# 3D Morphology and Motions of the Canis Major Region from Gaia DR3

Yiwei Dong,[1,2] Ye Xu,[1,2] Chaojie Hao,[1] Yingjie Li,[1] Dejian Liu,[1,2] Yan Sun,[1] and Zehao Lin[1]

[1]*Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210023, People's Republic of China*
[2]*School of Astronomy and Space Science, University of Science and Technology of China, Hefei 230026, People's Republic of China*

Reporter：Zeng Guangya

# outline

- 1. Introduction
- 2. Data
- 3. Results
- 4. Discussion
- 5. Conclusions

# Introduction

- Young stellar objects (YSOs) are newborn stars that typically remain closely associated with their natal molecular clouds (MCs). Recently, it has become a new research trend to combine YSOs to unveil the three-dimensional (3D) morphology and kinematics of MCs, thus helping to decipher the local star formation history.
- The study focuse on the Canis Major (CMa) starforming region, situated at the Galactic longitude of ~$225^{\circ}$, Galactic latitude of ~$-1.5^{\circ}$, and a distance of ~1 kpc from the Sun. Notably, there are scarcely any overlapping foreground or background star-forming regions towards the CMa, making it a highly desirable target for the detailed studies of 3D morphology and motions.
- The study integrate the high-precision astrometric data of YSOs from Gaia DR3 with high-quality molecular gas data from the MWISP project, investigate their three-dimensional structure and motion based on the close spatial and kinematic connection between YSOs and molecular clouds (MCs) in the CMa region.

# Data

# Molecular Clouds & YSOs Sample

- The study utilize the $^{12}CO$, $^{13}CO$, and $C^{18}O$ (1–0) data from the MWISP project, observed with the Purple Mountain Observatory (PMO) 13.7 m millimeter-wave telescope.

- Given that an extensive search for young stellar objects (YSOs) in the CMa region has been conducted using advanced infrared data, The study compile the published catalogs of YSOs and YSO candidates. A total of 1,895 YSOs records from 9 references have been included.
- The study cross-match the YSOs sample with Gaia DR3 in the Gaia database1 to obtain high-precision astrometric measurements for YSOs. The result was a total of 1,241 cross-match entries. The sample was then cleaned and selected, removing low-quality sources, objects with unclear classifications, and those that significantly deviated in distance, space (l, b), and proper motion. Ultimately, 298 YSOs were obtained.

