Planck Galactic Cold Clumps in Two Regions: The First Quadrant and the Anticenter Direction Region

Chao Zhang1,2, Yuefang Wu2,3, Xuchuan Liu2,3, Sheng-li Qiu1, Tie Liu4, Jinghua Yuan5, Di Li6,7, Fanyi Meng8, Tianwei Zhang8, Mengyao Tang1, Lixia Yuan5, Chenlin Zhou5, Jarken Esimbek9,10, Yan Zhou1, Ping Chen2,3, and Runjie Hu7

1 Department of Astronomy, Yunnan University, and Key Laboratory of Particle Astrophysics of Yunnan Province, Kunming 650091, People’s Republic of China; chaozhangchz@163.com, shjwm@bao.ac.cn
2 Department of Astronomy, School of Physics, Peking University, Beijing 100871, People’s Republic of China; ywu@pku.edu.cn
3 Kavli Institute for Astronomy and Astrophysics, Peking University, Beijing 100871, People’s Republic of China
4 Shanghai Astronomical Observatory, Chinese Academy of Sciences, 80 Nandan Road, Shanghai 200030, People’s Republic of China
5 National Astronomical Observatories, Chinese Academy of Sciences, 20A Datun Road, Chaoyang District, Beijing 100012, People’s Republic of China
6 CAS Key Laboratory of FAST, National Astronomical Observatories, CAS, Beijing 100012, People’s Republic of China
7 NAOC-UKZN Computational Astrophysics Centre (NUCAC), University of KwaZulu-Natal, Durban 4000, South Africa
8 1. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, D-50937 Köln, Germany
9 Xinjiang Astronomical Observatory, Chinese Academy of Sciences, Urumqi 830011, People’s Republic of China
10 Key Laboratory of Radio Astronomy, Chinese Academy of Sciences, Urumqi 830011, People’s Republic of China

Received 2019 August 28; revised 2020 January 23; accepted 2020 January 27; published 2020 March 10

Abstract

Sixty-five Planck Galactic cold clumps (PGCCs) from the first quadrant (IQuad) and 39 from the anticenter direction region (ACent) were observed in 12CO, 13CO, and C18O J = 1–0 lines using the 13.7 m telescope of the Purple Mountain Observatory. All the targets were detected in all three lines, except for 12 IQuad and 8 ACent PGCCs without C18O detection. Seventy-six and 49 velocity components were obtained in IQuad and ACent respectively; 146 cores were extracted from 76 IQuad clumps and 100 cores from 49 ACent clumps. The average Tav of IQuad cores and ACent cores is 12.4 K and 12.1 K, respectively. The average line widths of 13CO of IQuad cores and ACent cores are 1.55 km s−1 and 1.77 km s−1, respectively. Among the detected cores, 24 in IQuad and 13 in ACent have asymmetric line profiles. The small blue excesses, ∼0.03 in IQuad and 0.01 in ACent, indicate that star formation is not active in these PGCC cores. Power-law fittings of the core mass function to the high-mass end give indices of −0.57 in IQuad and −1.02 in ACent, which are flatter than the slope of the initial mass function given by Salpeter. The large turnover masses of 28 M⊙ for IQuad cores and 77 M⊙ for ACent cores suggest low star formation efficiencies in PGCCs. The correlation between virial mass and gas mass indicates that most PGCC cores in both regions are not likely pressure-confined.

Unified Astronomy Thesaurus concepts: Dark interstellar clouds (352); Interstellar molecules (849); Star formation (1569)

Supporting material: extended figures, machine-readable tables

1. Introduction

Examining the initial conditions is essential for studying star formation. Astronomers have been searching for gravitationally bound starless cores prior to the protostar phase (also called prestellar cores; Ward-Thompson et al. 1994, 2016) and obtaining their parameters (Myers & Benson 1983), because it is believed that the properties of prestellar cores are the key to answering some important questions about star formation, such as the initial mass function (Miller & Scalo 1979). But progress is still limited. The first quadrant (hereafter IQuad, 10° ≤ l ≤ 100°, −10° ≤ b ≤ 10°) and the anticenter direction region (hereafter ACent, 175° ≤ l ≤ 210°, −9° ≤ b ≤ 7°) are two of the most widely studied molecular regions in our Galaxy; they were first observed by Dame et al. (1987) and Huang (1985) respectively. Star formation activities such as outflows have frequently been reported in the molecular complexes Cygnus X and Monoceros OB1 located in IQuad and ACent respectively (e.g., Garden et al. 1991; Leung & Thaddeus 1992; Wang et al. 2003; Wolf-Chase et al. 2003; Gottschalk et al. 2012). In IQuad, observations of far-infrared (FIR) 160 μm and 260 μm emission as well as the H110α recombination line revealed that FIR sources are coincident with H II regions and associated with molecular clouds (Myers et al. 1983a). Triggered star formation has been observed in Vul-OB1 in IQuad (Ehlerová et al. 2001; Billot et al. 2010). In ACent, Spitzer aperture photometry toward the Mon-OB1 East giant molecular cloud (GMC) shows that the ratio of gas column density to the surface density of young stellar objects (YSOs) is large, and thus ongoing star formation is suggested by Rapson et al. (2014). However, most previous works about these two regions have focused on particular regions with active star formation. Our understanding of the initial conditions of star formation is limited. A study of prestellar cores is thus urgently needed.

The Planck satellite all-sky survey provided us with the Planck Galactic cold clump (PGCC) sample (Planck Collaboration et al. 2011a). PGCCs are cold with dust temperatures ranging from 10 to 15 K and they have modest column densities NH from 0.1 to 1.6 × 1022 cm−2. To investigate the properties of molecular clouds associated with PGCCs, a survey toward 674 PGCCs was carried out soon after the release of the Early Cold Core (ECC) catalog (Planck Collaboration et al. 2011b) compiled using the 13.7 m telescope of the Purple Mountain Observatory (PMO) in the J = 1–0 transitions of 12CO, 13CO, and C18O in single-point mode (Wu et al. 2012). The well-correlated centroid velocities of the three lines and narrow line widths (with ΔV3−1 characteristic
smaller than 2 km s\(^{-1}\)) indicate that PGCCs are not very active. However, about 10% of PGCC spectra show asymmetric profiles, indicative of star formation activity. A large sample of observations using the dense gas tracers HCN and HCO\(^+\) toward PGCCs showed that the intensities of HCN and HCO\(^+\) are well correlated, while no correlation was found between dense gas tracers and CO (Yuan et al. 2016). The observations also showed that some PGCCs are directly associated with dense cores in prestellar phases of star formation (Planck Collaboration et al. 2011a, 2016; Liu et al. 2015, 2016, 2018a, 2018b, 2019; Tang et al. 2018). The fact that they are cold and sufficiently compact makes them good targets for investigating the initial evolutionary stages in the two regions. We describe our samples in Section 2.1 and observations in Section 2.2. The results are presented in Section 3. Detailed discussion follows in Section 4. We summarize our main conclusions in Section 5.

2. Samples and Observations

2.1. Samples

In order to obtain an overview of the PGCCs in the northern sky after being combined with the PGCCs in the second quadrant (IIQuad, 98° ≤ l ≤ 180°, −4° ≤ b ≤ 10°) (Zhang et al. 2016), we broaden the longitude scope of ACent to 175°–230°. IIQuad includes some subregions, such as Serpens, Aquila, Vulpecula, Cygnus, Cepheus, Cloud A, and Cloud B (Dame et al. 1987). The subregions Auriga, Gemini, Monoceros, and Canis Major are included in ACent. The sample in this paper is a subset of 674 PGCCs observed by Wu et al. (2012) located in IIQuad and ACent, selected from the ECC catalog (Planck Collaboration et al. 2011b). Sixty-five IIQuad PGCCs and 39 ACent PGCCs were selected. The names, coordinates, and locations of 25 samples are listed in Table 1. The longitude–latitude positions of the sample sources are shown in Figure 1.

2.2. Observations

Observations of the 65 IIQuad PGCCs and 39 ACent PGCCs were carried out with the 13.7 m millimeter-wavelength telescope of PMO in the J = 1–0 transition of \(^{12}\)CO, \(^{13}\)CO, and \(^{18}\)O from 2011 April to May and from 2011 December to January 2012. The 3 × 3-beam sideband separation Superconduction Spectroscopic Array Receiver system was used as the front end (Shan et al. 2012). The half-power beam width is 52″ in the 115 GHz band. The mean beam efficiency is about 50%. The pointing accuracy is better than 5″. The fast Fourier transform spectrometers (FFTSs) were used as the backend. Each FFTS with a total bandwidth of 1 GHz provides 16,384 channels. The velocity resolutions are 0.16 km s\(^{-1}\) for \(^{12}\)CO, and 0.17 km s\(^{-1}\) for \(^{13}\)CO and \(^{18}\)O. The \(^{12}\)CO emission line was observed in the upper sideband with the system temperature \((T_{\text{sys}})\) around 210 K, while the \(^{13}\)CO and \(^{18}\)O emission lines were observed simultaneously in the lower sideband with \(T_{\text{sys}}\) around 120 K. The typical rms was 0.2 K in \(T_A^*\) for \(^{12}\)CO, and 0.1 K for \(^{13}\)CO and \(^{18}\)O. The on-the-fly (OTF) observing mode was applied. The antenna continuously scanned a region of 22′ × 22′ centered on the PGCCs with a scanning rate of 20″ per second. Because of the high rms noise level at the edges of OTF maps, only the central 14′ × 14′ regions were used for analyses in this work. The data were reduced by CLASS and GREG in the GILDAS package (Guilloteau & Lucas 2000; Pety 2005). All statistical figures were plotted using the open-source Python package.

