Herschel investigation of cores and filamentary structures in the Perseus molecular cloud

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Abstract Cores and filamentary structures are the prime birthplaces of stars, and play key roles in the process of star formation. Latest advances in the methods of multi-scale source and filament extraction, and in making high-resolution column density map from Herschel multi-wavelength observations enable us to detect the filamentary network structures in highly complex molecular cloud environments. The statistics for physical parameters shows that core mass strongly correlates with core dust temperature, and $M/L$ strongly correlates with $M/T$, which is in line with the prediction of the blackbody radiation, and can be used to trace evolutionary sequence from unbound starless cores to robust prestellar cores. Crest column densities of the filamentary structures are clearly related with mass per unit length ($M_{\text{line}}$), but are uncorrelated by three orders ranging from $\sim 10^{20}$ to $\sim 10^{22}$ cm$^{-2}$ with widths. Full width at half maximum (FWHM) have a median value of 0.15 pc, which is consistent with the 0.1 pc typical inner width of the filamentary structures reported by previous research. We find $\sim 70\%$ of robust prestellar cores (135/199) embedded in supercritical filaments with $M_{\text{line}} > 16 M_\odot$/pc, which implies that the gravitationally bound cores come from fragmentation of supercritical filaments. And on the basis of observational evidences that probability distribution function (PDF) with power-law distribution in the Perseus south is flatter than north, YSO number is significantly less than that in the north, and dust temperature difference. We infer that south region is more gravitationally bound than north region.

Key words: ISM: individual objects: Perseus complex – stars: formation – ISM: clouds – ISM: structure

1 INTRODUCTION

Molecular clouds (MCs) are dense regions of the cold interstellar medium (ISM), mainly composed of gas and dust, which are the cradles of stars (e.g. Bergin & Tafalla 2007; Andrè et al. 2014; Zhang et al. 2018). Molecular clouds are hierarchical in structure (Men'shchikov et al. 2010; Pokhrel et al. 2018; Men'shchikov 2021b). The substructure of MCs is a complex pattern consisting of filaments, cores, large scale background, local fluctuation, etc. The detection for core and filamentary structure and statistics for their physical parameters help us understand the initial condition for star formation.

Herschel’s far-infrared (FIR) observations of thermal radiation from dust provide an unprecedented opportunity to study the substructure of molecular clouds and thereby demystify star formation (e.g. Kényves et al. 2015; Arzoumanian et al. 2019; Zhang et al. 2020). Space telescopes avoid
the absorption, distortion and contamination of light by Earth’s atmosphere. The detected cores with \textit{Herschel} can be an order of magnitude more in number than ground-based telescopes (e.g. Könyves et al. [2015], Zhang et al. [2015]). Observations with \textit{Herschel} show that filamentary structures are found in supercritical filamentary structures (Linear density $M_{line} > 16 M_{\odot} \text{pc}^{-1}$) (Könyves et al. [2015]) and the typical inner width of the filamentary structure is 0.1 pc which is independent of the column density (Arzoumanian et al. [2011], [2019]). In supercritical filaments observations have revealed quasi-periodic chains of dense cores with spacing of 0.15 parsec comparable to the filament inner width by Zhang et al. (2020). This implies dense filaments will fragment into gravitationally bound cores, most of which can evolve into stars. The detailed fragmentation manner of the filaments may be controlled by $M_{line}$, geometrical bending, continuous accretion of gas, and magnetic fields (e.g. Zhang et al. [2020]).

The distance of Perseus MC is $\sim 294 \text{ pc}$ (Zucker et al. [2019]). The overall structure can be divided into north and south parts (See Figure 1). The Perseus MC contain several star-forming dust condensations such as B1, B5, IC348, NGC1333, L1455 and L1448 (Zari et al. [2016]). About 300 young stellar objects (YSOs) have been identified in Perseus MC (Mercimek et al. [2017]). Different from convolving all maps to \textit{Herschel}’s lowest low resolution of $36.3''$ and then fitting spectral energy distribution (SED) to get a column density map to study Perseus MC, or single-dish low-resolution molecular line mapping (e.g. Ridge et al. [2006], Sadavoy et al. [2014]), that resolution is not high enough to get the full sample of cores and filaments, we adopted high-resolution column density images that derived using an improved difference term algorithm that uses all unresolved or slightly resolved structures for enhanced contrast (Men’shchikov [2021b]). And latest advances in the methods of multi-scale source and filament extraction: \textit{getsf} (Men’shchikov [2021b]), enable us to detect the sources and filamentary network structures in highly complex MC environments and perform statistical analysis on physical parameters such as, source luminosity, mass, size, and filament width, linear density, curvature etc, as well as exploring the correlation of various parameters.

