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Radio Search for Formaldehyde in Comet Bennett (1969i)

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A search was conducted for the $1_{1,1}-1_{1,0}$ rotational transition of formaldehyde and the H 109 α recombination line in comet Bennett during its perihelion passage. Probably due to excessive beam dilution, neither one of these lines could be identified with the NRAO 140-ft telescope.

THE suspected mother molecules of the radicals observed in comets have never been detected directly. Radio astronomy provides a modern tool to search for these molecules.

Comet Bennett (1969i) was a "young" comet, presumably with an undepleted supply of the icy component and with a favorable observing position (elongation about 32°) during perihelion. The angle of culmination on the day of perihelion, March 20, was about 37° at Green Bank. A reasonably large gas production had been expected (reduced brightness $m_0 \approx 5$), but a large dust-to-gas ratio has been reported.

Although formaldehyde (H₂CO) is not expected to be one of the more abundant constituents of a comet, this molecule has a large transition probability for the $1_{1,1}-1_{1,0}$ rotational line at 4829.7 MHz. Formaldehyde had recently been detected in interstellar space (Snyder *et al.* 1969), thus raising the speculation that it also may be present in a comet. The transition is one of the strongest to be expected in the wavelength region $\lambda > 1.7$ cm (Huebner 1970). A search for this line was undertaken at Green Bank, West Virginia, 15 March through 20 March 1970.

Observations were made with the NRAO (operated by Associated Universities, Inc., under contract with the National Science Foundation) 140-ft telescope, equipped with a cooled AIL parametric amplifier and the NRAO 413-channel autocorrelation receiver. The radiometer was operated with frequency switching in the first local oscillator. The half-power beamwidth of

the antenna at $\lambda = 6.2$ cm was about 6.6 arc min, and the beam efficiency was $\eta_B \approx 0.8$.

The observational data is summarized in Table I. Because of the availability of equipment, a brief search for the H 109 α recombination line at 5008.9 MHz was undertaken on 16 March. However, since the data is very limited, the results reported in Table I are not analyzed further. The comet was observed with individual scans lasting up to 45 minutes. The first three columns in Table I list the observation dates, spectral transition, and total integration times, respectively.

The fourth column in Table I gives $\Delta\nu_s$, the frequency range searched on either side of the Doppler-shifted line; the fifth gives the effective spectral resolution; the sixth the appropriately adjusted system temperature; and the last column gives the peak-to-peak temperature obtained from 5 times the rms fluctuation. In addition to the observations listed in Table I, scans off source

TABLE I. Observational data.

Date March	Transi- tion	Total integration time (sec)	$\Delta\nu_s$ (kHz)	Spectral resolution (kHz)	T_S (°K)	T_P (°K)
15 ^a , 17 18, 19	H ₂ CO $1_{1,1}-1_{1,0}$	15850	± 280	1.97	110	0.30
16	H 109 α	2580	± 560	3.94	150	0.72
20	H ₂ CO $1_{1,1}-1_{1,0}$	7500	± 140	0.985	110	0.62

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^a System temperature $T_S = 150^\circ\text{K}$ on this date, integration time adjusted accordingly.

from the comet were made to check for spurious and inherent signals.

The frequency dependence of the dissociation cross section, and therefore the lifetime of the molecule under the influence of the sun's radiation, is not known. However, the dissociation energy of H_2CO is comparable to that of CH and NH, from which one may conclude that formaldehyde should reach a distance of $\sim 10^4$ km from the nucleus before it is destroyed. Thus at a geocentric distance of the comet $\Delta \approx 0.7$ a.u., the diameter of the H_2CO region would subtend an angle of somewhat less than 1 arc min.

