EXPLORING MORPHOLOGICAL CORRELATIONS AMONG H$_2$CO, $^{12}$CO, MSX AND CONTINUUM MAPPINGS

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ABSTRACT

There are relatively few H$_2$CO mappings of large-area giant molecular cloud (GMCs). H$_2$CO absorption lines are good tracers for low-temperature molecular clouds towards star formation regions. Thus, the aim of the study was to identify H$_2$CO distributions in ambient molecular clouds. We investigated morphologic relations among 6-cm continuum brightness temperature (CBT) data and H$_2$CO (1$_{11}$ − 1$_{10}$; Nanshan 25-m radio telescope), $^{12}$CO (1−0; 1.2-m CfA telescope) and midcourse space experiment (MSX) data, and considered the impact of background components on foreground clouds. We report simultaneous 6-cm H$_2$CO absorption lines and H110α radio recombination line observations and give several large-area mappings at 4.8 GHz toward W49 (50′ × 50′), W3 (70′ × 90′), DR21/W75 (60′ × 90′) and NGC2024/NGC2023 (50′ × 100′) GMCs. By superimposing H$_2$CO and $^{12}$CO contours onto the MSX color map, we can compare correlations. The resolution for H$_2$CO, $^{12}$CO and MSX data was ∼10′, ∼8′ and ∼18.3′, respectively. Comparison of H$_2$CO and $^{12}$CO contours, 8.28-μ m MSX colorscale and CBT data revealed great morphological correlation in the large area, although there are some discrepancies between $^{12}$CO and H$_2$CO peaks in small areas. The NGC2024/NGC2023 GMC is a large area of HII regions with a high CBT, but a H$_2$CO cloud to the north is possible against the cosmic microwave background. A statistical diagram shows that 85.21% of H$_2$CO absorption lines are distributed in the intensity range from −1.0 to 0 Jy and the ΔV range from 1.206 to 5 km s$^{-1}$.

Subject headings: formation; massive; clouds; HII regions; imaging; individual (W49, W3, DR21/W75 & NGC2024/NGC2023)

1. INTRODUCTION

Absorption lines for formaldehyde (H$_2$CO; $J_{K_{a}K_{c}} = 1_{11} − 1_{10}$; ν$_0$ = 4829.659 4MHz), discovered in the interstellar medium by Snyder et al. (1969), are commonly detected toward star formation regions. H$_2$CO is a slightly asymmetric rotor molecule and is inherently sensitive to kinetic temperature. H$_2$CO is an accurate probe of physical conditions in dense molecular clouds (Mangum & Wootten 2002). Anomalous absorption lines can be seen against the 2.7 K cosmic microwave background (CMB; Palmer et al. 1969) and detected in dark clouds. Absorption is strongest at high density and temperature owing to the collisional pumping mechanism. A survey by Downes et al. (1980) between the intensity range from $-1.0$ to $0$ Jy and the $\Delta V$ range from $1.206$ to $5$ km s$^{-1}$.

In this paper, we report large-scale mappings of W49, W3, DR21/W75 and NGC2024/NGC2023.}

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PIEKENBRINK & WENDKER (1993) presented a first extensive survey of the Cyg X-region using H$_2$CO and H110α lines as measured with the 100 m-RT Effelsberg telescope. Heiles clouds 1 and 2 and Lynds cloud L134 were mapped using the Onsala 25-m telescope and the results show that H$_2$CO contours generally coincide with areas of optical obscuration (Sume et al. 1975). Rodríguez et al. (2006) carried out a blind search of anomalous H$_2$CO absorption lines in the general direction of the galactic anticenter radiation using the Onsala 25-m radio telescope. This large-area mapping shows that H$_2$CO absorption and $^{12}$CO emission lines spatially coexist and all H$_2$CO absorption features observed are associated with known $^{12}$CO emission. In addition, Rodríguez et al. (2007) mapped a large region around L1204/S140 using H$_2$CO absorption line as measured with the Onsala 25-m telescope and concluded that $^{12}$CO emission and H$_2$CO absorption lines correlate fairly well, both qualitatively and quantitatively. Nevertheless, large-scale mappings of star formation regions using H$_2$CO absorption lines, especially for large-area GMCs, are relatively few.

McKee & Ostriker (2007) offered a basic description of turbulence, magnetic fields and self-gravity for the key dynamic processes involved in star formation. These three mechanisms influence the systematic velocity and broaden the line width. In general, most massive star formation regions deposit ultracompact HII (UCHII) regions, which are dense and compact bubbles of photoionized gas of less than 0.1 pc in diameter and are surrounded by massive young stellar objects (YSOs; Thompson et al. 2006). Measurement of H110α radio recombination lines (RRLs; ν$_0$ = 4874.157 MHz) and H$_2$CO absorption can be used to determine the kinematic distance of UCHII regions (e.g. Araya et al. 2002; Westerhout 1958). To discern the overall structure of GMCs, correlations among various molecular clouds should be considered and large-scale surveys are necessary.

In this paper, we report large-scale mappings of W49, W3, DR21/W75 and NGC2024/NGC2023 GMCs, almost all of which have a thermal background. We compare the relations among H$_2$CO, $^{12}$CO and MSX data and the continuum brightness temperature (CBT). The remainder of the paper is organized as follows. Section 2 describes the observations, data...
production and relevant parameters. In Section 3, we presents mappings for H$_2$CO, $^{12}$CO, MSX and CBT data. In addition, we report some associations among $^{12}$CO, H$_2$CO and continuum spectra, and define ranges for relations between line width and intensity. Finally, conclusions are presented in Section 4.

2. OBSERVATIONS AND DATA

2.1. Observations

Observations were made discontinuously from October 2009 to January 2011 using the Urumqi Nanshan 25-m telescope, which affords a half-power beam size (HPBW) of approximately 10' at 4.8 GHz. H$_2$CO absorption and H110α RRL spectra were simultaneously obtained using a 4096-channel digital autocorrelation spectrometer at a bandwidth of 80 MHz using position switching. The central velocity was $V_{LSR} = 0.0$ km s$^{-1}$, the frequency was $F_{center} = 4851.9102$ MHz, and the velocity channel width was 1.206 km s$^{-1}$. To achieve a better signal-to-noise ratio (S/N), the ON-source integration time was tens of minutes to up to several hours. CBT data at 4.8 GHz were processed with a bandwidth of about 400 MHz. The CBT error was approximately 1% and sensitivity was approximately 75 mJy. The system temperature during observations was 23 K. A diode noise source was used to calibrate the spectra and the flux error was 15%. The pointing accuracy was better than 15' for all observations and the antenna efficiency was 62%. The DPFU (degrees per flux unit) value was 0.116 K Jy$^{-1}$.

