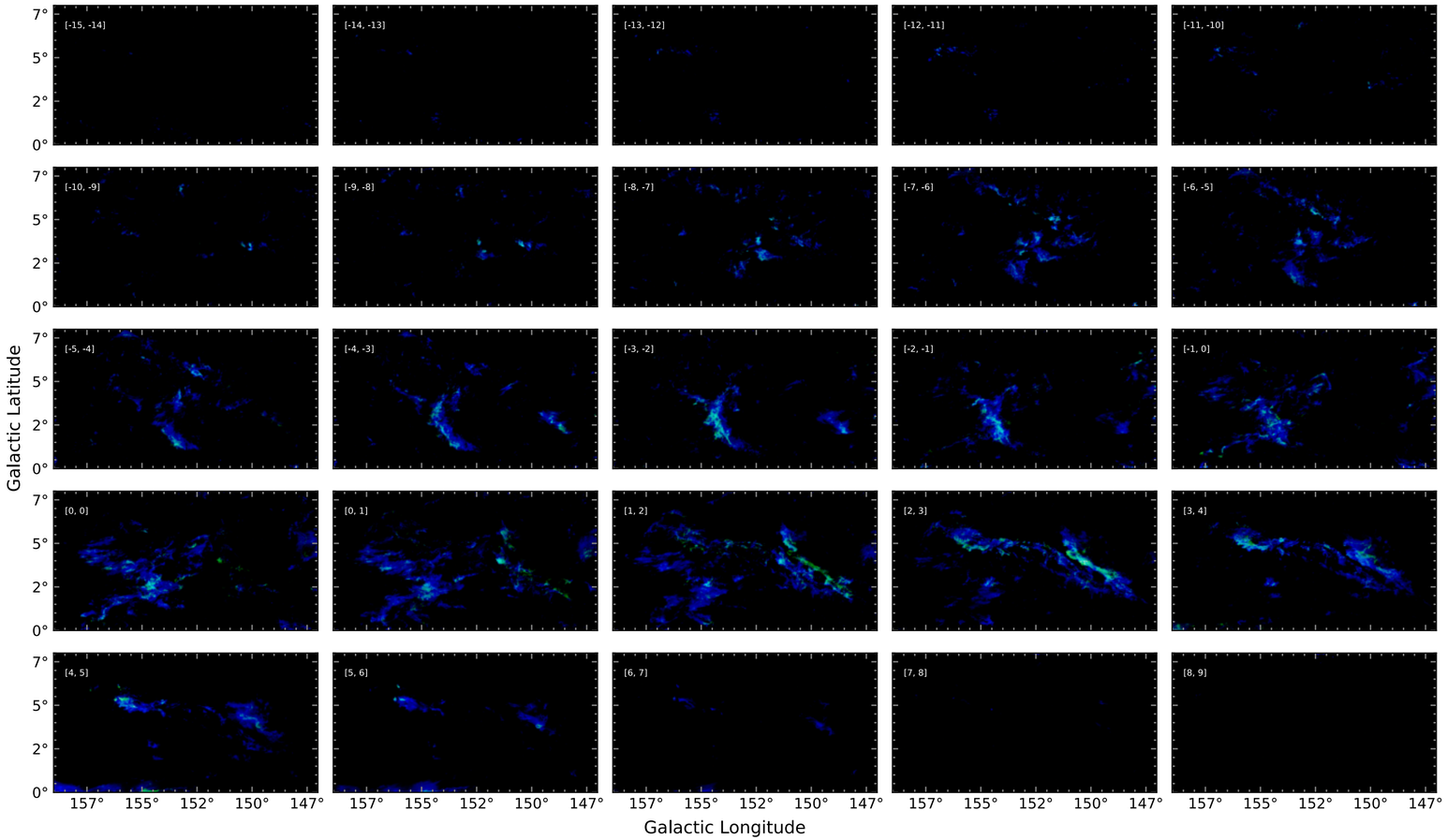
Properties and Distribution of Camelopardalis region