3. Results

\(^{12}\)CO(1–0) and \(^{13}\)CO(1–0) emission lines were detected in all 65 IIQuad PGCCs and 39 ACent PGCCs. \(^{18}\)O emissions were detected in 53 (81.5%) IIQuad PGCCs and in 31 (79.5%) IIQuad PGCCs. The detection rates of \(^{13}\)CO in both regions are comparable with those in Taurus (77.5%; Meng et al. 2013) and IIQuad (84.4%; Zhang et al. 2016). We noted that some PGCCs have two or more velocity components. If the distributions of the two integrated maps are not highly coherent, we confirm that the two peak components were two velocity components. Eight IIQuad PGCCs have double velocity components and one has quadruple velocity components. Ten ACent PGCCs have double velocity components. In total, 76 and 49 velocity components were obtained in IIQuad and ACent, respectively. The integrated intensity maps of different velocity components show dissimilar features. We thus considered each velocity component as a separate clump. Centroid velocities of the clumps were obtained by Gaussian fitting. On the basis of the Milky way rotation curve, the spiral arm model, and the GMCs with a measured parallax, if the \((l, b, v)\) coordinates of the sources are given, the distance distributions in the light-of-sight direction of the sources can be obtained from the Bayesian distance calculator (Reid et al. 2016). The kinematic distances were derived with the highest probabilities of the distance distributions. Galactic face-on positions of the 125 clumps are shown in Figure 2.

The integrated intensity maps of CO are plotted and 15 of them are presented as sample maps in Figure 3, in which the clumps show different morphologies, such as isolated features, filamentary structures, and chains of dense cores. Eight clumps —G015.16+07.23a, G034.69-06.57, G048.82-03.82, G056.84+04.81, G093.22+04.59, G188.04-03.71, G191.00-04.59, and G198.96+01.41b—show filamentary structures with sausage shape. In this paper, we mainly focus on the dense cores, which have an isoline of 50% \(^{12}\)CO peak intensity and are denser than surrounding regions in the same clump. These cores are known as starless if there are no embedded stars (Benson & Myers 1989). If the cores are bound by gravity, we refer to prestellar cores. Components of a PGCC are denoted as “a, b, c, ...,” while the cores are labeled as “1, 2, 3, ...,” following Wu et al. (2012). The velocities of the different components \((V_a, V_b, V_c, ...)\) in one PGCC must satisfy \(V_a < V_b < V_c\). Thirty-six clumps contain one dense core and 73 contain more than one. In 14 maps, CO emission is too diffuse to identify a dense core. In total, 146 cores were identified in 70 IIQuad clumps, and 100 cores in 39 ACent clumps.

---

**Note:** The last paragraph indicates a citation number that is not present in the text. The correct citation should be included to ensure proper attribution. The text continues with more detailed analysis and discussion of the findings.
| Name          | Galactic Longitude (deg) | Galactic Latitude (deg) | R.A. (J2000) (h:m:s) | Decl. (J2000) (d:m:s) | R.A. (B1950) (h:m:s) | Decl. (B1950) (d:m:s) | Subregions\(^a\) | OB Association\(^b\) |
|---------------|--------------------------|-------------------------|----------------------|-----------------------|----------------------|-----------------------|-------------------|---------------------|
| G013.86+04.55 | 13.864745                | 4.5556397               | 17:59:03.17          | −14:41:26.77          | 17:56:11.93          | −14:41:16.39          | Serpens           |
| G014.74+04.06 | 14.743651                | 4.0693364               | 18:02:34.88          | −14:09:59.84          | 17:59:44.29          | −14:10:04.91          | Serpens           |
| G015.16+07.23 | 15.161132                | 7.2371593               | 17:52:06.35          | −12:14:27.93          | 17:49:18.15          | −12:13:47.29          | Serpens           |
| G026.45+08.02 | 26.455076                | 8.0275078               | 18:11:02.76          | −02:02:51.60          | 18:08:26.64          | −02:03:34.20          | Aquila            |
| G028.45+06.39 | 28.454588                | −6.3918767              | 19:06:09.21          | −06:52:51.78          | 19:03:27.70          | −06:57:31.44          | Aquila            |
| G031.26+05.37 | 31.267088                | −5.3793736              | 19:07:35.28          | −03:55:38.37          | 19:04:57.11          | −04:00:24.16          | Aquila            |
| G034.69+06.57 | 34.694824                | −6.5795875              | 19:18:04.25          | −01:26:07.30          | 19:15:28.89          | −01:31:36.81          | Aquila            |
| G038.36−00.95 | 38.364254                | −0.95123816             | 19:04:45.73          | +04:23:50.61          | 19:02:16.91          | +04:19:16.36          | Aquila            |
| G058.97−06.39 | 58.974606                | −6.3918767              | 19:47:54.71          | +22:10:14.34          | 19:45:45.23          | +22:02:43.88          | Vulpecula          |
| G060.75−01.23 | 60.754391                | −1.2310537              | 19:50:13.23          | +23:55:19.72          | 19:48:05.76          | +23:47:40.19          | Vulpecula          |
| G178.48+06.76 | 178.48387                | −6.7673697              | 05:16:16.57          | +26:29:58.11          | 05:13:10.22          | +26:26:41.39          | Auriga            |
| G178.72−07.01 | 178.72557                | −7.0115962              | 05:15:59.71          | +26:09:46.55          | 05:12:53.85          | +26:06:28.65          | Auriga            |
| G178.98−06.74 | 178.98924                | −6.7485881              | 05:17:37.38          | +26:05:53.18          | 05:14:31.56          | +26:02:42.26          | Auriga            |
| G179.14−06.27 | 179.14305                | −6.279283               | 05:19:43.91          | +26:14:18.94          | 05:16:37.83          | +26:11:17.07          | Auriga            |
| G180.92+04.53 | 180.92284                | 4.5369301               | 06:05:48.75          | +30:25:11.40          | 06:02:35.79          | +30:25:29.78          | Auriga            |
| G181.16−04.33 | 181.16454                | 4.3311534               | 06:05:31.15          | +30:06:33.65          | 06:02:18.68          | +30:06:50.77          | Auriga            |
| G181.42−03.73 | 181.42821                | −3.7328291              | 05:34:46.40          | +25:44:48.16          | 05:31:40.70          | +25:42:51.33          | Auriga            |
| G181.71+04.16 | 181.71385                | 4.1628323               | 06:06:03.83          | +29:32:54.89          | 06:02:52.23          | +29:33:14.43          | Auriga            |
| G181.84+00.31 | 181.84569                | 0.31707302              | 05:51:10.62          | +27:31:08.15          | 05:48:02.13          | +27:30:22.71          | Auriga            |
| G181.88−04.49 | 181.88963                | 4.4995117               | 06:07:48.53          | +29:33:27.39          | 06:04:36.92          | +29:33:54.55          | Auriga            |

Notes:

\(^a\) The limits of the subregions are from Dame et al. (1987) and Humphreys (1978).

\(^b\) The limits of the OB associations are from Humphreys (1978).

(This table is available in its entirety in machine-readable form.)
3.1. Line Parameters

Gaussian fittings were made to the three CO lines for each velocity component at each core center. The centroid velocity ($V_{\text{lsr}}$), main beam brightness temperature ($T_b$), and FWHM ($\Delta V$) were obtained and are listed in Table 2. The centroid velocity of the $^{13}$CO $J = 1 - 0$ line of each core was adopted as the systemic velocity, because the $^{12}$CO $J = 1 - 0$ line is optically thick and the $^{18}$O $J = 1 - 0$ line has a low signal-to-noise ratio.

The statistical properties of $V_{\text{lsr}}$, $\Delta V$, and $T_b$ of the three CO lines, including the ranges of values, the mean values, the medians, and the standard deviations, are listed in Table 3. The median absolute deviation (MAD) of line width for both IQuad cores and ACent cores is 0.42 km s$^{-1}$ in $^{13}$CO lines, which is large enough to affect the comparison of the median values between the two regions, suggesting that there are no obvious differences in line width between the two regions.

3.2. Line Profiles

The CO, $^{13}$CO, and $^{18}$O spectra are extracted from the peak positions of the dense cores. Figure 4 presents sample spectra of nine cores. One can see that the spectra of G028.45-06.39C3 and G096.30+10.01C1 show double-peaked $^{12}$CO emission lines and single-peaked $^{13}$CO and $^{18}$O emission lines, and that the $^{13}$CO and $^{18}$O lines peak at absorption dips of the $^{12}$CO lines. Line shoulders are found in the $^{12}$CO lines toward G028.45-06.39C2, G097.38+09.95C1, G181.84+00.31bC2, and G201.13+00.31C3. The spectra of G095.51+09.97aC1, G181.84+00.31bC2, G182.04+00.41aC1, and G182.04+00.41bC2 have two velocity components. Wide $^{12}$CO line wings are found toward the left velocity component of G095.51+09.97aC1.