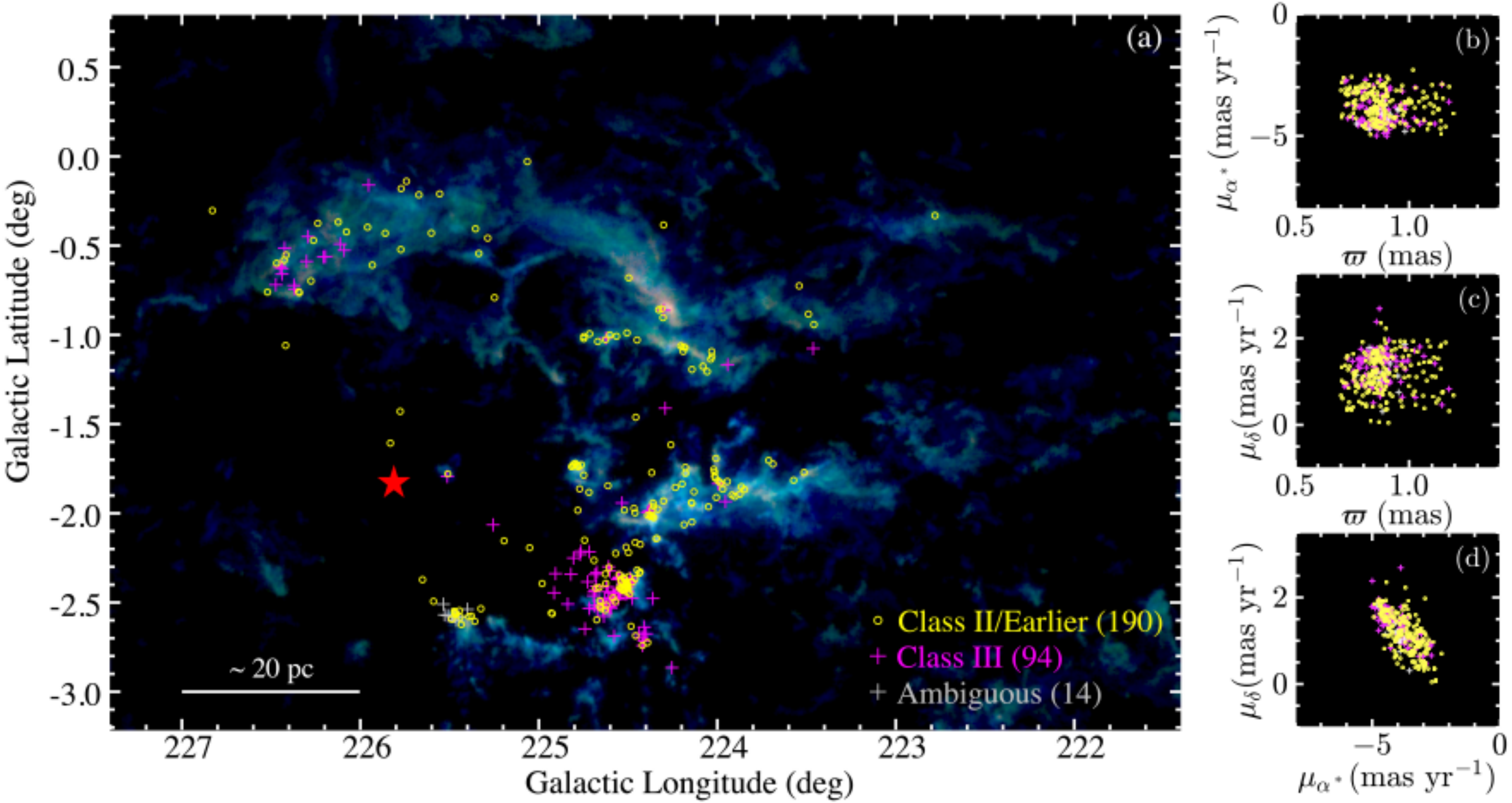



**Figure 1.** Distributions of YSOs satisfying all the selection criteria. (a): the $l$–$b$ distribution of YSOs overlaid on the $^{12}$CO (blue), $^{13}$CO (green), and C$^{18}$O (red) intensity maps of the three MCs. The yellow circles, magenta crosses, and gray crosses indicate YSOs in the Class II or earlier classes, Class III, and ambiguous evolutionary stages, respectively. The numbers of sources are also annotated. The red star represents the center of the CMa shell proposed by Fernandes et al. (2019). (b)–(d): the $\varpi$–$\mu_{\alpha*}$, $\varpi$–$\mu_\delta$, and $\mu_{\alpha*}$–$\mu_\delta$ distributions of YSOs.

# Results

# Division of Subregions

- The above studies provide compelling evidence that MCs in the CMa region consist of multiple components in the position-position-velocity (PPV) space, and different components may feature distinct dynamical states, and display varying levels of star formation activity.