2.2. Data Reduction

Data reduction for H$_2$CO absorption lines and H110α RRLs was performed using CLASS and GREG, which are part of the GILDAS software developed by IRAM. Furthermore, 8.28-$\mu$m mid-infrared MSX archive data were handled using SAOImage DS9, Adobe Photoshop 7.0.1, Origin 8 and Adobe Illustrator CS software. Starlink software was used to process $^{12}$CO cube data (Dame et al. 2001) to obtain parameters (integration intensity, velocity, intensity and line width) for comparison with H$_2$CO parameters.

2.3. Data Exhibition

MSX data traces star formation regions, and mainly traces the dust continuum emission from core, so that we could compare the distributional relation between H2CO and MSX data, and shed light on the background environment for star formation regions, CBT data at 4.8 GHz and MSX data for the 8.28-$\mu$m band were used as the background for H$_2$CO contours. The correlation between MSX colorscale images and H$_2$CO absorption contours is described in Section 3. The 2.6-mm $^{12}$CO data from the 1.2-m Cfa telescope (Dame et al. 2001) were used as a background to determine their relationship. The CO beam size was ~8', which is comparable to that for H$_2$CO (~10').

The optical depth, column density and mass for measured H$_2$CO absorption lines were calculated in the usual way. According to Bieging et al. (1982), the optical depth is

$$\tau_{app} = -\ln[1 + \frac{T_L}{T_c + T_{bgd} - T_{ex}}],$$

where $T_L$ is the line intensity measured, $T_c$ is the CBT and $T_{bgd}$ is the 2.7 K cosmic background temperature. $T_{ex}$ is the 1.7 K excitation temperature of the H$_2$CO $1_{10} - 1_{11}$ transition.

The H$_2$CO column density was calculated at the $1_{11}$ level as:

$$N(H_2CO) = 9.4 \times 10^{13} \tau_{app} \cdot \Delta V,$$

where $\Delta V$ is the H$_2$CO FWHM in km s$^{-1}$. Thus, the column density is (Scoville & Solomon 1973):

$$N(H_2) = 0.8 \times 10^9 N(H_2CO).$$

Finally, we used the following equation (Poeppel et al. 1983)

$$M(H_2) = S \cdot \frac{N(H_2) \cdot m_H \cdot r^2}{(arcmin)^2 \cdot N(H_2) \cdot M_\odot \cdot r^2},$$

where $S$ is the observational area, $N(H_2)$ is the average column density, $m_H$ is the mass of the H$_2$-molecular and $r$ (kpc) is their distances.

Table 1 lists ID numbers corresponding to the (0, 0) offset position in Figs. 1, 2, 3 and 4 for the four sources. Columns 3 and 4 show equatorial coordinates for the (0, 0) offset position. The distance in Column 5 comes from references (1, 2, 3 and 4) in Column 7. The size ($\alpha \times \delta$) in Column 6 is the approximate survey region, which is much larger than in previous studies. Column 7 lists the $H_2$ clouds mass and Column 8 the total integration time in the ON-position for every point source. In Column 9, $A$ is the number of all observational positions toward the sources, $B$ is the number of H$_2$CO absorption lines, and $C$ is the number of H110α RRLs. Hence, the detection rate is 56.95% for H$_2$CO absorption lines and 10.60% for H110α RRLs.

Figs. 1, 2, 3 and 4 present spectral mosaics of H$_2$CO absorption lines and H110α RRLs toward W49, W3, DR21 and NGC2024 GMCs. The relative observational positions and the corresponding parameters are listed in Tables 2, 3, 4 and 5. The offset position is indicated on the relative coordinate axis and the step size is 10'. The velocity components were identified by Gaussian fitting. All spectra are included, regardless of whether they contain signals. There are many blank panels for which sources could not be detected. Finally, all H$_2$CO absorption lines exhibited are stronger than 3σ in intensity. However, some of the H110α RRLs did not reach 3σ in intensity, as denoted by a in Tables 2, 3, 4 and 5. For faint (< 3σ) H110α RRLs, the spectra are shown for information only and were not studied further.

Tables 2, 3, 4 and 5 list the relevant parameters for H$_2$CO absorption lines and H110α RRLs. The serial number and coordinate offset are listed in Columns 1 and 2 for the corresponding spectral mosaics (Figs. 1, 2, 3 and 4). Columns 3–6 lists parameter data for H$_2$CO absorption lines, while those for H110α RRLs are in Columns 11–14. Columns 3 and 11 list line-of-sight velocity data relative to the Sun. Columns 4 and 12 list the integration intensity flux for each velocity component. Columns 5 and 13 list line width (FWHM) data with $\Delta V$. Columns 6 and 14 list spectral intensity data. Columns 7–10 list the CBT at 4.8 GHz, the H$_2$CO optical depth, and the H$_2$CO and H$_2$ column density, respectively. The optical depth ($\tau_{app}$) range is approximately 0.007–0.188, so H$_2$CO is optically thin. The column density ($N(H_2CO)$) range is approximately $0.121 \times 10^{13}$ cm$^{-2}$–$3.59 \times 10^{13}$ cm$^{-2}$. In addition, $N$ indicates that the corresponding spectra could not be detected. H110α RRL data with a signal intensity of < 3σ are denoted by a.
Fig. 5 shows an overlay of the integration intensity for H$_2$CO and $^{12}$CO contours onto the 8.28-µm MSX color map. And, several representative objects are indicated in the maps. From Fig. 5, we find that the large area distributions of them are consistent, but there are some off-peak discrepancy between $^{12}$CO peaks and others. We also compare the relations between velocity (Fig. 8), integration intensity (Fig. 9), intensity (Fig. 10) and line width (Fig. 11) to look for the relations between H$_2$CO and $^{12}$CO. Moreover, we also overlay the H$_2$CO contours onto the 4.8 GHz continuum temperature contours in Fig. 6. From Fig. 6, we find that there is a good consistent morphologic distribution between H$_2$CO and CBT, and we also made a relation (Fig. 7) between integration intensity of H$\alpha$CO and CBT to derive a formula (Eqn. 6). Basing above, we suggest that H$_2$CO contours are more strongly correlated with the distribution of the continuum components than $^{12}$CO, so that it is possible to produce the off-peak discrepancy. The character of these four GMCs is analyzed in Section 3.

