Meteor spectra in the EDMOND database

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We present a selection of five interesting meteor spectra obtained in the years 2014 and 2015 via CCTV video systems with a holographic grating, working in CEMENT and BRAMON meteor observation networks. Based on the EDMOND multi stations video meteor trajectory data an orbital classification of these meteors was performed. Selected meteors are members of the LYR, SPE, DSA and LVI meteor streams, one meteor is classified as sporadic background (SPO). In calibrated spectra the main chemical components were identified. Meteors are chemically classified based on relative intensities of the main spectral lines (or multiplets): Mg I (2), Na I (1), and Fe I (15). Bolide EN091214 is linked with the 23rd meteorite with known orbit (informally known as "Žďár"), two fragments of the parent body were found in the Czech Republic so far (August, 2015). For this particular event a time resolved spectral observation and comparison with laboratory spectra of LL3.2 chondritic meteorite are presented.

1 Introduction

One of our research goals is to better understand the physical and chemical properties of meteoroids by using simultaneous video and spectral observations of meteors compared with meteoritic material laboratory spectra. Spectral observations of meteors are now obtained via fixed (at Valašské Meziříčí observatory) and mobile spectroscopic CCTV systems. All records of meteors and processing data (orbital elements, speed of deceleration, etc.) are inserted into the EDMOND database (Kornoš et al., 2014a, 2014b) together with spectral information. Another very valuable source of the physical and chemical properties of meteoroids are spectra taken by BRAMON (BRAzilian Meteor Observation Network). This network covers the southern hemisphere and is a source of information about the little-known meteor showers.

Simultaneously, our target is the systematization of spectroscopic emission lines for the comparative analysis of meteor spectra. The solids will be irradiated using excimer and PALS lasers (Na, Ti, Mg, Al, Si, Fe, and Ca), their simple binary oxides, sulfides, minerals and real sample of meteorites). The LIDB (laser-induced dielectric breakdown) in a gas media representing the atmospheres (O_2, N_2, Ar, and CO_2) will also be spectroscopically characterized. These spectra will be recorded in-situ on the discharges and excimer laser ablations using Fourier time-resolved high-resolution spectrometer Bruker, high resolution Echelle spectrograph LLA and CCD spectrograph Ocean Optics. Complying data will allow for not only qualitative determinations of the impacting body composition but also the assignment of spectral lines for products from the meteorite alterations and plasma interactions in the atmosphere.

2 Equipment and data reduction

The spectrograph uses a highly sensitive CCD video camera VE 6047 EF/OSD. The camera is equipped with 1/3" CCD chip Sony ICX 673AKA with an effective resolution of 720 x 576 px. Video is recorded in a standard PAL B signal at resolution 700 TVL, the sensitivity of the camera in BW mode is 0.002 lx. The field of view is 60^o x 48^o, the system uses a fast Tokina lens (f/0.98) with a variable focal length (3-8 mm). FOV and resolution of the CCD chip enables the use of a holographic diffraction grating with density of 500 lines/mm. In this configuration the spectrograph reaches a stellar limiting magnitude +4.5^m, the faintest recorded meteors then have a relative magnitude up to +2.0^m. The magnitude of meteors with a measurable spectrum have to be at least -2.0^m. The detection of meteors is done by UFOCapture software (SonotaCo 2005), and for the astrometric and photometric processing UFOAnalyzer software (SonotaCo 2007) is used. The resulting video is divided into individual images (frames), every image is subsequently a dark frame and a flat field corrected with frames captured by the camera VE 6047 EF/OSD. The orbits of meteoroids in the solar system are calculated using the software UFOOrbit (SonotaCo 2007b). Deceleration is counted out of this software as an exponential fit of the actual speed of the meteor for each frame. Spectrograph calibration in the x-axis (wavelength) was performed using a calibration neon lamp. Calibration was performed as non-linear, using 6 multiplets of neon emission lines at wavelengths between 5852 and 7032 Å. The resulting basic spectrograph resolution was determined from 5 independent measurements at 30.4 Å/px.

