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Meteor spectra from AMOS video system

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ABSTRACT

Here we demonstrate the capability of the updated All-Sky Meteor Orbit System (AMOS) (called AMOS-Spec) to measure the main element abundances of meteors. The AMOS-Spec program has been created with the intention of carrying out regular systematic spectroscopic observations. At the same time, the meteoroid trajectory and pre-atmospheric orbit are independently measured from data collected by the AMOS camera network. This, together with spectral information, allows us to find the link between the meteoroid and its parent body, from both dynamical and physical consideration. Here we report results for 35 selected cases.

1. Introduction

A meteor is the phenomena created by ablation processes when a meteoroid enters the Earth's atmosphere. Spectrograph cameras allow us to observe the meteor spectra, which contain emission lines belonging to meteoroid vapours as well as lines of atmospheric origin. Studying the meteor spectrum gives us an opportunity to determine the chemical composition of the meteoroid itself, and in turn, the spectral characteristics of meteors are a parameter that can be used to link a parent body to a meteoroid stream. Most spectroscopic observations of meteors are routine measurements carried out during meteor shower campaigns. The AMOS-Spec program has been created with the intention of use within a regular systematic survey to take full advantage of meteor spectroscopy. Here, we report results from a sample of meteor spectra collected by AMOS-Spec camera since November 2013.

The study of meteor spectra started in XIX century (Millman, 1963). Nevertheless systematic works using photographic and video techniques started in following centuries, with extensive spectroscopic programs that were and still are carried out in Europe and North America (Borovicka, 1994; Borovička and Boček, 1995; Ceplecha et al., 1998; Hemenway et al., 1971; Jenniskens et al., 2014; Madiedo, 2014; Mukhamednazarov and Maltseva, 1989; Zender et al., 2004). Meteor spectroscopy has received much attention in recent years due to its ability to measure of the main elemental composition of small bodies of the Solar System, which offers important scientific information. In generally, meteoroids originate from comets and asteroids. We are particularly interested in meteor showers that originate from asteroids. As shown in several recent papers (Borovička et al., 2013, 2015; Porubčan et al., 2004; Tóth et al., 2011b; Trigo-Rodríguez et al., 2007; Schunová et al., 2014; Spurný et al., 2003), there are various physical and dynamical ways to form asteroidal meteoroid streams. Detection of such weak meteor showers and study of their particular meteor spectra by large field of view spectrographs such as the AMOS-Spec camera can help us better distinguish between asteroidal and cometary materials, especially among NEO parent objects, where extinct cometary nuclei are also present (Jewitt, 2012).

In Section 2 we describe the spectroscopic AMOS-Spec camera and data reduction of collected meteor spectra. Section 3 focuses on the obtained results, while in Section 4 we present our conclusions and perspectives for future work.

2. AMOS-Spec system

The All-Sky Meteor Orbit System (AMOS), of which previous version are described in Tóth et al. (2011a), Zigo et al. (2013) and Tóth et al. (2015), has been upgraded by the addition of the AMOS-Spec camera to record meteor spectra. Installed in Modra Observatory station, the camera is equipped with a 30 mm f/3.5 lens, an image intensifier (Mullard XX1332), a projection lens (Opticon 1.4/19 mm), and a digital camera (Imaging Source DMK 51AU02) with a resolution of 1600 × 1200 pixels and frame rate per second of 12. The setup provides a circular field of view of 100° with the centre pointing to the zenith. We used 500 (November 15, 2013–July 16, 2014) and 1000 (July 17, 2014–present) grooves/mm holographic grating in front of the fish-eye lens. The typical absolute limiting magnitude of a meteor for our system is around

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−2 magnitude. However, with optimal geometry of meteor light in front of the camera, and meteor velocity, the limiting absolute magnitude might be even higher at about 0.

A disadvantage of the wide-field camera is interference from the moonlight. As a consequence, some of our detections were hampered by moonlight or a bright spectrum of the Moon. This reduces the number of usable meteor spectra. We will improve the system in the close future by shifting the orientation of the centre of the field of view by 30° from zenith to the North. The collected data has been reduced and the first stage of spectral analysis has been conducted. The spectral events were corrected for dark current, the flat-field, and the camera's spectral response. The curvature of the spectra due to the all-sky geometry complicates measurements. Because we have not yet developed automatic software to reduce curved spectra, we measure the intensities of spectral lines on individual video frames manually using ImageJ program.[1] The scale for each spectrum was determined by means of known lines in the calibration spectrum, with a spectral resolution of 2.5 nm/pix and 1.3 nm/pix, using grating with 500 and 1000 grooves/mm respectively. The spectral response curve of the AMOS-Spec camera systems is shown in Fig. 1. Our system covers whole visual spectrum range from 300 nm and beyond 900 nm, with the sensitivity level of 10% at 900 nm. The curve was obtained by measuring the spectra of Jupiter, and is normalized to unity at 480 nm.

