The spectrum of fireball light taken with a 2-m telescope

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Abstract. A bright fireball appeared on the sky during the spectrophotometric observations with the 2.2-m telescope at the Calar Alto Observatory. The CCD spectrum of the scattered light of the fireball has been recorded. The spectrum is typical for a very bright, slowly moving fireball. For the first time, the spectral region 6600 – 7150 Å could be studied in such a case. Six spectral lines were identified here, the most remarkable being the lithium line at 6708 Å. The estimated lithium abundance proved to be consistent with meteoritic values.

Key words: meteors, spectra, lithium

1 Observation

On December 18/19, 1988, a routine spectrophotometry of Blue Dwarf Compact Galaxies was made at the Calar Alto Observatory (Almeria, Spain) with the 2.2-m telescope. The exposure times were long (typically one hour) and the detector was a RCA CCD. When exposing Mkr 8, a very bright fireball appeared on the sky, causing complete illumination inside the dome for approximately 3 seconds. The spectrum of the fireball light scattered in the atmosphere has been superimposed on the observed galaxy spectrum and on the simultaneously taken spectrum of the night sky. Here we present the analysis of the fireball spectrum.

The frame containing the fireball spectrum is displayed in Figure 1 on the left. The frame was obtained on December 19, 1988, 00:41–01:23 UT and the observed object was Mkr 8(N). In Fig. 1 on the right, a frame without fireball is displayed. It was obtained immediately after, between 01:29–02:15 UT, and the observed object was Mkr 8(S), i.e. the southern part of the same galaxy.

The spectra extracted from the frames (after flat-fielding) and transformed into wavelength scale are given in Fig. 2. The width of the frames is 512 pixels, the dispersion is 6 Å/pixel, and the spectral range is 3850 – 7150 Å. Both spectra were scaled to the same exposure time. The remaining difference in the background level has been caused by different intensity of Moon illumination during the two consecutive exposures. The sky spectrum contains emission lines of [O I], Na I and OH (in the red), while the fireball spectrum contains much more lines. The pure calibrated spectrum of the fireball, after subtracting the sky spectrum and the background and correcting the intensities according to the spectral sensitivity of the detector, is given in Fig. 3.

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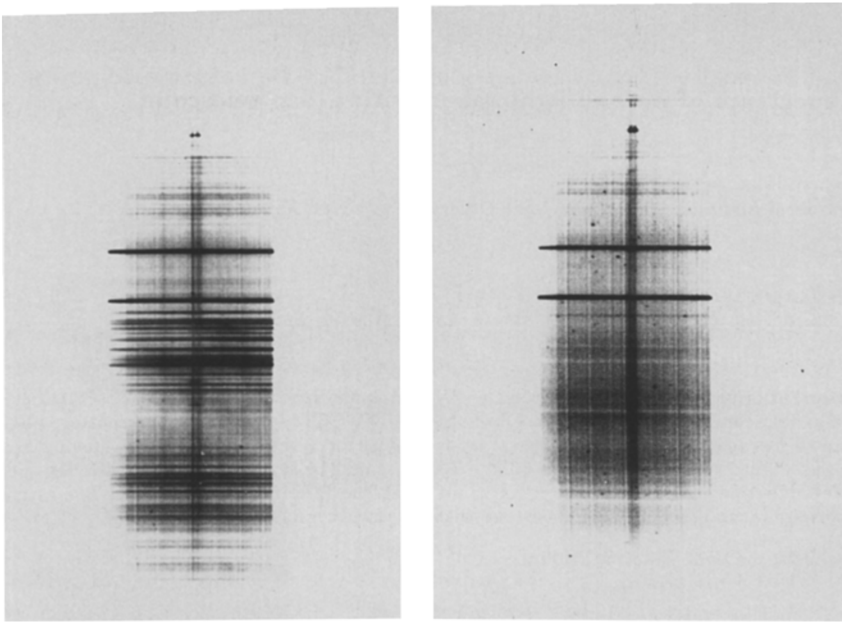

Fig. 1. Two spectra obtained with the 2-m telescope. The wavelengths increase from bottom upwards. The central channel of each frame contains the galaxy spectrum while on both sides is the background sky spectrum. The spectrum of the scattered fireball light is superimposed in the left frame.

