Journal of The Korean Astronomical Society
39: 19 ∼ 24, 2006

A SEARCH FOR MOLECULAR CLOUDS AT HIGH GALACTIC LATITUDE

Seungyoup Chi and Yong-Sun Park
Astronomy Program, SEES, Seoul National University, Seoul 151-742, Korea
E-mail: csyoup@astro.snu.ac.kr
(Received November 24, 2005; Accepted December 19, 2005)

ABSTRACT

We carried out CO survey toward IR-excess clouds using SRAO 6-m telescope in search of molecular H_2. These clouds, which show far-infrared excess over what is expected from HI column density, are considered to be candidates of molecular clouds. In order to find new high Galactic latitude clouds, we made mapping observations for 14 IR-excess clouds selected from Reach *et al.*(1998) in ^{12}CO $J = 1-0$ line, supplementing the similar survey in southern hemisphere (Onishi *et al.* 2001). ^{12}CO emission is detected from three IR-excess clouds among 14 objects. Three newly detected clouds exhibit somewhat clumpy morphology and column densities amount to $\sim 10^{21}$ cm^{-2}. One of three clouds, DIR120-28, show discrepancy between IR-excess center and CO emission center. It seems that IR-excess may not be an effective tracer of molecular gas. Instead, optical depth(τ) excess, i.e., IR-excess corrected for temperature dependence, may be more effective tracer of molecular clouds, since, by combining statistics from both hemispheres, we found that the detection rate is higher for IR-excess clouds with lower dust temperature.

Key words : ISM: cloud—ISM: molecules

I. INTRODUCTION

The infrared all-sky survey by the *Infrared Astronomical Satellite (IRAS)* opened new perspectives on interstellar medium. The Galactic radiation in the far-IR appears to arise mostly from dust grains well mixed with interstellar gas (Mathis *et al.* 1983). The *IRAS* 100 μm emission intensity generally has been found to be correlated with the HI column density (de Vries *et al.* 1987; Boulanger *et al.* 1996). Therefore, if the IR emission arises from both atomic and molecular phase of interstellar gas, then the regions that show more IR emission than what is expected from HI column density are the likely locations of molecular gas. Consequently, one can use I_{100} excess, the excess of IR intensity at 100 μm, as a tracer of molecular clouds.

On the basis of this idea, several groups identified IR-excess clouds, which show the excess of IR intensity, to investigate the distribution of molecular gas. However, there is a substantial difference between the distribution of IR-excess clouds and that of CO molecular clouds (Désert *et al.* 1988; Blitz *et al.* 1990; Heithausen *et al.* 1993; Reach *et al.* 1994). This discrepancy between the two distributions is in a sense expected, because (1) the dust abundance and radiation-field strength vary, (2) the CO abundance is low in diffuse molecular clouds, and (3) the IR emissivity of the dust associated with molecular gas is low (Kim *et al.* 1999).

On the other hand, Reach *et al.* (1998) studied the distribution of IR-excess clouds at high Galactic latitude ($|b| > 20°$) using far-IR data from the *Cosmic Background Explorer (COBE)* and HI data from combined Leiden-Dwingeloo and Parkes 21 cm line surveys. The *COBE* observations at 100, 140, and 240 μm wavelengths provide a reliable measure of the emission from large grains at thermal equilibrium that dominate the dust mass (Désert *et al.* 1990). They created an atlas of IR-excess clouds. These clouds may be good candidates of molecular clouds, but these IR-excess clouds could be caused either by dust that is just warmer than average or by dust associated with molecular gas. In their IR-excess clouds catalog, warm clouds, which appeared relatively bright at 60 μm, are just a few. In addition, they found the dust temperature in known high Galactic latitude clouds (HLCs) is 15.5±1, while dust temperature in atomic gas is 19±2 K. Therefore, they suggested that IR-excess clouds in their catalog, which are not identified before, are similar to HLCs.

