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MOLECULAR CORES OF THE HIGH-LATITUDE CLOUD MBM7

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ABSTRACT

We have investigated the properties of the high-latitude cloud MBM 7 using the 3 mm transitions of CO, CS, HCN, HCO^+, C_3H_2, N_2H^+, and SiO. The molecular component of MBM 7 shows a very clumpy structure with a size of ≤ 0.5 pc, elongated along the northwest–southeast direction, perpendicularly to an extended H I component, which could be resulted from shock formation. We have derived physical properties for two molecular cores in the central region. Their sizes are 0.1–0.3 pc and masses 1–2 $M_\odot$ having an average volume density $\sim 2 \times 10^3$ cm^{-3} at the peak of molecular emission. We have tested the stability of the cores using the full version of the virial theorem and found that the cores are stabilized with ambient medium, and they are expected not to be dissipated easily without external perturbations. Therefore, MBM 7 does not seem to be a site for new star formation. The molecular abundances in the densest core appear to be much less (by about one order of magnitude) than the 'general' dark cloud values. If the depletions of heavy elements are not significant in the HLCs compared with those in typical dark clouds, our results may suggest different chemical evolutionary stages or different chemical environments of the HLCs compared with dense dark clouds in the Galactic plane.

Key words : ISM : clouds – ISM : individual(MBM7) – ISM : molecules – radio lines : ISM

I. INTRODUCTION

More than 100 high-latitude clouds (HLCs) have been identified at Galactic latitudes $|b| \geq 20°$ via *IRAS*, H I, and CO observations (e.g. Low et al. 1984; Blitz et al. 1984; Magnani et al. 1985). These HLCs are usually distinguished from dense clouds located in the Galactic plane by their low-visual extinctions ($A_v^{tot} \sim 1 - 2$ mag) and low masses (10–100 $M_\odot$). HLCs span a wide range of physical and chemical properties and occupy an intermediate regime between diffuse and dense dark clouds. About 90% of HLCs are falling into a category known as translucent clouds (van Dishoeck & Black 1988). They often appear to be extended sometimes to a few square degrees mainly because of their proximity to us (~ 100 pc), which makes these sources ideal objects to study the physical and chemical properties of the interstellar clouds and their evolutions. The morphologies of many HLCs suggest that they have been shocked. The observed lines toward HLCs often show much larger linewidths than expected in the cold and quiet gas, which may suggest that the internal turbulence plays a significant role in their kinematical evolution. The HLCs are supposed to be disrupted eventually in a time scale of $10^5 - 10^6$ yrs (Magnani et al. 1985; Keto & Myers 1986; Magnani et al. 1993; Minh et al. 1996).

The mm-wave CO lines have been detected in many HLCs of $A_v^{tot} > 1$ mag. The CO/H_2 abundance ratios for HLCs have been found to be between the dark cloud values ($\sim 10^{-4}$) and the diffuse cloud values ($\sim 10^{-6}$, Blitz et al. 1984; van Dishoeck 1998). The translucent cloud locates in the region where atomic carbons transform to molecular forms. As the chemical models of van Dishoeck & Black (1988) suggest that small variations in physical parameters by a factor of ~ 2 can result in an order of magnitude different CO densities in the translucent regime, the physical and chemical properties of HLCs are very interesting but still controversial. Our recent study on the CO and IRAS 100μm intensities in MBM 40 (Minh et al. 2000) also suggests a possible difference in the degree of CO depletion in HLCs and dense dark clouds in the Galactic plane.

In several HLCs many other molecules except CO have also been detected, such as CS, OH, C_3H_2, NH_3, and H_2CO (Drdla et al. 1989; Mebold et al. 1987; Heithausen et al. 1987; Turner et al. 1989; Minh et al. 1994). These molecules suggest that there exist dense cores ($n(H_2) \geq 10^3$ cm^{-3}) in HLCs, and star formations may be taking place in these clouds. In a few HLCs the signs of star formation, such as T Tauri stars or outflows, have actually been found (Sandell et al. 1987; Sato & Fukui 1989), but it is controversial whether very dense cores such as those in dark clouds ($n(H_2) \sim 10^4$–10^5 cm^{-3}) exist in HLCs. The molecular cores in HLCs are thought to be in hydrostatic equilibrium (Turner et al. 1989, 1992; Turner 1993), but it is not certain that these cores are collapsing gravitationally.