3. RESULTS AND DISCUSSION

3.1. GMC descriptions

3.1.1. W49 GMC

The W49 GMC radio source was discovered in a 21-cm continuum survey by Westerhout (1958). The W49 GMC complex consists of a thermal component (W49A) and a nonthermal component (W49B). W49A is one of the most luminous galactic giant radio HII regions (Dreher et al. 1984; de Pree et al. 1997), and W49B is a supernova remnant (SNR). W49B and W49A are separated by 12.5’ along an east-west line at a kinematic distance of 11.4 kpc (Gwinn et al. 1992). At this distance, 10’ = 33.16 pc. A giant-scale area (approx. 50’ × 50’) was surveyed toward W49 GMC. During 966 minutes of integration, we observed five H$_2$CO absorption lines and two H110α RRLs. In our spectra (Fig. 1(a)), three H$_2$CO components of $\sim$15.9, $\sim$40.9 and $\sim$64.3 km s$^{-1}$ were detected. Brogan & Troland (2001) mapped the HII region of W49A and W49B with 21-cm HI data, which revealed velocities of $\sim$4 and $\sim$7 km s$^{-1}$ toward W49A, and $\sim$40 and $\sim$60 km s$^{-1}$ toward W49A and W49B. H$_2$O emission lines were also observed at $\sim$39 and $\sim$60 km s$^{-1}$ in W49A (Buhl et al. 1969). Furthermore, three absorption features at velocities of $\sim$15, $\sim$40 and $\sim$60 km s$^{-1}$ were found for 18-cm OH absorption lines (Pastchenko & Slysh 1973). It is possible that the W49 GMC has an intricate kinematic structure or different velocity subclouds piled up in the line of sight. The multiple velocity components may arise from the Sagittarius spiral arm clouds (Brogan & Troland 2001). There is no clear evidence that W49B is closer to the Sun than W49A. However, many researchers are interested in whether W49A and W49B are physically correlated. Considering the uniform velocity components $\sim$4.5, $\sim$10.5, $\sim$15.9, $\sim$40.9 and $\sim$64.3 km s$^{-1}$ from W49A and W49B, a physical association between them can be inferred.

3.1.2. W3 GMC

W3 GMC, at 1.95 kpc from the Sun (Xu et al. 2006), lies to the western edge of W4 GMC. At this distance, 10’ = 5.672 pc. W3 GMC is made up of three knots of molecular gas known as W3 Main, W3 North, and W3 OH. The Central Cluster, located between W3 Main and W3 OH, contains a large number of Class II YSOs (Ruch et al. 2007). A giant-scale area (approx. 70’ × 90’) was surveyed toward W3 GMC. We detected 19 H$_2$CO absorption lines and four H110α RRLs during 2370 minutes of integration. The W3 GMC is a complex of massive star formation regions, where there are strong H$_2$CO absorption lines, H110α RRLs, $^{12}$CO emission lines, MSX sources and a CBT. We can clearly distinguish two cores for W3 GMC. At the junction (W3(OH)) of the two clouds, we cannot detect H$_2$CO absorption lines and the CBT is low, but the integration intensity for $^{12}$CO clouds and MSX sources is relatively strong. We hypothesize that many young stars in W3(OH) are surrounded by a thin gas envelope. The velocity for H$_2$CO and H110α ranges from approximately −46.0 to $-$35.0 km s$^{-1}$, which is similar to HI observations (Read 1981). Table 3 reveals a strange phenomenon: a sharp velocity gradient is apparent, which is consistent with $J = 1-0$ $^{12}$CO observations (Thronson et al. 1985). From northwest to southeast, the velocity varies strongly from $-$35.02 km s$^{-1}$ (No. 08) to $-$45.14 km s$^{-1}$ (No. 37) (Fig. 2(a) and Table 3).

3.1.3. DR21/W75 GMC

DR21/W75 GMC is located in the Cygnus constellation, approximately 3.0 kpc from the Sun (Campbell et al. 1982). At this distance, 10’ = 8.727 pc. The MSX color map reveals that DR21/W75 GMC exhibits a complex and dispersive structure, with many separate subclusters assembled together. We surveyed DR21 and W75 GMCs, which include W75N, W75, DR21(OH), DR21, L906E and Diamond Ring (source name). DR21 and W75 GMCs are associated with massive dense cores and are separated by approximately 30’ (Wilson & Mauersberger 1990; Shirley et al. 2003). A giant-scale area (approx. 60’ × 90’) was surveyed toward DR21/W75 GMC. We detected 34 H$_2$CO absorption lines and 8 H110α RRLs during 2742 minutes of integration. The velocity components are multiple and rather intricate (Fig. 3(a)). The velocity is smaller for the northeastern and larger for the southwestern section than for the central section. A velocity gradient exists within these subclouds, and probably arises from GMC rotation. A UCHII region was detected using H110α RRLs as a tracer. The data in Table 4 reveal that the H110α RRL intensity is so weak (indicated by $q$) that we could not obtain a good signal, even with long-time integration. In addition, we only detected part of the DR21/W75 GMC. In particular, for the western part there is a giant and strong MSX region, while the $^{12}$CO cloud is relatively faint. To determine whether or not there is association between H$_2$CO and $^{12}$CO clouds and MSX sources, the western edge of the DR21/W75 GMC should be observed.

3.1.4. NGC2024/NGC2023 GMC

NGC2024/NGC2023 GMC is situated in Orion B at a distance of 415 pc (Menten et al. 2007). At this distance, 10’ = 1.207 pc. The NGC2024/NGC2023 GMC is a bright emission nebula crossed by a prominent dust lane. NGC2024 GMC includes a number of protostars along the star-forming ridge extending in a north–south direction coincident with an HII region, which is in front of filamentary shaped dense molecular material (Gaume et al. 1992). A giant-scale area (approx. 50’ × 100’) was surveyed toward NGC2024/NGC2023 GMC. The area has similar velocity components and integration intensity contours to those reported by Cohen et al. (1983), but our observational instrument was more sensitive than theirs. We detected 28 H$_2$CO absorption lines and two H110α RRLs during 3378 minutes of integration. The H$_2$CO velocity is approximately 11.70 km s$^{-1}$ and comprises a single component.
et al. (2007) and our results. It is suggested that there exists correlation between $H_2$ and $^{12}$CO emission and $^{12}$CO emission lines are widely distributed in this area. Hence, it is possible that the northern $H_2$ and $^{12}$CO absorption lines arise from CMB excitation.

3.2. Comparison of $H_2$ CO distributions and the CBT

It is well known that the $H_2$CO absorption is strongly biased by the high CBT which is being absorbed by the $H_2$CO molecules along the line of sight to the source of the continuum. Here we will give the empirical relationship between $H_2$CO and CBT. In Fig. 6, continuum contours are overlaid on the $H_2$CO contour maps for W49, W3, DR21 and NGC2024 GMCs. The morphology of the $H_2$CO and continuum distributions matches very well. The $H_2$CO peaks are biased to the CBT peaks. For the offset (0, 0) positions of four GMCs, the CBTs are so high that $H_2$CO maybe mainly come from the CBT collision excitation. According to Tables 2, 3, 4 and 5, the $H_2$CO column density shows an irregular distribution that does not match the morphology of $H_2$CO intensity contours. By comparing the integration intensity contours for $H_2$CO with the CBT for GMCs (Fig. 7) and by polynomial fitting, we obtained the following equation:

$$Flux(H_2CO) = 0.70457 + 0.48347T_c + 0.1576T_c^2,$$

where $Flux(H_2CO)$ is integration intensity of $H_2$CO, and $T_c$ is 6-cm CBT. This further suggests in quantity that the $H_2$CO and $^{12}$CO absorption is weak.

