IDENTIFICATION OF EMISSION LINES IN A METEOR SPECTRUM OBTAINED ON AUGUST 2, 2011

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ABSTRACT. 125 emission lines were found in a meteor spectrum obtained on August 2, 2011. The identification of most of the lines is given. The following species were found in the spectrum: CrI, FeI, MgI, SiI, AlI, MnI, CaI, TiI, NaI, FeII, CaII, MgII, SiII, SrII.

Key words: meteors, spectra, line identification

1. Introduction

Meteors are phenomena in the Earth's atmosphere caused by particles of cosmic origin. Meteor is an unpredictable and short-term phenomenon. To capture it is not so easy, but it is harder to get a good meteor spectrum.

It was found that the average time interval between two penetrations of cosmic particles with masses 10^{-2} g in the atmosphere of our planet is 7.2×10^{-3} s (Churyumov et al., 2012). It is about 140 particles per second. That is a constant interaction of meteoric matter with Earth's atmosphere. Due to this we are able to explore the structure, to determine physical parameters and study the chemical composition of interplanetary matter.

The main method of study of meteoroid composition is meteor spectroscopy.

Each meteor spectrum has a great scientific value. By processing it we can get information about the chemical composition of the cosmic body that invaded into the Earth's atmosphere and the nature of the glow of its substance.

The research of meteor spectra will allow to establish the genetic relationships of meteoroids with comets and asteroids.

The results of studies of meteoric phenomena can be also used as data about the physical and chemical processes in the upper Earth's atmosphere.

Meteor spectra provide information on the ablation process, hydrodynamics of meteors and on meteoroid masses (Borovicka, 1999).

In this paper we present the results of lines identification in a meteor spectrum.

2. Observational data

The meteor spectrum studied here was obtained on August 2, 2011 at 21:56:11 UT. The observations were made at the Ondrejov Observatory (Astronomical Institute of the Academy of Sciences of the Czech Republic).

The beginning of the phenomenon was detected above the point with coordinates: λ_E=15˚,7699, φ_N=49˚,3814, and the end coordinates: λ_E=15˚,61661, φ_N=49˚,13797.

The beginning and end heights of the meteor event were h=115,71 km and h=80,628 km respectively. The average velocity of the meteoric body in the Earth's atmosphere was 48 km/s. The meteor was sporadic with very eccentric orbit with perihelion at 0,969 AU and inclination of 79,7˚.

The spectral record was obtained with a fixed camera Tessar (1:4,5; f=360 mm) equipped with 600 grooves/mm diffraction grating.

The spectrum was recorded on FOMAPAN 200 24×18 cm sheet film. The fireball image was divided into 5 segments due to the rotating shutter, which covered the camera 15,2 times per second (Fig.1).

There are places with high intensities of spectral lines in the image. Clearly visible are the lines of the first and the second spectral order. The spectral line of CaII barely visible also in the third order. The dispersion in the first order is 45 Å/mm. The spectral region 3500 – 6400 Å was covered. Meteor wake can be seen between the segments.

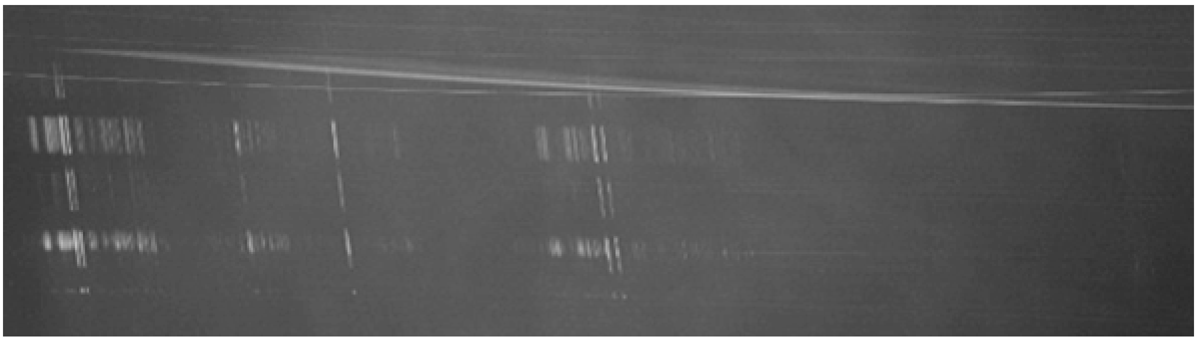

Figure 1: Meteor spectrum obtained on August 2, 2011. The flight direction was from the top to the bottom. The spectrum was divided into segments using rotating shutter. The first spectral order is on the left and a part of the second spectral order is in the middle. The horizontal trails are star zero order images. The bright star with spectrum is α Oph.

