Advances in Astronomy and Space Physics, **2**, 173-176 (2012)

Low-resolution spectrum of comet C/2004 Q2 (Machholz)

O. Shubina[1]*, *P. Korsun*[2], *Yu. Ivashchenko*[3]

[1]Faculty of Physics, Taras Shevchenko National University of Kyiv, Glushkova ave. 4, Kyiv, Ukraine
[2]Main Astronomical Observatory of the National Academy of Sciences of Ukraine, Zabolotnoho 27, 03680, Kyiv, Ukraine
[3]Andrushivka Astronomical Observatory, Andrushivka, Ukraine

We analysed the spectroscopic data for comet C/2004 Q2 (Machholz), obtained on the Zeiss–600 telescope in Andrushivka Astronomical Observatory on January 29, 2005. The observed spectrum covers a wavelength range 3600–9200 Å with a spectral resolution of 6.2 Å. The molecular-line features of C_2, C_3, CN, NH_2, CH, H_2O^+, and CH^+ were found in the spectrum.

Key words: comet, spectrum, emissions

INTRODUCTION

Comet C/2004 Q2 (Machholz) was discovered by Donald Machholz on August 27, 2004 as an object of 11 magnitude [6]. The comet was at a heliocentric distance of 2.47 AU and at a geocentric distance of 2.16 AU at the moment of the observation. The eccentricity of its orbit is 0.999473 and the original barycentric value of $1/a$ is +0.000404. The original value suggests that this is probably not a "new" comet from the Oort cloud [14]. The comet passed its perihelion on January 24.9127, 2005 at the heliocentric distance of 1.2 AU. Comet C/2004 Q2 (Machholz) was clearly visible to the naked eye and had brightened to about 3.5^m around perihelion passage.

H. Kobayashi and H. Kawakita [10] performed high-dispersion spectroscopic observations of comet C/2004 Q2 (Machholz) in the near-infrared spectral region. They detected emission lines of H_2O, HCN, C_2H_2, NH_3, C_2H_4, C_2H_6, CH_3OH and H_2CO in the cometary spectra and determined the mixing ratios of the detected volatiles relative to water. The authors also found that C/2004 Q2 was formed in the region where the initial abundance of C_2H_2 was depleted and the conversion efficiency from C_2H_2 to C_2H_6 was comparable with other comets.

In another paper H. Kobayashi and H. Kawakita [8] analysed the infrared spectral region. Their results indicated that the cometary molecules (at least, water and methane) in C/2004 Q2 might be processed under higher temperature conditions than typical Oort Cloud comets (~30 K), probably in the region closer to the proto-Sun. Alternatively, the materials in C/2004 Q2 might be processed at the epoch different from that the other comets.

H. Kawakita and M. J. Mumma [9] presented fluorescence excitation models for ammonia and NH_2 in comets. They provide quantitative g-factors for four values of the rotational temperature in the range typical for cometary comae, and present its values at perihelion of 1 AU. Then they applied their models to spectra of C/2004 Q2 (Machholz) obtained in the near-infrared spectral region, and derived the mixing ratio of ammonia relative to water. They claimed that the ammonia is the main parent molecule for the NH_2 radical.

E. Picazzio et al. [16] performed analysis of the spectra of comets 9P/Tempel 1, 37P/Forbes, and C/2004 Q2 (Machholz) in the optical spectral region. The gas component expansion u and the lifetime of the particles in the comae of these comets are calculated. Using the Shulman's model they derived the gas component expansion and the lifetime of the particles for the observed species in the comae of these comets. The spectra of the comets show evidence for a luminescent cometary continuum which may be connected to the luminescence of organic component of the cometary dust particles.

OBSERVATIONS AND REDUCTION

We observed the comet C/2004 Q2 (Machholz) with the Zeiss–600 telescope at Andrushivka Astronomical Observatory (A50). The observations were made on January 29, 2005, when the comet moved near its perihelion. The spectra were recorded with the UAGS spectrograph equipped with the 325 g mm^{-1} diffraction grating and attached to the Cassegrain focus of the telescope. The two-dimensional spectrograms were recorded on the S1C-017AP CCD chip with a thermo-electric cooling system. The dimension of the used CCD is 1024×1024 pixels with a pixel size of 16×16 μm that is equival to 0.46×0.46 arcsec at the sky plane.

*belkalenaastronom@gmail.com

Table 1: The journal of the observations of the comet C/2004 Q2 (January 29, 2005).

