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From meteor observations to meteoroid orbits: propagation of uncertainties

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1. Introduction

Observations of the meteors by photography, radar, video or CCD technique result in determination of the orbit of the meteoroid particles. Concerning the precision of the observations, in case of radar, video and CCD techniques we deal with an exceptional situation. The accuracy of the meteoroid velocity vector $\dot{\mathbf{r}}$ is not high, of the order ± 0.1 [km/s]. Whereas the accuracy of the position vector $\mathbf{r}$ is very high, better than $\pm 30[km] \approx 0.0000002[AU]$, what is quite unusual among the small bodies of the Solar System.

On the other hand, the osculating orbital elements $\{q, e, \omega, \Omega, i\}$ — the counterparts of $\{\mathbf{r}, \dot{\mathbf{r}}, T\}$, where T is the time of osculation — are published with a scanty amount of decimal digits, most often with 3-5 significant digits, see in [7, 3, 1, 5]. [1] In our opinion, such practices, unnecessarily decrease the information related with the the meteoroid orbit determination, namely, that the meteoroid, on sure, hit the Earth.

2. Calculation of the orbit

Total precision of the meteoroid orbit depend on two components. The first one includes the precision of the geocentric radiant coordinates α_g, δ_g and the geocentric velocity V_g of the meteoroid. The second one depends on the precision of the time registration of the meteor phenomenon, and is directly related to the accuracy of the meteoroid position vector $\mathbf{r}$. Because the meteor is observed from the Earth surface, the accuracy of the vector $\mathbf{r}$ will not be greater than the accuracy of the position of the Earth mass center at the meteor instant. In some older papers, the authors proposed substantial simplification, namely in [2] one can read — *within the limits of precision with which the orbits of meteors can be calculated, it is necessary to assume that the observer and the meteor were located in the plane of the ecliptic at the time of observation, and that their position is given by the coordinates of the center of the Earth.*". Also in [8], the classic paper on *"Reduction Methods for photographic meteor trails"* the distance of the meteoroid from the center of the Earth was neglected. Such assumption decreases the accuracy of the vector $\mathbf{r}$ by two orders of magnitude, which now equals ± 0.00004 [AU] only. Today, due to high precision of the time registration of the meteor phenomenon, such assumption is not necessary.

Neglecting the Earth dimension, was the source of an additional approximation, which by some astronomers is considered as the unquestionable truth. Namely, the heliocentric distance of the observed meteoroid is assumed to be equal with the nodal distance of its orbit given by: $r = q(1+e)/(1 \pm e \cos\omega)$. As it is properly described in [4], it is not true, especially for low-inclination orbits. In the orbital catalogue [9] one can find a Super-Schmidt meteor, number 9194, reduced by McCrosky and Saho, observed on 1956 09 28.19157, and with the radiant parameters $\alpha_g = 14.5$, $\delta_g = 6.2$ and $V_g = 29.19$ [km/sec]. The nominal catalogue orbits has the inclination $i = 0$. One can calculate that for the possible orbit of this meteoroid, the nodal distances are close to 0.45 and 1.5 [AU], see Figure 1.

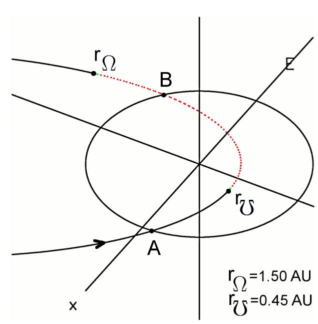

Figure 1: The orbit of a real meteoroid observed in point A, not at the nodes of its orbit.

[1] As a nice exception, lastly published by Japan amateur Sonotaco Network, (http://sonotaco.jp/doc/SNM/) two sets of the meteoroids orbital elements are given with 6-9 significant digits.

Table 1: A two examples of meteoroids observed by a video technique. For each meteoroid, the first row lists the catalogue geocentric radiant coordinates, velocity and the osculating orbital elements. In the second row the uncertainties of these parameters are given. Third and fourth rows contain recalculated mean orbital elements and their uncertainties obtained by a numerical propagation of the uncertainties of the geocentric parameters. The accuracy of the date of the meteor observation we assumed as ± 1 second. All MOID distances were calculated using the meteoroid orbital elements as they are given in this table, with a limited amount of the significant digits.

Meteor code and source	Date (UTC)	α_g (deg)	δ_g (deg)	V_g (km/s)	q (AU)	e	ω (deg)	Ω (deg)	i (deg)	MOID (km)
98422003	1998 04 22	343	85.0	18.35	0.982	0.721	160.7	32.538	26.13	46500
[5]	20:35:57	3	0.30	0.14	0.001	0.011	0.3	0.001	0.18	
Recalculated		-	-	-	0.9818	0.7215	160.76	32.537	26.12	2550
	-	-	-	-	0.0007	0.0090	0.32	0.000	0.15	
99423006	1999 04 23	187.38	-16.92	14.16	0.846	0.599	54.78	213.436	5.14	4350
[5]	00:49:27	0.08	0.09	0.04	0.001	0.002	0.10	0.001	0.04	
Recalculated					0.8403	0.5898	56.11	212.460	5.17	19.5
					0.0005	0.0019	0.10	0.000	0.03	

3. Propagation of uncertainties

We give an example of propagation of the uncertainties of the meteoroid dynamical parameters. In table 1 the geocentric and heliocentric dynamical parameters of a few meteoroids are given. Also the MOIDs of the orbits relative to the Earth orbit are given, their nominal values should equal to zero. However, we do not know how the Earth ephemeris were determined when the meteor data has been reduced in [5], so in case of the orbits taken from this catalogue, we should expect the values of the MOID on the level $1 \cdot 10^{-6}[AU] \approx 150km$ — the accuracy of the subroutines used by us for calculation of the Earth ephemeris. For the meteor 98422003 the MOID distance of the catalogue orbit is about seven times greater then the Earth radii. The amount of significant digits of the orbital elements given in this catalogue, is not sufficient to obtain small MOID for this orbit. We have recalculated the orbit of this meteoroid using catalogue geocentric radiant and velocity and their uncertainties. The Earth position and velocity we calculated using subroutines given in [6]. Assuming normal noise of the geocentric parameters about 3000 orbits has been calculated. Their average orbital elements are given in table 1. For this mean recalculated orbit, using significant digits as they are given in this table, the MOID distance proved to be about 18 times smaller. The accuracy of the parameters of meteor 98422003 is not very high. When we have repeated the same calculation for very precisely reduced meteor 99423006, we observed similar tendency. The MOID of the catalogue orbit is now by one order of magnitude better, however, for the recalculated orbit, for which we took the values of q and e with one significant digit more, the MOID distance improved by two orders of magnitude.

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