Submillimeter wavelength molecular spectroscopy of the Orion molecular cloud

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SUBMILLIMETER WAVELENGTH MOLECULAR SPECTROSCOPY OF THE ORION MOLECULAR CLOUD

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ABSTRACT

A submillimeter wavelength spectroscopic study of the Orion molecular cloud has been made in the $J = 4$–3 HCN, $H^{13}CN$, HCO^+, $H^{13}CO^+$, and $J = 7$–6 CS molecular transitions. Densities of up to a few times 10^6 cm^{-3} are found coupled with high inferred brightness temperatures, indicating kinetic temperatures of 120 K. Evidence for lower densities in the surrounding ambient molecular cloud is presented along with maps of HCN and HCO^+ emission. The maps indicate different spatial distributions in the two lines. The abundances of HCN and HCO^+ in the plateau source are found to be enhanced relative to those in the surrounding molecular cloud, and there is a suggestion that a number of small-angular-diameter clumps may be present. The present observations do not confirm the previously reported detection of CO^+ in the interstellar medium.

Subject headings: interstellar: molecules — nebulae: abundances — nebulae: Orion Nebula

I. INTRODUCTION

The region of the Orion molecular cloud is one of considerable complexity, manifesting a wide range of physical processes and conditions. In particular, the core is the site of massive star formation which appears associated with considerable dynamical activity. The presence of high-velocity gas in the core, extending over a radial velocity range of 150 km s^{-1}, was first noted by Zuckerman, Kuiper, and Rodriguez-Kuiper (1976) and has since been observed in a number of molecular lines by numerous authors. The high-velocity emission is known to be spatially compact and centered about 10″ northeast of the infrared source IRC 2. Erickson *et al.* (1982), using the 26″ beam of the Multiple Mirror Telescope at the CO $J = 3$–2 line frequency, were able to establish that the high-velocity material is in the form of a bipolar outflow with its axis aligned with the two maxima of the 2 μm H_2 emission detected by Gautier *et al.* (1976) and Beckwith *et al.* (1978).

Several studies of the physical conditions in the outflow and surrounding matter have been carried out using molecular lines with various excitation properties (e.g., Huggins *et al.* 1979; Plambeck, Snell, and Loren 1983; Richardson *et al.* 1985). These studies indicate the presence of dense molecular gas with $n_{H_2} > 10^5$ cm^{-3}. At these densities, the well-studied three lowest CO lines are all essentially thermalized and, hence, not well suited as density probes. Fortunately, the Orion outflow and core region is a strong source of emission from molecules such as HCN and HCO^+ which, by virtue of their large dipole moments, are much less susceptible to thermalization.

In this paper we report observations of the $J = 4$–3 transitions of HCN, HCO^+, and the $J = 7$–6 transition of CS in the Orion molecular cloud. These submillimeter line results are combined with published lower excitation transitions of HCN and HCO^+ to model the density and temperature conditions in this region.

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II. THE OBSERVATIONS

The observations were obtained using the 3.8 m United Kingdom Infrared Telescope (UKIRT) situated at Mauna Kea, Hawaii, during the period 1982 November 29–December 7. The Queen Mary College submillimeter spectral line receiver (White, Phillips, and Watt 1981) was mounted at the f/9 focus of the telescope. System noise temperatures, including all optics and losses, were measured to be typically 400–500 K (equivalent to SSB noise temperature), for a perfect antenna above the atmosphere. Calibration was performed at 15–30 minute intervals using a rotating chopper vane. This technique is well suited for observations at submillimeter wavelengths, where the dominant atmospheric absorber is water vapor. The beam size was measured to be 55 ± 3″, from observations of Saturn. All observations are calibrated in terms of T_R^* (Kutner and Ulich 1981, where η_{fss} in our case was determined to be 0.88). Calculation and measurements of the feed and antenna patterns were made to determine the coupling efficiency η_c as a function of source size.

Using this coupling factor, it becomes possible to estimate the true radiation temperature T_R from the relationship $T_R = T_R^*/\eta_c$, if the source brightness distribution is known (Richardson *et al.* 1985).

The pointing of UKIRT was estimated to have an rms error of about 5″. The observations of the Orion molecular cloud were obtained toward the position R.A. (1950) = $05^h32^m46^s.8$, decl. (1950) = −05°24′17″ [referred to as the (0, 0) position hereafter], unless otherwise stated. Observations of the CO $J = 3$–2 transition (345.79598 GHz) show the line to have $T_R^* = 82$ K at the (0, 0) position, in close agreement with previously reported observations of Orion in this transition (Phillips, White, and Watt 1982; Erickson *et al.* 1982; Richardson *et al.* 1985). Measurements obtained of the Orion CO $J = 3$–2 profile since 1979 with two different receiver systems have consistently given chopper-calibrated intensities which agree to within ±5%. The absolute calibration is believed to be good to ±15%.

In Table 1, a list is given of the lines observed during this study and their rest frequencies.