In this paper we report results from mm-wave observations of interstellar molecules toward the high-latitude cloud MBM 7, which is located at a distance of

Table 1. Gaussian Fit Parameters of the Observed Molecular Lines[a] and Column Densities

Molecule	Transition	T_{peak} (K)	Δv_{FWHM} (km s^{-1})	v_{lsr} (km s^{-1})	N_{col}[b] (cm^{-2})
^{12}CO	1–0	4.89	1.70	5.03	1.5×10^{17} [c]
^{13}CO	1–0	2.01	0.99	5.09	3.3×10^{15}
$C^{18}O$	1–0	0.17	0.47	5.19	1.6×10^{14}
CS	2–1	0.13	0.90	5.26	9.4×10^{11}
HCN	1–0 F=2–1	0.13	0.47	5.25	3.5×10^{11}
HCO^+	1–0	0.35	0.42	5.32	2.3×10^{11}
C_3H_2	$2_{1,2}$–$1_{0,1}$	0.16	0.31	5.27	1.4×10^{12}
N_2H^+	1–0 F_1=2–1	$\leq$0.19[d]	-	-	$\leq7.5\times10^{11}$
SiO	2–1 v=0	$\leq$0.24[d]	-	-	$\leq8.0\times10^{11}$

[a] Observed toward the offset (0, 3′) position with the 14-m telescope of TRAO.
[b] Derived assuming optically thin emission except the ^{12}CO results.
[c] Derived using the ^{13}CO (1–0) result and the ratio $^{12}C/^{13}C = 45$.
[d] 3 σ value of the observed spectrum.

~ 150 pc from us (with ±50% error, Blitz et al. 1984), and discuss the physical and chemical properties of the molecular cores. The observations were made toward molecular components located in the central region of the atomic H I gas cloud extended over a region larger than a few square degrees. In Section II we summarize our observational procedures for ^{13}CO (1–0) line observations and for 3 mm observations of several interstellar molecules toward the peak position of the ^{13}CO (1–0) line emission. Previously we have studied the H I and CO properties of this source (Minh et al. 1996), which is summarized briefly in Section III. The observational results and discussions on the physical and chemical properties of MBM 7 cores are included in Section III. And in Section IV we summarize our conclusions.

II. OBSERVATIONS

(a) ^{13}CO (1–0) Mapping

The ^{13}CO (J=1–0) line was observed with the 20-m radio telescope of the Onsala Space Observatory in Sweden in 1996 October. The HPBW of the telescope is about 38″ and its main-beam efficiency is 0.52 at the observed frequency of 110 GHz. A cryogenic SIS mixer receiver was used and the typical system temperature was about 400 K (SSB). A 1600 channel correlator was used which gives the total frequency bandwidth of 40 MHz.

Fig. 1 shows the integrated intensity map of the ^{13}CO (1–0) line. The (0, 0) position of the map is $(\alpha, \delta)_{1950} = (2^h19^m36^s, 19°40'00'')$. The observations were made with a 3′ spacing for a total observed region of 40′ × 40′ (R.A. × Decl.). The usual position switching method was applied and the observed temperature scale was shown in T_A^*, which has been corrected for antenna and atmospheric losses by the standard chopper wheel method, but not corrected for possible beam dilution. The typical noise value (rms) of the spectra is about 60 mK (1σ).

(b) Molecular Line Observations at 3 mm

The 3 mm observations were made with the 14-m radio telescope of Taeduk Radio Astronomy Observatory (TRAO) during 1998 May and June toward the peak position of the ^{13}CO (J=1–0) observations, $(\Delta\alpha, \Delta\delta) = (0', 3')$ from the map center of Fig. 1. The observed 3 mm transitions are CO (1–0), CS (2–1), HCN (1–0), HCO^+ (1–0), C_3H_2 ($2_{1,2}$–$1_{0,1}$), N_2H^+ (1–0), and SiO (2–1, v=0).

The HPBW and main-beam efficiency of the antenna are about 50″ and 0.5, respectively, at 100 GHz. The cryogenic SIS mixer receiver was used which gives a system noise temperature of about 400 K (SSB). The 1024 channel correlator was used as a spectrometer and the total frequency bandwidth was 20 MHz. Data were taken with position switching to an emission-free region and the typical noise value (rms) of the observed spectra is 70–100 mK. The temperature scale is given in terms of T_A^* as the Onsala data. Their spectra are shown in Fig. 2 and the observed parameters are included in Table 1.

