Molecular Gas toward the Gemini OB1 Molecular Cloud Complex. I. Observation Data

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Abstract
We present a large-scale mapping toward the GEM OB1 association in the galactic anti-center direction. The 9° × 6.5° area was mapped in 12CO, 13CO, and C18O with ∼50″ angular resolution at 30″ sampling. The region was divided into four main components based on spatial distribution and velocity: the Gemini OB1 Giant Molecular Cloud (GGMC) Complex, the Lynds Dark Clouds and the West Front Clouds, the Swallow and Horn, and the Remote Clouds. The GGMC Complex is located in the Perseus arm, while the Lynds Dark Clouds and the West Front Clouds are located in the Local arm. Swallow and Horn are revealed for the first time in this paper. The two clouds have a similar velocity interval ([11, 21] km s\(^{-1}\)) and have similar sizes (0.6 and 0.8 deg\(^2\)). We analyzed the structure of these clouds in detail and calculated their parameters (mass, temperature, etc.). Two elongated structures were discovered in a longitude–velocity map in the velocity interval [11, 30] km s\(^{-1}\). We also found an interesting filament that shows a 0.8 km s\(^{-1}\) pc\(^{-1}\) gradient perpendicular to the direction of the long axis.

Key words: ISM: clouds – ISM: individual objects (Gem OB1) – ISM: molecules

1. Introduction

CO emission plays an essential role in the study of molecular clouds (MCs), because it is readily detected even in diffuse molecular gas (Evans 1999). This tracer reveals the distributions of molecular gas and the kinematic information of detected clouds (Shu et al. 1987). MCs are thought to be the place where stars form, so studying them helps us to understand the star formation process and even galactic structures (Shu et al. 1987; Evans 1999; McKee & Ostriker 2007).

Over the past several decades, many large MC surveys have been performed. The first galactic plane (|b| < 10°–20°) survey was conducted by Dame et al. (1987, 2001) using the CO molecular spectral line (J = 1–0) with an angular resolution of ∼8′. Thanks to this survey, we gained insight into the large-scale structures of MCs in our galaxy.

With the degeneracy of the radial velocity in the Galactic anti-center, the kinematic distances in this region have large uncertainties. Hence, it is difficult to distinguish different MCs and to investigate their properties.

Kawamura et al. (1998) performed a large-scale MC survey in 13CO (J = 1–0) of the Gemini region using the two 4 m millimeter-wavelength telescopes at Nagoya University. They showed that the 13CO clouds associated with IRAS point sources, which are regarded as star-forming sites, have higher column densities N(H\(_2\)) sizes (R), and cloud masses (M\(_{\text{cloud}}\)) but lower M\(_{\text{gas}}\)/M\(_{\text{cloud}}\) than the other clouds. Carpenter et al. (1995a, 1995b) investigated the morphology and physical properties of the Gem OB1 cloud complex by mapping more than 32 deg\(^2\) of the complex in 12CO and 13CO (J = 1–0) with QUARRY on the F CRAO 14 m telescope, and also conducted a study of global star formation activities along with a combination of CS (J = 2–1) and infrared data. They analyzed the spatial structure of the MC in the region and revealed that the arc-like molecular gas and dense cores might be related to star formation. They concluded that star the formation activity in such regions is mainly triggered.

Although Kawamura et al. (1998) and Carpenter et al. (1995a, 1995b) achieved fruitful results for this region, there are some interesting structures and clouds that still need to be studied in detail. In particular, unbiased 13CO and C18O emission will help reveal denser areas, and a study of the CO isotopic abundance ratio and outflow in this region is also needed. Such studies will be discussed in forthcoming papers (C. Wang et al. 2017, in preparation, Y. Li et al. 2017, in preparation). The current paper instead focuses on the distribution of molecular gas and the properties of each cloud.

2. Observations

We performed observations of the J = 1–0 transitions of 12CO, 13CO, and C18O of the GEM OB1 complex with the Purple Mountain Observatory (PMO) 13.7 m telescope at Delingha from 2012 September to 2013 May. These observations were obtained as part of the Milky Way Imaging Scroll Painting (MWISP) project, which is a Multi-Line Galactic Plane Survey of CO and its Isotopic Transitions. This area was mapped using a 3 × 3 pixel Superconducting Spectroscopic Array Receiver (SSAR), which was made with Superconductor-Insulator-Superconductor mixers. The SSAR works in sideband separation mode and employs a fast Fourier transform spectrometer (Shan et al. 2012; Zuo et al. 2011).

Our observations were made in 234 cells of dimension 30′ × 30′, which covered an area of total 58.5 deg\(^2\). The cells were mapped using the on-the-fly (OTF) observation mode with a scan speed of 50″ s\(^{-1}\) and a step of 15″ along the Galactic longitude and latitude, while the standard chopper wheel method was used for calibration (Penzias & Burrus 1973). Observations of 12CO, 13CO, and C18O in the J = 1–0 transition were obtained simultaneously, as the instantaneous bandwidth of 1 GHz was arranged for the backends. Each spectrometer provides 16,384 channels, resulting in a spectral resolution of 61 kHz, equivalent to a velocity resolution of about 0.16 km s\(^{-1}\) for 12CO and 0.17 km s\(^{-1}\) for 13CO and C18O. The half-power beamwidth

\[ \text{FWHM} = \frac{\lambda}{c} \times 1.22 \delta \]
of the telescope was about 49″ for 12CO and 51″ for 13CO and C18O, while the pointing accuracy of the telescope was better than 4″ for each observing epoch. The typical system temperatures during the observations were ∼280 K for 12CO and ∼185 K for 13CO and C18O.

All of the CO data used in this study are expressed in brightness temperature, which is the antenna temperature, $T_A$, divided by the main beam efficiency ($T_R = T_A/(f_b \times \eta_{mb}$). $\eta_{mb} = 0.46$, assuming a beam filling factor of $f_b \sim 1$). The calibrated OTF data were then re-gridded to 30″ pixels and mosaicked to a FITS cube using the GILDAS software package (Guilloteau & Lucas 2000). A first-order baselining was applied to the spectra. The resulting mean rms noise was ∼0.45 K for 12CO and ∼0.25 K for 13CO and C18O. These data represent the largest 12CO, 13CO, and C18O maps to date for such a moderately fine resolution, with fully sampled grids and low noise levels, which are essential for understanding the large-scale structure of the GEM OB1 complex.

3. Overview

Our observations cover not only the GEM OB1 complex, but also other MCs that are close to the field-of-view. IC 443 is a supernova remnant (SNR) associated with the GEM OB1 association, and as Su et al. (2014) have already presented an up-to-date analysis of its properties, it will not be investigated in this paper.

Figure 1 presents an integrated map of CO and its other two isotope molecules. Various interesting objects are marked in the figure, including 10 H II regions (Sharpless 1959; Blitz et al. 1982), 4 Lynds dark clouds (Lynds 1962), and 2 SNRs (Milne & Hill 1969; Caswell 1970). The H II regions Sh 247, Sh 254-258, Sh 252, and BFS 52 are associated with the GEM
OB1 association, and are located in the Perseus Arm at a distance of 2 kpc from Earth (Carpenter et al. 1995a; Reid et al. 2009; Rygl et al. 2010; Niinuma et al. 2011). The molecular gas with the strongest CO emission is spatially associated with these HII regions. The HII region Sh 259 is at a distance of 8.71 kpc (Foster & Brunt 2015), which we will discuss in more detail in Section 8. We note that there is no CO emission along the line-of-sight (LoS) to Sh 261. The Lynds dark clouds are located in the middle of Figure 1 and they form a straight chain.

The velocity distribution of the clouds in this area is presented in the longitude–velocity (L–V) map shown in Figure 2. The local standard of rest (LSR) velocity range of all the molecular gas is confined to [−14, 30] km s⁻¹, and most of the gas is concentrated in the range [−3, 10] km s⁻¹.

In order to distinguish clouds with different velocity ranges, we separated the velocity into three bins according to the peak positions of the spectra. The three velocity ranges are [−10, 5], [5, 11], [11, 26] km s⁻¹, as shown in Figure 3. Based on the observations and the discussions of Carpenter et al. (1995a, 1995b), Kawamura et al. (1998), Reid et al. (2009), Rygl et al. (2010), and Niinuma et al. (2011), we suggest that the area is mainly divided into the 12 MCs that are shown in Figure 3. The details of the MCs are listed in Table 1. Two new clouds have been discovered in this survey: “Swallow” and “Horn.” Figure 4 shows individual ¹²CO, ¹³CO, and C¹⁸O spectra of the clouds.

