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THE DISTRIBUTION OF 6 CENTIMETER H_2CO IN ORION MOLECULAR CLOUD 1

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ABSTRACT

Measurements of 6 cm H_2CO emission associated with the Orion Molecular Cloud (OMC-1) show that the peak of the emission feature at 7.4 km s^{-1} is centered close to the infrared source IRc5, in the southern part of the KL nebula. The peak main-beam brightness is 9 K, and the emission region has a deconvolved size of 25″ × 11″ (0.06 × 0.03 pc). The low peak brightness temperature implies that the H_2CO excitation is thermal. Absorption by H_2CO is seen toward the southern peak found at 400 μm. This source is probably behind the optical H II region; it has a deconvolved size of ≤ 30″. The weaker absorption and emission features are consistent with sizes greater than 15″, showing clumpiness in the H_2CO emission and absorption.

Subject headings: interstellar: molecules — nebulae: Orion Nebula

I. INTRODUCTION

Although the 6 cm H_2CO line is most often seen in absorption, it can appear in emission at sufficiently high densities. The prime example of this phenomenon is the Kleinmann-Low (KL) nebula. Zuckerman, Palmer, and Rickard (1975), using a 2′.6 beam, detected unambiguous 6 cm H_2CO emission from OMC-1 and found the maximum was toward the KL nebula (the extended IR source which contains the compact sources IRc2–IRc5 [Rieke, Low, and Kleinmann 1973]). Evans, Plambeck, and Davis (1979), from observations of the $3_{12} \rightarrow 2_{11}$ H_2CO line and a reexamination of previous observational and theoretical results, argued that this was thermal emission from a small condensation approximately 25″ in size and with a density of approximately 10^6 cm^{-3}. OMC-1, then, should be quite different from NGC 7538–IRS 1, the only other source that displays 6 cm H_2CO in emission (Downes and Wilson 1974). In the latter case, the radiation is maser emission, since the main-beam brightness temperature as observed with the VLA, is approximately 10^5 K (Rots *et al.* 1981).

In this *Letter* we report VLA observations of the H_2CO 6 cm line at a resolution of several arc seconds. Our mapping results yield: (1) a measure of the general clumpiness of the molecular cloud, (2) the position of the H_2CO gas clouds and their relation to the IR sources, and (3) a more realistic model of the physical conditions of this region by directly determining the source size, which had been a free parameter in earlier calculations.

II. OBSERVATIONS

The observations were made on 1981 September 11 using the Very Large Array of the National Radio Astronomy Observatory.[5] Eighteen antennas were used in the D configuration, for which the minimum spacing of two antennas was 42 m and the maximum spacing was 1 km. A radial velocity range of 12.1 km s^{-1} centered on a velocity of 8.7 km s^{-1} was studied with a spectral resolution of 0.46 km s^{-1}. The source 0500+019 ($\alpha[1950] = 05^h00^m45^s.160, \delta[1950] = +01°58'59''.1$) was used to calibrate the amplitude and phase data. The flux density scale was established by assuming a flux density of 7.45 Jy for 1328+307 at 4829.660 MHz, the rest frequency of the 1_{11}–1_{10} H_2CO line.

The data were calibrated in the standard manner. Figure 1*a* displays the CLEANed continuum map together with the synthesized beam (crosshatched ellipse = 16″ × 13″, P.A. = −45°). Figure 1*b* displays the difference map for the radial velocity range from 8.7 to 6.4 km s^{-1}, which covers the lower velocities in the emission measured by Zuckerman, Palmer, and Rickard (1975) (the signal-to-noise ratio for the higher velocity portion of this line was not adequate to map the emission). The emission, which we show, has a peak flux density of 28 mJy. This is equivalent to a main-beam brightness temperature of 9 K. This peak is at $\alpha(1950) = 5^h32^m46^s.847$,