Object	Angle of grating, deg	Start time (UT)	Exp., seconds	Air mass
C/2004 Q2	29.25	19:57:53	300	1.169
C/2004 Q2	29.25	20:02:56	300	1.177
C/2004 Q2	29.25	20:08:00	300	1.185
C/2004 Q2	29.25	20:15:42	300	1.198
C/2004 Q2	29.25	20:20:46	300	1.206
C/2004 Q2	31.50	20:32:47	300	1.228
C/2004 Q2	31.50	20:37:51	300	1.237
C/2004 Q2	31.50	20:42:54	300	1.247
C/2004 Q2	31.50	20:47:58	300	1.257
HD 26630	31.50	21:00:47	300	1.081
HD 26630	29.25	19:43:12	300	1.081

A slit with the dimensions of 8×0.3 mm is equivalent to 78123.6×2929.6 km at the coma of the comet. To study the most part of the optical spectral region we made expositions at two rotation positions of the grating relative to the incident beam. Blue and red sections of the spectrum were recorded fixing the grating at the angles equal to 29.25° and 31.5°, respectively. The journal of observations is given in Table 1.

An incandescent lamp spectrum was taken in order to account for different sensitivities of the CCD's pixels. The wavelength calibration was made by fitting a polynomial function of the second degree to the observations of the Ne-Ar-N_2^+ lamp. The spectral response of the used telescope-instrument configuration and the spectral dependence on the atmospheric extinction were obtained from the spectrophotometric standard star HD 26630 exposures [11].

The available dark current was removed from the observed spectra subtracting the dark current frames obtained under the same conditions as for the observed objects. For the frames, related to each position of the grating, the median was calculated at each pixel across a set of 2D images. This allowed to filter the cosmic ray events and to increase the signal-to-noise ratio of the spectra. The one-dimensional spectra were formed by summing along the spatial dimension with no attempt to preserve the spatial information. Finally, the composite spectrum was formed joining the blue and red one-dimensional sections. This composite spectrum covers the wavelength range of 3600-9200 Å with a resolution of about 6.2 Å.

The flux of the comet was derived from the following formula:

$$F_c(\lambda) = F_{st}(\lambda)\,\frac{I_c(\lambda)}{I_{st}(\lambda)}\,p^{-\Delta M}(\lambda),$$

where F_c and F_{st} are the absolute fluxes of the comet and the standard star, respectively; I_c and I_{st} are the measured data for the comet and the standard star; $p(\lambda)$ is the spectral transparency of the Earth atmosphere; ΔM is the difference between the air masses of the comet and the standard.

To identify the cometary emissions the available continuum was removed. It was estimated using a scaled solar spectrum which was convolved with the observed spectroscopic resolution and corrected for the reddening effect.

RESULTS AND CONCLUSIONS

In order to identify the observed emission features we calculated the theoretical spectra of molecules that had been already recorded in the cometary spectra. The intensities of individual rotation lines were calculated assuming the thermodynamic equilibrium. In this particular case, vibration and rotation energy levels are populated according to the Boltzmann distribution and determined by rotational and vibrational temperatures. It is understood that the thermodynamic equilibrium is not realised in a cometary coma and the population of the energetic levels is caused by the absorption and reemission of solar quanta. Nevertheless, the thermodynamic equilibrium approach is successfully applied so far for the identification of molecular emissions in cometary spectra and in this particular case the values of the temperatures are considered as parameters that are used to fit the observed spectrum with the highest possible accuracy [1, 2].

Using this technique we found the molecular emissions of C_2, C_3, CN, NH_2, CH, H_2O^+, and CH^+ in the optical spectral region of comet C/2004 Q2 (Machholz).

CN: The most prominent features in C/2004 Q2 spectrum are due to the CN emission transitions. The Δv=0 and Δv=+1 vibration bands of the violet system of CN attributed to the electronic transition $B^2\Sigma^+$–$X^2\Sigma^+$ were detected in the blue region of the spectrum. This identification was done with the `LIFBASE` programme package [13] developed for calculation of the electronic spectra of some diatomic molecules. In the red section of the spectrum we detected some features, which we assigned to the electronic transition $A^2\Pi$–$X^2\Sigma^+$, the so called red system of CN, with $\Delta v = +4$, $\Delta v = +2$, and $\Delta v = +1$. Our detections of the CN emissions are shown in Fig. 1 (violet system) and in Fig. 2 (red system).