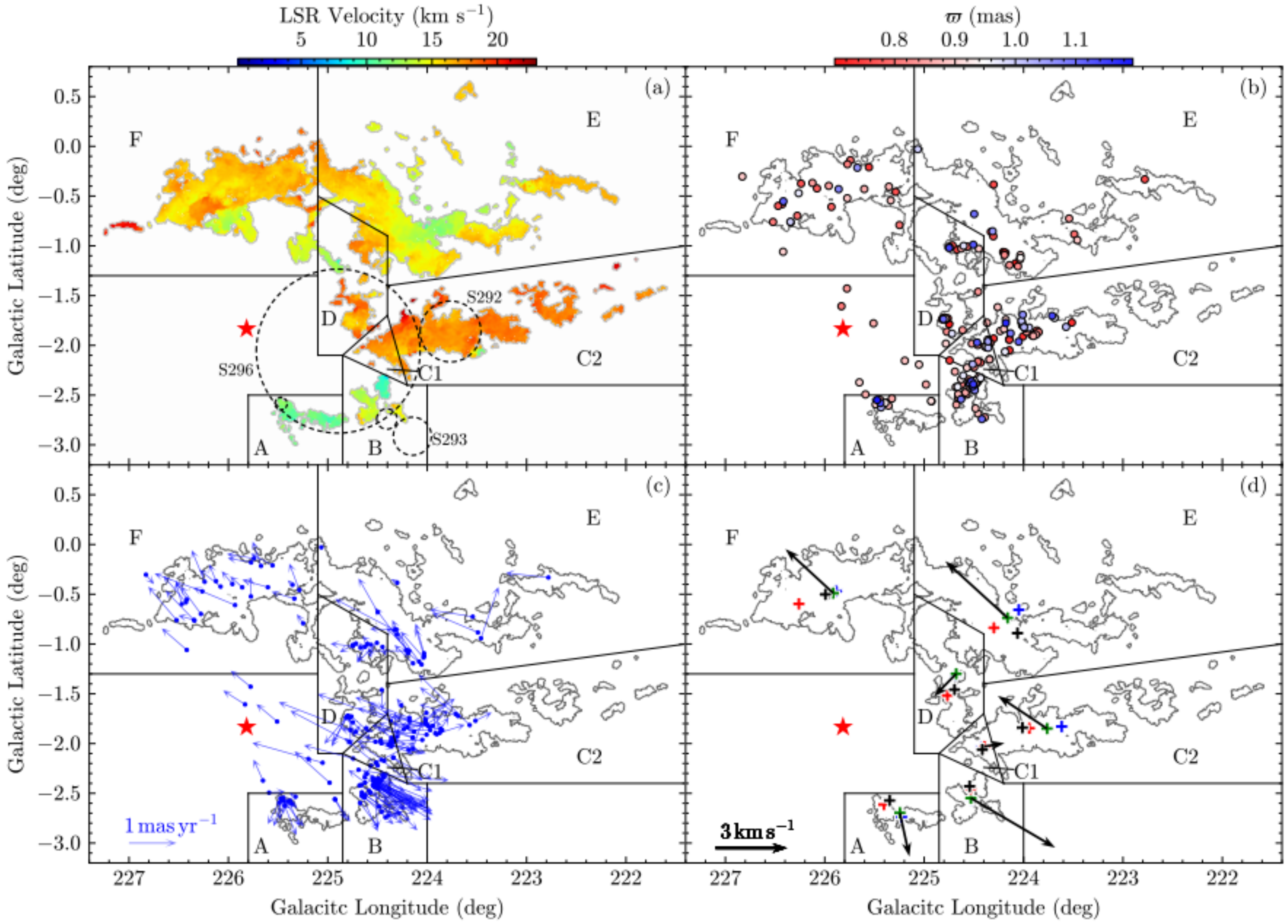
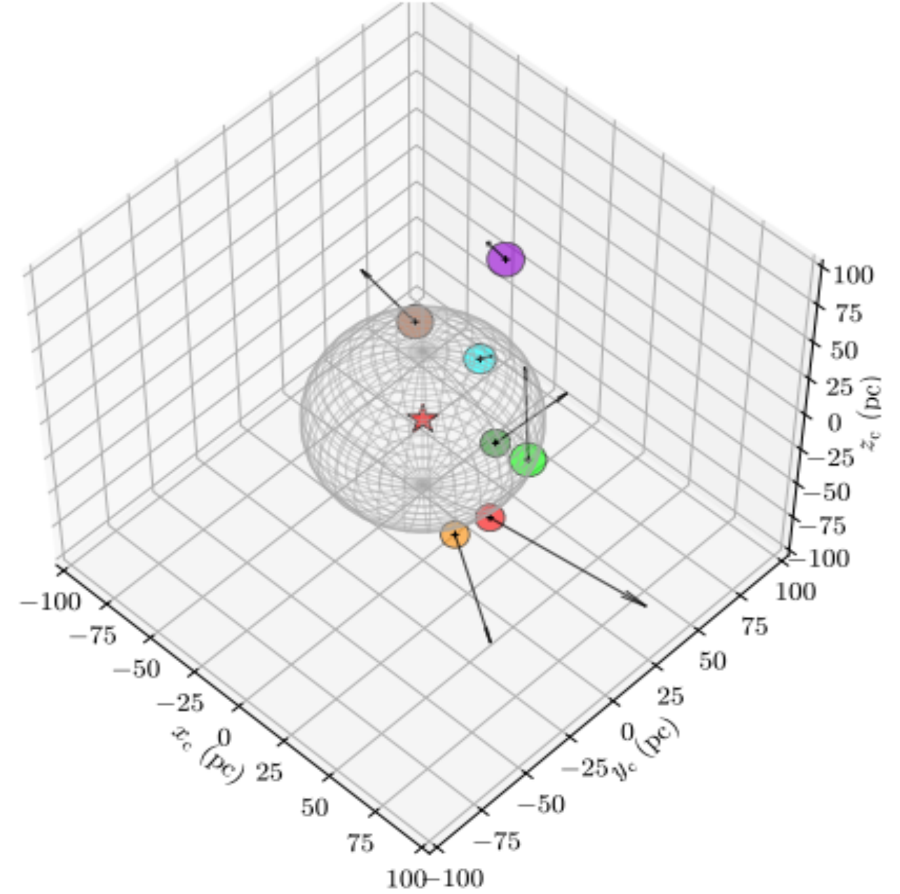