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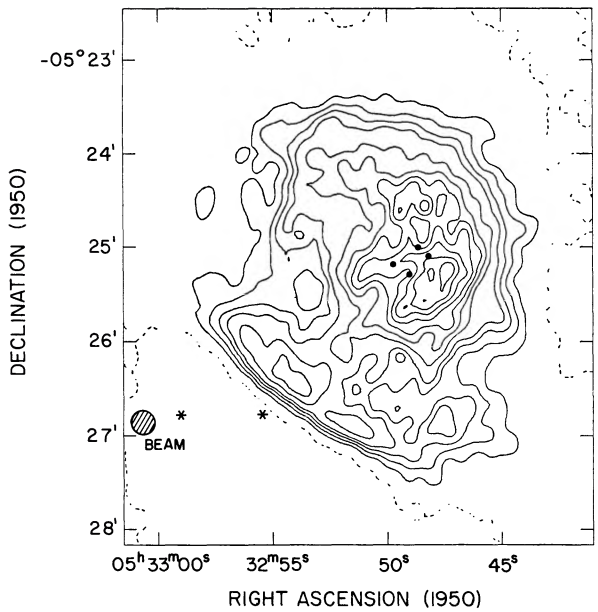

FIG. 1a

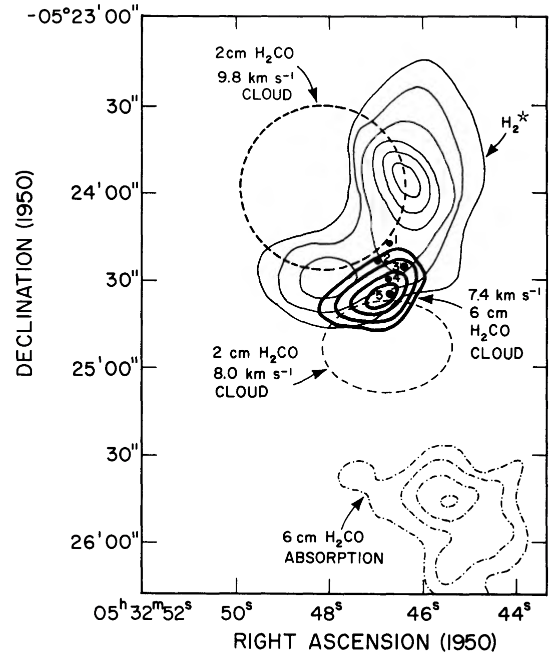

FIG. 1b

FIG. 1.—(*a*) The 6 cm continuum emission from Orion A. The contour levels are −5%, 5%, 10%, 15%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% of the peak flux density which is 1.39 Jy per beam (= 446 K, main beam T_B). The synthesized beam is denoted by the crosshatched ellipse (size = 16″ × 13″, P.A. = −45°). The dashed contours denote negative values. The four filled circles are the Trapezium stars θ^1 Orionis. The asterisks denote the position of stars in the θ^2 Orionis complex. (*b*) The 6 cm H_2CO emission in the velocity range from 8.7 to 6.4 km s^{-1} from the region Orion A. The contour intervals are −90%, −70%, −50%, −30%, 30%, 50%, 70%, and 90% of the peak flux density which is 28 mJy per beam area (= 9.0 K, main beam T_B). Positive contours are the heavy dark lines. Negative contours are shown by dash-dot lines. The synthesized beam is the crosshatched ellipse shown in (*a*). The positions of the BN object (IRc1) and IRc2–IRc5 (Rieke *et al.* 1973 as they appear at 20 μm in Downes *et al.* 1981) are denoted by filled circles. The H_2 emission contours are also shown as light solid lines (Beckwith *et al.* 1978). The 2 cm H_2CO emission-line regions are shown by dashed lines (Bastien *et al.* 1981).

δ(1950) = −05°24′35″.5. (This position and all the positions quoted in this *Letter* are conservatively estimated to be accurate to 0″.5.) The emission region has an elliptical shape, with a position angle of −60°. The size of the condensation is 25″ × 11″ after deconvolving a Gaussian beam. Assuming the distance to the KL nebula is 500 pc, the linear size is 0.06 × 0.03 pc. The total integrated flux density of this source is 87 ± 20 mJy. The center of the KL nebula lies north of this condensation, as Figure 1*b* shows, with IRc5 being near the peak of the emission.