Table 1. Identification of spectral lines

no.	λ_{obs} [Å]	λ [Å]	Atom	Measured signal in relative units	Intensities in erg $s^{-1}\times$ $\times$Å^{-1}ster^{-1}	$\lvert\Delta\lambda\rvert$	no.	λ_{obs} [Å]	λ [Å]	Atom	Measured signal in relative units	Intensities in erg $s^{-1}\times$ $\times$Å^{-1}ster^{-1}	$\lvert\Delta\lambda\rvert$
1	3685,50	3679,92	FeI(5)	97	355	5,58	54	4427,00	4427,31	FeI(2)	4166	1033	0,31
		3683,05	FeI(5)				55	4435,00	4434,96	CaI(4)	112	34	0,04
		3687,46	FeI(21)				56	4455,00	4454,78	CaI(4)	102	33	0,22
2	3708,00	3705,57	FeI(5)	164	528	2,43	57	4461,50	4461,65	FeI(2)	2356	593	0,15
		3707,83	FeI(5)				58	4481,00	4481,24	MgII(4)	5531	1369	0,24
		3709,25	FeI(21)						4482,17	FeI(2)			
3	3720,50	3719,94	FeI(5)	784	2389	0,56			4482,26	FeI(68)			
		3722,56	FeI(5)				59	4489,50	4489,74	FeI(2)	235	59	
4		3733,32	FeI(5)				60	4493,50	4494,57	FeI(68)	109	27	1,07
		3734,87	FeI(21)				61	4528,00	4528,62	FeI(68)	234	61	0,62
	3736,50	3737,13	FeI(5)	1191	3391	0,63	62	4531,00	4531,15	FeI(39)	110	35	0,15
5	3745,00	3745,56	FeI(5)	1804	4893	0,56	63	4549,00	4549,47	FeII(38)	99	29	0,47
		3745,90	FeI(5)				64	4571,00	4571,10	MgI(1)	264	73	0,10
6		3763,79	FeI(21)						4571,98	TiII(82)			
	3766,50	3767,19	FeI(21)	298	728	0,69	65	4583,00	4583,83	FeII(38)	117	37	0,83
7		3798,51	FeI(21)				66	4647,00	4646,17	CrI(21)	53	17	0,20
	3798,00	3799,55	FeI(21)	263	556	1,55			4647,43	FeI(409)			
8	3815,00	3815,84	FeI(45)	314	577	0,84	67	4703,00	4702,99	MnI(11)	67	36	0,01
9	3820,00	3820,43	FeI(20)	701	1315	0,43	68	4859,50	4859,75	FeI(318)	51	37	0,25
10	3824,50	3824,44	FeI(4)	1394	2562	0,06	69	4871,50	4871,32	FeI(318)	95	73	0,18
		3825,88	FeI(20)						4872,14	FeI(318)			
11		3827,83	FeI(45)				70		4890,76	FeI(318)			
	3828,50	3829,35	MgI(3)	1707	3061	0,85		4891,00	4891,50	FeI(318)	183	156	0,50
12	3832,00	3832,30	MgI(3)	2149	3767	0,30	71		4919,00	FeI(318)			
13	3837,50	3838,29	MgI(3)	2358	4018	0,79		4920,00	4920,51	FeI(318)	234	230	0,51
14	3856,00	3856,37	FeI(4)	1008	1549	0,37	72	4923,50	4923,92	FeII(42)	244	243	0,42
15	3859,50	3859,91	FeI(4)	3733	5566	0,41	73		4957,30	FeI(318)			
16		3878,02	FeI(20)					4957,50	4957,60	FeI(318)	354	414	0,10
	3878,00	3878,58	FeI(4)	963	1309	0,58	74	4983,00	4982,81	NaI(9)	57	75	0,19
17	3886,00	3886,28	FeI(4)	2403	3074	0,28			4981,73	TiI(38)			
18	3894,50	3895,66	FeI(4)	1161	1418	1,16	75	4994,00	4994,13	FeI(16)	44	68	0,13
19	3899,00	3899,71	FeI(4)	935	1125	0,71	76	5006,00	5006,13	FeI(318)	49	90	0,13
20		3902,95	FeI(45)				77	5012,00	5012,07	FeI(16)	61	127	0,07
	3905,50	3905,53	SiI(3)	1179	1346	0,03	78	5018,50	5018,43	FeII(42)	294	428	0,07
		3906,48	FeI(4)				79	5041,50	5041,07	FeI(16)			
21		3920,26	FeI(4)						5041,76	FeI(36)	173	267	0,26
	3922,50	3922,91	FeI(4)	1231	1250	0,41	80	5051,50	5051,64	FeI(16)	58	92	0,14
22	3933,50	3933,67	CaII(1)	43294	41074	0,17	81	5056,00	5056,02	SiII(5)	86	133	0,02