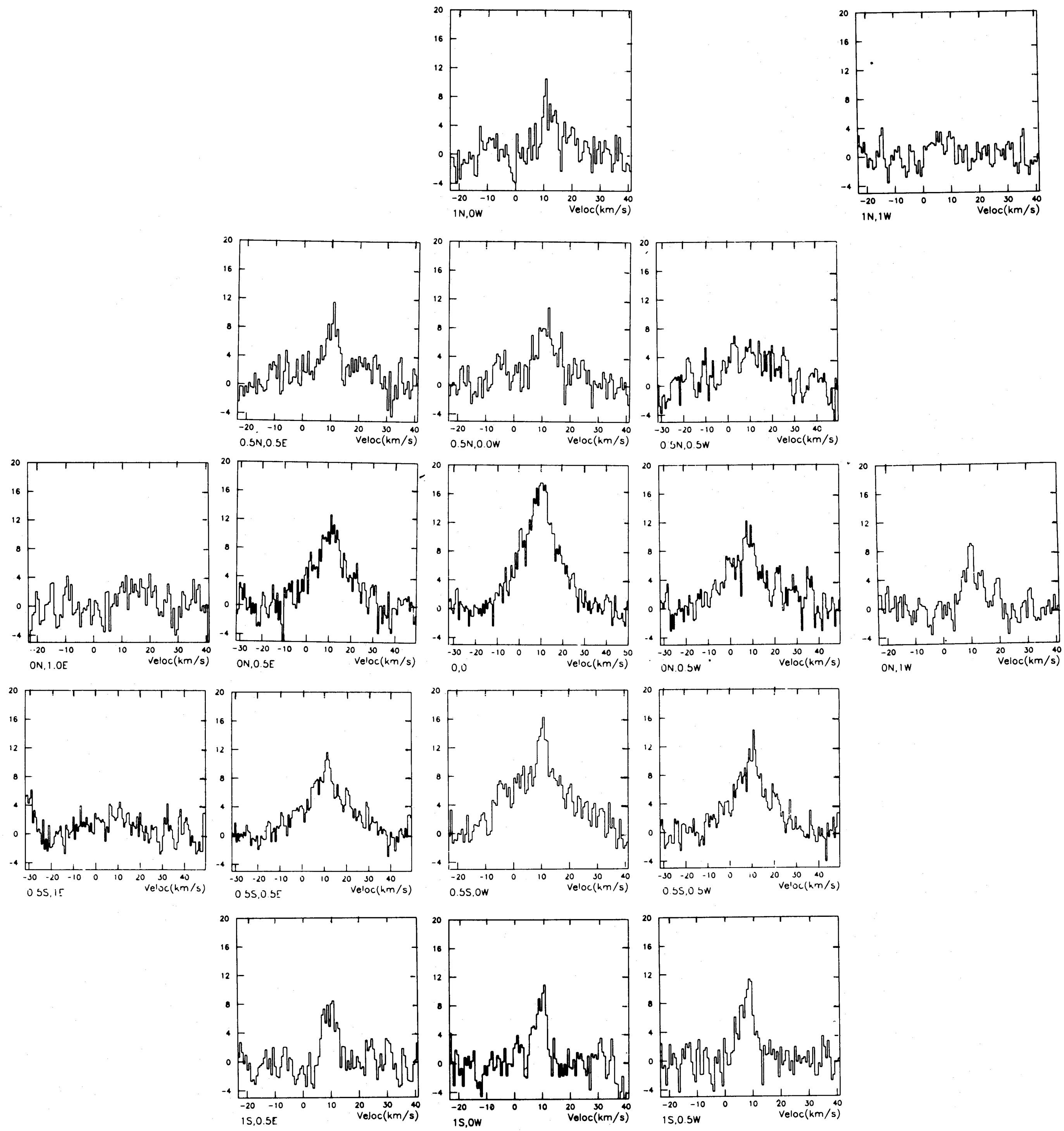

FIG. 1.—HCN $J = 4$–3 spectra obtained toward the Orion high-velocity molecular flow. The panels are separated by 30″ steps. The vertical scales are units of T_R^* (K).

TABLE 1

MOLECULAR LINE REST FREQUENCIES

Molecular Species	Transition	Frequency (GHz)
CS	$J = 7\text{–}6$	342.88327
$H^{13}CN$	$J = 4\text{–}3$	345.33976
CO................	$J = 3\text{–}2$	345.79598
$H^{13}CO^+$	$J = 4\text{–}3$	346.99869
CO^+	$N = 3\text{–}2,\ J = 7/2\text{–}5/2$	354.014247
HCN	$J = 4\text{–}3$	354.50547
HCO^+	$J = 4\text{–}3$	356.73429

III. RESULTS AND DISCUSSION

a) HNC

In Figure 1, HCN spectra are shown for 17 positions around the "plateau" (broad-velocity) source. Toward the (0, 0) position (*central panel*), a broad line with $T_R^* = 18.1$ K is observed, having a full width at half-maximum (FWHM) of 30 km s^{-1}, and full width at the 1 K level of 55 km s^{-1}. To the south, the line exhibits a narrow "spike" component, of FWHM 5 km s^{-1}, which appears on top of the broader plateau emission. This spike emission originates in the ambient molecular cloud. The HCN plateau source is unresolved by the telescope beam, whereas the spike component extends beyond the present map boundaries, particularly in the north-south direction.

In Figure 2, the integrated line emission is shown binned into 5.2 km s^{-1} velocity intervals. The angular resolution and signal-to-noise ratio of the present data are inadequate to detect the bipolar nature of the outflow, as indicated by observations of CO and HCO^+ (Phillips, White, and Watt 1982; Erickson *et al.* 1982; Olofsson *et al.* 1982). The velocity centroid of the $J = 4\text{–}3$ HCN pedestal at the (0, 0) position is $V_{LSR} = 10$ km s^{-1}, close to that for the lower HCN transitions (Rydbeck *et al.* 1981; Erickson *et al.* 1980; Padman *et al.* 1980).

Figure 3 shows the spectrum of the $J = 4\text{–}3$ $H^{13}CN$ transition taken at the (0, 0) position. This has the appearance of being almost wholly due to emission from the plateau source, no prominent spike component being visible. The line is symmetrical, with peak $T_R^* = 6.8$ K, FWHM = 22 km s^{-1}, and a full width at the 1 K level of 50 km s^{-1}. We note that the peak velocity of the $H^{13}CN$ line is at a velocity of 11.5 km s^{-1}, consistent with the HCN velocity reported earlier, given the high noise levels.

Welch *et al.* (1981) have measured the size of the HCN plateau emitting region to be approximately 15″ × 20″. Correcting our measured peak plateau temperatures for the coupling of the UKIRT beam to a Gaussian-shaped source of this size ($\eta_c = 0.09$), we estimate T_R, the true brightness temperature, to be 120 and 45 K for the $J = 4\text{–}3$ HCN and $H^{13}CN$ lines respectively. The derived brightness temperature is similar to that estimated for the SO_2 plateau source, and the average dust temperature in the center of the nebula (Schloerb *et al.* 1983; Werner 1977).

In order to estimate the properties of the HCN excitation in the plateau source, a large velocity gradient (LVG) calculation was made for a source with a kinetic temperature of 120 K. A best-fit solution was sought which was consistent with the observed HCN and $H^{13}CN$ $J = 1\text{–}0$ and $J = 4\text{–}3$ transitions. The results of these calculations are illustrated in Figure 4. The $J = 1\text{–}0$ and the $J = 4\text{–}3$ data for the intergrated emission have been modeled using the LVG technique, and a best-fit solution was found having an HCN abundance per unit velocity gradient $X/(dV/dR) = 5 \times 10^{-10}$ km^{-1} s pc and $n_{H_2} = 2.2 \times 10^6$ cm^{-3}. An uncertainty of $\pm 30\%$ in the calibrations of the various spectra results in an uncertainty of less than a factor of 2 for the best-fit solution. The observed ratio of integrated emission in the HCN and $H^{13}CN$ lines was 2.4. These results refer to the *integrated plateau emission*, and are based on the assumptions that the isotopic abundance ratio of HCN/$H^{13}CN$ is 40 and the $J = 1\text{–}0$ and 4–3 lines originate in the same volume of gas. Since the plateau and spike features are blended together, we have been unable to remove the contribution of the spike component; however, it represents only a small fraction of the integrated plateau emission. The best-fit values are in close agreement with those determined by Huggins *et al.* (1979) from HCN $J = 3\text{–}2$ observations.

