# Astrometric precision and orbit determination by AMOS

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The astrometric precision of the new version of the all-sky AMOS camera is evaluated. The 4th polynomial astrometric reduction in UFOAnalyzer (SonotaCo, 2009) and all-sky procedure (Borovička et al., 1995) is compared. In addition the uncertainty of a bolide atmospheric trajectory observed by cameras of the European Fireball Network and Slovak Video Meteor Network is assessed. A new program is presented which determines meteor orbits and also reports the uncertainties in the orbital parameters. One particular bolide orbit is compared with the result obtained by the Ondřejov Observatory.

## 1 Introduction

The AMOS camera (All-Sky Meteor Orbit System) is an all-sky system for meteor observation and orbit determination. The acronym AMOS is connected with Czech theologist, philosopher and pedagogue Jan Amos Komenský, in Latin Comenius. He is considered the father of modern education. The Comenius University in Bratislava is named after him.

The aim of the system AMOS is to monitor meteor activity, and to obtain orbital and geophysical parameters for video meteors.

AMOS has been developed and constructed at the Modra Observatory of the Comenius University in Bratislava (Tóth et al., 2011; Zigo et al., 2013). The opto-electronic system consists of a fish-eye lens, image intensifier, imaging (projecting) lens and CCD digital camera. Hence, the system is optically more complicated than most cameras used in video observations.

There are six AMOS cameras active at present. Four of these are in Slovakia, Slovak Video Meteor Network (Astronomical and Geophysical Observatory in Modra – AGO, Arborétum Mlyňany – ARBO, Važec, Kysucké Nové Mesto – KNM) and two are in the Canary Islands, at Teide Observatory (Tenerife) and at Roque de los Muchachos Observatory (La Palma).

The cameras used in Slovakia have 1280 x 960 pixels with a resolution 8.4 arcmin/pixel and frame rate 15 per second. The cameras working in the Canary Islands have 1600 x 1200 pixels, resolution 6.8 arcmin/pixel and 20 frames per second. The field of view (FOV) is 180 x 140 degrees.

Currently, we use the UFOCapture, UFOAnalyzer and UFOOrbit software (SonotaCo, 2009) for the recording of meteors, for astrometric reduction and for orbit determination.

## 2 Astrometry

To assess the astrometric precision in the FOV of the AMOS camera, we determined the distribution and size of errors in the positions of reference stars. We compared the catalogued stars with their positions after the astrometric reduction. As an example, in *Figure 1*, we show one set of results for reference stars in the FOV of the AGO camera. The black points are the catalogue positions of the stars and red (grey) points are the positions determined by the astrometric reduction. The shifts of the reduced stars have been enlarged by 50 times to provide better visibility. This makes it easier to see errors that are mainly systematic (Borovička, personal communication).

The left side of *Figure 1* shows the distribution of stars after the 4th polynomial reduction using the UFOAnalyzer program and the right side shows the all-sky reduction according to Borovička et al. (1995).

The mean errors of the star positions do not differ too much between the two methods of reduction but the error distribution through the FOV is more even in the case when the all-sky procedure is used. In addition, according to SonotaCo (personal communication), the UFO software was developed for narrower FOV and it is not suitable for all-sky systems.

The optical system in the AMOS camera is more complicated and so it is not straightforward to find the convergent solution of the all-sky procedure. In addition, the cameras are constructed by hand and so the parameters characterizing the optical system will be different in each case. Hence the visual display used in *Figure 1* is helpful in searching for a successful iteration process of the all-sky procedure.

Next we assessed the uncertainty in the atmospheric trajectory of a bolide recorded by three stations of the Slovak Video Meteor Network. This bolide was also recorded by stations of the European Fireball Network (EFN) (Spurný et al., 2007) operated by Ondřejov Observatory, AS CR. The trajectory computed from the