**Figure 2.** Division of subregions of CMa. Black solid lines delineate the boundaries of 7 subregions. Red stars denote the center of the CMa shell (Fernandes et al. 2019). (a): velocity distribution map of $^{13}$CO. Black dashed circles mark H II regions (parameters from the WISE catalog; Anderson et al. 2014). (b): locations of YSOs. The YSOs are displayed as circles color-coded by their parallaxes. The background gray contours delineate the regions traced by $^{13}$CO. (c): motions of YSOs. Blue arrows represent residual tangential motions after subtracting the average motions of YSOs. (d): the average positions of $^{12}$CO, $^{13}$CO, C$^{18}$O, and YSOs of subregions are shown as blue, green, red, and black crosses, respectively. Black arrows represent the average residual tangential velocities (converted to km s$^{-1}$) of YSOs within subregions.

# 3D Morphology and Motions of the CMa Region

- Using multiwavelength (optical, infrared, radio) images, Fernandes et al. (2019) proposed that the most prominent arcshaped nebula in CMa, Sh 2-296, is part of a large shell with a diameter of ~60 pc, designated the “CMa shell”.
- With the aim of establishing its 3D morphology and motions，the study employe the center of the CMa shell proposed by Fernandes et al. (2019) as the reference point ((l, b)=(225.82°, −1.83°)).
- The distance of the shell center is the aforementioned average distance (1128±15 pc), and the $\mu_{\alpha*}$ , $\mu_{\delta}$, and $v_{LSR}$ of the shell center are obtained from the average parameters of the 7 subregions, yielding values of $-3.68 \pm 0.01$ mas $yr^{-1}$ , $1.11 \pm 0.01$ mas $yr^{-1}$ , and $15.1 \pm 0.5$ km $s^{-1}$ , respectively.

