The Molecular Structures of the Local Arm and Perseus Arm in the Galactic Region of 
\[l = [139^\circ.75, 149^\circ.75], b = [-5^\circ.25, 5^\circ.25]\]

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Received 2017 January 5; revised 2017 January 29; accepted 2017 January 30; published 2017 March 29

Abstract

Using the Purple Mountain Observatory Delingha (PMODLH) 13.7 m telescope, we report a 96 deg\(^2\)\(^12\)CO/\(^13\)CO/C\(^18\)O mapping observation toward the Galactic region of \(l = [139^\circ.75, 149^\circ.75], b = [-5^\circ.25, 5^\circ.25]\). The molecular structures of the Local Arm and Perseus Arm are presented. Combining H\(_1\) data and part of the Outer Arm results, we obtain that the warp structure of both atomic and molecular gas is obvious, while the flare structure only exists in atomic gas in this observing region. In addition, five filamentary giant molecular clouds on the Perseus Arm are identified. Among them, four are newly identified. Their relations with the Milky Way large-scale structure are discussed.

Key words: Galaxy: structure – ISM: clouds – ISM: molecules

1. Introduction

The Milky Way (MW) galaxy is our home galaxy. Since we are located at the Galactic plane, which is full of gas and dust, the difficulty in studying its structure is greater than that for some external galaxies. Up to now, although many previous works have already revealed its global appearance (e.g., Oort et al. 1958; Bok 1959; Georgelin & Georgelin 1976), its detailed structure is still under debate (e.g., Russell et al. 2007; Vallée 2008; Reid et al. 2014). For researching the Milk Way structure, the most basic requirement is the high-quality and large-scale survey data. In the past several decades, lots of molecular line surveys, especially the CO line surveys, have been conducted (see Heyer & Dame 2015). Among them, two remarkable CO surveys conducted by Heyer et al. (1998) and Dame et al. (2001) have provided a lot of precious data. Currently, many MW models are largely based on those two surveys (e.g., Hou & Han 2014). However, such data with relatively low resolution or low sensitivity gradually become insufficient for more detailed research. Fortunately, the ongoing Milky Way Imaging Scroll Painting (MWISP) project,\(^4\) which is the first no-bias, highly sensitive large-scale \(^12\)CO/\(^13\)CO/C\(^18\)O survey toward the Galactic plane, somewhat solves this problem. As one of the target regions of the survey, a Galactic region of \(l = [139^\circ.75, 149^\circ.75], b = [-5^\circ.25, 5^\circ.25]\) (hereafter the G140 region) has been completely covered by nearly 2 yr of observation. The total observing area is 105 deg\(^2\), and this paper takes a 96 deg\(^2\)-part (see Figure 2 for the used part) to study the spiral arm structure. Another 9 deg\(^2\)-part has been used for another study, which will be published soon (Xiong et al. 2017).

The G140 region is located in the second quadrant of the MW, which is a better place to study the arm structure since the kinematic distance here is a monotonic function of LSR velocity. Starting from \(V_{LSR} \sim 0 \text{ km s}^{-1}\), increasingly negative velocities successively trace the Local Arm, the Perseus Arm, the Outer Arm, and a new segment of the spiral arm discovered by Sun et al. (2015; hereafter New Arm). In most MW spiral arm models, the Perseus Arm, the Outer Arm, and the New Arm all comprise the major spiral arm of the MW (see Steiman-Cameron 2010; Sun et al. 2015). The Local Arm was once thought to be a spur structure, until recently, when Xu et al. (2013, 2016) provided strong observational evidence proving that it is a larger structure, such as a branch.

Interestingly, since the G140 region is just the intersection point of the Gould Belt and the Galactic plane (see Figure 2 in Grenier 2004), the Local Arm in this place is made up of two layers: the Gould Belt layer, which is associated with the Lindblad Ring traced by H\(_1\) gas (Lindblad 1967; Strauss et al. 1979), and the Cam OB1 layer, which is associated with the Cam OB1 association (Digel et al. 1996; Stražys & Laugalys 2008). The Cam OB1 layer is a star-forming active layer that locates the famous young stellar object GL 490 and two Sharpless H\(_2\) regions, as well as the Cam OB1 association. The star-forming activities in this region have been studied in detail by Stražys & Laugalys (2007) and their series of works. But the molecular cloud structure of this region was rarely studied. Except for a small part studied by Digel et al. (1996), up to now there has been no systematic CO observation completely covering this region.

In this paper, we report the \(^12\)CO/\(^13\)CO/C\(^18\)O mapping observation toward the G140 region. We mainly focus on studying the molecular structure of the Local Arm and Perseus Arm here. The study of star-forming activity will be presented in our next paper. Section 2 presents the CO observation condition and archival data of atomic hydrogen. Section 3 presents the physical parameters of the Local Arm and Perseus Arm derived by CO data. Combing H\(_1\) data and part of the Outer Arm results (Du et al. 2016), Section 4 discusses the arm structures in the G140 region. Section 5 presents five filamentary giant molecular clouds identified in the Perseus Arm and discusses their relations to the MW large-scale structure. Finally, Section 6 provides the summary.

2. Observation

2.1. CO Observation

The \(^12\)CO (1 − 0), \(^13\)CO (1 − 0), and C\(^18\)O (1 − 0) lines were observed using the Purple Mountain Observatory

\(^4\) http://english.dlh.pmo.cas.cn/ic/ or http://www.radioast.nsdc.cn/mwisp.php; One can submit an application to download the data.
Delingha (PMODLH) 13.7 m telescope from 2013 September to 2015 December as one of the scientific demonstration regions for the MWISP project. The three lines were observed simultaneously with the nine-beam superconducting array receiver (SSAR) working in sideband separation mode and with the fast Fourier transform spectrometer (FFTS) employed (Shan et al. 2012). The $^{12}$CO line is at the upper sideband (USB), and the $^{13}$CO and C$^{18}$O lines are at the lower sideband (LSB). Both of the bandwidths are 1000 MHz with 16,384 channels. With on-the-fly (OTF) observing mode, an area of $l = [139.275, 149.75]$, $b = [-5.25, 5.25]$ (105 deg in total) was covered, and a 96 deg part is used in this work. All the data were sampled every 30″. For the $^{12}$CO observations (at USB), the main-beam width was about 49″, the main-beam efficiency ($T_{MB,USB}$) was about 0.46, and the typical rms noise level was about 0.5 K, corresponding to a channel width of 0.16 km s$^{-1}$. For the $^{13}$CO and C$^{18}$O observations (at LSB), the main-beam width was about 51″, the main-beam efficiency ($T_{MB,LSB}$) was about 0.48, and the typical rms noise level was about 0.3 K, corresponding to a channel width of 0.17 km s$^{-1}$. All the data were corrected by $T_{MB} = T_{A} / T_{MB}$.

