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CO OBSERVATIONS OF A HIGH VELOCITY CLOUD

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ABSTRACT

We report a null detection of ^{12}CO emission from a sub-condensation in a High Velocity Cloud (HVC). As a consequence of this, an upper limit of $n(H_2)\frac{X(CO)}{DV/DR} \leq 2 \times 10^{-5}$ was set. This implies that ^{12}CO abundance is deficient by at least a factor of 10 if the HVC is predominantly molecular, otherwise the CO abundance of the HVC might be normal.

I. INTRODUCTION

High velocity gas has a hierarchical structure with small, bright condensations, typically less than 30 minutes of arc, embedded in larger regions of low emissivity. The velocity widths of the profiles associated with the diffused component are typically about 25 km/sec while those associated with the small condensations are typically less than 10 km/sec (Giovanelli *et al.* 1973), suggesting a two-phase thermal structure where cold (below 1000 K) cores coexist with warm (10000 K) envelopes, respectively associated with narrow and broad velocity components in the line profiles. Notably, synthesis observations reported by Schwarz and Oort (1981) in complex A reveal a wealth of structure at the arcminute scale, often exhibiting filamentary morphology. The dense material has a kinetic temperature below 500 K, and is expected to have densities in excess of 30 cm^{-3} (at an arbitrary distance of 2 kpc).

Intriguing, apart from the origin and formation of high velocity gas, is the existence of

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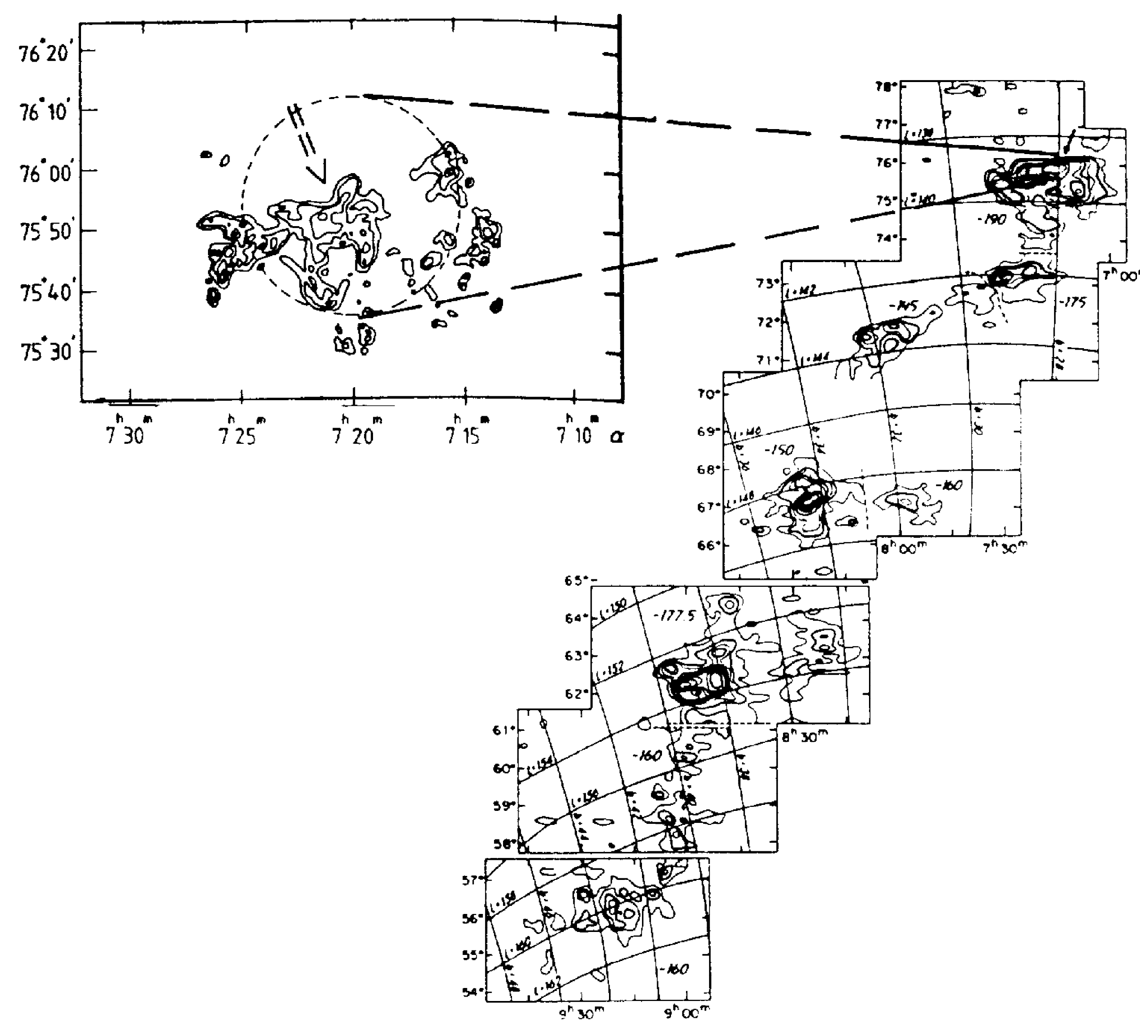