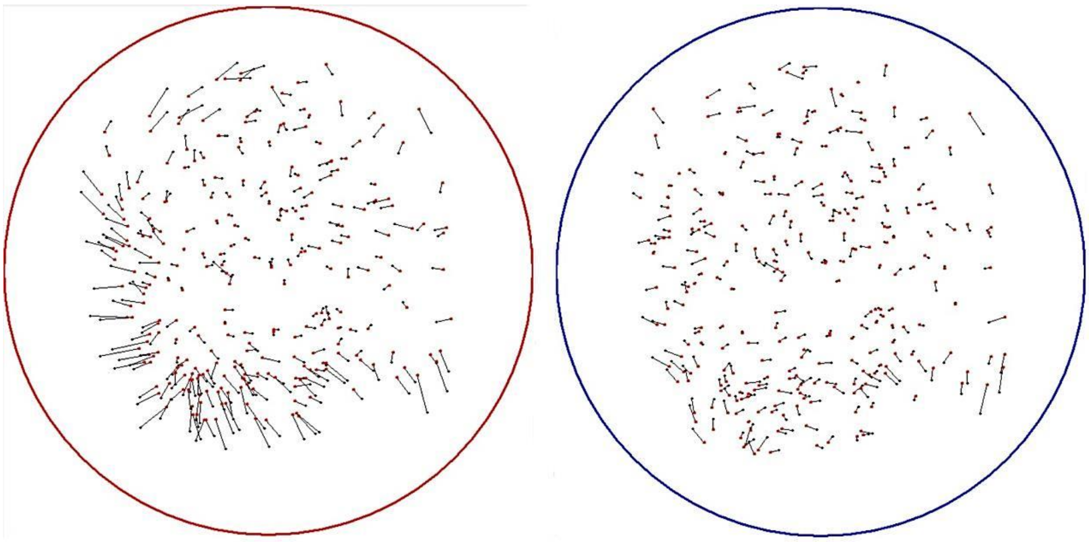

*Figure 1* – The comparison of astrometric reduction. Left – 4th polynomial reduction used in UFOAnalyzer (SonotaCo, 2009), right – all-sky procedure by Borovička et al. (1995).

data of EFN stations (Spurný, personal comm.) can be considered to be a reference, because the resolution of these cameras is about 1 arcmin per pixel (photographic grain). The observations from the three stations of SVMN (AGO, ARBO, KNM) were compared with the mean atmospheric trajectory computed by Spurný. Lateral deviations along the length of the trajectory were quite large for the KNM station because there were cloud issues at the station and so it used a mask of reference stars from some of the previous nights. The station ARBO was reduced by UFOAnalyzer and its lateral errors are mostly less than 100 meters, only approaching 200 meters in one part. The station AGO was reduced by the all-sky procedure (Borovička et al., 1995) and its lateral deviations are less than 30 meters, similar to photographic ones. In this special case, the AGO station was the closest to the meteor trail. In general, the deviations reach several tens of meters (*Figure 2*).

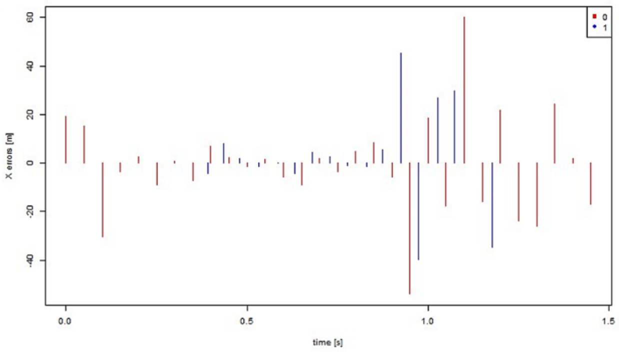


*Figure 2* – Lateral errors of measured points along the atmospheric trajectory of a meteor.

## 3 Orbit determination

We have developed a new program based on a Ceplecha (1987) paper for the computation of meteor orbits. The program works in three modes: double-station and multi-station modes are for orbits of single meteors and are, suitable for a more detailed inspection, and a batch mode when processing a database of meteor observations. In the batch mode, as in the UFOOrbit program of SonotaCo (2009), pairs of single station meteors within a small time interval (currently set to 2 seconds) are assumed to be the same meteor and are combined.

The program computes orbital and geophysical parameters together with their uncertainties based on a Monte Carlo simulation within an uncertainty in the radiant position and geocentric velocity. The number of clones is optional and in the first tests we set this to one thousand.

The program has several options (*Figure 3*): enable/disable Earth's rotation (sidereal time of each meteor point includes the elapsed time since the beginning of the meteor observation), enter a default value of the radiant position's error, insert preatmospheric velocity obtained from external source, and choose the initial parameter values (a, b, c, $x^p$) to fit the atmospheric velocity. Some of the options are only temporary; they are useful in the development of the program.

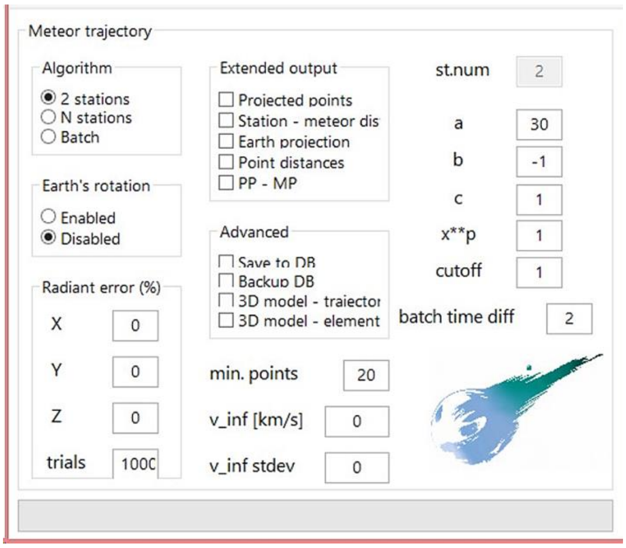


*Figure 3* – The main menu of the program for orbit determination.

