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Spectrophotometric study of the comet C/2001 Q4 (NEAT)

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Abstract. Spectrophotometric observations of the comet C/2001 Q4 (NEAT) were taken on three nights of May 13, 18 and 19, 2004 near its perihelion distance using 104-cm telescope of ARIES, Nainital. The Cassegrain HR- 320 spectrograph with 1K × 1K CCD camera gives a visible spectral coverage of 3500-7000 Å.

The prominent emission bands CN (3888 Å) and C_2 (4695, 5165 and 5538 Å) were identified. An estimate of the CN and C_2 abundances and the production rates for these molecules and dust at those heliocentric distances were determined.

Keywords : Comet spectrophotometry, column densities and production rates

1. Introduction

Comets are exciting objects to us because they are unpredictable. They can suddenly brighten or fade, can lose their tails or develop multiple tails. Some of the comets can even split into two or more pieces. Many astronomers are convinced that early collisions between earth and comets brought the vast amount of water that now make up the oceans. The oceans enabled life on earth. Mass extinction of different life-forms may have also been caused by a comet and earth collision.

Comet nuclei are the frozen reservoirs of dust and ices from early solar nebula. Of all

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solar system bodies comets suffered the least post-formation alteration in their composition. After the spacecraft Giotto[1] photographed the nucleus of Halley's comet in 1986, it is now known that a comet nucleus has a surface that is best described as a black crust. This black crust helps the comet in absorbing heat, which in turn causes some of the ices under the crust to turn to gas, building pressure beneath the crust. The weakest areas of the crust shatter from the pressure and the gas shoots outward. Any dust that had been mixed in with the gas is thrown out as well and a tenuous gas and dust shell forms around the nucleus, which is called coma. As a comet approaches the sun, the particles streaming out from the sun provide enough force so as to act as a wind and blow the gas and dust particles away from nucleus and coma which forms comet tails. This is when the ground based small telescopes can take meaningful observations.

The LINEAR (Lincoln Near Earth Asteroid Research) and the NEAT (Near Earth Asteroid Tracking) programmes discover a large number of comets every year. Some of them become observable from the ground based telescopes. Every comet is unique and travels through an unique path in the solar system. Therefore, extensive observations of every comet in all possible modes of observations are significant.

Comet C/2001 Q4 (NEAT) was discovered by NEAT team on August 24, 2001. At the time of discovery it was a 20th magnitude object beyond the orbit of saturn. This is the most distant record of the comets discovery. This comet was observed using Space Telescope Imaging Spectrograph on the Hubble space telescope and the first detection of atomic deuterium emission in a comet was reported by Weaver et al. (2004). Observations of this comet with the Far Ultraviolet Spectroscopic Explorer (FUSE) show that in addition to the CO and atomic lines of O, H, N there are roughly two dozen emission lines present, which are yet to be identified (Feldman et al. 2004). 10 micron silicate features have also been observed (Wooden et al. 2004, Sitko et al. 2004 and Harker et al. 2004). Observations of atomic emissions of oxygen and carbon and an estimate of the production of CO, OH and water is reported by Spasojevic et al. (2004).

We observed the comet C/2001 Q4 spectrophotometrically to detect the emission features due to various molecules as a function of heliocentric distance. An estimate of the abundance and production rates of the observed species and dust has also been made using these observations.

2. Observations and data reductions

The spectrophotometric observational system consists of a HR-320 spectrograph, a CCD detector, a detector interface and a computer. The spectrograph gives a dispersion of 2.4 Å/pixel with a grating having 300 g/mm blazed at 5000 Å. At the entrance slit of the spectrograph, a circular diaphragm of 9 mm diameter corresponding to 2.33 arcmin as

[1] http://www.spds.nasa.gov/planetary/giotto.html

Table 1. Basic data of the coma of the comet C/2001 Q4 (NEAT) at the time of observations (Bradfield 2004), Δ = Geocentric distance; r = Heliocentric distance, m_1 = Predicted integrated magnitude; ρ = Radius of circular region in the sky at Δ, D = Aperture diameter of the coma projected on the sky.

Date(UT)	Δ (AU)	r (AU)	m_1	ρ ($\times 10^4$km)	D (arcmin)
May 13.62, 2004	0.389	0.963	1.2	1.977	2.33
May 18.59, 2004	0.495	0.963	1.7	2.511	2.33
May 19.63, 2004	0.520	0.964	1.9	2.643	2.33

projected on the sky (ρ) and centered on the coma of the comet was used. The 1k $\times$ 1k CCD chip covers about 2500 Å wide spectrum in a single exposure. Using a 9mm diameter circular aperture for this extended source produces a strong degradation of the spectrum. CN emission is blended with CH + C_3 (4050 Å) and the three C_2 bands are strongly blended between each other. Basic data of the comet at the time of observation is given in Table 1.