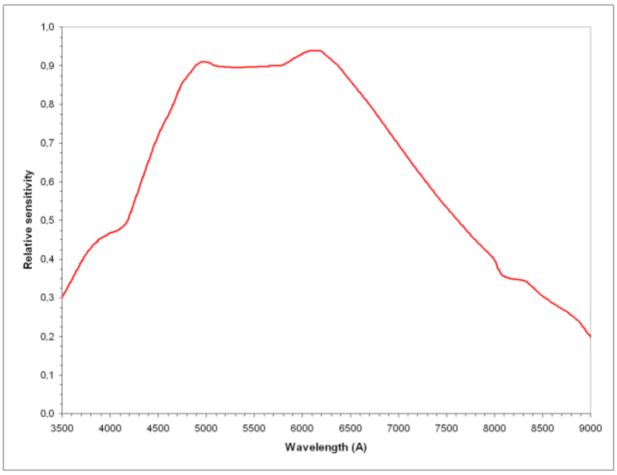

Figure 1 – Relative spectral sensitivity of CCD chip Sony ICX 673AKA.

Calibration of the emission line intensity (y-axis) was performed using a diagram of relative sensitivity CCD Sony ICX 673AKA at a wavelength between 3500 and 9000 Å. For identification of the emission wavelengths of the individual elements revised tables were used (Moore, 1972).

3 Observations and results

Figures 2 and 3 show spectrum No.18 (20140829_015039 SPO) – combined spectrum image and calibrated spectrum of a sporadic meteor. Due to a low geocentric velocity the atmospheric emissions in the spectrum (NI, OI) are proportionally low compared to the dominant emissions of NaI-1, and MgI-2. Atmospheric emissions of N_2 are not practically detectable.

Figure 2 – Combined spectrum image of meteor No.18 (20140829_015039 SPO).

Emissions of the FeI-15 multiplet are relatively high, with the NaI-MgI-FeI ratio 0.340-0.396-0.264, and the OI-1 to MgI-2 multiplets emissions ratio only 0.339. The orbital elements of the analyzed meteor are in *Table 1*.

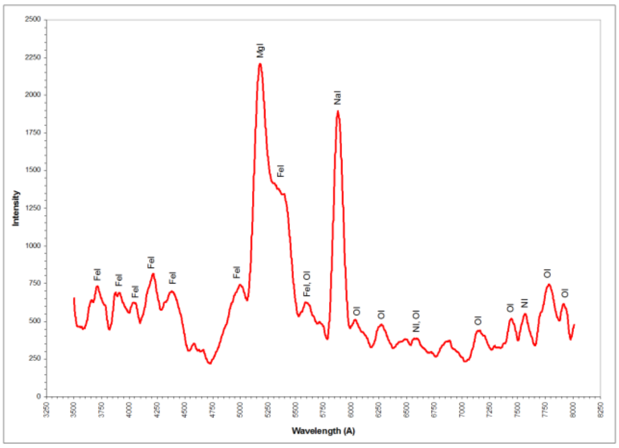

Figure 3 – Calibrated spectrum of meteor No.18 (20140829_015039 SPO).

Figures 4 and 5 show spectrum No.19 (20140908_224429 #208 SPE) – combined spectrum image and calibrated spectrum of a September Perseids shower member. The geocentric velocity of the meteor was very high, the atmospheric emissions of NI, OI in the spectra are of high intensities, the OI-1 to MgI-2 multiplets emissions ratio is 2.906.

Figure 4 – Combined spectrum image of meteor No.19 (20140908_224429 #208 SPE).

Among the atmospheric emissions of N_2 is the most intensive (N_2 1^{st} positive, $\Delta v=3$) multiplet in the range between 6200-6800 Å. The NaI-MgI-FeI ratio is 0.411–0.381–0.209, the most prominent part is the FeI-15 multiplet emission line with a wavelength of 5270 Å. Relatively high is the FeI-5 (3679-3705 Å) and CaI-9 (3644 Å) multiplet emissions combination, with the FeI-5+CaI-9 to MgI-2 ratio 0.905. Also CrI, MnI emission lines were identified, for example MnI-2 (4030–4034 Å) multiplet emission. The orbital elements of the analyzed meteor are in *Table 1*.