In addition to the integrated emission, it is of interest to

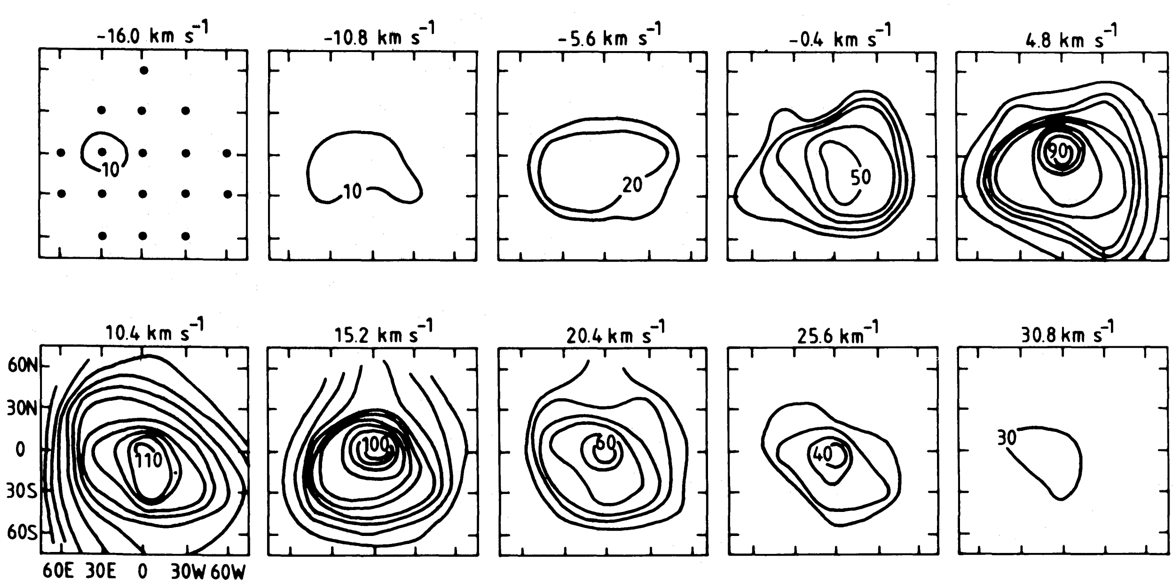

FIG. 2.—Integrated corrected antenna temperature in the HCN $J = 4\text{–}3$ transition in Orion, binned in 5.2 km s^{-1} intervals

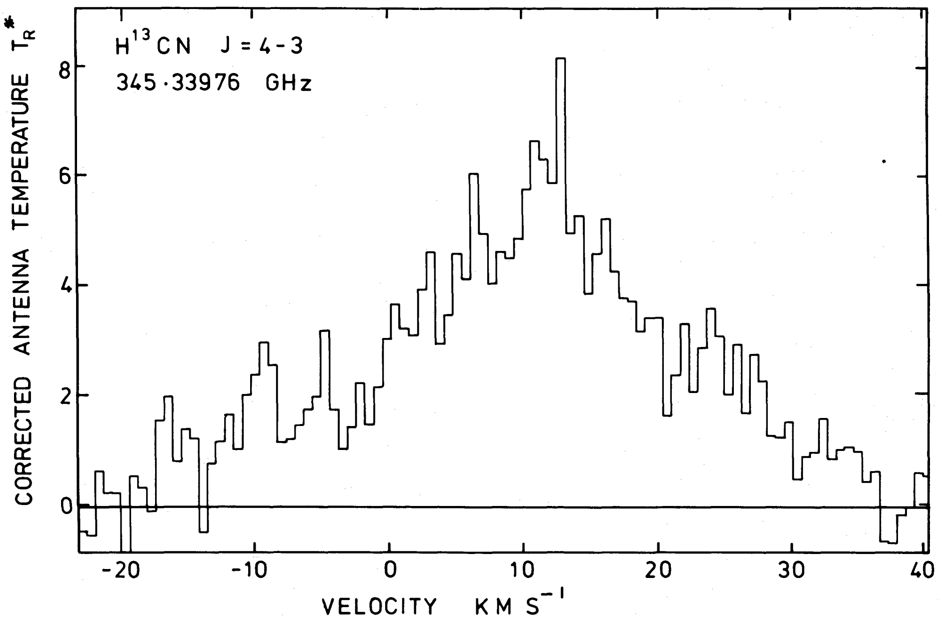

FIG. 3.—$H^{13}CN$ $J = 4$–3 spectrum obtained toward the Orion high-velocity molecular flow

consider the flow properties at different velocities. In Figure 5, the ratio of $J = 4$–3 HCN and $H^{13}CN$ spectra obtained with similar velocity resolution, pointing position, and atmospheric conditions is shown. The ratio of $HCN/H^{13}CN$ antenna temperatures near the line center is 2.5, whereas, toward the edges

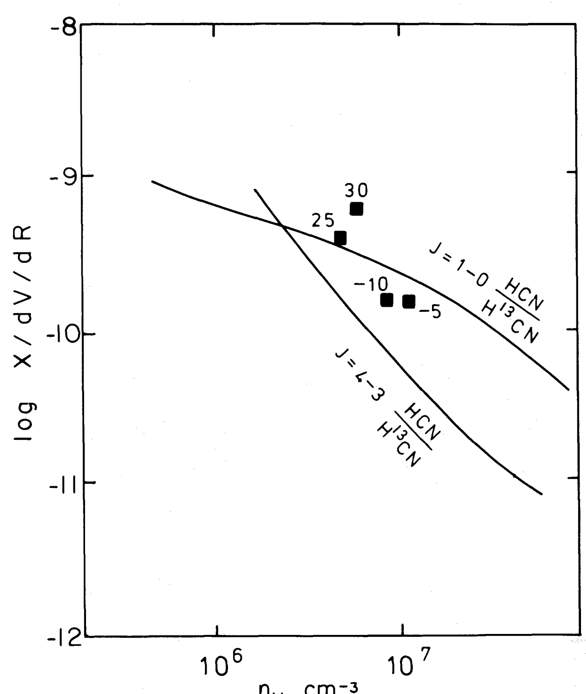

FIG. 4.—$HCN/H^{13}CN$ brightness temperature ratios for the plateau component in the $J = 1$–0 and 4–3 transitions overlaid on an n_{H_2} vs. $X/(dV/dR)$ grid, calculated using an LVG code for a kinetic temperature of 120 K. The $J = 1$–0 data are from Rydbeck *et al.* (1981). The solid curves correspond to the integrated plateau emission, the four points to emission at discrete velocities. See text. The corrected values of T_R were taken to be 120 K and 23 K for the $J = 1$–0 HCN and $H^{13}CN$ transitions.