The outline of the present paper is as follows. In Sect. 2 we describe the \textit{Herschel} submillimeter dust emission data FCRAO 14m molecular line observations of the Perseus MC and give a brief overview for \textit{getsf}. Results are presented in Sect. 3. In Sect. 4 we discuss different evolution stages of the north and south of the Perseus MC, core evolution, as well as characteristic physical parameters of filamentary structure. We summarize our conclusions in Sect. 5.

2 DATA REDUCTION AND OBSERVATIONS

2.1 \textit{Herschel} Archive data

The \textit{Herschel} imaging observations of the Perseus molecular cloud include PACS 70 $\mu$m and 160 $\mu$m (Poglitsch et al. [2010]) and SPIRE 250, 350, and 500 $\mu$m (Griffin et al. [2010]). The beam sizes of the PACS data at 70 and 160 $\mu$m are 8.4 and 13.5", respectively. The beam sizes of the SPIRE data at 250, 350, and 500 $\mu$m are 18.2, 24.9, and 36.3", respectively. The SPIRE PACS Parallel Mode with a scanning speed of $0.9''$/s is adopted to simultaneously observe this large area of sky in orthogonal mapping directions for the above five bands. We downloaded \textit{Herschel} maps from ESA \textit{Herschel} Science Archive \footnote{http://archives.esac.esa.int/hsa/whsa/}. The observed identifiers are 1342190326, 1342190327, 1342214504, 1342214505, 1342214506. Different from \textit{Herschel}’s high-resolution observations, \textit{Planck} and \textit{IRAS} sacrifice resolution for all-sky observations. \textit{Planck} and \textit{IRAS} data are set as a reference benchmark, then use the blackbody radiation model to derive the various bands of \textit{Herschel}, and compare with the \textit{Herschel} data to obtain the Zero-level offsets. They are 40, 242.9, 96.8, 36.7 and 10.6 MJy/sr at \textit{Herschel} 160, 250, 350, and 500 $\mu$m, respectively in the south region, and -3.2, 37.5, -0.6, -0.9 and -0.1 in the north region. Pixel-by-pixel SED fitting to the \textit{Herschel} 160–500 $\mu$m data with a modified blackbody function was used to create a high-resolution (13.5") $H_2$ column density map with the method described in the \textit{getsf} paper (Men’shchikov [2021b]). Our column density map has a resolution that is triple as high as the...
Fig. 1: Red-Green-Blue (RGB) composites image showing the 250 µm (blue), 350 µm (green), and 500 µm (red) SPIRE fluxes for the Perseus molecular cloud derived from Herschel and Planck observations. In areas outside the Herschel coverage, dust models were applied to predict the corresponding SPIRE fluxes using Planck/IRAS data. Planck data have a lower resolution than Herschel’s, allowing us to identify their spatial boundaries.

36.3\arcsec-resolution map commonly used in previous studies, and can help us see more details of the MC structure. There is a comparison in Fig 2.

2.2 Sources and filamentary structure detection algorithm: getsf

We use getsf to extract sources and filaments by separating their structural components in multi-wavelength astronomical images (Men'shchikov 2021b). The algorithm has been validated using a set of benchmark images (Men’shchikov 2021a). Here is a brief introduction of the data processing steps of getsf: (1), we need to cut the multi-band dust continuum images observed by Herschel into images with same pixel size, number of pixels and coordinate system, with getsf’s built-in script: prepobs. (2), then we fit the SED pixel by pixel with getsf’s built-in script: hires, to obtain a set of column density maps and temperature maps with resolution at Herschel each observed band. (3), next, getsf uses spatial separation techniques to separate the source and filamentary structures from each other and remove their large-scale background. There are also local fluctuations and residual noise in the source and filamentary structure images, getsf will use the flattening technique to remove them. After the above process of background removal and flattening, source and filamentary structures have been cleaned on the single scale images. (4), next, getsf will combine single scales together at each wavelength observed by Herschel. (5), then getsf will detect location of the sources and the skeleton of the filamentary structures in the combined images. (6), Finally, getsf will measure properties and create catalog of detected sources and filamentary structures with its built-in script: smeasure and fmeasure. getsf is a almost fully automatic algorithm, and the parameters in the configuration file are the optimal choices after ex-
Fig. 2: 13.5″ and 36.3″ resolution comparison. The top panel is a column density map with a resolution of 36.3″. The bottom panel is a high-resolution column density image (13.5″) which is derived using an improved difference term algorithm. This algorithm uses all unresolved or slightly resolved structures for enhanced contrast.