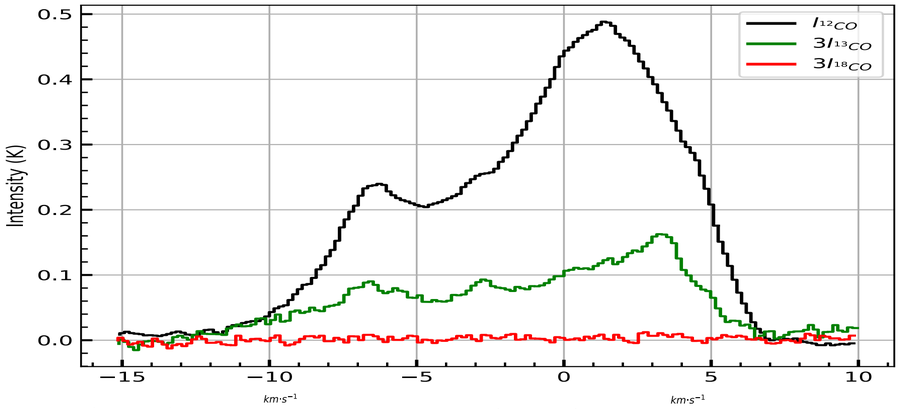
Bow and Shell structures

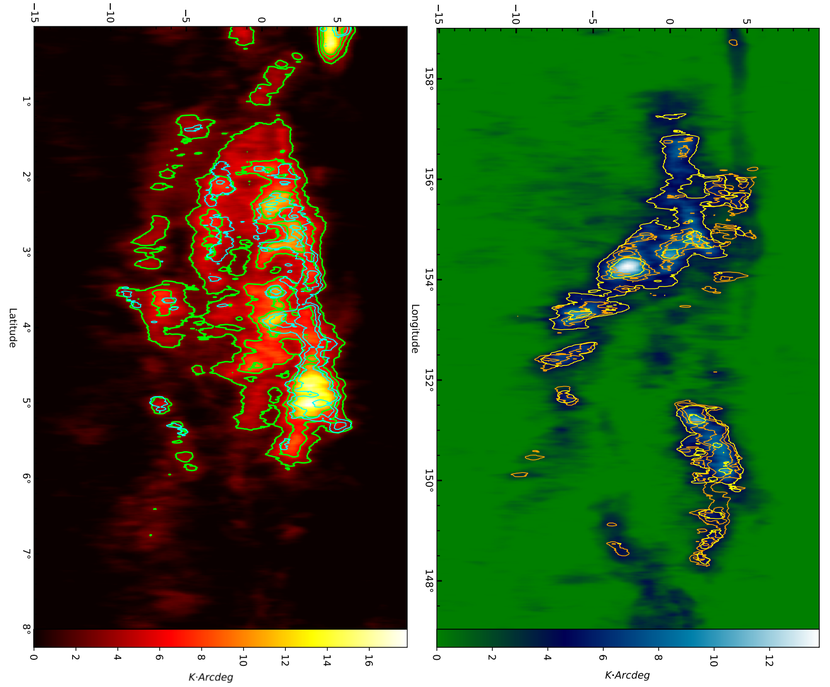
Wang Dong 2024.09.22

Overview of the region

CO Emissions and spectra







^{12}CO, ^{13}CO and $C^{18}O$ emissions toward Camelopardalis direction

Identification of MCs

- Spectra decomposition
  - *GaussPy+*
  - A total of 228340 velocity components were decomposed
- Velocity Component Clustering
  - *Acrons* $(N_{min} = 25)$
  - A total of 99 molecular clouds with hierarchical structures were obtained
  - See Figure 1 for spatial distribution

