A Morphological Classification of 18,190 Molecular Clouds Identified in $^{12}$CO Data from the MWISP Survey

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Abstract

We attempt to visually classify the morphologies of 18,190 molecular clouds, which are identified in the $^{12}$CO(1–0) spectral line data over $\sim$450 deg$^2$ of the second Galactic quadrant from the Milky Way Imaging Scroll Painting project. Using the velocity-integrated intensity maps of the $^{13}$CO(1–0) emission, molecular clouds are first divided into unresolved and resolved ones. The resolved clouds are further classified as nonfilaments or filaments. Among the 18,190 molecular clouds, $\sim$25% are unresolved, $\sim$64% are nonfilaments, and $\sim$11% are filaments. In the terms of the integrated flux of $^{12}$CO(1–0) spectra of all 18,190 molecular clouds, $\sim$90% are from filaments, $\sim$9% are from nonfilaments, and the remaining $\sim$1% are from unresolved sources. Although nonfilaments are dominant in the number of the discrete molecular clouds, filaments are the main contributor of $^{12}$CO emission flux. We also present the number distributions of the physical parameters of the molecular clouds in our catalog, including their angular sizes, velocity spans, peak intensities of $^{12}$CO(1–0) emission, and $^{12}$CO(1–0) total fluxes. We find that there is a systematic difference between the angular sizes of the nonfilaments and filaments, with the filaments tending to have larger angular scales. The H$_2$ column densities of them are not significantly different. We also discuss the observational effects, such as those induced by the finite spatial resolution, beam dilution, and line-of-sight projection, on the morphological classification of molecular clouds in our sample.

Unified Astronomy Thesaurus concepts: Interstellar medium (847); Interstellar molecules (849); Molecular clouds (1072)

Supporting material: machine-readable table

1. Introduction

Molecular clouds usually exhibit complex and hierarchical structures, whose boundaries can be defined by their CO emission at the lower rotational transitions (Heyer & Dame 2015). The spatial power spectrum (Ingalls et al. 2004; Gazol & Kim 2010) and the $\Delta$-variance (Stutzki et al. 1998; Bensch et al. 2001; Elia et al. 2014; Dib et al. 2020) techniques have been used to quantitatively analyze the fractal structures of molecular clouds. Falgarone et al. (1991) and Stutzki et al. (1998) have characterized the boundaries of clouds using fractal dimensions and gave a value of about 1.5 for the 2D projections, and $\sim$2 in the 3D structures (Beattie et al. 2019). Dib et al. (2020) investigated the structures of the Cygnus-X North molecular cloud using the $\Delta$-variance spectrum and indicated that its characteristic scales were in a range of $\sim$0.5–1.2 pc.

Since the systematic discovery of filamentary structures in molecular clouds by the Herschel observations (André et al. 2010; Molinari et al. 2010), more and more attention has been focused on filaments. Numerous studies have revealed that star-forming clouds usually exhibit filamentary structures, within which a significant fraction of gravitationally bound dense cores and protostars are embedded (Schneider et al. 2012; André et al. 2013, 2014; Contreras et al. 2016; André 2017; Yuan et al. 2019, 2020). There is also a fair amount of nonfilaments, e.g., globules, cometary, and extended structures (Bok & Reilly 1947; Bourke et al. 1995a; Mäkelä & Haikala 2013; Goicoechea et al. 2020), which either harbor a few young stars or are less opaque and less dense, with little or no star formation (Bourke et al. 1995a, 1995b; Reipurth 2008; Haikala et al. 2010; Goicoechea et al. 2020). However, the percentages and mass fractions of filaments and nonfilaments in molecular clouds are still unclear. It is interesting and important to explore the morphologies of molecular clouds, e.g., to investigate the fraction of filaments and nonfilaments in the molecular cloud populations.

A large-scale, unbiased, and high-sensitive spectral survey is essential to investigate the morphologies of molecular clouds in a wide range of the spatial scales. The ongoing unbiased Galactic plane CO survey, the Milky Way Imaging Scroll Painting (MWISP), provides us with opportunities to promote the research of the morphologies of molecular clouds to a huge sample with rich details. The mapping area of MWISP covers the Galactic longitude from $l = 9^\circ.75$ to $230^\circ.25$ and the Galactic latitude from $b = -5^\circ.25$ to $5^\circ.25$. This CO survey is performed using the 13.7 m telescope of Purple Mountain Observatory (PMO) and observes $^{12}$CO, $^{13}$CO, and C$^{18}$O ($J = 1–0$) lines simultaneously (Su et al. 2019).

In this paper, we focus on the unbiased catalog of molecular clouds in the Galactic plane with $10^4.75 < l < 150^\circ.25$, $-5^\circ.25 < b < 5^\circ.25$, and $-95$ km s$^{-1} < V_{LSR} < 25$ km s$^{-1}$ provided by the MWISP (Yan et al. 2021a). This catalog consists of 18,190 molecular clouds. We attempt to perform a morphological classification to this sample through visual inspection. These molecular clouds are first divided into the resolved and unresolved ones, and then the resolved clouds are further classified as nonfilaments and filaments. This paper is

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organized as follows. Section 2 introduces the \(^{12}\)CO(1–0) spectral line data and the unbiased catalog of molecular clouds. Section 3 presents the morphological classification for molecular clouds, including the criteria, processes, and results of the classification. In Section 4, we compare the physical properties of filaments and nonfilaments. Section 5 discusses the effects of the finite spatial resolution, beam dilution, and 2D projection on the morphological fractions of molecular clouds.

2. Data

2.1. The \(^{12}\)CO(1–0) Emission in the Second Galactic Quadrant

\(104^\circ \leq l \leq 150^\circ\), \(|b| < 5^\circ\), and \(-95 \text{ km s}^{-1} < V_{\text{LSR}} < 25 \text{ km s}^{-1}\)

The large-scale distribution of the molecular gas across the second Galactic quadrant of 450 deg\(^2\) is shown in Figure 1. The upper color map represents the velocity-integrated intensity of the \(^{12}\)CO(1–0) line emission covering \(104^\circ < l < 150^\circ\), \(|b| < 5^\circ\). The integrated velocity range is \(V_{\text{LSR}}\) from \(-95\) to 25 km s\(^{-1}\). The lower color map shows the distribution of the latitude-integrated intensity of the \(^{12}\)CO(1–0) line. The integrated latitude range is \(b\) from \(-5^\circ\) to 5\(^\circ\). To display the gas structures clearly, we divided the whole region into three parts whose Galactic longitudes are in the range of \(l = (104^\circ, 120^\circ), (120^\circ, 135^\circ), \) and \((135^\circ, 150^\circ)\), respectively. Their velocity-integrated intensity and latitude-integrated intensity maps are presented in Figures A1–A3, respectively. The molecular gas distributes inhomogeneously and hierarchically. In the longitude–velocity diagram, molecular gas mainly concentrates in the range of \(V_{\text{LSR}} = (-25, 10)\) and \((-65, -30)\) km s\(^{-1}\). Also, the well-known molecular clouds located within the map regions have been noted. Parts of the observations in this region previously were published in Yan et al. (2021a), Sun et al. (2020), Du et al. (2016), and Du et al. (2017).