3 RESULTS

3.1 Physical environment of Perseus

A high-resolution column density map (13.5″) can be derived, using hires in getsf. This map is helpful for better detection and deblending of dense structures. The zero offset level of the north and south regions is very different. Therefore the column density distribution maps of the north and south regions are made respectively. The total mass is \( \sim 1.2 \times 10^4 \, M_\odot \) obtained by adding up the value of each pixel in the column density map and then multiplying by the mass and weight of the hydrogen molecule. The masses in north and south regions are \( \sim 5 \times 10^3 \, M_\odot \) and \( \sim 7 \times 10^3 \, M_\odot \) respectively.

The PDF can be computed as the histograms of the column density and can be used to characterize physical properties the structure of molecular clouds. The PDF of a variable is a one-point statistics that the relative fraction of the mass in a given range (Vázquez-Semadeni & García 2001). The PDF at 13.5″ resolution of the column density map in Perseus north and south region is shown in Figure 3. The Herschel column density converted to visual extinction units with assumption of \( N_{H_2} \text{(cm}^{-2}) = 0.94 \times 10^{21} \, A_v \text{(mag)} \) (Bohlin et al. 1978). The PDF can be well fitted with parabola and the peak value at \( \sim 1 \text{ mag} \). But high density region >2 mag, Perseus north can be well fitted with a power-law with a
Fig. 3: Probability distribution function (PDF) at 13.5“ resolution of the column density map in Perseus north and south region. The lower axis of the horizontal axis is the column density ($N_{\text{H}_2}$), the upper axis of the horizontal axis is the corresponding extinction $A_V$ (mag).

### Table 1

| Linear density | Unbound starless | Candidate prestellar | Robust prestellar | Protostellar |
|----------------|------------------|----------------------|-------------------|--------------|
| $M_{\text{line}}>16$ | 57 (10.6%) | 26 (29.9%) | 135 (67.8%) | 66 (50.8%) |
| $8<M_{\text{line}}<16$ | 62 (11.6%) | 19 (21.9%) | 36 (18.1%) | 10 (7.7%) |
| $M_{\text{line}}<8$ | 172 (32.1%) | 28 (32.2%) | 19 (9.5%) | 6 (4.6%) |
| Not in filament | 245 (45.7%) | 14 (16.1%) | 9 (4.5%) | 48 (37.0%) |

The cores are classified according to the method described by (Könyves et al. 2015). We briefly outline this method here. The integrated flux measured at each wavelength by getsf were used to fit a SED with a modified blackbody function, to obtain physical parameters such as mass, temperature, and bolometric luminosity of each core. Prestellar cores are gravitationally bound starless cores most likely to form stars (Ward-Thompson et al. 2007; André et al. 2014). Self-gravitational isothermal equilibrium Bonnor-Ebert (BE) sphere is bounded by surrounding gas, similar to the physical state of the prestellar core. The critical BE mass can be expressed as (Bonnor 1956) $M_{\text{crit}}^\text{BE} \approx 2.4 R_{\text{BE}}^2 c^2 / G$, where $R_{\text{BE}}$ is the BE radius, and $G$ is the gravitational constant. Assuming a ambient cloud temperature of 10 K, the
isothermal sound speed $c_s$ is $\sim 0.2$ km/s. We use this model to select prestellar cores. The core size is defined as the mean deconvolved FWHM diameter at the resolution of $18.2''$ of an equivalent elliptical Gaussian source: $R_{\text{dec}} = \sqrt{\text{AFWHM} \times \text{BFWHM} - \theta_{18.2''}^2}$, where $\theta_{18.2''}$ is the angular resolution at Herschel 250 µm band. Assuming an ambient cloud temperature of 10 K, the isothermal sound speed $c_s$ is $\sim 0.2$ km s$^{-1}$. If the ratio $\alpha_{\text{BE}} = M_{\text{crit}}^{\text{BE}}/M_{\text{core}} \leq 2$, we deem this starless core is self-gravitating and classified as a robust prestellar core. Kőnyves et al. (2015) propose an empirical size-dependent ratio $\alpha_{\text{BE, emp}} \leq 5 \times (\sqrt{\text{AFWHM} \times \text{BFWHM} / \theta_{18.2''}^2})^{0.5}$ is also considered to select candidate prestellar cores. And cores with at least one protostar in the half-power column density profile are considered to be protostellar cores.