In addition to the 12 MCs, there is some gas in the range of [10, 30] km s⁻¹ (Figure 2). The gas shows two elongated structures in the L–V map, one connecting the Remote Clouds and Horn, and another connecting Swallow and Horn. We will study these elongated structures in detail in future works.

The Gemini OB1 giant molecular cloud (GGMC) complex is the largest MC complex in this area, which includes GGMC 1, GGMC 2, GGMC 3, and GGMC 4. Detailed information about these clouds is presented in Section 4. Section 5 studies the Lynds dark clouds, which are located 400 pc away, while the West Front clouds are introduced in Section 6. Section 7 presents the two newly discovered Swallow and Horn MCs, while the Remote Clouds are also introduced in this section.
| Cloud      | Distance | V_{range} (kpc) | Size (deg^2) | T_{peak} (K) | N_{H2} (10^{21} cm^{-2}) | Mass (M_\odot) | V_{range} (km s^{-1}) | Size (arcmin^2) | T_{peak} (K) | N_{H2} (10^{19} cm^{-2}) | Mass (M_\odot) |
|------------|----------|----------------|--------------|--------------|---------------------------|----------------|-----------------------|----------------|--------------|------------------------|----------------|
| GGMC1      | 2(1)     | [−3, 10]       | 3.7          | 9.5          | 2.0                       | 2.0 \times 10^5 | [−0.3, 10]           | 1.48           | 5.8          | 0.9                    | 3.6 \times 10^4 |
| GGMC2      | 2(1), (2)| [−5, 16]       | 2.1          | 41.7         | 3.1                       | 1.8 \times 10^5 | [−1.5, 16]           | 1.15           | 17.2         | 1.9                    | 7.4 \times 10^4 |
| GGMC3      | 2(1), (2)| [−5, 16]       | 3.8          | 37.9         | 3.1                       | 2.8 \times 10^5 | [−1.5, 16]           | 1.93           | 16.8         | 2.3                    | 1.1 \times 10^5  |
| GGMC4      | 2(1), (2)| [−4, 15]       | 2.3          | 29.2         | 2.6                       | 1.6 \times 10^5 | [−4, 14]             | 0.98           | 13.2         | 2.0                    | 5.5 \times 10^4  |
| L1570      | 0.4(3)   | [−6, 7]        | 0.1          | 9.3          | 1.2                       | 1.7 \times 10^2 | [−5, 6.8]            | 0.04           | 5.8          | 1.2                    | 4.6 \times 10^1  |
| L1574-5    | 0.4(3)   | [−6, 7]        | 0.3          | 15.2         | 2.2                       | 7.3 \times 10^2 | [−5, 6.8]            | 0.13           | 5.9          | 1.5                    | 2.1 \times 10^2  |
| L1576      | 0.4(3)   | [−6, 7]        | 0.2          | 11.0         | 2.6                       | 6.3 \times 10^2 | [−5, 6.8]            | 0.13           | 5.3          | 1.5                    | 2.0 \times 10^2  |
| L1578      | 0.4(3)   | [−6, 7]        | 0.1          | 10.2         | 1.8                       | 2.2 \times 10^2 | [−5, 6.8]            | 0.04           | 4.6          | 1.3                    | 5.5 \times 10^1  |
| West Front | 0.56(4)  | [−7, 10]       | 13.9         | 14.1         | 1.7                       | 5.0 \times 10^4 | [−5, 8]              | 4.85           | 8.5          | 0.8                    | 8.4 \times 10^3  |
| Swallow^a  | ...      | [11, 20]       | 0.8          | 16.5         | 1.2                       | ...            | [11, 19]             | 0.31           | 7.6          | 0.8                    | ...            |
| Horn^a     | ...      | [11, 21]       | 0.6          | 16.1         | 1.3                       | ...            | [11, 20]             | 0.21           | 4.9          | 0.6                    | ...            |
| Remote Clouds^a | ... | [16, 32] | 2.2          | 21.3         | 0.6                       | ...            | [16, 32]             | 0.49           | 5.5          | 0.5                    | ...            |

**Notes.** Columns are cloud names, distances, and the properties derived from 12CO, 13CO, and C18O respectively, including velocity ranges, sizes with pixels greater than 3$\sigma$ of integrated intensity, the maxima of spectra peak, mean column densities of H_2, and mass. The column density and mass for 12CO are derived with the X-factor, and those for 13CO and C18O are derived based on the LTE assumption. The masses of Swallow, Horn, and Remote Clouds are absent.

^a The masses of Swallow, Horn, and Remote Clouds are absent because the distances are undetermined; see the discussion of Section 8.

**References.** (1) Carpenter et al. (1995a), (2) Reid et al. (2009), Niinuma et al. (2011), Rygl et al. (2010), (3) Bok & McCarthy (1974), Esowaraiah et al. (2013), (4) Planck Collaboration et al. (2016).
4. The Gemini OB1 Molecular Cloud Complex

The GGMC complex is mainly located in the upper part of Figure 1, where four independent giant molecular clouds (GMCs) are shown in the upper parts of Figure 3. The size of the complex is $6.6 \times 2.8$° along the direction of the GGMC arrangement. The complex is located in the Perseus arm, and it is associated with Sh 247, Sh 252, Sh 254-258, BFS 52, and the GEM OB1 association, and its distance is suggested to be 2 kpc (Carpenter et al. 1995a; Reid et al. 2009; Rygl et al. 2010; Niinuma et al. 2011).

4.1. GGMC 1

GGMC 1 is located to the south of the complex (in this paper, we define north as the top and east as the left, in Galactic Coordinates) and has a velocity interval of $[-3, 10]$ km s$^{-1}$ (Figure 3(a)). The $^{12}$CO emission shows the overall distribution of the clouds (Figure 5(a)). Two distinct structures can be identified: one is a filamentary structure near the top of the cloud, and the other is a semi-circular structure in the middle of the cloud. These structures are more clearly shown in the $^{13}$CO emission contours in Figure 5(a). We note that very little CO emission is located at the center of the semi-circular structure, which will be discussed in future papers. The C$^{18}$O emission in this cloud is relatively weak, and it is mainly located to the west of the semi-circular structure (Figure 5(d)) and northeast of the cloud (Figure 5(c)). We divided the cloud into eight subregions (Figure 5(b)), and their detailed information is shown in Table 2.

Assuming $^{12}$CO is optically thick, the excitation temperature can be calculated (Bourke et al. 1997) as

$$T_{\text{ex}} = \frac{h \nu_{12}/k}{\ln\left(1 + \frac{h \nu_{12}/k}{T_{\text{MB,CO}}^{12} + \frac{h \nu_{12}^2}{2 k T_{\text{bg}}}}\right)}.$$  \hspace{1cm} (1)

where $h$ and $k$ are the Planck constant and Boltzmann constant, respectively. $\nu_{12}$ and $T_{\text{MB,CO}}^{12}$ are the frequency and peak main beam temperature of $^{12}$CO, respectively. $T_{\text{bg}} = 2.7$ K is the temperature of the cosmic microwave background. When the constants are substituted for their numerical values, the formula can be simplified to

$$T_{\text{ex}} = \frac{5.532}{\ln\left(1 + \frac{5.532}{T_{\text{MB,CO}}^{12} + 0.819}\right)} \text{K.} \hspace{1cm} (2)$$

Figure 5(b) shows the distribution of the excitation temperatures of GGMC 1, which are within the range of...
The molecular gas near the semi-circular structure has higher temperatures than the other regions.

By analyzing the kinematic information of GGMC, we find that subregion F1 has a special velocity structure. Figure 6 shows the position–velocity (P–V) diagram of F1 (the black arrow has a width of 11 arcmin in Figure 5(a)). There is no obvious velocity structure from the $^{12}$CO data, but four velocity components can be clearly seen from the $^{13}$CO data. The velocity ranges of these components, respectively, are $[0, 2.4]$, $[2.4, 4.1]$, $[4.1, 5.1]$, and $[5.1, 7.2]$ km s$^{-1}$. Figure 7 shows the distribution of the integrated intensity of these components. Component 1 ($[0, 2.4]$ km s$^{-1}$) is located in the middle of the filament, while the others orderly line up along the axis of the filament. The interesting velocity structure of filament F1 will be discussed in the future. Subregion C6, which is in the southwest of Figure 5(b), overlaps with SNR G 192.8-1.1 (Milne & Hill 1969; Caswell 1970) along the LoS. We will discuss this association in our follow-up paper.