3.3. Comparison of $H_2$ CO, $^{12}$CO and MSX data

The velocity correlation between $H_2$CO and $^{12}$CO is described in Fig. 8 for W49, W3, DR21 and NGC2024 GMCs. The fitting line passes through (0, 0) and the points are distributed almost on or near the line. The correlations of integration intensity between $H_2$CO and $^{12}$CO are plotted in Fig. 9 (ignoring these points of $|Flux(H_2CO)| > 5JyKms^{-1}$) for W3, DR21 and NGC2024 GMCs. The best least-squares fit to a straight line for W3, DR21 and NGC2024 GMCs GMC data sets yield respectively

$$W3 : Flux(H_2CO) = 5.64 \times 10^{-3}Flux(^{12}CO) + 65.59 \times 10^{-3}Kkms^{-1},$$

$$DR21 : Flux(H_2CO) = 4.25 \times 10^{-3}Flux(^{12}CO) + 44.36 \times 10^{-3}Kkms^{-1},$$

$$NGC2024 : Flux(H_2CO) = 0.74 \times 10^{-3}Flux(^{12}CO) + 80.48 \times 10^{-3}Kkms^{-1}.$$  

Fig. 9 shows that the integration intensity relation between $H_2$CO and $^{12}$CO for three GMCs is scattered. And the equation coefficients are different but similar between Rodríguez et al. (2007) and our results. It is suggested that there exists different physical condition for different GMCs, however, the correlation between $H_2$CO and $^{12}$CO is inherent.

Fig. 10 shows the intensity correlation for $H_2$CO and $^{12}$CO (ignoring these points of $|Intensity(H_2CO)| > 1.2Jy$). For W3, DR21 and NGC2024 GMCs, the correlation coefficient is 0.558, 0.499 and 0.297, respectively. Thus, the linear relation is better for W3 and DR21 GMCs than for NGC2024. The reason may be that $H_2$CO absorption to the north of the NGC2024 GMC arises from CMB excitation, whereas bright continuum sources are responsible for $H_2$CO absorption in the other regions. The two excitation mechanisms possibly produce different $H_2$CO intensities. The intensity of $H_2$CO absorption is related to the molecular density and background continuum sources. Using Origin Software to draw and calculate, the Pearson’s correlation coefficients for line width between $^{12}$CO emission and $H_2$CO absorption are 0.480, 0.556 and 0.478 for W3, DR21 and NGC2024 GMCs respectively (Fig. 11). The line width is greater for $^{12}$CO emission than for $H_2$CO absorption on the whole. In general, there is good correlation between $^{12}$CO and $H_2$CO clouds basing on these correlation coefficients.

Comparison of $H_2$CO and $^{12}$CO contours and MSX data reveals great uniformity in morphology in the large area, especially between $H_2$CO and MSX data. The integrated intensity peaks are located at almost the same positions, but the $^{12}$CO peaks are offset from the $H_2$CO peaks. MSX clouds are always located within star formation regions, where the hot core is the energy source for star formation. Basing above, under ambient conditions, $H_2$CO and $^{12}$CO clouds form a blanket around star formation regions in morphology. This leads to a uniform structure that can be used as a tracer for star formation regions.

3.4. $^{12}$CO peak offset from $H_2$CO and CBT

For the large-area distribution, $^{12}$CO and $H_2$CO contours are fairly similar in morphology, but there is a peak offset (about 10’’ in Fig. 5(b) and 5(d)) for the small-area distribution. Heithausen et al. (1987) did not find a morphologic correlation between $^{12}$CO and $H_2$CO data using a 100-m telescope, but Rodríguez et al. (2007) reported a discrepancy between $^{12}$CO and $H_2$CO peaks toward the L1204 dust cloud using the Onsala 25-m telescope. Their $H_2$CO clouds were against the CMB, but our sources are against high CBT sources in HII regions. The background continuum temperature has a strong effect on the $H_2$CO distribution as we showed in Fig. 6, which reveals a fairly consistent morphology between $H_2$CO and the continuum. However, Fig. 5 shows that $^{12}$CO peaks are offset from $H_2$CO peaks, although this offset is different from that observed by Rodríguez et al. (2007). Their $H_2$CO peaks were offset from the bright continuum source, while our $^{12}$CO peaks are offset from the bright continuum source. Rodríguez et al. (2007) argued that the $H_2$CO peak offset arises from photodissociation in the UV interstellar radiation field. In our opinion, several factors explain the peak offset. First, the $H_2$CO distribution is strongly biased by the background CBT, while the strong HII region background has a relatively weak impact on $^{12}$CO emission. Second, differences in star formation regions and evolution stages between sources will lead to discrepancy. Third, it is likely that $H_2$CO absorption is optically thin ($< 0.188$) and $^{12}$CO emission is optically thick (Buckle et al. 2010), so $^{12}$CO is a poor tracer for density. Finally, the different resolution may lead to discrepancy.

3.5. Statistical relationship between line width and intensity

Fig. 12 shows a statistical diagram of the relationship between line width and intensity for $H_2$CO absorption lines toward W49, W3, DR21/W75 and NGC2024/NGC2023 GMCs,
and for W43 GMC observations made by Wu et al. (2010) using the same dish. These data points are corresponding to 169 velocity components from our detected 86 H$_2$CO absorption lines. The statistical results show that the most (approximately 85.21%) of the velocity components of the H$_2$CO absorption lines are in the intensity range from −1.0 to 0 Jy and in the $\Delta V$ range 1.206–5.0 km s$^{-1}$.

In Fig. 12 the width for most H$_2$CO absorption lines is relatively narrow and may be narrower than the 1.206 km s$^{-1}$ for the velocity channel. However, a few lines are rather wide, even up to 9.67 km s$^{-1}$. According to Bieging et al. (1982), the width of all H$_2$CO absorption lines observed in this paper far exceeds the thermal line width for any reasonable gas kinetic temperature (e.g., Δ$V$ (thermal) = 0.3 km s$^{-1}$ for H$_2$CO at 30 K), so the thermal broadening mechanism can be ignored. We suggest that line broadening is mainly the result of turbulence and velocity dispersion along any given line of sight. Thus, H$_2$CO line broadening should mainly reflect the blending of many velocity components.

4. SUMMARY

H$_2$CO absorption lines are important tracers for detecting the ambient conditions in star formation regions. So far very few people have carried out such large-scale H$_2$CO mapping as ours, especially for GMCs. We conducted discontinuous observations toward four GMCs from October 2009 to January 2011 using the Nanshan 25-m telescope. Long-time integration observations and analysis revealed the following results.