23	3961,50	3961,53	AlI(1)	340	272	0,03	82	5110,50	5110,41	FeI(1)	670	1188	0,09
24	3968,50	3968,47	CaII(1)	36620	28239	0,03	83	5168,00	5167,32	MgI(2)	8369	17538	0,68
		3969,26	FeI(43)						5167,49	FeI(37)			
25	4005,50	4005,25	FeI(43)	191	122	0,25	84		5171,60	FeI(36)			
26		4030,76	MnI(2)					5172,50	5172,68	MgI(2)	7948	16834	0,18
		4033,07	MnI(2)				85	5183,50	5183,60	MgI(2)	8033	17488	0,10
	4034,00	4034,49	MnI(2)	941	546	0,49	86	5195,00	5194,94	FeI(36)	204	443	0,06
27	4045,50	4045,82	FeI(43)	1646	921	0,32	87		5204,52	CrI(7)			
28	4063,50	4063,60	FeI(43)	921	488	0,10		5205,50	5206,04	CrI(7)	334	710	0,54
29	4071,50	4071,74	FeI(43)	827	428	0,24	88	5208,00	5208,44	CrI(7)	359	758	0,44
30	4077,00	4077,71	SrII(1)	370	212	0,71	89		5215,19	FeI(553)			
31	4131,50	4132,06	FeI(43)	606	268	0,56		5216,50	5216,28	FeI(36)	149	303	0,22
32	4143,50	4143,87	FeI(43)	753	326	0,37			5217,40	FeI(553)			
33	4201,50	4202,03	FeI(42)	721	271	0,53	90	5227,00	5227,19	FeI(37)	1287	2533	0,19
34	4216,00	4216,19	FeI(3)	1157	418	0,19	91	5233,00	5232,95	FeI(383)	122	233	0,05
35	4226,50	4226,73	CaI(2)	3824	1354	0,23	92	5270,00	5269,54	FeI(15)	6577	10405	0,46
36	4251,00	4250,79	FeI(42)	492	166	0,21			5270,36	FeI(37)			
		4250,13	FeI(152)				93	5328,00	5328,04	FeI(15)	3345	4456	0,04
37	4254,00	4254,35	CrI(1)	1137	375	0,35			5328,53	FeI(37)			
38	4260,00	4260,48	FeI(152)	554	180	0,48	94		5339,94	FeI(553)			
39		4271,16	FeI(152)					5341,00	5341,03	FeI(37)	161	206	0,03
	4271,50	4271,76	FeI(42)	2174	690	0,26	95	5371,50	5371,49	FeI(15)	1440	1758	0,01
40	4275,00	4274,80	CrI(1)	2006	555	0,2	96	5383,00	5383,37	FeI(1146)	25	65	0,37
		4274,60	CrI(1)				97	5397,50	5397,13	FeI(15)	715	814	0,37
41	4282,00	4282,41	FeI(71)	133	47	0,41	98	5406,00	5405,78	FeI(15)	681	766	0,22
42	4289,50	4289,72	CrI(1)	498	152	0,22	99	5415,00	5415,20	FeI(1165)	51	57	0,20
43	4293,50	4294,13	FeI(41)	692	208	0,63	100	5424,00	5424,07	FeI(1146)	48	78	0,07
44	4298,00	4299,24	FeI(152)	225	66	1,24	101	5430,00	5429,70	FeI(15)	741	786	0,30
45	4302,00	4302,52	CaI(5)	91	38	0,52	102	5434,50	5434,53	FeI(15)	285	298	0,03
46	4307,50	4307,91	FeI(42)	1750	506	0,41	103	5447,00	5446,92	FeI(15)	592	607	0,08
47	4325,50	4325,77	FeI(42)	1801	513	0,27	104	5456,00	5455,61	FeI(15)	356	350	0,39
48	4340,00	4339,45	CrI(22)	92	31	0,55	105	5506,00	5506,78	FeI(15)	26	33	0,78
		4339,72	CrI(22)				106	5528,50	5528,41	MgI(9)	139	105	0,09
49		4351,05	CrI(22)				107	5587,00	5586,76	FeI(686)	106	61	0,24
	4351,50	4351,77	CrI(22)	325	87	0,27			5588,76	CaI(21)			
		4351,91	MgI(14)				108	5593,50	5594,47	CaI(21)	27	16	0,97
50	4375,50	4375,93	FeI(2)	4774	1235	0,43	109	5616,00	5615,65	FeI(686)	183	90	0,35
51	4383,50	4383,55	FeI(41)	4671	1218	0,05	110	5688,00	5688,21	NaI(6)	101	37	0,21
52	4404,50	4404,75	FeI(41)	2015	511	0,25	111	5890,00	5889,95	NaI(1)	24016	11255	0,05
53	4414,50	4415,13	FeI(41)	769	190	0,63	112	5895,50	5895,92	NaI(1)	16425	8796	0,42