The mass of GGMC 1 is $2 \times 10^5 M_\odot$, according to the $^{12}$CO integral intensity and X-factor (1.8 $\times 10^{20}$ cm$^{-2}$ (K km s$^{-1}$)$^{-1}$, Dame et al. 2001). The LTE molecular gas mass derived from $^{13}$CO is $3.6 \times 10^4 M_\odot$ (Bourke et al. 1997, $N(H_2)/N(^{13}CO) = 7 \times 10^2$), while the LTE molecular gas mass derived from C$^{18}$O is $2.0 \times 10^3 M_\odot$ (Bourke et al. 1997, $N(H_2)/N(C^{18}O) = 7 \times 10^6$).

4.2. GGMC 2

GGMC 2 is located in the middle of the complex with a velocity interval of $[-1.5, 16]$ km s$^{-1}$, as shown in Figure 3(b). Figure 8(a) shows the molecular gas distribution of the GGMC.
Table 2
Properties of the Subregions in GGMC 1

| Subregion | $T_{ex}$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ ($10^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ ($10^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ ($10^{21}$ cm$^{-2}$) | Mass ($M_\odot$) |
|-----------|-------------|----------------------|------------------------|-----------------------------|-----------------|----------------------|------------------------|-----------------------------|-----------------|----------------------|------------------------|-----------------------------|-----------------|
| A1        | 13          | 1297                 | 2.0                    | $1.9 \times 10^4$           | 592             | 1.3                  | 1.3                    | $5.8 \times 10^3$               | 20              | 0.5                  | 4.4                    | $1.7 \times 10^3$               |                  |
| C1        | 12          | 996                 | 1.2                    | $5.2 \times 10^3$           | 167             | 1.2                  | 0.9                    | $1.2 \times 10^3$               | 5               | 0.6                  | 4.4                    | $3.3 \times 10^2$               |                  |
| C2        | 12          | 1640                | 1.3                    | $1.4 \times 10^4$           | 252             | 0.7                  | 0.6                    | $1.1 \times 10^3$               | ...             | ...                  | ...                    | ...                         |                  |
| C3        | 12          | 1637                | 2.2                    | $2.4 \times 10^4$           | 462             | 0.9                  | 0.8                    | $3.3 \times 10^3$               | ...             | ...                  | ...                    | ...                         |                  |
| C4        | 11          | 1511                | 2.4                    | $2.7 \times 10^4$           | 800             | 1.0                  | 0.7                    | $4.5 \times 10^3$               | ...             | ...                  | ...                    | ...                         |                  |
| C5        | 13          | 1072                | 2.8                    | $2.1 \times 10^4$           | 686             | 1.3                  | 1.2                    | $6.4 \times 10^3$               | ...             | ...                  | ...                    | ...                         |                  |
| C6        | 12          | 4235                | 2.4                    | $6.8 \times 10^4$           | 1744            | 1.3                  | 0.9                    | $1.2 \times 10^4$               | ...             | ...                  | ...                    | ...                         |                  |
| F1        | 12          | 1637                | 2.6                    | $2.2 \times 10^4$           | 520             | 1.1                  | 0.8                    | $3.3 \times 10^3$               | ...             | ...                  | ...                    | ...                         |                  |

Note. Columns are subregion names, maximas of excitation temperature, and the properties derived from $^{12}$CO, $^{13}$CO, and C$^{18}$O respectively, including size with pixels greater than 3$\sigma$ of integrated intensity, line widths of averaged spectra, mean column density of H$_2$, and mass.
Figure 6. (a) *P–V* diagram of $^{12}$CO along the arrows in Figure 5(a); the width of the belt is 22 pixel ($11'$, solid rectangle in Figure 5(a)). (b) *P–V* diagram of $^{13}$CO along the arrows in Figure 5(a); the width of the belt is the same as in (a). Four velocity components can be identified in $^{13}$CO (dashed lines in the figure). Figure 7 shows the spatial distribution of those components.

Figure 7. False color map of $^{13}$CO in GGMC1. Blue, green and red represent the integrated intensity of $^{13}$CO within $[2.5, 4.1]$, $[4.2, 5.1]$, and $[5.2, 7.2]$ km s$^{-1}$, respectively. The white contours indicate the integrated intensity of $^{13}$CO within $[0, 2.4]$ km s$^{-1}$, and the contour levels begin at 0.8 K km s$^{-1}$ with increments of 0.48 K km s$^{-1}$ (3$\sigma$).
2 main body. The $^{12}$CO emission of the main body of GGMC 2 is concentrated in subregions C5 and C6, which is consistent with the work of Bieging et al. (2009), who used CO ($J = 2–1$ and $J = 3–2$) mapping. There are two shell structures to the west of subregion C6, while C6 itself is associated with five optical HII regions: Sh 254, Sh 255, Sh 256, Sh 257, and Sh 258. There is no $^{13}$CO emission along the LoS to Sh 254 (Figure 8(b)), while the molecular gas is distributed to the east of the Sh 254, which is the largest optical HII region in GGMC 2. Subregion F1 is a diffuse and elongated cloud, which was identified via its $^{12}$CO emission (Figure 8(a)); it is seen, however, that its $^{13}$CO emission is very weak (Figure 8(b)). Two distinct filamentary structures, labeled Ridge A and Ridge B, are seen in the $^{13}$CO emission map (red lines in Figure 8(b)).

$^{18}$O emission in the main body of GGMC 2 is stronger than that in GGMC 1 (Figure 8(c)), and it is concentrated into subregions C5, Ridge A, and Ridge B. Bieging et al. (2009) identified three structures: Ridge A, Ridge B, and Cloud C. These structures are also identified in our map (red letters and a + symbol in Figure 8(b)), and we newly identify two structures, Cloud D and Cloud E, based on our $^{13}$CO and $^{18}$O emission. Ridge A and Ridge B are both filamentary structures. Their $P$–$V$ diagrams are shown in Figures 9(a) and (b), respectively. According to their distance of 2 kpc, the lengths of Ridge A and ridge B are 14 pc and 10.5 pc, respectively.

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There are some intriguing clouds located to the northwest of the main body of GGMC 2, which are named BFS 52 cloud (Figure 10(a)). These clouds are a part of GGMC 2, and are associated with H II region BFS 52 (Blitz et al. 1982; Carpenter et al. 1995a). There is a shell structure that connects the GGMC 2 main body and BFS 52 cloud to the east of the BFS 52 cloud (Figure 10(a)). To the west of the BFS 52 cloud, three filamentary structures are seen. F4 and F3 have strong $^{13}$CO emission, but F2 is invisible in $^{13}$CO (Figure 10(b)). The H II region BFS 52 is located to the south of F4. C$^{18}$O emission in the BFS 52 cloud is concentrated in the region near BFS 52 (Figure 10(c)).

The excitation temperature of GGMC 2 is higher than that of GGMC 1 (Figures 8(d) and 10(d)). The maximum excitation temperature of GGMC 2 is 45 K, while for BFS 52 cloud it is 31 K (Table 3). Ridge A and Ridge B have higher excitation temperatures than the other subregions in GGMC 2, and the temperatures of the molecular gas in Ridge A and Ridge B are above 20 K. The excitation temperature of F1 is higher than that in other subregions in the BFS 52 cloud.

Using the adopted X-factor, the mass traced by $^{12}$CO emitted by GGMC 2 is $1.8 \times 10^5 M_\odot$, where the main body of GGMC 2 accounts for 80% of the total mass (Tables 1 and 3). The molecular masses derived from $^{13}$CO and C$^{18}$O are $7.4 \times 10^4 M_\odot$ and $1.0 \times 10^4 M_\odot$, respectively (Table 1).

