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First result of June Boötid meteor spectrum

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Abstract. This paper shows the first observational result of a spectrum of a June Boötid meteor obtained by the High-Definition TV observational system. The very faint spectrum appeared at $15^{\rm h}59^{\rm m}29.693^{\rm s}$ on 2004 June 23 UT, which was about 5th magnitude. Wavelengths between 360−620 nm were observed, and the strong emissions of neutral atoms as MgI, FeI and NaI were identified. Emissions of single ionized atoms were not observed. The abundances of metallic atoms, their excitation temperature were obtained under the Local Thermal Equilibrium (LTE) conditions. The results, Fe/Mg = 0.15 and Na/Mg = 0.00027 suggest the possibility that the abundances of June Boötid meteor are extremely different from the solar system abundances. The excitation temperature value, 3867 ± 13 K is low in agreement with their slow moving velocity.

Key words. June Boötid meteor spectrum – dust stream resonance theory – solar system abundance

1. Introduction

The June Boötid meteor shower had been inactive except in three occasions: 1916, 1927 and 1998. The outburst on 1998 June 27. was unexpected and it resembled the 1916 and 1927 outbursts (Arlt et al. 1999). In other years, although the shower was detectable (e.g. Seifert 1998), the shower was not bright meteor and lower activity in comparison with other meteor showers. Additionally, the June Boötid meteor shower is not related to the orbital period or the perihelion passages of the parent comet 7P/Pons – Winnecke. Thus, all outburst cases were unexpected appearances.

Comet 7P/Pons – Winnecke belongs to the Jupiter family of comets, and its orbit is subject to major gravitational perturbations. The perihelion and inclination has been increasing since discovery in 1819 (Arlt et al. 1999). The orbit of the comet has been completely outside Earth's orbit since 1921 (Arlt et al. 1999). The velocity of the June Boötid meteoroid stream is 18 km $\rm s^{-1}$. Both the parent comet and the meteoroid stream has been considered that they are probably a consequence of the 2:1 resonance with Jupiter (Arlt et al. 1999; Asher & Emel'yanenko 2002; Jenniskens 1995).

On the basis of the proposed theories the June Boötid had been predicted to show a possible activity in 2004 (e.g. M. Sato (`http://kaicho.pobox.ne.jp/tenshow/meteor/s7p2004/se1.html`), J. Vaubaillon (`http://www.imcce.fr/s2p/JBO/2004JBO.html`), R. Arlt (`http://www.imo.net/news/news.html`)).

It is a precious chance to obtain scientific data for such minor meteor shower because of its low activity. Therefore, we set up several observation instrument's on June 23 UT, when this shower was expected to be active over Japan.

We succeed to obtain the spectroscopic data of a faint meteor belonging to the June Boötid. The first result of the metallic abundances of this June Boötid meteor is shown in this paper.

2. Observation

The HDTV spectroscopic observation was performed at Yamanashi Prefecture in Japan from at $12^{\rm h}00^{\rm m}00^{\rm s}$ UT to $18^{\rm h}40^{\rm m}00^{\rm s}$ UT on 23 June 2004. Then, we obtained one spectrum at $15^{\rm h}59^{\rm m}29^{\rm s}$ UT. That meteor was taken from

