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ScienceDirect
Advances in Space Research 39 (2007) 538–543
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Search for OH(A–X) and detection of N_2^+(B–X) in ultraviolet meteor spectrum

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Received 4 October 2004; received in revised form 16 March 2007; accepted 21 March 2007

Abstract

An ultraviolet–visible spectrum between 300 and 450 nm of a cometary meteoroid originated from 55P/Tempel-Tuttle was investigated. The spectroscopy was carried out an intensified high definition TV camera with a slit-less reflection grating during the 2001 Leonid meteor shower over Japan. A best fit calculation mixed with atoms and molecules confirmed the first discovery of $N_2^+ B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$ bands in the UV meteor spectrum. N_2^+ temperature was estimated to 10,000 K with a low number density of 1.55×10^5 cm^{-3}. We also discuss the possibility that enhanced emissions in a meteor and a train around 310 nm are caused by the band head of OH $A^2\Sigma^+ \rightarrow X^2\Pi$. Since cometary dust may have contributed organics and water to the Earth from its early period until now, OH A–X (0,0) must be investigated.

Keywords: Astrobiology; Comets: individual(55P/Tempel-Tuttle); Interplanetary medium; Meteors; Meteoroids; Molecular processes

1. Introduction

Spectroscopic observations of meteors reveal not only chemical composition of the cometary meteoroids but also emission processes of hypervelocity impacts in the atmosphere, which are difficult to reproduce in laboratory experiments at present. Leonid meteoroids which correspond to cometary grains from the comet 55P/Tempel-Tuttle have produced the best meteor shower for its high incident velocity at ~72 km s^{-1} among known annual meteor showers and bright flux of its meteors as ~10,000 h^{-1}.

Of particular interest is the question whether meteoroids could have delivered organics and water to the early Earth Jenniskens et al. (2000). Rietmeijer (2002) suggested that the survival of meteoritic compounds would be feasible even at high entry velocities. According to this author, cometary meteoroids are aggregates that might include the precursors of the Interplanetary Dust Particles (IDPs) collected in the upper atmosphere. To determine whether large cometary grains contain mineral water or trapped water in any forms, it is necessary to confirm the presence of OH $A^2\Sigma^+ \rightarrow X^2\Pi$ emission around the wavelength of 310 nm. Harvey (1977), Abe et al. (2003a, 2005) and Jenniskens et al. (2002) reported an excess of emission at 310 nm.

Here we report the discovery of $N_2^+ B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$ (N_2^+(1−)) in the wavelength of 320–450 nm meteor emission from a Leonid meteoroid through the investigation of OH A–X (0,0) band. The N_2^+(1−) plasma emission in meteors has been argued by Millman et al. (1971) and Mukhamednazarov and Smirnov (1977). Meanwhile Jenniskens et al. (2004a) found a $N_2^+ A^2\Pi_u \rightarrow X^2\Sigma_g^+$ Meinel

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0273-1177/$30 © 2007 Published by Elsevier Ltd on behalf of COSPAR.
doi:10.1016/j.asr.2007.03.051

band in the range of 780–840 nm. Thus, our discovery is important to identify unknown meteor emissions in ultraviolet region, in particular for understanding the variety of emission phases in meteors and delivery mechanisms of organic matters and content minerals.

2. Observations and data reduction

During 2001 Leonid maximum, spectroscopic observations were carried out using an Image-Intensified High Definition TV (II-HDTV) cameras in ultraviolet (UV), visible (VIS) and near-infrared (near-IR) wavelength regions (250–700 nm). The II-HDTV system consisted of an UV image intensifier (ϕ 18-mm photo-cathode: S20), two relay lenses ($f = 50$ mm, F/1.4) and HDTV camera with 2M pixels CCD. In order to focus precise optical concentration on the wavelength in 250–1000 nm, we developed UV lenses of $f = 30$ mm, F/1.2 with a field of view of $23° \times 13°$ and wide converter lenses with a field of view of $70° \times 40°$. The HDTV digital imagery has 1920(H) × 1035(V) pixels that results in 6 times higher resolution than NTSC and PAL standard video system. The recording rate was 29.97 frames (59.94 fields) per second. Spectroscopic observations were performed by the II-HDTV system equipped with a reflection grating, which is 600 grooves per mm, blazed at 330 nm, manufactured by the Richardson Grating Laboratory.