4.3. GGMC 3

GGMC 3 is located to the right of the BFS 52 cloud and has the same velocity range (Figure 3). It includes two fragments, which are, respectively, the western cloud fragment (WCF; Lada & Wooden 1979), and are located at the eastern and western sides of Sh 252 (Figure 11(a)). ECF includes six subregions, all of which are filamentary structures. The $^{12}$CO emission intensity of the WCF is much stronger than that of the ECF. The $^{12}$CO molecular gas is concentrated to the northwest of the WCF. A finger-like structure is found to the south of the WCF. $^{13}$CO emission of GGMC 3 shows a shell-like structure that surrounds the H II region Sh 252, and the $^{13}$CO emission is enhanced at the wall of the shell structure (Figure 11(b)). To the northwest of the WCF, C$^{18}$O emission presents two structures (Figure 11(c)).

The excitation temperature of GGMC 3 is higher than that of GGMC 1 (Figure 11(d)). The maximum temperature of GGMC 3 is 41 K, which is close to that of GGMC 2 (Tables 3, 4). The WCF has higher temperature than the ECF (Figure 11(d)). The molecular gas near H II region Sh 252 has the highest temperature, which is above 20 K. We note that the maximum temperatures of all subregions of the ECF are above 20 K.
The GMC includes four compact H II (CH II) regions (Felli et al. 1977) and five embedded clusters (Bonatto & Bica 2011) (Figure 11(b)). Most of the objects are located near Sh 252 (Figure 11(b)). Jose et al. (2012, 2013) have identified 577 YSOs in the MCs. This indicates that GGMC 3 has strong star formation activities.

The total mass of GGMC 3 traced by $^{12}$CO is found to be \(2.8 \times 10^5 M_\odot\) using the adopted X-factor (Table 1). Under the assumption of LTE, the masses of molecular gases traced by $^{13}$CO and $^{13}$CO data are calculated to be \(1.1 \times 10^5 M_\odot\) and \(2.8 \times 10^5 M_\odot\), respectively (Table 1). The mass traced by $^{13}$CO of GGMC 3 is about three times higher than that of GGMC 2.

4.4. GGMC 4

The last GMC in the complex is GGMC 4, which is located to the west of the complex, and is associated with Sh 247 (Figure 3(a)). Figure 12(a) shows the overall molecular gas distribution of GGMC 4, where most of the $^{12}$CO emission is located in subregion C3. The size of C1 is larger than that of C3, but the $^{12}$CO emission of C1 is more diffuse. A distinct filament, F1, can be identified in subregion C3, and Sh 247 is located southwest of the filament. Three compact H II regions (Ghosh et al. 2000) line up along the filament. The $^{13}$CO emission shows another filament, F2, which is parallel to F1 (Figure 12(b)). The $^{13}$CO emission in GGMC 4 is also strong (Figure 12(b)), where five clumpy structures are detected. Four of the $^{13}$CO MCs are along filament F1, and three of them are associated with compact H II regions.

Figure 12(c) shows the excitation temperature of GGMC 4. The maximum temperature of GGMC 4 is 33 K, which is higher than that of GGMC 1 but lower than that of GGMC 2 and GGMC 3 (Table 5). Subregion C3 has a higher temperature than the other subregions.
| Subregion | $T_{ex}$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ ($10^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ ($10^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ ($10^{21}$ cm$^{-2}$) | Mass ($M_\odot$) |
|-----------|-------------|---------------------|-----------------|------------------|-----------------|---------------------|-----------------|------------------|-----------------|---------------------|-----------------|------------------|-----------------|
| A1        | 18          | 997                 | 2.5             | 1.1              | $1.5 \times 10^4$ | 330                 | 1.7             | 0.7              | $1.6 \times 10^2$ | ...          | ...               | ...              | ...              |
| C1        | 9           | 316                 | 3.3             | 1.5              | $5.6 \times 10^3$ | 116                 | 2.1             | 0.5              | $4.2 \times 10^2$ | ...          | ...               | ...              | ...              |
| C2        | 13          | 327                 | 3.8             | 3.8              | $9.6 \times 10^3$ | 278                 | 2.1             | 1.5              | $3.1 \times 10^3$ | 2             | 1.2               | 5.0              | $8.4 \times 10^1$ |
| C3        | 13          | 323                 | 4.3             | 3.9              | $9.5 \times 10^3$ | 293                 | 2.2             | 1.1              | $2.4 \times 10^3$ | ...          | ...               | ...              | ...              |
| C4        | 16          | 657                 | 3               | 2.9              | $1.5 \times 10^4$ | 468                 | 1.8             | 1                | $3.4 \times 10^3$ | ...          | ...               | ...              | ...              |
| C5        | 27          | 351                 | 3.1             | 5.1              | $1.4 \times 10^4$ | 311                 | 2               | 3.3              | $7.9 \times 10^3$ | 20            | 1.5               | 10.6             | $1.6 \times 10^3$ |
| C6        | 45          | 1010                | 3.5             | 5.9              | $4.5 \times 10^4$ | 905                 | 2.3             | 4.3              | $3.0 \times 10^4$ | 74            | 1.7               | 13.2             | $7.4 \times 10^3$ |
| C7        | 16          | 946                 | 4.1             | 4.7              | $3.4 \times 10^4$ | 798                 | 2.5             | 1.8              | $1.1 \times 10^4$ | 12            | 1.5               | 5.8              | $5.4 \times 10^2$ |
| F1        | 11          | 901                 | 2.9             | 1.9              | $1.4 \times 10^4$ | 399                 | 1.9             | 0.7              | $2.0 \times 10^3$ | ...          | ...               | ...              | ...              |
| F2        | 13          | 490                 | 2.1             | 1.2              | $5.9 \times 10^3$ | 70                  | 1.6             | 0.7              | $3.4 \times 10^2$ | ...          | ...               | ...              | ...              |
| F3        | 18          | 556                 | 2.7             | 2.2              | $1.1 \times 10^4$ | 372                 | 1.7             | 1.1              | $3.3 \times 10^3$ | 2             | 1.3               | 4.3              | $7.2 \times 10^1$ |
| F4        | 31          | 269                 | 2.3             | 2.5              | $6.3 \times 10^3$ | 173                 | 1.7             | 2.5              | $3.3 \times 10^3$ | 8             | 1.4               | 12.9             | $7.5 \times 10^2$ |

Note. Columns are the same as Table 2.
The GGMC 4 includes two major components, according to the spectral analysis. Figure 13 shows a $P$–$V$ diagram along the black arrow in Figure 12(a). The width of the belt is 24 arcmin. We identify the first component with the velocity interval $[-3, 5]$ km s$^{-1}$ (typical LSR velocity $\sim 2$ km s$^{-1}$), while the other is $[5, 13]$ km s$^{-1}$ (typical LSR velocity $\sim 8$ km s$^{-1}$). This is consistent with the $^{12}$CO ($J = 2$–1) measurements of Shimoi-kura et al. (2013), who identified 11 IR clusters in 2MASSPSC, and concluded that the two components probably collided at some point in the past, which then triggered the observed star formation. Figures 14(a) and (b) show the $^{13}$CO and $^{13}$CO gas distribution of the two velocity components, respectively. The figures present the spatial coincidence between the 2 and 8 km s$^{-1}$ components, where it is seen that these two components are mainly detected to the west and east, respectively. Interestingly, the IR clusters and enhanced molecular gas are located at the interface between the two components. We will discuss the possibility of a previous collision in a future paper.

We calculated the mass of GGMC 4 traced by $^{12}$CO to be $1.6 \times 10^5 M_\odot$ using the adopted X-factor (Table 1). Next, by assuming LTE, the masses of the molecular gas traced by $^{13}$CO and $^{13}$CO data are $5.5 \times 10^4 M_\odot$ and $1.1 \times 10^4 M_\odot$, respectively (Table 1).

