Meteor spectra from AMOS video system

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We introduce the updated spectral All-Sky Meteor Orbit System (AMOS-Spec) and present its capability to measure the relative abundances of the main elements in meteoroids. Initial results from the spectroscopic observations are presented and are compared with independently measured meteoroid trajectories, heliocentric orbits and material strength parameters in data collected by the Slovak Video Meteor Network and the Central European Meteor Network. We aim to use this complex set of data to define the various meteoroid streams both dynamically and physically, and thus to identify the link between a meteoroid stream and its parent body.

1 Introduction

Spectroscopic observations of meteors are performed with the intention of studying emission lines produced during the ablation of the meteoroid. Comparison of the relative intensities of these lines allows us to determine relative abundances of main elements and thus to study the chemical composition of meteoroid bodies. Whereas most spectroscopic observations of meteors are carried out during meteor campaigns, the AMOS-Spec program was created with the intention of providing continuous systematic survey. The ability to measure the main elemental composition of small bodies of the solar system offers important scientific knowledge, particularly when this is linked to their parent asteroids and comets. Here, we present an analysis of the first batch of spectra captured by the AMOS-Spec during the period November 2013 – December 2014.

2 Amos-Spec system

Specifications

The first AMOS-Spec system installed in the Astronomical and Geophysical Observatory in Modra was created by upgrading the original AMOS system (Tóth et al., 2011; Zigo et al., 2013; Tóth et al., 2015) established in four stations of the Slovak Video Meteor Network and in two stations on the Canary Islands. The system uses a 30 mm f/3.5 fish-eye lens, an image intensifier (Mullard XX1332), a projection lens (Opticon 1.4/19mm), and a digital camera (Imaging Source DMK 51AU02) with a 1600x1200 px resolution and 12 fps rate. The field of view is circular and 100 degrees in size with the center pointing to the zenith. We have been using a 1000 grooves/mm holographic diffraction grating since July 17, 2014 (previously we used 500 grooves/mm grating) placed in front of the lens. As a result of the geometry of the light diffracting on the grating, we are also able to capture the spectrum from a meteor approximately 20 degrees outside the FOV on each side. The absolute limiting magnitude of the system is at optimal geometry and observing conditions close to magnitude 0. Due to the wide field of view of the camera, some of our observations are affected by the presence of the Moon. We plan to improve the system by shifting the orientation of the center of the field of view 30 degrees towards the North.

Data processing and sensitivity

The reduction of spectra from a raw video file is performed in several steps. First, dark current and flat-field corrections are applied to the recorded spectrum. Background removal is also applied. Due to the all-sky geometry of the lens, the observed spectra are usually slightly curved. As we have not yet developed automatic software for the reduction of curved spectra, we measure the spectral line intensities manually frame by frame. The scale of each spectrum is determined by identifying the positions of known lines in the calibration spectrum. The spectral resolution obtained using the 1000 grooves/mm grating is 1.3 nm/px (2.5 nm/px with the 500 grooves/mm grating). The measured spectrum is corrected for the spectral sensitivity of the system by applying the spectral response curve. The curve is determined by measuring the known spectrum of Jupiter and is normalized to unity at 480 nm. Next, we reduce the continuum level of the spectrum by fitting a blackbody spectrum for various temperatures, depending on the meteor velocity. Atmospheric lines are also reduced before we read out the relative line intensities of Na, Mg and Fe. Our system covers the whole range of the visual spectrum from 300 nm to over 900 nm, with a sensitivity level of 10% at 900 nm.

3 Results

The Amos-Spec system has been operated on every clear night since its installation on November 15, 2013. During observations up to the end of 2014, the system recorded 2361 meteors, with spectra of variable quality being captured in 433 cases. The majority (over 340) of these spectra were too faint to be used for line analysis (signal to noise ratio lower than 4). In other cases the meteor spectra were not suitable for reduction due to issues such as saturation, disruption by moonlight, or part of the spectrum falling outside the field of view. So far, we have been able to reduce and analyze 35 spectral events described here. In addition, 22 of these events were observed by multiple AMOS stations in the Slovak Video Meteor Network (SVMN), allowing us to determine heliocentric orbits for these meteoroids.

Spectral classification

In order to gain a better understanding of the chemical composition of the studied meteoroids, we analyzed emission lines from multiplets Mg I (2), Na I (1), and Fe I (15), and calculated relative intensity ratios for Na/Mg and Fe/Mg. These ratios can be used for spectral classification (Borovička et al., 2005) of the recorded meteoroids (*Figure 2*). The classification differentiates between standard meteoroid material represented by mainstream classes (normal, Na-poor, Fe-poor, and enhanced Na), and distinct meteoroid bodies (Irons, Na free, and Na rich classes). Our sample of 35 meteor spectra is dominated by mainstream classes including 19 normal type, 14 Fe-poor, 1 Na-poor, and 1 Na enhanced meteoroid bodies. Although we lack samples from the distinct spectral classes, there are variations of the Na line intensity among the mainstream meteoroids.