2.2. Archival Data of Atomic Hydrogen

The 21 cm line data were retrieved from the Canadian Galactic Plane Survey (CGPS; Taylor et al. 2003). We downloaded data of $l = [140^\circ, 150^\circ]$, $b = [-3^\circ, 5^\circ]$ from the Canadian Astronomy Data Centre. The velocity coverage of the data is in the range of $-153$ to $40$ km s$^{-1}$, with a channel separation of 0.82 km s$^{-1}$. The survey has a spatial resolution of 58″, which is comparable to our CO observations.

3. Physical Parameters

3.1. Slicing the Region

Figure 1 presents the LSR velocity distribution of the G140 region. The $^{12}$CO, $^{13}$CO, and C$^{18}$O FITS cube data of the whole region were integrated over all latitudes with 3σ thresholds (namely, $^{12}$CO emission $\geq 1.5$ K and $^{13}$CO/C$^{18}$O emission $\geq 0.9$ K are not integrated). Then three high signal-to-noise ratio $I - V$ maps of those molecules are obtained. Since the velocity resolutions are not the same (0.16 km s$^{-1}$ at $^{12}$CO and 0.17 km s$^{-1}$ at $^{13}$CO/C$^{18}$O), the velocity dimensions of the $^{12}$CO and C$^{18}$O $I - V$ maps have been interpolated for comparison with the $^{12}$CO data. Then, we define Mask 1 as the area where only $^{12}$CO emission exists, Mask 2 as the area where $^{12}$CO and $^{13}$CO emission both exist but C$^{18}$O emission does not, and Mask 3 as the area where $^{12}$CO, $^{13}$CO, and C$^{18}$O emission exists. The blue, green, and red colors in Figure 1 indicate Mask 1, Mask 2, and Mask 3, respectively. Obviously, from LSR velocity $\sim 10$ to $-50$ km s$^{-1}$ the Gould Belt layer, Cam OB1 layer, and Perseus Arm are successively located. The black lines in Figure 1 outline their boundaries. In addition, some Outer Arm and New Arm structure can also be seen in this map because of the high-quality data. In order to show those two arms more clearly, the molecular clouds and arm spiral projections (identified and fitted by Sun et al. 2015; Du et al. 2016; see the caption of Figure 1 for more details) are plotted.

According to the $I - V$ map, the FITS cube of the three molecules is integrated over the velocity ranges, which are shown as the black lines in Figure 1. Also the integrated thresholds are $3\sigma$. Then the integrated intensity maps of the three molecules are obtained. We also define Mask 1, Mask 2, and Mask 3 of the integrated maps, and the definitions of the masks are the same as in the above presentation. Figure 2 shows the final results. It can be seen that lots of molecular gas presents filamentary structure, especially in the Perseus Arm (this will be discussed in Section 5). In addition, C$^{18}$O is not rich in this region: it is rarely distributed on the Gould Belt layer, some is concentrated on the position of ($l, b$) $\sim (140^\circ, 2^\circ)$ (where GL 490 is located) on the Cam OB1 layer, and on the Perseus Arm some is distributed on the position of ($l, b$) $\sim (148^\circ, 0^\circ)$. This roughly indicates that the gas is relatively less dense in this region.

The distance of the Local Arm in this region has many photometric results. The distance of the Gould Belt layer is in the range of 160–300 pc (Straižys et al. 2001; Zdanavičius et al. 2005), and the Cam OB1 layer is about 1.0 kpc away from us (Humphreys 1978; Lyder 2001; Straižys & Laugalys 2007). Although there is no photometric distance of the Perseus Arm in this region, the nearby high-mass star-forming regions W 3OH (i.e., G133.94+01.06) and S Per (i.e., G134.62-02.19) have the trigonometric parallax results, which are 1.95 kpc (Xu et al. 2006) and 2.42 kpc (Asaki et al. 2010), respectively. In addition, according to the Perseus Arm spiral fitted by Reid et al. (2014), at the positions of ($l, b$) $= (140^\circ, 0^\circ)$ and ($l, b$) $= (150^\circ, 0^\circ)$, the distances are calculated to be 2.0 and 2.2 kpc, respectively. Based on all the distance results presented above, we finally adopt 200 pc, 1.0 kpc, and 2.1 kpc as the distances of the Gould Belt layer, Cam OB1 layer, and Perseus Arm, respectively.

3.2. Physics of Layers

Assuming that $^{12}$CO is optically thick, following Bourke et al. (1997), the excitation temperature ($T_{ex}$) in each pixel of each layer can be calculated by

$$T_{ex} = \frac{k \nu_{12}}{ \ln \left( 1 + \frac{h \nu_{12}}{T_{MB,^{12}CO}^\ast T_{ex}^{\nu_{12}/k} \exp \left( \frac{-h \nu_{12}}{k T_{ex}} \right) } \right) },$$

where $h$ is the Planck constant, $k$ is the Boltzmann constant, $\nu_{12}$ is the frequency of $^{12}$CO, $T_{MB,^{12}CO}$ is the peak main-beam temperature in each pixel, and $T_{ex}$ is the temperature of the cosmic microwave background. The equation can be simplified as

$$T_{ex} = \frac{5.532 \nu_{12}}{ \ln \left( 1 + \frac{5.532 \nu_{12}}{T_{MB,^{12}CO}^\ast 0.0857} \right) } K$$

when all the constants are substituted.

The three left panels of Figure 3 show the distributions of $T_{ex}$ in the three layers. It can be seen that the excitation temperatures in this region are relatively low. In the Cam OB1 layer, most of the $T_{ex}$ of Mask 3 are in the range of 6–16 K, which are slightly higher than the other two layers ($T_{ex}$ $\sim$ 6–12 K). The reason may be that the Cam OB1 layer has more star-forming activities. Moreover, in each layer the $T_{ex}$ peak distributions of Mask 1, Mask 2, and Mask 3 are in the increasing trend. This may indicate that the region where C$^{18}$O exists is relatively hotter and the region where only $^{12}$CO exists is relatively colder.

5 http://cadc.hia.nrc.ca
The H$_2$ column densities of the three masks are calculated by two different methods. For Mask 1, where only 12CO is detected, we use the X-factor to estimate the column density (hereafter the X-factor method):

$$N_{\text{Mask1},H_2} = X \int T_{\text{MB,}^{12}\text{CO}} dV,$$

where $\int T_{\text{MB,}^{12}\text{CO}} dV$ is the integrated intensity of $^{12}$CO in each pixel, and the factor $X$ is adopted from the results of Abdo et al. (2010), namely, $0.87 \times 10^{20}$ cm$^{-2}$ (K km s$^{-1}$)$^{-1}$ in the Gould Belt layer, $1.59 \times 10^{20}$ cm$^{-2}$ (K km s$^{-1}$)$^{-1}$ in the Cam OB1 layer, and $1.9 \times 10^{20}$ cm$^{-2}$ (K km s$^{-1}$)$^{-1}$ in the Perseus Arm.