no.	λ_{obs} [Å]	λ [Å]	Atom	Measured signal in relative units	Intensities in erg $s^{-1}\times$ $\times Å^{-1} ster^{-1}$	|Δλ|	no.	λ_{obs} [Å]	λ [Å]	Atom	Measured signal in relative units	Intensities in erg $s^{-1}\times$ $\times Å^{-1} ster^{-1}$	|Δλ|
113	6101,50	6102,72	CaI(3)	53	23	1,22	119	6229,50	6230,73	FeI(207)	78	34	1,23
114	6121,00	6122,22	CaI(3)	81	34	1,22	120	6245,50	6246,33	FeI(816)	42	20	0,83
115	6136,00	6136,62	FeI(169)	87	37	0,62	121	6251,50	6252,56	FeI(169)	64	29	1,06
		6137,70	FeI(207)				122	6334,00	6335,34	FeI(62)	5206	34	1,34
116	6161,00	6162,17	CaI(3)	204	86	1,17	123	6346,50	6347,10	SiII(2)	472	354	0,60
117		6169,06	CaI(20)				124	6358,00	6358,69	FeI(13)	49	37	0,69
	6169,50	6169,56	CaI(20)	54	22	0,06	125	6370,50	6371,36	SiII(2)	142	131	0,86
118	6190,50	6191,56	FeI(169)	55	24	1,06							

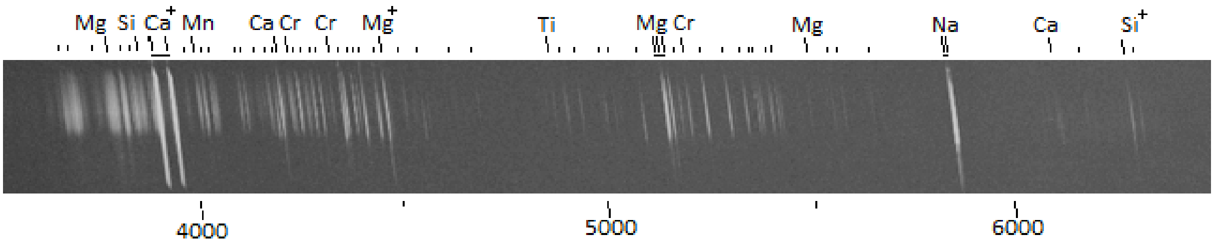

Figure 2: A part of the meteor spectrum during the flare. The important lines are identified. The short dashes show iron lines.