For the cores with double-peaked optically thick lines, if the optically thin lines peak at an absorption dip of the optically thick lines, we can identify the double-peaked optically thick lines as a red- or blue-asymmetric profile according to whether (Figure 1.) Longitude–latitude positions of 104 PGCCs. The sample sources are marked as red dots. The background grayscale map is the intensity map of H$_2$O (Haffner et al. 2003). Contours show the velocity-integrated CO intensity map in the velocity range $[-50, 50]$ km s$^{-1}$ from the Columbia 1.2 m CO survey (Dame et al. 1987). The contour level is $5 \times 2$ K km s$^{-1}$ ($1\sigma$). Twenty-four OB associations are marked by red dashed rectangles and numbered 1–24 respectively: SGR-OB1, SGR-OB7, SGR-OB4, SGR-OB6, Ser-OB1, SCT-OB3, Ser-OB2, SCT-OB2, Vul-OB1, Vul-OB4, Cyg-OB3, Cyg-OB1, Cyg-OB8, Cyg-OB9, Cyg-OB2, Cyg-OB4, Cyg-OB7, Cep-OB2, Cep-OB1, Aur-OB1, Gem-OB1, Mon-OB1, Mon-OB2, and CMa-OB1. The limits of the OB associations are from Humphreys (1978).

Figure 2. Galactic face-on position of 125 clumps. The clumps are marked as red crosses. The solar system was defined as the origin of coordinates. The $x$ and $y$ axes show the distance in kiloparsecs. The black circle indicates a distance of 1 kpc from the Sun. Orange lines are the Galactic longitude.

3.1. Line Parameters

Gaussian fittings were made to the three CO lines for each velocity component at each core center. The centroid velocity ($V_{\text{lsr}}$), main beam brightness temperature ($T_b$), and FWHM ($\Delta V$) were obtained and are listed in Table 2. The centroid velocity of the $^{13}$CO $J = 1 - 0$ line of each core was adopted as the systemic velocity, because the $^{12}$CO $J = 1 - 0$ line is optically thick and the $^{18}$O $J = 1 - 0$ line has a low signal-to-noise ratio.

The statistical properties of $V_{\text{lsr}}$, $\Delta V$, and $T_b$ of the three CO lines, including the ranges of values, the mean values, the medians, and the standard deviations, are listed in Table 3. The median absolute deviation (MAD) of line width for both IQuad cores and ACent cores is 0.42 km s$^{-1}$ in $^{13}$CO lines, which is large enough to affect the comparison of the median values between the two regions, suggesting that there are no obvious differences in line width between the two regions.

3.2. Line Profiles

The CO, $^{13}$CO, and $^{18}$O spectra are extracted from the peak positions of the dense cores. Figure 4 presents sample spectra of nine cores. One can see that the spectra of G028.45-06.39C3 and G096.30+10.01C1 show double-peaked $^{12}$CO emission lines and single-peaked $^{13}$CO and $^{18}$O emission lines, and that the $^{13}$CO and $^{18}$O lines peak at absorption dips of the $^{12}$CO lines. Line shoulders are found in the $^{12}$CO lines toward G028.45-06.39C2, G097.38+09.95C1, G181.84+00.31bC2, and G201.13+00.31C3. The spectra of G095.51+09.97aC1, G181.84+00.31bC2, G182.04+00.41aC1, and G182.04+00.41bC2 have two velocity components. Wide $^{12}$CO line wings are found toward the left velocity component of G095.51+09.97aC1.

For the cores with double-peaked optically thick lines, if the optically thin lines peak at an absorption dip of the optically thick lines, we can identify the double-peaked optically thick lines as a red- or blue-asymmetric profile according to whether
the blue peaks are higher or lower than the red peaks respectively. A blue or red profile indicates inward or outward motion (Zhou 1992). Usually, dense gas tracers such as HCO$^+$, HCN, CS, and N$_2$H$^+$ are used to identify collapse in compact cores (Mardones et al. 1997; De Vries & Myers 2005; di Francesco et al. 2007; Stahler & Yen 2010). Observations have suggested that PGCCs have a low temperature and modest density (Planck Collaboration et al. 2011a, 2016), so the dense gas tracers HCO$^+$ and HCN in PGCCs are difficult to excite and have lower detection rates than $^{12}$CO and $^{13}$CO (Yuan et al. 2016). In the past, intermediate-density gas tracers of $^{12}$CO and $^{13}$CO were employed to observe infall motion in both low-mass cores. Figure 3. Velocity-integrated intensity maps. The integrated intensities of $^{13}$CO are represented as red contours from 30% to 90% of the peak value in steps of 10%. The grayscale is the integrated intensity of $^{12}$CO. The identified core positions are marked as white “+.” The blue, yellow, and white stars indicate the Class I/II YSO candidates, Class III YSO candidates, and IRAS pointing sources respectively. The Class I/II and III YSO candidates are selected from the WISE All-Sky survey catalogs presented by Marton et al. (2016). The IRAS pointing source catalog is presented by Helou & Walker (1988). (An extended version of this figure is available.)
### Table 2
Line Parameters of Core Centers

| source | D (kpc) | \( T_d \) (K) | \( \nu_d \) (km s\(^{-1}\)) | \( \Delta V_{\text{ICQ}} \) (km s\(^{-1}\)) | \( T_d \) (K) | \( \nu_d \) (km s\(^{-1}\)) | \( \Delta V_{\text{ICQ}} \) (km s\(^{-1}\)) | \( T_d \) (K) | \( \nu_d \) (km s\(^{-1}\)) | \( \Delta V_{\text{ICQ}} \) (km s\(^{-1}\)) | \( V_{\text{peak}} \) (km s\(^{-1}\)) | Profile \( a \) |
|--------|---------|-------------|----------------|----------------|-------------|----------------|----------------|-------------|----------------|----------------|----------------|----------------|
| G013.86+04.55C1 | 0.29 | 6.98(0.30) | 8.84(0.03) | 2.06(0.07) | 2.37(0.18) | 8.91(0.04) | 1.81(0.10) | ... | ... | ... | 9.18 | ... |
| G013.86+04.55C2 | ... | 8.19(0.26) | 8.92(0.02) | 2.10(0.05) | 4.48(0.18) | 8.97(0.02) | 1.43(0.04) | 0.94(0.20) | 9.00(0.10) | 1.39(0.22) | 8.71 | ... |
| G013.86+04.55C3 | ... | 7.34(0.23) | 9.05(0.02) | 2.36(0.05) | 4.44(0.15) | 9.31(0.01) | 1.39(0.04) | 0.98(0.17) | 9.35(0.07) | 1.11(0.14) | 9.18 | ... |
| G013.86+04.55C4 | ... | 7.78(0.38) | 9.70(0.03) | 2.87(0.11) | 3.89(0.16) | 9.49(0.02) | 1.69(0.05) | 0.82(0.17) | 9.44(0.09) | 1.13(0.17) | 9.98 | ... |
| G013.86+04.55C5 | ... | 8.31(0.49) | 10.03(0.03) | 2.31(0.09) | 4.34(0.20) | 10.15(0.02) | 1.54(0.05) | 1.56(0.25) | 9.93(0.04) | 0.74(0.09) | 10.13 | ... |
| G014.74+04.06C1 | 1.08 | 6.37(0.24) | 28.71(0.03) | 3.52(0.11) | 3.13(0.12) | 28.64(0.02) | 1.64(0.05) | 0.96(0.16) | 28.60(0.05) | 1.00(0.13) | 28.26 | ... |
| G014.74+04.06C2 | ... | 10.89(0.25) | 29.20(0.00) | 1.95(0.03) | 4.69(0.09) | 29.07(0.01) | 1.51(0.02) | 1.00(0.10) | 29.01(0.04) | 1.22(0.09) | 29.04 | ... |
| G015.16+07.23C1 | 0.25 | 9.09(0.19) | 3.10(0.01) | 1.47(0.02) | 5.36(0.15) | 2.99(0.01) | 1.21(0.02) | 0.48(0.14) | 2.82(0.09) | 0.98(0.22) | 3.33 | ... |
| G015.16+07.23C1 | ... | 6.63(1.57) | 6.41(0.07) | 1.12(0.21) | 2.55(0.61) | 6.38(0.04) | 0.68(0.13) | ... | ... | ... | 6.51 | ... |
| G015.16+07.23bC2 | ... | 5.14(0.53) | 6.69(0.06) | 1.64(0.12) | 1.31(0.28) | 6.58(0.06) | 1.05(0.18) | ... | ... | ... | 6.35 | ... |

#### The First Galactic Quadrant (IQuad)

#### The Galactic Anticenter Direction Region (ACent)

**Note.**

* The abbreviations are: RA: red asymmetry; BA: blue asymmetry; RP: red profile; BP: blue profile.

(This table is available in its entirety in machine-readable form.)
and high-mass star-forming regions (e.g., Kutner & Tucker 1975; Snell & Loren 1977; Remijan & Hollis 2006; Guan et al. 2008; Shi et al. 2010). Therefore, we can identify blue and red line profiles by use of the optically thick $^{12}$CO line and optically thin $^{13}$CO line (see Section 7). The blue profile can be verified with an asymmetric parameter $\delta V < -0.25$, where $\delta V = (V_{\text{thick}} - V_{\text{thin}})/\Delta V_{\text{thin}}$ (Mardones et al. 1997). $V_{\text{thick}}$ is the velocity of the $^{12}$CO line peak ($V_{\text{peak}}^{^{12}\text{CO}}$), $V_{\text{thin}}$ is the centroid velocity of the $^{13}$CO line ($V_{\text{lsr}}^{^{13}\text{CO}}$), and $\Delta V_{\text{thin}}$ is the line width (FWHM) of the $^{13}$CO line. A red profile would have $\delta V > 0.25$. In total, eight blue profiles and three red profiles were identified in 146 IQuad.

