TV spectra of shower meteors

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1 TV spectroscopy of meteors

If we wish to study a faint interplanetary material we have to either collect samples of it (IDPs, or in situ measurement of probes to Comet Halley) or record the spectrum of meteoric light.

In the second case only large bodies (fireballs) can easily be recorded photographically, but fireballs are a phenomenon too rare to be used for statistical comparative studies. This drawback can be eliminated by using more sensitive television equipment which is capable of recording of large number of spectra of smaller particles. Another advantage of the use of television techniques instead of classical photographic method is the good temporal resolution. On the other hand, the spatial resolution is lower.

At the Ondřejov Observatory, regular TV observations of meteor spectra started in 1990. Now we have reduced a set of meteors spectra which is enough large for statistical processing.

The results of important relating works give hypotheses about features we can expect in our TV meteor spectra:

1.1 Components in meteor spectra

"Through an analysis of fireball spectra it was found that meteor heads consist of two parts with quite different temperatures. The spectra of both parts can be fitted with a simple thermal equilibrium model. The temperature of the main spectrum is about 4 000 K, and that of the second spectrum is about 10 000 K. There is little evidence for a dependence of temperatures on the meteor velocity. However, the mass and luminosity of the second part relative to the main part grows rapidly with meteor velocity. The high temperature part forms only 0.02 % of the meteor vapor envelope in slow meteors but accounts for more than 5 % in fast meteors. ...This region is very probably related to the meteor shock wave."

(From (Borovička 1994).)

Our set of spectra of meteor showers with various velocities allows to study the above mentioned dependence of luminosity of the second spectrum on the meteor velocity.

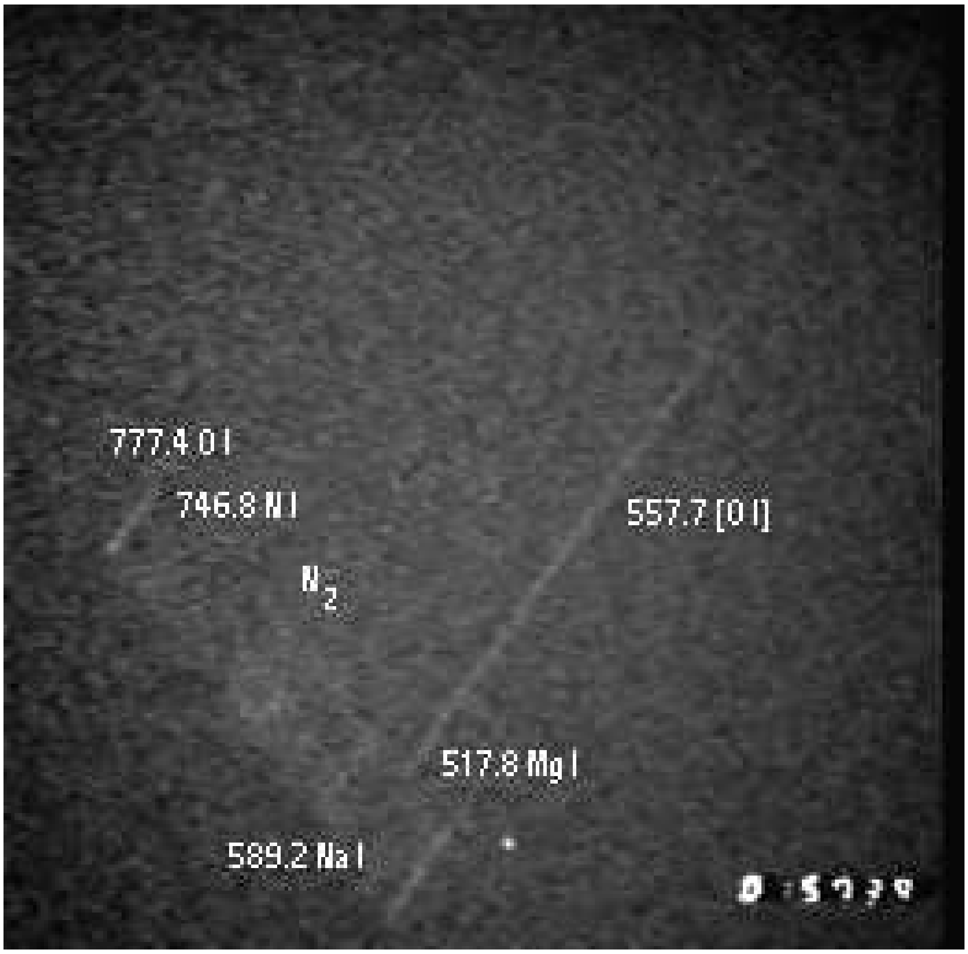

Figure 1: Typical digitized image of the meteor spectrum (`S74.74F`)