Background stars were removed by subtracting a median frame shortly before or after the meteor spectrum. After flat-fielding and averaging of meteor spectrum, wavelength was determined carefully by means of numerous well-known atomic lines in the meteor emission. Following lines were used for wavelength determination, Fe I (438.4, 373.5, 357.6, 344.1, 323.9, and 302.1 nm) Mg I (383.4 nm), Mg II (448.1 nm) Ca I (422.7 nm) and Ca II (393.4 and 396.9 nm). The effective spectral sensitivity of the instrument including atmospheric extinction during the observations was constructed by measuring spectra of bright stars in the observing field. Its sensitivity covered the wavelength at 300–700 nm, with the maximum at ~430 nm. The resulting dispersion of the spectrum is 0.37 nm pixel^{-1} and FWHM = 1.5 nm in the first order. Since no order-sorting filter was used, it turns out that first order spectrum was mixed with the second order spectrum in the wavelength longer than 600 nm. Details of the instrument and the first results of the II-HDTV spectrum of 1999 Leonids were described in Abe et al. (2000).

Ozone in the stratosphere strongly absorbs below 290 nm, preventing the UV light from reaching the Earth's surface. In order to prevent air extinction owing to mainly aerosol scattering in the UV wavelength below 380 nm, spectroscopic observation was performed at a high-altitude site in the Nobeyama Radio Observatory of National Astronomical Observatory of Japan (N+35°.93, E138°.48, altitude = 1340 m). Thanks to excellent observing conditions, clear weather and strong meteor storm activity during the Leonid maximum, its peak activity was well observed around 18:17 UT on November 18, 2001 with the Zenithal Hourly Rate (ZHR) of 3120 ± 100, based on reports of the Nippon Meteor Society (Uchiyama, 2002).

3. Results

A detailed spectrum of a Leonid meteor fireball is shown in Fig. 1, which was obtained at 18:58:20 UT on November 18, 2001 within a dust trail ejected by comet 55P/Tempel-Tuttle in 1866 (McNaught and Asher, 1999). Assuming the Leonid radiant ($\alpha = +153°$, $\delta = +22°$) and velocity (72 km s^{-1}), the meteor distance R and its altitude H at each frame were inferable. Altitudes to enter our field of view and that of disappearance of this fireball were $H = 108.1$ km ($R = 136.8$ km) and $H = 80.1$ km ($R = 124.6$ km), respectively. Though the 0th order image was out of the field of view, we could calculate the 0th position on the sky after calibration of pixel–wavelength relationship of the spectrum and distortion of the image, which leaded to few hundred meters accuracy in altitude. The fireball terminated at the altitude of around 82 km. Just before the disappearance of the fireball, a strong enhancement of lines with continuum emissions were detected near the terminal point. Since the enhancement did not persist, within 1/30 s, intercombination lines is pointed out. The intercombination lines has been observed earlier in the spectra of wakes of bright fireballs (Halliday, 1968; Borovička and Spurný, 1996).

From comparison between meteor emission lines and field-star spectrum, the maximum brightness of the −4th visual magnitude at the standard range of 100 km was derived, which corresponded to a photometric meteoroid mass of ~1.8 g estimated by an equation given by Pawlowski et al. (2001). On the assumptions that density

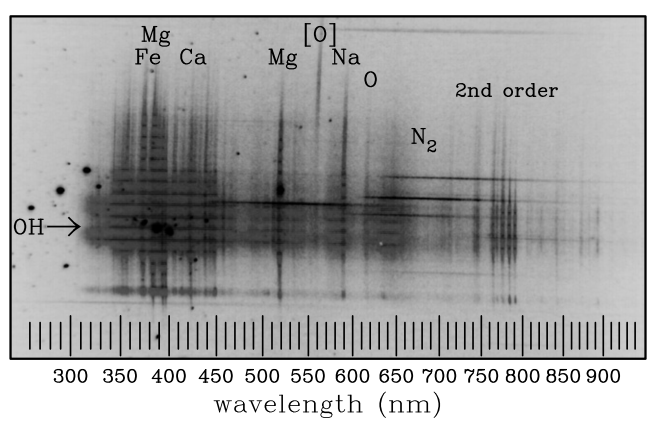

Fig. 1. Raw data of 1st and 2nd order spectrum of 2001 Leonid fireball at 18:58:20 UT on November 18, 2001. This image (the field of view of $23° \times 13°$) is composed of 15 consecutive frames during the total duration of 0.5 s. The meteor moved from top to bottom of this image. The dispersion direction is from left to right and parts of the 2nd and 3rd order spectra are on the right. A part of radiation comes from forbidden lines of neutral oxygen known as auroral green line at 557.7 nm. Forbidden green line has an evidently different origin than other lines. First meteors such as Leonids and Perseids form a short-living train caused by this line.