Figure 4. Sample spectra extracted from peak position of the cores. For each plot, the lines of $^{12}$CO, $^{13}$CO, and C$^{18}$O are colored blue, green, and red, respectively. The core name and the offset (in arcmin) between the core center and clump center are indicated in the top left corner of each plot. Asymmetric line profiles, if any, are listed in the top right corner of each plot: blue profile (BP), red profile (RP), blue asymmetry (BA), red asymmetry (RA), and wings. (An extended version of this figure is available.)

| Table 3: Statistics of Observed Parameters |
|-----------------------------------------|
| $D$                                      | $T_{\text{a}}^{^{12}\text{CO}}$ | $V_{\text{lsr}}^{^{12}\text{CO}}$ | $\Delta V_{\text{CO}}^{^{12}}$ | $T_{\text{a}}^{^{13}\text{CO}}$ | $V_{\text{lsr}}^{^{13}\text{CO}}$ | $\Delta V_{\text{CO}}^{^{13}}$ | $T_{\text{a}}^{\text{C}^{18}\text{O}}$ | $V_{\text{lsr}}^{\text{C}^{18}\text{O}}$ | $\Delta V_{\text{CO}}^{\text{C}^{18}}$ |
|-----------------------------------------|----------------------------------|----------------------------------|-------------------------------|----------------------------------|----------------------------------|-------------------------------|----------------------------------|----------------------------------|-------------------------------|
| Min.                                    | 0.23                            | 4.36                            | -4.55                         | 0.61                            | -4.81                            | 0.53                           | 0.36                            | -5.3                            | 0.17                           |
| Max.                                    | 4.15                            | 19.01                           | 29.2                          | 6.47                            | 9.36                             | 29.07                          | 4.39                            | 3.34                            | 29.01                          | 3.98                           |
| Mean                                    | 0.97                            | 9.05                            | 6.93                          | 2.20                            | 4.08                             | 6.88                           | 1.55                            | 1.07                            | 6.64                           | 1.05                           |
| Median                                  | 0.77                            | 8.11                            | 7.05                          | 2.11                            | 4.09                             | 6.68                           | 1.39                            | 0.96                            | 6.70                           | 0.84                           |
| Standard deviation                      | 0.75                            | 3.27                            | 6.66                          | 1.09                            | 1.33                             | 6.62                           | 0.78                            | 0.57                            | 6.65                           | 0.66                           |
| Median absolute deviation               | 0.25                            | 1.76                            | 4.33                          | 0.64                            | 0.77                             | 4.45                           | 0.42                            | 0.19                            | 4.49                           | 0.19                           |

The First Galactic Quadrant (IQuad)

The Galactic Anticenter Direction Region (ACent)
cores, and two blue and one red were identified in 100 ACent cores.

Some $^{12}\text{CO}$ line peaks are merely skewed and show line shoulders. $\delta V_{12}$ is defined as $(V_{\text{thick}} - V_{\text{bg}}(^{12}\text{CO}))/\Delta V_{\text{thin}}$ (Wu et al. 2012) to identify these skewed lines as blue or red asymmetries if $\delta V_{12}$ is smaller than $-0.25$ or larger than $0.25$ respectively. Five blue asymmetries and six red asymmetries were identified in IQuad, and five blue and five were identified in ACent. In total, 35 asymmetric profiles are detected.

Of the cores detected in both regions, eight were found to have wing(s). $P-V$ diagrams of the two cores (G095.51+09.97aC1 and G095.51+09.97aC2, which resolved from the same clump) show convex isolines (see Figure 5). The core components have constant velocity around the systemic velocity, while high-velocity wings show convex isolines and a velocity gradient with respect to the systemic velocity in the $P-V$ diagram. The high-velocity wings may originate from outflows (Lada 1985; Wu et al. 2005). Therefore we identified the two cores as outflow candidates. Spectral profile classifications are listed in the last column of Table 2.

### 3.3. Derived Parameters

The excitation temperatures ($T_{\text{ex}}$) and optical depths ($\tau$) can be derived from the solution of the radiation transfer equation

$$T_{\text{ex}} = \frac{\hbar \nu}{k} \left[ \frac{1}{\exp(h\nu/kT_{\text{ex}}) - 1} - \frac{1}{\exp(h\nu/kT_{\text{bg}}) - 1} \right] \times \left[ 1 - \exp(-\tau)f \right],$$  

(1)

where $T_{\text{bg}}$ is the background temperature (2.73 K). Under the assumptions that $^{12}\text{CO}$ $J=1-0$ is optically thick ($\tau \gg 1$) and the beam filling factor $f$ is equal to 1, the excitation temperature can be expressed as

$$T_{\text{ex}} = \frac{\hbar \nu}{k} \ln^{-1} \left\{ \frac{kT_{\text{ex}}(^{12}\text{CO})}{h\nu} + \frac{1}{\exp(h\nu/kT_{\text{bg}}) - 1} \right\}^{-1} + 1.$$  

(2)

Under conditions of local thermodynamic equilibrium, $^{12}\text{CO}$ and $^{13}\text{CO}$ have the same excitation temperature. We can obtain the optical depth of $^{13}\text{CO}$ ($\tau^{13}\text{CO}$) from

$$\tau^{13}\text{CO} = -\ln \left[ 1 - \frac{T_{\text{ex}}(^{13}\text{CO})}{T_{\text{ex}}(^{12}\text{CO})} \right].$$  

(3)

$T_{\text{ex}}$ of the 246 cores ranges from 7.2 to 23 K with a median value of $\sim 11.5$ K and MAD of $\sim 2$ K. Only six cores (2.5%) have $T_{\text{ex}} > 20$ K. The dust temperature ($T_{\text{dust}}$) of all PGCCs ranges from 5.8 to 20 K with a median value between 13 and 14.5 K (Planck Collaboration et al. 2016). The similar temperature ranges for $T_{\text{ex}}$ and $T_{\text{dust}}$ indicate that the gas and dust are well coupled. However, their different median temperature ($T_{\text{dust,m}} > T_{\text{ex,m}}$) imply that the gas might be heated by the dust (Goldreich & Kwan 1974; Wu & Evans 1989). The derived optical depths of $^{13}\text{CO}$ lines range from 0.1 to 3.8 with an average value of 0.7, indicating that $^{13}\text{CO}$ lines in most of the PGCC cores are optically thick. Based on an abundance gradient of $^{13}\text{C}/^{12}\text{C} = (7.5 \pm 1.9)D_{\text{GC}} + 7.6 \pm 12.9$ (Wilson & Rood 1994), where $D_{\text{GC}}$ is the distance of the source from the Galactic Center, the $^{13}\text{C}/^{12}\text{C}$ of the cores in IQuad and ACent is derived and ranges from 59 to 124 with an average value of 75. If we take $^{12}\text{CO}^{13}\text{CO} = 59$, and the lowest $^{13}\text{CO}$ optical depth of $\sim 0.1$, the $^{12}\text{CO}$ optical depth is estimated to be 5.9, indicating that $^{12}\text{CO}$ lines of the cores are optically thick.

The column densities of $^{13}\text{CO}$ ($N_{^{13}\text{CO}}$) and C$^{18}$O ($N_{C^{18}O}$) can be derived from (Lang 1978; Garden et al. 1991)

$$N = \frac{3k}{8\pi B\mu_{g}} \frac{\exp(hBJ + 1)/kT_{\text{ex}}}{J + 1} \times \frac{T_{\text{ex}} + hB/3k}{1 - \exp(-h\nu/kT_{\text{ex}})} \int_{\nu_0}^{\nu_1} \tau_{0} \, dV,$$  