of the line, this ratio *decreases* slightly before disappearing into the noise, suggesting both HCN and $H^{13}CN$ to be optically thick within ± 20 km s^{-1} of the line center. Emission in the four velocity intervals of width ± 2.5 km s^{-1}, centered at V_{LSR} of $+30$, $+25$, -5, and -10 km s^{-1} was examined and compared with the Onsala $J = 1$–0 data. LVG analysis of these velocity ranges gave estimates for $X/(dV/dR)$ and n_{H_2} of 5×10^{-10} km^{-1} s pc and 5×10^6 cm^{-3} respectively for the red wing, and 1.6×10^{-10} km^{-1} s pc and 9.5×10^6 cm^{-3} for the blue wing. These latter estimates refer to the *high-velocity gas*, as opposed to the integrated plateau emission, and are illustrated in Figure 4 where the points indicated show the positions of intersection of the $J = 1$–0 and 4–3 isotopic ratio loci. We note that these measurements of isotopic ratios should produce estimates of the excitation conditions which are much less dependent on the absolute calibrations than the results based on absolute line strengths of different J-transition data, since they rely on comparison of the individual $J = 1$–0 and $J = 4$–3 *ratios* of $HCN/H^{13}CN$ determined using similar telescope properties (such as beam size, error pattern, coupling factor, etc) for each J-transition. The estimates from the LVG fitting imply opacities of 1–3 for the $J = 4$–3 $H^{13}CN$ line-averaged over the plateau and suggest that HCN is optically thick and thermalized at the cloud kinetic temperature.

Assuming the high-velocity source to lie at the front edge of the ambient Orion A cloud, the high opacity of the plateau source will render estimates of T_R^* for the ambient cloud somewhat uncertain toward the 0, 0 position. We have therefore taken the average T_R^* for the spike feature at positions 60″ north, south, and west (where the spike feature is not contaminated by plateau emission, to the noise level) to obtain a first-order estimate of T_R^* for the 1–0 and 4–3 transitions in the ambient (spike) cloud within 1′ of the (0, 0) position. We estimate T_R^* (spike) = 8 K for the $J = 4$–3 transition. After correction for coupling of the Onsala, MWO, and UKIRT beams to a 2′ diameter source, a series of LVG calculations was made for the Onsala $J = 1$–0 data, MWO $J = 3$–2 data of Erickson *et al.* (1980), and the present $J = 4$–3 data. A good fit is found to

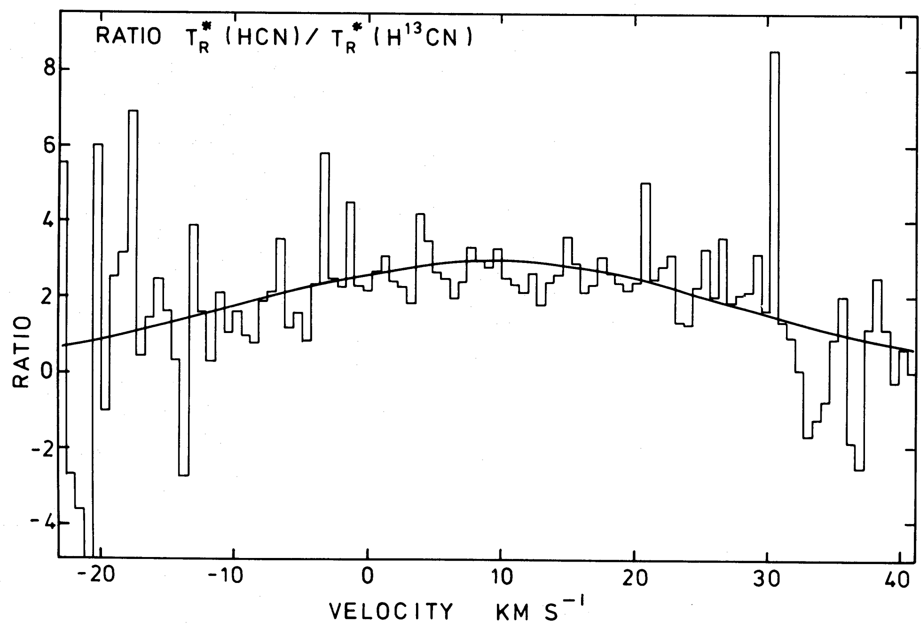

FIG. 5.—Corrected antenna temperature ratio of $J = 4\text{–}3$ HCN/H^{13}CN, superposed on an unconstrained Gaussian fit

the data for a model having kinetic temperature of ~ 100 K, $X/(dV/dR) = 1.6 \times 10^{-10}$ km^{-1} s pc, and $n_{H_2} = 2.5 \times 10^5$ cm^{-3}, similar to estimates of Huggins *et al.* (1979) and Padman *et al.* (1980). The results of these calculations are illustrated in Figure 6. In this example it is seen that the brightness temperature curves on the $X/(dV/dR)$ versus n_{H_2} plane are all very similar, and therefore any estimates derived are dependent on a knowledge of the [HCN]/[H^{13}CN] ratio.

For this case, the HCN $J = 4\text{–}3$ emission is optically thick with $\tau \approx 10$. For the above model calculations, the excitation temperature of the $J = 4\text{–}3$ HCN line is estimated to be 22 K. The failure of the inferred brightness temperature values to approach the cloud kinetic temperatures may again be indicative of small-scale structure or inhomogeneities which only partly fill the telescope beam, with a dilution factor $W \approx 0.2$, or alternatively, if $W = 1.0$, that the density is not high enough to thermalize the transition. It is not possible at the moment to choose between these two models until we can be more certain as to whether the HCN is clumped significantly. We emphasize that the estimates derived here are approximate, since it has

