Television spectra of meteors

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Abstract. The first results of the television observations of meteors at the Ondřejov Observatory are presented. It is shown that three spectral components may be distinguished in meteors: cool meteoric, hot meteoric and hot atmospheric. The intensity ratio of these components varies strongly even in meteors of the same velocity and within the records of single meteors. This is evidence for variations in the ablation process and in the formation of the shock wave. The so called calcium anomaly is in fact only a demonstration of these variations.

Key words: meteors, spectra

1 Introduction

The use of television techniques instead of the classical photographic method enables scientists to observe fainter meteors and therefore to study smaller members of the meteoroid population. The second advantage is the good temporal resolution. On the other hand, the spatial resolution is lower. The TV spectroscopy of meteors was started by the pioneering work of Millman *et al.* (1971). Further successful observations were performed in Ashchabad (e.g. Mukhamednazarov and Maltseva 1989). However, in general, relatively small attention has been devoted to the subject and the results published so far are limited to the identification of spectral lines and to the study of the behavior of the green oxygen line in meteor trains.

At the Ondřejov Observatory, regular TV observations of meteor spectra started in 1990. The limiting magnitude was about +3 and the time resolution was 0.04 s. The observations are being continued during the maxima of major meteor showers with the aim of studying the physics of the meteor phenomenon and to reveal possible chemical and structural differences among the meteoroids of different showers. The presently used instrumentation is summarized in Table I. After being digitized by the image processor, the individual frames are analyzed by means of a PC.

All frames are being dark-frame subtracted and flat-fielded which allows the lines in the spectrum to be readily identified and measured. Since frequently only the higher and overlapping spectral orders are recorded with only a part of the whole spectrum being in the field of view, the correct identification sometimes represents a challenge. Line intensities are influenced by the sensitivity of the detector at different wavelengths. The spectral sensitivity curve was obtained by the observation of spectra of bright standard stars and is presented in Figure 1. The spectral window is wide, the lines from 3933 Å (Ca II) to 8680 Å (N I) have actually been observed. The maximal sensitivity is between 5000–5500 Å.

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TABLE I
Instrumentation

camera	nightvision model HT 11-22/SIT (Hiradash Technika – Budapest)
detector	RCA 4804/H SIT-vidicon tube + S 20 photocathode
lens	Leitz-Noctilux f/1, f=50 mm
spectral grating	Milton-Roy 300 groves/mm, blazed to 4900 Å
frame rate	25 frames/s
field of view	15 × 11 degrees
mount	azimuthal
video recorder	S-VHS GRUNDIG GV 280S, bandwidth > 4 MHz
image processor	TESLA VUST
resolution	512 × 512 pixels
dispersion	10 Å/pixel in the first order

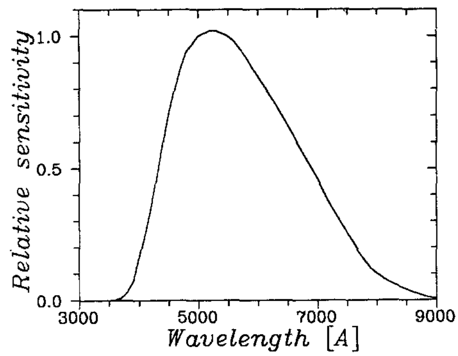

Fig. 1. The spectral sensitivity curve of our TV system (normalized to unity at 5500 Å).

The TV camera is present only in Ondřejov. As the observed meteors are too faint to be recorded by the photographic cameras of the fireball network, no additional information on meteor trajectories and velocities is available. The membership of a particular shower is inferred from the time of appearance, direction of flight and the angular velocity.

2 Results

2.1 Line identifications

Up to now, more than 40 spectra have been obtained. However, most of them are of low quality, showing only a few features. The results reported here are based on the detailed analysis of 6 good spectra (3 Perseids, 1 Geminid and 2 sporadic meteors). In Table II, the atoms, ions and molecules which were found in the spectra are given together with the numbers of observed multiplets. The multiplets in parentheses are less certain.

TABLE II

Radiators identified in the spectra. The numbers are the numbers of multiplets for which at least one line have been detected.

meteor head			the train
cool component	hot component		
meteoric	meteoric	atmospheric	atmospheric
Na I – 1	H I – 1	N I – 1, 2, 3, (8)	[O I] – 3F
Mg I – 2, 9	Mg II – 4	O I – 1, 4, (9), 10, (12), (20), (21)	
Ca I – 2	Si II – (2), 3, (5)	N_2 – 1st positive	
Fe I – 15, (37), 41, 42, 318, (686)	Ca II – 1, 2		
	Fe II – 42		