2.2. An Unbiased Catalog of Molecular Clouds

In this work, a molecular cloud is defined as a connected structure in a 3D space. In practice, a set of contiguous voxels in the position–position–velocity (PPV) cube with the intensities of \(^{12}\)CO emission above a certain threshold are extracted as a molecular cloud. The extracting method we used was developed by Yan et al. (2020), based on the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm, which was originally designed to discover clusters of arbitrary shape (Ester et al. 1996).

Yan et al. (2021a) have completed the identification of molecular clouds using the DBSCAN algorithm in the second Galactic quadrant with \(104^\circ < l < 150^\circ, |b| < 5^\circ\), and \(-95 \text{ km s}^{-1} < V_{\text{LSR}} < 25 \text{ km s}^{-1}\). We check the averaged \(^{12}\)CO(1–0) line profile and the velocity-integrated intensity map for each cloud and 18,190 out of 18,503 molecular clouds can be used for further analysis. Among the 313 excluded structures, 88 are fake structures caused by bad channels, which are mainly located at the velocity of \(-24 \text{ km s}^{-1}\), and 225 clouds located at the edges of the region \((l = 104^\circ, 150^\circ, b = \pm 5^\circ), V_{\text{LSR}} = 25 \text{ or } -95 \text{ km s}^{-1}\) are incomplete in this work.

The basic parameters for each molecular cloud are listed in Table 1, including the central Galactic coordinate, the peak
intensity and flux of the $^{12}$CO line emission, the projected angular area ($A$), and its velocity span ($V_{\text{span}}$, which is the velocity span of the molecular cloud cube in the velocity axis of PPV space). Figure 2 presents the number distributions of these parameters. The angular sizes of these molecular clouds, which are calculated as $\sqrt{A}$, range from $1^\circ$ to $246^\circ$ and concentrate in the scale of $2^\circ$–$43^\circ$. Their velocity spans are distributed in $(0.5$, $43.4)\text{ km s}^{-1}$ and are mainly located in $(1.5$, $3.0)\text{ km s}^{-1}$. The peak intensities of $^{12}$CO(1–0) emission for these molecular clouds are distributed in a wide range of 1.2–50.8 K, although the values for most sources are located in a narrow range of 2.6–4.2 K, their $^{12}$CO(1–0) emission flux distributes in a range of $0.53$–$3.9 \times 10^{4} \text{ K km s}^{-1} \text{ arcmin}^{2}$ and concentrates in $(4.4$, $27.4) \text{ K km s}^{-1} \text{ arcmin}^{2}$. The typical range of each parameter, which is from the quantile of 0.25 to 0.75 in its sequential data, has been listed in Table 2. Although Yan et al. (2021a) have calculated the distance of 76 molecular clouds in this catalog, most of the molecular clouds in this catalog do not have the available distance information. Thus, we group the 18,190 molecular clouds into two parts, corresponding to the near and far ranges, respectively. As shown in Figure 1, molecular clouds in the near range are in the velocity range of $(0.25, 30) \text{ km s}^{-1}$ and clouds in the far range are in $(-95, -30) \text{ km s}^{-1}$.

### 3. Morphological Classification

The morphologies of molecular clouds are usually thought to be complex and hierarchical. As a fundamental character of molecular clouds, the morphology still lacks a systematic description. Since a profusion of filament in the Galactic molecular clouds have been revealed in the Herschel infrared Galactic Plane Survey (Hi-GAL) imaging surveys with Herschel (André et al. 2010; Molinari et al. 2010) and the role of interstellar filaments in the star formation process has been emphasized (Schneider et al. 2012; André et al. 2013; Hacar et al. 2013; Kirk et al. 2013; André et al. 2014; Contreras et al. 2016), the filamentary clouds have gained more and more attention. We wonder if all of the molecular clouds are filamentary. The MWISP CO survey provides us with opportunities to promote the research of the morphologies of molecular clouds to a huge sample with rich details. As the first step in the morphological classification of molecular clouds, after visually inspecting all of the molecular cloud samples in our catalog, we find that the main features of molecular clouds can be simplified and labeled as filaments and nonfilaments. Thus we attempt to take a systematic and binary classification for the morphologies of molecular clouds. This simplified classification may provide a new dimension for us to further understand molecular clouds.

For each molecular cloud in our catalog, we draw its $^{12}$CO(1–0) intensity maps integrated along three different directions ($l$, $b$, $v$) and its averaged $^{12}$CO(1–0) spectrum. We show these maps of the four molecular clouds in Figure 3. The morphological classifications for these 18,190 molecular clouds are performed by visually inspecting their integrated $^{12}$CO(1–0) intensity maps.

#### 3.1. Classificatory Criteria

After preliminarily visual inspections of all of the samples, we attempt to classify all of the molecular clouds into unresolved sources, nonfilaments, and filaments. While André et al. (2013, 2014) have revealed that the observed filaments in the nearby star-forming clouds of our Galaxy share common properties, and the characters of larger-scale and dense filaments also have been systematically analyzed in Li et al. (2013) and Wang et al. (2015, 2016), and a quantitative definition for filaments is still lacking. In this work, according to the beam size of the MWSIP CO data, we empirically define a filament segment as an elongated, narrow, or twisty structure, whose aspect ratio (the ratio between its length and width, $A_{\nu}$) is larger than 4 ($A_{\nu} \geq 4$). The length of a filament segment is defined as the length along its spine, and its width is estimated as the radial cuts across the spine. Once the length of an