Onishi *et al.* (2001) observed 68 IR-excess clouds among 82 unidentified objects of Reach *et al.* (1998) in ^{12}CO (J=1–0) line using NANTEN 4-m telescope at Las Campanas, Chile. CO emission was detected from 32 IR-excess clouds, corresponding to a CO detection rate of 47%. The CO detection rate for cold ($T_{dust} < 17K$) IR-excess clouds is 72%, which is about a factor of two higher than that for warmer ones, 33%. And they suggested additionally that IR-excess clouds without CO emission are most likely to be molecular hydrogen clouds because the temperature of these clouds is similar to, or lower than, that of the surrounding HI gas.

In this study, we observed 14 IR-excess clouds which are not observable from NANTEN to cover all IR-excess clouds catalogued by Reach *et al.* (1998), and

Corresponding Author: S. Chi

newly identified three molecular gas at high Galactic latitude. The observation is described in section II and the observational results are presented in section III. Section IV discusses implication of this observational study.

II. ^{12}CO SURVEY TOWARD IR-EXCESS CLOUDS

We have observed ^{12}CO J=1−0 (115.271204 GHz) molecular line for 14 IR-excess clouds by using SRAO (*Seoul Radio Astronomy Observatory*) 6-m telescope in Seoul National University (Table 1). The beam size of the telescope is 100″ and the main beam efficiency is 0.70 at 115 GHz. The pointing accuracy was measured to be better than 10″ in both azimuth and elevation. A 1024 channel auto-correlator with a bandwidth of 50 MHz was used as a backend and the antenna temperature, T_A^*, was calibrated by the chopper wheel method. The spectral resolution is 49 kHz, corresponding to a velocity resolution of 0.127 km s^{-1} at the CO frequency (Koo *et al.* 2003).

The first observational session was carried out from 2002 March to April. We mapped the central 80′ × 80′ area of the 14 IR-excess clouds by position-switching mode, with 8′ spacing and $\Delta T_R^* \sim 0.2$ K in the spectral resolution of 0.25 km s^{-1}. And the second run was from 2002 November to 2003 April. The second observations were carried out by frequency-switching mode with the velocity offset of 20 km s^{-1} or 30 km s^{-1} considering the telluric CO line. The spectral resolution and the sensitivity were the same as the first. We observed the central 40′ × 40′ area of each object with 4′ spacing. The second observation is for reconfirming the ^{12}CO detection. The third, which is for extending the mapping area for three clouds which show CO emission, is also carried out with position-switching mode from 2003 October to December. The spacing, spectral resolution, and sensitivity of the third term are the same as those of the second.

III. OBSERVATIONAL RESULTS

We detected ^{12}CO emission from three objects, DIR 070+23, DIR 120-28, and DIR 150-29, among the 14 IR-excess clouds through the first and second observations (Table 1). Figure 1 presents ^{12}CO integrated intensity maps and *IRAS* 100 μm images of these three detected clouds. The (0, 0) position of ^{12}CO map is indicated by a white cross in each *IRAS* image. ^{12}CO map of each clouds shows clearly its clumpy structure, so these clouds seem small cloudlets. In the case of DIR 120-28, we could not detect any CO emission in the planned region, where is around white cross, but mistakenly made additional observation toward the southwest region, 1° × 1° off from the planned region and detected CO. These three IR-excess clouds have not been discovered so far. Although Hartmann *et al.* (1998) and Magnani *et al.* (2000) surveyed all sky with 1.2 meter Columbia telescope, the surveys were very coarse (1° spacing) and significantly undersampled.

The peak CO intensities of the detected clouds are 2.9, 6.1, and 3.6 K. The line width (FWHM) is from 0.8 to 2.0 km s^{-1}. We calculated the column density for the clouds assuming the H_2 to CO conversion factor, $[N(H_2)/W(CO)]$, of 1.3×10^{20} cm^{-2}(K km s^{-1})$^{-1}$ (Reach *et al.* 1998). The column densities are found to be $9 \times 10^{19} \sim 1.5 \times 10^{21}$ cm^{-2} (Table 1).

The cloud detection rate of our observation is 20%, and when we consider the cold IR-excess clouds only with dust temperature less than 17 K, the detection rate increases to 25% (1/4). This value is still less than the value of ∼ 70% obtained for southern clouds (Onishi *et al.* 2001).