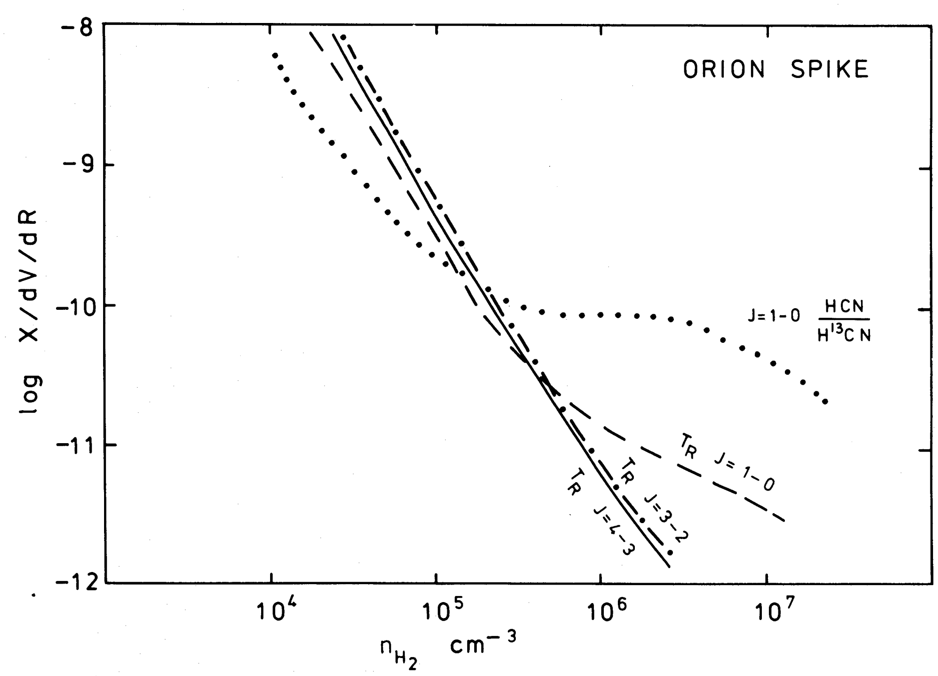

FIG. 6.—HCN brightness temperatures and ratios for the ambient cloud, corrected for source size and telescope coupling overlaid on an n_{H_2} vs. $X/(dV/dR)$ grid, calculated using an LVG code for a kinetic temperature of 120 K. The corrected values of T_R were calculated for a 2′ diameter source to be 17 K, 16 K, and 9 K for the $J = 1\text{–}0$ (Onsala), $J = 3\text{–}2$ (Texas), and $J = 4\text{–}3$ (this work) lines.

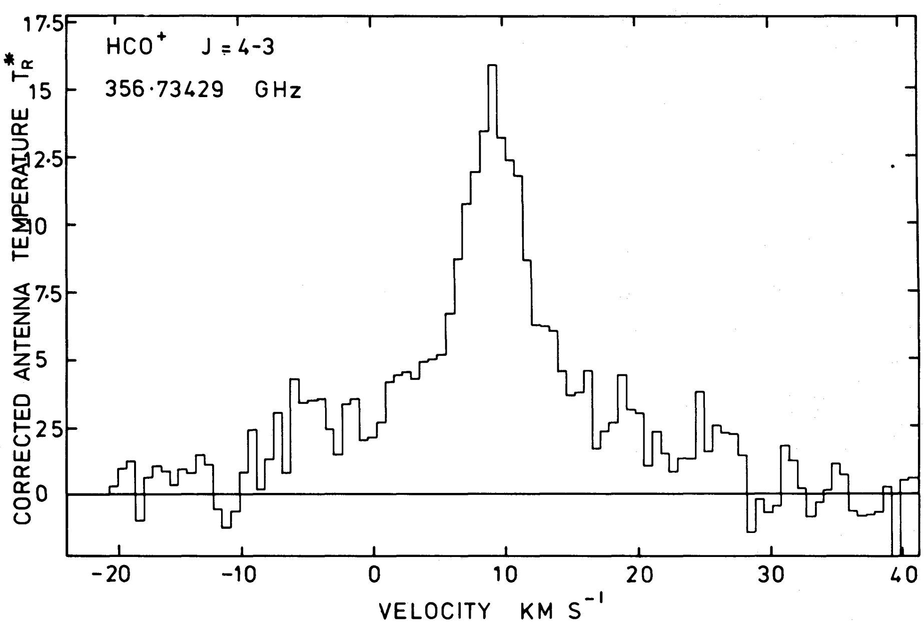

FIG. 7.—HCO^+ $J = 4$–3 spectrum observed toward the (0, 0) position

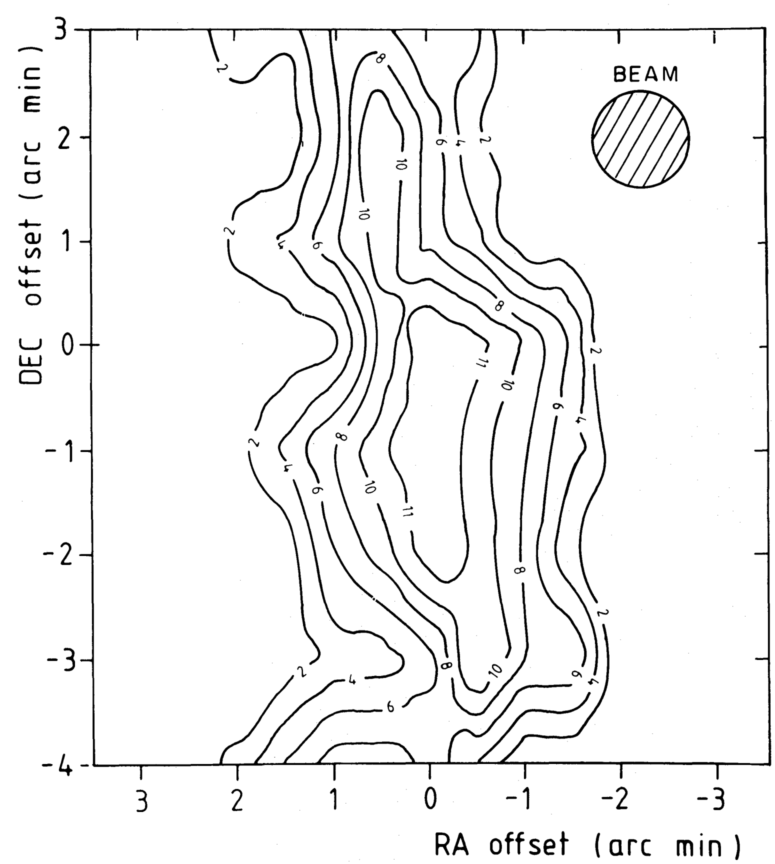

FIG. 8.—Intensity maps of HCO^+ $J = 4$–3 in Orion. The data are in terms of T_R in a single velocity channel of width 1.3 km s^{-1} centered at 9.0 km s^{-1} sampled at half-beam width spacings.