III. RESULTS AND DISCUSSION

(a) Summary for the Previous Study

In the previous study for MBM 7 (Minh et al. 1996), we have observed the H I 21cm and CO (1–0) lines and compared the results with the IRAS data. We have found that the high-latitude cloud MBM 7 consists of a cold dense core of 5 $M_\odot$ surrounded by atomic and molecular gases of a mass of about 25 $M_\odot$, which is embedded in hotter and more diffuse H I gas. The dense molecular cores have sizes of 0.1–0.3 pc (FWHM), masses ~ 1 $M_\odot$, and volume densities $n(H_2) \geq 2000$

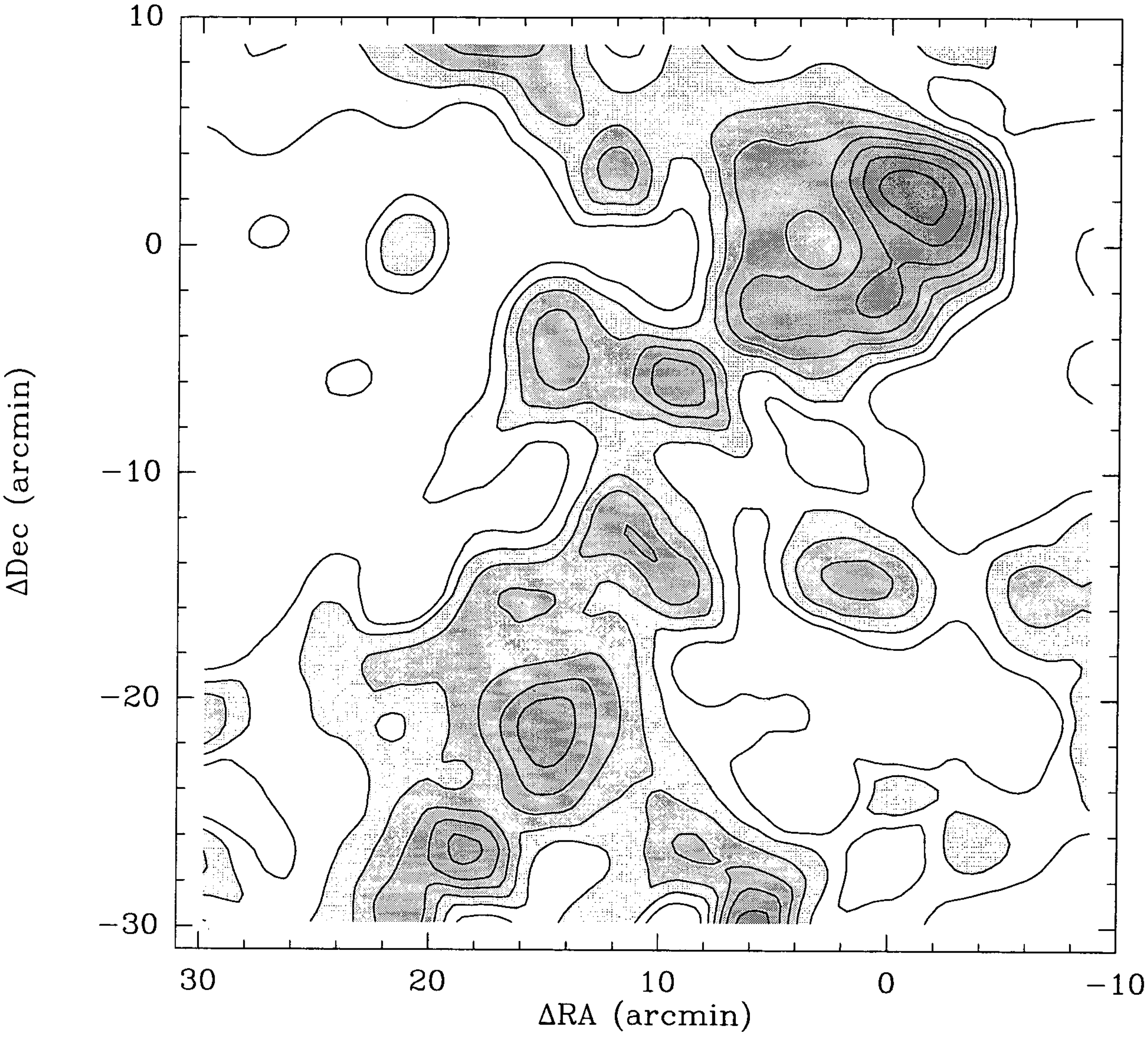

Fig. 1.— An integrated intensity map of the ^{13}CO (1–0) line ($\int T_A^* dv$). The contours increase by 0.5 K km s^{-1} from the lowest value 0.5 K km s^{-1}. The (0, 0) position is $(\alpha,\ \delta)_{1950} = (2^h19^m36^s,\ 19°40'00'')$.

