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Spectrophotometry of the comet C/2002 V1 (NEAT)

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Abstract. We took spectrophotometric observations of the coma of the comet C/2002 V1 (NEAT) on January 24 , 25 and February 4, 2003, with 104-cm telescope of the State Observatory, Nainital. CN (3883 Å) and C_2 swan bands (4695, 5165 and 5538 Å) were identified. An estimate of CN and C_2 abundances and their production rates were made. Dust production rates have also been determined.

Keywords : Comet spectrophotometry, column densities and production rates

1. Introduction

The 1.2-m Schmidt telescope at Haleakala found a comet on November 6, 2002 during the Near Earth Asteroid Tracking (NEAT) and it was reported by S.H.Pravdo. At the time of discovery its magnitude was around 17.3. Several recorded positions of the comet enabled B. G. Marsden to establish the perihelion date as February 18.30, the perihelion distance as 0.099 AU and the orbital period as about 37 years for the comet. Visual magnitude estimates reported during December by several observers were inconsistent. The total visual magnitude was between 8.0 and 8.5 around December 29. The comet brightened in January. The magnitudes ranging from 6.8 to 7.5 and coma diameter estimates ranging from 5 to 12 arcmin around January 14 were reported. CCD images on January 17 revealed an apparent tail disconnection event. The comet's rate of brightening slowed around February 3, as observers were reporting brightness estimates below the predicted values. This comet entered the field of view of the Solar and Heliospheric Observatory (SOHO) on February 16 and was observed by its coronograph (website - http://soho.nascom.nasa.gov). It displayed complex dust and ion tails and exhibited the

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brightest and largest (10^7 km long) dust tail to date, with a peak gas production rate of 10^{31} mol/sec. This rate is similar to the huge rate found for comet Hale-Bopp and comet Machholz 1 at perihelion.

Most of the comets come into the solar system for the first time and their orbits are found to be randomely distributed. Thus every comet is an unique comet and travels through an unique path in the solar system. Therefore, extensive observations of every comet in all possible modes of observations are important. As a comet approaches the sun it liberates gas and dust and its spectrum shows a set of emission lines of simple molecules. It is easier to study the spectral lines of the molecules like C_2, CN etc. in comets using the standard techniques as their lines lie in the visible region. Spectrophotometry of the comet C/2002V1 was done to identify the emission due to various molecules and dust and to estimate their production rates as a function of heliocentric distance. Basic data for the dates of our observations are given in Table 1.

Table 1. Basic data of the coma of the comet C/2002 V1 (NEAT) at the time of observation, Δ = Geocentric distance; r = Heliocentric distance, m_1 = Predicted integrated magntude; ρ = Radius of circular region in the sky at Δ, D = Aperature diameter of the coma projected on the sky

Date(UT)	Δ (AU)	r (AU)	m_1	ρ ($\times 10^4$km)	D (arcmin)
Jan 24.57, 2003	0.912	0.835	5.1	4.636	2.33
Jan 25.55, 2003	0.916	0.810	4.9	4.656	2.33
Feb 04.47, 2003	0.947	0.536	2.3	4.814	2.33

2. Observations and Data reductions

The spectrophotometric observational system is mounted at the Cassegrain focus of the 104cm telescope of State Observatory Nainital. It consists of a HR-320 spectrograph, a SBIG ST7 CCD camera and a computer. The system gives a dispersion of 0.9 Å/pixel with a grating having 300 g/mm blazed at 5000 Å. At the entrance slit of the spectrograph, a circular diaphram of 9 mm diameter corresponding to 2.33 arcmin as projected on the sky (ρ) and centered on the coma of the comet was used. ST7 is a 765 X 510 pixel CCD with 9 micron pixel size. In our setup one frame covers 688Å only. Therefore, four successive frames were taken to cover wavelength range 3500Å to 6000Å by changing the grating angle of the spectrograph. A minimum of three observations were recorded for each drum setting. An exposure time of 10 minute was kept for all the observations.

Along with the comet, standard star ξ^2 Ceti was also observed to calibrate the flux of the comet spectra. Sufficient bias, twilight flats and sky frames were also taken. Data reduction was done using spectroscopic reduction software package of IRAF. The flux and wavelength calibrated spectra (converted to frequency) are shown in Figure 1. We have an usable range in spectrum from 3550 Å to 6000 Å for all dates.