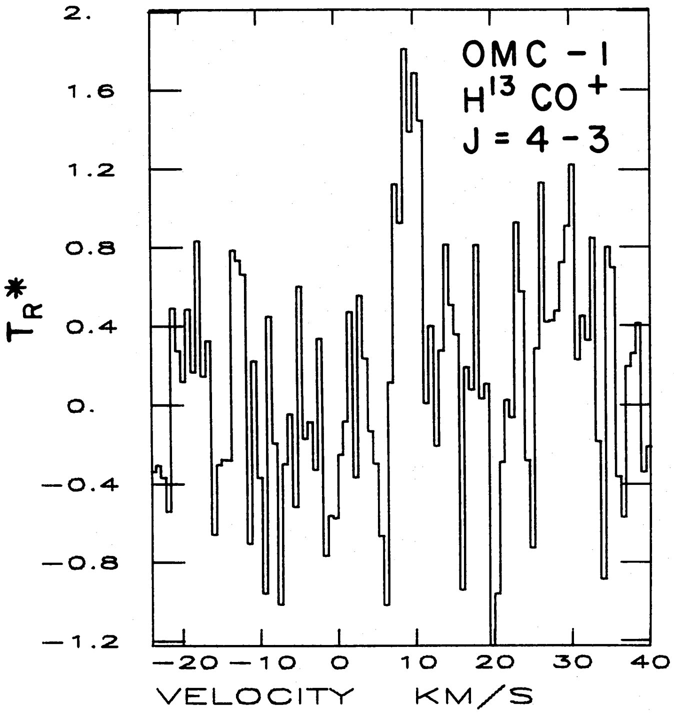

FIG. 9.—Spectrum of the $H^{13}CO^+$ $J = 4$–3 transitions toward the (0, 0) position. These data were obtained with 0.65 km s^{-1} velocity resolution.

been necessary to use positions lying close to the cloud core which are relatively uncontaminated by plateau emission. Thus, it appears that X(HCN) in the plateau may be 3 times X(HCN) in the spike region—however, this ratio is dependent on spatial structure in the source distribution. [See *Note added in manuscript.*]

b) HCO^+

The $J = 4$–3 HCO^+ transition has been observed toward the (0, 0) position. The spectrum, shown in Figure 7, shows clearly both the spike and plateau components. The plateau is fitted by a Gaussian profile of intensity $T_R^* = 4.5$ K and FWHM = 25 km s^{-1} centered at 9 km s^{-1}. Emission extends over a velocity range of 35 km s^{-1}. The spike component has a peak $T_R^* = 16.2$ K centered at $V_{LSR} = +8.2$ km s^{-1} and with FWHM = 6.4 km s^{-1}.

In Figure 8, a map is shown of the spatial distribution of HCO^+ emission for $7.25 < V_{LSR} < 8.75$ km s^{-1} observed with half-beam spacings. The north-south ridge, which is seen in many molecular lines as well as the lower HCO^+ transitions, is prominent in the map. The northern section of the ridge is coincident with the area reported from MWO $J = 3$–2 observations by Erickson *et al.* (1980), which shows a high ratio for T_R ($J = 3$–$2/J = 1$–0), suggesting the presence of extremely high densities. Our mapping also finds that the $J = 4$–3 emission is strong in the same area of the ridge to the north of the (0, 0) position, as indicated by the $J = 3$–2 observations. A more detailed mapping of this area of the ridge is urgently required to elucidate its nature and to confirm these suggested high densities.

Inspection of the velocity-position maps for the $J = 1$–0 HCO^+ transition (Olofsson *et al.* 1982) indicates that a suitable choice for the HCO^+ source size would be a Gaussian of FWHM ≈ 100″ in the north-south direction, and an east-west extension of ≤30″, centered about 50″ north of the Kleinmann-Low position. (However, as seen in the data of Vogel *et al.* 1984, the HCO^+ distribution is considerably more complex.) Applying appropriate coupling corrections to the Onsala $J = 1$–0, MWO $J = 3$–2, and UKIRT $J = 4$–3 data for this brightness distribution, we estimate values of $X/(dV/dR) = 1.6 \times 10^{-12}$ km^{-1} s pc and $n_{H_2} = 7.9 \times 10^5$ cm^{-3}, for a kinetic temperature of 120 K. It should be noted that this analysis assumes the value of the dipole moment of HCO^+ to be 4.07 debyes (Haese and Woods 1979). Most previous analyses have used an earlier value of $\mu = 3.30$. These results imply a moderate opacity of 0.7 for the $J = 3$–2 and 4–3 transitions in the plateau. Assuming $V/R \approx 500$ km s^{-1} pc^{-1} in this region, we estimate the abundance $X(HCO^+)$ in the plateau to be 8×10^{-10}. This value is at the high end of the values in other warm-centered molecular clouds of 10^{-11} (Wootten, Snell, and Evans 1980), although lower than the estimate by Vogel *et al.* (1984) of more than 10^{-8}. In view of the complexity of the spatial structure of the region, these discrepancies may reflect the inability of a simple LVG model to adequately describe the geometry; and, at least in this case, the modeling technique adopted here may have been too simplistic. In particular, the applicability of $V/R = 500$ km s^{-1} pc^{-1} is questionable.

In Figure 9, a spectrum of the $J = 4$–3 $H^{13}CO^+$ transition is shown. For the frequencies listed in Table 1, the velocity of the $H^{13}CO^+$ line is +8.6 km s^{-1}. We do not detect emission from the nearby $J = 5_{14}$–4_{13} $H_2C^{18}O$ line (which would occur in the channel corresponding to 20 km s^{-1} on the $H^{13}CO^+$ spectrum) to an upper limit of $T_R^* < 1$ K. The $H^{13}CO^+$ line appears as a single component of width 3.4 km s^{-1}, no emission from the plateau being observed with the present signal-to-noise ratio.

We have modeled the HCO^+ spike component taking account of the antenna beam coupling onto the more extended cloud and the effects of opacity in the plateau source which has been assumed to lie at the front edge of the extended cloud (Phillips *et al.* 1977). These calculations show, for a source size 2′ or more, a fit to data with $X/(dV/dR) = 2.2 \times 10^{-11}$ km^{-1} s pc and $n_{H_2} \approx 6.3 \times 10^5$ cm^{-3}, where we have compared the present data with published Onsala $J = 1$–0 (Olofsson *et al.* 1982) and MWO $J = 3$–2 (Erickson *et al.* 1980) data corrected in a similar way. Assuming a value of $V/R = 5$ km s^{-1} pc^{-1} (Huggins *et al.* 1979), we estimate $X(HCO^+)$ to be 1.1×10^{-10}. This value just lies within the spread of values observed for warm molecular clouds by Wootten, Snell, and Evans (1980) and is a factor of ~8 less than that estimated for the plateau. In this case the line is optically thick, with $\tau \approx 3$–5 in the $J = 3$–2 and 4–3 lines. These calculations confirm the previous estimate of Huggins *et al.* (1979) from an independent set of NRAO 11 m ($J = 1$–0) and Palomar 5 m ($J = 3$–2) observations (which were not used in the present analysis). In Figure 10 we show the fit for various data obtained from our LVG calculation.

c) CS

We detected the $J = 7$–6 transition of CS toward the central (0, 0) position. The resulting spectrum is shown in Figure 11. No strong evidence for emission from the plateau source is seen above $T_R^* = 2$ K, despite the fact that characteristic broad-line emission is clearly visible in the data of Thronson and Lada (1984). For the observed CS $J = 7$–6 line, $T_R^* = 7.8$ K at $V_{LSR} = +10.1$ km s^{-1} and FWHM = 7.0 km s^{-1}.