| Name | Number (1) | $l_{\text{cen}}$ (deg) | $b_{\text{cen}}$ (deg) | $V_{\text{LSR}}$ (km s$^{-1}$) | $A$ (arcmin$^{2}$) | $V_{\text{span}}$ (km s$^{-1}$) | Peak Intensity (K) | Flux (K km s$^{-1}$ arcmin$^{2}$) | Morphology Type |
|------|------------|------------------------|------------------------|-----------------------------|-------------------|-----------------------------|-------------------|-----------------------------|-----------------|
| G105.434+00.481-050.97 | 105.434 | 00.481 | $-50.97$ | 0.275 | 0.150 | 2.4 | 1.73 | Unresolved |
| G105.435+00.996-012.20 | 105.435 | 00.996 | $-12.20$ | 0.757 | 0.020 | 3.8 | 10.38 | Nonfilament |
| G105.441+03.708+008.23 | 105.441 | 03.708 | $-8.23$ | 0.400 | 0.167 | 2.8 | 4.15 | Unresolved |
| G105.445+03.776+047.29 | 105.445 | 03.776 | $-47.29$ | 0.295 | 0.030 | 10.2 | 103.38 | Nonfilament |
| G105.445+03.338+042.96 | 105.445 | 03.338 | $-42.96$ | 0.052 | 0.351 | 3.2 | 10.51 | Nonfilament |
| G105.449+00.579+047.29 | 105.449 | 00.579 | $-42.87$ | 0.205 | 0.147 | 5.3 | 53.46 | Nonfilament |
| G105.459+00.514+045.21 | 105.459 | 00.514 | $-45.21$ | 0.045 | 0.024 | 2.3 | 5.04 | Nonfilament |
| G105.461+00.062+011.38 | 105.461 | 00.062 | $-11.38$ | 0.225 | 0.051 | 7.7 | 48.35 | Filament |
| G105.462+02.225+025.45 | 105.462 | $-22.25$ | $-25.45$ | 0.020 | 0.117 | 2.8 | 2.08 | Unresolved |
| G105.466+03.014+068.21 | 105.466 | 03.014 | $-68.21$ | 0.075 | 0.351 | 2.9 | 9.19 | Nonfilament |
| G105.466+00.593+048.35 | 105.466 | 00.593 | $-48.35$ | 0.103 | 0.043 | 6.8 | 320.12 | Filament |

**Note.** The central Galactic coordinates ($l_{\text{cen}}$, $b_{\text{cen}}$) for each cloud are the averaged Galactic coordinates in its velocity-integrated $^{12}$CO(1–0) intensity map, weighting by the value of the velocity-integrated $^{12}$CO(1–0) intensity. The central velocity ($V_{\text{LSR}}$) for each cloud is the averaged radial velocity in its radial velocity field, weighting by the value of the velocity-integrated $^{12}$CO(1–0) intensity. $A$ is the angular area of each cloud, which is projected along the line of sight. $V_{\text{span}}$ represents the velocity span of each cloud cube in the velocity axis of PPV space, which is calculated using the number of velocity channels in the cloud cube multiplied by a velocity resolution of $0.167 \text{ km s}^{-1}$. Peak intensity is the peak value of $^{12}$CO(1–0) line intensity in each cloud. The flux is the integrated flux of the $^{12}$CO(1–0) line emission for each cloud, $\int T_{\text{mb}}(l, b, v) \text{ d}l \text{ d}b \text{ d}v = 0.167 \times 0.25 T_{\text{mb}}(l, b, v) \text{ K km s}^{-1} \text{ arcmin}^{2}$, where $T_{\text{mb}}(l, b, v)$ is the $^{12}$CO line intensity at the coordinate of ($l$, $b$, $v$) in PPV space, $dv = 0.167 \text{ km s}^{-1}$ is the velocity resolution, $\text{ d}l \text{ d}b = 0.5 \times 0.5 = 0.25 \text{ arcmin}^{2}$, and the angular size of a pixel is $0.5^\circ$. (This table is available in its entirety in machine-readable form.)
The elongated, narrow, or twisty structure is estimated to be larger than 4 times its width by visual inspection, we label this structure as a filament segment. The criteria of our classifications are described below.

1. Molecular clouds are divided into unresolved sources and resolved clouds. The unresolved sources are defined as the structures with the projected angular areas less than $2.5 \times 2.5$ (5 $\times$ 5 pixel), corresponding to a diameter of $\sim$3 beam size.

2. The resolved clouds are further classified as nonfilaments or filaments. Filaments are defined as structures including at least one filament segment.

3. Nonfilaments are the resolved molecular clouds, which do not contain the resolved filament segments.

3.2. Processes and Results of Morphological Classification

According to the above criteria of morphological classification, three authors independently classified these 18,190 molecular clouds by visual inspection. As the scheme illustrated in Figure 3, molecular clouds are first divided into unresolved and resolved clouds. According to the results from three investigators, the consistent results from at least two investigators are considered to be types of molecular clouds, i.e., unresolved or resolved sources. After the classification of unresolved and resolved clouds is completed, the resolved ones are further visually classified as nonfilaments or filaments. We also use the consistent results from at least two investigators as the morphological types of molecular clouds. Finally, in a total of 18,190 molecular clouds, we find that the number of unresolved sources is 4448, which takes a percentage of about 25%, in the remaining $\sim$75%, there are $\sim$64% molecular clouds (11,680) classified as nonfilaments and $\sim$11% as filaments (2062). In addition, we compare the agreement fractions between the results labeled by two of three individuals; the agreements are on the level of 60–80%.

Generally, the morphologies of filamentary clouds include the single filamentary segment, the dominant filament with branches, the intersection of multiple filaments, and the complex network built by a system of filamentary segments and their sub-branches. A single filament is a single structure, which satisfies the definition for the filament segment. For a
single dominant filament with relatively few branches, its branches are along the main filament and have smaller lengths and less $^{12}$CO emission intensities than that of the main chunk, somewhat like the branches of a tree. Moreover, for the intersection of multiple filaments and the network connected by a system of filaments, their hierarchical and filamentary structures are complex, but contain at least one filamentary segment. In Figures A4 and A5, we show examples of molecular clouds classified as filamentary structures.

The morphologies of non-filament structures primarily include clumpy structures and extended structures. Clumpy structures present one clump or are dominated by one clump. For one clump, its $^{12}$CO emission intensity gradually decreases from the center to the outside, i.e., the distribution of $^{12}$CO(1–0) intensity nearly fits the 2D Gaussian profile. For a structure dominated by one clump, it may also contain a tail or several fibers but with lengths smaller than the size of the dominant clump. Compared with the clumpy structure, the extended structure is more stretched, and its shape is similar to a cylinder or an arc, but its aspect ratio is roughly less than 4 ($A_o \lesssim 4$). Figures A6 and A7 represent examples of nonfilaments, corresponding to the clumpy and extended structures, respectively.

We should note that the morphologies of molecular clouds are affected by the spatial resolution of the $^{12}$CO spectral lines. The morphologies of molecular clouds in this work are based on the spatial resolution (∼50") of the 13.7 m millimeter-wavelength telescope of the PMO. It is possible that the morphological characters and fractions may change under the higher spatial resolution data.