1.2 Unique composition of α Monocerotids

"...The double–station observations also provide clues regarding the structure of the dust particles within the α Monocerotid stream. They penetrate deeper into the atmosphere than meteoroids of the Orionid stream (P/Halley) or Perseid stream (P/Swift–Tuttle) and the light curves of the meteors do not show flares."

(From (Jenniskens et al. 1996).)

The Jenniskens' results imply that α Monocerotids are more compact than other showers meteoroids.

It can bear on lower amount of volatile elements and our α Monocerotid spectra allow us to test this hypothesis.

1.3 Image processing

The first step is digitizing of the video record. It produces a sequence of images with a step 0.04 s. All images are being dark-frame subtracted and flat-fielded. Typical image is shown in Fig. 1. The spectrum recorded on the image is scanned and the background signal is subtracted.

The examples of spectra are shown in Section 2.

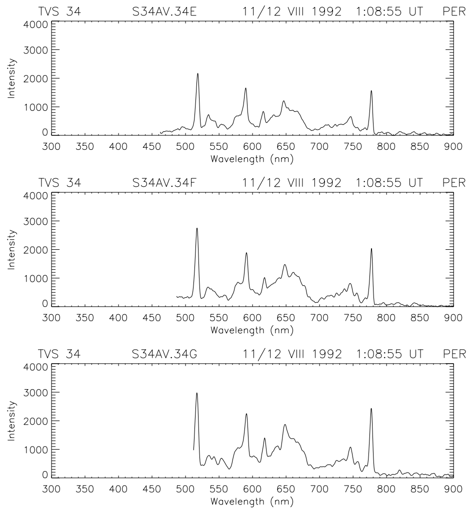

Figure 2: Perseid spectrum TVS 34

1.4 Recorded spectra 1990–1994

The results in the following Sections are based on the evaluation of TV spectra captured during the period 1990–1994. This set is the first one in Ondřejov programme which is enough numerous for statistical processing. Also, the α Monocerotids spectra (captured 21/22 XI 1995) were added to the set as a sample of interplanetary material of a distinct composition.

2 High quality spectra of cometary meteors

The examples of high quality spectra are shown in this Section. But we choose more (44) spectra (all with at least two recognized lines) for further analysis.

2.1 Perseids

Perseids are the most frequent spectra in our set. About one half of our spectra are Perseids and the points representing the Perseids on Fig. 9 are the best defined and other showers can be related to them. The velocity of Perseids is 61 km/s.

2.1.1 TVS 34

TVS 34 is one of our best spectra. Although captured in the moonshine time its signal/noise ratio is very good. Fig. 2 shows sequence of the three best consecutive images.

The blue rim is not recorded and the first important feature on the left is Mg I-2 line (517 nm). The next prominent line is Na I-1 (589 nm) and three fainter lines follows: a group of Fe I-15 (530–550 nm), O I-10 (616 nm), Fe I-168 (650 nm) and

