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Spectrophotometric observations of comet Hale Bopp (C/1995 O1)

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Abstract. Haser Model production rates of CN and C_2 in the coma of the comet Hale-Bopp (C/1995 O1) have been obtained. Molecular production rate, size of the nucleus and continuum flux at 484.0 nm have further been analysed to get the dust production rates. The comet appears to be dusty.

Key words : comet-production rates.

1. Introduction

Farnham and Schleicher (IAU Circular No. 6589) have obtained narrow band photometric observations of comet Hale-Bopp (C/1995 O1). We have observed the comet spectrophotometrically and identified emission features due to CN(Δv=0) and C_2(Δv=+1, 0, −1) at 383.3, 469.5, 516.5 and 553.8 nm respectively. In the frame work of Haser Model we have analysed these emission features. Using 484.0 nm continuum flux we have determined the dust production rates in the coma of the comet.

2. Observations

The comet was observed on four nights 26, 27 February, 4 March and 30 April 1997 in the wavelength region 360.0–610.0 nm, using spectrophotometer having the reticon array detector, mounted at the Cassegrain focus (f/13) of the 104 cm telescope of Uttar Pradesh State Observatory, Nainital. The spectral dispersion of the spectrograph attached with detector is 100 A/mm. The reticon array consists of 1024 elements of size 2 mm × 25 micron. A circular diaphragm of 2 mm corresponding to 30 arc second as projected on the head of the comet was adopted for obtaining the spectral scans.

Along with the comet the standard stars α Leo and γ Gem were observed to check the wavelength calibration of the scanner and to standardise the observations of the comet. The absolute values of the magnitude thus obtained corresponds to calibration of standard stars given by Taylor (1984). The area of the emission bands were measured and converted into total

Table 1. Observational data of the comet Hale Bopp (C/1995 O1).

rh (A U) date	rd (A U)	s (meter)	Phase angle (θ) (Degree)	scattering function $\phi(\theta)$	
26/2	1.085	1.520	1.654(7)	41	0.45
27/2	1.075	1.505	1.637(7)	42	0.45
04/3	1.032	1.436	1.562(7)	44	0.44
30/4	1.050	1.765	1.920(7)	30	0.50

Table 2. Production rates in the coma of the comet.

	log prod. rate			
date	CN	C2	gas (gm/sec)	dust (gm/sec)
26/2	27.5	27.8	7.9	8.3
27/2	27.7	27.8	8.0	8.8
04/3	28.1	28.2	8.5	9.2
30/4	28.0	28.2	8.4	9.2

flux. Basic data of the comet is given in Table 1 whereas the production rates are tabulated in Table 2. The standard deviation of an individual measurement does not exceed $0^m.03$ shortward of 400.0 nm and $0^m.02$ above 400.0 nm.

3. The size of the nucleus

We have assumed that the comet is a normal one and for normal comets H_2O production rate ($Q(H_2O)=H_2O$) can be estimated using the expression (Newburn and Spinard, 1985, 1989; Spinard, 1987)

$$Q(H_2O) = (H_2O/D_2O)(D_2O/CN)Q(CN) \qquad \text{(mol/s)} \ldots\ldots\ldots\ldots\ldots A$$

During quiet sun $H_2O/D_2O = 6$ and $D_2O/CN = 100$ (Festou, 1981). Hence in case of Hale-Bopp equation (A) can be written as

$$Q(H_2O) = 6\times 100 \times Q(CN) = 600\, Q(CN) \qquad \text{(mol/s)} \ldots\ldots\ldots\ldots B$$

Using the CN Haser model production rates equation (B) yields water production rates ranging from 3.8×10^{30} mol/s to 8.3×10^{30} mol/s.

Now determination of the size of the comet can be made following the water vaporization theory (Cowan and A'Hearn, 1979: Delsemme, 1982). Assuming that nucleus is spherically symmetric, $\cos\theta = 0.5$, $A_0 = 0.04$ (Delamere et al; 1986) and $A_1 = 0.03$ (Cochran, 1982), the water vaporization theory, under 50 percent activity of total spherical surface area yields nuclear diameter ranging from 46 km to 32 km for $1.05 < r_h < 1.075$ AU a value close to that found by other sources also.

4. Gas production rate

For gas mass production rate, we have considered the gas as a mixture of 90% H_2O and 10% other molecules of mean molecular weight of 40 amu. Then the mass of gas is

$$m_{gas} = (20.6/A_v) \times Q(H_2O) = (20.6 \times 600 \times Q(CN)) / (6.03 \times 10^{23}) \qquad \text{gm/s}$$

For a mixture of 80% of H_2O and 20% other molecules of mean molecular weight of 44, m_{gas} is,

$$m_{gas} = (23.2/A_v) \times Q(H_2O) \qquad \text{gm/s}$$

which is 13% higher than in the previous case. In the previous case gas production comes out in the range 1–3 $\times$ 10^8 gm/s.

5. Dust production rate

During an apparition of the comet the subliming gases drags away the dust particles embedded in the icy nucleus and it is due to the scattering by these dust grains which gives rise to the continuum emission at optical wavelengths. To find out the dust mass production we make use of the continuum flux. In case of Hale-Bopp we have used flux at 448.0 nm.