4. The Characteristics of Filaments and Nonfilaments

What are the different characteristics between the nonfilament and filament clouds? Is there any connection between them? To answer these questions, we further present the characteristics of filaments and nonfilaments, including their Galactic distributions, angular sizes, velocity spans, the peak intensities and fluxes of the $^{12}$CO line, and the averaged velocity-integrated $^{12}$CO line intensity ($W_{^{12}CO}$). The number distributions of these parameters are presented in Figures 2 and 4, and are also fitted with the power-law function as $dN/dX \propto X^{-\alpha}$. The typical ranges of these parameters, which are calculated from the quantile of 0.25–0.75 in their sequential data, are listed in Tables 2 and 3.

4.1. Galactic Distributions

Figure 5 presents the number distributions of molecular clouds in the Galactic longitude, Galactic latitude, and radial velocity, respectively. Furthermore, we utilize the kernel density estimation using Gaussian kernels in the PYTHON package, which is a way to estimate the probability density function (PDF) of a random variable in a nonparametric way (2D) to demonstrate the 2D PDF of the number of filaments.

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4 scipy.stats.Gaussian_kde
To quantitatively compare the Galactic distributions of filaments and nonfilaments, we normalized their histograms and presented their probability density function of the numbers in the Galactic longitude, Galactic latitude, and radial velocity in Figure 6. In the Galactic longitude $l$ from $104.75^\circ$ to $150.75^\circ$ we also perform the Kolmogorov–Smirnov test to compare the number distributions of filaments and nonfilaments using the scipy.stats.ks_2samp procedure in the scipy package, resulting in a $p$-value of 0.45. This suggests we cannot reject the identical distribution for the number distributions of filaments and nonfilaments at the 45% level. In the Galactic latitude $b$ from $-5^\circ$ to $5^\circ$ both filaments and nonfilaments appear to peak at more positive latitudes, concentrating in a range of $(-1^\circ, 3^\circ)$. This may be attributed to the gas layer in the outer Galaxy being systematically warped away from flatness. The first detection and descriptions of the warped HI gas layer of the outer Galaxy were given by Westerhout (1957), Burke (1957), Kerr (1957), and Oort et al. (1958), and more detailed and quantitative parameters of the HI warp and filaments were provided in Burton & te Lintel Hekkert (1986), Diplas & Savage (1991), and Voskes & Butler Burton (2006). Furthermore, Wouterloot et al. (1990) derived the distribution of molecular clouds in the outer Galaxy and found that it shows the same warped shapes and flaring thickness as that of the HI gas layer. We also find that the number distribution in the radial velocity for nonfilaments is close to that for filaments. Both of

![Graphs showing number distributions of filaments and nonfilaments.](image)

**Figure 4.** Upper panel: the number distributions of the averaged $^{12}$CO velocity-integrated intensity ($W_{^{12}CO}$) and the angular areas ($A$) for molecular clouds in the near range. Lower panel: same as above, but for molecular clouds in the far range. The green histograms represent molecular clouds showing nonfilaments, and the magenta ones are for filaments. The dashed black lines fit their power-law distributions, $dn/dX \propto X^{-\alpha_W}$, whose negative slopes are noted in each panel.

**Table 3**

| Types        | $A$ (arcmin$^2$) | $\alpha_A$ | $N_{H_2}$ ($10^{20}$ cm$^{-2}$) | $\alpha_W$ |
|--------------|------------------|------------|-------------------------------|------------|
|              | Near, Far        |            | Near, Far                     |            |
| Nonfilaments | 6.5–18, 6.8–17   | 1.7 ± 0.1  | 1.6–2.8, 2.2–4.0              | 3.9 ± 0.3  |
| Filaments    | 32.0–147.4, 35.8–144.8 | 0.9 ± 0.1 | 2.4–5.2, 3.4–7.6              | 3.1 ± 0.2  |

Note. The $H_2$ column density ($N_{H_2}$) is calculated using $N_{H_2} = X_{CO} W_{^{12}CO}$, where $X_{CO} = 2 \times 10^{20}$ cm$^{-2}$ (K km s$^{-1}$)$^{-1}$. The $\alpha_A$ and $\alpha_W$ represent the fitted slopes for the power-law distributions of the angular sizes and $W_{^{12}CO}$, respectively. Near represents the molecular clouds in the near range ($V_{LSR}$ from $-30$ to $25$ km s$^{-1}$) and far represents the molecular clouds in the far range ($V_{LSR}$ from $-95$ to $-30$ km s$^{-1}$). The typical range for each parameter is from the quantile of 0.25–0.75 in its sequential data.
them concentrate on the velocity ranges of $(-20, 5)$ km s$^{-1}$ and $(-65, -30)$ km s$^{-1}$.

4.2. Angular Size

In Figure 2 for the nonfilaments their angular sizes ($L$) are in a range of $2'\text{'}-40'$ and concentrate on a range of $\sim 2'6-4'2$. Their number distribution in the range of $L > 3'$ is fitted to a power law with an exponent ($\alpha_{L, \text{non}}$) of $3.7 \pm 0.2$. While for filaments, their angular sizes distribute in a range of $3'\text{'}-250'$ and mainly in $\sim 5'8-12'1$. Their number distribution in the range of $L > 8'$ also is fitted to the power law with an exponent of $1.9 \pm 0.1$ ($\alpha_{L, \text{fil}}$).

According to the spiral structure of the Milky Way, we estimated the kinematical distances to sources using the Bayesian distance
The angular areas of molecular clouds in the Local arm may have a distance of \( \sim 0.5 \) kpc, and those in the Perseus arm have a typical distance of \( \sim 2 \) kpc. The molecular cloud with an angular size of 1' in the Local arm has a physical scale of \( \sim 0.15 \) pc, and for that in the Perseus arm, its physical scale is \( \sim 0.6 \) pc.

As shown in Figure 1, based on the radial velocities of the molecular clouds, we separated them into two groups, i.e., the near and far ranges. As shown in Figure 4, in the near range, the angular areas \( (A) \) for the nonfilament structures are in a range of 2.5–1450 arcmin\(^2\) and concentrate on 6.5–18.0 arcmin\(^2\). Their number distribution in the range of \( A > 10 \) arcmin\(^2\) is fitted to a power law with an exponent of 1.7 \( \pm 0.1 \) (\( \alpha_{A,non} \)). Whereas, for filaments distributed in a range of 8.75–6.0 \times 10^4 \text{arcmin}^2\) and mainly in 32–147.4 arcmin\(^2\), the exponent for their power-law distribution fitted in the range of \( A > 100 \) arcmin\(^2\) is 0.9 \( \pm 0.06 \) (\( \alpha_{A,f}\)). In the far range, the angular areas for nonfilaments are in a range of 3–180 arcmin\(^2\) and focus on 6.75–17.0 arcmin\(^2\), and their number distribution in the range of \( A > 10 \) arcmin\(^2\) is fitted to the power law with an exponent of 2.0 \( \pm 0.1 \) (\( \alpha_{A,non} \)). For filaments distributed in a range of 10–21 \times 10^3 \text{arcmin}^2\) and mainly in 36–144.8 arcmin\(^2\), the exponent for their power-law distribution fitted in the range of \( A > 100 \) arcmin\(^2\) is 1.0 \( \pm 0.1 \) (\( \alpha_{A,f}\)). The fitted exponent of the power law for nonfilaments is twice that for filaments, either in the near or far range, and the filaments tend to have a larger spatial size than nonfilaments.