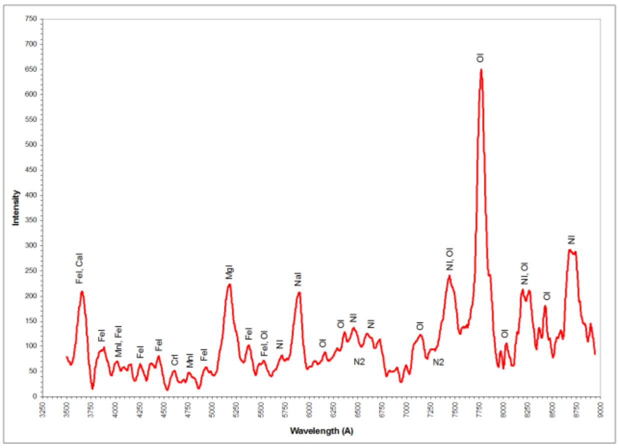

Figure 5 – Calibrated spectrum of meteor No.19 (20140908_224429 #208 SPE).

Figures 6 and 7 show spectrum No.28 (20150422_011758 #006 LYR) – combined spectrum image and calibrated spectrum of Lyrids shower member. Due to a high geocentric velocity, the atmospheric compounds (NI, OI) emissions present in the spectrum are extremely intense, the OI-1 to MgI-2 multiplets emissions ratio is 1.800.

Figure 6 – Combined spectrum image of meteor No.28 (20150422_011758 #006 LYR).

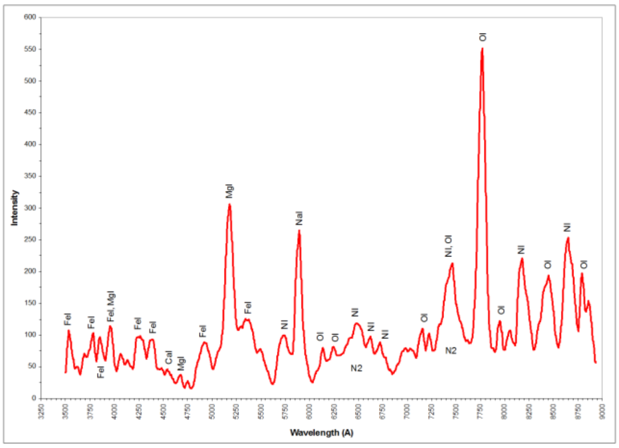

Figure 7 – Calibrated spectrum of meteor No.28 (20150422_011758 #006 LYR).

Among the atmospheric emissions of the N_2 are the most intensive (N_2 1st positive, Δv=3) between 6200–6800 Å and (N_2 1st positive, Δv=2) between 7000–7500 Å. The NaI-MgI-FeI emissions ratio is 0.440–0.380–0.180, contribution of FeI-15 multiplet is relatively low. The most intense FeI-15 multiplet emission line has a wavelength of 5405 Å. The CaI-23 (4578 Å) and the MgI-11 (4703 Å) emission lines were also identified. The orbital elements of the analyzed meteor are given in *Table 1*.

4 Bolide EN091214 (20141209_161645)

Figures 8 and 9 show bolide EN091214 (December Southern Arietids). This event is linked with the 23rd meteorite with known orbit (informally known as Vysočina or Žďár), of which two fragments were found in Czech Republic so far (August, 2015). In the recorded spectrum the 2nd order is obvious, and parts of the 3rd order.

Figure 8 – Combined spectrum image of bolide EN091214 (20141209_161645).

