Low dispersion spectroscopy of the comet 8P/Tuttle

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Abstract. Spectra of comets offer an opportunity to examine chemical composition of their comae in great details. Comets are very good "laboratories" to study transitions in atoms and molecules that cannot be observed on Earth. On the 10^{th} of January 2008, periodic comet 8P/Tuttle was observed in a spectroscopic mode with the 2-Channel Focal Reducer (FoReRo2) at the 2-m RCC Telescope of the Rozhen National Astronomical Observatory (NAO), in a framework of an international campaign. The spectrum of the comet was absolutely calibrated in units of erg/cm^2/s/Å. The main cometary emissions: CN, C_3, C_2, NH_2 and O[I], are identified. We present a preliminary analysis of the fluxes in the observed emission bands and an estimation of the continuum gradient. The results presented here are part of an extended observational program for monitoring of the gaseous and dust components of comet 8P/Tuttle.
Key words: comets, spectrum, 8P/Tuttle

Ниско дисперсна спектроскопия на кометата 8P/Tuttle

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Спектрите на комети ни дават възможност за детайлно изследване на химическия състав на кометната кома. Кометите са много добри "лаборатории" за изследване атомни и молекулни преходи, които не могат да се наблюдават на Земята. На 10 януари 2008 г. кометата 8P/Tuttle бе наблюдавана в спектралната мода на дву- каналния фокален редуктор (ФоРеРо2) и 2-метровия телескоп на Националната астрономическа обсерватория (НАО) — Рожен, в рамките на международна програма. Кометния спектър бе абсолютно калибриран в единици erg/cm2/s/Å. Идентифицирани са главните кометни емисии CN, C_3, C_2, NH_2 и O[I]. В настоящия доклад са представени предварителните резултати за потоците в наблюдаваните емисии и оценка за градиента на континуума. Ресултатите представени тука са част от по- широка наблюдателна програма за проследяване на газовата и праховата компонента на кометата 8P/Tuttle.

Introduction

Spectra of comets offer an opportunity to examine chemical composition of their comae in great details. The first spectra of comets were made by Huggins [1881] on photographic plates 120 years ago. Comets are very good "laboratories" to study transitions in atoms and molecules that cannot be observed on Earth. From analysis of comets continuum (which is caused by the reflected sunlight from dust particles in the coma) we can go by what is the nature of the comets dust.

In this paper we present spectral observations of the comet 8P/Tuttle, which was discovered by Horace Parnell Tuttle (Harvard College Observatory, Cambridge, Massachusetts) on 1858 January 5. The spectral observations are part of an observational campaign which includes as well imaging of the comet neutral coma and dust. The analysis of the tree main comet emission (CN, C_3 and C_2) and the reddening of the continuum are investigated.

1 Observations

1.1 2m RCC telescope equipped with 2-channel focal reducer

The observational material was obtained with the 2m RCC telescope at the Rozhen NAO. The focal length of the RC–focus is 16 000 mm. The 2-channel focal reducer (***FoReRo2***) was used to transform the focal length to 5 600 mm. The ***FoReRo2*** gives opportunity for observations at two different wavelengths simultaneously (*red* and *blue* channel). Detailed description of the ***FoReRo2*** is given in Jockers *et. al* [2000]

1.2 The detectors

CCD-cameras Photometrics, CE200A-SITe, comprising $1024 \times 1024\,\mathrm{px}^2$ and VersArray 512B, comprising $512 \times 512\,\mathrm{px}^2$ were used respectively on the blue and the red channel. Both CCD-cameras have pixel size of $24\,\mu m$ With these cameras and the described optical system the spatial scale is $0.89\,''$/px. A mean seeing of about $2''$ (which is usual for Rozhen NAO) is distributed on about two pixels, i.e. the optical system works with optimal sampling (Theorem of Nyquist or Shannon see Pierre Lèna [1988]).

1.3 Spectral mode of ***FoReRo2***

The FoReRo2 gives an opportunity to observe in two spectral regions: 3500Å–4500Åand 4500Å– 7000Å, simultaneously. The spectral mode of the ***FoReRo2*** is realized with two grisms placed in the blue and red channel, respectively. Their parameters are presented in table 1. The slit is placed in the focal plane

Table 1. Grisms

Lines/mm	Wavelength straight pass, nm	Dispersion Å/px	Range nm
600	392	2.6	355 – 460
300	530	5.2	480 – 750

of the telescope. Its width is $110\mu m$ which corresponds to 1.6 px, equivalent to $1''\!.42$. The length of the slit extends over the whole field of view.