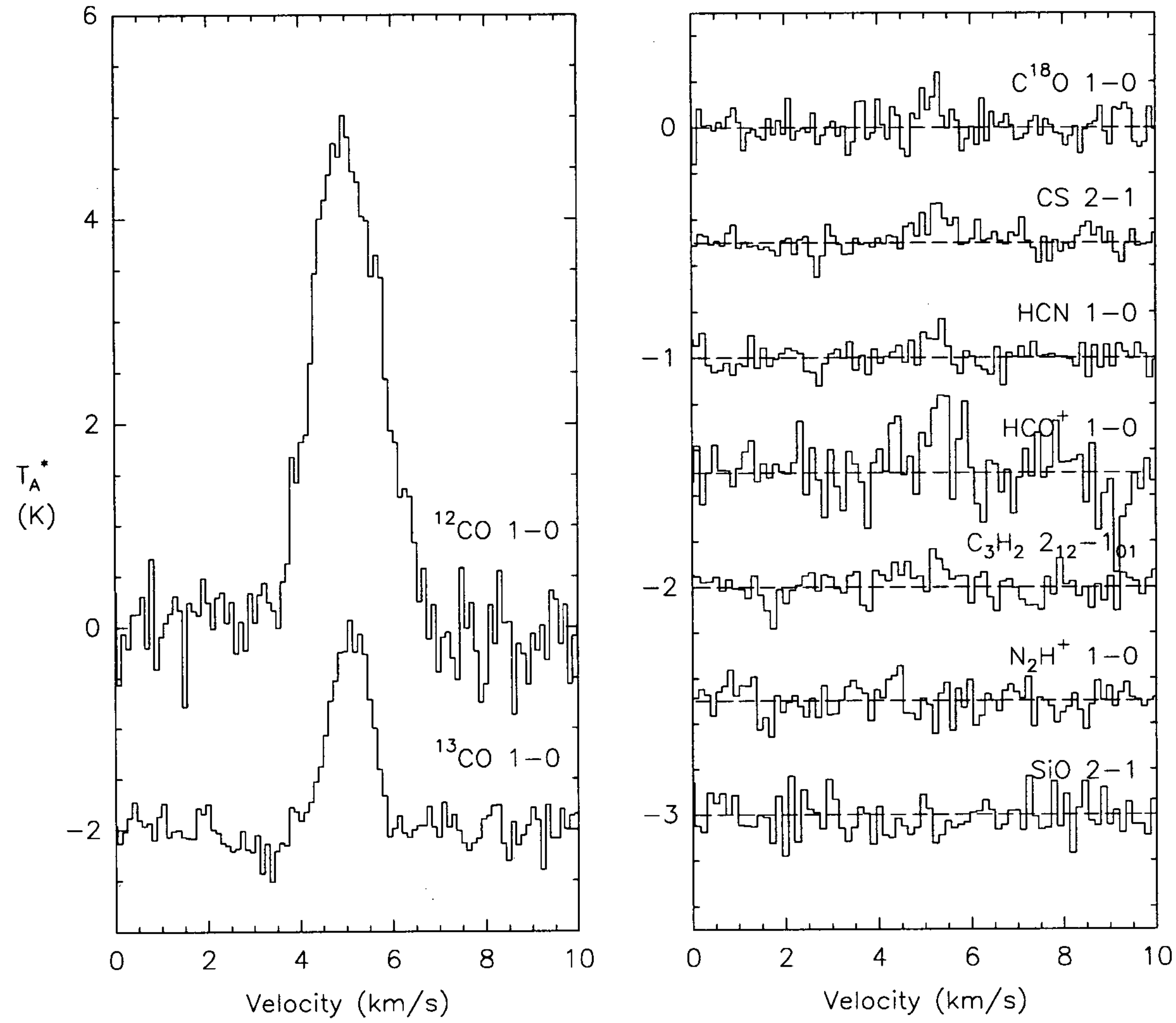

Fig. 2.— Molecular lines observed with the 14-m telescope of the Taeduk Radio Astronomy Observatory toward the offset ($\Delta\alpha$, $\Delta\delta$) = (0, 3′) from the (0, 0) position in Fig. 1.

Table 2. Properties of the Two Molecular Cores

Core	Position[a] (′, ′)	Size[b] (pc)	$N(H_2)$[c] (cm^{-2})	Mass ($M_\odot$)
Core 1	(−1, 2.5)	0.31	2.9×10^{21}	1.8
Core 2	(15, −21)	0.27	2.4×10^{21}	1.1

[a] Offset from the (0, 0) position which is included in Fig. 1.
[b] Size of the FWHM observed with the ^{13}CO (1–0) line.
[c] Derived using the ^{13}CO column density and the conversion ratio $H_2/^{13}CO = 6 \times 10^5$ (Dickman 1978).

cm^{-3}, which are similar to those in dense dark clouds in the Galactic plane. The observed CO linewidths (~ 2 km s^{-1}) suggest that turbulent motions exist and the cloud will disrupt in a time scale of 10^6 yrs.