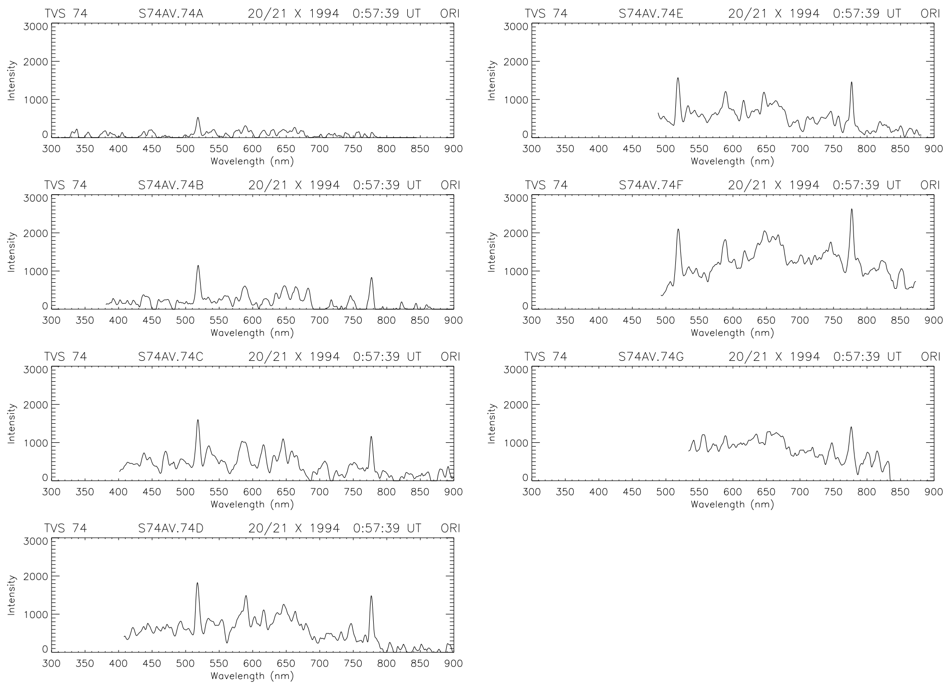

Figure 3: Orionid spectrum TVS 74

atmospheric N I-3 (745 nm). The lines are overlapped by three N_2 belts (570–600 nm, 635–670 nm, 730–760 nm). The bright line in the infrared part of the spectrum is O I-1 (777 nm).

2.2 Orionids

Orionids' characteristics are similar as Perseids' ones. Their velocity is 67 km/s (Perseids 61 km/s) and both showers come from well known comets. Also our spectra don't show exceptional differences.

2.2.1 TVS 74

TVS 74 is a good illustration of problems with the delayed forbidden line [O I]. As you can see on Fig. 1 the [O I] line is very bright. But it isn't featured in spectrum in Fig. 3 because the line is out of the scanned area.

The spectrum on Fig. 3 contains all of features described in the previous subsections. It means bright lines Mg I-2 (517 nm), Na I-1 (589 nm) and O I-1 (777 nm), fainter lines O I-10 (616 nm), Fe I-168 (650 nm), N I-3 (745 nm) and three N_2 belts (570–600 nm, 635–670 nm, 730–760 nm) are recorded.

CN bands were also recorded in this spectrum. They are overlapped with N_2 bands in the best images, but in the first images where atmospheric belts are enough faint they can be recognized. In the plot `S74AV.74B` you can see three belts in approx. 645 nm, 665 nm and 682 nm. The CN bands are significantly narrower than those of nitrogen.

2.3 Geminids

Geminids are slow meteors with the velocity 36 km/s. It means their spectra should show lower intensities of the second spectrum[1] lines (especially O I-1 (777 nm)). In addition the Geminids are known to come from the asteroidal body (3200 Phaeton). It indicates lower amount of volatile elements in meteoroids.

2.4 Quadrantids

Quadrantids are represented by only one point in Fig. 9 and we cannot make any conclusions about the entire shower. Nevertheless, our Quadrantid spectrum corresponds with linear dependencies on Fig. 9. The velocity of Quadrantids is 42 km/s.

2.5 δ Aquarids

δ Aquarids is another less populated shower in our set. Likewise Quadrantids the recorded δ Aquarids also can't give reliable results but they follow the general dependencies. The velocity of δ Aquarids is 44 km/s.

2.6 α Monocerotids

Although the aim of our work is a complete processing of collection 1990–1994 of Ondřejov TV meteor spectra we decided to add spectra from November 22, 1995 to our set. During that night α Monocerotids outburst was observed and several (at least four, the membership of another meteors is unsure) spectra were taken.

We suppose that α Monocerotids have lower amount of volatile elements (Section 1.2) and our spectra represent a sample of interplanetary material with a specific composition. They also bring new entries into a statistics in Section 3.

The velocity of α Monocerotids is 64 km/s but their spectra look unlike Perseids (61 km/s) and Orionids (67 km/s). The hypothesis concerning low amount of volatile elements (Section 1.2) is confirmed. The sodium line Na I-1 (589 nm) is very faint in all α Monocerotid spectra.