There is also a strong absorption condensation of peak flux density −21 mJy at α(1950) = $05^h32^m45^s.450$, δ(1950) = −5°25′46″.9. This absorption is amorphous (see Fig. 2*b*) with a size of ~ 37″ × ~ 13″, P.A. = 45° (Gaussian deconvolved size), and a total integrated flux density of −117 ± 20 mJy.

Since there are many other emission and absorption features present, which are too diffuse to show up in Figure 1*b*, the (*u*, *v*) data were tapered with a Gaussian taper of 0.5 km giving a synthesized beamwidth of 28″. Figure 2*a* displays the resulting continuum map and beam, while Figure 2*b* displays the difference map. The dominant emission and absorption peaks in Figure 2*b* appear to be Gaussian in shape. In our 28″ beam, the emission source has a peak flux density of 55 mJy and a total integrated flux density of 81 ± 20 mJy; the peak flux density of the absorption peak is −49 mJy and has a total integrated flux density of −94 ± 20 mJy. The positions of the absorption and emission peaks agree well with the lower resolution observations of Zuckerman, Palmer, and Rickard (1975). Other absorption and emission features appear to be consistent with size scales of approximately 15″. A north-south line at approximately $5^h32^m47^s$ appears to separate emission (to the east) from absorption (to the west).

The ionization front near θ^2 Orionis at the H I–H II interface (Becklin *et al.* 1976) is evident from inspection of Figures 1*a* and 2*a*. The H II emission appears to be very clumpy at the resolution of 15″–28″. Our map (Figs. 1*a* and 2*a*) shows that the structure in the core is contained within 2′ and is similar to the map by Martin and Gull (1976). The rectangular shape of the H II region appears to mimic the distribution of the four θ^1

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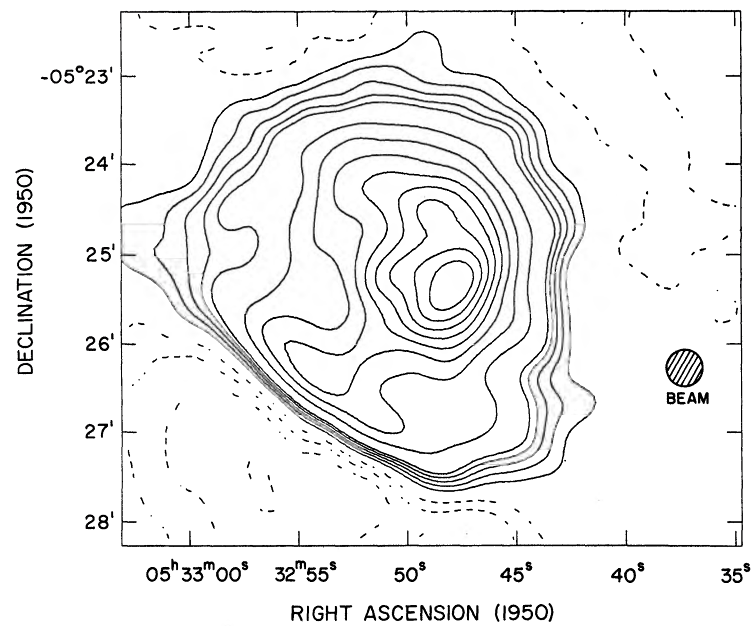