Clustering

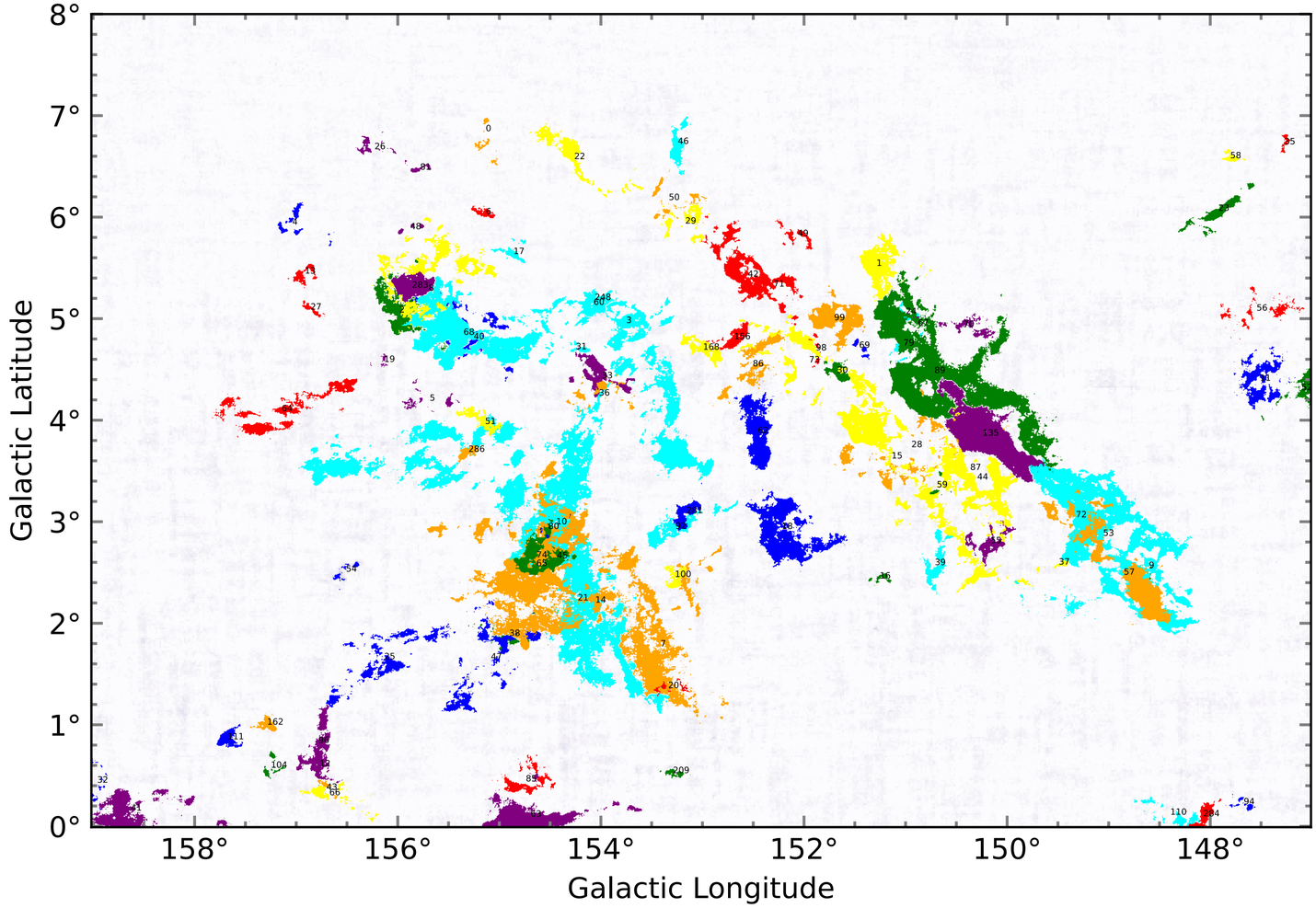


Figure 1

Distance and Properties

Distance Measurements and compiling of the Tables

- Distance
  - Technique: BEEP（Figure 2）
  - Number of measurable distances (approx. 40 % molecular cloud distance measurable)
  - Distribution（Figure 3）
- Properties
  - Size（Angular Area）
  - Optical Depth（$^{13}CO\,[LTE]$）
  - Column Density（^{12}CO & $^{13}CO\,[LTE]$）
  - Mass（^{12}CO & $^{13}CO\,[LTE]$）
    - $^{12}CO \rightarrow 40784 M_{\odot}$
    - $^{13}CO \rightarrow 25269 M_{\odot}$

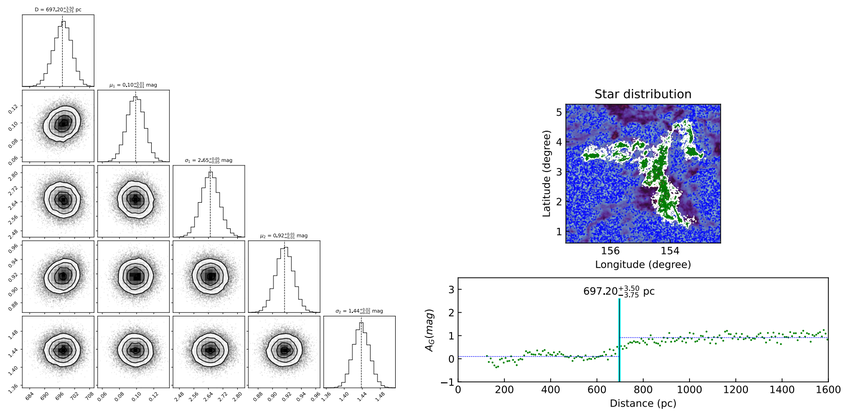


Figure 2

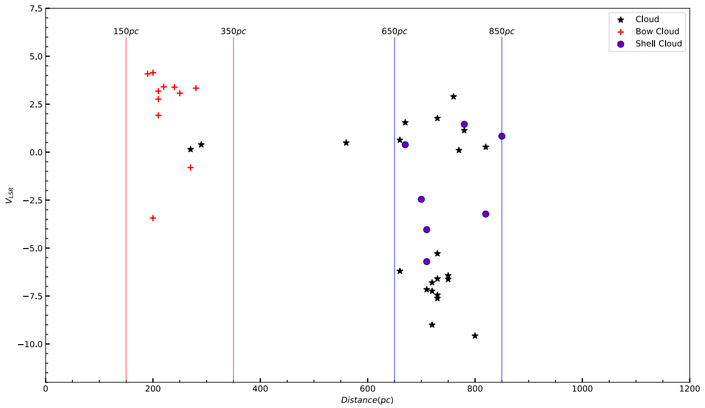


Figure 3

Table 2: Clouds Properties

Name	l	b	V	Area	d	M_{13}	M_{12}	$\bar{N}_{12}$	$\hat{N}_{12}$	τ	$\bar{N}_{13}$	$\hat{N}_{13}$	$\hat{T}_{ex}$	$\hat{T}_{ex}$
Cam 155.13+6.85	155.13	6.85	-7.93	70.25	-	-	-	13.43	22.88	0.28	5.64	20.37	7.33	9.25
Cam 151.29+5.52	151.29	5.52	1.54	534.25	670	443	786	17.08	29.61	0.30	9.63	39.22	9.60	12.52
Cam 155.99+5.06	155.99	5.06	4.14	512.75	200	79	100	25.40	46.29	0.38	19.94	69.18	10.49	13.58
Cam 153.75+4.96	153.75	4.96	2.89	568.50	760	719	1217	19.32	37.63	0.32	11.42	36.86	9.80	13.00
Cam 157.04+5.93	157.04	5.93	3.27	100.00	-	-	-	12.67	29.75	0.26	5.74	24.39	8.63	12.48
Cam 155.69+4.19	155.69	4.19	-8.78	90.75	-	-	-	24.04	54.08	0.29	10.69	41.04	8.57	11.64
Cam 155.13+6.03	155.13	6.03	-1.42	60.75	-	-	-	12.91	25.74	0.28	5.74	17.99	7.66	9.67
Cam 153.41+1.77	153.41	1.77	-5.71	1759.25	710	1843	3721	21.86	78.82	0.31	10.83	54.38	8.64	11.85
Cam 155.70+5.28	155.70	5.28	3.08	1130.25	250	144	261	19.28	57.07	0.28	10.63	67.80	9.47	12.96
Cam 148.60+2.54	148.60	2.54	-2.68	41.50	-	-	-	17.00	29.05	0.23	6.36	18.33	8.45	11.40
Cam 154.44+2.97	154.44	2.97	-2.46	7925.50	700	9906	16356	21.95	73.62	0.34	13.29	76.26	9.40	14.34
Cam 147.51+4.39	147.51	4.39	1.10	461.50	-999	447	606	6.85	15.96	0.47	5.06	23.57	7.16	9.96
Cam 156.77+0.59	156.77	0.59	1.46	138.75	-	-	-	13.47	34.21	0.25	6.29	37.22	9.40	12.83
Cam 156.92+5.44	156.92	5.44	-11.17	84.75	-	-	-	13.73	28.09	0.30	7.16	28.43	7.92	10.91
Cam 154.06+2.20	154.06	2.20	-4.04	125.50	710	230	269	22.12	62.70	0.42	18.94	75.01	9.37	12.40
Cam 151.14+3.62	151.14	3.62	1.92	1530.75	210	218	243	18.73	49.58	0.42	16.86	108.53	9.50	15.09
Cam 151.25+2.44	151.25	2.44	1.35	39.75	-	-	-	15.50	22.59	0.22	7.47	17.22	10.59	12.88