At least three spectral frames of the comet were obtained every night in the blue and red part of the spectrum. Along with the comet, standard star HR 4534 was also observed to calibrate the flux of the comet spectra. Sufficient bias, twilight flats and sky frames were also taken. Data reduction is done using spectroscopic reduction software package of IRAF[2]. We have used bright A-type spectrophotometric standards to calibrate wavelengths of the spectra and hence our wavelengths correction may have uncertainty of $\sim$ 10Å. The flux and wavelength calibrated spectra (converted to frequency) are shown in Figure 1. We have an usable range in spectrum from $\sim$ 3550 Å to 6000 Å for all dates.

3. Emission bands, column densities and production rates

The prominent features, as can be seen in Figure 1 are CN(Δv = 0) at 3888 Å, C_2(Δv = $+1, 0, -1$) at 4695, 5165 and 5538 Å respectively. The C_3 +CH (4050 Å) bands which are blended with CN (3888 Å) are not resolved because of poor resolution. In order to measure fluxes in these emission bands, the continuum in spectrum was located by selecting wavelengths 3600 Å, 4350 Å, 4850Å, 5400Å and 5800Å which are free from emission bands. The area of strong emission bands were measured between 3745 - 4378 Å, 4440 - 4780 Å, 4841 - 5340 Å, and 5360 - 5800 Å for CN and C_2(Δv = $+1, 0, -1$) bands respectively and converted into the total flux. Emission band fluxes relative to C_2 (5165 Å) are given in Table 2.

[2]ftpsite - iraf.noao.edu; IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation

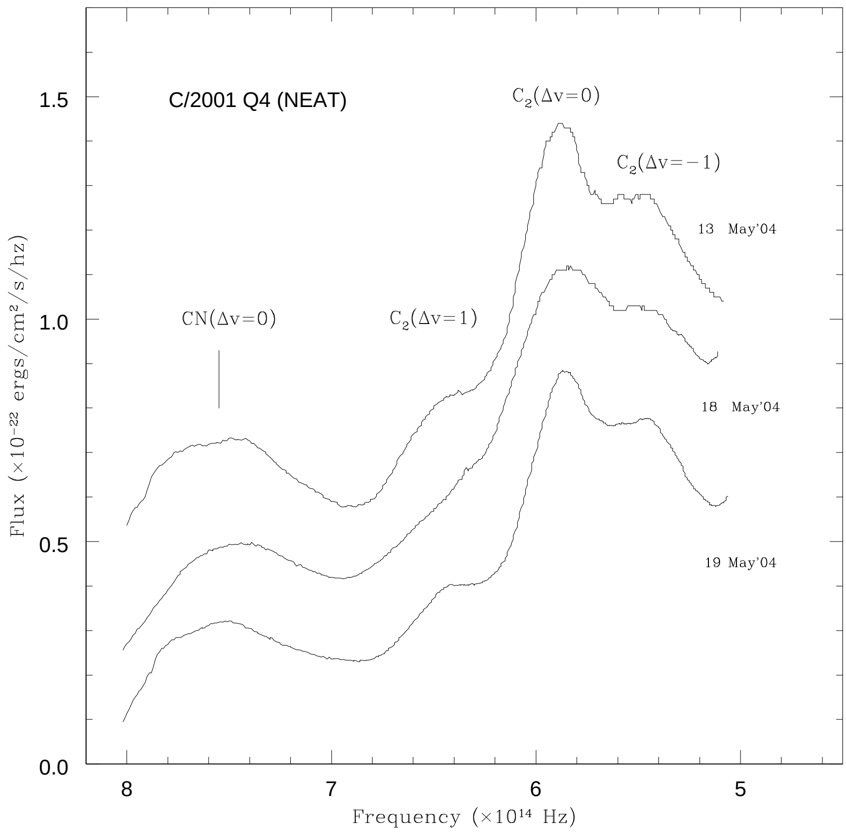

Figure 1. Absolute flux distribution of the head of the comet C/2001 Q4 (NEAT).

The number of molecules of each species, contained in a cylinder of radius defined by the diaphragm used, and extending entirely through the coma was evaluated using the expression (Millis et. al. 1982) which is given as,

$$\log M(\rho) = \log F(\rho) + 27.449 + 2\log(\Delta r) - \log g \tag{1}$$

where F is the observed flux in cgs units, ρ is the projected radius of circular region in the sky at Δ, r and Δ are the heliocentric and geocentric distances of the comet respectively in AU and g the fluorescence efficiency (in cgs units) per molecule at 1 AU. We used the values of fluorescence efficiency for C_2 and C_3 from Sivaraman et al. (1987). Because of the swings effect g varies significantly for CN with the comets heliocentric radial velocity.