2.6.1 TVS 161

TVS 161 is our brightest α Monocerotid spectrum taken during the 1995 outburst. The prominent lines on Fig. 4 are Mg I-2 (517 nm) and O I-1 (777 nm). Although the N_2 belts (570–600 nm, 635–670 nm, 730–760 nm) and the faint lines O I-10 (616 nm), Fe I-168 (650 nm), N I-3 (745 nm) are visible the intensity of Na I-1 (589 nm) is very low.

2.7 Unknown, sporadic meteors

It is hard to say anything about sporadic meteors generally. Their origin, composition and velocity is different, of course.

Selected TVS 43 is one of the most interesting cases. It is our only one record of a stationary meteor.

2.7.1 TVS 43

TVS 43 is a unique spectrum of stationary meteor. There is no problem with delayed [O I] line because lines are recorded as points in the row. Thus Fig. 5 is the best example showing the delay of forbidden line [O I] (558 nm).

[1] see Section 1.1

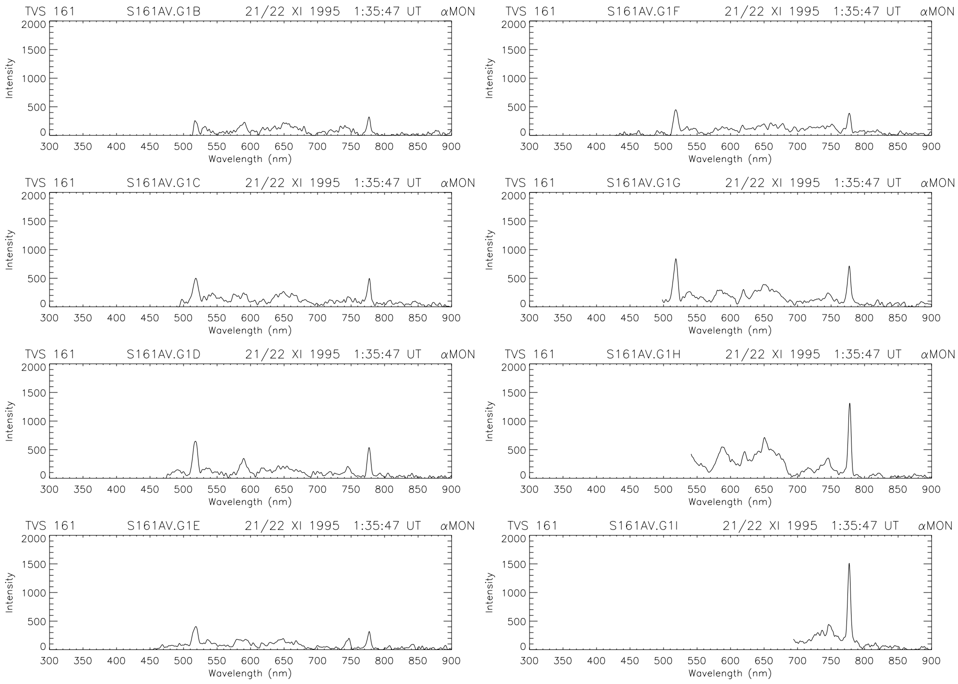

Figure 4: α Monocerotid spectrum TVS 161

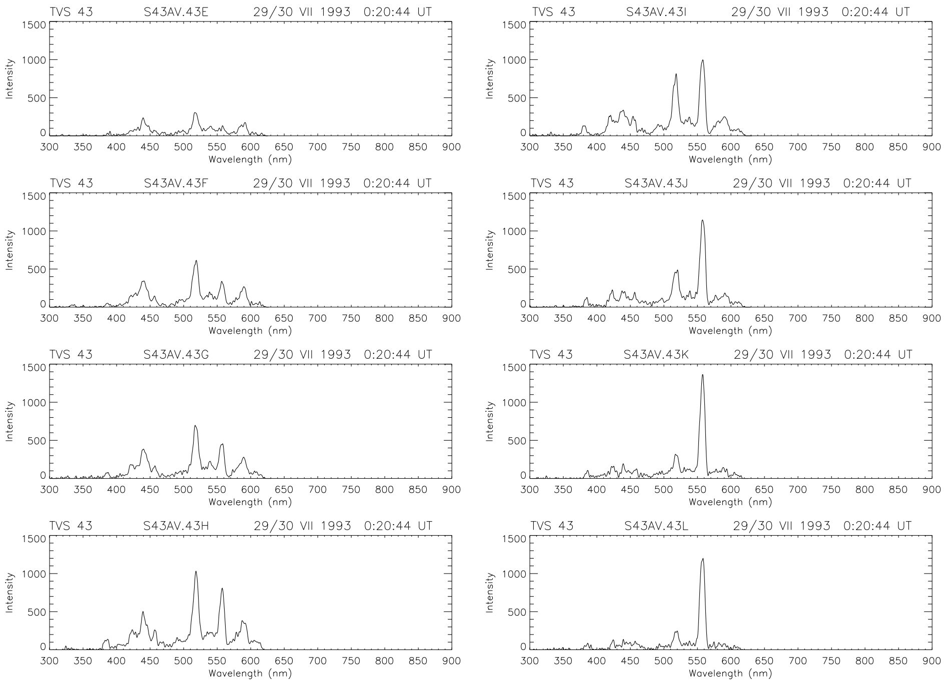

Figure 5: Meteor spectrum TVS 43

Other recorded features are Mg I-2 (517 nm), Na I-1 (589 nm) and Fe group (420–450 nm).

2.8 Very slow meteor TVS 73

The duration of TV meteors is usually several tenths of second. TVS 73 represent the only exception in our set of Ondřejov TV spectra. We have recorded 30 images with a step 0.04 s. Our field of view is 10×10 degrees, so the angular velocity was about 10 degrees per second. Elevation was about $45°$. Assuming the height was about 80 km we can estimate the lower limit of the meteor velocity. It is about 20 km/s.

Typical features of this slow meteor spectrum are the high ratio of mineral over atmospheric lines (main spectrum over second one) and also high Na/Mg ratio probably caused by higher excitation potential of Mg I-2.