3. Identification of spectral lines

For spectral lines identification the brightest part of the first spectral order during the main flare which took place at the heights h = 83,5 – 84,5 km was used (Fig. 2). The spectrum was scanned and the spectrogram was obtained. The plate background was measured between segments. The measurements were calibrated. The wavelengths scale was determined by means of known lines in the spectrum (Borovicka, 1993). Polynomial fit of degree 3 was used to relate the instrumental lengths to wavelengths.

For photometric calibration the characteristic curve was constructed from the zero orders of stars recorded on the plate. Limiting magnitude was 4. Figure 3 shows the linear part of the characteristic curve.

The relative spectral sensitivity of the system was determined by using the first order spectrum of Jupiter and Polar Star recorded on the same plate. The real energy distribution in the Jupiter's spectrum was taken from Karkoschka (1994). The resulting relative spectral sensitivity function is shown in figure 4. The maximum of sensitivity is around 4500 Å and minimum occurs at 5200Å.

The spectrum includes many individual emission lines belonging to atoms of different chemical elements.

There are 125 emission lines identified in the meteor spectrum. For identification the tables of Moore (1945) and Borovicka (1994) were used.

The identification of observed spectral lines is given in Table 1. The following quantities are given in Table 1: Number and wavelength of the observed line, catalogue wavelength, identification (atom and multiplet), measured signal in relative units, intensities in erg s^{-1} $Å^{-1} ster^{-1}$, difference between wavelength of the observed line and catalogue wavelength.

4. Conclusion

The basic processing of meteor spectrum was made. The meteor spectrogram was obtained and the identification of 125 emission lines found in the spectrum is presented. They were formed by CrI, FeI, MgI, SiI, AlI, MnI, CaI, TiI, NaI, FeII, CaII, MgII, SiII, SrII. Further analysis and theoretical interpretation of the spectrum is forthcoming.

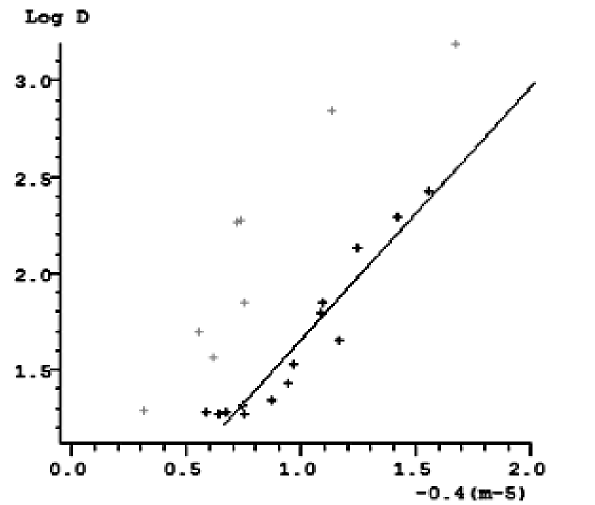

Figure 3: Characteristic curve of the plate. The opacity as a function of incident flux given by the stellar magnitude m. The crosses represent individual stars. Grey crosses were omitted from the fit.

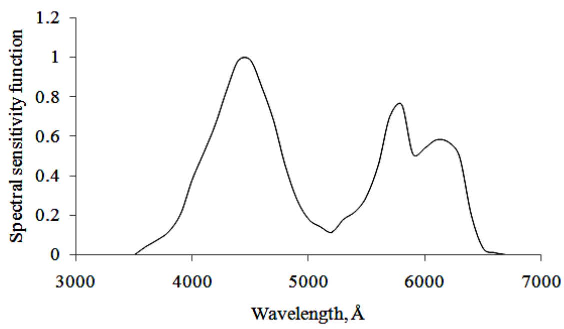

Figure 4: Relative spectral sensitivity of the spectrograph.

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