Identification of Clumps

Technique and Properties

- Technique
  - Search ^{13}CO clumps by *FacetClumps* ($N_{min} = 16$)
  - A total of 3128 non-boundary clumps were identified
- Distribution of Clumps
  - See Figure 4
- Properties of Clumps
  - See table in the right
- Statistical results
  - Clumps on MCs (3128→2109 → 2022[d])
    - Radius ($R_{med} = 0.4\,pc$)
    - Mass ($M_{med} = 5.85\,M_{\odot}$)
    - Velocity Dispersion ($\sigma_{med} = 0.33\,km/s$)
    - Virial Parameter ($\alpha_{med} = 0.78$)
  - In Bow (613 → 597[d])
  - In Shell (682[d])

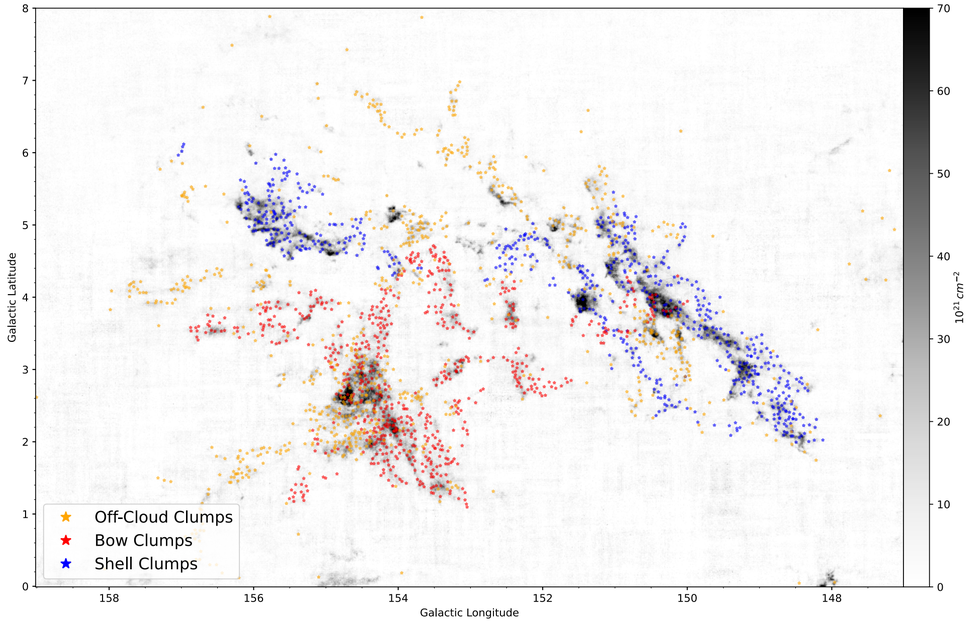
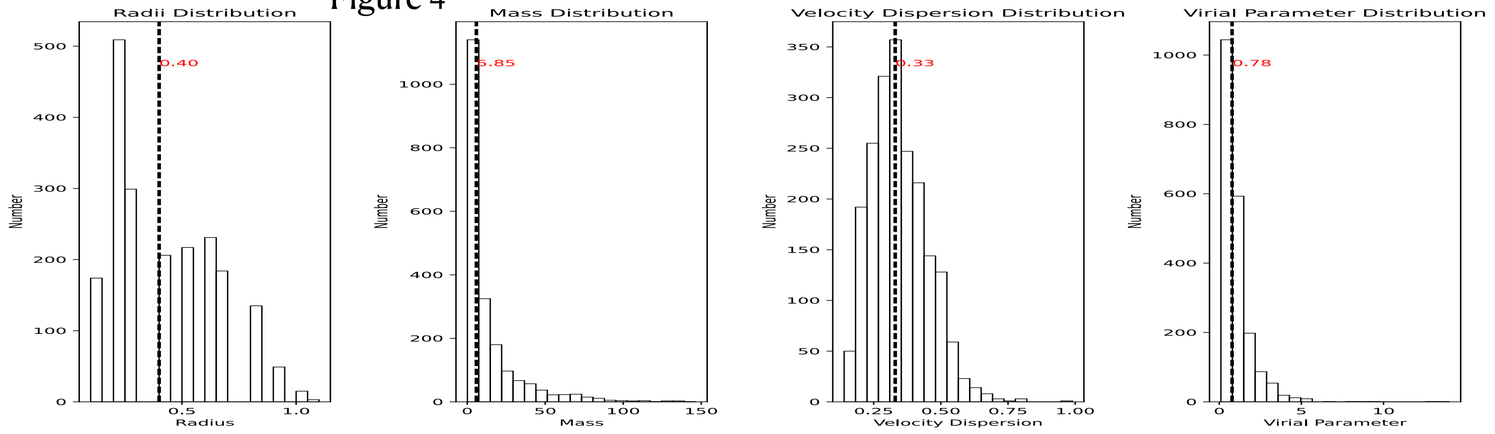