In case of DIR 120−28, the position of IR-excess peak is far from the region in which CO emission is detected. No CO emission is detected 40′ × 40′ area around IR-excess center. Instead, CO emission is bright in the southwest region, which is 1° × 1° off from IR-excess center. Considering the size of DIR 120−28 (∼ 2.4° in Table 1), the region that show bright CO intensity seems to be the rim of this IR-excess cloud. For IR-excess clouds without CO emission including DIR120−28, it seems that the IR-excess is not an effective tracer of molecular gas.

IV. DISCUSSION

Even though the number of our sample is not enough statistically, it looks like that the detection rate of our samples is much lower than that of Onishi *et al.* (2001). This is probably due to the fact that our samples are mainly in the northern hemisphere. In the samples observed by Onishi *et al.* (2001), 47 objects among 68 (70%) are in southern Galactic hemisphere (SGH), and 24 clouds of 32 (75%) which are detected at CO are located in SGH. In our samples, only three objects of 14 (21%) are located in SGH and the two CO detected clouds are in SGH. When we calculate the CO detection rate of 82 IR-excess clouds for each hemisphere, we find that the detection rate is 28% (NGH) and 52% (SGH), respectively. This difference between NGH and SGH could be explained by the fact that a lot of IR-excess clouds in NGH are already identified as molecular clouds through various kinds of observations and the known clouds are already excluded from the samples of Reach *et al.* (1998).

In figure 2, we display correlations among detection, dust temperature, and IR excess flux. Figure 2 clearly shows that IR-excess clouds of which dust temperature are hotter than 19 K have little CO emission. This is consistent with the result that dust temperature in atomic gas is 19 ± 2 K. Additionally, we find the detection rate of objects is highest in the upper-left region. Considering the simple relation, $I_{excess} = B_\lambda(T_{dust}) \cdot \tau_{excess}$, objects in this region have larger infrared optical depth excess, τ_{excess}. Thus the fig-

TABLE 1.
CO PROPERTIES OF IR-EXCESS CLOUDS

Name	l (deg)	b (deg)	V_{LSR} (km s^{-1})	Size (deg)[a]	T_{dust} (K) [b]	T_R^* (K) [c]	$N(H_2)$ (cm^{-2}) [d]
DIR 061+22	61.0	22.0	-	4.0	26.1	-	-
DIR 070+23	69.7	22.5	1.15	1.2	17.2	2.9	9.1×10^{19}
DIR 081+39	81.3	38.5	-	2.5	16.2	-	-
DIR 087+29	86.5	28.5	-	3.5	23.1	-	-
DIR 096+23	96.2	23.0	-	2.0	19.3	-	-
DIR 108+27	108.0	27.0	-	2.7	18.1	-	-
DIR 120−28	120.0	−28.0	−7.37	2.4	17.7	6.1	1.5×10^{21}
DIR 126+37	126.0	37.0	-	0.9	16.7	-	-
DIR 132−30	131.5	−29.5	-	1.9	18.4	-	-
DIR 135+38	134.5	38.0	-	1.4	23.4	-	-
DIR 135+41	134.7	40.6	-	1.4	17.0	-	-
DIR 150−29	150.2	−28.5	−6.99	1.7	16.2	3.6	4.2×10^{20}
DIR 177+33	177.2	33.0	-	1.5	16.3	-	-
DIR 184+26	183.5	26.0	-	1.8	17.8	-	-

[a]The approximate angular diameter

[b]The color temperature obtained from *COBE/DIRBE 100/240* μm ratio assuming emissivity proportional to ν^2

[c]Peak intensity calculated with the main beam efficiency of 0.70. $T_R^* = T_A^*/0.70$

[d]Assuming $[N(H_2)/W(CO)] \sim 1.3 \times 10^{20}$ cm^{-2} (K km s^{-1})$^{-1}$