Table 2. Observed fluxes in emission bands of the comet for the observed dates of Table 1.

Date(UT) (2004)	$F(C_2,\Delta v = 0)$ $\times 10^{-9} ergs/cm^2/s$ 5165Å	$F/F(C_2,\Delta v = 0)$			
		$CN(\Delta v = 0)$ 3883Å	$C_2(\Delta v = 1)$ 4695Å	$C_2(\Delta v = 0)$ 5165Å	$C_2(\Delta v = -1)$ 5538Å
May 13.62	1.77	0.723	0.108	1.000	0.265
May 18.59	1.61	0.720	0.057	1.000	0.185
May 19.63	1.35	0.933	0.118	1.000	0.228

Table 3. Column densities (M) and production rates (Q) of the comet for the observed dates of Table 1.

Date(UT) (2004)	log(M)				log(Q)		
	CN ($\Delta v = 0$)	C_2 ($\Delta v = 1$)	C_2 ($\Delta v = 0$)	C_2 ($\Delta v = -1$)	CN ($\Delta v = 0$)	C_2 ($\Delta v = 0$)	$Af\rho$* 4863Å
May 13.62	30.22	29.49	30.20	29.94	26.03	26.23	4.37
May 18.59	30.35	29.38	30.36	29.95	26.06	26.28	4.67
May 19.63	30.39	29.65	30.34	30.00	26.08	26.23	2.80

* This quantity is given in the unit of $\times 10^2$ cm.

The value of g was obtained for all the values of radial velocities is taken from Zucconi & Festou (1985). Therefore the variation of g has been incorporated in the calculation of column densities of the molecule CN. The column densities thus obtained are listed in Table 3.

The column densities thus calculated were converted into production rates (Q), assuming a Haser model, through the relationship given by A'Hearn and Cowan (1975),

$$M(\rho) = QV^{-1}\rho \left[\int_{x}^{\mu x} K_0(y)dy + (1/x)(1 - 1/\mu) + K_1(\mu x) - K_1(x) \right] \quad (2)$$

where V is the velocity of released species in km s^{-1}; x is the ratio between ρ and daughter molecule scale lengths; μ is the ratio between daughter and parent molecules scale lengths; K_0 and K_1 are modified Bessel functions of the second kind of order 0 and 1. Following Krankowsky et al. (1986) we assumed $V = 1.0/\sqrt{r}$. The parent and daughter molecular scale lengths are taken from Cocharan (1985). The resulting production rates are given in Table 3 and have a mean value of 1.14×10^{26} s^{-1}. Our estimates are lower to the HCN production rate determined by Friedel et al. (2005). However they agree within the errors.

An estimate of the relative dust production is made using the $Af\rho$ quantity as described by A'Hearn et al. (1989). The product Af is defined as $(2\Delta r/\rho)^2 F_{com}/F_{\odot}$, where Δ and ρ are in kilometers, r is in AU, $F_{\odot}$ is the solar flux at 1 AU, F_{com} is the observed cometary flux at 4863 Å in 20 Å band. The Solar flux $F_{\odot}$ is taken from Table II of Neckel and Labs (1981). The values of $Af\rho$, thus obtained is given in Table 3.

4. Discussions

The prominent emission features as seen in Figure 1 are CN($\Delta v = 0$) at 3888 Å and C_2 ($\Delta v = +1, 0, -1$) at 4690, 5160 and 5530 Å. The strongest feature in the whole spectrum is due to C_2 ($\Delta v = 0$) at 5165 Å. The activity was maximum on 13th May when it was nearest to the perihelion distance. This is reflected in the continuum and in the production rates of molecules and dust on 13th May. As the heliocentric distance increased the activity decreased. The calculated column densities $\log(M)$ and production rates $\log(Q)$ are almost in agreements with the values of comets C/2000 WM1 (LINEAR) and C1 (Ikeya-Zhang) (Sanwal et al.,2002). The emission features are strongly blended with each other and the continuum, because of poor resolution of the observing system. This has introduced error in the estimation of the band intensities and hence in the estimate of the production rates.

The comet was observed on three consecutive nights and hence there was very little change in the heliocentric distance. Therefore, the $Q(C_2)/Q(CN)$ ratio remained almost the same. Though a systematic decrease in $Q(C_2)/Q(CN)$ with heliocentric distance is suggested by A'Hearn et al. (1995).

The dust production rate at similar heliocentric distances for comet Bradfield (Rautela and Sanwal, 1988) and comet Austin (Rautela and Sanwal, 1992) show that there is no direct correlation of dust production rate with heliocentric distance of a comet, but most likely it is related to the intrinsic constitution of a comet. The dust content for the comet C/2001 Q4 is in between comet Bradfield and comet Austin.

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