Figure 4

Table 3: Clumps Properties

Name	l	b	V_{lsr}	M	$\hat{T}$	σ_V	R	α
Clumps 150.09+3.23	150.089	3.228	-10.128	12.00	3.05	0.28	0.5	0.38
Clumps 150.10+3.27	150.102	3.273	-9.882	46.20	3.49	0.33	0.8	0.23
Clumps 150.15+3.25	150.151	3.253	-9.603	21.80	3.11	0.31	0.6	0.30
Clumps 150.17+3.30	150.174	3.299	-9.73	5.50	2.04	0.28	0.4	0.64
Clumps 150.12+3.52	150.125	3.52	-9.56	104.10	4.86	0.45	0.8	0.18
Clumps 150.13+3.48	150.13	3.478	-9.36	57.50	4.26	0.43	0.7	0.26
Clumps 150.07+3.43	150.075	3.431	-9.492	39.30	3.37	0.49	0.7	0.49
Clumps 150.09+3.57	150.085	3.574	-9.448	44.10	3.57	0.46	0.8	0.44
Clumps 150.19+3.54	150.187	3.539	-8.737	5.50	2.39	0.30	0.4	0.75
Clumps 150.21+3.51	150.207	3.513	-9.031	3.50	1.86	0.22	0.4	0.66
Clumps 156.41+5.43	156.412	5.427	-11.345	2.50	1.54	0.17	0.4	0.56
Clumps 153.26+6.71	153.256	6.713	-9.511	36.00	3.05	0.43	0.7	0.41
Clumps 153.20+6.71	153.199	6.713	-9.569	29.40	3.80	0.45	0.6	0.48
Clumps 153.27+6.83	153.273	6.833	-9.847	20.60	2.39	0.41	0.7	0.67
Clumps 153.23+6.64	153.226	6.639	-9.273	19.10	2.32	0.54	0.6	1.07
Clumps 153.23+6.58	153.233	6.585	-8.61	28.90	2.63	0.47	0.7	0.62
Clumps 153.29+6.60	153.288	6.597	-9.566	10.80	1.81	0.42	0.5	0.93
Clumps 153.30+6.63	153.296	6.633	-9.91	4.60	1.38	0.29	0.4	0.85
Clumps 153.24+6.52	153.242	6.519	-9.507	2.90	1.52	0.22	0.4	0.79
Clumps 153.17+6.93	153.173	6.929	-9.962	13.50	1.92	0.32	0.6	0.51
Clumps 153.15+6.98	153.148	6.98	-10.06	3.40	1.60	0.22	0.4	0.68



Two Major Structures

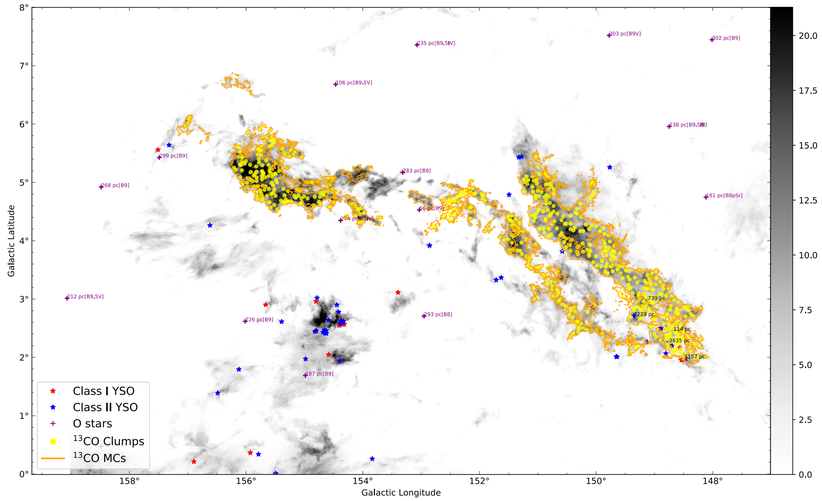
- Velocity Range
  - $v \in [1 \sim 8]\, km/s$
- Projection Area
  - $^{13}CO \rightarrow 70\, pc^2$ *or* $4.8\, deg^2$
- Distance
  - $d \approx 220\, pc$
- H_2 Column Density
  - $N_{Peak}^{12} \approx 5.7 \times 10^{21}\, cm^{-2}$ *or* $N_{Peak}^{13} \approx 1.1 \times 10^{22}\, cm^{-2}$
  - $N_{Mean}^{12} \approx 1.7 \times 10^{21}\, cm^{-2}$ *or* $N_{Mean}^{13} \approx 1.3 \times 10^{21}\, cm^{-2}$
- Mass
  - $^{12}CO \rightarrow 2878\, M_\odot$
  - $^{13}CO \rightarrow 2467\, M_\odot$
- Outflow——————Require further investigation
  - A total of XX outflow sources ($N_{Single} = XX$, $N_{Bipolar} = XX$)
- Clumps
  - Mass（$M_{med} = 2.3\, M_\odot$）
  - Velocity Dispersion（$\sigma_{med} = 0.34\, km/s$）
  - Virial Parameter（$\alpha_{med} = 1.19$）