3.1.2 Statistics of core physical parameters

We obtained physical parameters, which include temperature, bolometric luminosity and mass by using SED fitting for each core. Statistical and fitting result of all the cores show in Figure 5 and Figure 6. Figure 5 shows histogram of core temperature, mass, bolometric luminosity and radius. We obtained 12.48 K for median value of temperature, 0.16 $M_\odot$ for mass, 0.06 $L_\odot$ for bolometric luminosity and 40.28 arcsec for radius.

Figure 6 shows the correlation of each parameter, and blue, black, green and purple markers represent for robust prestellar cores, candidate prestellar cores, unbound starless cores and proto cores, respectively. Figure 6(a) and (d), show the definitely linear correlation ($R^2_2 = 74.9\%$, $R^2_3 = 79.4\%$) of temperature and mass or ratio of mass to temperature and ratio of mass to luminosity. However, Figure 6(b) and (c) show both temperature and mass are independent of bolometric luminosity.

3.2 Filamentary Structure Sample

3.2.1 Filamentary Structure Selection

We use the built-in script getsf: fmeasure to measure the filamentary structure along its skeleton on the background-subtracted 13.5'' resolution column density image of the filament components. Filamentary structures are three-dimensional structures in space, but what Herschel observed are their two-dimensional projections. Filamentary structures are twist in shape. They blend with themselves and with the surrounding structures. The column density contrast (C) of the filamentary structure is defined as $C = N_{\text{H}_2}^{\text{rest}}/N_{\text{H}_2}^{\text{bg}}$, where $N_{\text{H}_2}^{\text{rest}}$ is the filament crest column density and $N_{\text{H}_2}^{\text{bg}}$ is the filament crest background. To choose a clear structure we first select structures with $C > 0.5$ from the skeleton network. This resulted in a sample with 500 segments in the Perseus north region and 596 segments in the Perseus south region.

The beginning and end of filamentary structures are not easily objectively determined. And they have substructures, it is not easy to determine which are substructures and which are the main structures. So as to simplify this complex problem, the strategy adopted in getsf by splitting the skeleton network into single segments. Although, to some extent, the length of the filamentary structures is not objective, However, the longer the segment is, the more likely it is to be a filamentary structure, which is beyond doubt. In order to further improve the reliability of the sample, we select structures with segment length: $L > 0.2$ pc from the above sample of $C > 0.5$. This resulted in a sample with 162 segments in the Perseus north region and 229 segments in the Perseus south region.

3.2.2 Statistics of physical parameters of selected filamentary structures

fmeasure uses two methods to obtain the linear density ($M_{\text{line}}$) of the filamentary structures. One of the method is that fmeasure derives the mass ($M_{\text{fil}}$) of a filamentary structure by directly integrating its footprint and then get $M_{\text{line}} = M_{\text{fil}}/L_{\text{fil}}$, where $L_{\text{fil}}$ is filament length and filament footprint is defined as the area between the skeleton and the largest extent on each side. Another way is that density integration can be performed at any sampling point along the crest, and this integral is $M_{\text{line}}$ of
Fig. 4: Positions of the 952 dense cores identified in the Perseus overlaid on the Herschel high resolution 13.5'' column density map. Black, brown, red, and yellow circles mark the 536 unbound starless cores, the 130 protostellar cores, the 87 candidate prestellar cores, the 199 robust prestellar cores, respectively. The size of the circle is the geometric mean of the core’s FWHM.

this sampling point. We can use $M_{\text{line}}$ median value of all sampling points as $M_{\text{line}}$ of this filamentary structure.