(4)

where $B$, $\mu_{g}$, and $J$ are the rotational constant, permanent dipole moment of the molecule, and the rotational quantum number of the lower state in the observed transition. Adopting the typical abundance ratios, $[H_2]/[^{13}\text{CO}] = 89 \times 10^4$ (McCutcheon et al. 1980) and $[H_2]/[^{13}\text{CO}] = 7 \times 10^4$ (Frerking et al. 1982) for the solar neighborhood, the column density of hydrogen ($N_{H_2}$) can be calculated. We find that the values of $H_2$ column density derived from $^{13}\text{CO}$ and C$^{18}$O are quite close to each other, suggesting that both $^{13}\text{CO}$ and C$^{18}$O are optically thin and the optical depth effect in our calculation can be ignored.
The Galactic Anticenter Direction Region (ACent)
\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|}
\hline
Source & Offset & \(a \times b\) & \(R\) & \(n_{\text{col}}\) & \(M\) & \(M_{\text{vir}}\) & \(M_{\text{Jeans}}\) & \(\alpha_{\text{vir}}\) \\
(1) & (arcsec, arcsec) & (arcsec \times arcsec) & (pc) & \(10^3 \text{ cm}^{-3}\) & \((M_\odot)\) & \((M_\odot)\) & \((M_\odot)\) & \\
\hline
G013.86+04.55C1 & (−121, 292) & 197 \times 69 & 0.08 & 8.97 & 1 & 31 & 92 & 21.74 \\
G013.86+04.55C2 & (97, 84) & 201 \times 120 & 0.11 & 12.33 & 5 & 25 & 39 & 5.59 \\
G013.86+04.55C3 & (−48, 86) & 161 \times 155 & 0.11 & 12.04 & 5 & 24 & 38 & 5.19 \\
G013.86+04.55C4 & (−241, 95) & 252 \times 188 & 0.15 & 8.53 & 9 & 50 & 78 & 5.73 \\
G013.86+04.55C5 & (102, −175) & 197 \times 149 & 0.12 & 11.39 & 6 & 33 & 51 & 5.73 \\
G014.74+04.06C1 & (2, 140) & 196 \times 133 & 0.42 & 2.31 & 50 & 129 & 131 & 2.60 \\
G014.74+04.06C2 & (−58, −95) & 236 \times 212 & 0.59 & 2.49 & 143 & 152 & 107 & 1.07 \\
G026.45+08.02C1 & (263, 148) & 247 \times 197 & 0.13 & 11.75 & 7 & 19 & 22 & 2.69 \\
G028.45+06.39C1 & (119, −52) & 179 \times 117 & 0.08 & 17.69 & 3 & 14 & 21 & 4.73 \\
G028.45+06.39C2 & (7, −26) & 142 \times 121 & 0.08 & 17.90 & 2 & 11 & 17 & 4.72 \\
\hline
\end{tabular}
\caption{Emission Region Parameters}
\end{table}

\textbf{3.4. Emission Region Parameters}

The offset peak positions relative to the PGCCs, the Gaussian semimajor axis \((a)\), and the semiminor axis \((b)\) of the cores were estimated from elliptic Gaussian fitting of the isoline with 50% of the peak integrated intensity. The core radius is calculated as \(R = \frac{1}{2} \sqrt{ab} D\), where \(D\) is the distance. Volume density can be derived from \(n_H = N_{HI}/2R\). We estimated the gas mass from

\begin{equation}
M = \frac{2}{3} \pi R^2 m_{\text{HI}} N_{HI}.
\end{equation}

Assuming that the cores are gravitationally bound isothermal spheres and supported solely by random motions, we can calculate the virial mass \(M_{\text{vir}}\) as (Williams et al. 1994):

\begin{equation}
M_{\text{vir}} = \frac{5R \sigma_{3D}^2}{3\gamma G},
\end{equation}

where \(G\) is the gravitational constant. Assuming the density profile follows \(\rho \propto R^{-2}\), \(\gamma\) is equal to 5/3.

In molecular clouds, thermal pressure, turbulence, and magnetic field can support the gas against gravitational collapse. The Jeans mass is defined to describe the stability of the molecular core. When the gas mass is larger than its Jeans mass, gravitational collapse will occur. Taking thermal pressure and turbulence into account, the Jeans mass can be expressed as follows (Hennebelle & Chabrier 2008):

\begin{equation}
\frac{M_{\text{Jeans}}}{M_\odot} \approx 1.0 a_0 \left( \frac{T_{\text{eff}}}{10K} \right)^{3/2} \left( \frac{\mu}{2.35} \right)^{-1/2} \left( \frac{n}{10^3 \text{ cm}^{-3}} \right)^{-1/2},
\end{equation}

where \(a_0 = 1\) is a dimensionless parameter of the order unity, \(n\) is the volume density of \(H_2\), and the effective kinematic temperature \(T_{\text{eff}}\) is adopted as \(C_{\text{vis}}^2 T_{\text{eff}}/k\). The effective sound speed \(C_{\text{vis}}\) is adopted as \(\sqrt{\sigma_{\text{kin}}^2 + \sigma_{\text{vir}}^2}/2\) to account for the support of turbulence.

The radius, volume density, gas mass, virial mass, and Jeans mass are listed in Table 6 and their statistics are listed in Table 7. The median values of core size (\(R\)) are 0.32 pc in
IQuad and 0.43 pc in ACent. The difference in median core size between IQuad and ACent can be ignored since the MAD of $R$ has values of 0.14 pc in IQuad and 0.21 pc in ACent. We derived the typical $R$ of 207 cores with $D < 2$ kpc to be $0.1 - 0.6$ pc. The mean masses of IQuad cores ($291 M_\odot$) and ACent cores ($151 M_\odot$) are extremely different from their median values ($31 M_\odot$ in IQuad and $43 M_\odot$ in ACent). Most of the cores with extremely high mass tend to have distances larger than 2 kpc. According to Equations (9), (10), and (11), $M$, $M_{\text{vir}}$, and $M_{\text{Jeans}}$ are related to $R$ and thus depend on distance ($D$). Some distant cores have high mass and can enlarge the mean value but have little effect on the median.

4. Discussion

4.1. Galactic Distribution

As shown in Figure 1, the 104 PGCCs are mostly located on the edge of the CO(1−0) emission detected by Dame et al. using the Columbia 1.2 m telescope with spatial resolution 8′. Most PGCCs have deviated from the peak positions of the Hα emission (Haffner et al. 2003). Some PGCCs are beyond the edge of the CO(1−0) emission region, indicating that additional gas was detected by more sensitive observations using the PMO 13.7 m telescope under the guidance of PGCCs detected by the Planck Satellite. PGCCs G84.79-01.11, G201.84+02.81, and G224.47-00.65 have strong Hα emission, indicating that they are associated with the H II region and thus could be more active than others.

The positions of 125 clumps in the Galactic face-on map are shown in Figure 2, in which the black circle denotes a 1 kpc circle from the solar system. One can see that most IQuad clumps fall in the circle, but a considerable number of ACent clumps lie outside it, i.e., IQuad clumps are closer to us. It seems reasonable that the median values of core mass ($M$) and core size ($R$) in IQuad are smaller than those in ACent (see Table 7). The clumps in IQuad and ACent are located respectively at distances of 0.23–4.15 kpc from the Sun with a median value of 0.8 kpc and 0.4–9.17 kpc with a median value of 1.5 kpc. Some clumps are situated in the inter-arm region.

4.2. Emission Lines

The probability distributions of $^{12}$CO centroid velocities ($V_{\text{c}(^{12}\text{CO})}$) minus $^{13}$CO centroid velocities ($V_{\text{c}(^{13}\text{CO})}$) in IQuad and ACent are plotted in the top left panel of Figure 6, which shows that $V_{\text{c}(^{12}\text{CO})}$ and $V_{\text{c}(^{13}\text{CO})}$ coincide with each other quite well. As we

Figure 6. Top left: the centroid velocity of the $^{13}$CO emission line ($V_{\text{c}(^{13}\text{CO})}$) vs. the centroid velocity of $^{12}$CO minus that of $^{13}$CO ($V_{\text{c}(^{13}\text{CO})} - V_{\text{c}(^{12}\text{CO})}$). The curves show the distribution and their colors are as the same as for the symbols. Top right: the line width of the $^{13}$CO emission line ($\Delta V_{\text{c}(^{13}\text{CO})}$) vs. its optical depth ($\tau_{^{13}}$). Bottom left: the line width of the $^{13}$CO emission line ($\Delta V_{\text{c}(^{13}\text{CO})}$) vs. the line width of the $^{12}$CO emission line ($\Delta V_{\text{c}(^{12}\text{CO})}$). The black line is $y = x$. Bottom right: $\tau_{^{13}}$ integral to $\Delta V_{\text{c}(^{13}\text{CO})}$ vs. $\tau_{^{18}}$ integral to $\Delta V_{\text{c}(^{12}\text{CO})}$ multiplied by $\alpha_0$. $\alpha_0$ is the abundance ratio between $^{13}$CO and $^{12}$CO and has the value 5.5. The black line is $y = x$. The data of IQuad and ACent cores are represented as blue dots and orange triangles, respectively.
mentioned in Section 3.2, eight blue profiles, three red profiles, five blue asymmetries, and six red asymmetries (accounting for \( \sim 15.1\% \)) were detected in IQuad cores and two blue profiles, one red profile, five blue asymmetries, and five red asymmetries (accounting for 13%) in ACent cores. Only two IQuad cores are identified to have wings in the\(^{12}\)CO lines. The detection rates of asymmetry profiles in IQuad and ACent are similar to that (18.2%) found in IIQuad (Zhang et al. 2016), and are very low when compared with those in massive star-forming regions such as Orion, where the detection rate is as high as 70% (Velusamy et al. 2008).

The blue excess \( E \) defined as \( (N_{\text{blue}} - N_{\text{red}})/N_{\text{tot}} \) is \(-0.03\) in IQuad and 0.01 in ACent, where \( N_{\text{blue}} \) and \( N_{\text{red}} \) are the numbers of cores with detected blue and red profiles respectively and \( N_{\text{tot}} \) is the total number of cores (Mardones et al. 1997). Our samples have much smaller \( E \) than objects in Classes -1, 0, and I \( (E \approx 0.3) \); where a Class -1 object is a prestellar core, and a protostar spends \( 2 \times 10^5 \) yr in the Class 0 phase and \( 2 \times 10^7 \) yr in the Class I phase; Evans 2003) and ultracompact H II regions \( (E = 0.58; Wu et al. 2007) \), which may indicate that PGCC cores are still in the early evolutionary stages of star formation. Star formation is not yet active in the PGCC cores.