C_2: We found five vibrational band systems of C_2 ($\Delta v = -2$, $\Delta v = -1$, $\Delta v = 0$, $\Delta v = +1$, and $\Delta v = +2$), belonging to the electronic transition $d^3\Pi_g$-$a^3\Pi_u$, the so called the Swan system. For this purpose the theoretical spectrum was calculated using the line list derived from the laboratory measurements made by Phillips and Davis [15]. Obviously taking into account the moderate spectral resolution the rotational structure can be only partly resolved and we can detect groups of rotational lines and vibrational band heads of the vibrational band sequences. Our detection of the Swan system is shown in Fig. 1. Also we found two vibrational bands in the red part of the spectrum, $\Delta v = +2$ and Δv, belonging to the electronic transition $a^3\Pi_u$–$x^1\Pi_g$, the so called the Phillips system [17]. The identifications are shown in Fig. 2.

CH: The emission features of the $A^2\Delta$-$X^2\Pi$ system of the CH molecule are confidently identified in the blue region. They belong to the $\Delta v = 0$ vibrational band. For this identification we also used the `LIFBASE` package [13]. These features are marked in Fig. 1.

CH^+: Besides the neutral molecule CH, we detected three weak emissions originated from the $A^1\Pi$-$X^1\Sigma^+$ electronic transition of the CH^+ ion. They belong to the heads of the P-, Q-, and R-branches of the (0-0) vibrational band. The theoretical spectrum was calculated using the data of Douglas and Herzberg [3] and our identifications are presented in Fig. 1.

C_3: In the violet region of C/2004 Q2 (Machholz) spectrum we easily recognised the fluorescence bands of C_3. The corresponding electronic transition is $^1\Pi_u$-$^1\Sigma_g^+$. We found a most of the features which Gausset et al. [5] reported for comet Ikeya (1963a). The results of the this identification are marked in Fig. 1.

H_2O^+: It worth to note that the H_2O^+ bands turned out to be sufficiently strong in the investigated spectrum. The identified features belong to the (5-0), (6-0), (7-0), and (8-0) bands and appear along the spectrum [12]. The identifications are presented in Fig. 1, 2.

NH_2: The numerous weak emissions of NH_2 are dispersed along the observed spectrum. The spectrum of NH_2 is irregular and belongs to electronic transition A^2A^1-X^2B^1. In order to identify these features we used the results of the laboratory measurements of Dressler and Ramsay [4] and Huet et al. [7]. The comparison between the calculated spectrum of the NH_2 molecule and the observed C/2004 Q2 spectrum resulted in the identification of the emissions of this molecule belonging to the (15-0), (13-0), (12-0), (11-0), (10-0), (9-0), (8-0), (7-0), (6-0), (5-0), and (3-0) vibrational bands. The identified features are presented in Fig. 1, 2.

A lot of the OH atmospheric emissions are detected in our spectrum, but we did not indicate them in Fig. 1 and in Fig. 2.

REFERENCES

[1] Arpigny C. 1972, in Comets: Scientific Data and Missions, eds.: Kuiper G. P. & Roemer E., University of Arizona Press, 84

[2] Arpigny C. 1976, NASA Special Publication, 393, 797

[3] Douglas A. E. & Herzberg G. 1942, Canadian Journal of Research, 20, 71

[4] Dressler K. & Ramsay D. A. 1959, Royal Society of London Philosophical Transactions Series A, 251, 553

[5] Gausset L., Herzberg G., Lagerqvist A. & Rosen B. 1965, ApJ, 142, 45

[6] Green D. W. E. 2004, IAU Circular, 8394, 2

[7] Huet T. R., Hadj Bachir I., Bolvin H. et al. 1996, A&A, 311, 343

[8] Kawakita H. & Kobayashi H. 2009, ApJ, 693, 388

[9] Kawakita H. & Mumma J. 2011, ApJ, 727, 91

[10] Kobayashi H. & Kawakita H. 2009, ApJ, 703, 121

[11] Le Borgne J.-F., Bruzual G., Pelló R. et al. 2003, A&A, 402, 433

[12] Lew H. 1976, Canadian Journal of Physics, 54, 2028

[13] Luque J. & Crosley D. R. 1999, LIFBASE: Database and Spectral Simulation Program (version 1.5), SRI International Report MP 99

[14] Marsden B. 2004, Minor Planet Electronic Circular, 2004-U31

[15] Phillips J. G. & Davis S. P. 1968, 'Berkeley Analyses of Molecular Spectra', Berkeley: University of California Press

[16] Picazzio E., Churyumov K. I., Chubko L. S. et al. 2009, IAU Symposium, 263, 277

[17] Simoes da Silva A. 1968, Separata de O INSTITUTO, CXXXII, Coimbra Editora, 1