We drew all the filamentary network structure selected with contrast $C > 0.5$ in Figure 7 and the color of the filaments represent the intensity of linear density. The filament of whiter the color means higher linear density. In Figure 8 we counted the parameters of the filaments in the north and south regions respectively, and made histograms, in which the blue bars represent all the filaments and orange bars represent high reliable filaments. Figure 8(a) (c) (e) show the length, width and linear density of filaments in north region, then (b) (d) (f) show the parameters in south region. From the median value, the length of filaments in the south region is greater than that of the north region and the width of the filaments contrast between the north and south region is just the opposite. Although the linear density of filaments in the south is slightly lower than that in the north, it is obvious that the supercritical ($M_{\text{line}} > 16 M_\odot/\text{pc}$) filaments are more distributed in the south region. Figure 9 shows the correlation of the filaments between column and linear density or column density and width. Figure 9(a) (b) suggest clear correlation ($R^2_a = 92.5\%, R^2_b = 95.9\%$) of column density and linear density whether in the South or the north region. However (c) (d) show that column density are uncorrelated with width, and most (80%) width of filaments are distributed in gray areas. The blue dotted lines represent the median value, with 0.17 pc and 0.12 pc on the north and south region.
4 DISCUSSION

4.1 The evolution stages of the north and south are different.

The thickness of the molecular cloud traced by different probes is different in the direction of sight. This results in different density distributions detected by different probes of molecular cloud. But in general, there is a the rapidly decreasing trend of PDF at the high density range. This can deduced that the dense structures occupy only a small fraction of the volume of the molecular clouds and most of the volume is filled with low density background gas.

For isothermal, supersonic, turbulent gases, shock produces a random density enhancement proportional to the mean density. According to the central limit theorem, the PDF is a lognormal function (Vazquez-Semadeni 1994). PDF should be made only for those contours that are closed in the map. In numerical simulation, cloud boundaries are generally equivalent to non-closed density contours in numerical boxes. The range of these column densities is underestimated, resulting in spurious drops in the PDF. The PDF of the molecular cloud does not necessarily decrease at low densities, and inferring the physical properties of the molecular cloud by fitting the low-density region of the PDF may be wrong. Therefore, great care should be taken when extrapolating the PDF shape of the cloud in the numerical simulation to the real observation data (Alves et al. 2017). The background component of the molecular cloud that exhibits a log-normal function is uncorrelated with specific star formation activity, however...
spectrally, and the effective radii are 2.8 pc and 3.2 pc. The north.

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south region is flatter than Perseus north region and closer to power law exponent of -1.35 for stellar

PDF dense component exhibits a power-law distribution that is closely related to star formation

(Kainulainen et al. 2009). Numerical simulations predict that turbulence dominates the lognormal dis-

Fig. 6: Correlations among core physical parameters derived by SED fitting. Panel (a): A clear correla-

(c): Core luminosity has no significant correlation with dust temperature and mass. Panel (d): A clear

correlation between \( M/L \) and \( M/T \), \( \log_{10}(M/L) = 0.66 \log_{10}(M/T) + 1.67 \).

The PDF dense component exhibits a power-law distribution that is closely related to star formation

(Kainulainen et al. 2009). Numerical simulations predict that turbulence dominates the lognormal distri-

bution, while gravity leads to a power-law form (Kritsuk et al. 2011). The Perseus south region shows a

power law with an exponent of -1.8. The Perseus north region has an exponent of -2.55. The Perseus

south region is flatter than Perseus north region and closer to power law exponent of -1.35 for stellar

initial mass function (IMF) proposed by Salpeter (1955).

The gravitational potential energy is \( \Omega = -\alpha \frac{GM^2}{R} \), where \( \alpha \) is fudge factor of order unity that

depends on the internal density structure. \( M \) is the observed structure mass, and \( R \) is the effective radius.