4.3. \(^{12}\text{CO} \) Emission Intensity

In Figure 2, for the nonfilaments, the peak intensities \( (I) \) of \(^{12}\text{CO} \) line emission are in a range of 1.4–36.1 K and concentrate on 2.7–4.2 K, and the number distribution in the range of \( I > 3 \) K is fitted to a power law with an exponent of 3.5 \( \pm 0.2 \) (\( \alpha_{I,non} \)). For filaments distributed in a range of 2.0–50.8 K and are mainly located in 4.0–7.2 K, the fitted negative slope (\( \alpha_{I,f} \)) for the power-law distribution in the range of \( I > 6 \) K is 2.8 \( \pm 0.07 \).

Figure 4 presents the averaged \(^{12}\text{CO} \) velocity-integrated intensity, \( W_{12CO} = \int T_{mb}(l, b, v) d v \text{d}l \text{d}b \), for molecular clouds. In the near range, for the nonfilaments, the \( W_{12CO} \) ranges from 0.3 to 13.1 K km s\(^{-1}\) and focuses on 0.8–1.4 K km s\(^{-1}\), and the number distribution in the range of \( W_{12CO} > 1.0 \) K km s\(^{-1}\) is fitted to a power law with an exponent of 3.9 \( \pm 0.3 \) (\( \alpha_{W,non} \)). For filaments, the value of \( W_{12CO} \) is in a range of 0.5–12.3 K km s\(^{-1}\) and concentrates on 1.2–2.6 K km s\(^{-1}\), and the fitted power-law index for the number distribution in the \( W_{12CO} > 2.0 \) is 3.1 \( \pm 0.2 \) (\( \alpha_{W,f} \)).

In the far range, for the nonfilaments, the values of \( W_{12CO} \) are distributed in the range of 0.34–15.9 K km s\(^{-1}\) and mainly in 1.1–2.0 K km s\(^{-1}\), the exponent (\( \alpha_{W,non} \)) for the fitted power-law distribution in the range of \( W_{12CO} > 1.0 \) is 3.0 \( \pm 0.2 \). For the filaments, the values of \( W_{12CO} \) are in 0.6–18.5 K km s\(^{-1}\) and focus on 1.7–3.8 K km s\(^{-1}\), and the fitted power-law index (\( \alpha_{W,f} \)) for the number distribution in the range of \( W_{12CO} > 4.0 \) is 2.6 \( \pm 0.1 \). According to the analysis of beam filling factors (\( \eta \)) on molecular clouds using the MWISP CO data in Yan et al. (2021b), the value of \( \eta \) is about 0.5 for nonfilaments with an angular size of \( \sim 3' \) and about 0.8 for filaments in the range of 6'–12'. Taking the beam filling factor into account, we find that there are no large differences between the values of \( W_{12CO} \) for nonfilaments and filaments, i.e., the H\(_2\) column densities do not vary significantly among nonfilaments and filaments.

Compared with the number distributions of angular size and \( W_{12CO} \) for nonfilaments and filaments, we find the angular size that shows the most significant differences between nonfilaments and filaments. The typical values of \( W_{12CO} \) for filaments are \( \sim 1.5 \) times as large as those in nonfilaments; if we take the beam filling factor of \( \sim 0.5 \) into account for nonfilaments and 0.8 for filaments, the \( W_{12CO} \) for nonfilaments are more close to those for filaments. Their fitted slopes for the power-law distributions in the large-value ranges are also close. While the typical angular sizes for filaments are at least twice as those for nonfilaments, as well as their values of \( \alpha_{L} \).

4.4. The Integrated Flux of \(^{12}\text{CO}(1–0) \) Emission

Figure 2 presents the number distributions of the flux of \(^{12}\text{CO}(1–0) \) line emission for nonfilaments and filaments, i.e., \( \text{flux} = \int T_{mb}(p, l, b, v) d v \text{d}l \text{d}b \). For the nonfilaments, their \(^{12}\text{CO}(1–0) \) emission fluxes distribute in a range of 1.0–2262 K km s\(^{-1}\) arcmin\(^2\) and concentrate on \( \sim 6.7–25.5 \) K km s\(^{-1}\) arcmin\(^2\), and the number distribution in the range of \( 10 \) K km s\(^{-1}\) arcmin\(^2\) is fitted to a power law with an index of 1.7 \( \pm 0.1 \) (\( \alpha_{W,non} \)). For the filaments, the values of the flux range from 5.6 to 3.9 \times 10^2 K km s\(^{-1}\) arcmin\(^2\) and mainly from 50.4 to 420 K km s\(^{-1}\) arcmin\(^2\); and the fitted power-law index for the number distribution in the range of \( > 10 \) K km s\(^{-1}\) arcmin\(^2\) is 0.8 \( \pm 0.1 \) (\( \alpha_{W,f} \)). The filaments tend to have more \(^{12}\text{CO}(1–0) \) line emission flux than nonfilaments.

Furthermore, we calculated the \(^{12}\text{CO}(1–0) \) emission flux for the total molecular clouds, all of the nonfilaments, and all of the filaments in our catalog, respectively. In the \(^{12}\text{CO}(1–0) \) flux emission for the whole 18,190 molecular clouds (3.7 \times 10^6 K km s\(^{-1}\) arcmin\(^2\)), \( \sim 90\% \) are from filaments (3.4 \times 10^6 K km s\(^{-1}\) arcmin\(^2\)), \( \sim 9\% \) are from nonfilaments (3.3 \times 10^6 K km s\(^{-1}\) arcmin\(^2\)), and the remaining \( \sim 1\% \) are from unresolved sources. Although nonfilaments are dominant in the number of discrete molecular clouds, filaments are the main contributor of the \(^{12}\text{CO} \) emission flux.

