METEOR TOOLKIT - FREE DISTRIBUTABLE OPEN-SOURCE SOFTWARE FOR DETERMINATION AND ANALYSIS OF METEOROID ORBITS.

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Introduction: It is known that the orbits of meteoroids that collide with Earth are exposed to significant perturbations prior to the encounter, these are primarily from the influence of gravity and atmospheric drag at the end of its trajectory. A standard method of meteoroid orbit computation [1], is traditionally based on a set of corrections applied to the observed velocity vector. In particular, the popular concept of 'zenith attraction' is used to correct the direction of the meteor's trajectory and its apparent velocity in the Earth's gravity field.

Progress beyond the state of the art: In the recent work [2-3], we proposed other, more explicit approaches to orbit determination and to error propagation analysis. Our approach to meteor orbit determination is based on strict transformations of the coordinate and velocity vectors according to the IAU International Earth Rotation and Reference Systems Service (IERS) [4] and the backward numerical integration of differential equations of motion [5-6]. We have implemented this technique for the determination and analysis of meteoroid orbits into an open-source software entitled "Meteor Toolkit", accessible at https://sourceforge.net/projects/meteortoolkit/

The software has a graphics user interface and uses freely distributed routines and kernels from the SPICE system [7] for coordinate transformation and computing the ephemeris. The JPL ephemeris, DE421 [8], is used for transformation of the meteoroid's position and velocity vectors from a geocentric to a heliocentric coordinate system. The backward integration of equations of perturbed meteoroid motion:

$$\ddot{\vec{r}} = \frac{GM_{Sun}}{r^3}\vec{r} + \ddot{\vec{r}}_{Earth}(C_{nm}, S_{nm}, \vec{r}, t) + \ddot{\vec{r}}_{Moon}(\vec{r}, t) + \sum \ddot{\vec{r}}_{planets}(\vec{r}, t) + \ddot{\vec{r}}_{atm}(\vec{r}, t)$$

is performed by implicit single-sequence numerical methods [5-6]. The equations of perturbed meteoroid motion include central body (Sun) attraction, perturbations from Earth gravity field, Moon, other planets, and from atmospheric drag. To obtain an undistorted heliocentric orbit a backward integration is performed until the meteoroid intersects with the Hill sphere. The JPL Horizons On-Line Ephemeris System [9] database of comets and asteroids is then searched for the meteoroid's potential parent body. In addition, the software has a module for visualizing the computational results.

In summary, "Meteor Toolkit" enables robust analysis of the orbital motions of meteoroids through time prior to Earth's capture, enables search for their potential parent bodies, as well as to obtain characteristic physical meteoroid parameters and calculate the location of meteorite's impact with the ground [10-13].

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