The 3\( \sigma \) noise level is \( \sim 2 \times 10^{21} \text{ cm}^{-2} \), which was estimated at regions without sources. The masses of gas component with \( N_{\text{H}_2} > 3\sigma \) are \( \sim 1.8 \times 10^3 M_{\odot} \) and \( \sim 3.3 \times 10^3 M_{\odot} \) at north and south region respectively, and the effective radii are 2.8 pc and 3.2 pc. The \( \Omega \) at north region is \( 1.2 \times 10^6 \alpha G M_{\odot}^2 \text{ pc}^{-1} \), and the \( \Omega \) at south region is \( 3.4 \times 10^7 \alpha G M_{\odot}^2 \text{ pc}^{-1} \). Assuming that south and north region have the same \( \alpha \) value, the gravitational force of Perseus in south region is about three times stronger that in the north.

Perseus MC is a medium active star forming region. (Mercimek et al. 2017) identified 222 YSOs in

Perseus MC. Number of YSOs per unit area that is similar to NGC 2264, but higher than Orion B and

closer than Ophiuchus (Pokhrel et al. 2020). The number of YSOs (153) in south region is significantly
more than that in the north region (69). Most of the YSOs in the south region are class II/III, and the evolution stage is obviously later than that in the north region.

Because the gas and dust will block the photon radiation, the denser region of gas and dust in the molecular cloud will show lower temperature. We checked the temperature map officially released by Planck and found that there is a clear temperature difference between the north and south regions. The dust temperature of large-scale background gas of the north region is at 18 K. Dense gas components \((N_{\text{H}_2} > 3\sigma)\) are closely related to star formation. IC 348 Reflection Nebula reaches 20-24 K, which covers 70% of the area of dense gas component in the north region. The dust temperature of large-scale background gas of the south region is at 17 K. Dust temperature of dense gas component is about 14-15 K in the south region. Dust temperature as an indicator to characterize the difference between the two regions, which have a temperature difference of about 5 K in two regions for these dense gas components. To conclude, differences in PDF power law exponent of the PDF, gravity, number of YSOs, and dust temperature indicate that the evolution stages of the north and south regions of Perseus MC are different.

4.2 Core evolution

Core dust temperatures strongly correlated with masses and \(M/L\) strongly correlated with \(M/T\). Our results are similar to those of previous studies. Such as [Marsh et al. (2014)] and [Marsh et al. (2016)] show that central temperature linearly negatively correlated with masses of starless and prestellar cores in Taurus, and confirmed a more stronger correlation with peak column density. An intuitive explanation is that as the strength of the shielding core from interstellar radiation field increases, the temperature will decrease and the mass will increase, in theory, which may be explained by blackbody radiation.
Assuming dust radiation is optically thin at a certain frequency the measured fluxes can be written as:

\[ f_\nu = B_\nu(T) \kappa_0 (\nu/\nu_0)^\beta \eta MD^{-2}. \]  

(1)

For a core at a distance \( D \) and measured flux \( f_\nu \) at a certain frequency \( \nu \), the luminosity at this \( \nu \) is

\[ L_\nu = 4\pi D^2 f_\nu \]  

(2)

Bolometric Luminosity \( L_{\text{bol}} \) is the luminosity of a core measured over all frequency, which is derived by:

\[ L_{\text{bol}} = 4\pi D^2 \int f_\nu d\nu \]  

(3)

Then

\[ M/L_{\text{bol}} \sim \frac{M}{D^2 \int f_\nu d\nu} \]  

(4)

And

\[ \int f_\nu d\nu \sim \nu_{\text{peak}} \times \text{SED}_{\text{peak}} \]  

(5)

Then according to Wien’s law: \( \nu_{\text{peak}} \sim T \), we can deduce that \( M/L_{\text{bol}} \sim M/T \)

### 4.3 Physical properties of ubiquitous filamentary structures

*Herschel* observations show that filamentary structure are indeed ubiquitous in the molecular cloud (e.g. Hill et al. 2011; Men'shchikov et al. 2010) In the nearby clouds (< 500 pc), filamentary structures measured on *Herschel* column density map in the radial direction, show a typical inner width ∼ 0.1 pc and no wider than ∼0.2 pc (Arzoumanian et al. 2011, 2019). The origin of the typical inner width of filamentary structures remains a controversial topic. There are currently three explanations for typical inner width. The gravitational and thermal pressure equilibrium of the isothermal gas results in this typical inner width of 0.1 pc with a weak dependence on column density. Typical inner width is just a result of the mechanical equilibrium in thermodynamics in radial direction (Fischera & Martin 2012).