4.5. Velocity Span

Figure 2 presents the number distributions of the velocity spans (\( V_{span} \)) for nonfilaments and filaments. For nonfilaments, the values of \( V_{span} \) range from 0.67 to 22.4 km s\(^{-1}\) and concentrate on \( \sim 1.7–3.0 \) km s\(^{-1}\), and the number distribution in the range of \( V_{span} > 2 \) km s\(^{-1}\) is fitted to a power-law function with an exponent of 4.5 \( \pm 0.2 \) (\( \alpha_{V,non} \)). For the filaments, the \( V_{span} \) is distributed in a wide range of 1.0–43.4 km s\(^{-1}\), and the values for most sources are located in a range of 3.2–6.5 km s\(^{-1}\). The fitted power-law index for the number distribution in the range of \( V_{span} > 6 \) km s\(^{-1}\) is 3.1 \( \pm 0.2 \). Compared with nonfilaments, the filaments with larger angular sizes have wider velocity spans.

5. Discussion

5.1. Human Biases

Since the morphological classifications based on visual inspections are conducted independently by three authors, there may exist human biases. As mentioned in Section 3.2, the agreement rates of the morphological classifications by two individuals are about 60%–80%. The agreement level of the classified results of all three people is about 60%.
For unresolved sources and resolved clouds, we divide them by inspecting the CO emission area for clouds using the criterion of 5 pixels × 5 pixels. These unresolved morphologies with pixels less than 5 × 5 are clear and easy to confirm, which are less affected by human biases. However, the categories of nonfilaments and filaments are mainly determined by the estimation of the aspect ratios of filamentary segments. An elongated and narrow structure with its aspect ratio ≥4 is a filament, and the network connected by a set of multiple filamentary segments is also a filamentary cloud. For networks that usually present large spatial sizes, their hierarchical and filamentary structures are easy to experientially validate by eye.

The classification of the extended structures (nonfilaments in Figure A7) and a single filament (filaments in Figure A4) may be affected by the visual estimation of their aspect ratios. According to the distribution of the angular size of clouds in Figure 2, the nonfilaments with angular sizes larger than ~8′, which is the typical angular size for filaments, occupy ~2% of the total molecular clouds. Their morphologies may be more easily affected by human biases.

In addition, machine-learning techniques, which are more objective than visual inspections, have been widely used in the morphological classification for galaxies (Banerji et al. 2010; Cheng et al. 2020; Ghosh et al. 2020; Walmsley et al. 2020), the detection of interstellar shells, bubbles (Beaumont et al. 2014; Van Oort et al. 2019), and molecular outflows (Xu et al. 2020; Zhang et al. 2020). The agreement rates between galaxy classifications made by humans and machine-learning approaches are over 90% (Beck et al. 2018; Cheng et al. 2020, 2021; Walmsley et al. 2021). For the morphological classifications of compact star clusters and associations, the level of agreement is about 82% (Whitmore et al. 2021).

5.2. Observational Effect

5.2.1. Finite Angular Resolution

Due to the limited angular resolution of the $^{12}$CO line, the resolved morphologies of molecular clouds may be influenced by their distances. As mentioned in Section 4.2, the physical resolutions are different for molecular clouds with different distances.

In Figure 1, in the radial velocity range of (−95, 25) km s$^{-1}$, the 18,190 molecular clouds are grouped into two parts, corresponding to the near and far ranges, respectively. Molecular clouds in the near range are in the velocity range of (−30, 25) km s$^{-1}$, while clouds in the far range are in (−95, −30) km s$^{-1}$. In a total of 18,190 molecular clouds, there are 9544 clouds in the near range, including 1602 (16.8%) unresolved sources, 6747 (70.7%) nonfilaments, and 1195 (12.5%) filaments. While, for the 8646 clouds located in the far range, 2846 (32.9%) are unresolved sources, 4933 (57.1%) are nonfilaments, and 867 (10.0%) are filaments.

Figure 7 shows the morphological fractions of molecular clouds, i.e., the fractions of unresolved sources, nonfilaments, and filaments in the near and far ranges, respectively. The fraction of unresolved sources in the far range is nearly twice that in the near range. Due to the limited angular resolution, molecular clouds in the far range with larger distances usually have smaller angular sizes. There is about a ~3% difference in the filament fractions of molecular clouds in the near and far ranges, which is not very significant, as a result of that most of filaments have large spatial sizes.

It should be noted that the physical resolutions of our observed molecular clouds are still finite. The nonfilaments may present the filamentary and hierarchical structures under higher spatial resolutions.

5.2.2. Beam Dilution Effect

The beam smoothing on the observations of molecular clouds can diminish their brightness temperatures and flatten their structures. That may affect the observed morphologies of molecular clouds, particularly for the molecular clouds with small angular sizes. In this work, the resolved molecular clouds have observed angular areas larger than ~2.5′ × 2.5′, corresponding to a diameter of ~3 beam size. We estimate the actual angular size ($L_{\text{act}}$) of the molecular clouds as $\sqrt{L_{\text{obs}}^2 - \Theta^2}$, where the $L_{\text{obs}}$ is the observed angular size and $\Theta$ is the beam size. The value of $L_{\text{act}}$ is about 2/3 for the molecular clouds.
with an $L_{\text{obs}}$ of 2.5. Thus the effect of beam dilution on the angular sizes of the resolved clouds is less than $\sim$10%. These errors of the estimated aspect ratios of the structures, which are caused by the beam dilution effect, should be less than those caused by human bias.

In addition, as mentioned in Section 4.3, the observed values about the $W_{12\text{CO}}$ for filaments and nonfilaments have small differences. That also supports the notion that the beam dilution effect should not be severe for nonfilaments. This implies that there is only a small portion of nonfilaments that are actually slim filaments but are misclassified as nonfilaments due to their radial widths being broadened by beam convolution.

It should be noted that the finite angular resolution and sensitivity will limit the angular sizes of the observed structures. Maybe there are more tiny and hierarchical structures that are not detected and resolved by PIMO-13.7 m telescope. The follow-up observations with higher resolution can help us to reveal the structures of the unresolved sources. In this work, we mainly discuss the morphological classification of resolved clouds in our catalog.

### 5.2.3. Projectional Effect

The morphologies of molecular clouds are determined by their projected shapes along the line of sight, thus the morphologies of clouds may be influenced by the projection effect. For a filament, we assume the angle between its long axis and the line of sight is $\theta$, thus its aspect ratio ($A_\alpha$) becomes $A_\alpha \sin \theta$. That may cause a portion of filaments ($A_\alpha \gtrsim 4$) to present the morphologies of nonfilaments ($A_\alpha \lesssim 4$), while the line-of-sight projection changes the aspect ratios of molecular clouds, as well as their $H_2$ column densities ($N_{H_2}$). If the aspect ratios of filaments become $A_\alpha \sin \theta$, their $H_2$ column densities become $N_{H_2}/\sin \theta$ as well.