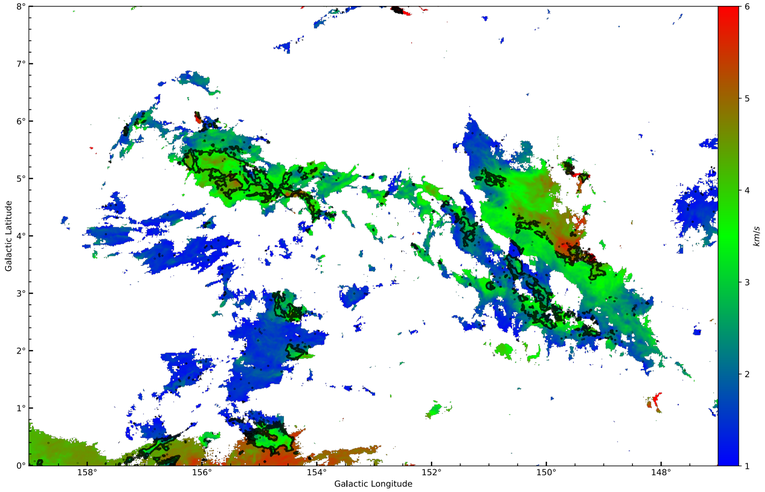
Bow

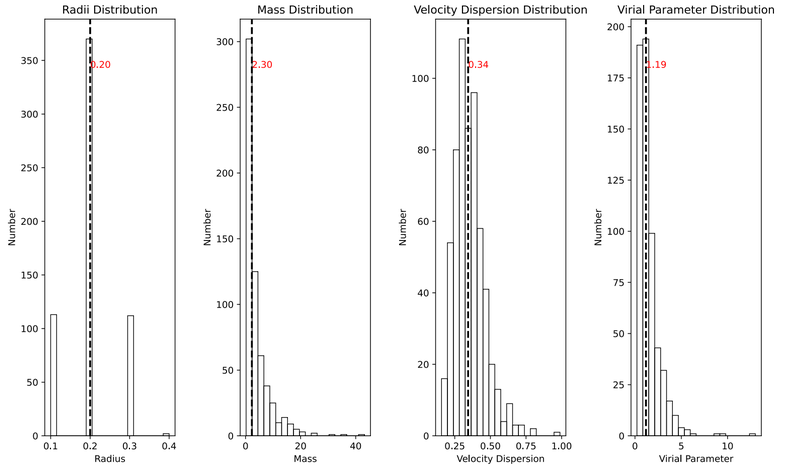
- How to determine the ^{13}CO boundary?
  - MCs whose distances are within $300\, pc$ and projected spatially to form a Bow shape
  - $v \in [1{,}8]\, km/s$, not measurable in distance and form a Bow in projected space
- How to search for outflow?
  - Spurs in $PV - diagram$, locate (l, b, v)
  - Integrated over $(l, b, v)'s$ line wings
- Outflow ?
  - Kinematic energy
  - Momentum
- Bubbles ?
  - Size
  - Energy required