1.4 Data for the observations

The comet was observed in spectral mode of ***FoReRo2*** on 2008-Jan-10. The exposure time was 1200 sec. In table 2 the date (Date) and time (UT) of the observations, the Right Accession (R.A.) and Declination (Dec.), airmass (A), the heliocentric distance (r) and velocity (ṙ), geocentric distances (Δ), apparent phase angle (S-T-O), the position angles of the extended Sun–target radius vector (PsAng) and the negative of the target's heliocentric velocity vector (PsAMV) orientations are presented.

Table 2. Observations

Date	UT	R.A.	Dec.	A	r	$\dot{r}$	Δ	S-T-O	PsAng	PsAMV
2008-Jan-10	18:39	02 07 28.50	-09 33 48.8	1.747	1.057	-6.257	0.299	67.766	66.488	339.594

2 Data reduction

The first steps of the data reduction were bias subtraction and flat fielding. Master bias was prepared by median filtering of 5 individual bias frames and was subtracted from each image. Flat field correction was applied together with the absolute calibration by dividing the spectrum of the comet by the spectrum of the standard star (see equation 4).

A night sky spectrum was obtained 1 degree sunwards of the comet. It was used to remove night sky emission lines from comet spectrum.

2.1 Absolute Calibration

The atmospheric extinction was obtained from narrowband photometry of standard star in 3 different filter (IF512, IF642 and IF713). For correction of differential extinction within the spectrum the extinction was fitted at those three wavelengths and then extrapolated over the wavelength range using λ^{-4} law. The final correction for extinction was made as follows:

$$S^0_\lambda = 10^{-0.4(-2.5\lg(S_\lambda)-k_\lambda A)}, \tag{1}$$

where index λ is the wavelength, S_λ is the observed signal, k_λ is the extinction coefficient, and S^0_λ is the corrected signal.
For flux calibration of the spectra the fluxes of standard star HD15318 from the catalog of Hamyu [1992, 1994] were used. The given magnitudes m_ν were converted to fluxes ([erg/cm^2/s/Å]) in two steps:

$$f_\nu = 10^{-0.4(m_\nu+48.59)} \tag{2}$$

$$f_\lambda = \frac{c}{\lambda^2} f_\nu, \tag{3}$$

where f_ν is monochromatic flux in erg/cm^2/s/Hz, f_λ is in erg/cm^2/s/Å, and c is the speed of light.

When observing a star part of its image is blocked. We estimate the coming through the slit fraction to be 31%. It was calculated by obtaining signals without grisms from the images of the star with and without slit. This number was used to obtain the whole signal from the star, which corresponds to the fluxes in the catalog.

Finally the flux calibration was performed by applying following equation to the comet spectrum.

$$F_\lambda^{com} = S_\lambda^{com} \frac{F_\lambda^*}{S_\lambda^*} \tag{4}$$

2.2 Wavelength calibration

The wavelength calibration was performed by using information contained in the spectra themselves. For the standard star the Ballmer absorption lines and for the comet the night sky emission lines were used. The obtained linear dispersions in Å/px are given in table 1.

3 Results

The flux calibrated spectrum of the comet 8P/Tuttle is presented in the figure 1. The main cometary emissions: CN, C_3, C_2, NH_2 and O[I], are well discernible.