Figure 4 shows the number distributions of the averaged velocity-integrated $^{12}$CO line intensity, i.e., $W_{12\text{CO}} = \int f_{\text{lab}}(l, b, v) dldbdv/\int dldb$, and the angular areas for molecular clouds. Furthermore, we could estimate the $H_2$ column density ($N_{H_2}$) using $N_{H_2} = X_{CO}W_{12\text{CO}}$, where $X_{CO} = 2 \times 10^{20}$ cm$^{-2}$ (K km s$^{-1}$)$^{-1}$ is the CO-to-$H_2$ conversion factor (Bolatto et al. 2013). In the near range, the values of $W_{12\text{CO}}$ for nonfilaments mainly distribute in a range of 0.8-1.4 K km s$^{-1}$ ($N_{H_2} \sim 1.6 \times 10^{20}$-$2.8 \times 10^{20}$ cm$^{-2}$), and those values for filaments concentrate on a range of 1.2-2.6 K km s$^{-1}$ ($N_{H_2} \sim 2.4 \times 10^{20}$-$5.2 \times 10^{20}$ cm$^{-2}$). In the far region, the values of $W_{12\text{CO}}$ for nonfilaments are mainly located in (1.1, 2.0) K km s$^{-1}$ ($N_{H_2} \sim 2.2 \times 10^{20}$-$4.0 \times 10^{20}$ cm$^{-2}$) and the typical range of $W_{12\text{CO}}$ for filaments is from 1.7 to 3.8 K km s$^{-1}$ ($N_{H_2} \sim 3.4 \times 10^{20}$-$7.6 \times 10^{20}$ cm$^{-2}$).

Due to the projection effect, a portion of filaments may present nonfilaments. Meanwhile, their $H_2$ column densities could be $N_{H_2,\text{fil}}/\sin \theta$, where $N_{H_2,\text{fil}}$ is the $H_2$ column density of the unprojected filament. Filaments have $A_\alpha \gtrsim 4$. If $\sin \theta \lesssim 0.5$, the value of $A_\alpha \sin \theta$ tends to be smaller than 4, thus the filaments may be projected as nonfilaments. Meanwhile, the $H_2$ column densities for these projected nonfilaments may be larger than $N_{H_2,\text{fil}}/\sin \theta \sim 2N_{H_2,\text{fil}}$. Thus, the nonfilaments that have a larger $N_{H_2}$ than $2N_{H_2,\text{fil}}$ may be affected by the projection. As the $W_{12\text{CO}}$ for filaments mainly focuses on 1.5-3.5 K km s$^{-1}$, the nonfilaments with $W_{12\text{CO}}$ larger than $\sim$5 K km s$^{-1}$ tend to be projected by filaments. Thus the $\sim$1% of molecular clouds in our sample classified as nonfilaments are probably due to the line-of-sight projection of filaments. If we take the beam filling factor of 0.5 into account for nonfilaments, the fraction is up to $\sim$3%.

We note that the values of $W(^{12}\text{CO})$ for molecular clouds are distributed in a range of more than an order of magnitude intrinsically. Thus the values of $W_{12\text{CO}}$, even larger than $\sim$5 K km s$^{-1}$, may also be the original values of nonfilaments not due to the enhancement of the column density caused by the projection of filaments.

Next, we attempt to discuss the projection effect of molecular clouds geometrically. We assume that the actual 3D structure of a filament is a cylinder with a diameter of $D$ and a height of $H$, $D$ will correspond to the width of the filament, and $H$ is the length. Furthermore, we assume the variable of $D$ is normally distributed,

$$f(D|\mu, \sigma^2) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(D-\mu)^2}{2\sigma^2}},$$

(1)

where $\mu$ is the mean of the $D$ and $\sigma$ is its standard deviation. $L$ is sampled from a power-law distribution

$$p(L) = kL^{-\alpha},$$

(2)

with $a < L < b$. From the requirement that $\int_a^b p(L)dL = 1$, we have

$$k = \frac{1}{b^{1-\alpha} - a^{1-\alpha}}.$$  

(3)

For the special case $\alpha = 1$,

$$k = \frac{1}{\ln(b/a)}.$$  

(4)

For a filament with a diameter of $D$ and a height of $L$, its aspect ratio is $L/D$ and its area is $LD$. $\theta$ is the angle between the line of sight and the long axis of a filament. If the filament has an angle $\theta$ with the line-of-sight direction, when viewed from the radial direction, its projected aspect ratio will be approximately

$$\frac{L \sin \theta}{D},$$  

(5)

and the projected area will be approximately

$$DL \sin \theta.$$  

(6)

According to the distribution of the angular sizes of resolved molecular clouds in Figure 2, their angular sizes are approximately larger than 2.5, and the fitted power-law exponent is about 2.0. After visually inspecting the cataloged filaments, the largest length of a filament is about 120'. Thus we assume $\alpha = 2.0$, $a = 2.5$, and $b = 120$ in the power-law distribution of $L$. In the normal distribution of $D$, we assume $\mu = 2.5$, which is the minimal resolved scale, and $\sigma = 1$.

In Figure 8, we choose two subsamples based on their observed aspect ratios ($A_\alpha = L \sin \theta/D$), i.e., nonfilaments ($A_\alpha < 4$) and filaments ($A_\alpha \gtrsim 4$), and present the number distributions of their areas ($LD$) and projected areas ($LD \sin \theta$), respectively. We also estimated the number fractions of nonfilaments and filaments in the samples, as well as those values in the samples after the projection. We find that the number fraction of filaments is 29% in the samples, and changes about 6% after the projection. In addition, we fit the power-law slopes for the number distribution of areas of nonfilaments. The fitted exponents for nonfilaments change from $2.76 \pm 0.09$ to $3.56 \pm 0.29$ after the projection. That is due to the fact that nonfilaments with larger angular areas usually have aspect ratios

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close to 4, and thus their number distribution is easily changed by the line-of-sight projection of filaments.

In addition, we find that the distribution of sampled filaments in the range with areas larger than $10^2$ is different from that for our observed filaments. We should note that the assumptions of cylinders and their parameters are extremely simplified. A portion of the observed filamentary clouds, especially for those with larger areas, contain more than one filament segment. This sample just is a side of the reflection of the projection effect on the morphologies of molecular clouds.

