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Optical low-dispersion spectroscopic observations of Comet 103P/Hartley 2 at Koyama Astronomical Observatory during the *EPOXI* flyby

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ABSTRACT

We performed low-dispersion spectroscopic observations of Comet 103P/Hartley 2 in optical wavelengths using the LOSA/F2 mounted on the 1.3 m-Araki telescope at Koyama Astronomical Observatory on UT 2010 November 4 during the close approach of the *Deep Impact* spacecraft to the nucleus of Comet 103P/Hartley 2 in the *EPOXI* mission flyby. Our observations have revealed the chemistry of the coma at optical wavelengths; including CN, C_3, C_2 and NH_2 along with H_2O from [OI] emission at 6300 Å. Resultant mixing ratios of these radicals put the comet into the normal group in chemical composition. The mixing ratios with respect to H_2O obtained in our observations are basically consistent with the previous optical spectro-photometric observations of Comet 103P/Hartley 2 in 1991 by A'Hearn et al. (A'Hearn, M.F., Millis, R.L., Schleicher, D.G., Osip, D.J., Birch, P.V. [1995]. Icarus 118, 223–270), the optical spectroscopic observations in 1998 by Fink (Fink, U. [2009]. Icarus 201, 311–334) and also consistent with the observations on UT 2010 October 27 and 29 by Lara et al. (Lara, L.M., Lin, Z.-Y., Meech, K. [2011]. Astron. Astrophys. 532, A87) (but only for the ratio relative to CN).

1. Introduction

Comet 103P/Hartley 2 (hereafter, Hartley 2) is a short period Jupiter-family comets with an orbital period of ~6.5 years. This comet was a target of the *EPOXI* mission (NASA), in which the comet was observed *in situ* from the *Deep Impact* spacecraft on UT 2010 November 4 (A'Hearn et al., 2011). To compliment data from the *EPOXI* flyby, many observations from ground-based and space observatories were conducted in various wavelength regimes before and after the *EPOXI* flyby (Meech et al., 2011).

Here we report the low-dispersion optical spectroscopic observations of Comet Hartley 2 on UT 2010 November 4, just a few hours after the closest encounter (at 13:59 UT) of the spacecraft to the nucleus of Comet Hartley 2. The observations were conducted with the LOSA/F2 spectrograph mounted on the 1.3 m Araki telescope at Koyama Astronomical Observatory (in Kyoto Sangyo University, Kyoto, Japan) as a part of the ground-based support for the *EPOXI* mission. As discussed below, there are no other reports about the optical spectroscopic observations on the date about the *EPOXI* flyby.

Lara et al. (2011) reported their spectroscopic observations of Comet Hartley 2 near perihelion (on UT 2010 October 27 and 29) using by the William Herschel Telescope (WHT) at La Palma Observatory. They reported a production rate ratio $Q(C_2)/Q(CN) \sim 1.3$, a typical comet in terms of long-chain hydrocarbon abundance (A'Hearn et al., 1995). They also reported that the gas-to-dust mass ratio of Comet Hartley 2 is ~3–6, concluding that the comet is gas-rich (A'Hearn et al., 1995). Spectro-photometric observations of cometary radicals observed in the optical wavelength region are also reported by Lara et al. (2011). Furthermore, Knight and Schleicher (2012) reported their long-term monitoring of the spectro-photometric observations of the Comet Hartley 2 during its 2010 apparition. However, spectroscopic observations are more favored for removal of the dust-continuum in order to more accurately derive the gas production rates than the spectro-photometric (imaging or photomultiplier tube) observations, in which each molecular species and dust continuum were generally observed at different times.

2. Observation

Spectroscopic observations of Comet Hartley 2 were conducted with the Low-dispersion Optical Spectrograph for Araki telescope with F/2 optics (hereafter LOSA/F2), mounted on the Araki telescope (D = 1.3 m, F/10) at Koyama Astronomical Observatory (in Kyoto Sangyo University, Kyoto, Japan). This spectrograph was developed at Koyama Astronomical Observatory in order to provide ground-based data that compliment the *EPOXI* flyby data. The LOSA/F2 is a grism spectrograph with a refractive collimator

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Table 1
Observational log.

UT Time on 2010 November 4	Target name	Exposure time (s)	Position angle of the slit (°)	Phase (∗1)	Remarks
14:26	HR718	2 × 10			Standard star (∗2)
16:01	HR718	2 × 5			Standard star
16:05	HR1544	2 × 5			Standard star (∗2)
16:31	Comet Hartley 2	300 × 3	178.2∼173.4	0.65–0.66	
17:05	Comet Hartley 2	300 × 3	167.1∼161.6	0.68–0.69	
17:23	HR3454	1 × 7			Standard star
17:39	HR1544	1 × 5			Standard star
17:43	Comet Hartley 2	300 × 3	152.7∼146.4	0.71–0.73	
18:17	Comet Hartley 2	300 × 3	138.3∼131.5	0.74–0.76	
18:37	HR3454	1 × 5			Standard star
18:52	HR1544	1 × 5			Standard star
18:54	Comet Hartley 2	300 × 3	121.4∼114.9	0.78–0.79	
19:34	Comet Hartley 2	300 × 3	106.8∼100.2	0.81–0.83	A bright star passing on comet
19:51	HR3454	1 × 5			Standard star
19:55	HR1544	1 × 5			Standard star