The brightest observed meteor in our sample was a μ Virginid of absolute magnitude -8.7. The spectrum of this bolide represents a normal type spectral class, while the analysis of its material strength suggests material close to carbonaceous chondrites. The photometric mass of this meteoroid was estimated to be 1.3 kg.

Meteoroid orbits

Supplemented by observations from other AMOS stations, we were able to calculate the trajectory, radiant position, and orbital parameters of 22 meteoroids and use them to better define the origin of studied bodies. This sample includes 11 sporadic meteors and 11 individual shower meteors with just 2 bodies belonging to the same meteor shower, the Southern δ Aquariids (SDA). Interestingly, the two spectra of the SDA are quite different. While one of them represents the normal type material with Na/Mg = 1.09 and Fe/Mg = 0.49, the other is Na-poor meteoroid with Na/Mg = 0.25 and Fe/Mg = 0.41. These results may imply that the SDA are an inhomogeneous meteoroid stream, possibly created during several perihelion passages. SDA originate from a sun grazing comet, which would explain the low content of sodium in one of the cases. However, any meteoroids that have made fewer perihelion passages will have experienced less solar heating and thus may still retain volatile sodium.

The orbital elements derived were also used to calculate the Tisserand parameter with respect to Jupiter (T_J), which can be used to distinguish cometary and asteroidal type orbits. We were able to identify 10 meteoroids that possibly originate from nearly isotropic comets (long-period comets, Halley type comets; $T_J < 2$), 6 meteoroids with orbits similar to ecliptic comets (Jupiter family comets; $2 < T_J < 3$), 5 asteroidal meteoroids ($T_J > 3$), and one case with a high value of the Tisserand parameter ($T_J = 8.5$) representing a retrograde cometary orbit with a small semi-major axis.

Material characteristics

Parameters such as the photometric mass, absolute magnitude, start and end heights of meteors, that have been determined from multi-station observations can be used to describe the material strength of bodies in our sample. This gives us further information about the origin of the studied meteoroids. We applied the classification based on the strength parameters K_B and *PE* (Ceplecha, 1967).

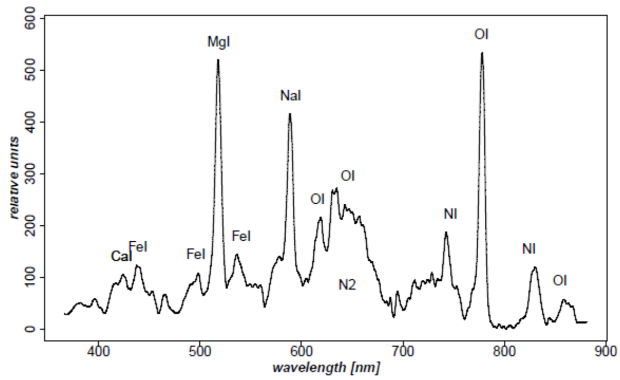

Figure 1 – Spectrum of a Fe-poor σ Hydrid meteoroid observed on December 4, 2013.

K_B parameter (function of beginning height) distinguishes material group A for particles similar to carbonaceous chondrites ($7.3 \leq K_B < 8$), group B for dense cometary bodies ($7.1 \leq K_B < 7.3$), group C including regular cometary material ($6.6 \leq K_B < 7.1$), group D consisting of soft cometary material ($K_B < 6.6$), and stronger asteroidal bodies ($K_B \geq 8.0$).

A similar classification based on the *PE* parameter (function of terminal height) divides meteoroids in three groups (Ceplecha and McCrosky, 1976). Group I represents stony asteroidal bodies ($-4.6 < PE$), group II is reserved for carbonaceous material ($-5.25 < PE \leq -4.6$), and group III includes cometary material ($PE \leq -5.25$).

We compared the determined meteoroid classes based on material strength with the orbital classification based on the Tisserand parameter and found the expected correlation. Meteoroids on asteroidal orbits are represented by only the strongest meteoroid material. Halley type orbits have mostly weaker type material (groups C, D, and III), although the meteoroid strength varied more widely among the JFC and HTC orbits. The correlation between the K_B and *PE* parameter had few exceptions. In two cases, for example, the K_B parameter suggested regular cometary material, whereas the *PE* indicated chondritic body. This could be explained by different meteoroid components (weak and strong) or by varying internal structure. In addition, as mentioned by Ceplecha (1988), some small particles of cometary origin can be observed in groups A or I.