The four GGMCs in the complex have similar masses, where the mean mass traced by $^{12}$CO is $2.1 \times 10^5 M_\odot$ (Table 1).
| Subregion | $T_{ex}$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) |
|-----------|-------------|---------------------|-----------------|-----------------------------|--------------|---------------------|-----------------|-----------------------------|--------------|---------------------|-----------------|-----------------------------|--------------|
| ECF1      | 40          | 444                 | 3.5             | 4.6                         | $1.5 \times 10^4$ | 376                 | 2.1             | 2.4                         | $6.7 \times 10^3$ | 18                   | 1.2             | $6.6 \times 10^2$                  |
| ECF2      | 23          | 181                 | 3.3             | 3.2                         | $6.0 \times 10^3$ | 135                 | 2.1             | 2.4                         | $2.4 \times 10^3$ | 8                     | 1.7             | $11.2 \times 10^2$                 |
| ECF3      | 30          | 302                 | 3               | 2.6                         | $6.9 \times 10^3$ | 156                 | 1.7             | 1.5                         | $1.8 \times 10^3$ | 1                     | 1               | $7.9 \times 10^1$                  |
| ECF4      | 22          | 834                 | 3               | 2.1                         | $1.6 \times 10^4$ | 461                 | 2               | 1.3                         | $4.7 \times 10^3$ | 3.5                   | 1.4             | $5.8 \times 10^2$                  |
| ECF5      | 20          | 1308                | 3.2             | 2.5                         | $2.9 \times 10^4$ | 773                 | 2.2             | 1.4                         | $7.9 \times 10^3$ | 3.5                   | 1.2             | $4.0 \times 10^2$                  |
| ECF6      | 22          | 837                 | 2.3             | 2.2                         | $1.6 \times 10^4$ | 487                 | 1.5             | 1.3                         | $4.8 \times 10^3$ | ...                   | ...             | ...                               |
| WCF       | 41          | 4117                | 4.3             | 4.7                         | $1.6 \times 10^5$ | 3140                | 3               | 3.2                         | $7.5 \times 10^4$ | 175                   | 2.1             | $19.4 \times 10^4$                 |

Note. Columns are the same as Table 2.
mean molecular mass traced by $^{13}$CO in the GGMCs is $6.9 \times 10^4 M_\odot$ (Table 1), which is similar to that of the W3/4/5 region (Lada et al. 1978) at a similar distance of 2 kpc (Xu et al. 2006). In total, the GGMCs appear to form a coherent 6'6 $\times$ 2'8 (230 pc $\times$ 98 pc) complex, which is comparable in size to that of the W3/4/5 region (Lada et al. 1978).

5. The Local Lynds Dark Clouds

In the middle of the observation area, there are a number of Lynds dark clouds (Lynds 1962), including LDN 1570 (also known as CB 44; Clemens & Barvainis 1988), LDN 1574-5, LDN 1576, and LDN 1578 (also known as CB 45) (Figure 3). These dark clouds form a straight chain extending from the northeast by LDN 1570 to the southwest by LDN1578, as shown in Figure 15(a). All of these dark clouds show prominent $^{13}$CO emission, while LDN 1574-5, LDN 1576 also show significant C$^{18}$O emission (Figure 15(b)).

The radial velocities of these dark clouds are within $[-6, 7]$ km s$^{-1}$, as shown in (Figure 2). Considering their proximity both in space and velocity, we regard these clouds to be at the same distance and are hence physically associated. As will be shown below, the similarity of their physical properties also supports this suggestion.

The distance of the chain of dark clouds has been estimated by several previous works. Tomita et al. (1979) estimated the...
Table 5
Properties of the Subregions in GGMC 4

| Subregion | $T_{ex}$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | $T_{ex}$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | $T_{ex}$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) |
|-----------|--------------|----------------------|------------------------|-------------------------------|-----------------|--------------|----------------------|------------------------|-------------------------------|-----------------|--------------|----------------------|------------------------|-------------------------------|-----------------|
| C1        | 14           | 2385                 | 3.2                    | 2.7                           | $4.8 \times 10^4$ | 1304         | 1.1                  | 1.2                     | $1.2 \times 10^4$             | $1.2 \times 10^4$ | ...           | ...                   | ...                     | ...                          | ...             |
| C2        | 17           | 1099                 | 2.5                    | 2.6                           | $2.2 \times 10^4$ | 606          | 0.8                  | 1.2                     | $5.5 \times 10^3$             | $5.5 \times 10^3$ | ...           | ...                   | ...                     | ...                          | ...             |
| C3        | 33           | 1913                 | 4.5                    | 4.5                           | $6.4 \times 10^4$ | 1160         | 2.4                  | 3.9                     | $3.4 \times 10^4$             | $3.4 \times 10^4$ | 87            | 0.4                   | 8.3                     | $1.1 \times 10^3$             | ...             |
| C4        | 12           | 878                  | 1.7                    | 1.2                           | $7.7 \times 10^3$ | 151          | 0.3                  | 0.8                     | $9.3 \times 10^2$             | $9.3 \times 10^2$ | ...           | ...                   | ...                     | ...                          | ...             |

Note. Columns are the same as Table 2.
dark cloud distance to be 300 pc, while Bok & McCarthy (1974) and Eswaraiah et al. (2013) obtained distances of 400 pc and 394 pc, respectively. Hilton & Lahulla (1995) suggested a distance between 400 and 600 pc. Since more groups found a distance of about 400 pc, including the recent result of Eswaraiah et al. (2013), we adopted a distance of 400 pc in our subsequent analysis. At this distance, these clouds are located in the Local arm, and therefore are not physically related to the GGMCs in Figure 3.

Figure 15(c) presents the distribution of the excitation temperature of the chain of local Lynds dark clouds. The excitation temperatures of all the dark clouds are within the range of 4.5–18.7 K (Table 6). Within these dark clouds, LDN 1574-5 shows relatively higher excitation temperatures than the others. Three major enhanced peaks can be identified within the cloud, as defined by their $^{13}$CO contours. It is also notable that the C$^{18}$O emission is enhanced toward the LDN 1574 area, which will also be discussed in later works.

The size of the dark cloud chain is $2.15'' \times 0.3''$, which corresponds to a physical size of 15 pc $\times$ 2.1 pc. Using the adopted X-factor between $^{12}$CO and molecular hydrogen, we calculated the total mass of all the dark clouds traced by $^{12}$CO to be $1750 M_\odot$. The mass of the dark cloud chain is similar to that of L1340 (Kun et al. 1994; Yonekura et al. 1997) and L1471 (also known as Barnard 5, Stenholm 1985; Goldsmith et al. 1986; Langer et al. 1989). Next, and again assuming LTE, the masses of molecular gas traced by $^{13}$CO and C$^{18}$O are $511 M_\odot$ and $89 M_\odot$, respectively.

In the coldest, densest parts of the clouds, especially in dark clouds and in dense, starless cores, the CO molecules freeze out onto dust grains, and are depleted from the gas (Lee et al. 2003). In such cases, the $^{13}$CO and C$^{18}$O lines do not trace the densest parts of the clouds. We will study this effect in our next paper (C. Wang et al. 2017, in preparation).
6. The West Front

A very long filamentary cloud is located in the lower part of the observation area, as shown in Figure 1. The cloud extends from the lower left to the right side of the middle of the observation area, and the length of the cloud is about 8°5 (Figure 16(a)). Carpenter et al. (1995a) called this cloud the West Front. 12CO emission is mainly located near the middle of the cloud, while gas near both ends of the cloud are fragmented. The 13CO emission is also concentrated in the middle of the cloud, especially in subregions C2, C3, and C4. The gas traced by 13CO at both ends of the cloud is more diffuse. The C18O emission is relatively weaker than that seen in the GGMCs, and the emission is distributed into four small areas (Figures 17(a)-(d)). The radial velocities of the West Front are within [−7, 10] km s$^{-1}$, as shown in (Figure 2). The velocity range is similar to that of the Lynds dark clouds chain. The H II region Sh 261 is located above subregion C1 in spatial projection.

The West Front is lacking in systematic research, and information related to its distance is poor. Fortunately, there are four Planck dark clouds in this region that are included in the Planck dark cloud catalog (Planck Collaboration et al. 2016). These dark clouds are PGCCG 190.18-2.45, PGCCG 192.04-2.59, PGCCG 192.71-2.39, and PGCCG 194.27-3.27, which have distances of 0.58 kpc, 0.59 kpc, 0.44 kpc, and 0.63 kpc, respectively (Figure 17(e)). Taking distance errors into account, we regard these clouds as being at the same distance. Since the dark clouds overlapped with the West Front in spatial projection, and there are no other velocity components except for the West Front, we suggest that the dark clouds are part of the West Front. We adopted a mean distance to the Planck dark clouds of 560 pc as the distance to the West Front in the subsequent analysis. At this distance, the West Front and Lynds dark clouds are locally gas. Additionally, Foster & Brunt (2015) estimated a spectrophotometric distance to Sh 261 of 1.89 kpc, which suggests that Sh 261 is not associated with the West Front.