The solar spectrum was equalized to the clear continuum zone at 443 nm of

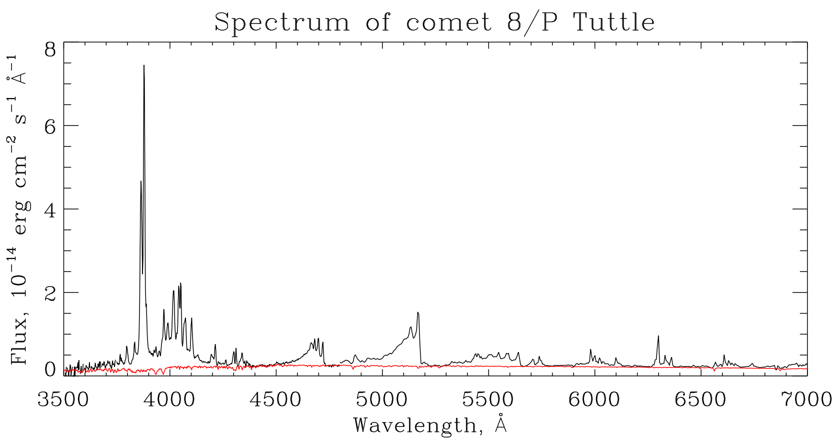

Fig. 1. The flux calibrated comets spectrum compared with solar one

the comet spectrum. The other good clear continuum zone is at 642 nm, where the comet spectrum is brighter than the solar one (see figure 2). From this difference the normalized spectral gradient of the cometary dust (the color of the

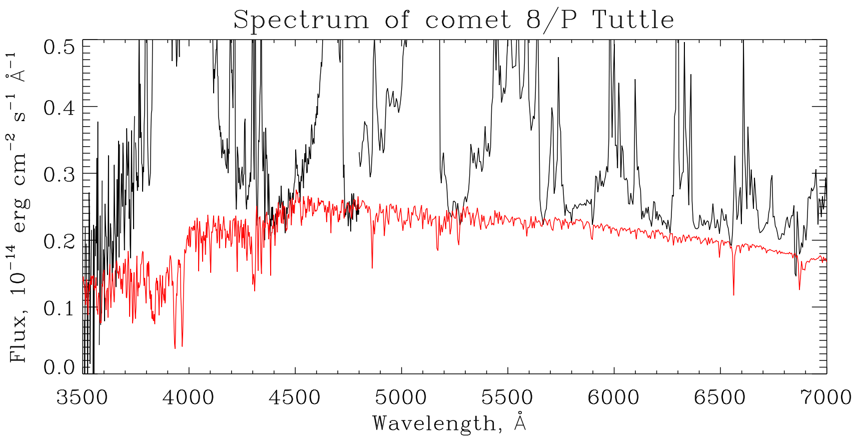

Fig. 2. The flux calibrated comet spectrum compared with solar one – continuum zone.

continuum) is calculated by the following relation:

$$C_{\lambda_1,\lambda_2} = \frac{1}{\bar{F}}\frac{\partial F}{\partial \lambda} \tag{5}$$

where $\bar{F}$ is the mean flux between λ_1 and λ_2 (Jewitt, [1991]).

The reddening of the cometary dust (C_{λ_1,λ_2}) was calculated to be 6% per 1000Å.

The total fluxes in the three main comet emissions - CN, C_3, C_2 - are measured from integration of their line profiles by wavelength after subtracting the continuum level. The fluxes are converted to column densities by following relation:

$$\bar{N} = \frac{F 4\pi r^2}{\omega g} \tag{6}$$

where F is the flux in [erg/cm^2/s] obtained from integration over the wavelength range of the emission band in the spectrum (see figure 3 and table 3), ω is solid angle of one pixel ($\omega = 1.8 \times 10^{-11}$ sr), r is the heliocentric distance, g is the fluorescence efficiency factor (Festou & Zucconi [1984]) of the corresponding molecule at 1 AU expressed in [erg/s/mol].

To obtain the gas production of the different molecules we compared our measurements with model calculations. The Haser model (Haser [1957]) was employed with parameters taken from A'Hearn [1995]. The total number of molecules, in the modeled coma, N_{ttl}^{mdl}, was obtained by integrating in space up to 7 scale lengths of the daughter molecules (CN, C_3, C_2). In the same model the number of molecules inside the slit and ± 10 px apart from the nucleus

Table 3. Spectrum measurements

Species	g-factor, g [photons/s/mol]	Flux, F_{mol}^{com} [erg/cm^2/s]	Column density[a] $\bar{N}$, [mol/cm^2]
CN	0.070	5.950×10^{-13}	2.54×10^{13}
C_3	0.035	6.865×10^{-13}	6.16×10^{13}
C_2	0.057	2.452×10^{-13}	1.71×10^{13}

[a] Sum of column densities inside the slit ±10 px apart from the nucleus.

(along the slit), N_{slt}^{mdl}, was derived. The parameters used in the model and the model results are presented in table 4.