FIG. 2a

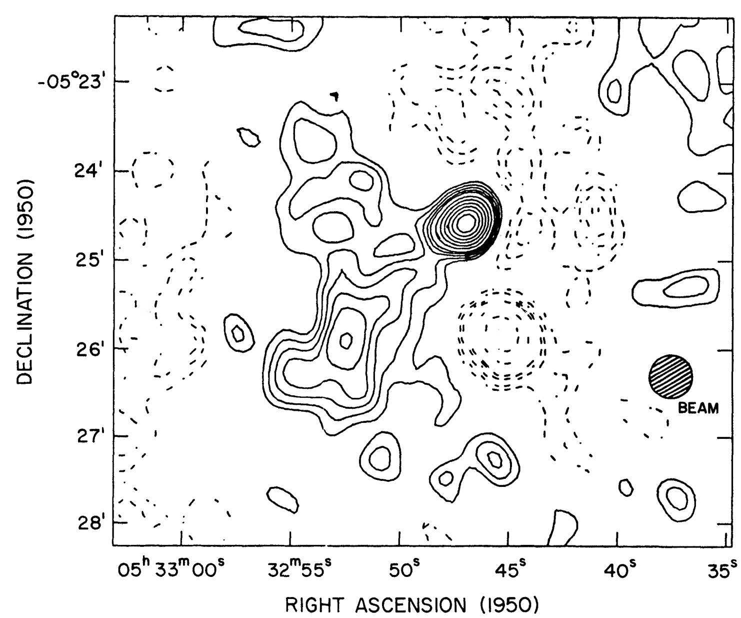

FIG. 2b

FIG. 2.—(a) The 6 cm continuum emission from Orion A with the (u, v) data tapered with a 0.5 km Gaussian. (Synthesized beam size of 28″ shown as a crosshatched ellipse). The contours are −10%, −8%, −6%, −2%, 2%, 4%, 6%, 8%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% of the peak flux density which is 4.75 Jy per beam area (= 318 K, main beam T_B). (b) The 6 cm H_2CO emission in the velocity range from 6.4 to 8.7 km s^{-1} from the region Orion A. The contour intervals are −90%, −70%, −50%, −30%, −25%, −20%, −15%, −10%, 10%, 15%, 20%, 25%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% of the peak flux density which is 55 mJy per beam area (= 3.7 K, main beam T_B). The negative contours are dashed lines. The synthesized beam is shown in Fig. 1b.

Orionis stars (see Fig. 1*a*) indicating that these may excite the H II region.

III. DISCUSSION

The two dominant condensations of Figure 2*b* appear clearly on the 400 μm map of Keene, Hildebrand, and Whitcomb (1982), the map of the NH_3 (2, 2) transition of Ziurys *et al.* (1981), the HCN map of Clark, Buhl, and Snyder (1974), and the 2 mm formaldehyde emission map of Thaddeus *et al.* (1971). In addition, the 3_{12}–3_{13} H_2CO emission (Wilson *et al.* 1980; Myers and Buxton 1980) and the 2_{11}–2_{12} H_2CO emission (Evans *et al.* 1975) have positions which are consistent with the location of our 6 cm H_2CO emission peak. However, the location and spatial structure of the two dominant features in our 6 cm H_2CO map do not agree in detail with the other IR and molecular line maps. The emission peak in our 6 cm H_2CO emission is located 10″ south of IRc2, but is within a few arc seconds of the peak of the 400 μm IR map. The 6 cm emission map presented here (Fig. 2*b*) has a filling factor of less than 0.3 for the high-density gas observed at arc minute resolutions.

The clump size of the main 6 cm H_2CO emission region is somewhat smaller than the 25″ size predicted by Evans, Plambeck, and Davis (1979). However, more than 33% of the flux density from the single-dish profile of Zuckerman, Palmer, and Rickard (1975) *in this velocity range* is missing, so there is extended structure. In addition, there is extended H_2CO emission found in single-dish maps (Evans *et al.* 1975; Myers and Buxton 1980) of higher lying transitions. Presumably, such extended emission is resolved out in our map. Still, this clump may contribute to some of the emission observed from higher K-doublet lines. For example, the 6 cm emission agrees roughly with the size measured in the 3_{12}–3_{13} H_2CO line, namely 40″ × 20″ (Wilson *et al.* 1980). Any theoretical analyses of the conditions require the use of the collisional cross sections of Green *et al.* (1978). Assuming these are correct, we have applied a large velocity gradient analysis, as described by Wilson *et al.* (1980). The kinetic temperature of the cloud is assumed to be 70 K, and the H_2 density is 10^6 cm^{-3}. The measured line width, ΔV, is 1.5 km s^{-1}, and the cloud size, r, is 0.05 pc. If $n(H_2CO)/(dV/dr) = 10^{-3}$ cm^{-3} pc/km s^{-1} (corresponding to an ortho-H_2CO column density of 10^{16} cm^{-2}), then the resulting brightness temperature of the 1_{11}–1_{10} line is 10 K, close to our measured value.