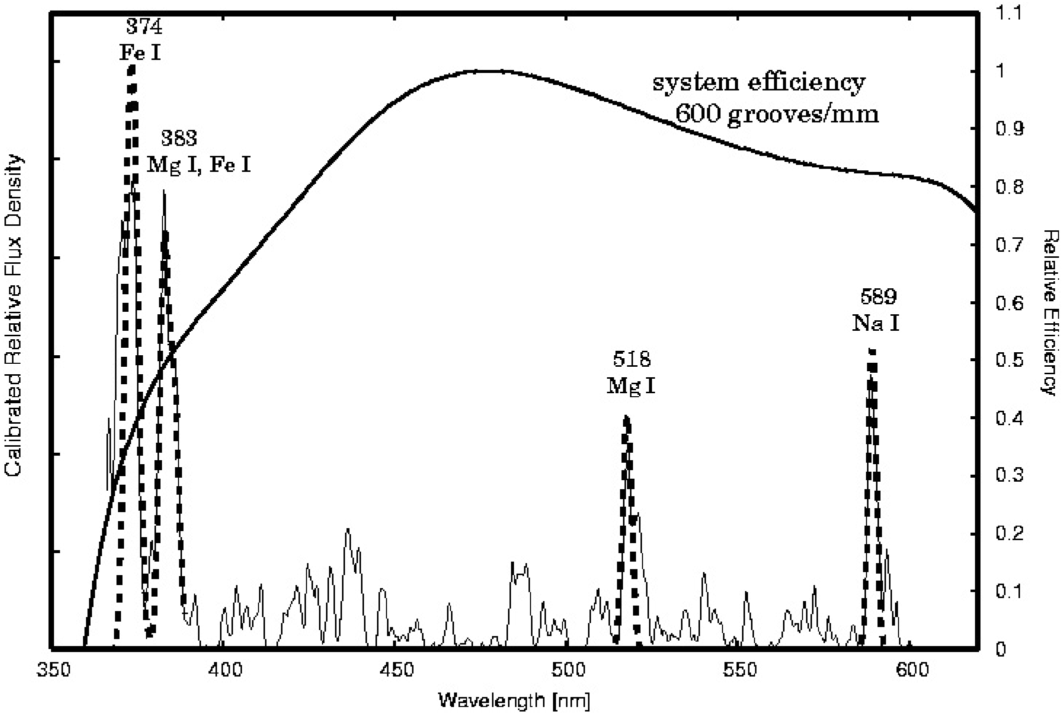

Fig. 1. The normalized system efficiencies (NSEs) with the transmission grating of 600 grooves/mm (blaze 420 nm) was calibrated by Vega and includes the air extinction. The thin line is calibrated June Boötid meteor spectrum obtained at $15^{\mathrm{h}}59^{\mathrm{m}}29.693^{\mathrm{s}}$ on June 23 UT and dotted lines are the best fit models of neutral atomic emissions derived from the least square value by using 374, 383, 518 and 589 nm.

$15^{\mathrm{h}}59^{\mathrm{m}}29.429^{\mathrm{s}}$ UT to $15^{\mathrm{h}}59^{\mathrm{m}}29.792^{\mathrm{s}}$ UT. The observation site was located at a latitude of +35.90° N, a longitude of 138.41° E and an altitude of 1220 m as measured by the GPS system.

The HDTV spectroscopic system consists of a grism, direct vision grating (600 grooves/mm, blazed wavelength 420 nm), an UV lens (f = 30 mm, F1.4), an image intensifier (I.I.), and a HDTV camera (Ebizuka, (`http://atlas.riken.go.jp/~ebizuka/Leo/HDTVe01.pdf`)).

A HDTV camera has been used for a meteor observation since 1998 (Watanabe et al. 1999). The HDTV camera with 1-inch FIT CCD of 2M pixels has a resolution as much as 1150 TV lines, and the meteors were recorded as 8 bit images. The time resolution of the HDTV frame is 0.033 s. The diagonal coverage of the field of view (FOV) was 30°, and the observable bands were in 360–620 nm. The maximum spectral resolution of $\sim$1.0 nm ($\lambda/\Delta\lambda \sim 360$) was achieved for the grism mentioned above.

We carried out the spectroscopic observation of the June 23 meteor.

Figure 1 shows the system efficiency of the observation using the 600 grooves/mm grism, calibrated observed spectrum and model spectrum of the June Boötid meteor. Observed and model spectrum were described in later.

The calibration star was Vega (α Lyr). Here, the system efficiency $f(\lambda)$ is defined as

$$f(\lambda) = \frac{\text{OSS [count value]}}{\text{CSS [erg s}^{-1}\text{ cm}^{-2}\text{ nm}^{-1}]}, \tag{1}$$

where OSS [count value] is observed data of Vega, and CSS [erg s^{-1} cm^{-2} nm^{-1}] is Vega data from the Pulkovo spectrophotometric catalog (Alekseeva et al. 1997).

The efficiency of the HDTV spectroscopic system includes the effect of air extinction and the system efficiency. The system efficiencies shown in Fig. 1 are normalized to be unity at their maxima.