3 Statistically significant differences in observed spectra

For statistical processing we choose 44 good quality spectra with several images of each.

3.1 Intensity plots

The spectra of which examples are shown in Section 2 contain several lines. However only four lines were found to be enough bright in the significant number of recorded spectra and can be used for statistical processing.

We measure spectrum intensity at wavelengths 517.8 nm (Mg I), 589.2 nm (Na I), 746.8 nm (N I) and 777.4 nm (O I). The intensity is produced by scanning pixel intensities of the recorded image and is given in the relative units only.

The measured values were calibrated by spectral sensitivity curve of our technique.

3.1.1 Na and O intensities

The points on Fig. 6 lie in a line and the meteor spectra show the correlation of Na and O lines. But some differences between showers are apparent.

The O I-1 line is fainter in spectra of slower meteors (Geminids and very slow meteor TVS 73). It's probably caused by a strong dependence of second spectrum amount, which O I-1 belongs to, on the meteor velocity (see Section 1.1).

On the other hand, α Monocerotids have lower amount of sodium and so the corresponding points on Fig. 6 are shifted to the left.

3.1.2 Mg and O intensities

Plots on Fig. 7 show linear dependence in individual showers, but they differ in the line slope.

As mentioned in the previous subsection the amount of second spectrum is lower in slow meteors. That is why the Geminids plots are shifted to the right and down. The shift of another slow meteor TVS 73 isn't so clear because both of Mg and O lines are very faint and affected by noise.

Also note the high spread in left lower part of the diagram. It's caused by worse signal/noise ratio in the case of faint meteors.