- Averaging the distances relative to the shell center of the 7 subregions, the study determine the radius of the shell to be 47±11 pc, which represents a 3D shell larger than the model of Fernandes et al. (2019).
- The study's calculations indicate that this molecular shell is slowly expanding at a velocity of 1.6 ± 0.7 km s−1, a value comparable to the velocity dispersions of MCs. This suggests that the global expansion of the molecular shell is unlikely to be dominated by cloud turbulence, but is likely to be attributed to the external force.



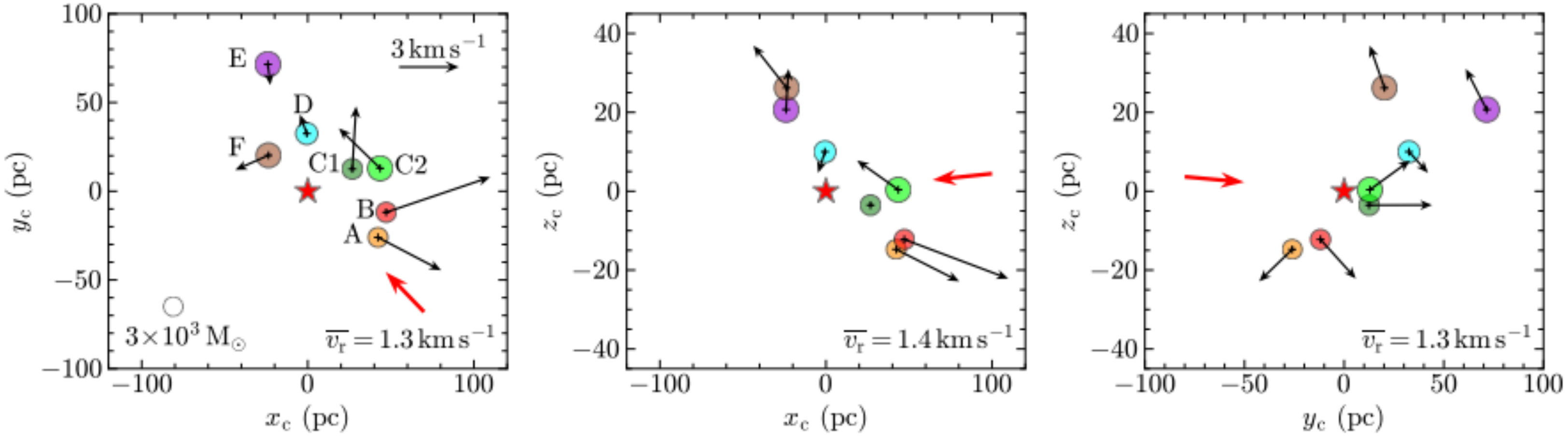




**Figure 4.** 3D distributions and motions of the subregions. The red star at the origin of the coordinate system is the center of the CMa shell, and the positive directions of the $x_c$, $y_c$, and $z_c$ axes are consistent with the Galactic Cartesian coordinate system of Reid et al. (2019). The positions and motions of the subregions are marked with colored circles and black arrows, respectively. The circle colors are aligned with Figure 3, and the circle sizes are proportional to the logarithm of the molecular masses of the subregions (listed in Table 4). Upper panel: the 3D view, with gray grid lines depicting a spherical shell with a radius of ∼47 pc. Lower panels: projected views on the $x_c$–$y_c$ (left), $x_c$–$z_c$ (middle), and $y_c$–$z_c$ (right) planes. Red arrows indicate the line-of-sight direction. The averaged radial components of velocities of the subregions are labeled in the bottom-right corners, with positive values pointing outwards and negative values pointing inwards.