An alternative explanation is that the filaments originate from plane-intersecting shock waves due to supersonic interstellar turbulence, and that the filament width corresponds to the (magneto-)sonic scale (Pudritz & Kevlahan 2013). Finally, another possible explanation is that the typical inner width of the filament may be set by a dissipation mechanism Magnetohydrodynamic (MHD) waves induced by ion-neutral friction (Hennebelle 2013). The width measured with selected filamentary structure with \( L > 0.2 \) pc and \( C > 0.5 \), has higher confidence than the entire filamentary network. This sample includes 162 segments in the Perseus north region and 229 segments in the south region. The width median value in north region is 0.17 pc and 0.12 pc in south region. Large-scale diffuse gas is more abundant in the north than in the south. The blending in the north is more severe, that the measured width is wider than the south. The measurement of width is consistent with the typical inner width of the filamentary structure is 0.1 pc measured by (Arzoumanian et al. 2011, 2019).

Supercritical filamentary structures play an important role in star formation. Stars are formed in molecular filaments with linear masses equal to or greater than the critical linear mass (e.g. Andrè et al. 2014). The critical linear mass of an isothermal cylindrical filamentary structure depends on temperature and mean molecular weight. Mean molecular weight is in turn depends on the metallicity, which in turn can have a dependence on the location in the Galaxy. If we adopt 10 K of ambient cloud temperature and 2.8 of mean molecular weight, the critical line mass should be 16 \( M_\odot/\text{pc} \). We find ∼70% of robust prestellar cores (135/199) embedded in supercritical filaments which implies that the gravitationally bound cores come from fragmentation of supercritical filaments.
5 CONCLUSIONS

With the latest improved difference term algorithm: hires, we made a high-resolution (13.5") column density map for Perseus MC with Herschel multi-wavelength dust continuum maps, and detected the source and filamentary structure using a new spatial decomposition method: <getsf>, and performed statistics on measured physical parameters so as to better understand the initial conditions of the star formation in the molecular cloud. Our findings can be summarized as follows:

- We find power-law distribution in PDF of the Perseus south region is flatter than north region, and the average temperature of dense gas component with \( N_{\text{H}_2} > 3\sigma \) in south region is about 5 K lower than the north region, and the number of YSOs in the south is significantly less than that in the north. Those observational evidences implies that south region is more gravitationally bound than north region, and suggests that evolution stages are different in two regions.
- We selected 952 reliable cores from original source catalog detected by <getsf>, and divided them into four groups: 536 unbound starless cores, 87 candidate prestellar cores and 199 robust prestellar cores, 130 protostellar cores. We find \( M \) strongly correlate with \( T \) and \( M/L \) strongly correlate with \( M/T \), which is in line with the prediction of the blackbody radiation. These two correlations shows a clear evolutionary sequence from unbound starless cores to robust prestellar cores.
- We find crest \( N_{\text{H}_2} \) of the filamentary structures are clearly related with \( M_{\text{line}} \), and are uncorrelated with \( W \) by three orders of magnitude from \( \sim 10^{20} \) to \( \sim 10^{22} \) cm\(^{-2}\). We find \( \sim 70\% \) of robust prestellar cores (135/199) embedded in supercritical filaments with \( M_{\text{line}} > 16 \, M_\odot/\text{pc} \), which implies that the gravitationally bound cores come from fragmentation of supercritical filaments.

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Fig. 8: Histogram of physical parameters of the filamentary structures. In this set of histograms, the sample "all" are the filamentary structures with $C > 0.5$; the sample "selected" are the filamentary structures with $C > 0.5$ and $L > 0.2$ pc. And we conduct separate statistics for filamentary structure in the north and south regions.
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Fig. 9: Crest column density ($N_{\text{H}_2}$) of filamentary structures as a function of linear density ($M_{\text{line}}$) and width ($W$) in the north and south regions of Perseus molecular cloud. $N_{\text{H}_2}$ and $M_{\text{line}}$ are clearly related. $N_{\text{H}_2}$ are uncorrelated with $W$ by three orders of magnitude from $\sim 10^{20}$ to $\sim 10^{22}$ cm$^{-2}$. 