If v is the velocity with which the molecules move radially outward from the center and τ_0 is their lifetime, then $r_0 = v\tau_0$ is the distance from the nucleus at which the molecules are destroyed. Assuming that the particle density at a distance r from the center is $Q/(vr^2)$ and that the destruction of the molecules occurs suddenly and completely at $r = r_0$, then the particle column density at a distance ρ from the center is

$$\mathfrak{N} = \int_{-\ell}^{\ell} \frac{bQ}{vr^2} d\ell = \frac{2bQ}{v\rho} \cos^{-1} \frac{\rho}{r_0} \quad (\rho \leq r_0). \quad (1)$$

Here Q is the molecular yield from the comet, expressed in number of molecules per unit time and per unit solid angle; b is the relative particle abundance of H_2CO in the gas ($b < 1$); and $\ell = (r^2 - \rho^2)^{1/2}$. For $\rho \geq r_0$, $\mathfrak{N} = 0$.

The average, uniformly smeared out, particle column density in the beam of the antenna is

$$\begin{aligned} \langle \mathfrak{N} \rangle &= \frac{2\pi}{\pi\Delta^2(\theta/2)^2} \int_0^s \mathfrak{N}\rho d\rho \\ &= \frac{16bQ}{v\Delta^2\theta^2} \left[s \cos^{-1} \frac{s}{r_0} - (r_0^2 - s^2)^{1/2} + r_0 \right], \quad (2) \end{aligned}$$

where θ is the total angle at half-power beamwidth and s is the smaller of $\Delta \cdot (\theta/2)$ or r_0 ; Δ is the geocentric distance of the comet. For the limit $s = r_0$, which is of interest for the observations made here,

$$\langle \mathfrak{N} \rangle = \frac{16bQ}{v\Delta^2\theta^2} r_0 \quad (s = r_0). \quad (3)$$

As usual, the antenna temperature is given by

$$T_A = B\eta_B T(1 - e^{-\tau}), \quad (4)$$

where B is the beam dilution factor, η_B the beam efficiency, T the cometary gas temperature—assumed to be in equilibrium with the surface of the icy nucleus—and τ the optical thickness. Two cases are of particular interest in the analysis of the $1_{1,1}-1_{1,0}$ transition of H_2CO in comets:

1. The comet is optically thin with a negligibly small optically thick center. In this case the antenna temperature is given by $T_A = B\eta_B T\bar{\tau}$. The optical depth

for asymmetric top molecules (Townes and Schawlow 1955), frequency averaged over the width at half-amplitude of a line, is

$$\bar{\tau} \approx \frac{4\pi^3 \mathfrak{N} (ABC h^3)^{1/2} \mu^2 S \nu^2}{3c(kT)^{3/2} \Delta \nu} e^{-W/kT}. \quad (5)$$

Here A , B , and C are the rotational constants of the molecule, μ is the dipole moment, S is the strength of the transition, W is the energy of the rotational level, ν is the transition frequency, and $\Delta \nu$ is the half-width at one-half of the maximum of the line. For H_2CO the constants are: $A = 282\,106$ MHz, $B = 38\,834$ MHz, $C = 34\,004$ MHz, $\mu = 2.34 \cdot 10^{-18}$ esu cm, and for the $1_{1,1}-1_{1,0}$ transition $S = 1.5$, $W/k = 15$, and $\nu = 4829.7$ MHz. The beam dilution B can be taken into account in Eq. (5) by using the average column density $\langle \mathfrak{N} \rangle$, as defined in Eq. (2), in place of \mathfrak{N} . Using the H_2CO molecular parameters, the frequency averaged optical depth and the antenna temperature become

$$\bar{\tau} \approx 2.2 \cdot 10^{-11} \frac{\langle \mathfrak{N} \rangle}{T^3} e^{-15/T}, \quad (6)$$

$$T_A \approx 1.8 \cdot 10^{-11} \frac{\langle \mathfrak{N} \rangle}{T^2} e^{-15/T}. \quad (7)$$

2. The comet is optically thick in the line center with a negligible optically thin outer gaseous shell. In that case, the beam dilution factor is

$$B = \left(\frac{S}{\Delta \cdot \theta/2} \right)^2$$

and the antenna temperature is

$$T_A = \eta_B T \left(\frac{S}{\Delta \cdot \theta/2} \right)^2 \quad (S < \Delta \cdot \theta/2), \quad (8)$$

from which S , the radius of the optically thick region, can be determined.