For Mask 2 and Mask 3, the local thermodynamic equilibrium (LTE) condition is assumed. Then, assuming that $^{12}$CO and C$^{18}$O are optically thin and they share the same $T_{\text{ex}}$ with $^{13}$CO, following Bourke et al. (1997) and Pineda et al. (2010), the $^{13}$CO column density of Mask 2 in each pixel can be calculated by

$$N_{\text{Mask2},^{13}\text{CO}} = 2.42 \times 10^{14} \frac{\tau_{13}}{1 - e^{-\tau_{13}}} \int T_{\text{MB,}^{13}\text{CO}} dV \text{ cm}^{-2},$$

and for Mask 3 the C$^{18}$O column density in each pixel can be calculated by

$$N_{\text{Mask3},^{18}\text{O}} = 2.42 \times 10^{14} \frac{\tau_{18}}{1 - e^{-\tau_{18}}} \int T_{\text{MB,}^{18}\text{O}} dV \text{ cm}^{-2},$$

where $\tau_{13}$ and $\tau_{18}$ respectively indicate the peak optical depth of $^{13}$CO and C$^{18}$O. $\int T_{\text{MB,}^{13}\text{CO}} dV$ and $\int T_{\text{MB,}^{18}\text{O}} dV$ respectively indicate the integrated intensities of $^{13}$CO and C$^{18}$O in units of K km s$^{-1}$, and $T_{\text{ex}}$ is in units of K. And $\tau_{13}$ and $\tau_{18}$ are calculated by

$$\tau_{13} = -\ln \left[ 1 - \frac{T_{\text{MB,}^{13}\text{CO}}}{5.29} \left( e^{5.29/T_{\text{ex}}} - 1 \right)^{-1} - 0.16 \right]^{-1}$$

and

$$\tau_{18} = -\ln \left[ 1 - \frac{T_{\text{MB,}^{18}\text{O}}}{5.27} \left( e^{5.27/T_{\text{ex}}} - 1 \right)^{-1} - 0.17 \right]^{-1},$$

where $T_{\text{MB,}^{13}\text{CO}}$ and $T_{\text{MB,}^{18}\text{O}}$ are the peak main-beam temperatures of $^{13}$CO and C$^{18}$O, respectively. Finally, according to the abundances of $^{13}$CO and C$^{18}$O (Frerking et al. 1982; Castets & Langer 1995), the H$_2$ column density of Mask 2 and Mask 3 in each pixel can be calculated by

$$N_{\text{Mask2},H_2} = 7 \times 10^3 \times N_{\text{Mask2},^{13}\text{CO}}$$

and

$$N_{\text{Mask3},H_2} = 7 \times 10^6 \times N_{\text{Mask3},^{18}\text{O}}.$$

Hereafter this column density estimation method is called the LTE method for short in this paper.

Figure 4 shows the H$_2$ column density result of the whole region. Clearly, the $N_{H_2}$ in the main part of the gas is about $10^{21}$-$10^{23}$ cm$^{-2}$. The three right panels of Figure 3 show the H$_2$ column density distribution of the three layers. One can see that the $N_{H_2}$ distribution of Mask 3 is much more concentrated (around a higher value of $10^{23}$ cm$^{-2}$) than that of Mask 2 and Mask 3. This indicates that the region traced by C$^{18}$O is relatively denser.

Knowing the $N_{H_2}$ in each pixel, we can then estimate the mass of each mask:

$$M_{\text{Mask}} = 2 \mu m_H a^2 d \Sigma N_{\text{Mask},H_2},$$

where $\mu (=1.36; \text{Hildebrand 1983})$ is the mean atomic weight per H atom in the ISM, $m_H$ is the H atom mass, $a (=30''=0.5'$) is the angular size of each pixel, $d$ is the distance of each layer (see Section 3.1), and $\Sigma N_{\text{Mask},H_2}$ refers to the $N_{H_2}$ summation of all the pixels in each mask. Table 1 shows the final results of pixel number, pixel percentage (the ratio of pixel number in one mask to the total pixel number in three masks), physical area (the physical area is estimated by “one pixel physical area” × “pixel number”), and mass of each mask in each layer. It is noticeable that the pixel percentage of Mask 2 and Mask 3 in the Cam OB1 layer is higher than that of the other two layers. This is perhaps because the Cam OB1 layer has more star-forming activities.

4. Arm Structure

4.1. Gas Distribution

Most works about the gas distribution of the MW are mainly focused on the global and radial structure (e.g., Burton et al. 1975; Sodroski et al. 1987; Nakanishi & Sofue 2003 and their serial papers; Duarte-Cabral et al. 2015). The distribution along the arm spiral direction is also meaningful. For example, in the study of external galaxies by La Vigne et al. (2006), the feather structure is well associated with the gas peak surface density (see Figures 19–20 of their paper). Their work presented a good way of thinking about studying the substructure of our MW. Substructures such as the branch,
spur, and feather will be discussed in detail in Section 5. In this section we just focus on the gas distribution along the Galactic longitude.

Figure 5 shows the distributions of HI and H$_2$ gases of the Local Arm and Perseus Arm along the Galactic longitude. Since the Local Arm shares two layers, the $N_{H_2}$ in each pixel of this arm is obtained by calculating the mean value in the same angular position of the Gould Belt layer and the Cam OB1 layer, while the H$_2$ mass is obtained by adding together the data of the two layers. Then, we calculate the mean value of $N_{H_2}$ every 0.2 Galactic longitude degree of the Local Arm and Perseus Arm, respectively. Thus, the $N_{H_2}$ distribution is obtained. And for the H$_2$ mass distribution, we calculate the summation of H$_2$ mass every 0.2 Galactic longitude degree. To obtain the parameters of HI gas, we first slice the data into three layers, and the LSR velocity ranges are the same with CO data (see Section 3.1). Second, assuming that HI is optically thin, the surface density of each layer is calculated by $\Sigma_{HI} = 1.82 \times 10^{18} m_H \int T_{MB,HI} dV$, where $\int T_{MB,HI} dV$ is the integrated intensity of HI. And then the HI column density is obtained by the relation of

\[ N_{HI} = \frac{\Sigma_{HI} \lambda^2}{m_H c} \]

Note that the data in the upper left corner of each panel (where the inset is located) were not used in this paper, since they have been used for another study that will be published soon (Xiong et al. 2017).
$1 \, M_\odot \, \text{pc}^{-2} = 1.25 \times 10^{20} \, \text{cm}^{-2}$. Third, combining the distance, the mass of HI in each pixel can be easily obtained, and the calculation method is the same as the one in Section 3.2. Finally, the HI column density and mass distributions along the Galactic longitude are obtained using the same approaches of H$_2$ that have been presented above, and the column density and mass ratios of H$_2$ and HI gas are simply calculated by division.