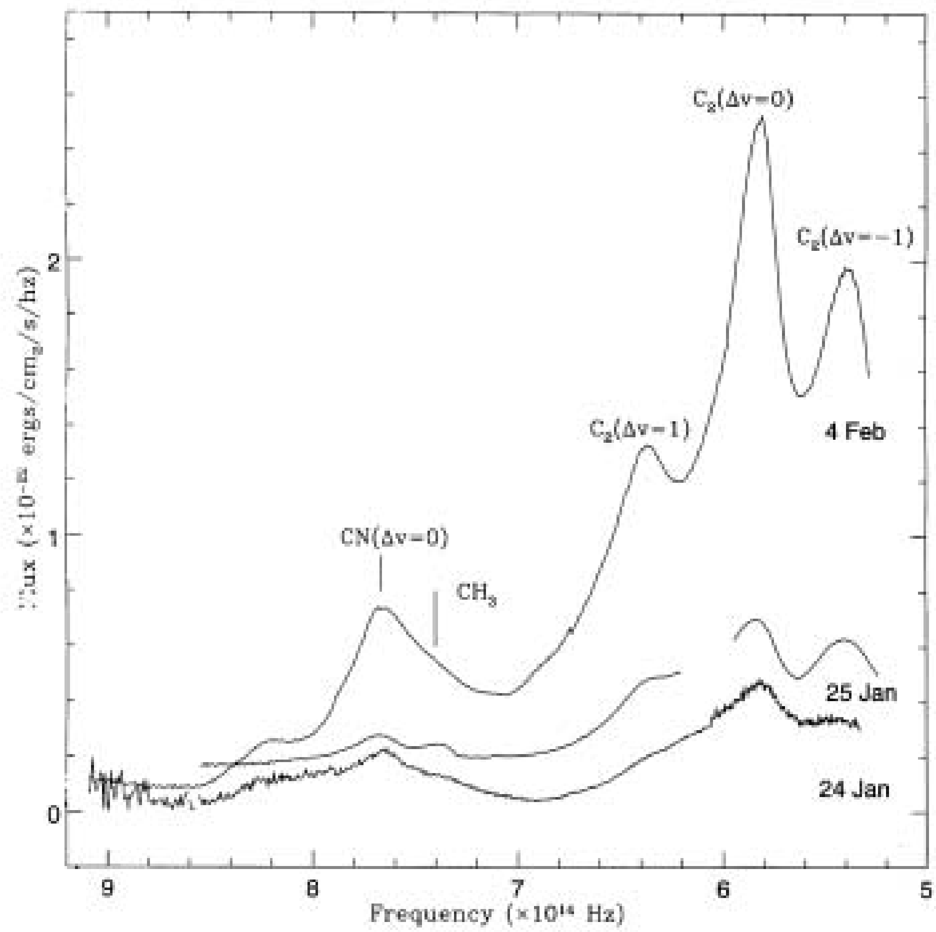

Figure 1. Absolute flux distribution of the head of the comet C/2002 V1 (NEAT)

3. Emission bands, column densities and production rates

The prominent features, as can be seen in Figures 1 are CN(Δv = 0) at 3883 Å, C_2(Δv = $+1, 0, -1$) at 4695, 5165 and 5538 Å respectively. In order to measure fluxes in these emission bands, the continuum in spectrum was located by selecting wavelengths which are free from emission bands. The area of strong emission bands were measured and converted into the total flux. Emission band fluxes relative to C_2 (5165 Å) are given in Table 2.

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

$F(C_2,\Delta v = 0)$ $\times 10^{-10} ergs/cm^2/s$ 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
9.776	1.830	0.008	1.000	0.087
13.571	0.344	0.015	1.000	0.595
65.030	0.478	0.154	1.000	0.307

The number of molecules of each species, contained in a cylinder of radius defined by the diaphragm used, and extending entirely through the coma, i.e. the column density $M(\rho)$ was evaluated using the expression given by Millis et al. (1982).

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

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 from Sivaraman et al (1987). 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),

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

where V is the velocity of released species; 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 Delsemme (1982) we assumed $V = 0.58/\sqrt{r}$. The parent and daughter molecular scale lengths are taken from Cocharan (1985). The resulting production rates are given in Table 3.

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

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 ($\Delta v = 0$)	dust 4850Å
30.85	28.67	30.50	29.76	26.10	25.96	10.95
30.31	30.13	30.68	30.78	25.55	26.13	11.19
30.82	30.48	31.03	30.83	26.14	26.55	11.24

Production rates for dust have been estimated on the simplest possible model, spherically symmetric, uniform outflow ignoring variations in particle sizes, scattering angle, etc. The relationship derived by A'Hearn and Cowan (1975) is used to evaluate the production rate, Q, of dust in arbitrary units.

$$Q = Lr^2/\rho \tag{3}$$

where L is the luminosity of the comet at $\lambda = 4850$ Å. The dust production rates evaluated are listed in Table 3.

The spectrophotometry of CN has been reviewed by Arpigny(1976). This radical shows a very strong Swings effect because the violet bands occur at a wavelength where solar spectrum is very irregular and the total intensity of the violet system is a strong function of heliocentric radial velocity. The effect has been evaluated theoretically by Tatum and Gillespie (1977) and Mumma et al. (1978). Since Mumma et al. used a spectrum of the whole solar disk rather a spectrum of the center of the disk, their results should be more reliable and therefore this was used to estimate the fluorescence efficiency for CN as the radial velocity of the comet varied during our observations.