# Discussion

# Gas Column Density Profile of Expanding Shell

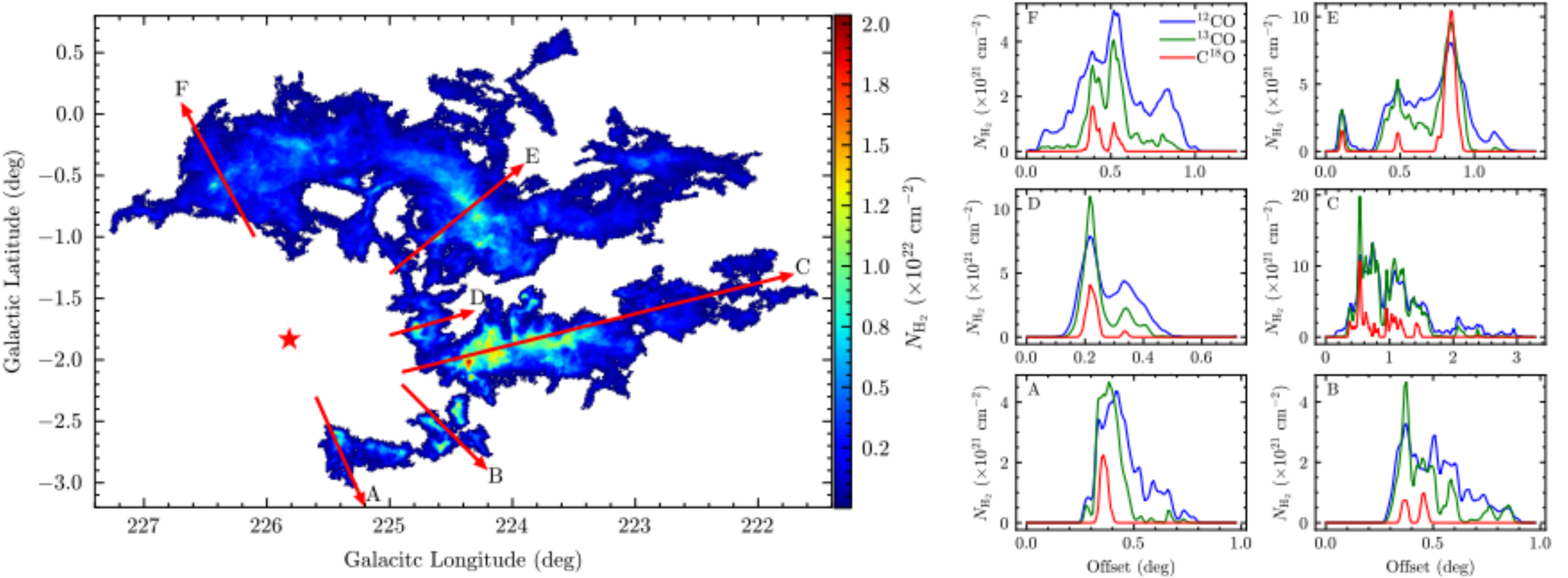



**Figure 5.** Gas column density features of the CMa region. Left panel: distribution of $N_{H_2}$ traced by $^{12}$CO, with the center of the CMa shell marked by a red star. Red arrows represent the 6 directions for P-$N_{H_2}$ slicing. Right panels: column density profiles along the 6 directions, arranged in the order of the arrows in the left panel, with the blue, green, and red lines depicting $N_{H_2}$ traced by $^{12}$CO, $^{13}$CO, and C$^{18}$O, respectively.

# Possible Origin of Expanding Shell

- To pinpoint the time when the 7 subregions are most compactly distributed, the study trace their past and future trajectories (within a time range of ±20 Myr) following the method of Großschedl et al. (2021).
- Concretely speaking, the study assume constant cloud velocities to calculate the sum of distances Σd(i, j) between the subregions at 0.1 Myr time bins and determine the minimum value. Figure 6 illustrates Σd(i, j) as a function of the evolutionary time, indicating that the expansion of the molecular shell seems to have started ~4.4 Myr ago.