The suprathermal line widths, instead of part of a global velocity structure (either collapse, expansion, or rotation; e.g., Liszt et al. 1974; Zhou 1992), the contributors to line width broadening are thermal and nonthermal motions and the effects of saturation (the opacity broadening effect; e.g., Goldsmith & Langer 1999). The opacity effect can seriously affect the optically thick \(^{13}\)CO emission line (Phillips et al. 1979). The top right panel of Figure 6 shows that few sources have \( \tau_{\text{VCO}} \sim 3.0 \) while most have \( \tau_{\text{VCO}} < 1 \). An optical depth of 3 will contribute to the line width smaller than 30% (see Equation (3) of Phillips et al. 1979), thus the effect of opacity broadening on \( \Delta V_{\text{VCO}} \) should not be significant. It may indicate that \(^{13}\)CO is only fully excited in the dense part of molecular cores, unlike \(^{12}\)CO. This can also be confirmed by comparison between the \( H_2 \) column densities derived from \(^{12}\)CO and \(^{13}\)CO. \( \Delta V_{\text{VCO}} \) and \( \Delta V_{\text{C^{18}O}} \) show good correlation in both IQuad and ACent regions, with \( \Delta V_{\text{VCO}} \) being slightly larger than \( \Delta V_{\text{C^{18}O}} \) (bottom left panel of Figure 6). From the bottom right panel of Figure 6, it is clear that the optical depth of \(^{13}\)CO integrated over velocity \(( \int \tau_{\text{VCO}} dV_{\text{VCO}} )\) is systematically larger than the optical depth of \(^{18}\)O integrated over velocity multiplied by \( \alpha_0 \) \(( \int \tau_{\text{C^{18}O}} dV_{\text{C^{18}O}} \alpha_0 )\).

\( \alpha_0 \) is the abundance ratio between \(^{13}\)CO and \(^{18}\)O and has the value 5.5 (Myers et al. 1983b, and references therein). There are two reasons that may result in \( \int \tau_{\text{VCO}} dV_{\text{VCO}} > \int \tau_{\text{C^{18}O}} dV_{\text{C^{18}O}} \). One is that the \(^{13}\)CO emission line may systematically trace more molecular hydrogen than \(^{18}\)O. The other reason may be a variation in \( x[\text{C^{18}O}]/x[\text{^{13}CO}] \) along the line to the Galactic Center (Wilson & Rood 1994; Pineda et al. 2013).

### 4.3. Nonthermal Motions

Analyzing nonthermal motions of dense cores is useful for understanding dynamical processes and heat transport in star formation (Cho & Lazarian 2003). The nonthermal motions originating from star-forming activities such as infall motions and outflows can broaden the nonthermal velocity dispersion. However, these motions are not very active in PGCCs when compared with typical star-forming regions (Wu et al. 2012). The nonthermal motions in these clumps are therefore mainly turbulent ones.

The ratio of nonthermal to thermal velocity dispersion \( R_p = \sigma_{\text{NT}}/\sigma_{\text{Th}} \) can be used to estimate the ratio of pressure contributed by the nonthermal and thermal motions (Lada et al. 2008; Liu et al. 2012). Our results show that \( R_p \) is larger than 1 for almost all sources, and thus turbulence in PGCC cores in both regions is typically supersonic. Increasing trends of \( \sigma_{\text{NT}} \) and \( R_p \) with respect to \( N_{\text{H}} \) are found in IQuad (see the left and middle panels of Figure 7). Similar relations are also found in ACent but with weak correlation. This implies that the nonthermal pressure is more dominant in denser cores. \( R_p \) for the IQuad cores \((3.4 \pm 0.19)\) is on average smaller than for ACent cores \((3.9 \pm 0.23)\), suggesting that turbulence has on average dissipated more in the IQuad cores. The uncertainty of each \( R_p \) is transferred by \( \sigma_{\text{NT}} \) and \( \sigma_{\text{Th}} \).

Since Larson (1981) put forward the idea that the internal velocity dispersion of a region is correlated with its size from 0.1 to 100 pc in a power-law form, lots of work has followed (Shetty et al. 2010; Murray et al. 2017; Traficante et al. 2018). We also test this correlation in IQuad and ACent (see the right panel of Figure 7). For IQuad cores, the correlation can be represented as

\[
\sigma_{3D} = (1.57 \pm 0.05) \times R^{0.33 \pm 0.04}, \tag{12}
\]

with \( R^2 = 0.37 \). The power-law index is similar to the Kolmogorov cascade \((\alpha \propto R^{1/3})\). The uncertainty in estimated
distance may be a reason for the weak correlation. However, the Larson relationship may be not valid on a small scale, since turbulence dominates the clump structure and density distribution on a large scale but not on a small scale (Vazquez-Semadeni 1994). Small cores are more easily affected by density fluctuations (Bonazzola et al. 1987). The velocity dispersion is not related to the core size in ACent, which can confirm that turbulence does not dominate the core structure.

4.4. PGCCs in Different Molecular Cloud Complexes

The internal velocity dispersion of a cloud is one of the important factors determining the mass of stars formed, as suggested by Saito et al. (2001). From the empirical correlation that line width is generally found to increase with luminosity (ΔV ∝ L^{0.13–0.19}; Myers et al. 1991; Jijina et al. 1999), Wang et al. (2009) tested the ΔV–L relation toward red IRAS sources and suggested that the ΔV criterion refers to ΔV_{13CO} > 2 km s⁻¹ as a characteristic value of high-mass cores. We classified 10 subregions to check whether the cores with broad line width are massive according to the line width criterion. The division of the subregions is from Dame et al. (1987) and Humphreys (1978).

When clumps are located within the (l, b) ranges of OB associations, we defined the clumps to be associated with OB associations. The limits of OB associations are from Humphreys (1978). In Figure 1, Serpens, Vulpecula, Cygnus, Cepheus, Auriga, Gemini, Monoceros, and Canis Major each host at least one OB association, and those in Vulpecula, Cygnus, Cepheus, Monoceros, and Canis Major contain some clumps. The statistics of ΔV_{13CO}, σ_{T,ex}, N_H2, and M in these subregions are listed in Table 8.

In Table 8, ΔV_{13CO} of the cores in Canis Major averages more than 2 km s⁻¹, but the average core mass in Canis Major is smaller than in every other subregions apart from Aquila. Additionally, PGCC cores toward Serpens, Cloud A/B, Vulpecula, Cepheus, and Auriga regions have narrow line widths with average values close to 1.3 km s⁻¹ (the typical line width of low-mass cores; Myers et al. 1983b) and high masses with average values larger than 8 M☉. These results indicate that the line width criterion seems to break down in our sample. Low-mass cores with a broad line width may be still turbulent (Saito et al. 2006). Fragmentation is suggested in some massive cores with a narrow line width.

4.5. Core Status

4.5.1. Core Mass Function

The core mass function (CMF) is usually found to follow dN/dM ∼ M^{−α_{CMF}}. The CMFs in the two regions are plotted in Figure 8. The left and middle panels present the CMF for the cores in IQuad and ACent respectively. Based on Equations (1), (2), (4), and (9), the mass is proportional to the brightness temperature (T_b) of 12CO, the integrated intensity of 13CO, the optical depth of 13CO (τ_{13}), the angular size of the source (σ√ab), and its distance (D). Most of the PGCC cores in this paper should have the median values of these parameters. However, the dense cores that we focus on have an isoline of 50% of the 13CO peak intensity. So, we adopted half of the median value of the peak 13CO integrated intensity (2.8 K km s⁻¹), the median values of T_b(12CO) (8.1 K), τ_{13} (0.6), source size (2.5), and the largest value of distance in each region (4.15 kpc in IQuad and 9.17 kpc in ACent) to calculate the mass completeness limit. The mass completeness limits in IQuad and ACent are 12 M☉ and 60 M☉ respectively. Power-law fits are found at the high- and low-mass ends of the CMF. The shape of the CMF may be affected by the incompleteness limit at the low-mass end. The fitting results give y = (696.98 ± 87.18)x^{-0.57±0.03} with R^2 = 0.99 in IQuad and y = (6337.97 ± 11.93)x^{-1.02±0.04} with R^2 = 0.99 in ACent. The α_{CMF} values for IQuad and ACent are 0.57 ± 0.03 and 1.02 ± 0.04 respectively. The slopes change at 28 M☉ (the turnover mass) in IQuad and 77 M☉ in ACent. The turnover mass in ACent is similar to the mass completeness limit and few data points can be used to fit the power-law function at the high-mass end. So the turnover mass and α_{CMF} in ACent are unreliable.