In Figure 5 one can see that the gases in the two arms vary smoothly, especially the HI gas. In addition, the H$_2$ column densities of the Local Arm and Perseus Arm are similar, and the H$_2$ mass of the Perseus Arm is a little higher than that of the Local Arm. However, the HI gas exhibits a largely different performance. Both the column density and mass of HI gas on the Perseus Arm are much higher than those on the Local Arm. Thus, the ratio of H$_2$ to HI (hereafter H$_2$/HI) of the Local Arm is higher than that of the Perseus Arm. This condition is also clearly shown in Table 2, which summarizes the gas masses of the Local Arm and Perseus Arm and also lists the masses of the Outer Arm in the G140 region for comparison (the Outer Arm data are obtained from Du et al. 2016). Since both the Outer Arm and Perseus Arm are in the major spiral arm of the MW and the Outer Arm is located farther away from the Galactic center (see Section 1), it may be reasonable that H$_2$/HI of the former is lower than that of the latter. However, that the Local Arm—as a subarm of the MW—has the highest H$_2$/HI is somewhat abnormal. Maybe it indicates a tendency that the H$_2$ gas is more compactly located around the Galactic center than that of HI gas. However, another probable reason should not be ignored—that the HI gas on the Local Arm is largely underestimated. This will be presented in Section 4.2.

### 4.2. Warp and Flare

Warp is a common phenomenon among disk galaxies (Binney 1992). The external galaxies with optical warps have long been recognized (Sandage 1961; Arp 1966), but they were just thought to be some special cases since only a few were observed at that time. Using HI gas observation data, Sancisi

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**Table 1**

| Layer Name   | Mask 1 Pixel Number | Pixel Percentage | Area ($\text{pc}^2$) | Mass ($M_\odot$) |
|--------------|---------------------|-----------------|----------------------|-----------------|
| Gould Belt   | 396, 409            | 83.3%           | 335                  | 1607            |
| Mask 2       | 75, 407             | 15.8%           | 64                   | 503             |
| Mask 3       | 4330                | 0.9%            | 4                    | 63              |
| Total        | 476, 146            | 400             | 2200                 |                 |
| Cam OB1      | 355, 608            | 75.6%           | 7522                 | 77, 395         |
| Mask 2       | 105, 156            | 22.4%           | 2224                 | 42, 464         |
| Mask 3       | 9251                | 2.0%            | 196                  | 7394            |
| Total        | 470, 015            | 9900            | 127, 300             |                 |
| Perseus Arm  | 178, 200            | 78.2%           | 16, 624              | 198, 130        |
| Mask 2       | 46, 954             | 20.6%           | 4380                 | 82, 472         |
| Mask 3       | 2725                | 1.2%            | 254                  | 8787            |
| Total        | 227, 879            | 21, 300         | 289, 400             |                 |

**Note.**

* Pixel percentage is the ratio of the pixel number in one mask to the total pixel number in three masks of each layer.
found that four out of five galaxies have gas warps. Thereafter more gas warps were identified in a large number of external galaxies (e.g., Huchmeier et al. 1980; García-Ruiz et al. 2002). As it deserved, from that time on warp was regarded with special attention. With no exception, our MW is also a warped galaxy. In fact, the HI gas warp was observed very early on (Burke 1957; Kerr 1957; Kerr et al. 1957; Westerhout 1957). The warp of our Galaxy has a large amplitude and is also asymmetric (Levine et al. 2006). Combing recent HI observation data, Kalberla & Kerp (2009) summarized a bended Galactic plane map (Figure 3 in their paper), which showed a general distribution of Galactic warp. Besides HI gas, the MW warp has been observed and studied by many other tracers, such as dust (Freudenreich et al. 1994), CO (Wouterloot et al. 1990), stars or OB stars (Miyamoto et al. 1988; Dehnen 1998), and IRAS point sources (Djorgovski & Sosin 1989). Besides warp, flare— as another gas behavior— is also an interesting phenomenon among galaxies, as well as our Galaxy. In addition, the MW flare has been confirmed in both gaseous and stellar tracers (e.g., Momany et al. 2006; Kalberla & Kerp 2009; Heyer & Dame 2015). Usually, flare and warp are discussed together under the hypothesis that they are the response of dark matter (e.g., Binney 1978; Kalberla et al. 2007). Unlike the difficult research situation in the MW spiral structure, the study of warp and flare in the MW is relatively less troublesome since the inclination problem that always exists among external galaxies can be discarded. In this exact G140 region, we will morphologically present the warp and flare of both H1 and H2 gases in the following paragraphs.

Figure 5. Column density (left panel) and mass (right panel) distributions of H2 and H1 gases along the Galactic longitude. Note that the column density and mass of H1 gas are divided by 2 and 5, respectively.

| Spiral Arm | H2 ($10^4 M_\odot$) | H1 ($10^4 M_\odot$) | H2 + H1 ($10^4 M_\odot$) | H2/H1 Ratio |
|------------|-----------------|-----------------|-----------------|-------------|
| Local      | 9               | 25              | 34              | 0.36        |
| Perseus    | 21              | 247             | 268             | 0.08        |
| Outer      | 15              | 624             | 639             | 0.02        |

Notes.

a This column lists the mass ratio of H2 to H1.

b The Outer Arm parameters are obtained from Du et al. (2016).

Figure 6. Gas distribution of the Local Arm and Perseus Arm along the Z scale. Note that the mass of H1 gas of the Perseus Arm is divided by 5.

Figure 7. Gas mass of the Perseus Arm. Note that the mass of H1 gas of the Perseus Arm is divided by 5.

The Astrophysical Journal Supplement Series, 229:24 (17pp), 2017 April Du et al.
distributions suddenly stop at Z scales of about $-120$, $-60$, 90, and 200 pc, respectively. In other words, the total mass of H I gas on the two spiral arms, especially on the Local Arm, is largely underestimated (which is one of the probable reasons that the H$_2$/H I of the Local Arm is largely higher than that of the Perseus Arm mentioned in Section 4.1).