The flux density F of the meteor spectra was calculated from the relative spectrum observed. Hereafter, OMS in units of the count value by using this relationship is given by

$$\frac{F(\lambda)}{\text{erg s}^{-1}\text{ cm}^{-2}\text{ nm}^{-1}} = \frac{\text{OMS [count value]}}{f(\lambda)}. \tag{2}$$

3. Analysis and discussion

3.1. line identification

Figure 1 shows the observed spectrum of the June Boötid meteor at $15^{\mathrm{h}}59^{\mathrm{m}}29.693^{\mathrm{s}}$ UT, when the emissions around 589 nm came into our FOV. The frame is the highest quality data in the $15^{\mathrm{h}}59^{\mathrm{m}}29^{\mathrm{s}}$ UT June 23. The magnitude of the spectrum data was about 5th mag, which causes the low S/N data. In this analysis, we focus on the strong emissions of 374 nm (FeI), 383 nm (MgI, FeI), 518 nm (MgI) and 589 nm (NaI) of these lines were identified. The observed meteor spectrum, which is calibrated by Vega, is shown in the thin line in Fig. 1. Note that singly ionized emissions, such as 393, 396 nm (CaII) and 448 nm (MgII) were not observed in all frames. In this analysis, a blackbody' spectrum was neglected.

3.2. Abundances of metallic elements

In this study, we assume Local Thermal Equilibrium (LTE) for the population of each energy level. Then, a total number of neutral atoms N_u in the upper energy level E_u is expressed as

$$N_u = \frac{g_u}{g_0} N_0 \exp\left(-\frac{E_u}{k_\mathrm{B} T_\mathrm{e}}\right), \tag{3}$$

where N_0 is total number of neutral atoms in the ground state energy level, g_u and g_0 are the statistical weights of the upper and ground state energy levels, respectively, T_e is the electronic excitation temperature, and k_B is the Boltzmann's constant. The flux $\widetilde{f}(\lambda)$ of a line emitted by atoms at a transition from a state u in the upper energy level E_u to a state l in the lower energy level E_l is expressed as

$$\widetilde{f}(\lambda) = \frac{N_0 hc\nu_{ul}}{4\pi r^2} A_{ul} \frac{g_u}{g_0} \exp\left(-\frac{E_u}{k_\mathrm{B} T_\mathrm{e}}\right) \cdot \exp\left(\frac{-(\lambda-\lambda_0)^2}{2\sigma^2}\right), \tag{4}$$

where h is Plank constant, c is the velocity of light, A_{ul} is the Einstein transition probability of spontaneous emission, $\nu_{ul} = (E_u - E_l)/hc$ is the wavenumber of the line, r is the distance from the meteor to the observer, λ_0 is the wavelength of the line center, and $\sqrt{2}\sigma$ is the width of the instrumental profile. The spectral profile is assumed to be Gaussian.

Here, we show the least square method to obtain the metallic abundances. We take the flux of the MgI line as a standard, which is one of the brightest lines observed in the June Boötid meteor spectrum, and then evaluate the abundance ratios of FeI/MgI and NaI/MgI on the ground state level from the ratios between observed fluxes of these emission lines. In Eq. (4), N_0 means the total number of MgI in the ground state energy level and the total number of any other neutral element in the ground state energy level is given by $N_{0\,\mathrm{X\,I}} = z_\mathrm{X\,I} N_0$, where $z_\mathrm{X\,I}$ is the abundance of element X I relative to MgI. Using Eq. (4), the abundance ratio of the neutral metallic atom X I relative to MgI, $z_\mathrm{X\,I} = N_\mathrm{X\,I}/N_\mathrm{MgI}$, on the ground state level is evaluated for spectrum in Fig. 1.