Assuming dust grains are roughly spherical we have for a dust mass production rate

$$m_d = \int_{a_0}^{a_m} (4\pi/3)a^3 \, \rho(a) \, n(a)da \qquad \text{gm/s}$$

where 'a' is the radius of the grain that lies between $a_0 = 0.1 \times 10^{-4}$ cm (minimum grain size) and maximum grain size (a_m). a_m is the maximum grain size which can be lifted from the nucleus against the drag forces. $\rho(a)$ is grain's density and n(a) is a distribution function defined by Newburn and Spinard (1985) as :

$$\rho(a) = 3000 - 2200 \, (a/(a+2 \times 10^{-6})) \text{ Kg/m}^3$$

$$n(a) = K(1 - a_0/a)^M \, (a_0/a)^N \text{ cm}^{-1}\text{s}^{-1}$$

The parameters M and N are the maximum in the distribution function and the slope of the function at large value of a, respectively. We have taken N = 4.2 and M = 14 (de Freites Pacheco et al. (1988). K is a normalization constant given as

$$K = 2A_p(\lambda)/(s\pi^2 p_g(\lambda)) \left[\int_{a0}^{a_m} (a^2/V(a)) \times (1-a_0/a)^M \, (a_0/a)^N \, da\right]^{-1} \qquad \text{cm/s}$$

where $p_g(\lambda)$ is the geometric albedo of grains. s is comets radius as viewed through 3mm diaphragm at telescope. focus. $A_p(\lambda)$ is the area-geometric albedo product, given as

$$A_p(\lambda) = r_h^2 \pi \Delta^2 f_{cont}(\lambda)/(\phi(\theta)\ f_{\odot}\ (\lambda)) \qquad cm^2$$

where f_{cont} (λ), $f_{\odot}(\lambda)$, $\phi(\theta)$ and Δ are, respectively the cometary continuum flux at wavelength λ, solar flux at wavelength λ, scattering function at phase angle θ and geocentric distance of the comet. For the determination of the grains velocity we have followed Newburn and Spinard(1985). For $\phi(\theta)$ we have used Divine (1981).

The dust production rate thus comes out in the range 1-2 $\times$ 10^9 gm/s.

6. Discussions

Analysis of CN and C_2 observed fluxes using Haser Model (1957) shows that Q(CN) and Q(C_2) decrease with increase of heliocentric distance. It is clear from Table 2 that C_2 is more abundant than CN. This shows that the comet belongs to the family of normal comets (Cochran, 1987). Table 2 also shows that the dust mass production rates and gas mass production rates, both decrease with increase of heliocentric distances. As is clear from the Table 2, on 27th February, there is a sudden rise in dust production rate. It seems there has been an outburst which caused the sudden rise in dust production rate (Delsemme, 1982). Further Fig. 1 shows that CN production rates are strongly correlated with C_2 production rates suggesting that C_2 and CN production rates scale do not vary differently with heliocentric distances. It is interesting to note that Haser Model production rates of CN and C_2 as obtained by Farnham and Schleicher (1997) using narrow band photometry also lie on the same correlation line.

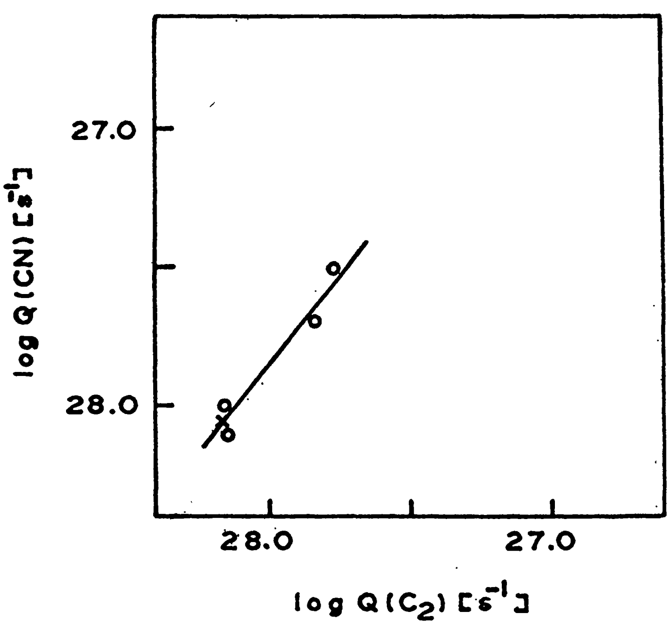

Figure 1. CN and C production rates correlation. Open circle denotes our observations and cross denotes the observation of Farnham and Schleicher (1997).

The determination of the dust mass production rates from continuum fluxes observed at wavelength 484.0 nm is based on the assumption that the nucleus is spherical having a diameter of about 40 km and its 50% of the total spherical surface area is active. We have assumed a value of $pg(\lambda) = 0.05$. Smaller the geometric albedo of the grain higher will be the dust required to get the same amount of continuum flux. Since continuum is manifestation of dust and in case of Hale Bopp we are measuring higher continuum flux at 484 nm, we therefore, expect the comet to be dusty.

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