5.3. Implications for Molecular Cloud Evolution in the Milky Way

It is interesting to explore the possible relation between filaments and nonfilaments. The systematic difference between them is the angular size, and their average H$_2$ column densities do not significantly vary among them. Previous studies suggest that the nonfilaments are formed by the fragmentation of filaments, which is caused by the gravitational instability (Larson 1985; Bonnell & Bastien 1992; Nakamura et al. 1993; Jackson et al. 2010; Clarke et al. 2017, 2020), or the agglomeration of nonfilaments build up filaments (Dobbs et al. 2008; Tasker & Tan 2009; Dobbs et al. 2011; Smith et al. 2016; Baba et al. 2017; Kobayashi et al. 2017). It is important to provide observational evidence to confirm these mechanisms systematically. Further observations and analysis, such as dense gas fractions in nonfilaments and filaments, may help us to further understand these questions. This visual classification also is a starting point for future attempts to improve automated morphological classification for a giant sample of molecular clouds from the whole MWISP CO project using machine-learning techniques.

Furthermore, our observational results can be compared with the results of numerical simulations on the evolution of molecular clouds in Milky Way-like galaxies, such as the formation and physical properties of larger-scale filaments (Burkert & Hartmann 2004; Zucker et al. 2019; Smith et al. 2020; Hoemann et al. 2021) and the time evolution of molecular clouds (Jeffreson et al. 2021).

6. Conclusions

We use an unbiased catalog of 18,190 molecular clouds, which is extracted from the $^{12}$CO(1–0) data of the MWISP survey in the Galactic plane over $104^\circ.75 < l < 150^\circ.25$, $-5^\circ.25 < b < 5^\circ.25$, and $-25$ km s$^{-1} < V_{LSR} < 95$ km s$^{-1}$, to classify the morphology of molecular clouds as unresolved sources, nonfilaments, and filaments. We further statistically analyze the parameters for nonfilaments and filaments. The main conclusions are as follows

1. The 18,190 molecular clouds are visually divided into unresolved and resolved ones, and the resolved ones are further classified as nonfilaments and filaments. In the 18,190 molecular clouds, ~25% are unresolved sources, ~64% are nonfilaments, and ~11% are filaments.
2. We calculate the flux of the $^{12}$CO(1–0) line emission of all of the 18,190 molecular clouds. Filaments contribute ~90% to the total flux of the whole sample, while nonfilaments contribute ~9%, and the remaining 1% is from unresolved sources.
3. We present the number distributions of parameters for the whole sample, including the angular size, velocity span, peak intensity, and the flux of the $^{12}$CO(1–0) line emission. Their distributions in the large-value ranges can be fitted by a power law. The fitted exponent for the power-law distribution of angular sizes is ~1 for filaments and 2 for nonfilaments. After comparing the physical parameters of filaments with those of nonfilaments, the major difference between filaments and nonfilaments lies in their spatial scales. The filaments tend to have larger spatial scales. The H$_2$ column density does not vary significantly among them.

Figure 8. Left panel: the number distribution of the area (LD) for the simulated clouds. Right panel: the number distribution of the projected area (LD sinθ) for the simulated clouds. The dashed black lines fit their power-law distributions, $dN/dX \propto X^{-\alpha_n}$, whose negative slopes are noted in each panel.
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Appendix

We separate the targeted region into three parts whose Galactic longitudes are in the range of $l = (104.75, 120)$, $(120, 135)$, and $(135, 150.25)$, respectively. Figures A1–A3 show their velocity-integrated intensity and latitude-integrated intensity maps, respectively.

![Figure A1](image_url)

**Figure A1.** Top panel: the velocity-integrated intensity map of the $^{12}$CO(1–0) emission in the region with $104°75 < l < 120°$ and $|b| < 5°25$. The integrated velocity ($V_{\text{LSR}}$) ranges from $-80$ to $20$ km s$^{-1}$. The coordinates of clumps (A–E) in Cepheus OB3 are from Yu et al. (1996). The H II region NGC 7538 that belongs to Cas OB2 is refereed in Fallscheer et al. (2013). The molecular clouds near Cassiopeia A and NGC 7538 are from Ungerechts et al. (2000). The Galactic young star cluster NGC 7380 is refereed in Chen et al. (2011). The H II region S155 and its neighboring molecular cloud NGC 7822 are refereed in Yang & Fukui (1992). Bottom panel: the latitude-integrated intensity map of the $^{12}$CO(1–0) emission in the region with $104°75 < l < 120°$ and $-80$ km s$^{-1} < V_{\text{LSR}} < 20$ km s$^{-1}$, and the integrated latitude $b$ ranges from $-5°25$ to $5°25$. 

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Figure A2. Top panel: the velocity-integrated intensity map of the $^{12}$CO(1–0) emission in the region with $120^\circ < l < 135^\circ$ and $|b| < 5^\circ.25$. The integrated velocity ($V_{\text{LSR}}$) range is ($-80, 20$) km s$^{-1}$. The molecular cloud M120.1+3.0 in Cepheus OB4 is from Yang et al. (1990). The molecular cloud L1287 is from Yang et al. (1991). The molecular cloud L1293 is refereed in Yang et al. (1990). The HII region S187 and its environment L1317 are from Joncas et al. (1992). The HII region S183 is refereed in Landecker et al. (1992). GMC W3 is refereed in Rivera-Ingraham et al. (2015). Bottom panel: the latitude-integrated intensity map of the $^{12}$CO (1-0) emission in the region with $120^\circ < l < 135^\circ$ and $-80$ km s$^{-1} < V_{\text{LSR}} < 20$ km s$^{-1}$, and the integrated latitude $b$ ranges from $-5^\circ.25$ to $5^\circ.25$.
Figure A3. Top panel: the velocity-integrated intensity map of the $^{12}$CO($1-0$) emission in the region with $135° < l < 150°25$ and $|b| < 5°25$. The integrated velocity ($V_{\text{LSR}}$) ranges from $-80$ to $20$ km s$^{-1}$. GMC W3, W4, and W5 are refereed in Rivera-Ingraham et al. (2015), Bieging & Peters (2011), and Ginsburg et al. (2011), respectively. Bottom panel: the latitude-integrated intensity map of the $^{12}$CO($1-0$) emission in the region with $135° < l < 150°25$ and $-80$ km s$^{-1} < V_{\text{LSR}} < 20$ km s$^{-1}$, and the integrated latitude $b$ ranges from $-5°25$ to $5°25$. 
Here we present the $^{12}\text{CO}(1-0)$ velocity-integrated intensity maps of molecular cloud samples classified as filaments in Figures A4 and A5 and nonfilaments in Figures A6 and A7.

**Figure A4.** Example images of filaments, which are randomly selected from molecular clouds presenting the elongated and narrow structures with $A_v \gtrsim 4$. 
Figure A5. Example images of filaments, which are randomly selected from molecular clouds built by a system of filaments.
Figure A6. Example images of nonfilaments, which are randomly selected from molecular clouds showing clumpy structures.
Figure A7. Example images of nonfilaments, which are randomly selected from molecular clouds exhibiting extended structures with $A_v \lesssim 4$. 
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