(∗1) The rotational period of Comet Hartley 2 was referred from Drahus et al. (2011).
(∗2) Stars were not perfectly centered in the slit because of inaccurate guiding. Therefore, we did not use those observations for the flux calibration. The mean seeing size determined from the spatial profiles of the stars along the slit, was FWHM = 5.0 ± 0.2" at that night.

and a refractive F/2 camera customized for long slit spectroscopic observations in the optical. The detector is an electric-cooled (with the assistance of chilled water) CCD camera equipped with the back-illuminated CCD chip (EEV CCD47-10; Q.E. is over 90% for 5000–6500 Å). The instrument can cover the optical wavelength region from 3800 to 7600 Å with $\Delta\lambda \sim 10$ Å for the slit size of 2.9 arcsec by 194 arcsec on the sky (1.03 arcsec/pixel). The wavelength coverage was chosen to cover the violet band of CN, C_3, C_2, NH_2, and [OI] forbidden emission lines at 6300 and 6364 Å, simultaneously. Moreover, the spectral resolution ($\Delta\lambda \sim 10$ Å) was intended to extract [OI] emission lines (used as a proxy of the water production) in the NH_2 (0,8,0) complex around 6300–6364 Å.

Optical low-dispersion spectroscopic observations of Comet Hartley 2 were performed on UT 2010 November 4 during the *EPOXI* flyby (the heliocentric and geocentric distances were 1.064 AU and 0.156 AU, respectively). The sky conditions were photometric. The slit was placed such that the comet nucleus was centered in the slit and integrated for 300 s in each frame (three successive frames were taken as a sequence). Although we got a total of six sequences on the comet, one sequence was not available since a bright star was passing near the nucleus of Comet Hartley 2. Therefore, we used the data taken in five sequences (4500 s as a total exposure time on source). Although the position angle of the slit was rotating on the sky during the observations (since the slit is physically fixed with respect to the telescope without an image de-rotator), the comet was always put on the center of the slit. We also observed spectrophotometric standard stars for the flux calibration (HR718, HR1544, and HR3454). Observing conditions are listed in Table 1. The wavelength calibration was performed using emission spectra of the Fe–(Ne, Ar) hollow-cathode lamp specialized for low-dispersion spectroscopic observations in the optical (emission lines from Ne and Ar gases are used as comparisons).

The data taken with the LOSA/F2 spectrograph were reduced using standard IRAF software routines (distributed from NOAO). Once the wavelength calibration was performed, the raw data were dark-subtracted and flat-fielded for each image. Next, those images were combined and rectified for spatial and wavelength axes. One-dimensional spectra are extracted from those images. We performed flux calibration by comparing the observed spectra of the comet with those of standard stars. We also determined the monochromatic extinction coefficients during our observations based on the standard stars' spectra and we applied them to the comet spectra for more accurate flux calibration.

Fig. 1 shows the wavelength and flux calibrated spectral image of Comet Hartley 2 taken on UT 2010 November 4, prior to subtraction of the sky background (e.g., Hg emissions from city lights). The one-dimensional emission spectrum of Comet Hartley 2 (inside the 2.9 arcsec × 82 arcsec) is shown in Fig. 2. Sky subtraction was performed by using data from the region of the slit 41–62 arcsec off-nucleus. However, this region is not sufficiently far enough from the nucleus to be completely free of cometary emission (i.e., the comet filled the entrance slit), resulting in over-subtraction of the sky. We will correct this over-subtraction of comet signals when the gas production rates are calculated, as described in the following section. The reflected sunlight by cometary dust grains in the coma has also been subtracted in Fig. 2. The subtraction was not

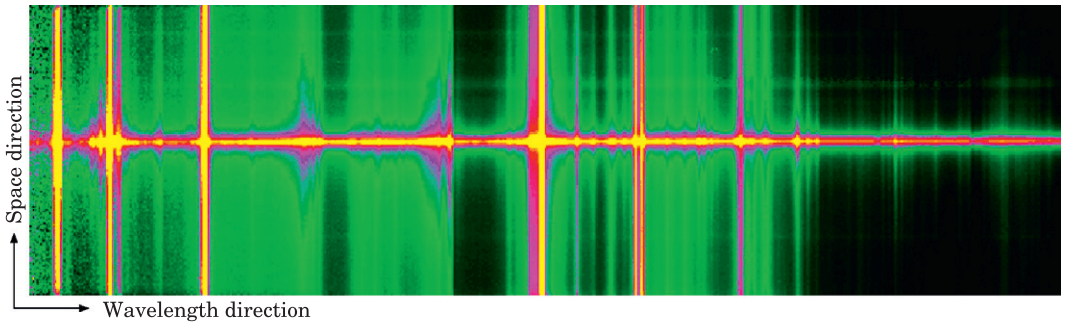

Fig. 1. The 2-dimensional calibrated spectrum of Comet Hartley 2 on UT 2010 November 4 (averaged for all exposures).