Despite the incomplete Z scale gas distribution, we can still estimate the thickness and height of each arm by fitting the distribution in a Gaussian curve. We define the FWHM as the arm thickness and the centric position at Z scale as the arm height. Table 3 lists the final results, as well as the parameters of the Outer Arm in the G140 region for comparison (data from Du et al. 2016). A more direct perspective on the arm distributions can be seen in Figure 7. We obtain the mean distance of the Gould Belt layer and Cam OB1 layer as the distance of the Local Arm. For the Outer Arm distance, we adopt the mean distance of all the Outer Arm clouds in the G140 region with the cloud mass as weight. One can see that the distance between the Outer Arm and Perseus Arm is much larger than that between the Perseus Arm and Local Arm, which cannot be obviously shown on the $l-V$ map. (However, the Outer Arm distance may be overestimated a little since the cloud distances adopted are kinematic distances; details are presented in Section 4.2 of Du et al. 2016.) In addition, both the Local Arm and the Perseus Arm are almost located at the Galactic plane, while the Outer Arm lies as high as $\sim150$–$200$ pc above it. This suggests that the MW warp in this region may start at a place between the Perseus Arm and the Outer Arm. In addition, the H I gas flare is obvious, but it does not exist in H$_2$ gas. The H$_2$ gas thickness of Perseus is a little thicker than that of the Local Arm, but it becomes much thinner on the Outer Arm. Maybe one of the reasons is that on the edge of the galaxy some arms become narrow (e.g., Honig & Reid 2015). But another possible reason should not be ignored—that the Outer Arm molecular clouds have not been completely detected yet.

Table 3

| Spiral Arm | Thickness $H_2$ (pc) | Thickness $H_1$ (pc) | Height $H_2$ (pc) | Height $H_1$ (pc) |
|------------|---------------------|---------------------|------------------|------------------|
| Local      | 117                 | 220                 | 18               | 2                |
| Perseus    | 149                 | 291                 | 16               | 19               |
| Outer$^a$  | 60                  | 550                 | 170              | 160              |

Note. $^a$ The Outer Arm parameters are obtained from Du et al. (2016).
and 13CO, respectively. In addition, the masses of 12CO and 13CO data, we totally identify the FGMCs with other works. The yellow filled circle indicates the mean value of each work. The standard deviation is marked by the red error bar. The green line in each panel indicates the value of “Nessie” (Jackson et al. 2010; Goodman et al. 2014); in panels (a) and (b) it indicates the value of “Nessie Classic,” and in panels (c) and (d) it indicates the value of the envelope of “Nessie Classic” traced by HNC. Note that (1) in panel (c), the H2 column densities of “This Work,” “Wang+ 2015,” and “Zucker+ 2015” are from the 13CO-derived result, SED fitting result, and an assumed value, respectively; and (2) in panel (d), the blue circles and triangles of “This Work” indicate the masses derived by 12CO and 13CO, respectively. In addition, the masses of “Ragan+ 2014,” “Wang+ 2015,” and “Zucker+ 2015” are derived by 13CO data, SED fitting column density, and assumed column density, respectively.

5. The Filamentary Giant Molecular Clouds in the Perseus Arm

Filament, as an important star-forming stage (André et al. 2014), has obtained a lot of attention in recent years. In the Gould Belt filament study of André et al. (2014, p. 27), the filament length is at a scale of ∼1–10 pc, while its scale width is ∼0.1 pc. But in the larger scale, there also exist some filamentary cloud structures. The first large-scale filamentary infrared dark cloud (IRDC), “Nessie,” was identified by Jackson et al. (2010), which is ∼80 pc long and ∼0.5 pc wide. Then, Goodman et al. (2014) added that “Nessie” might probably be as long as 430 pc. In addition, they related it to the MW structure and called it the “bone” of the Galaxy. Subsequently, more filamentary clouds with such a large scale were identified, and their relations with the large-scale structure of the MW were also under research (e.g., Li et al. 2013; Tackenberg et al. 2013; Battersby & Bally 2014; Su et al. 2016).

As mentioned in Section 3.1, one can clearly see that in Figure 2 the molecular gas presents filamentary structure, especially in the Perseus Arm. The molecular cloud complex of the Perseus Arm in this region was only partly studied by Digel et al. (1996) before. In this section, we have totally identified five filamentary giant molecular clouds (FGMCs) in the Perseus Arm, among which four are newly identified. Their properties, comparisons with “Nessie” and other large-scale filamentary clouds, and their relations to the MW structure will be presented in the following.

5.1. General Properties

Based on the spatial morphology and velocity continuity of 12CO and 13CO data, we totally identified five FGMCs in the Perseus Arm and named them “Grand Canal,” “Jakiro,” “Drumstick,” “Pincer,” and “Dachshund,” respectively. Among them, “Grand Canal” has been partly detected by Blitz et al. (1982) and studied by Digel et al. (1996) before (more details are presented in Section 5.2.1), while the other four clouds are newly identified. In addition, “Pincer” is a cloud that consists of two filamentary structures (“Pincer-longer” and “Pincer-shorter”). Figure 8 presents the distribution of the FGMCs (see the caption for more details). Table 4 lists the properties of FGMCs, including the centric position, the height to the Galactic plane, the angle between the longer side of FGMCs and the Galactic plane (hereafter FP angle), the mean and maximum excitation temperature, the dense gas mass function (DGMF), and the parameters traced or derived by 12CO, 13CO, and C18O, respectively. Among them, the 12CO and 13CO rows list the mean and maximum H2 column density, and the mass derived by 12CO and 13CO, respectively. Among them, the 13CO rows list the list of the similar parameters derived by C18O except length, width, and the length-to-width ratio, since the C18O distribution in the FGMC is patchy rather than filamentary. Note that (i) the “Pincer-longer” also lacks the parameters of length, width, and length-to-width ratio traced by 12CO for similar reasons, and (ii) the parameters traced by C18O of “Dachshund” are not listed since nearly no C18O emission is detected.

The estimation of all the physical parameters is similar to the method presented in Section 3. The only difference is that we do not define masks in this section. Namely, the area where we calculate 12CO-derived mass also includes the area where 13CO and C18O emission exists, and similarly for the area where we calculate 13CO-derived mass. The calculation methods for all the parameters are as follows.