Fig. 1. An overall continuum map indicates the structures within high velocity cloud A (Complex A) (observed at 21-cm with the 300 foot telescope of the NRAO Green Bank ; Giovanelli *et al.* 1973). The observed position is indicated with an arrow. For the HI column density map of the region, see Schwarz and Oort (1981) observed with the WSRT.

condensed H I clumps in HVC complexes and the possibility of that these clumps are potential sites of star formation. If a gas density in a clump is high enough, then onset of gravitational instability would lead the clump to collapse and thus form a denser core. If the core is relatively high in density and contains enough dust to be molecular, then we would expect CO emissions. However, there is several evidence showing that these clouds have relatively little dust and low metallicity (Giovanelli 1985 ; and references therein), which implies rather weak CO emissions. We briefly report here a null detection of CO emission from one of the sub-condensations in Complex A (see below). This result is used to set an upper limit in the CO abundance of the clumps.

II. OBSERVATIONS AND RESULTS

We have carried out CO observations with the FCRAO (Five College Astrophysical Observatory) in 1988. Compared with the FCRAO beam size at 2.6 mm (about 1 arcmin), the clumps are large in angular extent. Thus, as a test for detectability, CO observations were carried out on one of the three sub-condensations in clump A I listed in Table 1. In Table 1, physical parameters of the several concentrations in Complex A are listed. Since we expected the CO emissions from these to be weak, we allocated an integration time of slightly over 2 hours.

Table 1. List of Subclumps in HVC Complex A

Name	α (1950)	δ (1950)	V^* (km/s)	DV^* (km/s)	$T_b{}^*$ (K)	$N(H)^*$ (cm^2)	M/R^* (solar/kpc^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A I	7 20 15.0	75 55 00	~190	30	~3	4×10^{19}	~22
A III	8 26 40.0	67 04 36	—	13	—	—	—
A IV	9 01 48.5	62 09 00	~180	21	~4	5×10^{19}	~60

Column(1) : Source name.(2),(3) : Right ascension and declination. (4) : Radial velocity in km/s. (5) : Velocity dispersion in km/s. (6) : Brightness temperature measured at 21 cm. (7) : Hydrogen column density. (8) : Mass per kpc^2. Note : * : Data from H I observations of Giovanelli, Verschuur, and Cram (1973)

A reference point was chosen about 2° away in azimuth from the target position, sufficiently far away to ensure that the background level was not overly over/undersubtracted. Figure 1 shows the 21-cm continuum map of Complex A and the target postion is indicated with an arrow. In Figures 2 and 3, the results of the observations are shown at two velocity resolutions, 1 MHz and 250 KHz. Although there is a weak indication in Figure 2 for a line at $V_{LSR} \approx -180$ km/s, the noise fluctuation suggests that this one channel spike is likely due to noise. Note that 1 σ noise levels are ~18 mK and ~30 mK for channel resolutions of 1 MHz