The spatial structure of the CS source emitting region is

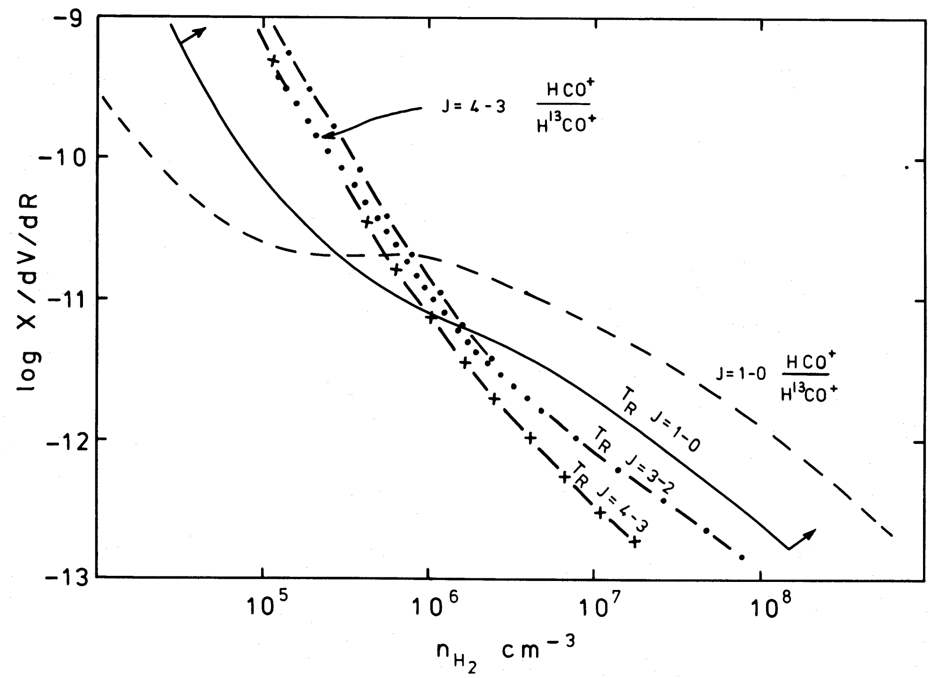

FIG. 10.—HCO^+ data corrected for source size and telescope coupling overlaid on an n_{H_2} vs. $X/(dV/dR)$ grid, calculated for a kinetic temperature of 120 K. The $J = 4$–3 observations are from this study, the $J = 1$–0 and $J = 3$–2 data are from Olofsson *et al.* (1982) and Erickson *et al.* (1980). The values of T_R corrected to a 2′ diameter source are 16 K, 46 K, and 24 K for the HCO^+ $J = 1$–0, 3–2, and 4–3 lines. The ratio of peak T_R values, $T_R(HCO^+)/T_R(H^{13}CO^+)$, was taken to be 28.0 and 10.8 respectively for the $J = 1$–0 and 4–3 lines.

complex and has been discussed by Goldsmith *et al.* (1980). In addition to a local condensation at the Kleinmann-Low position, they have detected an elongated north-south ridge, with structure variations on a size scale 10″ or less. We have modeled the data for the $J = 1$–0, 2–1, 5–4, and 7–6 transitions obtained with similar telescope beam sizes (Goldsmith *et al.* 1980; White *et al.* 1983; this paper) using an LVG calculation for an assumed kinetic temperature of 100 K. A fit was found for $X/(dV/dR) = 5 \times 10^{-10}$ km^{-1} s pc and $n_{H_2} = 1.6 \times 10^5$ cm^{-3}. (We assume T_R to be 9 K for the $J = 5$–4 and 7–6 transitions and have adopted the $J = 2$–$1/J = 1$–0 ratios given in Linke and Goldsmith 1980). These results are relatively insensitive to the kinetic temperature; a similar model run for $T_k = 75$ K gave $X/(dV/dR) = 5.6 \times 10^{-10}$ km^{-1} s pc and $n_{H_2} = 1.2 \times 10^5$ cm^{-3}.

d) CO^+

Erickson *et al.* (1981) have observed two spectral lines in OMC-1 which they suggested are the $N = 2$–1, $J = 5/2$–3/2, and $J = 3/2$–1/2 transitions of CO^+ at 236.063 GHz and