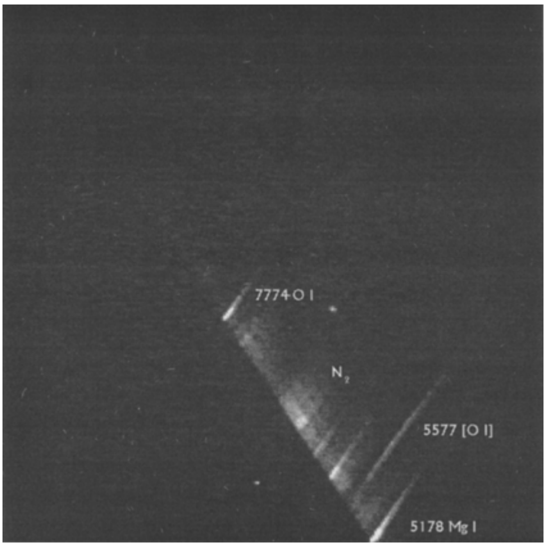

Fig. 2. Perseid meteor spectrum TVS 34 (1992 Aug 12, 01:08:55 UT). This is an example of the first order spectrum. The blue end is, however, out of the field of view.

Meteor spectra are known to consist of two components (Borovička 1994), the cool one ("the main spectrum", T = 4000–5000 K) and the hot one ("the second spectrum", T ≈ 10 000 K), which is probably connected with the meteor shock wave. This was fully confirmed here. Moreover, it proved useful to distinguish the radiation of meteoric origin and of the atmosphere in the hot component (no atmospheric emissions are present in the cool component because of the lack of permitted radiative transitions between low lying levels in N and O). The relative intensity of these three group of lines was found to vary strongly between meteors

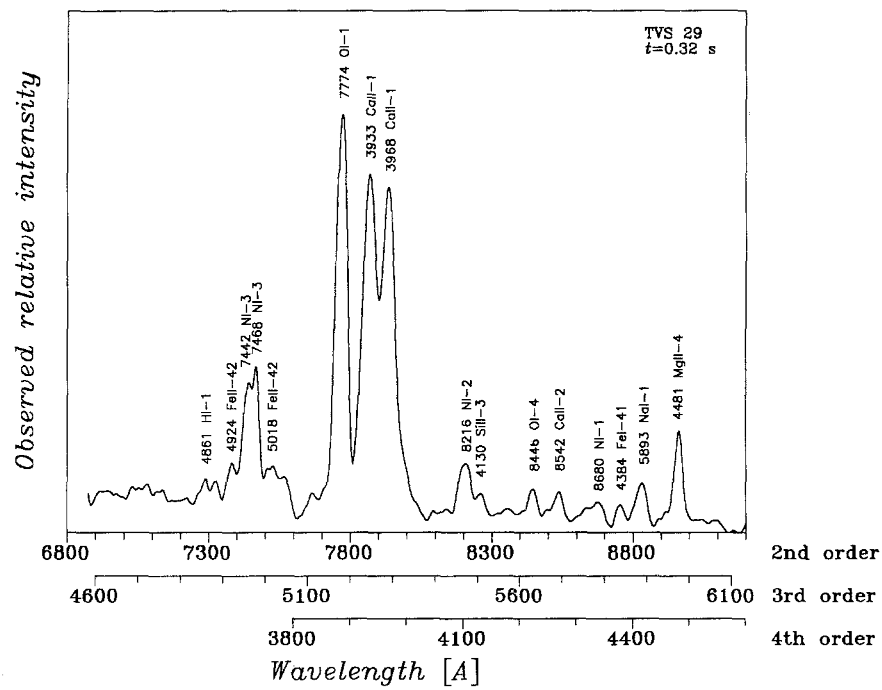

Fig. 3. The identification of spectral lines in the spectrum TVS 29.

and even for a single meteor as a function of time. The well known forbidden green oxygen line at 5577 Å forms the trains behind the fainter of the observed meteors.

As the first example, the Perseid spectrum TVS 34 is displayed in Fig. 2. The visual magnitude of the meteor was about 0. The first order spectrum above 5000 Å has been recorded. Taking into account the spectral sensitivity, by far the most intense line is the O I triplet (multiplet 1) at 7774 Å. Further bright lines are the Mg I triplet (m. 2) at 5178 Å and the Na I doublet (m. 1) at 5893 Å. Most of the fainter features belong to the N_2 molecule.

2.2 Time evolution of a spectrum

More interesting is another Perseid spectrum taken in the same night during the 1992 maximum, TVS 29. A bright flare was recorded during this event. Altogether 6 frames showing the development of the flare are displayed in Fig 4. The spectrum consists of overlapping parts of the 2nd to 4th spectral orders. Observed lines are identified in Fig. 3. Before the flare, only lines of O I and also of N I are very weakly visible in the field of view. During the flare, many other lines appear, in particular the very bright lines of Ca II. Taking into account the low sensitivity of the system at wavelengths below 4000 Å and the high spectral order involved (4th), the real brightness of these lines must have been extreme.