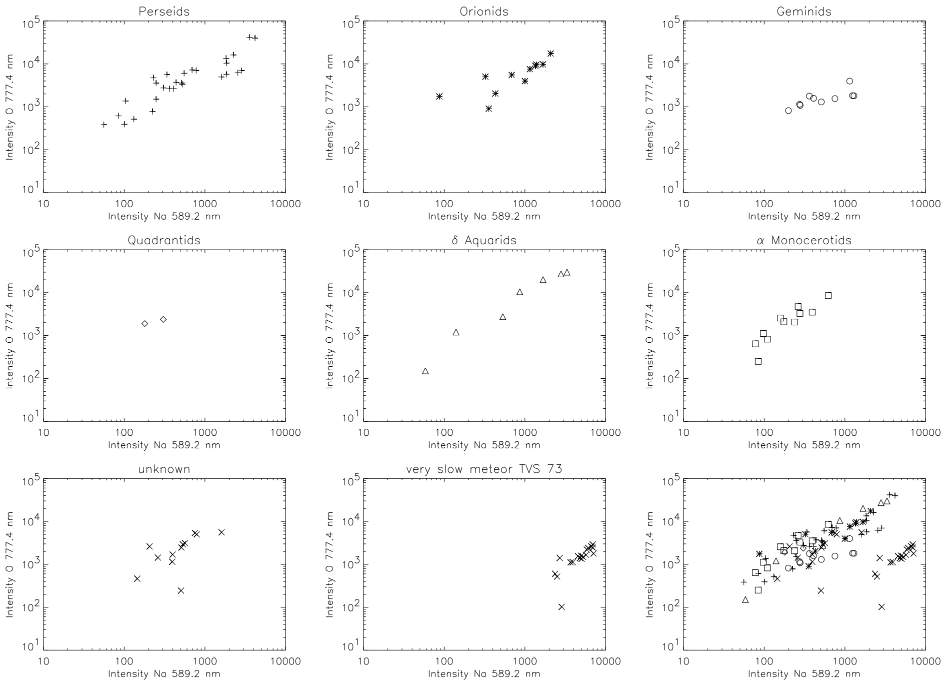

Figure 6: Na and O intensities in the studied spectra

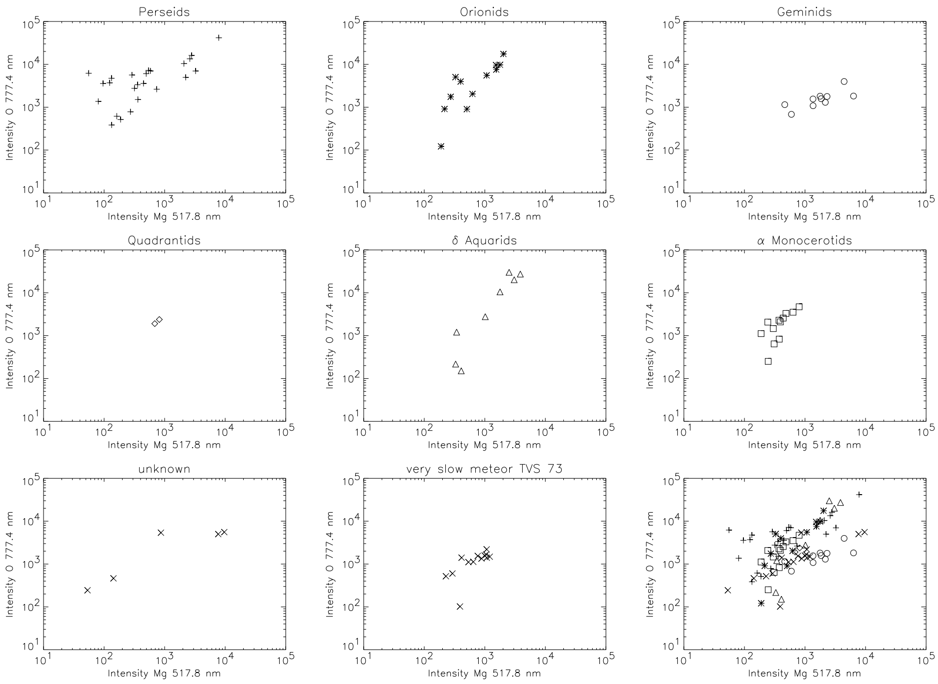

Figure 7: Mg and O intensities in the studied spectra

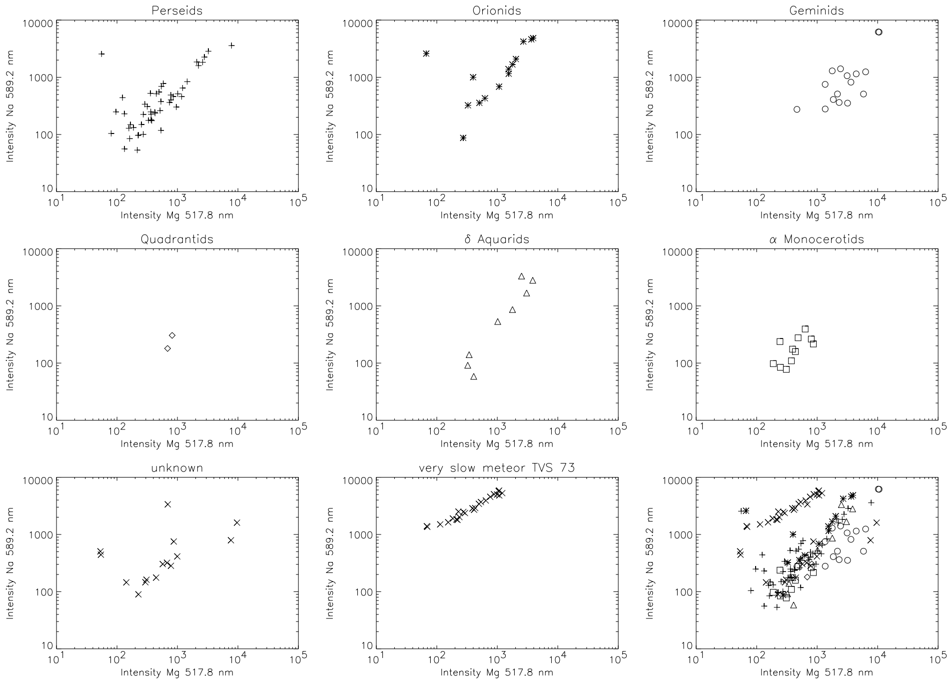

Figure 8: Mg and Na intensities in the studied spectra

3.1.3 Mg and Na intensities

The most important features of Fig. 8 are:

- The Geminid points are shifted to the right. Geminids are known to have lower amount of volatile elements because they originate from asteroid (3200) Phaeton.
- The Mg I-2 intensity is low in the slow meteor spectrum TVS 73. It may be caused by higher excitation potential of this line (Mg I-2 2.72 eV, Na I-1 0.00 eV). In case of higher velocities both lines are saturated and optically thick and this phenomenon isn't important.

3.1.4 O and N intensities

The O I-1 and N I-1 lines are both atmospheric and both belong to the second spectrum. So the correlation between those lines is the strongest one of all plotted combinations and points on the graph lie on the rather perfect line.