For W49, W3, DR21/W75 and NGC2024/NGC2023 GMCs, we observed 151 points using a beam width of 10′ and integration for 9456 min, and found 86 H$_2$CO absorption lines and 16 H110a RRLs. We processed H$_2$CO absorption lines for four large-area mappings. We described and gave some relevant physical parameters which are respectively flux, velocity, line width, intensity, CBT, apparent depth and column density for H$_2$CO absorption lines, H110a RRLs and continuum and clump’s H$_2$-mass for GMCs. Some good correlation coefficients between H$_2$CO and $^{13}$CO were gained in terms of velocity components, line width and intensity.

In the large area, comparisons among H$_2$CO and $^{13}$CO contours, the 8.28-μm MSX color map and CBT at 4.8 GHz revealed a consistent distribution. Regions with a high CBT had much higher collision excitation rates for H$_2$CO. However, in the small area, H$_2$CO and $^{13}$CO peaks were not located at the same position. It is likely that the H$_2$CO distribution is strongly biased by the background CBT, while the strong HI region of the background has a relatively weak impact on $^{13}$CO emission.

Many other results were observed for these four GMCs. E.g., W49B is a nonthermal SNR and has nearly the same velocity components as the thermal W49A. At the junction of two clouds for W3 GMC, we could not detect H$_2$CO absorption lines, whereas the $^{13}$CO and MSX data were relatively strong. DR21/W75 GMCs had a velocity gradient, possibly arising from GMC rotation. It is possible that H$_2$CO absorption lines to the north of NGC2024/NGC2023 GMC arise from CMB excitation.

A statistical diagram of the relation between line width and intensity was constructed for H$_2$CO absorption lines. Approximately 85.21% of the velocity components of H$_2$CO absorption lines were distributed in the intensity range from −1.0 to 0 Jy and in the Δ$V$ range 1.206–5.0 km s$^{-1}$.

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Fig. 1.— The spectral mosaic of (a) $\text{H}_2\text{CO}$ absorption line and (b) $\text{H}110\alpha$ RRL toward W49 GMC.
Fig. 2.— The spectral mosaic of (a) H$_2$CO absorption line and (b) H110$\alpha$ RRL toward W3 GMC.
Fig. 3.— The spectral mosaic of (a) H$_2$CO absorption line and (b) H110α RRL toward DR21/W75 GMC.
Fig. 4.— The spectral mosaic of (a) $\text{H}_2\text{CO}$ absorption line and (b) H110α RRL toward NGC2024/NGC2023 GMC.
Fig. 5.— Contours and color-scale maps of integrated area toward W49, W3, DR21/W75 and NGC2024/NGC2023. The black contours, the white contours and the color-scale map respectively indicates the integrated flux intensity of the H$_2$CO absorption line, $^{12}$CO emission line and the mid-infrared 8.28-µm MSX source. Triangle symbols indicate the location what we surveyed and the coordinate of the offset (0, 0) position. (a), (0, 0): R.A. = 19$^h$10$^m$15.25, DEC. = 09$^\circ$06'08''.4. Levels for black contours (H$_2$CO) with beam size 10$^\prime$ are 29.15, 22.67, 16.19, 9.71 and 3.24 Jy km s$^{-1}$ from inside to outside, while 100 to 20 by -10 K km s$^{-1}$ for white contours ($^{12}$CO) with beam size 8$^\prime$. The corresponding velocity component is from -29.8 km s$^{-1}$ to 89.8 km s$^{-1}$ for H$_2$CO and $^{12}$CO. (b), (0, 0): R.A. = 02$^h$25$^m$38'.79, DEC. = 62$^\circ$02'22''.0. Levels for black contours (H$_2$CO) with beam size 10$^\prime$ are 6.34, 5.22, 4.11, 2.99, 1.87 and 0.75 Jy km s$^{-1}$ from inside to outside, while 48 to 6 by -6 K km s$^{-1}$ for white contours ($^{12}$CO) with beam size 8$^\prime$. The corresponding velocity component is from -59.15 km s$^{-1}$ to -20.15 km s$^{-1}$ for H$_2$CO and $^{12}$CO. (c), (0, 0): R.A. = 20$^h$39$^m$01'.23, DEC. = 42$^\circ$19'33''.9. Levels for black contours (H$_2$CO) with beam size 10$^\prime$ are 14.92, 10.00, 5.08, 3.85, 2.62, 1.39 and 0.16 Jy km s$^{-1}$ from inside to outside, while 81 to 4 by -11 K km s$^{-1}$ for white contours ($^{12}$CO) with beam size 8$^\prime$. The corresponding velocity component is from -15.4 km s$^{-1}$ to 25.6 km s$^{-1}$ for H$_2$CO and $^{12}$CO. (d), (0, 0): R.A. = 05$^h$41$^m$45'.49, DEC. = -01$^\circ$54'46''.8. Levels for black contours (H$_2$CO) with beam size 10$^\prime$ are 8.69, 6.59, 4.50, 3.66, 2.83, 1.99, 1.15 and 0.31 Jy km s$^{-1}$ from inside to outside, while 124 to 4 by -12 K km s$^{-1}$ for white contours ($^{12}$CO) with beam size 8$^\prime$. The corresponding velocity component is from 0.33 km s$^{-1}$ to 20.48 km s$^{-1}$ for H$_2$CO and $^{12}$CO.
Fig. 6.— Integration intensity of H$_2$CO (Solid line) VS. Continuum brightness temperature of 4.85 GHz (Dotted line) for W49 GMC. For continuum brightness temperature, the contour levels from inside to outside are respectively (a) 4.601, 3.451, 2.301, 1.726, 1.150, 0.575, 0.431, 0.288 and 0.144 K, (b) 4.705, 3.529, 2.353, 1.765, 1.176, 0.588, 0.412 and 0.235 K, (c) 2.512, 1.884, 1.256, 0.942, 0.628, 0.534, 0.440, 0.345, 0.251, 0.157 and 0.063 K, and (d) 4.482, 3.361, 2.241, 1.681, 1.120, 0.560, 0.437, 0.314, 0.190 and 0.067 K, while they are same as Fig. 5 for integration intensity of H$_2$CO.
Fig. 7.— The relation between integration intensity of H$_2$CO and continuum brightness temperature of 4.85 GHz for W49, W3, DR21 and NGC2024 GMC.

Fig. 8.— Correlation between velocity of H$_2$CO absorption line and $^{12}$CO emission line for W49, W3, DR21/W75 and NGC2024/NGC2023 GMCs. From the data line, we can find the line passes through (0, 0) point and the points almost distribute on or near the line. So the relation between them is distinct.