4. Discussions

The prominent emission features as seen in Figure 1 are CN(Δ v=0) at 3888 Å and C_2 (Δ v $= +1, 0, -1$) at 4690, 5165 and 5530 Å. The strongest feature in the whole spectrum is due to C_2 (Δ v $= 0$) at 5165 Å. The molecular emission band of the CN molecule is blended by the emission from the CH_3 molecule therefore the estimate of the production rate for CN has large scatter. The production rates of molecular species CN and C_2 and dust as a function of heliocentric distance are given in the Figure 2. We have only three points. Thus the rough estimate of the variation of production rate is obtained. It varies approximately as $r^{-2.7}$ for C_2, $r^{-1.53}$ for CN and $r^{-.97}$ for dust which is in fair agreements within uncetrainty with the classical model of equilibrium vaporization of the nucleus.

The focal plane aperture used samples only the central portion of the comet coma and therefore is sensitive to the radial variation of brightness across the comet image.Thus, even if proper calibration and extinction correction is achieved, there is usually no way to satisfactorily extrapolate to the region outside the diaphragm. Thus it is difficult to compare the observations with different apertures. However, we have observed several comets viz. Bradfield (Sanwal and Rautela, 1990), Okazaki-Levy - Rudenko (Sanwal and Rautela, 1991), Austin (Rautela and Sanwal, 1992), Swift-Tuttle (Sanwal et al. 1994), Hale- Bopp (Sanwal and Singh, 1999), Ikeya-Zhang and C/2000 WM1(Sanwal et al., 2002) etc. with almost same setup and found that the production rates of CN and C_2 show a linear relationship indicating a constant ratio in the production rates between the two observed molecules. A'Hearn and Millis (1980) also showed that the CN and C_2 production rate ratio was remarkably constant ($\pm$.1 in log). However the ratio has also been found to vary from comet to comet and also with the heliocentric distances. This comet also shows similar ratio. Even with wide variation in the cometary properties, they all seem to show very little variation in the chemical abundances.

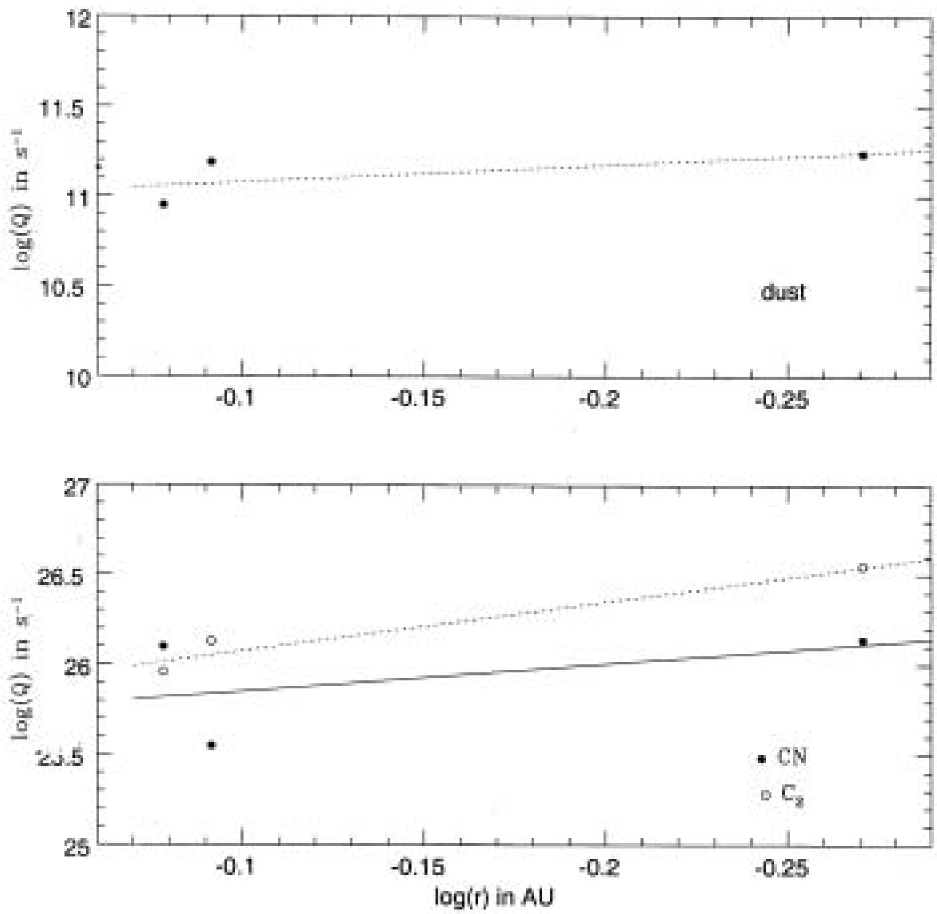

Figure 2. The production rates of molecular species CN, C_2 and dust as a function of heliocentric distance for the comet C/2002 V1. In the lower panel solid line represent CN and the dotted line represent C_2

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