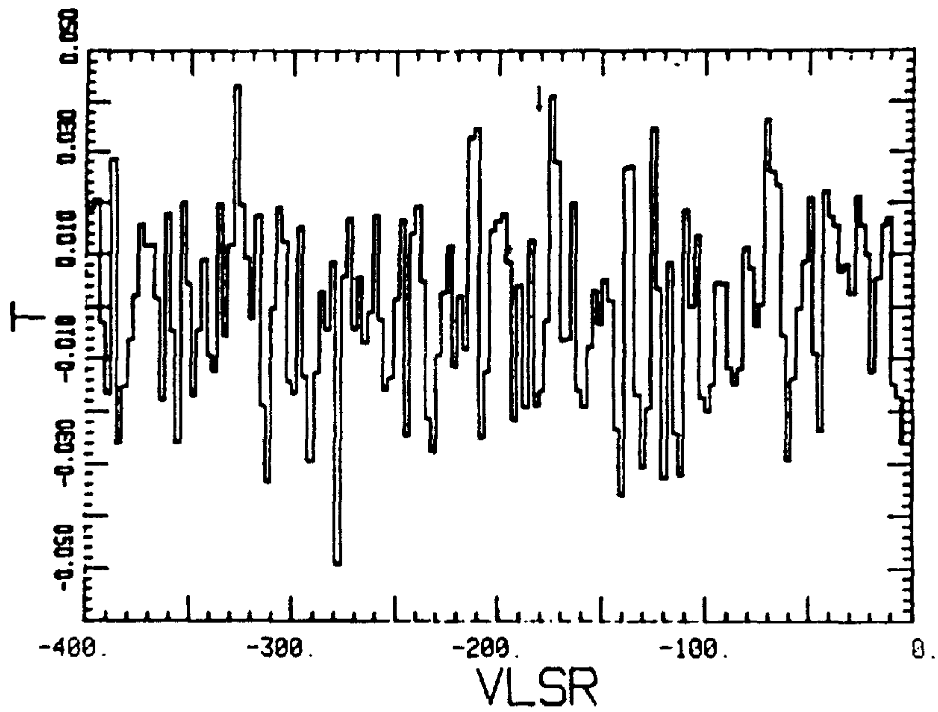

Fig. 2. Spectrum at 1 MHz channel resolution. Noise level is 17.9 mK.

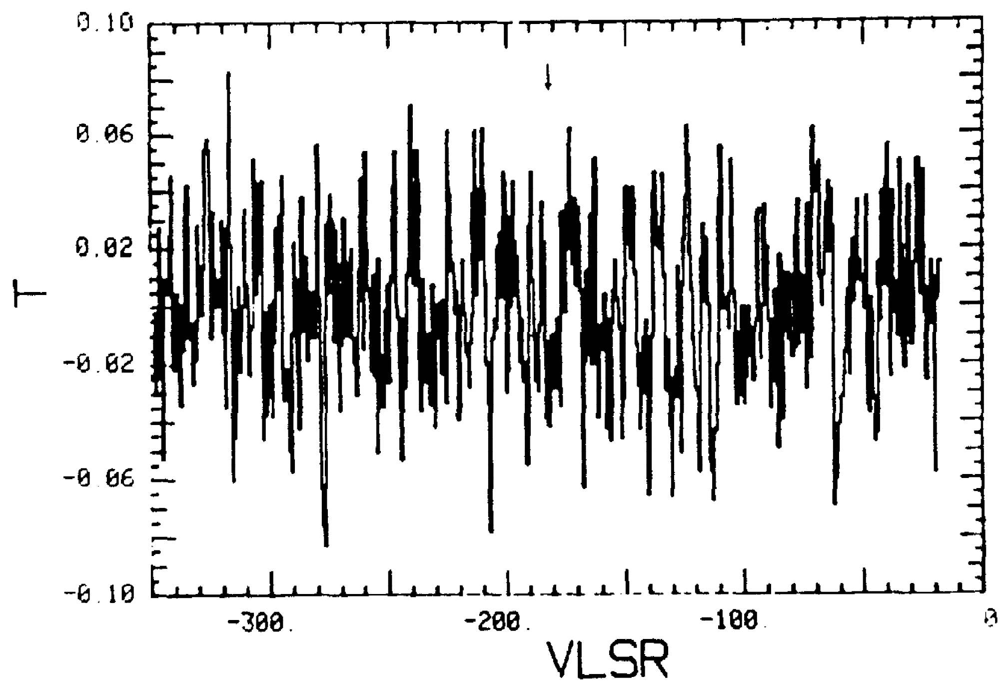

Fig. 3. Spectrum at 250 KHz channel resolution. Noise level is 28.9 mK

and 250 KHz, respectively.