Fig. 9.— For W3, DR21/W75 and NGC2024/NGC2023 GMCs, the correlation between the H$_2$CO integration intensity and the $^{12}$CO integration intensity.
Fig. 10.— For W3, DR21/W75 and NGC2024/NGC2023 GMCs, correlation coefficient respectively being 0.558, 0.499 and 0.297 between intensities of $^{12}$CO emission line and H$_2$CO absorption line.

Fig. 11.— For W3, DR21/W75 and NGC2024/NGC2023 GMCs, correlation coefficient respectively being 0.480, 0.556 and 0.478 between line widths of $^{12}$CO emission line and H$_2$CO absorption line.

Fig. 12.— Correlation between line width and intensity of H$_2$CO absorption line at each spectrum for W49, W3, DR21/W75 and NGC2024/NGC2023 GMCs and W43 GMC Wu et al. (2010). Each point comes from every velocity component of spectrum. The points in the range from −1.0 to 0 Jy and the $\Delta V$ range from 1.206 to 5 km s$^{-1}$ hold 85.21% of all points.
## TABLE 1  The relevant information of four GMCs.

| Sources ID | R.A.(J2000) | DEC.(J2000) | Distance (kpc) | Size(α × δ) (arcmin²) | M(H₂) (M₉) | Int. time (minutes) | A/B/C | References |
|------------|-------------|-------------|----------------|------------------------|-------------|---------------------|-------|------------|
| W49        | 12          | 19 10 15.25 | 09 06 08.4     | 11.4                   | 200×200     | 2296910             | 966   | 19/5/2     | (1), (5) |
| W3         | 17          | 02 25 38.79 | 62 02 22.0     | 1.95                   | 70×90       | 71615               | 2370  | 41/19/4    | (2), (5) |
| DR21       | 18          | 20 39 01.23 | 42 19 33.9     | 3.0                    | 60×90       | 444774              | 2742  | 45/34/8    | (3), (5) |
| NGC2024    | 27          | 05 41 45.49 | -01 54 46.8    | 0.415                  | 50×100      | 5609                | 3378  | 46/28/2    | (4), (5) |
| Total      |             |             |                |                        |             |                     | 9456  | 151/86/16  |            |

References:  (1) Gwinn et al. (1992); (2) Xu et al. (2006); (3) Campbell et al. (1982); (4) Menten et al. (2007); (5) Bieging et al. (1982).

Notes: — In Column 7 the clump’s H₂-masses (M(H₂)) are derived from Equation 5. In Column 9, A is the number of all observational positions toward the sources, B is the number of H₂CO absorption lines, and C is the number of H110α RRLs. Hence, the detection rate is 56.95% for H₂CO absorption lines and 10.60% for H110α RRLs.
| W49 | ID Offset(α, δ) | H$_2$CO | H10αr |
|-----|----------------|--------|--------|
|     | (No.)          | Velocity (km s$^{-1}$) | Flux (Jy km s$^{-1}$) | ∆V (km s$^{-1}$) | Intensity (Jy) | $T_c$ (K) | $\tau_{app}$ | N(H$_2$CO) (10$^{13}$ cm$^{-2}$) | N(H$_2$) (10$^{22}$ cm$^{-2}$) | Velocity (km s$^{-1}$) | Flux (Jy km s$^{-1}$) | ∆V (km s$^{-1}$) | Intensity (Jy) |
| 10  | 20, 0          | 4.73(0.68) -0.73(0.20) | 4.61(1.41) -0.14(0.036) | 0.406 0.112 | 0.503 0.403 | 4.18(0.11) -1.72(0.15) | 2.37(0.25) -0.68(0.036) | 0.406 0.058 | 1.286 1.029 |
|     |                | 45.51(0.32) -0.58(0.13) | 2.32(0.59) -0.23(0.036) | 0.406 0.019 | 0.418 0.334 | 12.68(0.69) -2.91(0.52) | 8.02(1.56) -0.34(0.073) | 2.060 0.013 | 0.978 0.782 |
| 11  | 0, 0           | 42.18(0.11) -1.72(0.15) | 2.37(0.25) -0.68(0.036) | 0.406 0.058 | 1.286 1.029 | 18.64(0.45) -0.84(0.41) | 2.94(1.12) -0.26(0.073) | 2.060 0.010 | 0.274 0.219 |
|     |                | 41.69(0.09) -3.46(0.22) | 2.77(0.23) -1.17(0.073) | 2.060 0.045 | 1.181 0.945 | 61.50(0.39) -2.84(0.49) | 5.00(0.77) -0.53(0.073) | 2.060 0.020 | 0.954 0.763 |
| 12  | 0, -10         | 10.49(0.81) -11.51(2.03) | 9.67(0.90) -1.12(0.099) | 5.705 0.020 | 1.779 1.423 | 15.88(0.16) -13.05(2.03) | 5.56(0.36) -2.20(0.099) | 5.705 0.039 | 2.028 1.622 |
|     |                | 40.86(0.11) -3.67(0.31) | 2.88(0.30) -1.20(0.099) | 5.705 0.021 | 0.568 0.454 | 64.25(0.12) -3.76(0.34) | 3.09(0.38) -1.15(0.099) | 5.705 0.020 | 0.584 0.467 |
| 14  | 20, -10        | 11.99(0.57) -0.26(0.14) | 1.39(0.71) -0.17(0.040) | 0.102 0.018 | 0.236 0.189 | 42.36(0.16) -1.37(0.18) | 2.73(0.47) -0.47(0.040) | 0.102 0.051 | 1.302 1.042 |
|     |                | 12.54(1.92) -1.10(0.41) | 8.99(4.15) -0.11(0.035) | 0.414 0.009 | 0.766 0.613 | 41.93(0.43) -1.14(0.23) | 4.15(0.92) -0.26(0.035) | 0.414 0.022 | 0.841 0.673 |
| 16  | 0, -10         | 60.91(0.82) -0.23(0.26) | 1.70(11.5) -0.13(0.035) | 0.414 0.011 | 0.171 0.137 | 63.63(0.70) -0.36(0.23) | 1.74(0.87) -0.19(0.035) | 0.414 0.016 | 0.257 0.206 |