(a) DIR 070+23

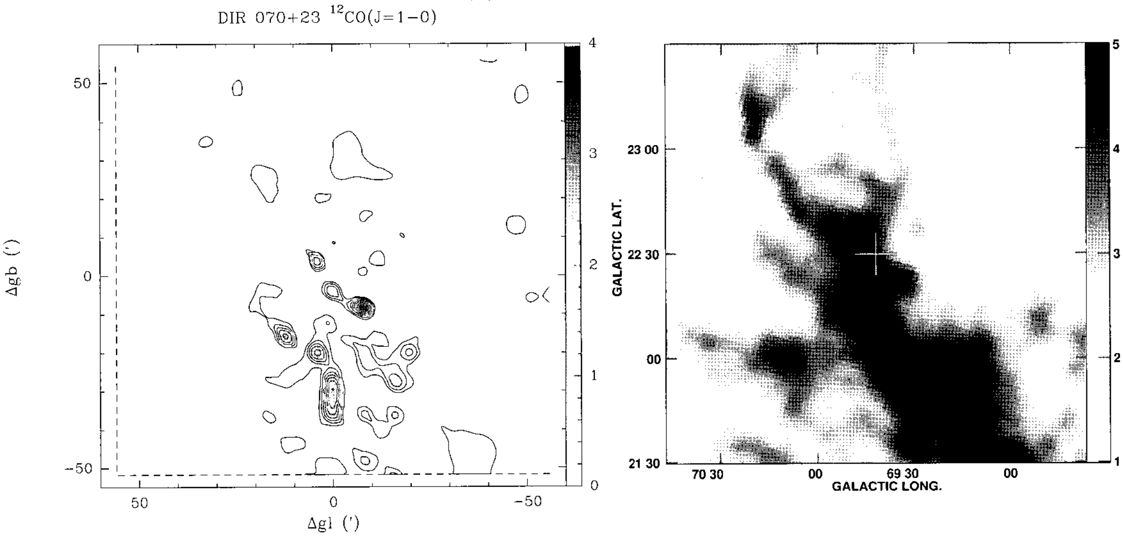
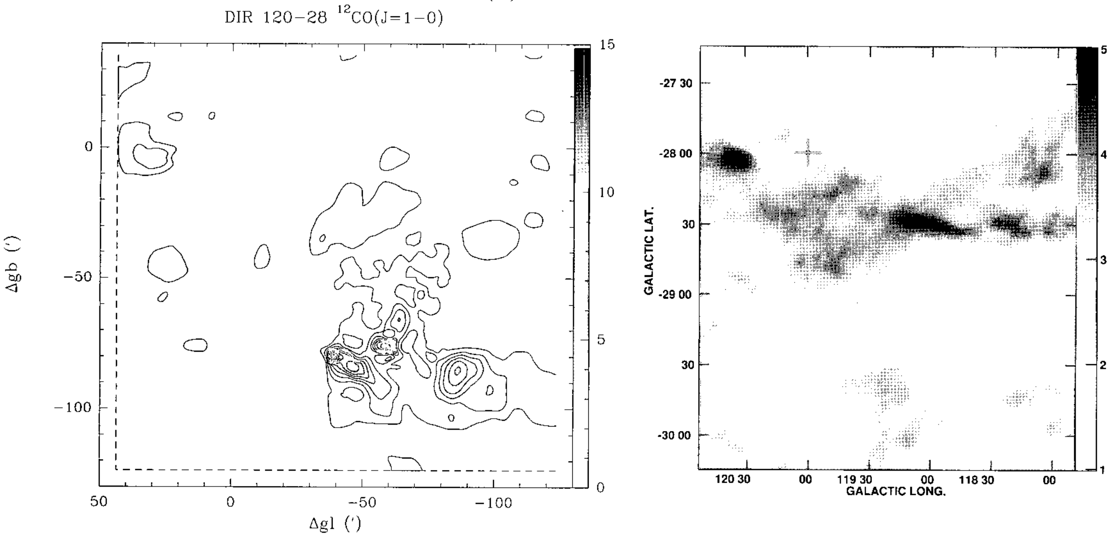


Fig. 1.— Continue to next page.

