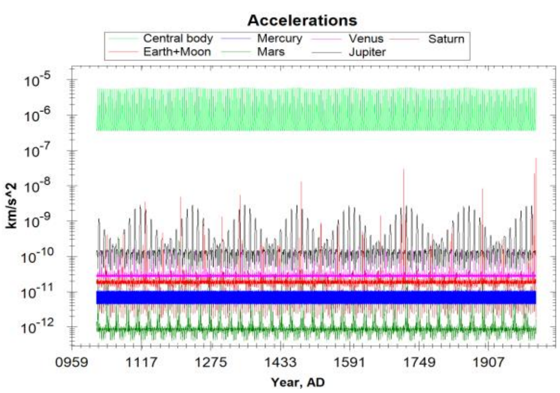

Figure **1**. Acceleration in motion FN20140925 during one thousand years backward integration.

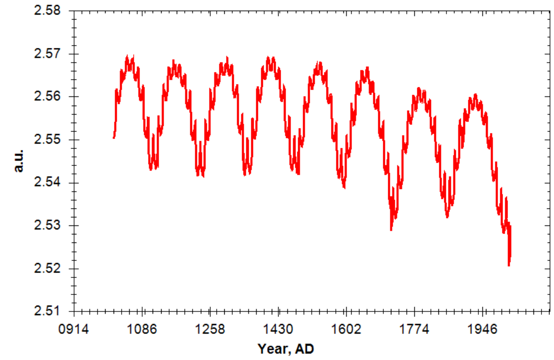

Figure **2**. Value of semi-major axis of FN20140925 during the one thousand years before impact.

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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