First, we respectively integrate the 12CO, 13CO, and C18O FITS cube of each FGMC over the velocity range that is listed in Table 4. The integrated threshold is also 3σ, and the pixels without signals in the final integrated map are set to be NULL. Then, we adopt “the total number of pixels that are not NULL” × “the angular area of each pixel” as the total angular area. According to the distance (2.1 kpc), the physical area can be easily estimated. Second, the length is adopted as the physical length of the longer side of the box that confines the FGMCs shown in the top panel of Figure 8. The width is obtained by dividing the physical area by the physical length. Then, the length-to-width ratio can be calculated accordingly. Third, the excitation temperature is calculated by the 12CO peak main-beam temperature, and the calculation method is the same as in Equation (2). Fourth, the
Figure 10. Properties of the FGMC “Grand Canal.” (a) Integrated intensity map of $^{12}$CO (blue), $^{13}$CO (green), and C$^{18}$O (red). Note that the value is logarithmic. The red circle indicates the location where the C$^{18}$O peak main-beam temperature is the highest. (b) $^{12}$CO velocity-coded map. (c) Excitation temperature map derived by $^{12}$CO. (d, e) H$_2$ column density map derived by $^{12}$CO and $^{13}$CO, respectively. Note that the value is logarithmic. (f) Averaged spectrum of $^{12}$CO (blue), $^{13}$CO (green), and C$^{18}$O (red) of 9 pixels of the red circle in panel (a). Note that the C$^{18}$O spectrum is multiplied by 3. (g) Average velocity–position map of the white rectangles in panel (a), and the white arrows in panel (a) indicate the position direction. Note that the white dotted line in panel (g) refers to the turning point in panel (a).
H$_2$ column density is also estimated by two methods. For the area traced by $^{12}$CO, the X-factor method is adopted, and the calculation method is the same as in Equation (3); for the area traced by $^{13}$CO and C$^{18}$O, the LTE method is adopted, and the calculation method is the same as in Equations (4)-(9).

Fifth, the calculation method of mass traced by different CO molecules is the same as in Equation (10). Finally, we consider C$^{18}$O tracing the dense gas and define the DGMF as the ratio of the molecular mass derived by C$^{18}$O to the one derived by $^{13}$CO.

Figure 11. Properties of the FGMC “Jakiro.” The meaning of each panel is consistent with Figure 10.
Generally, on morphology, these FGMCs are (i) at the scale length of \( \sim 100 \) pc, and (ii) at the scale width of \( \sim 10 \) pc and \( \sim l \) pc traced by \(^{12}\)CO and \(^{13}\)CO, respectively. On distribution, (i) except for “Dachshund,” the other FGMCs all distribute near the Galactic plane (the absolute height \( \sim 10 \) pc), and (ii) the FP angle range is as large as from \( \sim 0^\circ \) to \( \sim 90^\circ \). On physical property, (i) their excitation temperature is similar (\( \sim 10 \) K), (ii) the DGMF range is large (\( \sim 0\%–9\% \)), (iii) three FGMCs have relatively obvious velocity gradients (details in Section 5.2), (iv) the mean \( \text{H}_2 \) column densities are not high (the densities derived by \(^{12}\)CO, \(^{13}\)CO, and \(^{13}\)CO are all \( \sim 10^{21} \text{ cm}^{-2} \)), and (v) the masses derived by \(^{12}\)CO are all at the giant molecular cloud (GMC) scale.

The properties of these FGMCs are somewhat different from those of the giant filamentary IRDC “Nessie.” Their lengths are similar to “Nessie Classic” (namely, the part identified by Jackson et al. 2010), but their widths are \( \sim 10–100 \) times larger than that of “Nessie.” In addition, their mean \( \text{H}_2 \) column densities are lower than that of “Nessie” for one order of magnitude. However, the properties between the FGMCs traced by \(^{12}\)CO and the envelope of “Nessie Classic” traced by HNC (Goodman et al. 2014) are not very different: their width scale is similar, and also they share the same \( \text{H}_2 \) column density scale of \( 10^{21} \) cm\(^{-2} \).

In recent years, using the infrared and molecular line data, Ragan et al. (2014), Wang et al. (2015), and Zucker et al. (2015) have all systematically identified and studied several giant filamentary clouds. Figure 9 shows the comparisons of length, absolute height (namely, the absolute distance to the Galactic plane), \( \text{H}_2 \) column density, and mass between this work and theirs, as well as “Nessie.” One can see that the lengths, the masses derived by \(^{12}\)CO, and the absolute heights of this work are similar to those of others, while the \( \text{H}_2 \) column densities are relatively lower than in other works.

5.2. Individuals

5.2.1. “Grand Canal”

The FGMC “Grand Canal” is named after a famous canal in China—the Beijing–Hangzhou Grand Canal, which is the longest and one of the oldest man-made rivers in the world. Unlike other large rivers in China, the Beijing–Hangzhou Grand Canal is a south–north direction river, similar to the FGMC “Grand Canal,” which is almost vertical to the Galactic plane (FP angle \( \sim 81^\circ \)). Using a CO tracer, a point position of this FGMC was first detected by Blitz et al. (1982) with the name of BFS27. In Digel et al. (1996), “Grand Canal” was completely detected and was divided into three parts (with ID numbers of 50–52 in their catalog, and BFS27 is located at Number 52). Here using relatively highly sensitive and high-resolution data, we consider those three clouds as one filamentary structure and study it again in this section.

Figure 10 presents the properties of this FGMC. From panel (a), one can see that the \(^{13}\)CO distribution is clumpy. These \(^{13}\)CO clumps are located at \((l, b) \equiv (140^\circ 6, 0^\circ 6), (140^\circ 5, -0^\circ 2), (140^\circ 9, -0^\circ 7), \) and \((141^\circ 0, -1^\circ 3), \) where the excitation temperature and \( \text{H}_2 \) column density are relatively higher, as shown in panels (c)–(e). Among them, at the position of \((l, b) \equiv (141^\circ 0, -1^\circ 3) \) (which is also the position near BFS27), the \(^{13}\)CO main-beam temperature is the highest, and the three molecular line profiles at this position are shown in panel (f). In addition, the FGMC breaks at the position of \((l, b) \sim (140^\circ 75, -0^\circ 4) \) and bends at the position of \((l, b) \sim (140^\circ 5, 0^\circ 4) \). North of \( b \sim 0^\circ 4, \) the FGMC splits into two parallel parts with different velocity components, which can be seen in panels (b) and (g). Moreover, from panels (b) and (g), one can see that the FGMC presents a weak velocity gradient along the major axis. In panel (g), at the position of \( 0^\circ \) its velocity is \( \sim -41 \text{ km s}^{-1} \), while at the position of \( 3^\circ 3 \) the velocity becomes \( \sim -37 \text{ km s}^{-1} \). Thus, we can roughly estimate that the velocity gradient is \( \sim 0.04 \text{ km s}^{-1} \) pc\(^{-1} \).

Compared to other FGMCs, (i) its \(^{12}\)CO length-to-width ratio is the highest; (ii) its \( \text{H}_2 \) column densities derived by \(^{12}\)CO, \(^{13}\)CO, and \(^{13}\)CO are all the highest; (iii) its excitation temperatures are the highest; and (iv) it is the only FGMC of which the \(^{13}\)CO distribution is clumpy.