The abundance ratio $z_\mathrm{X\,I} = N_\mathrm{X\,I}/N_\mathrm{MgI}$, the excitation temperature T_e, the width of the instrumental profile σ, and the total number of MgI in the ground state energy level N_0 are determined by the least square method to minimize Δ:

$$\Delta \equiv \sum_n \left[F^{(n)}_\mathrm{X\,I\,obs} - F^{(n)}_\mathrm{X\,I\,cal}\right]^2 = \text{minimum} \tag{5}$$

$F^{(n)}_\mathrm{X\,I\,obs}$ is the observed flux of the nth line emitted by the atoms X I and $F^{(n)}_\mathrm{X\,I\,cal}$ is the calculated flux of the nth line emitted by the atoms X I obtained by summation of Eq. (4) for each element and line. N_0 and r is the arbitrary value. The result of the least square fit is shown as a dotted line in Fig. 1. The dotted line was obtained by applying the neutral atomic ratios of the ground state level for 374 (FeI), 383 (MgI, FeI), 518 (MgI) and 589 nm (NaI) neutral atomic catalog lines listed in Kasuga et al. (2004).

$z_\mathrm{X\,I} = N_\mathrm{X\,I}/N_\mathrm{MgI}$ and T_e, the summation over n is taken for the observed lines at 374, 383, 518 and 589 nm. Atoms in the ground state and all excited levels were summed to obtain the total abundance of MgI. This modification successfully resulted in the derivation of total neutral metallic abundance ratios. Here, we assume that T_e is common for all neutral metallic species because of the assumption of LTE. The results of abundances are shown in Table 1. The excitation temperature $T_\mathrm{e} = 3867 \pm 13$ K, and the spectral profile $\sigma = 1.13 \pm 0.03$. The errors of abundance derived from the least square calculation are removed because they are extremely small (Kasuga et al. 2004).

Table 1. Metallic abundances of the June Boötid meteor and solar system abundances.

	June Boötid meteor	Solar system abundance
Fe/Mg	0.15	0.84
Na/Mg	0.00027	0.054

In reality, the observed nth "line" is composed of several individual atomic lines, which cannot be separated due to a limitation of the wavelength resolution in the observations. Note that different ionization states of a chemical element are not necessary to be considered because ionized emissions were not observed.

Metallic abundances of the June Boötid meteor are extremely different from the solar system abundances (Anders & Grevesse 1989).

Fe/Mg is about 18% of that of the solar system abundances. This value is consistent with the value of the presence of the Mg-rich silicate meteoroid, for example as observed in Comet Hale-Bopp, and has the relation for the pristine solar nebula condensates (Wooden et al. 2000).

Na/Mg is only 0.5% of that of the solar system abundances. Borovička et al. (1999) reported that the sodium notice faint meteors like this case generally tend to be poor. It also has the possibility that Na was lost during drifting as dust trail in space for a long time, however it has not been revealed clearly.

The excitation temperature, $T_\mathrm{e} = 3867 \pm 13$ K is lower than other meteor showers (Kasuga et al. 2004; Borovička 1993; Borovička et al. 1996, 1999; Borovička & Jenniskens 2000; Trigo-Rodríguez et al. 2003, 2004). It has the possibility that June Boötid meteor is not evaporated enough because of their slow velocity.

4. Conclusion

We carried out HDTV spectroscopic observation of the 2004 June Boötid meteor shower at June 23, 2004, and we obtained the first spectrum of the June Boötid meteor. We also show the first result of the metallic abundances deduced from the June Boötid meteor spectrum. From these results, we achieved the following conclusion on this one meteoroids:

1. Metallic abundances to Mg are extremely different from their solar system abundance.
2. Mg-rich abundance to Fe is consistent with the result of Mg-rich silicate crystals, for example in Comet Hale-Bopp. That also suggests the relation for the pristine solar nebula condensates.

3. Na abundance is extremal lower than the solar system abundance. The observed June Boötid meteor is about 5th mag. Faint meteors tend to be poor in Na. This tendency is consistent with the results of other meteor showers.
4. The excitation temperature is low. It may correspond to the lower excitation due to the slow moving of the June Boötid meteor.

The metallic abundances of the June Boötid meteor can not be concluded completely as stated above. The observed meteoroid is a faint one. Further observations are needed to obtain high quality data and clarify the metallic abundances of the June Boötid meteors. Ionized emissions are also needed to evaluate the correlation the elemental abundances, although we can not recognize them in the June Boötid meteor on this observation.

It should be noted that the first of dust trail theory resulted in success of our observation.

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