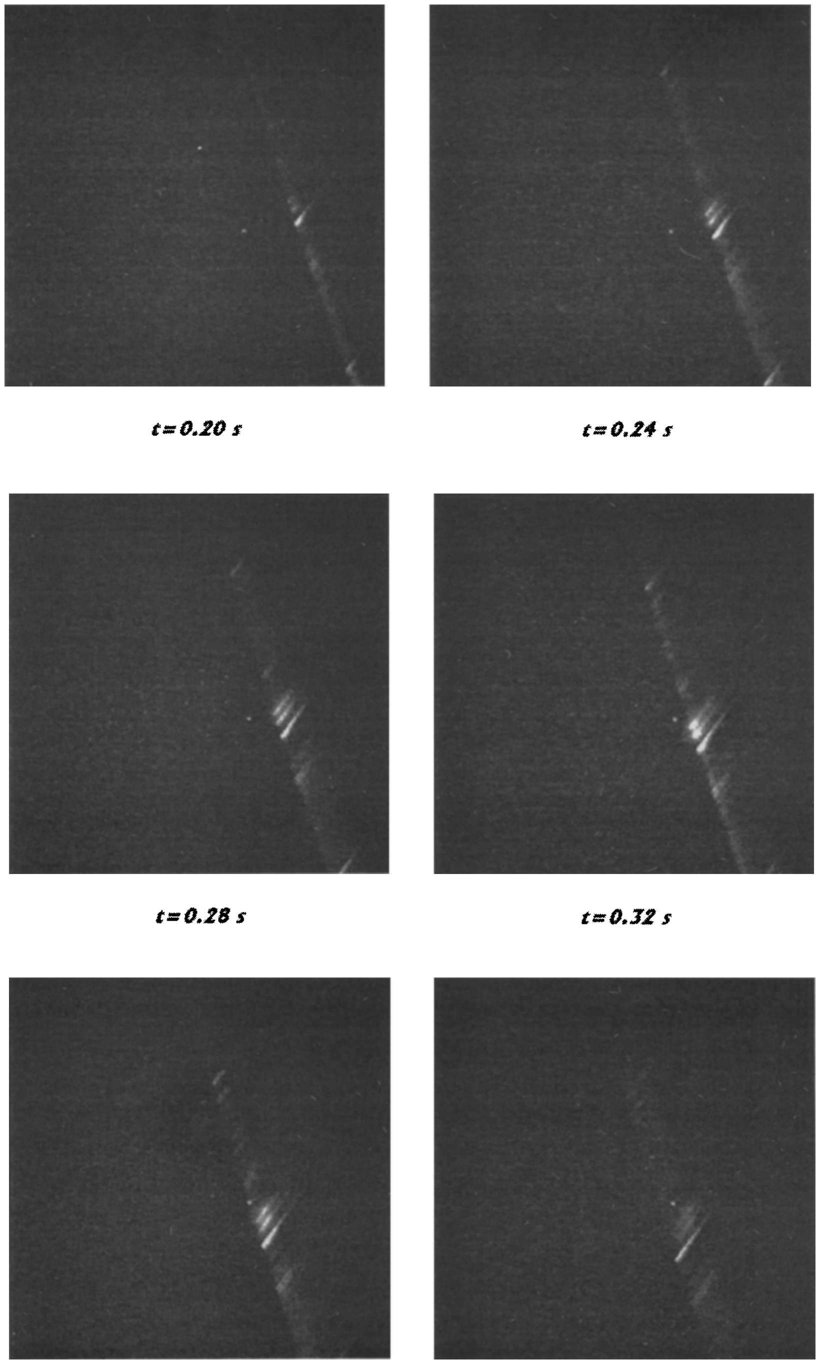

Fig. 4. The time evolution of the Perseid meteor spectrum TVS 29 (1992 Aug 11, 23:39:11 UT). A bright flare was recorded. Note the sharp increase of the intensity of the Ca II lines in the flare. The 2nd, 3rd and 4th spectral orders overlap. For more detailed line identification see Fig. 3.

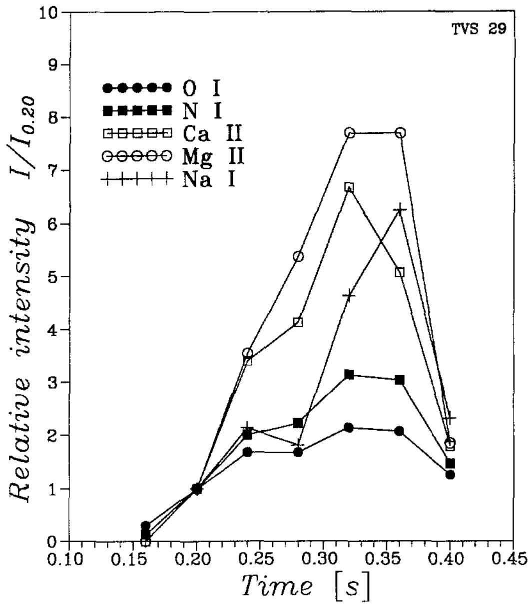

Fig. 5. The light curve of meteor TVS 29 in five different spectral lines. All light curves are normalized to unity at the relative time 0.20 s. Note the smaller amplitude of the flare in the atmospheric emissions of oxygen and nitrogen.