Figure 17(e) shows the distribution of the excitation temperatures in the West Front, which are within the range 4.5–17.5 K (Table 7). The maximum excitation temperature is located at subregion C5, while the excitation temperatures in the other subregions are less than 14 K. Thus, the temperature distribution of the West Front is similar to that of the Lynds dark clouds chain. In addition to the Planck dark clouds, six CB dark clouds (Clemens & Barvainis 1988) are also associated with the West Front (Figure 17(e)). Hence, we regard the West Front as a dark cloud complex.

At a distance of 560 pc, the physical length of the West Front is 83 pc. The total mass of the West Front traced by 12CO is found to be $5.0 \times 10^4 M_\odot$, when using the adopted X-factor. The LTE masses based on 13CO and C18O are $8.4 \times 10^3 M_\odot$ and $1.9 \times 10^2 M_\odot$, respectively. The mass of the West Front is similar to several giant molecular filaments reported by Ragan et al. (2014). Since the West Front is local, it is a good sample
Table 6
Properties of the Subregions in the Lynds Dark Clouds

| Subregion | $T_{ex}$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) |
|-----------|--------------|-----------------------|------------------------|----------------------------------|-----------------|-----------------------|------------------------|----------------------------------|-----------------|-----------------------|------------------------|----------------------------------|-----------------|
| L1570     | 13           | 563                   | 1.5                    | 1.2                             | $1.7 \times 10^2$ | 132                   | 0.9                    | 1.2                             | $4.6 \times 10^1$ | 4                   | 0.6                    | 4.2                             | $4.9 \times 10^0$ |
| L1574     | 19           | 1220                  | 2.7                    | 2.2                             | $7.3 \times 10^2$ | 473                   | 1.2                    | 1.5                             | $2.1 \times 10^2$ | 22                  | 0.6                    | 5.4                             | $3.6 \times 10^1$ |
| L1576     | 14           | 821                   | 2.7                    | 2.6                             | $6.3 \times 10^2$ | 452                   | 1.2                    | 1.5                             | $2.0 \times 10^2$ | 31                  | 0.5                    | 4.8                             | $4.5 \times 10^1$ |
| L1578     | 14           | 429                   | 2                      | 1.8                             | $2.2 \times 10^2$ | 140                   | 1.1                    | 1.3                             | $5.5 \times 10^1$ | 2                   | --$^a$                 | 4.0                             | $3.0 \times 10^4$ |

Notes. Columns are the same as Table 2.

$^a$ The line width of C1 derived from C$^{18}$O is not listed here because the emissions are so weak that the value is uncalculable.
| Subregion | \( T_{\text{ex}} \) (K) | Size (arcmin\(^{-2}\)) | \( \sigma \) (km s\(^{-1}\)) | \( N_{\text{H}_2} \) \( (10^{21} \text{ cm}^{-2}) \) | Mass \( (M_\odot) \) | Size (arcmin\(^{-2}\)) | \( \sigma \) (km s\(^{-1}\)) | \( N_{\text{H}_2} \) \( (10^{21} \text{ cm}^{-2}) \) | Mass \( (M_\odot) \) | \( T_{\text{ex}} \) (K) | Size (arcmin\(^{-2}\)) | \( \sigma \) (km s\(^{-1}\)) | \( N_{\text{H}_2} \) \( (10^{21} \text{ cm}^{-2}) \) | Mass \( (M_\odot) \) | \( T_{\text{ex}} \) (K) | Size (arcmin\(^{-2}\)) | \( \sigma \) (km s\(^{-1}\)) | \( N_{\text{H}_2} \) \( (10^{21} \text{ cm}^{-2}) \) | Mass \( (M_\odot) \) | \( T_{\text{ex}} \) (K) | Size (arcmin\(^{-2}\)) | \( \sigma \) (km s\(^{-1}\)) | \( N_{\text{H}_2} \) \( (10^{21} \text{ cm}^{-2}) \) | Mass \( (M_\odot) \) |
|-----------|----------------|------------------------|-----------------|-----------------|-------------|----------------|----------------|----------------|-------------|----------------|----------------|----------------|----------------|-------------|----------------|----------------|----------------|-------------|----------------|----------------|----------------|-------------|----------------|----------------|----------------|-------------|
| C1        | 11             | 2516                   | 2.1             | 1.3             | \( 2.9 \times 10^3 \) | 746          | 0.9           | 0.5            | \( 2.4 \times 10^3 \) | ...         | ...           | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         |
| C2        | 14             | 6257                   | 2.7             | 2.2             | \( 1.0 \times 10^4 \) | 4198         | 1             | 0.9            | \( 2.3 \times 10^3 \) | 16          | 0.5           | 3.6           | \( 1.6 \times 10^2 \) | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         |
| C3        | 12             | 2342                   | 3.3             | 2.5             | \( 4.2 \times 10^3 \) | 1564         | 1.7           | 1.0            | \( 1.0 \times 10^3 \) | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         |
| C4        | 12             | 6073                   | 3.8             | 2.7             | \( 1.2 \times 10^4 \) | 4003         | 1.8           | 1.0            | \( 2.3 \times 10^3 \) | 2           | 0.7           | 3.2           | \( 2.1 \times 10^4 \) | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         |
| C5        | 18             | 2491                   | 2.4             | 1.9             | \( 3.5 \times 10^3 \) | 1040         | 1             | 0.8            | \( 4.9 \times 10^2 \) | 1           | ...\(^a\) | 3.3           | \( 4.3 \times 10^0 \) | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         |
| D1        | 13             | 2313                   | 1.8             | 1.2             | \( 2.6 \times 10^3 \) | 871          | 0.8           | 0.5            | \( 2.5 \times 10^2 \) | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         |
| D2        | 11             | 8246                   | 2.2             | 1.4             | \( 9.8 \times 10^3 \) | 2714         | 0.9           | 0.6            | \( 1.0 \times 10^3 \) | 3           | 0.6           | 3.0           | \( 8.4 \times 10^0 \) | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         | ...           | ...           | ...           | ...         |

Notes. Columns are the same as Table 2.

\(^a\) The line width of C1 derived from C\(^{18}\)O is not listed here because the emissions are so weak that the value is uncalculable.
Figure 15. Gas distribution of Lynds Dark Clouds. (a) Integrated intensity map of $^{13}$CO with the range of $[-6, 7]$ km s$^{-1}$. The boxes represent regions of Lynds Dark Clouds in the optical band, while the circles represent H II regions. (b) The background is the integrated intensity of $^{13}$CO with the range of $[-5, 7]$ km s$^{-1}$. The contours indicate the integrated intensity of C$^{18}$O with the range of $[-3, 2]$ km s$^{-1}$; the steps are $3, 5 \times 0.27$ K km s$^{-1}$ (1σ). (c) The excitation temperature map of Lynds Dark Clouds.
Table 8
Properties of the Subregions in the Swallow

| Subregion | $T_{ex}$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) |
|-----------|--------------|----------------------|------------------------|---------------------------------|------------------|----------------------|------------------------|---------------------------------|------------------|----------------------|------------------------|---------------------------------|------------------|
| F1        | 20           | 596                  | 2.7                    | 1.9                             | ...              | 466                  | 1.7                    | 1.3                             | ...              | 6                    | 0.5                    | 4.8                              | ...              |
| F2        | 11           | 391                  | 1.7                    | 1                               | ...              | 202                  | 1.1                    | 0.5                             | ...              | ...                  | ...                    | ...                              | ...              |
| F3        | 13           | 752                  | 1.8                    | 1.1                             | ...              | 369                  | 0.9                    | 0.5                             | ...              | ...                  | ...                    | ...                              | ...              |

Note. Columns are the same as Table 2.
with which to study the physical properties and structures of elongated clouds.

7. The Other Clouds

In addition to the clouds that were discussed above, there are three other MCs presented here: Swallow, Horn, and the Remote Clouds. The typical velocities of these three clouds are higher than those of the clouds formerly discussed. Their details are introduced in the following.

7.1. Swallow

The Swallow cloud is to the southeast of GGMC 1, and the clouds appear close together, as projected on the plane of the sky (Figure 3). The $^{12}$CO emission of Swallow shows three filaments (Figure 18(a)). Filament F1 is an arc-like structure and is coherent in space, while the others are more diffuse. The $^{18}$O emission is concentrated to F1 (Figure 18(b)), while the $^{13}$CO emission is only located at the peak emission of F1 (Figure 18(b)). $^{18}$O shows a crescent-shaped structure in the integrated intensity map (Figure 18(b)).