It is important to compare the CMF to the stars’ initial mass function (IMF), which was originally derived by Salpeter (1955), since IMF is related to CMF (Nutter & Ward-Thompson 2007; Ward-Thompson et al. 2007). Based on 1.3 mm continuum observations of ρ Ophiuchi, Motte et al. (1998) derived a CMF with an index of ∼−1.5 for core mass ≥1 M☉ and ∼−0.5 for core mass ≤1 M☉. The derived CMF in ρ Ophiuchi has a similar power-law index to the IMF, suggesting that star mass is related to core mass. A similar conclusion was reached when studying Serpens (Testi & Sargent 1998) and Aquila Rift (Könyves et al. 2010). α_{CMF} of 0.57 for IQuad cores is flatter than the common IMF for stars with M ≥ M⊙ (−1.5; e.g., Taff 1974; Hughes & Daniels 1980; Casoli et al. 1984). Distant cores with high mass may have fragmented and may harbor multiple subcomponents that cannot be resolved in these low-spatial-resolution observations. This can explain the flatter slope of CMF found in IQuad. α_{CMF} of 0.95 for cores with distance less than 1 kpc (see the right panel of Figure 8) is significantly larger than 0.57 for IQuad cores, which may support the idea that the fragmentation exists in the distant cores. Alternatively, turbulent pressure and magnetic field tension may decrease the efficiency of rising core mass, which can explain the flatter slope found in CO gas cores (André et al. 2011).

Comparison of the turnover mass of the CMF M_{turnover}(CMF) to that of the IMF M_{turnover}(IMF) is useful for understanding the formation process of gas cores (Könyves et al. 2015). Star formation efficiency could be roughly estimated by M_{turnover}(IMF) divided by M_{turnover}(CMF) (Motte et al. 1998; Alves et al. 2007; Nutter & Ward-Thompson 2007). M_{turnover}(IMF) is about 0.25 M☉ for Cygnus X with a slope of ∼0.7 (Maia et al. 2016). We take the value of 0.25 M☉ as M_{turnover}(IMF) to calculate the star formation efficiency. The star formation efficiency is ∼0.9% for IQuad cores. For the cores with distance less than 1 kpc in the two regions, the star formation efficiency is ∼1.1%. The star formation efficiencies found here are significantly lower than ∼3%–6% for common star formation regions (Evans et al. 2009), suggesting that PGCC cores are in the early evolutionary stage of star formation, and whether the cores can form stars is yet to be determined. The argument in the preceding paragraph that distant cores may have unresolved fragmentation seems to suggest that the more distant objects are clumps rather than individual star-forming cores. This might also be an additional or alternative explanation for the apparent low star formation efficiency of the PGCC cores.
4.5.2. Gravitational Stabilities of the Dense Cores

The virial parameter $\alpha = M_{\text{vir}}/M$, shown in column (9) of Table 6, can be applied to describe the stabilities of gas cores (Kauffmann et al. 2013). We defined that virial mass is consistent with a mass within a factor of 3 (Liu et al. 2012). In IQuad, 103 (70.5%) dense cores have virial masses consistent with the core masses. This ratio is larger than that in ACent (56%), but smaller than that in the Orion complex (88%; Liu et al. 2012). About 58% (85) IQuad cores and 45% (45) ACent

![Figure 8](image-url). The core mass function. The left and middle panels are plotted for the cores in IQuad and ACent respectively. The right panel is plotted for the cores with distance less than 1 kpc. The error bars correspond to statistical uncertainties of $\sqrt{N}$. The black dashed line is plotted as the mass completeness limit.

| Table 8 |
|---|
| Statistics of $\Delta V_{\text{CO}}$, $\sigma_{\text{D}}$, $T_{\text{ex}}$, $N_{\text{H}_2}$, and $M$ in Different Subregions |
| (1) Serpens (2) Aquila (3) Cloud A/B (4) Vulpecula (5) Cygnus (6) Cepheus (7) Auriga (8) Gemini (9) Monoceros (10) Canis Major (11) |
| All cores$^a$ | 7 | 19 | 19 | 27 | 67 | 7 | 26 | 20 | 40 | 11 |
| Regions | IQuad | ACent |
| $\Delta V_{\text{CO}}$ (km s$^{-1}$) | | |
| Min. | 1.39 | 0.56 | 0.53 | 0.78 | 0.72 | 1.08 | 0.44 | 0.72 | 0.75 | 0.80 |
| Max. | 1.81 | 2.03 | 1.85 | 2.54 | 4.39 | 1.45 | 2.31 | 3.01 | 5.15 | 3.15 |
| Median | 1.57 | 1.05 | 0.88 | 1.47 | 1.93 | 1.26 | 1.41 | 1.80 | 1.90 | 2.24 |
| Standard deviation | 0.14 | 0.44 | 0.42 | 0.54 | 0.87 | 0.15 | 0.52 | 0.69 | 1.08 | 0.67 |
| $\sigma_{\text{D}}$ (km s$^{-1}$) | | |
| Min. | 1.07 | 0.49 | 0.48 | 0.66 | 0.59 | 0.84 | 0.47 | 0.61 | 0.60 | 0.66 |
| Max. | 1.37 | 1.52 | 1.38 | 1.90 | 3.24 | 1.10 | 1.74 | 2.25 | 3.82 | 2.35 |
| Mean | 1.20 | 0.83 | 0.72 | 1.14 | 1.47 | 0.97 | 1.09 | 1.36 | 1.44 | 1.68 |
| Median | 1.17 | 0.72 | 0.59 | 1.16 | 1.30 | 0.99 | 1.05 | 1.20 | 1.12 | 1.70 |
| Standard deviation | 0.10 | 0.31 | 0.29 | 0.38 | 0.63 | 0.11 | 0.36 | 0.49 | 0.78 | 0.48 |
| $T_{\text{ex}}$ (K) | | |
| Min. | 9.72 | 8.45 | 7.64 | 7.72 | 7.71 | 8.41 | 7.47 | 7.59 | 7.24 | 9.42 |
| Max. | 14.32 | 20.74 | 13.80 | 22.50 | 22.43 | 12.85 | 16.94 | 16.70 | 21.80 | 14.81 |
| Mean | 11.36 | 11.11 | 10.94 | 13.44 | 13.13 | 10.67 | 11.73 | 11.45 | 12.57 | 12.14 |
| Median | 11.16 | 10.64 | 11.32 | 12.92 | 12.03 | 10.66 | 11.87 | 10.68 | 11.33 | 13.33 |
| Standard deviation | 1.37 | 2.66 | 1.51 | 3.73 | 3.59 | 1.40 | 2.17 | 2.43 | 3.76 | 2.06 |
| $N_{\text{H}_2}$ ($10^{21}$ cm$^{-2}$) | | |
| Min. | 4.55 | 1.34 | 2.16 | 1.86 | 1.86 | 0.68 | 4.81 | 0.56 | 2.62 | 1.55 |
| Max. | 9.04 | 18.66 | 10.45 | 18.42 | 68.67 | 9.23 | 12.18 | 22.73 | 27.33 | 19.46 |
| Mean | 7.54 | 6.83 | 4.93 | 7.26 | 12.06 | 7.12 | 7.37 | 7.63 | 8.48 | 9.97 |
| Median | 8.29 | 7.21 | 3.88 | 6.65 | 7.88 | 7.53 | 8.02 | 5.13 | 6.62 | 7.71 |
| Standard deviation | 1.50 | 4.03 | 2.55 | 3.68 | 11.62 | 1.62 | 2.57 | 5.25 | 6.74 | 5.69 |
| $M$ ($M_\odot$) | | |
| Min. | 1.4 | 0.1 | 2.8 | 1.3 | 1 | 37.6 | 1.2 | 15.2 | 0.7 | 2.7 |
| Max. | 142.5 | 15.4 | 36.5 | 236.7 | 7612.8 | 147.7 | 244.6 | 338.5 | 840.5 | 18.9 |
| Mean | 31.0 | 4.1 | 13.6 | 214.0 | 515.6 | 71.1 | 77.4 | 108.9 | 76.1 | 9.0 |
| Median | 5.7 | 2.35 | 11.2 | 36.4 | 62.8 | 54.1 | 59.55 | 72.8 | 37.6 | 5.9 |
| Standard deviation | 48.1 | 4.4 | 9.9 | 486.4 | 1302.7 | 38.5 | 69.4 | 92.4 | 144.8 | 5.7 |

Note. $^a$ The numbers of cores in different subregions.

4.5.2. Gravitational Stabilities of the Dense Cores

The virial parameter $\alpha = M_{\text{vir}}/M$, shown in column (9) of Table 6, can be applied to describe the stabilities of gas cores (Kauffmann et al. 2013). We defined that virial mass is consistent with a mass within a factor of 3 (Liu et al. 2012). In IQuad, 103 (70.5%) dense cores have virial masses consistent with the core masses. This ratio is larger than that in ACent (56%), but smaller than that in the Orion complex (88%; Liu et al. 2012). About 58% (85) IQuad cores and 45% (45) ACent
cores have Jeans masses consistent with masses within a factor of 3, i.e., the other cores have Jeans instability and will be fragmentations or collapses (Furuya et al. 2008).

The relationship between $M_{\text{vir}}$ and $M$ in both regions is shown in the left panel of Figure 9. The power-law fitting gives a power index of $0.58 \pm 0.03$ and $0.50 \pm 0.04$ for IQuad and ACent, respectively. According to Equations (9) and (10), power-law indices of $\sim 0.5$ may indicate that the relationship between $M_{\text{vir}}$ and $M$ is almost entirely dependent on $R$ and thus the velocity dispersion between cores has random variation. The power-law indices for the cores obtained here are significantly larger than $1/3$ for pressure-confined cores (Bertoldi & McKee 1992), indicating that the cores are most likely not pressure-confined but gravitationally bound (Ikeda et al. 2009), unless the pressures are significantly supported by magnetic fields (Kauffmann et al. 2013).