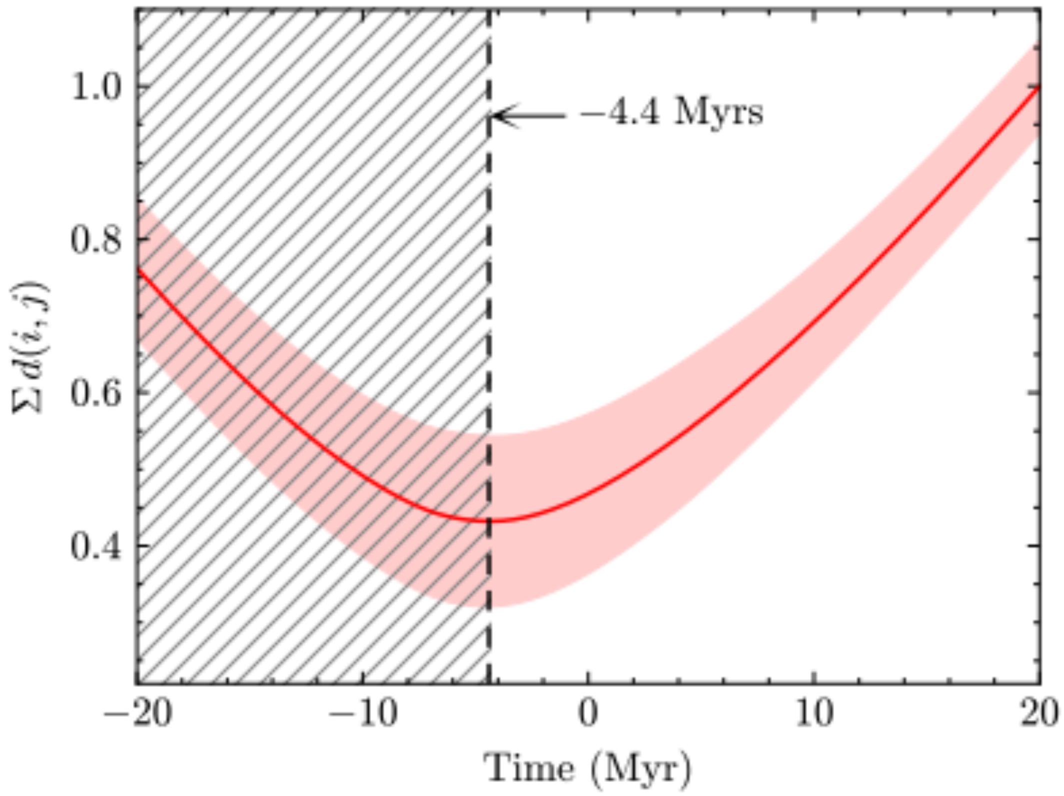



**Figure 6.** The sum of the distances between the 7 subregions $\Sigma\, d(i,j)$ as a function of evolutionary time, normalized by its maximum value. The red shaded area represents the standard deviations of the Monte Carlo sampling. The time range is ±20 Myr with a step size of 0.1 Myr. The vertical dashed line marks the moment when $\Sigma\, d(i,j)$ reaches a minimum.

# Conclusions

- Integrating the high-precision astrometric data of YSOs from Gaia DR3 with the high-quality $^{12}CO$, $^{13}CO$, and $C^{18}O$ (1–0) data from the MWISP project, the study investigate for the first time the 3D morphology and motions of the CMa region.
- The study partition the CMa region into 7 subregions based on the discrepancies in the PPV distribution, integrated intensity, and radial velocity of the molecular gas, as well as the differences in distance and motion of the YSOs.
- The central (l, b) coordinates and radial velocities of the subregions are determined by the TMB-weighted average parameters of the $^{13}CO$ gas, and the distances and proper motions of the subregions are represented by the average parameters of the YSOs.
- The study find that the subregions are distributed around a shell with a radius of 47 ± 11 pc. The radial components (relative to the shell center) of the 3D motions indicate that this molecular shell is slowly expanding at a velocity of 1.6 ± 0.7 km $s^{-1}$ .
- Through the traceback analysis assuming constant velocities, we observe that the expansion appears to have started ~4.4 Myr ago. Additionally, the momentum analysis suggests that the expanding molecular shell may be shaped by at least 2 SNe events.

# Thanks