5.2.2. “Jackiro”

The FGMC “Jackiro” is named after its complicated velocity components, as shown in panels (b), (f), and (g) of Figure 11. Figure 12 shows its channel map. One can see that this FGMC seems to be composed of two “S” shapes that twist together, while the \(^{13}\)CO seems to be mainly distributed in one of the “S” shapes, as shown in panel (e) of Figure 11. In addition, \(^{13}\)CO distribution is very diffused.

Compared to other FGMCs, (i) it is the only one that is located above the Galactic plane, (ii) its \(^{12}\)CO length-to-width ratio is the lowest, and (iii) its physical areas and masses traced and derived by \(^{12}\)CO and \(^{13}\)CO are both the largest.

5.2.3. “Drumstick”

The FGMC “Drumstick” is named after its shape—one narrower part at the northeast side and one wider part at the southwest side, as shown in Figure 13. These two parts break at the position of \((l, b) \sim (145^\circ 8, -0^\circ 4) \). The wider part contains more complicated velocity components. As shown in panel (g) of Figure 13, the wider part is composed of about four velocity components: the main component is at the major axis with velocity \( \sim -30 \text{ km s}^{-1} \), and the other three components distribute at both sides of the main one with velocity \( \sim -35, -28, \) and \( -23 \text{ km s}^{-1} \), respectively. In addition, this FGMC presents a weak velocity gradient along the major axis. At the position of \( 0^\circ \), its velocity is \( \sim 33 \text{ km s}^{-1} \), and at the position of \( 3^\circ 1, \) the
velocity becomes $\sim -30 \text{ km s}^{-1}$. Thus, the velocity gradient is $\sim 0.03 \text{ km s}^{-1} \text{ pc}^{-1}$. The excitation temperature and H$_2$ column density of the wider part are higher than those of the narrower part. The C$^{18}$O distribution is relatively diffused in this FGMC, and almost all the C$^{18}$O distributes in the wider part.

### 5.2.4. “Pincer”

The FGMC “Pincer” consists of two filamentary structures—the “Pincer-longer” and the “Pincer-shorter.” Those two parts present very different properties, as shown in Figure 14.
“Pincer-longer” is very diffused. The \(^{13}\)CO on it is even too diffused to form a complete filamentary structure. The C\(^{18}\)O is also rare. The \(H_2\) column density and excitation temperature are both very low. On the other hand, “Pincer-shorter” is more compact, and its \(H_2\) column density and excitation temperature are both higher. The C\(^{18}\)O is rich and largely concentrated in the vicinity of \((l, b) \sim (148.1^\circ, 0.3^\circ)\), where its excitation temperature is relatively higher.

Figure 14. Properties of the FGMC “Pincer.” The meaning of each panel is consistent with Figure 10. Note that in panel (g), the left map and right map refer to the velocity–position maps of “Pincer-longer” and “Pincer-shorter,” respectively.
Compared to other FGMCs, (i) this FGMC is the only one that consists of two filamentary components, (ii) the $^{13}$CO and C$^{18}$O on “Pincer-shorter” are the richest, and (iii) the DGMF of “Pincer-shorter” is the highest.

5.2.5. “Dachshund”

The shape of FGMC “Dachshund” is interesting. It looks like a dog running from the northwest to the southeast, as

![Image of FGMC Dachshund properties](image-url)
The Astrophysical Journal Supplement Series, 229:24 (17pp), 2017 April
Du et al.

Table 4
Properties of FGMCs

| Name       | (1) | Grand Canal | Jakiro | Drumstick | Pincer-longer | Pincer-shorter | Dachshund |
|------------|-----|-------------|--------|-----------|---------------|---------------|-----------|
| Glon       | (deg) | 140.6      | 145.4  | 145.3     | 148.7         | 148.0         | 147.2     |
| Glat       | (deg) | 0.1        | 0.9    | -0.8      | -0.3          | -0.1          | -3.8      |
| FP Angle   | (deg) | 81         | 0      | 33        | 22            | 56            | 39        |
| Height     | (pc) | 4          | 33     | -27       | -9            | -3            | -140      |
| \(T_C\)   | (K)  | 9/26       | 7/16   | 8/16      | 6/12          | 7/21          | 6/12      |
| DGMF       | (%)  | 3.2        | 0.1    | 0.8       | 0.7           | 8.7           | 0         |

\[^{12}\text{CO}\] \(V_{\text{LSR}}\) (km s\(^{-1}\)) (8) \([-45, -33]\) \([-43, -23]\) \([-37, -26]\) \([-38, -29]\) \([-38, -29]\) \([-34, -19]\)

\[^{13}\text{CO}\] \(V_{\text{LSR}}\) (km s\(^{-1}\)) (14) \([-45, -34]\) \([-41, -25]\) \([-36, -27]\) \([-37, -30]\) \([-37, -30]\) \([-30, -20]\)

\(^{13}\text{CO}\) \(V_{\text{LSR}}\) (km s\(^{-1}\)) (19) \([-43, -36]\) \([-32, -28]\) \([-34, -29]\) \([-37, -31]\) \([-37, -31]\) \([-30, -20]\)

Table 5
Comparison of Filamentary Structure

| Structure       | Length | Angle | Location       | References |
|-----------------|--------|-------|----------------|------------|
| Gould Belt filament | 1–10 pc | …     | Subarm         | (1)        |
| FGMC            | ~100 pc | 0°–90° | Major arm      | …          |
| Other giant filament | ~100 pc | 0°–70° | Major arm and interarm | (2) |
| Feather         | ~1 kpc | ~50°  | Major arm      | (3), (4)   |
| Spur            | ~1 kpc | ~60°  | Interarm       | (4), (5)   |
| Local Arm       | >5 kpc | ~11°  | …              | (6), (7)   |
| Major arm of MW | >10 kpc | 7°–20° | …              | (7), (8)   |

Note. Row (1): the name of the FGMC. Rows (2)–(3): the central position of the FGMC in Galactic coordinates. Row (4): the angle between the longer side of the FGMC and the Galactic plane. Row (5): the height to the Galactic plane, which is calculated by height = distance \times \sin(latitude). Row (6): mean/excitation temperature of the FGMC. Row (7): dense gas mass function of the FGMC. Rows (8)–(13): parameters traced or derived by \(^{12}\text{CO}\), respectively, are LSR velocity range, length × width, ratio of length to width, area, mean/max H\(_2\) column density, and mass. Rows (14)–(18) and Rows (19)–(22): parameters traced or derived by \(^{13}\text{CO}\) and \(^{13}\text{CO}\), respectively. The meaning of each row is consistent with Row \(^{12}\text{CO}\). Note that Rows (14)–(15) of “Pincer-longer” and Rows (19)–(22) of “Dachshund” are null because of the weak emission.