The radial velocities of Swallow are within $[10, 20]$ km s$^{-1}$, which is different from that of GGMC 1 (Figure 2). Hence, they are probably independent clouds. The excitation temperature distribution of Swallow is shown in Figure 18(c), where the maximum temperature is 20 K (Table 8), which is located at the center of filament F1. The excitation temperatures of F2 and F3 are below 14 K. We note that the southermost part of filament F1 has a maximum temperature of 17 K. Its distance will be discussed in Section 8.

Interestingly, there is a cloud (194.9-01.2) in the catalog of Kawamura et al. (1998) that is located in the Swallow area. By comparing 194.9-01.2 with our $^{12}$CO, $^{13}$CO emission map (Figures 18(a), (b)), we find that it is located in subregion F1.

7.2. Horn

The Horn is located to the southwest of GGMC 3, and it overlaps with the West Front in spatial distribution (Figure 3(c)), but with a different velocity interval of $[11, 21]$ km s$^{-1}$ (Figure 2). Thus, the Horn and the West Front are probably independent clouds. The cloud is filamentary, as shown in Figure 19(a). The $^{13}$CO emission shows two structures in subregions C1 and C2 (Figure 19(b)). The $^{18}$O emission is weak, and it is located in an area of enhanced $^{13}$CO emission (Figures 19(c), (d)).

Figure 20 shows the excitation temperature distribution of Horn. The Horn has two temperature maxima: one is 20 K, which is located in subregion C1, which has strong $^{13}$CO emission and weak $^{18}$O emission, while the other is 18 K, which is located in the southermost part of Horn that has weak

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**Figure 16.** (a) $^{12}$CO integrated intensity map in the range of $[-7.5, 10]$ km s$^{-1}$. The dashed lines show the boundaries of the subregions, and the circles represent H II regions. (b) $^{13}$CO integrated intensity map in the range of $[-5, 8]$ km s$^{-1}$. The four rectangles show the area of Figures 17(a)–(d).
13CO emission and no C18O emission (Table 9, Figure 20). Most of the molecular gas temperatures in the cloud are below 14 K. The distance information of Horn will be discussed in Section 8.

In a past study, Kawamura et al. (1998) found two clouds in this area, which they named 188.8-01.5 and 189.2-01.1. By comparing these clouds with our 12CO map, we find that the 13CO emission map (Figures 19(a), (b)), corresponds to the middle of the C3 and C1 subregions.

7.3. Remote Clouds

The Remote Clouds are located to the east of the observation area, with a maximum velocity of [16, 28] km s⁻¹ (Figure 3(c)). These clouds are probably the most distant clouds according to Galactic rotation curves. The 12CO emission of the Remote Clouds shows six distinct subregions (Figure 21(a)). The cloud area is about 2°7 × 2°9 in Galactic coordinates. Subregion C2 is the largest cloud in the area, and there are three filaments to the south and west of this area. C3 is located to the northwest of F3, which is a cloud with a small size but relatively strong 12CO emission. The mean 12CO integrated intensity of the Remote Clouds is less than that of the other clouds studied in this paper. The 13CO integrated intensity of the Remote Clouds shows a clumpy distribution (Figure 21(b)) and the mean intensity is weaker than that of the GGMC complex and local clouds presented above. C18O emission is absent in most subregions except for C2 (Figure 21(d)).

Sh 259 is a small H II region (Sharpless 1959) located in the peak emission of the subregion F3 area (Figure 21(c)), thus indicating they are physically associated (Carpenter et al. 1995a). Moreover, the WISE band 3 (12 micrometers) map also shows a filamentary structure near Sh 259, which also suggests a physical correlation with our CO filamentary structure.

The excitation temperature distribution of the Remote Clouds is presented in Figure 22. The maximum temperatures of C1 and F1 are 23 K and 25 K, respectively (Table 10). The small cloud C3 is within the range of 4.5–19 K, and the other three cloud temperatures are below 20 K. We note that cloud C2, which is the only one that has C18O emission in the Remote Clouds along with relatively strong 13CO emission, is very cold, with a maximum temperature of 10 K. The distance to the Remote Clouds will be discussed in Section 8.

8. Discussion

Due to the degeneracy of the radial velocity in the Galactic anti-center, the kinematic distance uncertainties of the MCs are
large. Some groups have searched for celestial bodies that are associated with the cloud, such as HII regions, massive stars, and maser sources, to determine a distance to a given cloud (Carpenter et al. 1995a; Reid et al. 2009; Rygl et al. 2010; Niinuma et al. 2011). Other groups obtained cloud distances via extinction measurements (e.g., Eswaraiah et al. 2013). In this work, the distances to the GGMCs, Lynds dark clouds and West Front Clouds are discussed in Sections 4–6.

So far there is no distance information for Swallow and Horn, and there are no other sources nearby that can be traced to determine their distances. There is a dark cloud that just overlaps with Horn, which is listed in the Planck dark clouds catalog as PGCG 188.82-1.46 at a distance of 3.78 kpc (Planck Collaboration et al. 2016). We note that the dark cloud has strong CO emission in subregion C3 in the Horn, but there is some weak $^{12}$CO emission from the West Front along the LoS to the Planck dark cloud. As the West Front is local, while the distance of the Planck dark cloud is 3.78 kpc, we regard the dark cloud as being associated with the Horn and it is in the background of the West Front. It is consistent

Figure 18. Gas distribution of Swallow. (a) $^{12}$CO integrated intensity map in the range of [11, 20] km s$^{-1}$. The dashed lines show the boundaries of the subregions. The red rectangle shows the area of Figure 18(b). (b) The background is the $^{13}$CO integrated intensity in the range of [11, 19] km s$^{-1}$. The contours indicate the integrated intensity of C$^{18}$O with the range of [12, 18] km s$^{-1}$; the steps are 4, 6, 8 × 0.25 K km s$^{-1}$ (1$\sigma$). (c) The excitation temperature map of the Swallow MCs.
Figure 19. Gas distribution of Horn. (a) $^{12}$CO integrated intensity map in the range of [11, 21] km s$^{-1}$. The dashed lines show the boundaries of the subregions. (b) Map of the $^{12}$CO integrated intensity in the range of [11, 20] km s$^{-1}$. The rectangles show the areas of Figures 19(c) and (d). (c) and (d) The background is a map of the $^{13}$CO integrated intensity. The contours indicate the integrated intensity of C$^{18}$O with the range of [12, 18] km s$^{-1}$; the steps are 4, 6, 8 $\times$ 0.25 K km s$^{-1}$ ($1\sigma$).

Figure 20. Excitation temperature map of the MC Horn. The dashed lines show the boundaries of the subregions.
| Subregion | $T_{ex}$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ (10$^{21}$ cm$^{-2}$) | Mass ($M_\odot$) |
|-----------|--------------|---------------------|----------------|-----------------------------|----------------|---------------------|----------------|-----------------------------|----------------|---------------------|----------------|-----------------------------|----------------|
| C1        | 20           | 228                 | 1.9           | 1.3                         | ...            | 136                 | 1.1            | 0.8                         | ...            | 1                   | ...            | ...                         | ...            |
| C2        | 11           | 146                 | 2.1           | 1.3                         | ...            | 95                  | 1.4            | 1                           | ...            | 4                   | 0.9            | 4.5                         | ...            |
| C3        | 15           | 697                 | 2.1           | 1.5                         | ...            | 371                 | 1              | 0.7                         | ...            | ...                 | ...            | ...                         | ...            |
| C4        | 18           | 280                 | 2.1           | 1.5                         | ...            | 169                 | 1              | 0.6                         | ...            | ...                 | ...            | ...                         | ...            |
| D1        | 10           | 165                 | 1.3           | 0.7                         | ...            | 82                  | 0.7            | 0.4                         | ...            | ...                 | ...            | ...                         | ...            |

**Notes.** Columns are the same as Table 2.

$^a$ The line width of C1 derived from C$^{18}$O is not listed here because the emission is so weak that the value is uncalculable.
with the velocity of Horn, which is higher than that of the West Front. Since the influence of weak $^{12}$CO emission is from the foreground, 3.78 kpc should be considered as an upper limit to the distance to the Horn.