In this previous study (Minh et al. 1996) the ^{12}CO and ^{13}CO (1–0) lines were obtained using the 15-element focal plane array of the Five College Radio Astronomy Observatory (FCRAO). In the early days of QUARRY the spectrometer for each array element was the 16 channel filter bank of 250 kHz resolution. During our observing time the backend system was unstable and we could not have obtained full informations of the detected lines. Therefore, we have used the Onsala Telescope, which has a better resolution (250 kHz vs. 25 kHz per channel approximately) spectrometer to study properties of the dense cores with the ^{13}CO (1–0) line.

(b) Properties of the Molecular Cores Identified with the ^{13}CO (1–0) Line

The molecular component in HLCs has been thought to be condensed from extended H I gas, and the process could be initiated from shocks or large-scale instabilities (cf. Blitz 1987; Elmegreen 1988; Meyerdierks et al. 1991; Burrows et al. 1993; Magnani et al. 1993). As was mentioned in the previous section, the morphology of the molecular component in MBM 7 suggests a result from a shock compression. Since the cooling or recombination time scales after the shock are thought to be short ($10^3 - 10^4$ yrs), molecules could be formed in the early phase of cloud formation. The relatively small scale structures in MBM 7 could be formed via thermal instabilities or dynamical processes.

Fig. 1 shows the integrated intensity map of the ^{13}CO (1–0) line. The molecular cores appear to be very clumpy and elongated along the northwest–southeast direction, perpendicularly to the extended H I component. We derive physical parameters for the two cores identified in the ^{13}CO (1–0) map and present them in Table 2. The distance to MBM 7 was assumed to be 150 pc as was mentioned earlier and the size was estimated from the FWHM (Full Width at Half Maximum) of the cores identified in the ^{13}CO (1–0) map. The cloud parameters are included in Table 2. The total H_2 column density in the table has been derived from the observed ^{13}CO (1–0) line, assuming optically thin emission, $T_{rot} = 10$ K, and the conversion ratio of $H_2/^{13}CO = 6 \times 10^5$ (Dickman 1978).

We estimate a mean volume density of $n(H_2) = 1.7 \times 10^3$ cm^{-3}, assuming that the size of the core in the line of sight is about twice the projected size of FWHM in Table 2. The structure of MBM 7 is very complicated and the filling factor may be less than 50%. So our value should be a low limit and the actual volume density in the dense region could be as high as $n(H_2) > 10^4$ cm^{-3} as Reach et al. (1995) have estimated using the mm-wave transitions of CS, HCO^+, and HCN.

The masses of the cores are determined using

$$M = N(H_2) \times \mu m_H \times 2 \times \text{Area(inside of FWHM)} \tag{1}$$

where $\mu = 1.36$ amu per H nucleus accounts for the mass of He and other elements. We derive the masses of the MBM 7 cores to be 1–2 $M_\odot$ (Table 2). The results would depend largely on the size (FWHM) which is determined by the distance to the source and the observed spatial resolution of the telescope used. Our values for the cores are similar to those found in another HLC MBM 40 (Minh et al. 2000) and dense dark globules in the Galactic plane (Kim 1997) within a factor of 2–3. It is an interesting subject whether there is a basic *unit* of clump embedded in dark clouds and we think that, if there is such a unit, our results for MBM 7 cores may close to the representative parameters of the basic unit for general dark clouds.

(c) Stability Test of the Molecular Cores

We have tested the stability of the cores and their possible evolutions using the full version of the scalar virial therom. The theorem includes the external pressure (P_{ext}) and the systematic motion of the cloud (ΔV_{sys}). The further details of this theorem can be found in Kim (1997), Kim & Hong (2000), and Minh et al. (2000). The relation is,

$$\frac{3}{5} M R \ddot{R} = -\frac{3}{5}\frac{GM^2}{R} + M < V_{tur}^2 > - 4\pi R^3 P_{ext}, \tag{2}$$

where $<V_{tur}^2>$ is $(3/8\ln 2)\,\Delta V_{FWHM}^2$ and R is the radius of the clump. Multiplying $\dot{R}/R$ to both sides and integrating with respect to time, the equation can be expressed for the effective total energy ϵ,

$$\epsilon = \Psi(r; p_{ext}) + \frac{1}{10}\left(\frac{\Delta V_{sys}}{< V_{tur}^2 >^{1/2}}\right)^2, \tag{3}$$

and the dimensionless effective potential energy Ψ of the system is defined as

$$\Psi(r; p_{ext}) = -\frac{1}{r} - \frac{4}{3}\ln r + \frac{1}{9} p_{ext}\, r^3, \tag{4}$$