3.2 Dependence on velocity

The Fig. 9 shows the ratio of the line intensities versus the meteor velocity. The measured spectral lines are Mg I-2 (517.8 nm), Na I-1 (589.2 nm), N I-1 (746.8 nm), O I-1 (777.4 nm). The plotted symbols correspond to the following meteor showers: asterisk — Orionids (67 km/s), square — α Monocerotids (64 km/s), plus sign — Perseids (61 km/s), triangle — δ Aquarids (44 km/s), diamond — Quadrantids (42 km/s), circle — Geminids (36 km/s) and x — very slow meteor (about 20 km/s).

The Na/O ratio decreases with increasing velocity. All showers are in compliance with this relation except α Monocerotids. The differences in α Monocerotids spec-

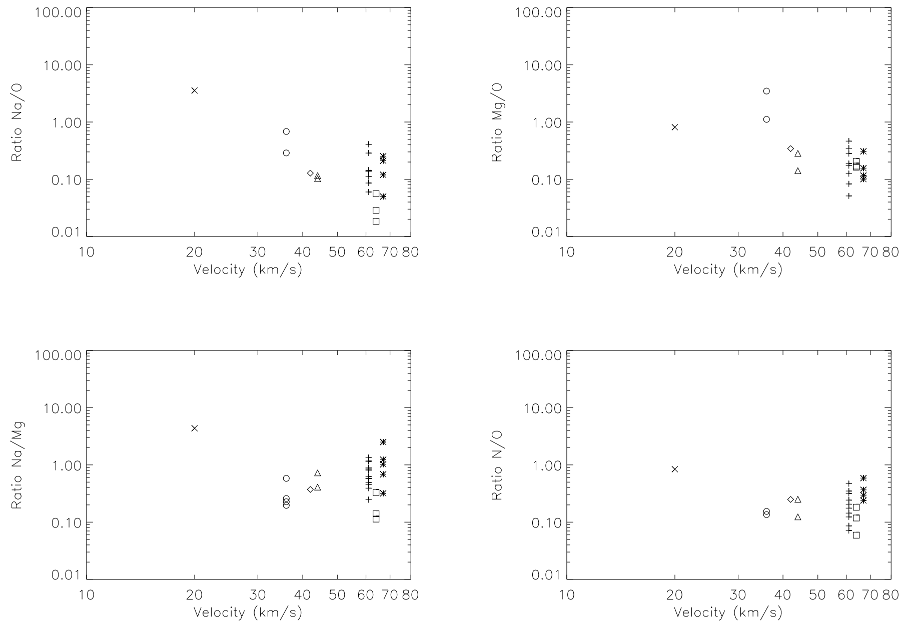

Figure 9: Dependence on velocity

tra aren't caused by velocity and so they indicate rather differences in meteoroids composition.