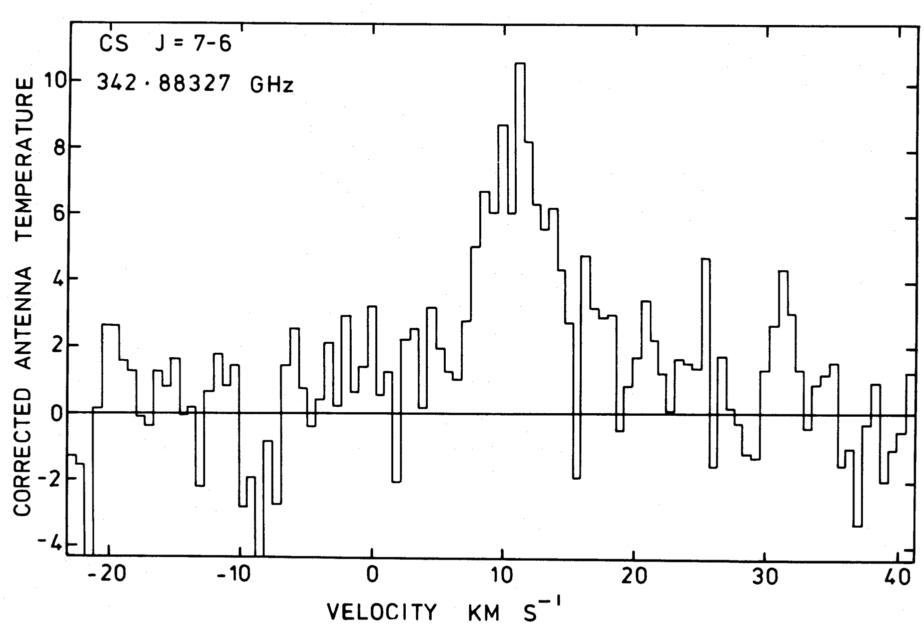

FIG. 11.—CS $J = 7$–6 spectrum obtained toward the Orion (0, 0) position

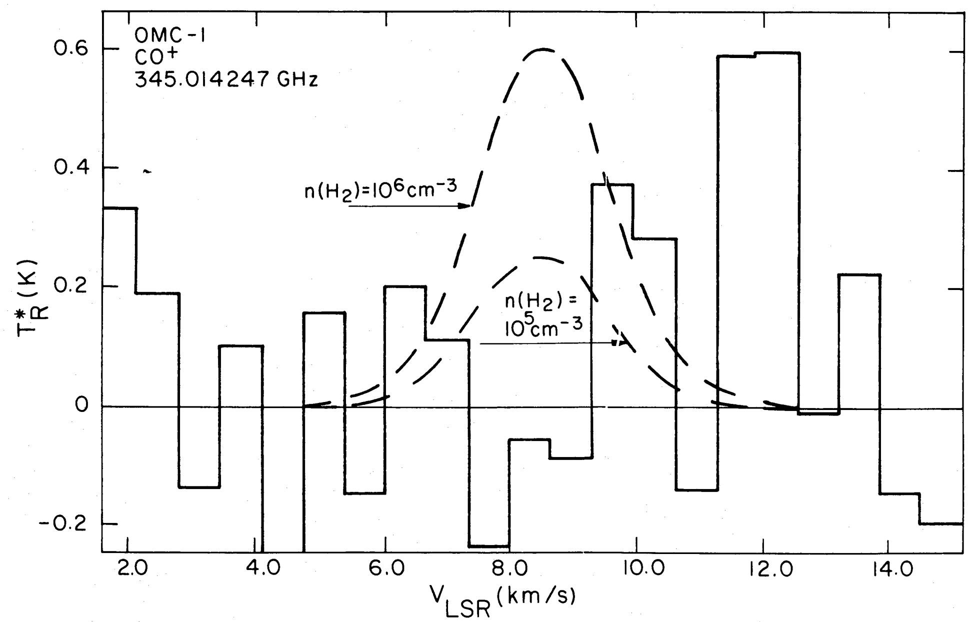

FIG. 12.—CO^+ spectral region towards the Orion A position observed by Erickson *et al.* (1981). Calculated line profiles for two densities are indicated for a kinetic temperature of 100 K.

235.790 GHz. Recently, Blake *et al.* (1984) have identified these features as due to $^{13}CH_3OH$. We have attempted to confirm whether CO^+ has been detected by searching for the next higher CO^+ rotational transition, the $N = 3$–2 $J = 7/2$–$5/2$ line at 354.014247 GHz (Sastry *et al.* 1981).

We searched for this line in OMC-1 at the position used by Erickson *et al.* (1981) (R.A. [1950] = $05^h32^m46\overset{s}{.}7$, decl. [1950] = $-05°24'25''$). We did not detect a line at the velocity reported for the $N = 2$–1 line. Our spectrum after a total of three hours integration is shown in Figure 12. It is unlikely that our negative result can be attributed to pointing errors or equipment malfunction, because other molecular lines at nearby frequencies were successfully observed at this position on the same night.

The expected strength of the $N = 3$–2, $J = 7/2$–$5/2$ line has been estimated on the assumption that the feature detected by Erickson *et al.* (1981) arises from CO^+. We assumed, as they did, that CO^+ is optically thin and extended relative to our beam size. As collisional rates for CO^+ are unavailable, we have solved the statistical equilibrium equations using the rate coefficients for N_2H^+ and HCO^+ scaled by a factor of 1.5 (Green 1975) to correct for the fact that H_2, not He, is the principal collision partner. The dipole moment of CO^+ is 2.5 debyes (Certain and Woods 1973).

We have drawn Gaussians in Figure 12 representing the expected amplitude and width of the $N = 3$–2, $J = 7/2$–$5/2$ line for $T_k = 100$ K and $n_{H_2} = 10^5$ and 10^6 cm^{-3}. We have corrected the velocity of the line reported by Erickson *et al.* (1981) on the basis of the accurate frequency measurements by Sastry *et al.* (1981). It appears that if the carrier of the 236.063 GHz line is CO^+, then it must originate in a region where $n_{H_2} < 5 \times 10^5$ cm^{-3} in OMC-1. There is no information on the size of the emitting region reported by Erickson *et al.* (1981). Assuming it to have a diameter of 2′, a value typical for many molecular species on Orion, then the true source radiation temperature T_R for the MWO could be larger by a factor of up to 2 times the observed T_R^* values, whereas for UKIRT the observed T_R^* values would be increased by 10%. *This will have the effect of lowering our estimate for* n_{H_2} *by about half, setting an upper limit below* 3×10^5 cm^{-3}.

In summary, we have searched unsuccessfully for the $N = 3$–2, $J = 7/2$–$5/2$ line of CO^+. Our negative results are consistent with one of two conclusions: either CO^+ is not the carrier of the two lines detected by Erickson *et al.* (1981), or, if these do arise from CO^+, then $n_{H_2} < 5 \times 10^5$ cm^{-3} in the emitting region for kinetic temperature above 30 K. The non-detection of the $N = 3$–2 line is consistent with the recently reported identification of the 236 GHz line with $^{13}CH_3OH$ by Blake *et al.* (1984).

IV. CONCLUSIONS

Submillimeter wavelength spectroscopic observations of the HCN, $H^{13}CN$, HCO^+, and $H^{13}CO^+$ in the Orion plateau source indicate high densities (up to 2×10^6 cm^{-3}) and temperatures of order 100 K. The observed profiles for HCN, $H^{13}CN$ and HCO^+ show the lines to be optically thick, whereas for $H^{13}CO^+$ the plateau emission is optically thin. The spatial distribution of HCN is centered on the Kleinmann-Low nebula; the HCO^+ distribution has a more extended structure, in a north-south direction.

The ambient cloud has been observed at frequencies corresponding to various rotational lines of HCN, $H^{13}CO^+$, CS, and CO^+. The derived cloud densities typically correspond to $n_{H_2} = 2$–6×10^5 cm^{-3}. For both HCN and HCO^+, the molecular abundance relative to H_2 as indicated by LVG modeling techniques is less than an order of magnitude greater in the plateau source than in the ambient cloud. We have been unable to confirm the reported detection of CO^+ in the interstellar medium, although more sensitive observations are needed to set stringent upper limits.

Note added in manuscript 1985 October 14 (*see* § III*a*).—After this paper was accepted, Dr. H. A. Wootten kindly pointed out to us the possibility of blending between the $H^{13}CN$ $J = 4$–3

line and the nearby $13_{2,12}$–$12_{1,11}$ transition of SO_2. Based on the intensities of a number of other SO_2 transitions detected in a more extensive submillimeter line search of Orion A (White *et al.* 1985), we estimate that the $13_{2,12}$–$12_{1,11}$ transition should have $T_r^* \approx 2$ K. Thus, the SO_2 transition may contribute up to 30% to the integrated intensity in the $H^{13}CN$ transition. This would have the effect of decreasing our estimates of $X/(dV/dR)$ and density by about a factor of 2.

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