The Swallow and Horn MCs have the same velocity interval, $[11, 21] \text{ km s}^{-1}$, but their spatial separation is quite large ($\sim 4^\circ$). They have a similar spatial size (0.6 and 0.8 deg$^2$), and the mean column densities derived from $^{12}$CO and $^{13}$CO are also similar (Table 1). They are probably at the same distance from Earth on the basis of the galactic rotation curve. If we assume that the distance of the clouds is 3.78 kpc, the masses of Swallow and Horn respectively are $9.2 \times 10^4 M_\odot$ and...
7.9 × 10^4 M_☉, as derived from 12CO. If their distance is 2 kpc, their respective masses are 2.6 × 10^4 M_☉ and 2.2 × 10^4 M_☉, as derived from 12CO.

The Remote Clouds include six subregions (Figure 21(a)). Those subregions are close to each other in space, and they have the same velocity interval. However, the sizes and the shapes of the clouds are different. Since Sh 259 is physically associated with subregion F3, the distance of F3 can be determined. Moffat et al. (1979) suggested that Sh 259 is 8.3 kpc distant, based on spectroscopy of the excited star, while Foster & Brunt (2015) found a distance of 8.71 kpc. In this paper, we suggest that the distance to F3 is 8.71 kpc, which is consistent with the small size and lower intensity of the CO emission detected in F3. Hence the masses of subregion F3 are 2.1 × 10^4 M_☉ and 4.7 × 10^3 M_☉, as derived from 12CO and 13CO, respectively.

As there is no distance information of the other subregions, we are not sure if the clouds are located at the same distance. Assuming the clouds are at the same distance, we calculated the mass of the clouds, which are presented in Table 10. Under this assumption, the masses of the Remote Clouds are 1 × 10^6 M_☉, 2.3 × 10^5 M_☉, and 3.1 × 10^4 M_☉, as derived from 12CO, 13CO, and C18O, respectively. Next, the size of the complex is 410 pc × 440 pc. These inferred sizes and the masses suggest that the Remote Clouds are larger if located at a distance of ~17 kpc from the Galaxy Center. We thus conclude that the clouds probably are not at the same distance as F3.

Our survey includes many clouds with different types, for example: massive star formation regions (GGMC 2, GGMC 3, GGMC 4), dark clouds (Lynds Dark Clouds, the West Front), and other types (GGMC 1, Swallow, Horn). The molecular gas associated with massive star formation regions has higher maximum excitation temperatures than the other regions (Figure 23(a)). Massive star formation regions have higher molecular gas column densities traced by 13CO than others (Figure 23(b)). There is a relationship between the maximum excitation temperature and molecular gas column density (Figure 23(c)). Dark clouds and other cloud types have lower excitation temperatures and column densities. Because CO molecules freeze out onto dust grains in the coldest, densest parts of the clouds, the column densities of the dark clouds (Lynds Dark Clouds and the West Front) estimated above are hence lower limits. In massive star formation regions, the gas column densities are positively correlated with excitation temperature, as seen in Figure 23(c). We note that the subregions with higher excitation temperatures are associated with H II regions, except GGMC 2 C5; thus, the molecular gas in these subregions may be heated by the H II regions and the density of the subregions may be enhanced. The relation between the column density and excitation temperature in massive star formation regions is also present in the Rosette Nebula (Y. Li et al. 2017, in preparation). We will study the physical properties and chemical abundances of the clouds pixel-by-pixel in our next paper (C. Wang et al. 2017, in preparation).

9. Summary

We have presented large-scale observations in the 12CO, 13CO, and C18O (1–0) transitions of the GEM OB1 MC complex. The observed region covers a total area of 58.5 deg², with ranges of 186°25 < l < 195°25 and −3°75 < b < 2°75. We presented the large-scale distribution and physical properties of the MCs studied in this paper. Our main results are summarized as follows.
Table 10

Properties of the Subregions in the Remote Clouds

| Subregion | $T_e$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ ($10^{21}$ cm$^{-2}$) | Mass ($M_e$) | $T_e$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ ($10^{21}$ cm$^{-2}$) | Mass ($M_e$) | $T_e$ (K) | Size (arcmin$^{-2}$) | $\sigma$ (km s$^{-1}$) | $N_{H_2}$ ($10^{21}$ cm$^{-2}$) | Mass ($M_e$) |
|-----------|-----------|----------------------|------------------------|-------------------------------|-------------|-----------|----------------------|------------------------|-------------------------------|-------------|-----------|----------------------|------------------------|-------------------------------|-------------|
| C1        | 23        | 540                  | 1.5                    | 0.9                           | $1.1 \times 10^5$ | 261       | 1.1                  | 0.7                    | $2.3 \times 10^4$          |             | 10.3      | 0.4                  | 1.6                    | $3.1 \times 10^4$          |             |
| C2        | 10        | 2082                 | 1.8                    | 1.1                           | $5.1 \times 10^5$ | 1106      | 1                    | 0.6                    | $8.9 \times 10^4$          |             | ...       | ...                  | ...                    | ...                          |             |
| C3        | 19        | 20                   | 1.7                    | 1.2                           | $5.8 \times 10^3$ | 12        | 1                    | 0.8                    | $1.2 \times 10^3$          |             | ...       | ...                  | ...                    | ...                          |             |
| F1        | 25        | 803                  | 1.9                    | 1                             | $2.0 \times 10^5$ | 385       | 1.6                  | 0.6                    | $3.2 \times 10^4$          |             | ...       | ...                  | ...                    | ...                          |             |
| F2        | 9         | 448                  | 1.2                    | 0.7                           | $7.1 \times 10^4$ | 112       | 0.8                  | 0.5                    | $4.7 \times 10^3$          |             | ...       | ...                  | ...                    | ...                          |             |
| F3        | 17        | 91                   | 1.3                    | 0.7                           | $2.1 \times 10^4$ | 81        | 1                    | 0.5                    | $4.7 \times 10^3$          |             | ...       | ...                  | ...                    | ...                          |             |

Note. Columns are the same as Table 2. These clouds are probably associated because of spatial vicinities and consistent velocity ranges. Here we set the distance of the other clouds to be the same as the cloud F3, for which the distance is determined to be 8.71 kpc (Foster & Brunt 2015). However, the mass of the clouds calculated through the assumed distance seems to be higher. So, the masses are listed here for reference.
1. We divided the CO emission region into four MC components based on their spatial distribution and velocity ranges: the GGMC complex, the Lynds Dark Clouds and the West Front Clouds, the Swallow and the Horn, and the Remote Clouds. The GGMC Complex includes four GMCs and is located in the Perseus arm at a distance of 2 kpc. The Lynds Dark Clouds and the West Front Clouds are local clouds, with distances of 400 pc and 560 pc, respectively. Swallow and Horn are presented for the first time in this paper. They have velocity intervals of $[11, 21]$ km s$^{-1}$; however, their distances could not determined. The velocity of the Remote Clouds is the highest, and we suggest that one cloud in the Remote Clouds, F3, is at a distance of 8.71 kpc.

2. The physical size of the GGMC complex is about $230 \times 98$ pc. A special filament was discovered in GGMC 1, which includes four components. One is located in the middle of the filament, while the others line up along the axis of the filament. GGMC 4 contains two components with velocity intervals of $[-3, 5]$ and $[5, 13]$ km s$^{-1}$. There are enhanced gas and IR clusters at the interface between the two components.

3. Swallow and Horn have similar angular sizes (0.8 and 0.6 deg$^2$) and mean column densities determined from $^{12}$CO and $^{13}$CO. The C$^{18}$O emission in Swallow shows a crescent-shaped structure.

4. Two elongated structures were discovered in an $L-V$ map within the velocity interval $[11, 30]$ km s$^{-1}$. One component, $[10, 18]$ km s$^{-1}$, connects Swallow and Horn, while the other $[15, 30]$ km s$^{-1}$, connects the Remote Clouds and Horn.

5. The C$^{18}$O emission in this survey was mainly detected from the GGMC Complex. The intensity of the C$^{18}$O emission in all the other clouds was relatively weak.

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Figure 23. (a) Histogram of the excitation temperature maximum from different subregions. (b) Histogram of the mean column density of gas derived from $^{13}$CO. (c) $N(^{13}$CO) vs. $T_{ex}$. The relation between the mean column density of gas derived from $^{13}$CO and excitation temperature maximum. The red histograms (in a) and (b) and squares (in c) represent data from massive star formation region; the black histograms (in a) and (b) and the crosses (in c) represent data from dark clouds; and the green histograms (in a) and (b) and the triangles (in c) represent data from other clouds, except the Remote Clouds.
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