Table 2a. Model 1 with $n(CO)/n(H_2)=1\times10^{-6}$

$\frac{n(CO)}{n(H)}$	$n^*(H)$	$[n(H)+n(H_2)]$	T_k / $n(H_2)$	400 K	200 K	100 K	50 K	25 K
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2.5×10^{-7}	40	30	10	0.028	0.028	0.029	0.30	τ
				2.93K	2.90K	2.86K	2.82K	T_{ex}
				4.5mK	3.9mK	3.2mK	2.4mK	T_R
3.3×10^{-7}	60	40	20	0.052	0.053	0.054	0.56	τ
				3.13K	3.07K	2.99K	2.91K	T_{ex}
				16.2mK	14.0mK	11.4mK	8.5mK	T_R
4.0×10^{-7}	100	60	40	0.090	0.094	0.099	0.104	0.110
				3.55K	3.42K	3.27K	3.11K	2.96K
				56.5mK	49.3mK	40.5mK	30.4mK	20.0mK
4.4×10^{-7}	180	100	80	—	0.15	0.16	0.18	0.20
				—	4.16K	3.85K	3.53K	3.22K
				—	163mK	137mK	106mK	72mK

Table 2b. Model 2 with $n(CO)/n(H_2)=0.5\times10^{-6}$

$\frac{n(CO)}{n(H)}$	$n^*(H)$	$[n(H)+n(H_2)]$	T_k / $n(H_2)$	400 K	200 K	100 K	50 K	25 K
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1.3×10^{-7}	60	40	20	—	0.027	0.027	0.028	—
				—	3.06K	2.99K	2.91K	—
				—	7.0mK	5.7mK	4.2mK	—
2.0×10^{-7}	100	60	40	—	0.047	0.050	0.052	—
				—	3.39K	3.25K	3.10K	—
				—	24.5mK	20.0mK	15.0mK	—
2.2×10^{-7}	180	100	80	—	0.076	0.083	0.092	—
				—	4.11K	3.80K	3.49K	—
				—	82.4mK	69.0mK	53.5mK	—

Column (1) : CO abundance. (2) Number of H nuclei. (3)-(9) : Self-explanatory. Note : τ, T_{ex}, and T_R are the optical depth, excitation temperature and brightness temperature for $J=1$ to $J=0$ transition, respectively.

From the observations, we can set some limits on relevant physical parameters of the subclumps. With fixed numerical parameters

$$n(\mathrm{H\,I})=20\ \mathrm{cm}^{-3},\ DV=10\ \mathrm{km/s,\ and}\ DV/DR=10\ \mathrm{km/s/10pc},$$

where n(H I) is the H I number density and DV/DR is the ratio of a line width (DV) to a typical condensation size (DR), LVG(Large Velocity Gradient) model calculations were done for the $J=1$ to $J=0$ transition in two cases of $n(CO)/n(H_2)$. These are summarized in Tables 2a and 2b. The use of the LVG model (following Langer *et al.* 1980 and Wilson *et al.* 1981) is a convenient method for estimating excitation condition from the peak antenna temperature and is not intended to imply that such a velocity field exists. LVG results are often found to be accurate to a factor of 2.

As shown in the Tables, T_R is insensitive to the choice of $T_k<400$ K or so. However, in the regime of low density and low X(CO) (the logarithmic CO abundance in $n(CO)/n(H_2)$, T_R is most sensitive to $n(H_2)$, and is roughly linearly proportional to $\frac{X(CO)}{DV/DR}$. Note that on average X(CO) in giant molecular clouds is known to be about 10^{-5}. Since metallicity in the HVC is known to be less than this, our choice was $X(CO)=10^{-6}$. Since our models cannot separate X(CO) from DV/DR, our result can be summarized in the following forms:

$$\text{Assuming } T_R<20\ \mathrm{mK\ and}\ 25\ \mathrm{K}<T_k<400\ \mathrm{K},$$

we have

$$n(H_2)<30\ \mathrm{cm}^{-3},\ \text{if}\ \frac{X(CO)}{DV/DR}=1\times10^{-6},$$

$$n(H_2)<40\ \mathrm{cm}^{-3},\ \text{if}\ \frac{X(CO)}{DV/DR}=5\times10^{-7}.$$

These results indicate two possible cases: firstly CO abundance is deficient by at least a factor of 10 if the high velocity H I cloud is predominantly molecular (i.e., $n(H_2)>n(H)$). Otherwise, and secondly, if this cloud is basically an atomic gas cloud (i.e., $n(H_2)<n(H)$), then the CO abundance might be normal. We encourge further CO observations.

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