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Spectroscopy of a κ-Cygnid fireball afterglow

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ABSTRACT

A bright fireball with an absolute magnitude of -10.5 ± 0.5 was recorded over the South of Spain on August 15, 2012. The atmospheric trajectory, radiant position and heliocentric orbit of this event are calculated. These data show that the parent meteoroid belonged to the κ-Cygnid meteoroid stream. The emission spectrum of this bolide, which was obtained in the wavelength range between 350 and 800 nm, suggests a chondritic nature for the progenitor meteoroid. Besides, the spectrum of the meteoric afterglow was also recorded for about 0.7 s. The evolution with time of the intensity of the main emission lines identified in this signal is discussed.

1. Introduction

Bright fireballs, specially those moving at high velocity, may produce long-lasting glows called persistent trains. These phenomena, which often form as a consequence of bright meteor flares, can be visible for several minutes after the meteor has disappeared. Once it is formed, the luminosity of the persistent train falls quickly within a few seconds during the so-called afterglow phase.

Meteor spectroscopy is a fundamental technique to get data about the physicochemical composition in meteoric plasmas, and also to get an insight about the chemical composition of meteoroids ablating in the atmosphere (Borovička, 1993; Jenniskens, 2007). Besides, the analysis of fireball afterglow spectra can provide useful information about the physical processes taking place in persistent meteor trains. However these afterglow spectra are not abundant in the literature (see e.g. Borovička and Jenniskens, 2000; Abe et al., 2004; Jenniskens et al., 2000; Madiedo et al., 2014a).

Despite the κ-Cygnids do not move at very high speeds, since these meteoroids impact the atmosphere with a velocity of about 25 km s^{-1}, bright κ-Cygnids meteors tend to exhibit a final flare as a consequence of the sudden disruption of the progenitor meteoroid when the particle enters denser atmospheric regions (see e.g. Trigo-Rodríguez et al., 2009). On 15 August 2012 at 23 h 44 m 59.7 s UTC, a κ-Cygnid fireball with an absolute magnitude of -10.5 ± 0.5 was simultaneously recorded from two meteor observing stations located in the South of Spain. The emission spectrum of the bolide was also recorded. The event reached its maximum luminosity during a very bright flare that took place by the end of its atmospheric path, giving rise to a persistent train. The emission spectrum of the meteoric afterglow was recorded during about 0.7 s. This paper focuses on the analysis of this spectrum afterglow. The emission spectrum of the fireball is also discussed. Besides, the atmospheric trajectory and radiant position of this fireball are calculated, and the orbital parameters and tensile strength of the progenitor meteoroid are obtained.

2. Instrumentation and methods

The fireball discussed in this paper was recorded from two meteor observing stations located in the South of Spain: Sevilla (latitude: 37°20′46″N, longitude: 5°58′50″W, height: 28 m), and El Arenosillo (latitude: 37°06′16″N, longitude: 6°43′58″W, height: 40 m). These stations employ an array of low-lux monochrome CCD cameras (models 902H2 and 902H Ultimate, manufactured by Watec Co.) that generate interlaced video imagery at 25 frames per second (fps) with a resolution of 720 × 576 pixels. Full details about the operation of this array of video cameras are given in Madiedo and Trigo-Rodriguez (2008) and Madiedo et al. (2010). For data reduction the AMALTHEA software was employed (Madiedo et al., 2011, 2013a), which calculated the fireball atmospheric trajectory, radiant position and meteoroid orbital data by following the methods described in Ceplecha (1987).

To obtain meteor spectra, holographic diffraction gratings (with 1000 grooves/mm) are attached to the objective lens of some of the CCD video cameras that operate at the above-mentioned stations. Their spectral response is shown in Fig. 1. These slitless videospectrographs

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operate in the framework of the SMART Project, which was started in 2006 (Madiedo, 2014). The spectra have been analyzed with the CHIMET software (Madiedo et al., 2013b, 2014b; Madiedo 2014, 2015).

3. Observations and results

3.1. Atmospheric path and meteoroid orbit

The atmospheric trajectory of the fireball was triangulated from the analysis of the video images obtained by the CCD cameras operating at Sevilla and El Arenosillo. According to this, the meteoroid impacted the atmosphere with a velocity $V_\infty = 27.3 \pm 0.3$ km s^{-1} and with an inclination of 26.4° with respect to the local vertical. The fireball began at a height of 109.7 ± 0.5 km above the sea level, and ended at a height of 72.0 ± 0.7 km. When the fireball was located at a height of 75.2 ± 0.7 km, it exhibited a bright flare. At this stage the event reached its maximum luminosity, which corresponded to an absolute magnitude of -10.5 ± 0.5. Table 1 shows the main parameters of this atmospheric path and the position of the geocentric radiant (J2000). The orbital parameters of the progenitor meteoroid are listed in Table 2. These data confirm the association of this event with the κ-Cygnid meteoroid stream. Thus, the value of the Southworth & Hawkins D_{SH} dissimilarity function (Southworth and Hawkins, 1963) is obtained by comparing the orbit of this stream (Sekanina, 1973) with the orbit of the meteoroid yields $D_{SH} = 0.08$. This value remains below the cut-off value of 0.15 usually adopted to establish a valid association (Lindblad, 1971a, 1971b).