Note. (1) André et al. 2014; (2) Ragan et al. 2014; Wang et al. 2015; Zucker et al. 2015; (3) Lynds 1970; (4) La Vigne et al. 2006; (5) Elmegreen 1980; (6) Xu et al. 2013, 2016; (7) Reid et al. 2014; (8) Steiman-Cameron 2010; Sun et al. 2015; Du et al. 2016.

Note that the angle of “FGMC” and “Other giant filament” refers to the angle between the filamentary structure and the Galactic plane, whereas the angle in the other rows refers to the pitch angle.

shown in Figure 15. This FGMC is a very diffused cloud. The \(^{13}\text{CO}\) is too weak to be detected. In addition, its excitation temperature is also very low. However, it is noticeable that along its minor axis it presents an obvious velocity gradient. At the “belly” of the dog, the velocity is \(\sim23\) km s\(^{-1}\), and at the “back” of the dog, it becomes \(\sim27\) km s\(^{-1}\). Thus, the velocity gradient is estimated to be \(\sim0.25\) km s\(^{-1}\) pc\(^{-1}\).

The spiral arms of many galaxies are not smooth (Weaver 1970). On the arms there exist the so-called substructures, such as the branch, spur, and feather (e.g., Lynds 1970; Piddington 1973; Elmegreen 1980; La Vigne et al. 2006). In the study of seven galaxies, Elmegreen (1980) has found that the width and length of the spur structure are at the order of magnitude of 100 pc and 1 kpc, respectively. In fact, the substructures of our Galaxy were also observed and studied early on (e.g., Sofue 1976; Rickard & Cronyn 1979). Recently, a spur with kiloparsec length between the Local Arm and the Sagittarius Arm has been identified by Xu et al. (2016), which further implies the complicated situation of the MW substructures.

Apparent, those substructures are also filamentary. However, they are hugely longer and wider than the FGMCs and other giant filamentary clouds studied by Ragan et al. (2014), Wang et al. (2015), and Zucker et al. (2015). In
addition, up to now the longest giant filamentary cloud in the MW is just \(\sim 500\) pc long (Li et al. 2013). Such FGMCs are indeed too small compared to substructures like the spur. On the other hand, they are about 10 times larger than the traditional Gould Belt filaments studied by André et al. (2014). Table 5 lists a comparison among several filamentary structures with different scales. There exists to exist a delicate trend in angle (FP angle or pitch angle) such that the angle range and value become small as the filamentary structure becomes large. In addition, their locations also change from subarm to major arm and then to interarm. As mentioned at the beginning of Section 5, the relations between such a giant filament and MW large-scale structure are under research. Some subtle trends have indeed been found (e.g., Ragan et al. 2014), but strong evidences still need more observational samples.

### 6. Summary

The G140 region, namely, the Galactic region of \(l = [139.7^\circ, 149.7^\circ], b = [-5.25^\circ, 5.25^\circ]\), is one of the target survey areas of the ongoing MWISP project. The \(^{12}\)CO (1 – 0), \(^{13}\)CO (1 – 0), and \(^{13}\)CO (1 – 0) lines were observed simultaneously using the PMOD/HL 13.7 m telescope. With nearly 2 yr of observations, this region has been completely covered. We take a 96 deg\(^2\) part of this region to mainly study the molecular structure of the Local Arm and Perseus Arm. Combining the H\(_{\text{I}}\) data and part of theOuter Arm results, the gas distribution, warp, and flare are discussed. In addition, five FGMCs on the Perseus Arm are identified, and their relations to the MW large-scale structure are discussed. The main results of the G140 region are as follows:

1. The Local Arm consists of two layers: the Gould Belt layer and the Cam OB1 layer. Their molecular masses are \(\sim 2.2 \times 10^3 M_\odot\) and \(\sim 12.7 \times 10^4 M_\odot\), respectively. In total the Local Arm molecular mass is \(\sim 12.9 \times 10^4 M_\odot\). The Perseus Arm molecular mass is \(\sim 28.9 \times 10^4 M_\odot\).

2. The mass ratios of H\(_2\) to H\(_{\text{I}}\) gas on the Local Arm, Perseus Arm, and Outer Arm are 0.36, 0.08, and 0.02, respectively. However, the ratio of the Local Arm may be overestimated since the H\(_{\text{I}}\) gas on the Local Arm is indeed too small compared to substructures like the spur. On the other hand, they are about 10 times larger than the traditional Gould Belt filaments. On the other hand, they are about 10 times larger than the traditional Gould Belt filaments studied by André et al. (2014). Table 5 lists a comparison among several filamentary structures with different scales. There exists to exist a delicate trend in angle (FP angle or pitch angle) such that the angle range and value become small as the filamentary structure becomes large. In addition, their locations also change from subarm to major arm and then to interarm. As mentioned at the beginning of Section 5, the relations between such a giant filament and MW large-scale structure are under research. Some subtle trends have indeed been found (e.g., Ragan et al. 2014), but strong evidences still need more observational samples.

3. The H\(_2\) gas thicknesses of the Local Arm, Perseus Arm, and Outer Arm are 117, 149, and 60 pc, respectively. However, the ratio of the Local Arm may be overestimated since the H\(_{\text{I}}\) gas on the Local Arm is indeed too small compared to substructures like the spur. On the other hand, they are about 10 times larger than the traditional Gould Belt filaments. On the other hand, they are about 10 times larger than the traditional Gould Belt filaments studied by André et al. (2014). Table 5 lists a comparison among several filamentary structures with different scales. There exists to exist a delicate trend in angle (FP angle or pitch angle) such that the angle range and value become small as the filamentary structure becomes large. In addition, their locations also change from subarm to major arm and then to interarm. As mentioned at the beginning of Section 5, the relations between such a giant filament and MW large-scale structure are under research. Some subtle trends have indeed been found (e.g., Ragan et al. 2014), but strong evidences still need more observational samples.

4. Five FGMCs with lengths \(\sim 100\) pc on the Perseus Arm are identified, among which four are newly identified. Their masses derived by \(^{12}\)CO, \(^{13}\)CO, and \(^{18}\)O are \(\sim 10^4\), \(\sim 10^3\), and \(\sim 10^2 M_\odot\), respectively, and their mean H\(_2\) column densities derived by \(^{12}\)CO, \(^{13}\)CO, and \(^{18}\)O are all \(\sim 10^{21} \text{cm}^{-2}\).
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