If an event was recorded simultaneously by more than one AMOS station (AGO Modra, Arboretum T. Mlyňany, Kysucké Nové Mesto Obs., and Važec), we were able to determine a heliocentric orbit for that meteor. Using the trajectory and orbit from AMOS, combined with the simultaneously measured spectrum from AMOS-Spec, we can identify the source of the meteoroid and its characteristics.

We have already developed Matlab code for the identification of spectral lines, correction of the spectral response efficiency, and calculation of ratio of the relative intensity of spectral lines. Most parameters of the data reduction pipeline are provided manually. The outcome of our findings will extend our knowledge of the chemical composition of meteoroids.

3. Results

The AMOS-Spec camera has been in operation every clear night since November 15, 2013. Up until the end of 2014, we were able to collect 2361 meteors, including 433 cases captured with meteor spectra of variable quality. At least 339 of these spectra are too faint to be used for further analysis. The S/N ratio of these faint meteor spectra is typically lower than 4, as was estimated by measuring the S/N ratio for 10 faint spectra per frame and calculating the average value. Other difficulties with reducing spectra are related to occurrences such as saturation, the presence of the Moon, the acute angle of the meteor or missing part of the spectra in the field of view. In this paper, we present results for 35 reduced cases shown in Figs. 3–6 and Tables 1 and 2. Double or multi-station observations from other AMOS cameras are available for 22 of these meteors, enabling us to determine their orbital characteristics.

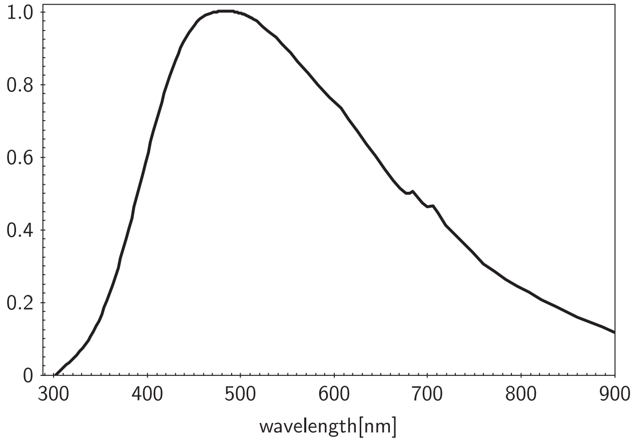

Fig. 1. Spectral sensitivity curve of the AMOS-Spec camera.

Table 1 contains a summary of all meteors analysed in this paper, providing atmospheric trajectory and spectral information, if available. The first column in both tables shows a reference number for each event that is used further in the paper in figures. Additionally, each event has its own ID describing the moment of its detection (the second column). In Table 1 a meteor's ID is preceded by the absolute magnitude of meteor (M), the photometric mass (m_p) calculated according to Hill et al. (2005), and its geocentric velocity (v_g). Next are the beginning and terminal heights of the meteor (H_b and H_e). The following three columns describe the quality of a spectrum (Q), measured average intensity ratios (Na/Mg, Fe/Mg), and spectral classification. In the last columns we present material strength parameters (K_B and PE), a meteor class according to those parameters (Ceplecha, 1988), and the Tisserand parameter to enable direct comparison of orbital classification with spectral and physical one. Table 2 provides the orbital elements (a, q, ω, Ω, and i) of all meteors for which spectral and double-station observations are available. The heliocentric orbital parameters are followed by the Tisserand parameter T_J, and the meteor shower designation.

In order to get an insight into the chemical composition of collected spectra, the emission from multiplets Mg I (2), Na I (1), and Fe I (15) has been analysed according to the Borovička et al. (2005) meteor spectra classification. According to this classification, the most distinct classes are irons, Na-free, and Na-rich. However, a majority of meteoroids represents one of the mainstream classes: normal, Na-poor, Fe-poor, and enhanced Na meteoroids. The contribution of Mg I (2), Na I (1), and Fe I (15) multiplets to our meteor spectrum was measured frame by frame in a video. Next, these measures were summed to obtain their integrated intensity along the atmospheric path of the meteor. The spectral response correction, removal of the blackbody continuum and atmospheric lines was also applied before the Na/Mg and Fe/Mg intensity ratios were calculated.

3.1. Meteor spectra description

Fig. 2 shows examples of a meteor spectra measured with 500 and 1000 grooves/mm grating. In the figures we present mostly the brightest meteor spectra. Those meteors were recorded simultaneously by other AMOS stations to facilitate trajectory and orbit calculations. This allows us to identify them as members of particular meteor showers: November λ Draconids, σ Hydrids, μ Virginid, and one sporadic meteor (No. 1, No. 3, No. 8, and No. 32, respectively). The spectra presented in Fig. 2 and the line intensities plotted in Fig. 3 are obtained by integration along the whole path of the meteor, i.e. we sum up signals for a given wavelength that is read from each frame with spectrum individually.

The spectrum of the σ Hydrid (No. 3) meteoroid has been captured together with spectrum of Jupiter. The latter is used to obtain the spectral response of a camera. Another three cases are examples of difficulties that we may come across during data reduction process. For example, a few

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[1] http://imagej.nih.gov/ij/index.html