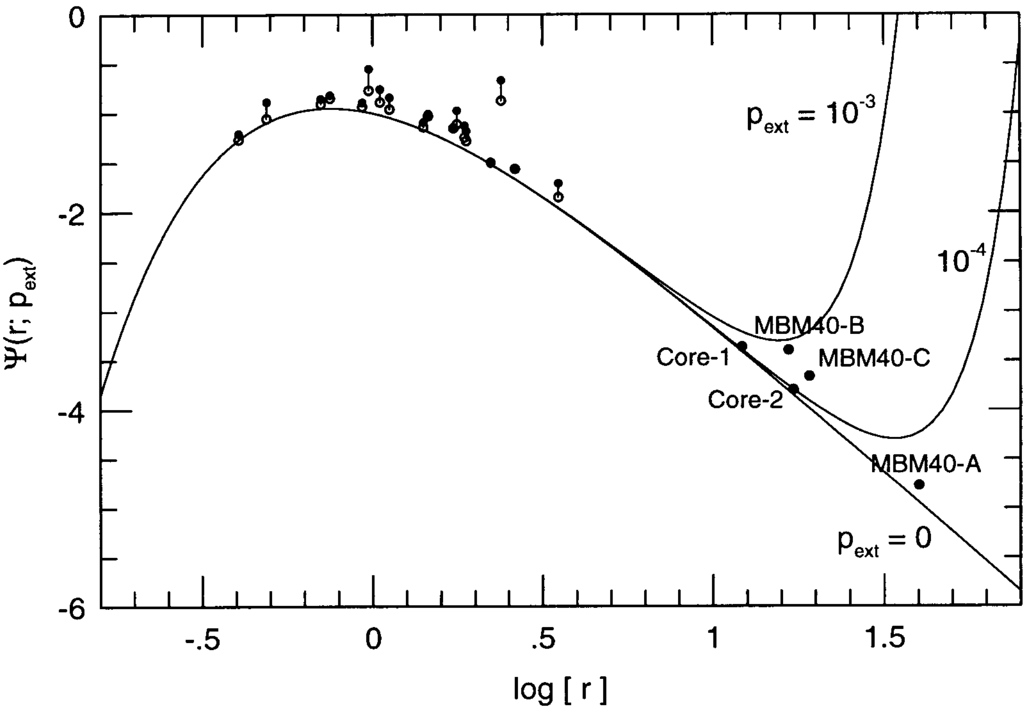

Fig. 3.— A schematic illustration of the normalized effective potential energy Ψ. The values for dense globules sampled by Kim (1997) are indicated. The vertical lines in these samples indicate the amount of ΔV_{sys}. The MBM 40 results (Minh et al. 2000) are also shown.

where r ($\equiv R/R_o$) and p_{ext} ($\equiv P_{ext}/P_o$) are normalized dimensionless radius and pressure, respectively, for

$$\begin{aligned} R_o &= \frac{4}{5}\frac{GM}{<V_{tur}^2>} \\ &\simeq 3.44 \times 10^{-3}[\mathrm{pc}] \left[\frac{M}{M_\odot}\right] \left[\frac{\mathrm{km\ s^{-1}}}{<V_{tur}^2>^{1/2}}\right]^2 \end{aligned} \qquad (5)$$

and

$$\begin{aligned} P_o &= \left(\frac{1}{4}\right)^4 \frac{5^3}{4\pi} <V_{tur}^2>^4 \frac{1}{G^3M^2} \\ &\simeq 3.31 \times 10^{-7}\,[\mathrm{dynes\ cm^{-2}}] \left[\frac{<V_{tur}^2>^{1/2}}{\mathrm{km\ s^{-1}}}\right]^8 \left[\frac{M_\odot}{M}\right]^2 . \end{aligned} \qquad (6)$$

The function Ψ is shown in Fig. 3.

If a clump collapses gravitationally, its normalized radius r is smaller than 1 (i.e. $R \leq R_o$). Otherwise the size of the clump will oscillate between the radii bounded by the function Ψ, if there are no external perturbations (i.e. it is in the 'oscillatory equilibrated phase'). The figure also includes the results for the dense globules in the Galactic plane (Kim 1997), a high-latitude cloud MBM 40 (Minh et al. 2000). The test by Kim (1997) suggests that about one third of the dense dark globules sampled in the galactic plane are in the possible gravitational collapse, which is somewhat smaller than the previous thought on the collapsing rate of about 50% (Clemens & Barvainis 1988).