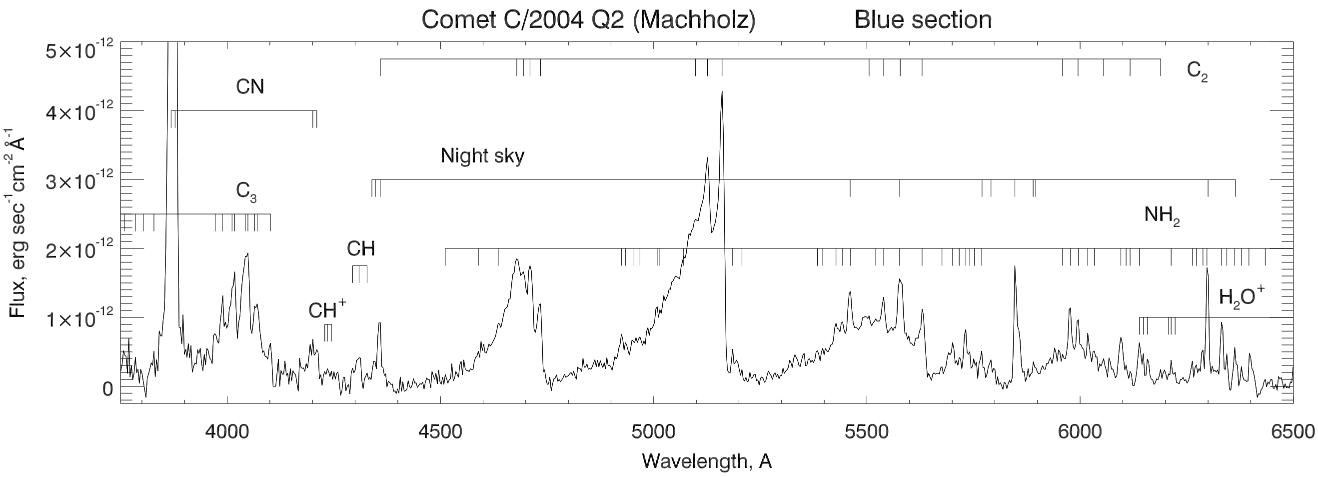

Fig. 1: Emissions in comet C/2004 Q2 (Machholz) spectrum (blue part).

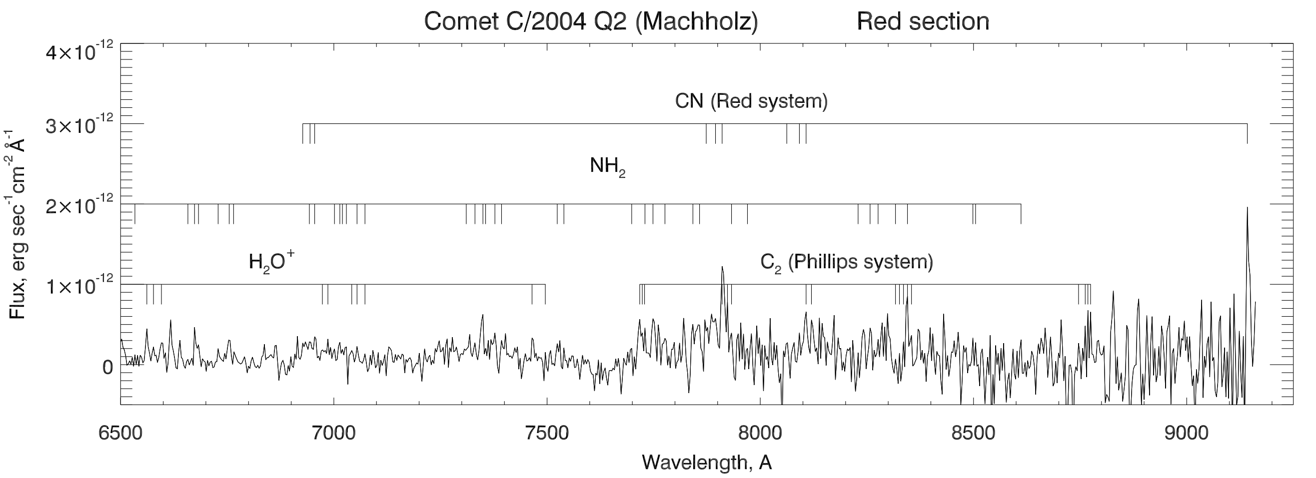

Fig. 2: Emissions in comet C/2004 Q2 (Machholz) spectrum (red part).