(b) DIR 120−28



(c) DIR 150−29

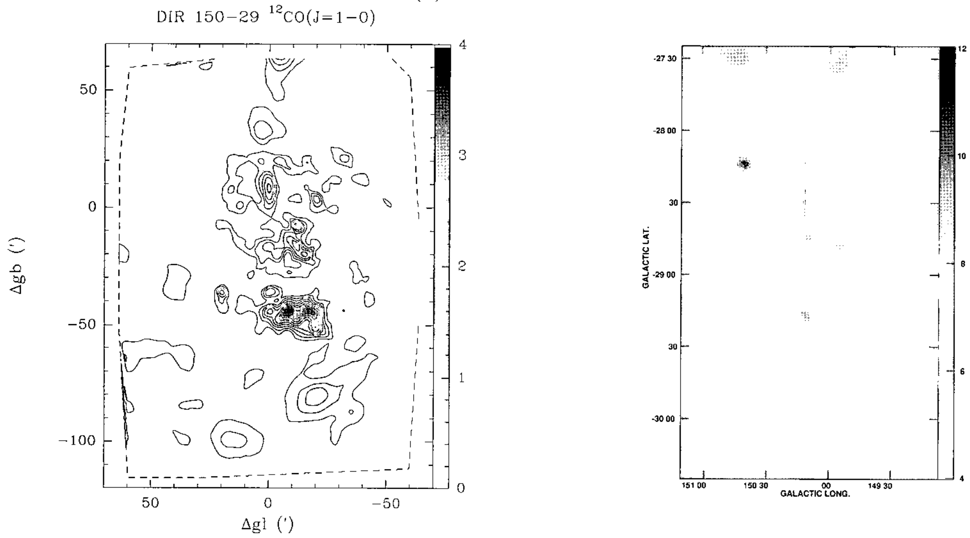


Fig. 1.— ^{12}CO integrated maps of which velocity range is $-10 \sim 10$ km s^{-1} and *IRAS* 100 μm(right) images of three detected objects. The white cross of each *IRAS* 100 μm image represents (0, 0) position in the CO map.

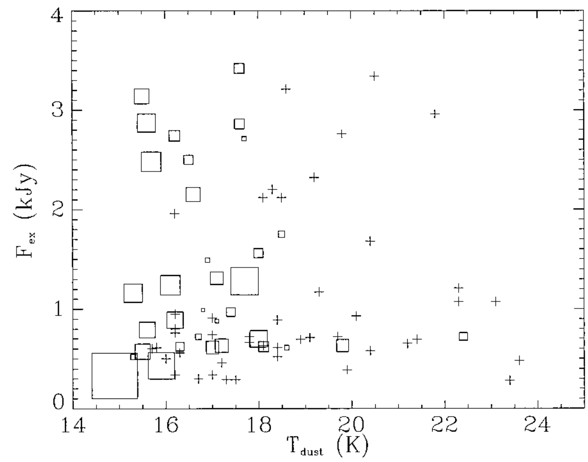


Fig. 2.— Dust temperature versus total amount of IR-excess diagram for all 82 IR-excess clouds. F_{ex} is the averaged value of infrared excess surface brightness at 100 μm within the cloud boundary. Cross symbols indicate IR-excess clouds without CO emission, whereas squares for IR-excess clouds with CO emission. The size of the squares is proportional to CO intensity.

ure suggest that detection rate is higher for objects with larger τ_{excess} and thus the τ_{excess} might be better tracer of molecular clouds. Actually this has been well known on small scale (Reach *et al.* 1994; Boulanger *et al.* 1996; Kim *et al.* 1999; Lee *et al.* 1999). The figure seems to suggest that it holds true even for larger scale. Therefore it is necessary to make τ_{excess} map rather than intensity excess map in order to find molecular gas at high galactic latitude. However, one concern is that we may suffer from dust temperature variation along a line of sight. CO observation toward HLCs revealed by τ-excess map will answer this question.