3.2. Fireball spectrum

The fireball spectrum is shown in Fig. 2. It was obtained in the wavelength range between 350 and 800 nm with a video spectrograph operating at station #1. The signal, which was initially obtained on each video frame as an intensity profile (in arbitrary units) versus pixel number, was converted into intensity versus wavelength by identifying some of the emission lines in the spectrum. This calibration in wavelength was performed by using the contributions from Na I-1 (588.9 nm) and Mg I-2 (517.2 nm), where Moore's multiplet numbers have been employed (Moore, 1945). Then, the contributions from different frames were added to get an integrated spectrum along the whole meteor path. This spectrum was corrected by taking into consideration the spectral sensitivity of the spectrograph shown in Fig. 1. Only frames corresponding to the bright flare exhibited by the fireball by the end of its atmospheric path were excluded from this analysis, since most of the signal was saturated at that stage and so it was of very limited use. In Fig. 2, the main contributions identified in the fireball spectrum have been indicated. As usual in meteor spectra, most of the lines identified in the signal correspond to Fe I. The strongest emissions caused by the meteoroid in this spectrum are those from Fe I-5 at 374.5 nm, the Na I-1 doublet at 588.9 nm and the Mg I-2 triplet at 517.2 nm. Several contributions from atmospheric nitrogen and oxygen are also present. Thus, N_2 bands have been identified in the red region of the spectrum, although the most important atmospheric contribution corresponds to the O I line at 777.4 nm.

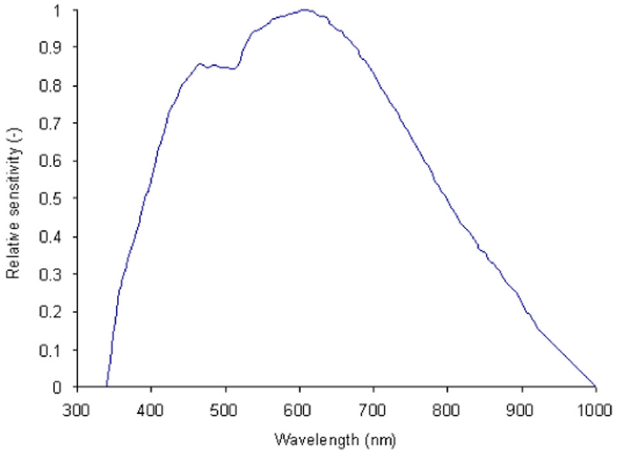

Fig. 1. Relative spectral sensitivity of the spectrographs employed in this research.

3.3. Afterglow spectrum

The same videospectrograph that recorded the fireball spectrum also recorded the emission spectrum of the persistent train produced after the bright flare that took place next to the end of the atmospheric path of the bolide. This spectrum corresponded to the afterglow phase, and it was recorded for around 0.7 s after the formation of the persistent train. The total duration of the train is unknown, since the cameras that recorded the event are configured to stop recording 1 s after the fireball ends. The brightest emission lines in this signal were saturated at the beginning of the train formation. So, the actual intensity of these lines could only be measured after some time. Fig. 3 shows the afterglow spectrum at $t = 0.34$ s after the formation of the persistent train. The afterglow spectrum covered the range between 400 and 800 nm, since the region in the ultraviolet between 350 and 400 nm, which could be recorded for the fireball spectrum, was out of the field of view of the camera at the moment of the train formation. This signal was calibrated in wavelength and corrected for the spectral sensitivity of the recording device by following the same technique employed for the fireball spectrum.

The most important contributions in the afterglow spectrum correspond to multiplets Na I-1 (589 nm), Fe I-1 (511–517 nm), Fe I-2 (437–449 nm) and Ca I-2 (422.6 nm). The emissions due to Fe I-15 (527–545 nm) and Na I-6 (568 nm) were also identified, together with those of Ca I-3 (610–616 nm) and Ca I-1 (657 nm). The contribution of FeO “orange arc” emission between 550 and 650 nm is also very likely, as was found by Jenniskens et al. (2000) and Abe et al. (2004) in the afterglow spectrum of Leonid fireballs.

4. Discussion

4.1. Meteoroid initial mass and strength

The initial (pre-atmospheric) mass of the meteoroid was estimated from the lightcurve of the fireball, which is shown in Fig. 4, by using the following classical meteor luminous equation:

Table 1
Atmospheric trajectory and radiant data (J2000).

H_b (km)	H_e (km)	α_g (deg)	δ_g (deg)	V_∞ (km s^{-1})	V_g (km s^{-1})	V_h (km s^{-1})
109.7 ± 0.5	72.0 ± 0.7	291.5 ± 0.3	60.6 ± 0.2	27.3 ± 0.3	25.0 ± 0.3	37.7 ± 0.3