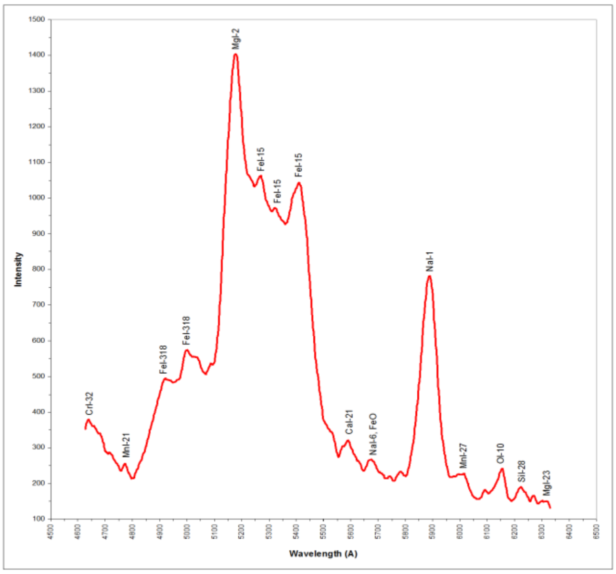

Figure 9 – Calibrated spectrum of bolide EN091214 (20141209_161645) - 2nd order.

Overall 14 video frames of the bolide with 2nd order spectrum were analyzed and a time resolved evolution of emission in the range from 4600 to 6400 Å was examined. Except for the dominant emissions of MgI-2 and NaI-1, the FeI-15 (5270, 5328 and 5405 Å) multiplet, CrI (32 multiplet), MnI (21, 27), FeI (318), CaI (21), MgI (23) and NaI (6) in combination with the emission line of FeO were also identified in the 2nd order. The orbital elements of the analyzed meteor are in *Table 2*.

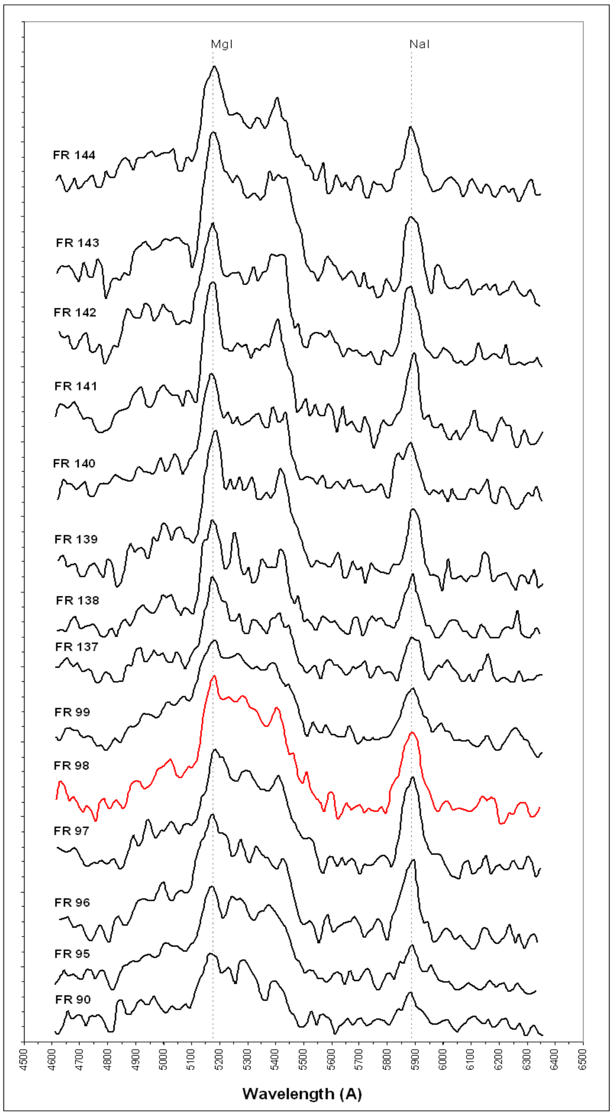

Figure 10 – Uncalibrated evolution of a meteor spectrum in selected frames - 2nd order.

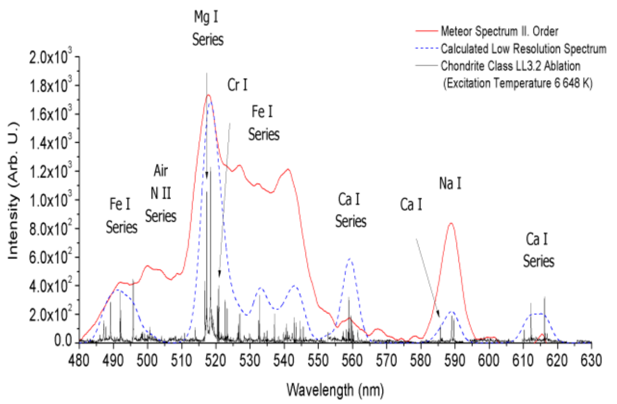

Figure 11 – Calibrated spectrum (2nd order) of bolide EN091214 (20141209_161645) compared with a spectrum of a chondrite (class LL3.2). The spectrum of the chondrite meteorite was obtained by the laser ablation spectrograph (Echelle LLA spectrograph).