V. SUMMARY

We have carried out ^{12}CO observation toward 14 IR-excess clouds using SRAO 6-m telescope in order to search for new HLCs. The IR-excess clouds are considered to be good candidates of molecular clouds. The main conclusions of this survey are as follows.

1. We detected ^{12}CO emission from three objects, DIR070+23, DIR128-28, and DIR150-29, among 14 IR-excess clouds. These new detected clouds exhibit clumpy morphology.

2. The column densities of these three clouds are $9 \times 10^{19} \sim 1.5 \times 10^{21}$ cm^{-2}.

3. In the case of DIR120-28, IR-excess center is located far from the region in which CO emission was detected. This results, together with overall low detection rate, could suggest that the IR-excess which has dependence on dust temperature, might not be a good tracer of molecular clouds.

4. The optical depth excess, which is actually temperature corrected IR-excess, might be the more reliable tracer of molecular clouds.

ACKNOWLEDGEMENTS

This study was financially supported from Korea Astronomy and Space Science Institute.

REFERENCES

Blitz, L., Bazell, D., & Désert, F. X., 1990, Molecular Clouds Without Detectable CO, ApJ, 352, L13

Boulanger, F., Abergel, A., Bernard, J. P., Burton, W. B., Désert, F. X., Hartmann, D., Lagache, G., & Puget, J. L., 1996, The Dust/Gas Correlation at High Galactic Latitude, A&A, 312, 256

Désert, F. X., Bazell, D., & Boulanger, F., 1988, An all-sky Search for Molecular Cirrus Clouds, ApJ, 334, 815

Désert, F. X., Boulanger, F., & Puget, J. L., 1990, Interstellar Dust Models for Extinction and Emission, A&A, 237, 215

de Vries, H. W., Heithausen, A., & Thaddeus, P., 1987, Molecular and Atomic Clouds Associated with Infrared Cirrus in Ursa Major, ApJ, 319, 723

Hartmann, D., Magnani, L., & Thaddeus, P., 1998, A Survey of High-Latitude Molecular Gas in the Northern Galactic Hemisphere, ApJ, 492, 205

Heithausen, A. Stacy, J. G., de Vries, H. W., Mebold, U., & Thaddeus, P., 1993, A Composite Large-Scale CO Survey at High Galactic Latitudes in the Second Quadrant, A&A, 268, 265

Kim, K. -T., Lee, J. -E., & Koo, B. -C., 1999, Infrared Excess and Molecular Gas in the Galactic Worm GW 46.4+5.5, ApJ, 523, 306

Koo, B. -C., Park, Y. -S., Hong, S. S., Yun, H. -S., Lee, S. -G., Byun, D. -Y., Lee, J. -W., Choi, H. -K., Lee, S. -S., & Yoon, Y. -Z., 2003, Performance of the SRAO 6-Meter Radio Telescope, JKAS, 36, 43

Lee, J. -E., Kim, K. -T., & Koo, B. -C., 1999, Infrared Excess and Molecular Gas in Galactic Supershells, JKAS, 32, 41

Magnani, L., Hartmann, D., Holcomb, S. L., Smith, L. E., & Thaddeus, P., 2000, A Survey of High-Latitude Molecular Gas in the Southern Galactic Hemisphere, ApJ, 535, 167

Mathis, J. S., Mezger, P. G., & Panagia, N., 1983, Interstellar Radiation Field and Dust Temperatures in the Diffuse Interstellar Matter and in Giant Molecular Clouds, A&A, 128, 212

Onishi, T., Yoshikawa, N., Yamamoto, H., Kawamura, A., Mizuno, A., & Fukui, Y., 2001, A Survey for High-Latitude Molecular Clouds toward Infrared-Excess Clouds with NANTEN, PASJ, 53, 1017

Reach, W. T., Koo, B. C., & Heiles, C., 1994, Atomic and molecular gas in interstellar cirrus clouds, ApJ, 429, 672

Reach, W. T., Wall, W. F., & Odegard, N., 1998, Infrared Excess and Molecular Clouds: A Comparison of New Surveys of Far-Infrared and HI 21 Centimeter Emission at High Galactic Latitudes, ApJ, 507, 507