4 Conclusion

This work introduced the new AMOS-Spec system and presented its capability and benefits in the research of physical characteristics of meteoroids. The analysis of the data collected from the first year of the Slovak meteor spectroscopic survey resulted in the acquisition of the main element abundances of 35 meteoroids,

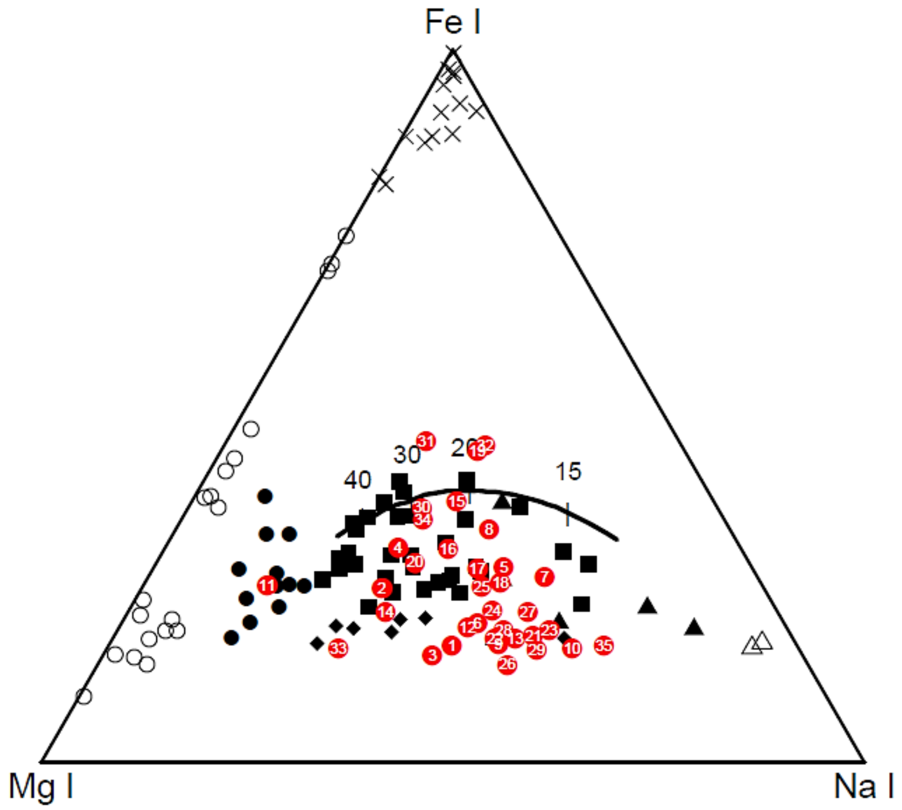

Figure 2 – Spectral classification of 35 analysed meteor spectra (numbered) along with data from a sample of 97 spectra observed by Borovička et al. (2005) represented by symbols ■ normal, ● Na-poor, ◆ Fe-poor, ▲ enhanced-Na, X Irons, ○ Na-free, and △ Na-rich.

supplemented by orbital characteristics, geocentric parameters, and material properties. The majority of the studied meteoroids represented the mainstream spectral classes with normal type and Fe-poor spectra. However, our results also show diversity of material on Halley type and Jupiter family cometary orbits (similarly to Borovička et al. (2005); Kikwaya (2011)).

The suggested origin of observed meteoroids based on their Tisserand parameter was in correlation with the classification based on the material strength parameters K_B and *PE*. We aim to expand our analysis with new observed spectra to gain a more complex view of meteoroid streams and the sporadic background from both the physical and the dynamical side.

Acknowledgment

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References

Borovička J., Koten P., Spurný P., Boček J. and Štork R. (2005). “A survey of meteor spectra and orbits: evidence for three populations of Na free meteoroids”. *Icarus*, **174**, 15–30.

Ceplecha Z. (1967). “Classification of meteor orbits”. *Smithsonian Contributions to Astrophysics*, **11**, 35–60.

Ceplecha Z., McCrosky R. E. (1976). “Fireball end heights - A diagnostic for the structure of meteoric material”. *Journal of Geophysical Research*, **81**, 6257–6275.

Ceplecha Z. (1988). “Earth's influx of different populations of sporadic meteoroids from photographic and television data”. *Bulletin of the Astronomical Institutes of Czechoslovakia*, **39**, 221–236.

Kikwaya J.-B. (2011). “Bulk density of small meteoroids”. Ph.D. thesis, University of Western Ontario.

Tóth J., Kornoš L., Vereš P., Šilha J., Kalmančok D., Zigo P. and Világi J. (2011). “All-sky video orbits of Lyrids 2009”. *Publications of the Astronomical Society of Japan*, **63**, 331–334.

Tóth J., Kornoš L., Zigo P., Gajdoš S., Kalmančok D., Világi J., Šimon J., Vereš P., Šilha J., Buček M., Galád A., Rusňák P., Hrábek P., Ďuriš F. and Rudawska R. (2015). “AMOS: All-sky Meteor Orbit System - preliminary results of exceptional meteor showers”. *Planetary and Space Science* (submitted).

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.