*Table 1* – The comparison of a bolide orbital and geophysical parameters computed independently from EFN and SVMN. See in the text.

| Stations | RA | Dec | $V_g$ | a | q | e | i | ω | Ω |
|---|---|---|---|---|---|---|---|---|---|
| 3 st. EFN | 266.60 | 35.65 | 14.612 | 2.862 | 0.98230 | 0.6568 | 19.15 | 165.48 | 209.79975 |
| ± | 0.03 | 0.03 | 0.017 | 0.008 | 0.00005 | 0.0010 | 0.02 | 0.03 | 0.00000 |
| AGO-ARBO | 266.59 | 35.44 | 14.64 | 2.89 | 0.98216 | 0.661 | 19.1 | 165.43 | 209.80450 |
| ± | 0.05 | 0.09 | 0.09 | 0.04 | 0.00049 | 0.005 | 0.1 | 0.06 | 0.00002 |
| AGO-ARBO-KNM | 266.79 | 35.68 | 14.75 | 2.94 | 0.98246 | 0.666 | 19.3 | 165.63 | 209.8047 |
| ± | 0.06 | 0.10 | 0.10 | 0.05 | 0.00060 | 0.005 | 0.1 | 0.07 | 0.00002 |

To determine the atmospheric velocity of a meteor, the package of the R Project for Statistical Computing is used. If there are a sufficient number of points, the exponential formula is used in the form

$$y \sim a + b * x^p * \exp(c*x) \qquad (1)$$

where (a, b, c, p) are parameters of the fit. The term $x^p$ expresses our belief that the preentry speed is approximately the same as the speed at the beginning of the meteor observation (this term can be switched off by setting p=0). However, if the exponential fit does not converge, the program tries to find a continuous section of the meteor trajectory (starting at the beginning) over which the meteor speed is constant. If successful (there are some constraints on the success), the average speed with 2 sigma check of this part of the meteor trajectory is taken to be the preentry speed. If not, the arithmetic mean of all points with 2 sigma check is computed.

The determination of the atmospheric velocity and its uncertainty is not yet fully resolved. The main problem is mostly that we have a small number of points and a large spread of data. We are also still working on the rules that will determine when a particular fit method should be used.

Program outputs are both textual and graphical. The textual information contains orbits and geographical data as well as intermediate data that might be interesting. Regarding the graphical data, the program produces many graphs (real-time 3D graphs are optional as well) depicting input as well as output data.

Finally we compared the computed orbital and geophysical parameters of a bolide recorded by three stations of the EFN and three stations of the SVMN. The orbit of the EFN was computed by Spurný (personal comm.) and the orbits of stations of the SVMN (AGO, ARBO) and (AGO, ARBO, KNM) were computed independently by our new program (*Table 1*). The derived parameters compare well and are mostly within the uncertainty ranges.

## 4 Conclusion

We assessed the astrometric precision in the FOV of the all-sky AMOS system by comparing the astrometric reduction used in UFOAnalyzer software (SonotaCo, 2009) with the all-sky procedure according to Borovička et al. (1995). The all-sky procedure provides a more even distribution of errors in the positions of catalogued reference stars and is more suitable for the AMOS.

The atmospheric trajectory of a meteor can be determined from AMOS data with a lateral precision of several tens of meters.

We introduced a new program for orbit determination. The program computes orbital and geophysical parameters together with the uncertainties in the parameters, as determined via a Monte Carlo method. If a sufficient number of points along the atmospheric trajectory is available, an exponential function is used for the fit of velocity. For a lower number of points, an arithmetic mean with 2 sigma check is computed. The velocity determination is still being worked on.

An independent check of orbital and geophysical parameters derived by our new program and by the Ondřejov Observatory software (Spurný, personal comm.) showed that the AMOS system is able to provide orbital and geophysical characteristics in relatively high precision.

When we have completed the new program for orbit determination, the database EDMOND will be recomputed and analyzed in detail.

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## References

Borovička J., Spurný P. and Keclíková J. (1995). “A new positional astrometric method for all-sky cameras”. *Astron. Astrophys. Suppl. Ser.*, **112**, 173–178.

Ceplecha Z. (1987). “Geometric, dynamic, orbital and photometric data on meteoroids from photographic fireball networks”. *Bulletin of the Astronomical Institutes of Czechoslovakia*, **38**, 222–234.

SonotaCo (2009). “A meteor shower catalog based on video observations in 2007-2008”. *WGN, Journal of the IMO,* **37**, 55–62.

Spurný P., Borovička J. and Shrbený L. (2007). “Automation of the Czech part of the European fireball network: equipment, methods and first results”. In Valsecchi G. B., Vokrouhlický D. and Milani A., editors, *Proceedings of the IAU Syposium 236.* Cambridge: Cambridge University Press, pages 121–130.

Tóth J., Kornoš L., Vereš P., Šilha J., Kalmančok D., Zigo P. and Világi J. (2011). “All-Sky Video Orbits of Lyrids 2009”. *Publ. Astron. Soc. Japan*, **63**, 331–334.

Zigo P., Tóth J. and Kalmančok D. (2013). “All-Sky Meteor Orbit System (AMOS)”. In Gyssens M. and Roggemans P., editors, *Proceedings of the International Meteor Conference*, La Palma, Canary Islands, Spain, 20-23 September 2012. IMO, pages 18–20.

The author, *Leonard Kornoš,* during his lecture (Photo by *Axel Haas*).