Most of the cores have $M_{\text{Jeans}} > M$ (see right panel of Figure 9). In fact, 104 IQuad cores and 78 ACent cores have $M_{\text{Jeans}} > M$. The two cores G093.51-04.31C1 and G181.71+04.16C2 having $M_{\text{Jeans}} < M$ show a blue profile, which indicates that they may be gravitationally bound and tend to collapse.

### 4.5.3. Associated Objects

Matching gas cores with stellar objects is very useful for understanding the environment and evolutionary status of the cloud cores. Based on the Always catalog released by the Wide-field Infrared Survey Explorer (WISE) mission, Marton et al. (2016) presented a catalog of 133,980 identified Class I/II YSO candidates (CIs) that have a significant IR excess. A good correlation between the surface density distribution of CIs and that of clumps is found in the Taurus–Auriga–Perseus–California region (Marton et al. 2016). We have matched clumps with the CIs from this catalog, and the Class III YSO candidates (CIIIs) from the CIIIs catalog (Marton et al. 2016) and IRAS point source (IR-source) catalog (Helou & Walker 1988). The CIIIs have IR excess and IR color similar to main-sequence stars. The CIs, CIIIs, and IR sources are believed to be associated with clumps if they are located in the mapped area of $14' \times 14'$. About 61% of IQuad clumps (46) and 59% of ACent clumps (29) are associated with CIs, indicating that CIs have a good correlation in spatial distribution with clumps in IQuad and ACent. About 95% of IQuad clumps (72) and 80% of ACent clumps (39) are associated with objects that are CIs, CIIIs, and/or IR sources.

An objects is believed to be associated with a core if it has an offset to the core center of less than a beam size ($\sim 1'$) and a distance (if we can get it from the catalogs) similar to the core. We found that $\sim 8.9\%$ (13) of IQuad cores are associated with CIs, and 18% (18) of ACent cores are associated with CIs excluding two cores that have associated CIs but the difference between core distance and CI distance is very large. In total, 31 of 246 cores ($\sim 12.6\%$) are associated with CIs, which cannot indicate that there is a good correlation between the CIs and the cores in this work. In total, 58 cores ($\sim 23.6\%$) are identified to be associated with the objects. Of these, the three cores G091.45-06.39C2, G095.51+09.97C1, and G226.80-07.04C1 have signs of star formation in the $^{12}$CO line, indicating that they are more evolved than other cores. All these PGCC cores with associated objects are listed in Table 9.

### 5. Summary

We have performed a mapping survey in the $J = 1 \rightarrow 0$ transition of $^{12}$CO, $^{13}$CO, and C$^{18}$O with the PMO 13.7 m telescope toward 104 PGCCs. Among the mapped sources, 65 are located in IQuad and 39 in ACent. $^{12}$CO and $^{13}$CO lines were detected in all of them, while the C$^{18}$O line was detected in 53 IQuad PGCCs (a detection rate of about 81.5%) and in 31 ACent PGCCs (a detection rate of about 79.5%). One hundred and twenty-five velocity components (hereafter clumps) are identified in total, 76 in IQuad and 49 in ACent. We identified 246 dense cores from the velocity-integrated intensity maps, with 146 cores in IQuad and 100 in ACent. The parameters of detected lines and identified cores were derived. We have discussed their properties and morphologies, and compared the differences of the two regions. The main findings are summarized as follows.

1. Our samples are mostly located on the edge of the CO gas detected in the Columbia 1.2 m telescope, indicating that additional gas was detected.
2. The excitation temperature ($T_{\text{ex}}$) ranges from 7.6 to 22.5 K in IQuad cores and from 7.2 to 21.8 K in ACent cores. The excitation temperature is similar to the dust temperature ($T_{\text{dust}}$) obtained in Planck Collaboration et al. (2016). However, the median value of $T_{\text{ex}}$ is smaller than that of $T_{\text{dust}}$, suggesting that gas and dust are well coupled in these cores and that gas might be heated by dust.
### Table 9
Fifty-eight Cores Associated with Objects

| Cores (1) | Class I/II YSO Candidates (2) | Class III YSO Candidates (3) | IRAS Point Source (4) |
|----------|-----------------------------|-----------------------------|----------------------|
| G013.86-04.55C1 | 0 | 1 | 0 |
| G013.86-04.55C4 | 0 | 1 | 0 |
| G013.86-04.55C5 | 0 | 1 | 0 |
| G015.16 | 0 | 0 | 1 |
| G015.16 | 0 | 0 | 1 |
| G028.45-06.39C2 | 0 | 0 | 1 |
| G034.69-06.57C4 | 0 | 1 | 0 |
| G038.36-06.95bC1 | 0 | 0 | 1 |
| G060.75-01.23C2 | 1 | 0 | 1 |
| G065.30-08.44C1 | 0 | 1 | 0 |
| G067.41-01.54C5 | 0 | 0 | 1 |
| G089.29-04.01C2 | 1 | 0 | 1 |
| G089.36-06.67C1 | 2 | 0 | 0 |
| G089.64-06.59C1 | 1 | 0 | 1 |
| G089.75-02.16C3 | 0 | 0 | 1 |
| G089.93-07.03C1 | 1 | 0 | 1 |
| G090.76-04.55C1 | 0 | 0 | 1 |
| G092.79+09.14C3 | 0 | 0 | 1 |
| G093.75-04.59C1 | 1 | 0 | 1 |
| G093.99-04.91C3 | 1 | 0 | 0 |
| G093.91+10.02C2 | 1 | 0 | 1 |
| G095.51 | 0 | 0 | 1 |
| G095.51 | 1 | 0 | 0 |
| G097.20+09.87C2 | 0 | 0 | 1 |
| G097.77+08.59C1 | 3 | 0 | 1 |
| G097.77+08.59C3 | 3 | 0 | 0 |
| All | 18 | 7 | 24 |

The Galactic Anticenter Direction Region (ACent)

| Cores (1) | Class I/II YSO Candidates (2) | Class III YSO Candidates (3) | IRAS Point Source (4) |
|----------|-----------------------------|-----------------------------|----------------------|
| G180.92-04.53C1 | 2 | 0 | 0 |
| G180.92-04.53C2 | 1 | 0 | 0 |
| G181.42-03.73C1 | 0 | 0 | 1 |
| G181.42-03.73C2 | 0 | 0 | 1 |
| G181.42-03.73C3 | 1 | 0 | 1 |
| G181.84 | 3 | 0 | 1 |
| G181.84 | 1 | 0 | 0 |
| G181.84 | +0.31bC1 |
| G181.84 | +0.31bC4 |
| G182.04 | 1 | 0 | 1 |
| G182.04 | +0.41bC1 |
| G185.33-02.12C2 | 2 | 0 | 1 |
| G185.33-02.12C3 | 0 | 0 | 1 |
| G188.04-03.71C3 | 1 | 0 | 1 |
| G201.13+00.31C2 | 0 | 0 | 1 |
| G201.26 | 1 | 0 | 0 |
| G201.44+00.65C2 | 1 | 0 | 0 |

3. The nonthermal velocity dispersion and the increase in the ratio of nonthermal to thermal pressure with $H_2$ column density indicate that the nonthermal pressure dominates in denser cores. The correlation of the velocity dispersion with core size is weak in IQuad and the velocity dispersion is not related to core size in ACent, suggesting that the Larson relationship seems not to be valid in PGCC cores in IQuad and ACent.

4. CMF fittings give the power-law indices $-0.56$ for IQuad cores and $-1.02$ for ACent cores. The flat slope may be caused by fragmentation in the distant cores. The turnover mass of the CMF is $28 M_\odot$ in IQuad and $77 M_\odot$ in ACent. The mass completeness limit is $12 M_\odot$ in IQuad and $60 M_\odot$ in ACent. The similarity between mass completeness limit and turnover mass found in ACent imply that the latter is unreliable. A lower star formation efficiency of $\sim 0.9\%$ is found in IQuad when we compare the turnover mass of the CMF and that of the IMF, indicating that PGCC cores are in the early evolutionary stage of star formation.

5. The correlation of $M_{\text{vir}}$ with $M$ shows a power-law index of 0.58 for IQuad cores and 0.50 for ACent cores, which are significantly larger than $1/3$ for pressure-confined cores (Bertoldi & McKee 1992), indicating that most of the cores are likely not pressure-confined but gravitationally bound.

6. Non-Gaussian profiles, including eight blue profiles, three red profiles, and two wings, are detected in IQuad cores, while two blue profiles and one red one are identified in ACent cores. The lower blue excess of $\sim 0.03$ in IQuad and 0.01 in ACent suggests that star formation is not active in PGCC cores. We have identified 58 cores as being associated with Class I/II YSO candidates, Class III YSO candidates, and/or IRAS pointing sources, 34 of them in IQuad and 24 in ACent. Of these 58 cores, three have signs of star formation in the detected $^{12}$CO lines and may be more evolved than other cores.

We are grateful to the staff at the Qinghai Station of PMO for their assistance during the observations. The Wisconsin H$\alpha$ Mapper and its H$\alpha$ Sky Survey have been funded primarily by the National Science Foundation. The facility was designed and built with the help of the University of Wisconsin Graduate School, Physical Sciences Lab, and Space Astronomy Lab.