Comparison of the modeled results with observed number of molecules inside the same spatial area inside the slit, N_{slt}, gives the total "observed" number of molecules, N_{ttl}:

$$N_{ttl} = N_{slt} \frac{N_{ttl}^{mdl}}{N_{slt}^{mdl}} \tag{7}$$

N_{slt} was obtained from spectrum as follows: $N_{slt} = \sum_{i=1}^{20} \bar{N}_i S_{px}$, where S_{px} is the area of one pixel in [cm^2] (for the day of observations $S_{px} = 5.88 \times 10^{14}\,\mathrm{cm}^2$). Then the production rate is calculated using the lifetime of daughter molecules (τ) taken from A'Hearn [1995]:

$$Q = \frac{N_{ttl}}{\tau} \tag{8}$$

In December 2007 Schleicher [2007] obtained production rates $Q_{CN} = 1.66 \times$

Table 4. Models and Results.

Mol.	L_p [km]	L_d [km]	τ_d [s]	N_{ttl}^{mdl}	N_{slt}^{mdl}	Q^{mdl} [s^{-1}]	N_{ttl}	Q [s^{-1}]
CN	1.3×10^4	2.1×10^5	2.1×10^4	1.85×10^{16}	4.62×10^{12}	3.24×10^{25}	5.98×10^{31}	2.85×10^{27}
C_3	2.8×10^3	2.7×10^4	2.7×10^4	2.17×10^{14}	1.11×10^{12}	2.95×10^{24}	7.08×10^{30}	2.62×10^{26}
C_2	2.2×10^4	6.6×10^4	6.6×10^4	8.21×10^{15}	4.02×10^{12}	4.57×10^{25}	2.05×10^{31}	3.11×10^{26}

10^{25}, $Q_{C_3} = 6.6 \times 10^{24}$, $Q_{C_2} = 2.46 \times 10^{25}$. These observations were made on 3, 4 and 5 Dec 2007 when the comet was at heliocentric distance 1.3 AU. Our results are in moderate agreement with these measurements obtained earlier during this apparition of the comet.

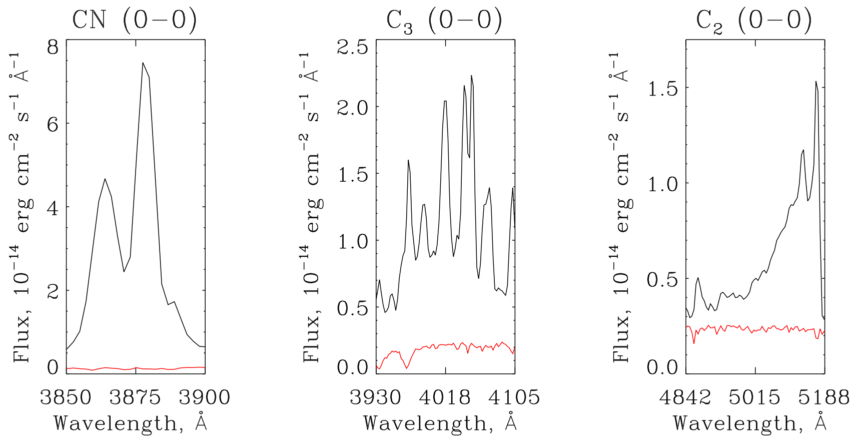

Fig. 3. The spectral line for the three main emissions of the comet spectra.

Conclusion

A spectrum of the comet 8P/Tuttle was obtained with the 2m RCC telescope equipped with 2-channel focal reducer in a framework of an international campaign.

The spectrum was calibrated to erg/cm^2/s/Å.

The fluxes and production rates were calculated for the three main comet emissions: CN, C_3, C_2.

The results are in moderate agreement with results of other authors obtained one month before our observations.

The results presented here will contribute to the overall campaign, the ultimate goal of which is to describe composition, kinematics and photochemistry of the gaseous component, infer properties and dynamics of the dust, and possibly characterize the spin state and the activity pattern of the nucleus. In this campaign additional observations, such as narrowband optical imaging and high resolution radio spectroscopy at 18-cm and 1.1-mm, were also obtained. In future, deeper analysis of the spectrum presented here will be performed in combination with the imaging data and with the data from other instruments.

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