In Fig. 5 the light curves of the flare in several spectral lines are given. The total intensity of the radiation in the lines were measured in each frame and related to the intensity at the beginning of the flare at time $t = 0.20$ s. The lines of atmospheric origin, O I and N I, show the smallest amplitude, while the amplitude of the meteoric part of the hot component (lines of Ca II and Mg II) is very large. The cool component, represented by the Na I line, also has large amplitude and the maximum is shifted to a later time.

Another fact, which is not obvious from these light curves, is that the intensity of the hot meteoric component relative to the cool component is unusually high in the flare. The observed ratio of the Mg II–4 line (in the 4th order) to the Na I–1 line (in the 3rd order) is nearly 5:2 at $t = 0.32$ s. In another relatively bright Perseid, TVS 26, both lines are also visible, but the ratio is 1:8, i.e. 20 times lower. TVS 26 does not exhibit a flare. The absence of Ca II lines in the 2nd order in TVS 34 just behind the O I line is also in contrast to TVS 29.

These facts demonstrate that the flare in TVS 29 was caused by a sudden ablation with the immediate consequence of increasing magnitude of the meteor shock wave (which is responsible for the hot spectral component).

2.3 Chemical differences

The consideration of possible differences in chemical composition among faint meteors proved to be more difficult. The method which enables to determine the chemical composition, temperature and column density of the radiating gas from individual spectrum (Borovička 1993) could be applied to bright meteors with rich spectra but cannot be used here because of only few lines available in the cool meteoric component. Unfortunately, most radiation in fast and faint meteors comes from atmospheric species (see also Mukhamednazarov and Maltseva, 1989). Statistical approach, comparing large number of spectra, is to be used for faint meteors. The present work is important for the revelation of the behavior of different spectral components. We did not found any striking difference in chemical composition in our six spectra. The preliminary examination of further spectra revealed one sporadic meteor dominated by iron radiation.

3 Discussion

The Perseid spectra observed here can be compared to the image orthicon Perseid spectra obtained by Millman *et al.* (1971). Their spectra cover different wavelengths (3300–6600 Å) but in the overlapping region are similar to our spectra. A few identifications of Millman *et al.* may be, however, questionable, e.g. for their feature no. 23 we favor O I–10 as the main contributor instead of Ca I–3. In general, they slightly underestimated the role of the atmospheric emissions.

The atmospheric emissions of O I, N I and N_2 are strong in the TV spectra of faint (+3 mag) meteors of Mukhamednazarov and Maltseva (1989), especially in the infrared. Surprisingly, also in their paper, the line near 6150 Å is identified with Ca I–3. Harvey (1977) identified this line correctly with O I–10 in his photographic Perseid spectrum.

Millman and Halliday (1961) noticed the varying intensity ratio of the infrared Ca II lines to the lines of O I and N I among bright photographic Perseids. They also mentioned that the intensity of the Ca II lines usually increases towards the end of a meteor and in particular in terminal flares. The sharp brightening of the H & K lines of Ca II in flares was called the calcium anomaly by some authors and special processes for its explaining were searched for (e.g. Harvey 1971). In this paper we have shown in one particular case that the intensity of Ca II lines is correlated with other lines of the hot meteoric component and that the effect is therefore not specific for calcium.

The origin of the hot meteoric component in the shock wave is an assumption which has no independent observational support. Some authors believe that shock waves develop only in very bright meteors. However, Rajchl (1972) concluded that shock waves can be formed in meteors of ≈ -3 mag which is consistent with our observations. On the other hand, the hot atmospheric component is probably not connected with the shock wave because it is present also in much fainter meteors in our sample and exhibits different temporal variation.

4 Conclusions

The most striking evidence from the television spectra is that the intensity ratio of hot/cool component and of atmospheric/meteoric radiation varies strongly in meteors of the same velocity and even in single meteors. This is an evidence for variations in the ablation process and in the formation of the shock wave. These variations are probably larger among faint meteors than among fireballs. One can speculate that the cause of the variations is some difference in the mechanical structure among meteoroids of the same shower. No calcium anomaly seems to exist.

Our observations are still continuing and we expect to obtain more data on the time evolution of meteor events and, hopefully, also on the chemical composition of small meteoroids.

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