The vertical lines indicate the size of the observed ΔV_{sys}, which is negligible for high-latitude clouds. For MBM 7 cores we derive $p_{ext} \sim 10^{-4}$ assuming the pressure of the general interstellar medium, $P_{ext} = 1 \times 10^4$ K cm^{-3} (Shull & Woods 1985; Pound & Blitz 1993). The MBM 7 cores appear to be stabilized as $\Delta V_{sys} \approx 0$ but will oscillate between the present size and about 3 × present radius (the range of r bounded by $p_{ext} = 10^{-4}$). Therefore the MBM 7 cores will not collapse gravitationally without a sufficient external perturbations such as shocks or cloud-cloud collisions, and we think that MBM 7 is not a site for new star formation.

(d) Molecular Abundances of the Core

We have observed the 3 mm transitions from 7 interstellar molecules toward the offset (0, 3′) position. The observed spectra are shown in Fig. 2. The molecular lines in the right panel of Fig. 2 are expected to be optically thin. We derive their abundances assuming LTE and $T_{rot} = 10$ K as was discussed previously, in addition to the assumption of optically thin emission. Table 1 includes the beam-averaged column densities in the last column.

We show the comparisons of the fractional abun-

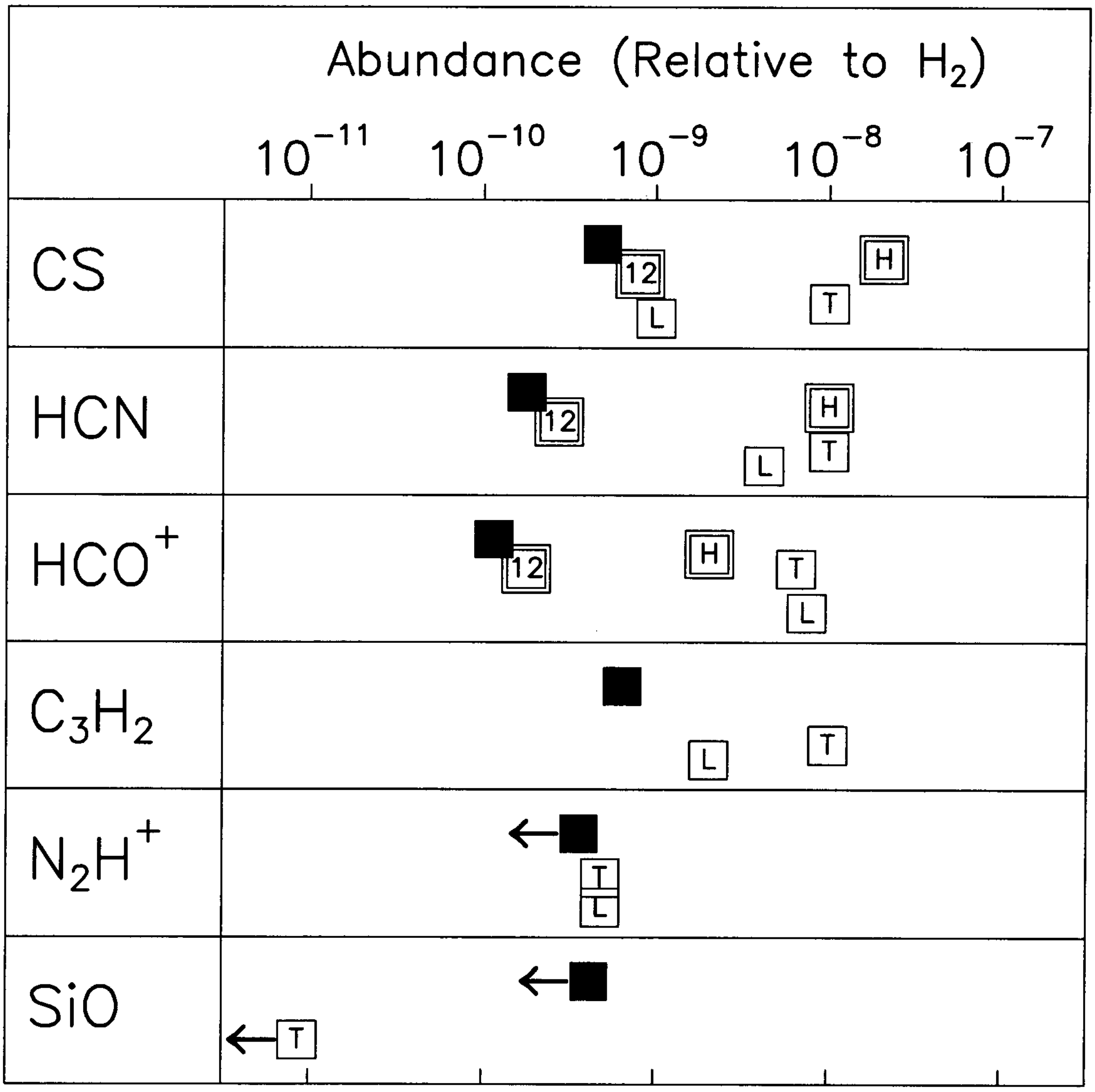

Fig. 4.— Comparisons of the fractional abundances relative to H_2 of the observed molecules toward high-latitude clouds and typical dark clouds. The black squares are for MBM 7, 12 for MBM 12 (Minh et al. 1994), H for a translucent cloud HD169454 (Gredel et al. 1994), T for TMC1, and L for L134N (Ohishi et al. 1992). The upper limits of the abundances are indicated as arrows.

dances relative to H_2 for the observed species in Fig. 4. The black squares are the results of this study and we also include the data for another high-latitude cloud MBM 12 (Minh et al. 1994), a translucent cloud HD169454 (Gredel et al. 1994), and typical dense dark clouds TMC1 and L134N (Ohishi et al. 1992). The results for HLCs, MBM 7 and MBM 12, show much less molecular abundances than those for other sources by orders of 1 or more. It is not clear whether this difference is real since the abundances are beam-averaged values which largely depend on the filling factor and also there should be many error sources in deriving the abundances.

Since the total hydrogen column densities of HLCs are much lower than other sources, the optical depth problems of the observed lines may be less serious in HLCs. One of the other possible error sources is the partition function, which is a critical parameter in deriving the total column density but depends largely on the rotational temperature. The 50% error in T_{rot}, however, gives about 10–20% error in the final values. Considering other error sources, such as telescope efficiencies, spectral noises, possible multi-component structures of the sources, etc., we think that the total error in deriving the 'beam-averaged' molecular abundances should be less by a factor of 2.