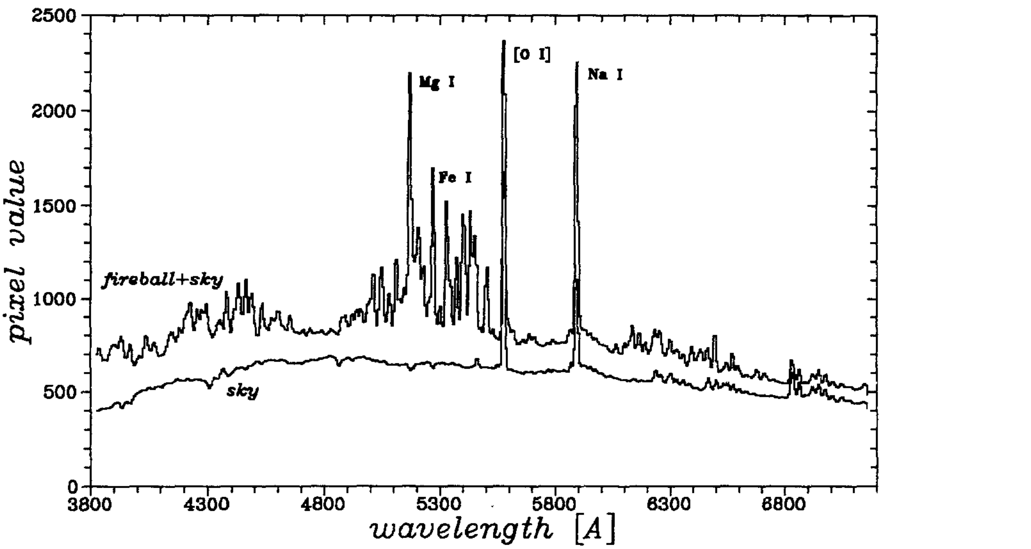

Fig. 2. Raw spectra of the fireball and the sky.

Note that this is not the first case when a fireball spectrum was obtained with a large telescope. Stauffer and Spinrad (1978) detected accidentally the spectrum of a bright fireball with the 3.05-m telescope at the Lick Observatory on June 18, 1977. Their spectrum covers wavelength range 3550 – 6050 Å and has a resolution of 7 Å.

2 Analysis

The present spectrum could be analyzed by the method used for the EN 151068 fireball (Borovička 1993) and compared with the photographic spectrum of that fireball. The present spectrum has about 10 times lower resolution but extends more to the red – the EN 151068 spectrum ends at 6600 Å. In the overlapping part, all lines found here were found also in EN 151068 (except for the forbidden [O I] line, which originates in the meteor train and the sky). The following atoms were identified: Na I, Mg I, Ca I, Ca II, Cr I, Mn I, Fe I, and Ni I.

There is in principle sufficient number of lines to compute physical parameters of the radiating gas such as temperature. However, the recorded spectrum is time-integrated and all parameters change during the fireball flight. An unambiguous solution was not obtained, but it was found that the spectrum can be best fitted with the temperatures in the range 3500 – 4000 K and the column densities of Fe I atoms in the range 4×10^{16} – 1×10^{17} cm^{-2}. Note that in EN 151068 temperature varied between 3400 and 4800 K and column density of Fe I varied between 3×10^{15} and 3×10^{16} cm^{-2}. The higher column density in the present case corresponds to larger fireball. The somewhat lower temperature may suggest that the maximal brightness was reached at medium heights, 50–60 km above the surface (for EN 151068 it was 44 km). No lines of the second spectrum (a high temperature component) are present. This is an evidence that the fireball was slowly moving, with the velocity of about 15 km/s (see Borovička 1994). The actual magnitude of the fireball is unknown.

The resulting elemental abundances depend on the assumed temperature and density and could be therefore only roughly estimated. No significant deviations from the EN 151068 values were found. Chemical composition of the meteoroid was normal, i.e. nearly chondritic, and the effect of incomplete evaporation, i.e. the depletion of the refractory elements in the radiating gas (Borovička 1993), took place also in this meteor.

More interesting is the spectral region 6600 – 7150 Å. To our knowledge, no lines have been reported in meteor spectra in this region up to now. The infrared spectra of fast meteors show strong lines above 7400 Å but the region below 7150 Å is empty (e.g. Millman and Halliday 1961). No very bright and slow fireball has been yet photographed on infrared film and the present fireball offers therefore the possibility to extend the spectral window for these cases to 7150 Å. Only several faint lines were found in this region. They are given in Table I. Their intensities

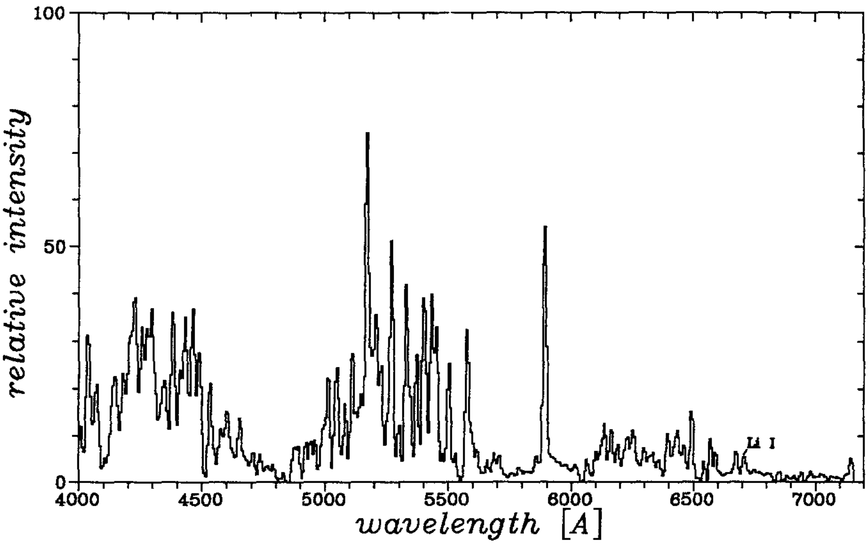

Fig. 3. Calibrated observed spectrum of the fireball.