An estimate for b , the fractional number of H_2CO molecules in the cometary gas, is found from

$$b = 5.8 \cdot 10^{13} \frac{ST^{7/2}}{Q \cos^{-1} S/r_0} e^{15/T}, \quad (9)$$

where

$$S = \rho|_{\tau_e=1}, \quad \tau_e = 2\bar{\tau}(\ln 2/\pi)^{1/2}$$

is the peak optical depth at the center of the Doppler-broadened line and a typical value of $v = 2.4 \times 10^3 \sqrt{T}$ cm/sec was assumed.

Table II contains several of the parameters which have been calculated for $T_A = 0.3^\circ\text{K}$, the most favorable peak-to-peak temperature in Table I. Typical values used in the evaluation are $\theta = 1.78 \times 10^{-3}$ rad for $\lambda = 6.2$ cm, $\Delta \approx 0.74$ a.u. near perigee, and $r_h = 0.54$

TABLE II. Parameters for the icy nucleus and for $T_A = 0.3^\circ\text{K}$.

L (kcal per mole)	T ($^\circ\text{K}$)	Z (molecules per $\text{cm}^2 \text{ sec sr}$)	$\langle \mathfrak{N} \rangle$ (molecules per cm^2)	S (cm)
3	63	$5.0 \cdot 10^{18}$	$8.4 \cdot 10^{13}$	$7.6 \cdot 10^8$
4	84	$4.0 \cdot 10^{18}$	$1.4 \cdot 10^{14}$	$6.6 \cdot 10^8$
5	105	$3.0 \cdot 10^{18}$	$2.2 \cdot 10^{14}$	$5.9 \cdot 10^8$
6	126	$2.5 \cdot 10^{18}$	$3.0 \cdot 10^{14}$	$5.4 \cdot 10^8$
7	147	$2.0 \cdot 10^{18}$	$4.0 \cdot 10^{14}$	$5.0 \cdot 10^8$

a.u. at perihelion. The first column in Table II gives the range of the heat of vaporization L which is applicable for the icy nucleus of a "young" comet. In view of the high dust-to-gas ratio reported, the larger of these values of L may be more likely for this comet. The second and third columns list the corresponding values for T and the gas production rate $Z = Q/R^2$, where R is the radius of the cometary nucleus (Huebner 1965).

For $T_A < 0.3^\circ\text{K}$ the values of the projected density, $\langle \mathfrak{N} \rangle$, in column 4 are an upper limit obtained from Eq. (7) for the optically thin case. The last column lists the upper limit of S , the radius of the optically thick region, appropriate for the antenna temperature T_A , as obtained from Eq. (8).

If $R = 10^6$ cm and $r_0 = 10^9$ cm—which are typical values in order of magnitude—one finds, from Eq. (3), an upper limit on the relative H_2CO abundance ranging from $b \cong 0.01$ to 0.15 for $L = 3$ to 7 kcal/mole in the optically thin case. However, at $b = 0.15$ the optically thick central region is no longer negligible since it approaches the value of S listed in the last column of Table II. The optically thin case, as mentioned earlier, involves a smearing out of the particle column density over the entire area subtended by the antenna angle and loses its significance for excessive beam dilution, i.e., for

$\Delta \cdot (\theta/2) \gg r_0$. For the same values of R and r_0 , the abundance in the optically thick case would range from $b \approx 0.03$ to 0.59 for $L = 3$ to 7 kcal/mole.

The negative result of our comet observations is probably due to the large beam dilution, the high dust-to-gas ratio, and the absence of the enhancement of emission through solar radiation. The effective beam dilution could be reduced by observing comets with smaller perigee (< 0.2 a.u.), by using a radio telescope with larger diameter, or by searching for other favorable molecular transitions at higher radio frequencies. Our calculations indicate that it should be possible to detect fairly low molecular abundances in a comet if the beam dilution problem can be eliminated.

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