5 Lambda Virginids (BRAMON)

Two rare meteor spectra of the λ Virginids meteor shower members were obtained on the station Goiania (Carlos Augusto di Pietro, BRAMON). Due to a low perihelion distance of the meteor shower #049 LVI (q~0.343 AU) the NaI-1 emission intensity varies. As in the case of the Geminids meteor shower, the NaI-1 emission intensity varies between “NaI normal”, “NaI poor” and “NaI free” classification. Both spectra which are presented, belongs to the group “Na poor”, with the NaI-1 to MgI-2 multiplets emissions ratio only 0.238, respectively 0.393 (*Figures 12 and 13*).

Figure 12 – Combined spectrum image of meteor 20150417_033110 (#049 LVI).

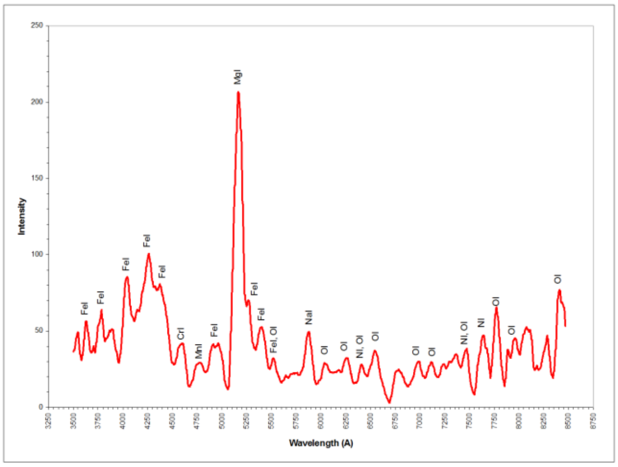

Figure 13 – Calibrated spectrum of meteor 20150417_ _033110 (#049 LVI).

6 Conclusions

The observatory in Valašské Meziříčí is successfully employed in the European Video Meteor Network (EDMOND), which consists of 224 CCD cameras across Europe. The main goal of this network is to determine meteoroid trajectories. Additionally, we increase the scientific quality of the data upgrading our EDMOND stations by spectrographs. For instance, recently (June 25, 2015), there are 28 spectra in the EDMOND database, of which 17 were recorded using the spectroscopic system in Valašské Meziříčí and 11 with mobile spectrographs. Within the frame of the EDMOND database a new section of meteor spectra is gradually arising, which contains the combined observations taken with a mobile spectrograph in 2013, and observations collected since 2014 with spectrograph at Valašské Meziříčí. There are also 18 meteor spectra in the database (June 7, 2015) from BRAMON, which were recorded using the same spectroscopic system as the mobile spectrograph (Watec 902H2 Ultimate, diffraction grating 500 lines/mm).

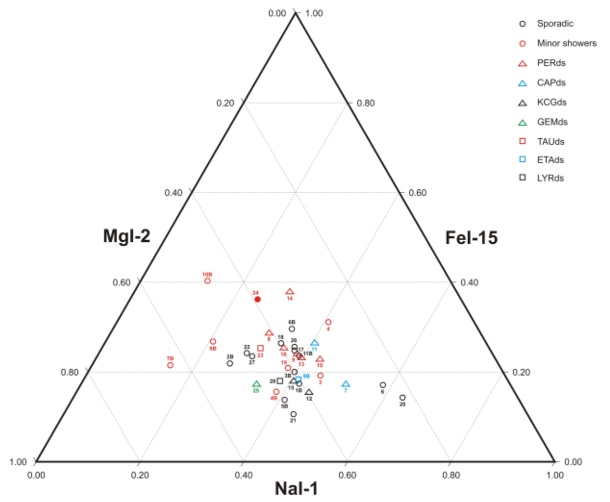

Figure 14 – Position of the parent meteor shower of meteoroids in the ternary graph of the Mg I (2), Na I (1), and Fe I (15) multiplet relative intensities. Every shower is represented with a different symbol, spectra from BRAMON are marked with the letter “B”.