Since we compare the 'fractional' abundances relative to H_2, another important error could result from the estimation of the total hydrogen abundance. In this study we derive the total H_2 abundance from the ^{13}CO (1–0) results and the conversion ratio $H_2/^{13}CO = 6\times 10^5$ (Dickman 1978). The ^{13}CO (1–0) line optical depths could be larger in dense dark clouds in the Galactic plane than in HLCs, which may result in another factor of 2–3 error in comparisons of molecular abundances. Our study for MBM 40 (Minh et al. 2000) also suggests that there is a possibility for different degrees of depletion in dense dark clouds and HLCs, which suggest that the $^{13}CO/H_2$ conversion ratio could be larger in HLCs.

Even though we consider all these uncertainties, we conclude that the abundances of several heavy molecules, such as CS, HCN, and HCO^+ often used as tracers of important parameters, are less in HLCs than in dense dark clouds in the Galactic plane. Our results may suggest the different chemical evolutionary stage or different chemical environments for HLCs compared to typical dark clouds in the Galactic plane. The HLCs belong to the category of the translucent cloud (van Dishoeck & Black 1988) which is the region where the atomic carbon ion C^+ transforms to the molecule CO, and there are many evidences that HLCs were affected by shocks and their evolutions could be very different with the dense dark clouds in the Galactic plane (e.g. Minh et al. 1996). We think that the chemistry in HLCs could be much different with that in dense dark clouds in the Galactic plane and needs to be studied much further.

IV. SUMMARY

The ^{13}CO (1–0) line was observed with the 20-m radio telescope of the Onsala Space Observatory and the 3 mm-wave transitions from several other molecules with the 14-m telescope at TRAO. The molecular component appears to be very clumpy and elongated along the northwest–southeast direction, perpendicularly to the extended H I component, which could be resulted from shock formation. We derive physical parameters of the two cores identified from the ^{13}CO (1–0) map, the sizes of the cores are 0.1–0.3 pc, masses 1–2 $M_\odot$, and the mean volume density $n(H_2) \sim 2 \times 10^3$ cm^{-3}.

We tested the stability of the cores using the full version of the virial theorem and found that the cores in MBM 7 are stabilized with the ambient medium in the oscillatory equilibrated phase. Therefore they will not be dissipated easily without the external perturbations but hardly a place for a region of new star formation.

We have observed the mm-wave transitions of $C^{18}O$, CS and ^{13}CS, HCN, HCO^+, C_3H_2, N_2H^+, and SiO using the 14-m radio telescope of TRAO. Several molecules observed toward the core of MBM 7 are found to be less in their fractional abundances relative to H_2 by more than 1 order of magnitude compared to those in the typical dense dark clouds. If the depletions of heavy elements, such as C or O, are not *abnormally* significant in HLCs, our results may suggest the different chemical evolutionary stages or different chemical environments of HLCs compared to typical dark clouds in the Galactic plane.

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