**Notes:** Parameters listed about simultaneously observing H$_2$CO absorption line and H10α RRL, and each one of both. The serial number and offset are indicated in Column one and two corresponding to spectra and color map. "--" indicates that the corresponding spectra could not be detected. These intensity data of H10α RRL is not able to achieve 3σ with "a" to line out, so we do not consider them as signal to analysis.
| W3 | H$_2$CO | H110$\alpha$ |
|----|--------|----------|
| (1) Offset(\(\alpha, \delta\)) (arcmin) | (2) Velocity (km s\(^{-1}\)) | (3) Flux (Jy km s\(^{-1}\)) | (4) \(\Delta V\) (km s\(^{-1}\)) | (5) Intensity (Jy) | (6) \(T_{C}\) (K) | (7) \(\tau_{app}\) | (8) \(N(H_2CO)\) \(10^{13}\) cm\(^{-2}\) | (9) \(N(H_2)\) \(10^{22}\) cm\(^{-2}\) |
| | | | | | | | | | |
| 05 10, 20 | -38.73(0.28) | 4.37(0.62) | -0.22(0.069) | 0.892 | 0.014 | 0.558 | 0.446 |
| 08 -20, 20 | -35.02(0.58) | 3.90(1.29) | -0.18(0.022) | 0.305 | 0.016 | 0.591 | 0.473 |
| 10 10, 10 | -39.37(0.18) | 2.54(0.45) | -0.75(0.078) | 2.269 | 0.027 | 0.644 | 0.515 |
| 11 0, 10 | -36.79(0.13) | 4.66(0.33) | -1.04(0.104) | 2.784 | 0.032 | 1.419 | 1.135 |
| 12 -10, 10 | -37.32(0.42) | 3.73(0.73) | -0.19(0.031) | 0.514 | 0.015 | 0.514 | 0.411 |
| 13 -20, 10 | -37.42(0.26) | 1.70(0.39) | -0.36(0.002) | 0.368 | 0.031 | 0.495 | 0.396 |
| 14 -30, 10 | -41.79(0.18) | 1.20(3.01) | -0.18(0.022) | 0.304 | 0.031 | 0.591 | 0.477 |
| 16 10, 0 | -36.47(0.39) | 4.45(0.95) | -0.21(0.035) | 1.659 | 0.009 | 0.385 | 0.308 |
| 17 0, 0 | -36.57(0.09) | 3.79(0.24) | -1.80(0.075) | 5.850 | 0.031 | 1.103 | 0.882 |
| 18 -10, 0 | -40.86(0.31) | 2.33(0.81) | -0.26(0.009) | 0.957 | 0.016 | 0.346 | 0.277 |
| 19 -20, 0 | -37.15(0.16) | 1.86(0.38) | -0.54(0.009) | 0.957 | 0.033 | 0.569 | 0.455 |
| 20 -30, 0 | -39.58(0.12) | 2.91(0.28) | -0.63(0.048) | 0.475 | 0.051 | 1.390 | 1.112 |
| 22 10, -10 | -39.78(0.20) | 2.24(0.54) | -0.49(0.070) | 0.375 | 0.042 | 0.889 | 0.711 |
| 23 0, -10 | N | 8.44 | 0.844 |
| 24 -10, -10 | -40.93(0.29) | 1.20(2.09) | -0.48(0.016) | 0.660 | 0.034 | 0.385 | 0.308 |
| 25 -20, -10 | -39.61(0.27) | 3.15(0.82) | -0.32(0.016) | 0.660 | 0.023 | 0.670 | 0.536 |
| 26 10, -30 | -46.30(0.18) | 3.14(0.38) | -0.71(0.055) | 1.000 | 0.042 | 1.241 | 0.993 |
| 27 0, -30 | -45.04(0.14) | 3.04(0.34) | -0.82(0.054) | 0.658 | 0.059 | 1.688 | 1.351 |
| 28 -10, -30 | -45.14(0.14) | 3.32(0.31) | -0.68(0.061) | 0.948 | 0.041 | 1.290 | 1.032 |
| 29 -20, -30 | -45.20(0.16) | 1.64(0.64) | -0.41(0.016) | 0.646 | 0.029 | 0.452 | 0.362 |

**Notes:** Parameters listed about simultaneously observing H$_2$CO absorption line and H110$\alpha$ RRL, and each one of both. The serial number and offset are indicated in Column one and two corresponding to spectra and color map. "N" indicates that the corresponding spectra could not be detected. These intensity data of H110$\alpha$ RRL is not able to achieve 3\(\sigma\) with "a" to line out, so we do not consider them as signal to analysis.
| DR21 | H$_2$CO | H110α |
|------|---------|--------|
| No.  | (No.)   | Velocity (km s$^{-1}$) | Flux (Jy km s$^{-1}$) | $\Delta V$ | Intensity (Jy) | $T_c$ (K) | $r_{app}$ | $N$(H$_2$CO) (10$^{13}$ cm$^{-2}$) | $N$(H$_2$) (10$^{22}$ cm$^{-2}$) | Velocity (km s$^{-1}$) | Flux (Jy km s$^{-1}$) | $\Delta V$ | Intensity (Jy) | |
| 04   | -10, 30 | 0.740(0.31) | -0.06(0.16) | 2.10(0.06) | -0.27(0.019) | 0.680 0.019 | 0.372 0.297 | N |
| 05   | -20, 30 | 3.43(0.46) | -1.16(0.24) | 4.84(1.10) | -0.24(0.025) | 0.402 0.020 | 0.913 0.730 | N |
| 07   | 10, 20  | 13.97(0.43) | -0.39(0.19) | 2.09(0.84) | -0.31(0.052) | 0.393 0.026 | 0.514 0.411 | N |
| 08   | 0, 20   | -0.60(0.24) | -1.73(0.16) | 2.79(0.54) | -0.51(0.019) | 0.476 0.026 | 0.514 0.411 | 2.95(2.00) | 2.09(0.47) | 17.76(4.62) | 0.11(0.055)a |
| 09   | -10, 20 | 11.90(0.26) | -0.63(0.18) | 2.13(0.85) | -0.28(0.019) | 0.476 0.022 | 0.445 0.356 | N |
| 10   | 10, 20  | 11.23(0.29) | -1.34(0.11) | 1.20(0.55) | -0.26(0.019) | 0.766 0.021 | 0.233 0.186 | 0.60(0.03) |
| 11   | 20, 20  | 10.82(0.33) | -1.12(0.20) | 3.16(0.35) | -0.87(0.034) | 0.434 0.073 | 2.18(1.73) | N |
| 12   | -10, 10 | 0.00(0.11) | -1.97(1.28) | 1.44(0.90) | -0.47(0.026) | 0.628 0.034 | 0.461 0.369 | N |
| 14   | -10, 10 | N | N | N | N | N | N | N |
| 16   | 0, 20   | 6.39(0.32) | -1.00(1.16) | 2.06(0.19) | -0.12(0.017) | 0.467 0.010 | 0.140 0.158 | 4.70(1.79) | 1.40(0.49) | 10.35(4.29) | 0.12(0.086)d |
| 17   | 0, 10   | 11.01(0.16) | -0.54(0.19) | 2.10(0.26) | -0.23(0.010) | 0.724 0.029 | 0.491 0.393 | 5.49(1.64) | 2.52(0.49) | 15.19(2.89) | 0.15(0.097)d |
| 18   | 0, 10   | 2.14(1.32) | -0.61(0.18) | 2.79(0.54) | -0.51(0.019) | 0.476 0.026 | 0.514 0.411 | 4.26(3.59) | 3.07(0.79) | 26.44(10.2) | 0.10(0.070)d |
| 19   | 0, 10   | -0.70(0.24) | -1.16(0.20) | 2.79(0.54) | -0.51(0.019) | 0.476 0.026 | 0.514 0.411 | 4.73(0.96) | 4.10(0.46) | 17.85(2.46) | 0.21(0.069)d |

### Notes
- Parameters listed about simultaneously observing H$_2$CO absorption line and H110α RRL, and each one of both. The serial number and offset are indicated in Column one and two corresponding to spectra and color map. "N" indicates that the corresponding spectra could not be detected. These intensity data of H110α RRL is not able to specify $\alpha$ to line out, so we do not consider them as signal to analysis.