The Mg/O plots don't show clear relation. Geminids are known to have a bright Mg line. But the TVS 73 point is not sure because, as mentioned in the subsection 3.1.2, both lines are faint and the signal/noise ratio is very bad. In addition, Mg excitation potential phenomenon (see subsection 3.1.3) probably influences this plot too.

The relation of Na/Mg ratio on the velocity should be divided into two parts. In case of slow meteor Mg line isn't saturated and is optical thin (also see subsection 3.1.3). In that velocity range Na/Mg ratio decreases with increasing velocity. In the second part both lines are saturated and optical thick. Here Na/Mg ratio slightly increase with increasing velocity. The low amount of sodium in the α Monocerotids spectra is already mentioned.

The ratio N/O should be constant, independent on velocity. It approximately is. The TVS 73 point is uncertain, because the N line is very faint in this spectrum and thus affected by the noise.

4 Results

Our hypotheses mentioned in the Section 1 are confirmed and the expected features were really found. Also, we obtained other interested results:

4.1 Components in meteor spectra

Plots in Section 3 indicate differences between fast and slow meteors mentioned in Section 1.1.

The brightest lines of second spectrum are N I-3 (745 nm) and O I-1 (777 nm). Incidentally, whereas the bright lines of the main spectrum is a radiation of the mineral, meteoritic material the N I-3 (745 nm) and O I-1 (777 nm) are atmospheric lines. Thus the variation of ratio of second spectrum lines is small, because composition of Earth atmosphere is same in all cases. But the ratio of main spectrum lines varies due to the different element abundance in meteoritic material.

The dependence of intensities ratio on velocity (plots on Fig. 9) shows interesting trends:

1. The most prominent one is decreasing trend of Na/O ratio, which confirm higher intensity of second spectrum in high velocity meteors.
2. Also Mg/O plots show similar trend but affected by the anomalous value of Geminids.
3. The Na/Mg case is a more complicated and the dependence should be divided into two velocity ranges. See Section 3.1.3.
4. N and O are both atmospheric lines and both become to the second spectrum. The N/O ratio should be constant and roughly speaking it is.

4.2 Peculiar features of α Monocerotids

Jenniskens et al. 1996, 1997 found that α Monocerotids penetrate deeper into the atmosphere than meteoroids of the Orionid stream or Perseid stream (meteoroids with similar velocity) and that their light curves do not show flares. The Jenniskens' results imply that α Monocerotids are more compact than other showers meteoroids and can therefore contain lower amount of volatile elements. (Section 1.2).

Our spectra show very low abundance of Na in all recorded α Monocerotid spectra (Sections 2.6 and 3.2) and the hypothesis concerning low amount of volatile elements could be confirmed, at least for sodium.

4.3 Peculiar features of Geminids

The parent body of Geminids is asteroid (3200) Phaeton. So, they are supposed to be compact and have lower amount of volatile elements too. But unlike α Monocerotids (64 km/s) their velocity is only 36 km/h and spectra should shows high ratio of main/second spectrum intensity.

Our Geminid spectra really show high intensity of Mg I line (517.8 nm) relatively to the second spectrum (O I (777.4 nm)). Another main spectrum line Na I (589.2 nm) is not so bright and it is probably caused by specific Geminids composition and origin.

See Sections 2.3, 3.1.2, 3.1.3 and 3.2.

4.4 Detection of CN

Detection of CN bands on the photographs is very complicated and CN bands aren't surely demonstrated. The reasons are:

1. The dispersion of photographic spectra is high and allows to detect individual band lines. That lines are faint and lower dispersion of TV spectra is an advantage here. The individual lines aren't recognized and the cumulative brightness of band is higher.
2. It's hard to detect CN bands by observation without temporal resolution. On photograph CN bands are overlapped by N_2 bands and other lines. The TV technique allows to obtain spectrum in the specific moment when CN bands are brightest feature in their spectral range.

We found spectrum where CN bands are recorded and it demonstrates well the advantage of the TV recording technique. See Section 2.2.1.

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