The size of the dominant absorption feature is not well measured but is certainly larger than 15″, as Figures 1*b* and 2*b* show. Its peak brightness temperature is −5 K which indicates that this feature cannot be absorbing only the 2.7 K background radiation. This clump is probably behind the H II region since no substantial optical absorption is seen at this position and it is centered within 12″ of the southern maximum found by Keene, Hildebrand, and Whitcomb (1982) at 400 μm. It is possible that the H_2CO absorbs a more extended region of H_2CO emission or continuum radiation from a source since the absence of detectable absorption in the 2 cm line of H_2CO implies that the $n(H_2)$ density is estimated to be less than 10^4 cm^{-3}.

The masses of the two features on the 400 μm map are estimated to be 50 and 60 $M_\odot$, in a 35″ region (Keene, Hildebrand, and Whitcomb 1982). If these are the regions of the dominant 6 cm H_2CO absorption and emission, then assuming a uniform, spherically symmetric density distribution, the H_2 density is estimated to be 3×10^6 cm^{-3}. This is consistent with the density of the dominant emission component but is far in excess of the density of 10^4 cm^{-3} estimated for the absorption component. Assuming that our H_2CO excitation model is correct, this may be reconciled if we assume a more complex geometry for this source. One simple model is a high-density core (10^8 cm^{-3}), 10″ in size, surrounded by a halo of 35″ size that contains less than 5% of the total mass at a density of 10^4 cm^{-3} and in which the optical depth of 6 cm H_2CO is 1. This would account for the fact that no 2 cm absorption or 6 cm emission from H_2CO is associated with this source. A more complex geometry for this source may be indicated as the 6 cm H_2CO absorption peak is 10″ west and 2″ north of the southern peak on the 400 μm map.

The 6 cm H_2CO emission lies between 9.8 km s^{-1} and 8.0 km s^{-1} clouds seen at the 2 cm H_2CO (Bastien *et al.* 1981; as shown in Fig. 1*b*). The 2 cm map was made with an angular resolution of 1′. New unpublished 3_{12}–3_{13} data, made with the 100 m telescope (35″ resolution), shows a 15″ shift of the 8 km s^{-1} cloud, to the north; this cloud may have a sharp edge to the north and may be the compact emission region in our VLA map. From the alignment of the 2 cm H_2CO emission and the vibrationally excited 2 μm H_2 emission (Beckwith *et al.* 1978), Bastien *et al.* (1981) suggested that the clouds containing the 2 cm H_2CO emission confined the outflow of gas from the KL region, delineated by the H_2 emission contours. Plambeck *et al.* (1982) have applied a similar idea to explain their SO results. The simplest model for this region is that high-velocity (≥ 50 km s^{-1}) outflow of gas is driven by a source in the northern part of KL, perhaps IRc2 (Downes *et al.* 1981), or some other object (Goldsmith 1983). The 6 cm H_2CO emission peaks south of IRc2. Our emission does not show the wide velocity wings; hence, it is not participating in the outflow. It is possible that H_2CO is dissociated by conditions in the high-velocity flow. Then what we observe are warm, dense, rather quiescent regions where H_2CO is produced.

When looking at the 6 cm H_2CO emission, the question immediately arises whether there are infrared sources south of IRc5. There are two possible answers: (1) yes, since the extinction in the KL nebula increases southeastwards with that at IRc1 (BN) being a minimum, the sources south of IRc5 are not seen due to high IR extinction; (2) no, the H_2CO emission displayed south of IRc5 is caused by a density gradient in the molecular cloud near the H I–H II interface, such as in the model by Icke, Gatley, and Israel (1980).

IV. SUMMARY

Measurements of the 6 cm H_2CO emission and absorption associated with OMC-1 show the line radiation to have sizes $\geq 15''$. The dominant features on the map are those from high-density regions ($n_H > 10^4$ cm^{-3}). The dominant emission condensation is located near the KL nebula and is centered near IRc5. It is 0.06×0.03 pc in size. The dominant absorption condensation is approximately 2′ south of KL and is $\leq 30''$ (< 0.06 pc) in size. Both the dominant emission and absorption condensations appear in the 400 μm maps, HCN maps, and 2 mm H_2CO emission maps of OMC-1. The other, weaker absorption and emission features are consistent with sizes greater than 15″ and show clumpy structures.

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