### References
- $^a$ Indicates that the corresponding spectra could not be detected.
- $^d$ Indicates the corresponding spectra could not be detected. These intensity data of H110α RRL is not able to specifically identify $\alpha$ to line out, so we do not consider them as signal to analysis.
**TABLE 5 The parameters of NGC2024/2023 GMC.**

| NGC2024 | H$_2$CO | H100a |
|---------|---------|--------|
| (No.)   | (ID)    | (Offset, $\delta$) | (Velocity (km s$^{-1}$)) | (Flux (Jy km s$^{-1}$)) | ($\Delta V$ (km s$^{-1}$)) | (Intensity (Jy)) | ($T_c$ (K)) | ($\tau_{app}$) | ($N$(H$_2$CO)) | ($N$(H$_2$)) | Velocity (km s$^{-1}$) | Flux (Jy km s$^{-1}$) | ($\Delta V$ (km s$^{-1}$)) | Intensity (Jy) |
| 01      | 20, 30  | 5.40(0.35) -0.88(0.17) 3.51(0.64) -0.25(0.032) 0.058 0.026 0.842 0.674 | N |
| 03      | 0, 50   | 7.49(0.29) -0.19(0.07) 1.20(1.74) -0.14(0.01) 0.024 0.016 0.180 0.144 | N |
| 05      | 20, 40  | 12.27(0.21) -0.29(0.08) 1.39(0.42) -0.19(0.001) 0.024 0.022 0.284 0.227 | N |
| 06      | 10, 40  | 4.13(0.19) -0.75(0.18) 1.91(0.72) -0.37(0.029) 0.060 0.041 0.742 0.594 | N |
| 07      | 0, 40   | 11.28(0.26) -0.80(0.15) 2.57(0.51) -0.29(0.050) 0.038 0.033 0.796 0.637 | N |
| 08      | -10, -40| 11.43(0.08) -1.31(0.15) 1.82(0.36) -0.67(0.002) 0.034 0.078 1.337 1.070 | N |
| 10      | 20, 30  | 5.17(0.49) -1.15(0.22) 4.54(1.10) -0.23(0.028) 0.125 0.024 1.025 0.820 | N |
| 11      | 10, 30  | 11.47(0.27) -0.73(0.25) 1.20(34.1) -0.56(0.028) 0.125 0.059 0.671 0.537 | N |
| 12      | 0, 30   | 11.23(0.27) -1.11(0.18) 3.16(0.58) -0.33(0.040) 0.125 0.035 1.028 0.823 | N |
| 13      | -10, 30 | 11.46(0.08) -0.69(0.12) 1.20(1.29) -0.53(0.000) 0.092 0.058 0.654 0.523 | N |
| 16      | 10, 20  | 11.46(0.13) -0.49(0.12) 1.77(1.21) -0.26(0.015) 0.180 0.026 0.431 0.345 | N |
| 17      | 0, 20   | 11.79(0.16) -1.27(0.17) 2.27(0.34) -0.52(0.024) 0.201 0.052 1.100 0.880 | N |
| 18      | -10, 20 | 11.11(0.40) -0.53(0.17) 2.41(0.97) -0.20(0.023) 0.001 0.023 0.531 0.425 | N |
| 21      | 10, 10  | 7.51(0.15) -0.78(0.12) 1.73(0.44) -0.42(0.005) 0.300 0.038 0.621 0.497 | N |
| 22      | 0, 10   | 6.67(0.23) -0.62(0.17) 2.02(0.74) -0.29(0.008) 0.783 0.019 0.362 0.289 | N |
| 23      | -10, 10 | 11.26(0.08) -2.02(0.14) 0.22(0.22) -0.83(0.008) 0.783 0.056 1.185 0.948 | N |
| 26      | 10, 0   | 12.19(0.66) -0.85(0.29) 2.72(1.66) -0.29(0.081) 0.485 0.023 0.586 0.469 | N |
| 27      | 0, 0    | 11.21(0.02) -10.49(0.27) 2.18(0.08) -4.51(0.029) 5.619 0.082 1.687 1.250 | N |
| 28      | -10, 0  | 11.53(0.40) -1.11(0.19) 4.35(0.75) -0.24(0.044) 0.603 0.018 0.716 0.573 | N |
| 30      | 20, 10  | 12.68(0.12) -1.02(0.16) 1.91(0.51) -0.50(0.020) 0.254 0.047 0.850 0.680 | N |
| 32      | 10, -10 | 12.82(0.17) -1.14(0.16) 2.42(0.41) -0.44(0.049) 0.305 0.040 0.908 0.726 | N |
| 33      | 0, -10  | 13.89(0.16) -1.17(0.16) 2.15(0.38) -0.51(0.041) 0.392 0.043 0.878 0.702 | N |
| 36      | 10, -20 | 13.48(0.24) -0.71(0.15) 1.51(0.68) -0.44(0.004) 0.324 0.039 0.558 0.446 | N |
| 37      | 0, -20  | 12.66(0.10) -1.83(0.15) 2.26(0.24) -0.76(0.010) 0.307 0.070 1.483 1.186 | N |
| 38      | -10, -20| 12.40(0.19) -0.47(0.14) 1.20(28.9) -0.36(0.000) 0.314 0.032 0.364 0.291 | N |
| 41      | 0, -30  | 12.34(0.22) -1.56(0.23) 2.98(0.51) -0.49(0.071) 0.313 0.044 1.240 0.992 | N |
| 42      | -10, -30| 13.15(0.29) -0.55(0.15) 1.80(0.44) -0.28(0.004) 0.371 0.024 0.406 0.325 | N |

Notes:—— Parameters listed about simultaneously observing H$_2$CO absorption line and H100a RRL, and each one of both. The serial number and offset are indicated in Column one and two corresponding to spectra and color map. "N" indicates that the corresponding spectra could not be detected. These intensity data of H100a RRL is not able to achieve 3$\sigma$ with "a" to line out, so we do not consider them as signal to analysis.