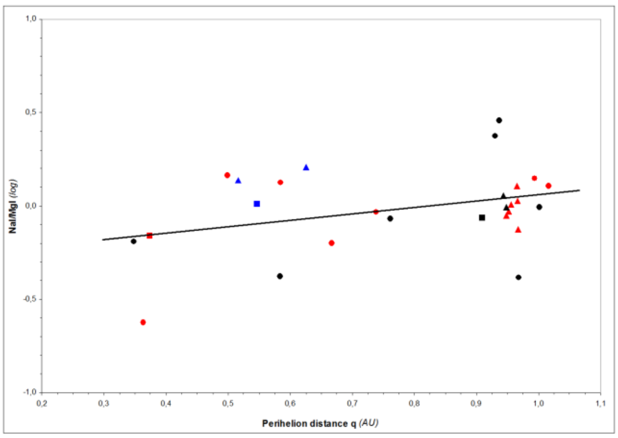

Figure 15 – Intensity ratio of the Na/Mg lines in meteor spectra as a function of the perihelion distance.

Acknowledgement

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Table 1 – Orbital elements and radiant data of the analyzed meteors. The following parameters for each meteor are mentioned: a – semi-major axis, q – perihelion distance, e – eccentricity, ω – argument of perihelion, Ω – ascending node, i – inclination, v_g – geocentric velocity, a_{mag} – absolute magnitude, α, δ – geocentric radiant position, H_1 – beginning height, H_2 – terminal height, m_i – estimated initial mass (Jacchia et al., 1967).

Number	**Date**			**Time**			**a**	**q**	**e**	**ω**	**Ω**	**i**
	YYYY	*MM*	*DD*	*HH*	*MM*	*SS*	*AU*	*AU*	-	*°*	*°*	*°*
18	2014	8	29	1	50	39	2.086	0.7606	0.635	248.625	155.472	32.687
								0.0005	*0.005*	*0.102*		*0.183*
19	2014	9	8	22	44	29	16.223	0.7379	0.955	243.111	166.000	138.021
								0.0004	*0.002*	*0.099*		*0.020*
28	2015	4	22	1	17	57	14.908	0.9094	0.939	216.537	31.403	79.226
								0.0001	*0.002*	*0.037*		*0.024*

Number	$\mathbf{v_g}$	$\mathbf{a_{mag}}$	**α**	**δ**	$\mathbf{H_1}$	$\mathbf{H_2}$	$\mathbf{m_i}$
	km/s		°	°	*km*	*km*	*g*
18	23.58	-3.17	322.29	37.67	88.0	57.2	20.8
	0.15		*0.04*	*0.01*			*3.9*
19	64.20	-4.44	46.80	40.15	124.5	84.2	1.6
	0.04		*0.00*	*0.00*			*0.2*
28	46.48	-3.44	270.76	32.85	112.1	82.3	2.8
	0.03		*0.02*	*0.01*			*0.4*

Table 2 – Orbital elements of bolide EN091214 (20141209_161645). Following parameters for each meteor are mentioned: a – semi-major axis, q – perihelion distance, e – eccentricity, ω – argument of perihelion, Ω – ascending node, i – inclination, v_g – geocentric velocity.

Number	**Date**			**Time**			**a**	**q**	**e**	**ω**	**Ω**	**i**	$\mathbf{v_g}$
	YYYY	*MM*	*DD*	*HH*	*MM*	*SS*	*AU*	*AU*	-	*°*	*°*	*°*	*km/s*
24	2014	12	9	16	16	45	2.260	0.6675	0.705	257.260	257.303	3.120	19.17
								0.0005	*0.002*	*0.021*		*0.022*	*0.06*