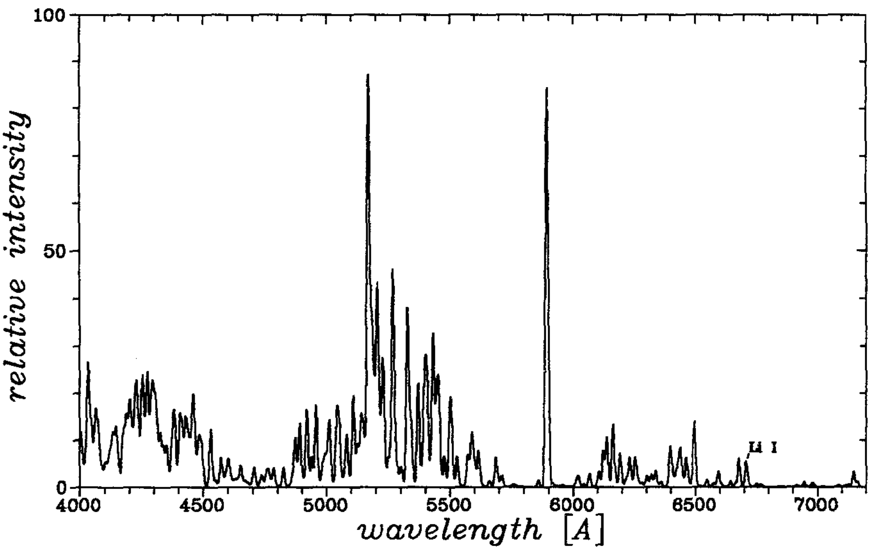

Fig. 4. Synthetic spectrum of the fireball.

are in accordance with the theoretical expectations using the physical parameters mentioned above.

TABLE I

Lines certainly identified in the region 6600 – 7150 Å.

λ [Å]	atom	multiplet
6678	Fe I	268
6708	Li I	1
6750	Fe I	111
6945	Fe I	111
6979	Fe I	111
7148	Ca I	30

The most remarkable of the new lines is the lithium line at 6708 Å. It represents the first evidence of the presence of lithium in meteor spectra. Their intensity corresponds to the relative abundance (by number of atoms) of Li I/Fe I $\approx 9 \times 10^{-7}$. As most of the lithium atoms are expected to be ionized under the conditions in question, this yields Li/Fe $\approx 1.5 \times 10^{-5}$. It is still lower than the abundance of lithium in C1-chondrites (6×10^{-5}). Lithium is depleted in the radiating gas similarly as other refractory elements.

In Fig. 4 the computed synthetic spectrum is given for temperature 3850 K, column density of Fe I atoms 6×10^{16} cm^{-2} and the appropriate abundances of other atoms. The synthetic spectrum can be compared with the observed spectrum in Fig. 3. Note, however, that the synthetic spectrum does not include molecular emissions (FeO bands are in fact present, mainly at 5850 – 6000 Å) and the contribution of the wake and train radiation. Moreover, as mentioned above, the observed spectrum represents the sum of the all radiation during the fireball flight and the temperature and density certainly varied. Despite all these facts, the overall agreement between the observed and computed spectrum is rather good.

The possible influence of this bright fireball on the spectrum of the night sky was also evaluated. The sky spectrum taken during the Mkr 8(S) exposure (the next after the fireball) was compared to the sky spectra from preceding nights. No new emissions were found, nor a strong brightening of any line. The sodium D line is brighter than average but the enhancement does not significantly exceed usual night to night variations in December 1988.

The spectrum of Stauffer and Spinrad (1978) differs from our spectrum by the presence of the high temperature spectral component (the lines of Mg II and Si II) and the high intensity of Ca I lines. The former fact suggests higher velocity of that meteor while the latter shows much more complete evaporation which probably means that the meteor reached the maximum evaporation rate at higher atmospheric densities, below the height of 30 km. An alternative explanation is a different chemical composition of the meteoroid.

3 Conclusions

The spectrum of the December 19, 1988 fireball over Spain shows that the fireball was slowly moving and probably radiating most intensively at medium heights. It was comparable to EN 151068 but brighter. For the first time, the spectral region 6600 – 7150 Å could be studied in such bright and slow fireball. Six spectral lines were identified here, the most remarkable being the lithium line at 6708 Å. Taking into account the incomplete evaporation of refractory elements, the estimated lithium abundance proved to be consistent with meteoritic values.

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