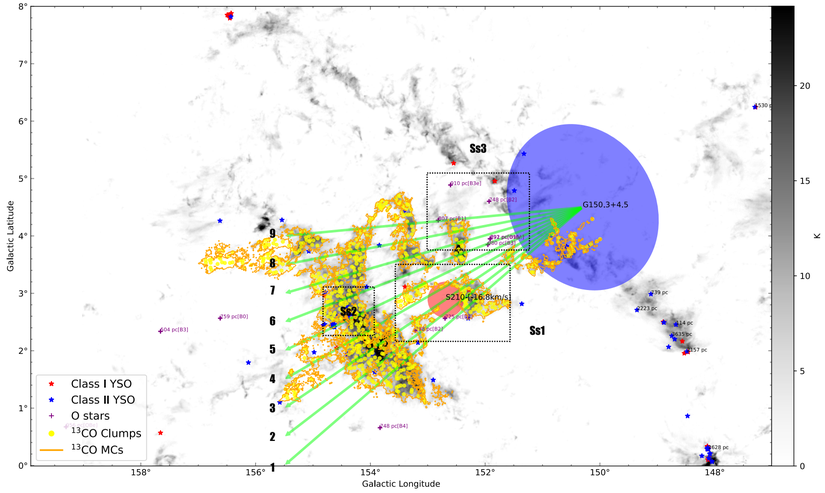
Two Major Structures

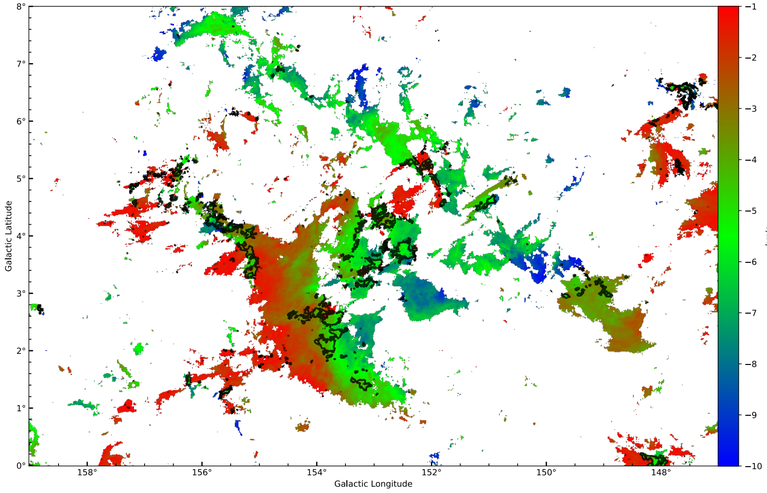
Bow and Shell

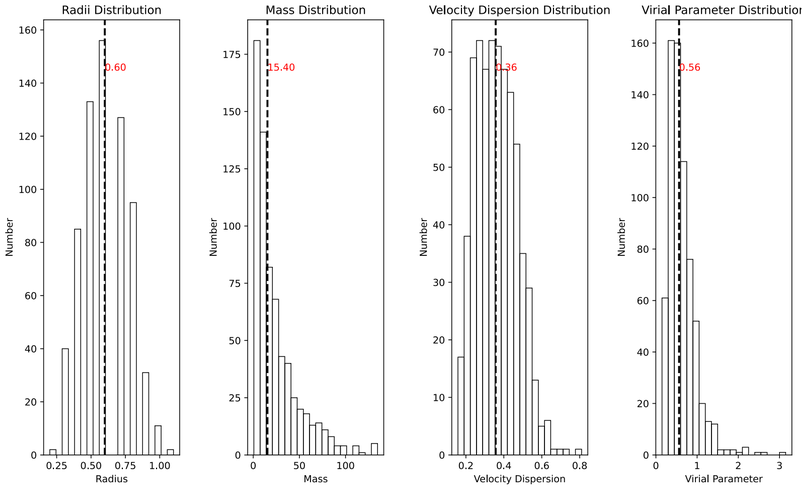






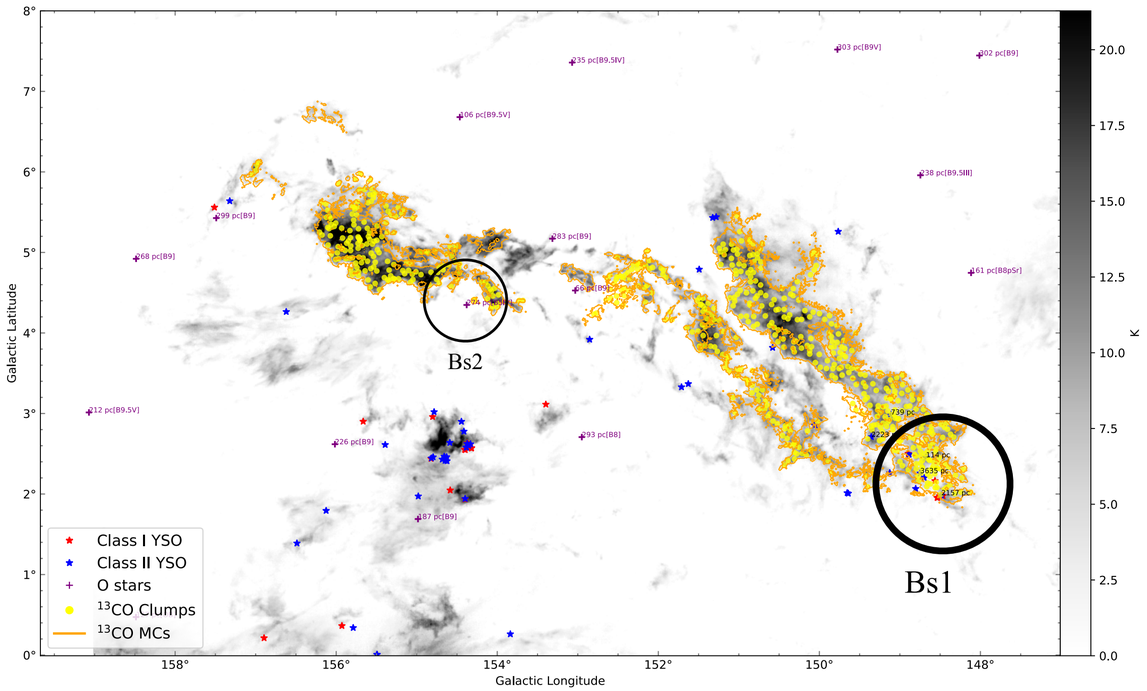


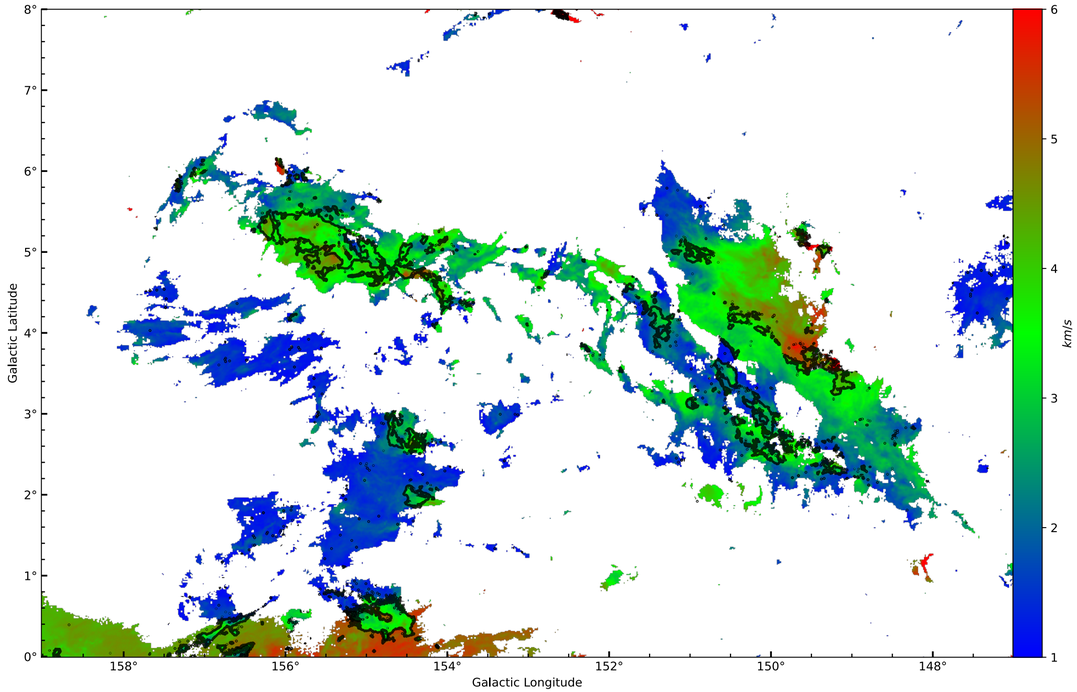




Two Major Structures

Bow



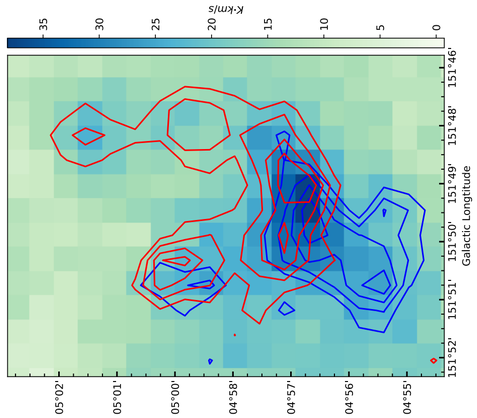


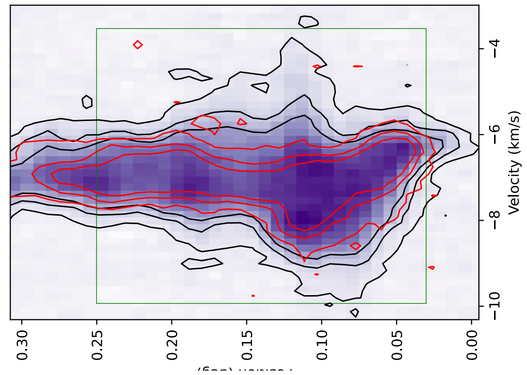
- Left: Distribution of MCs, Clumps, YSOs and OB stars
  - YSOs gathered in Bs1 (Without Distance), only B stars have been found ⇒ Early stage of Star Formation (Starless MCs) or Late stage of Star Formation
- Right: Distribution of Central Velocity and Velocity Dispersion
  - The Bow MCs have similar velocities and relative larger velocity dispersion than ambient MCs ⇒ More Turbulent than ambient MCs ⇒ Under Stellar Feedback? Or Dissipating?

Two Major Structures

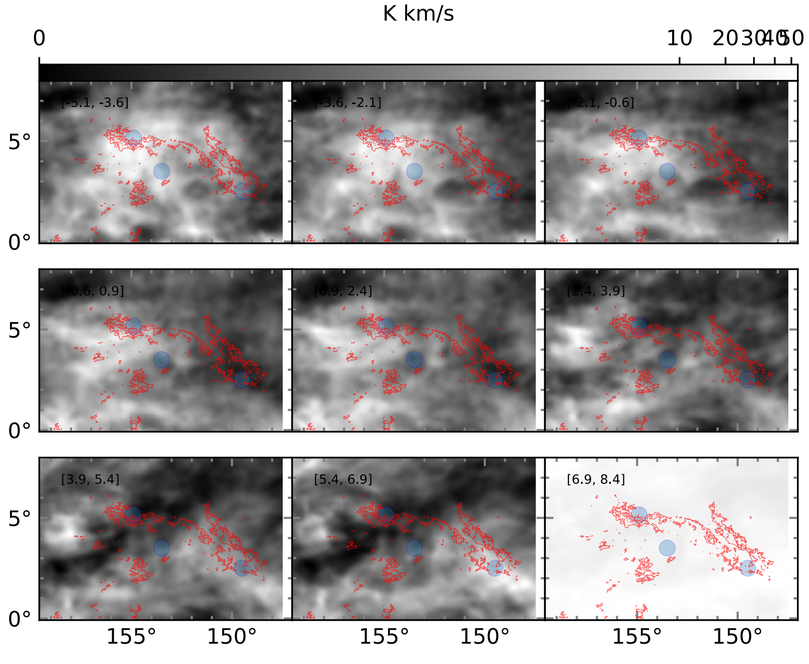
Outflows and Bubbles

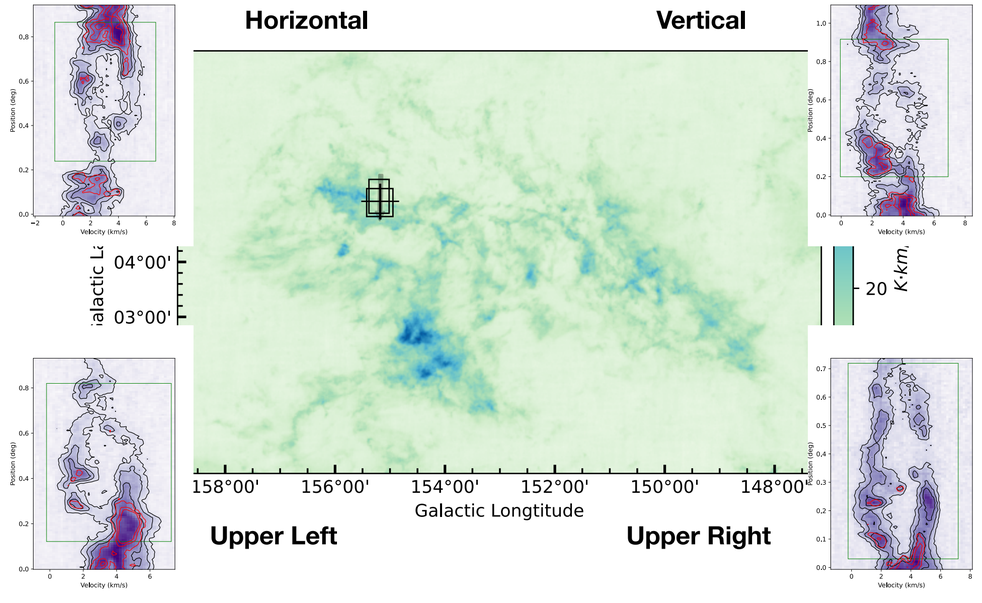
- Outflow
  - Low velocity Wings
  - Mostly single lobe

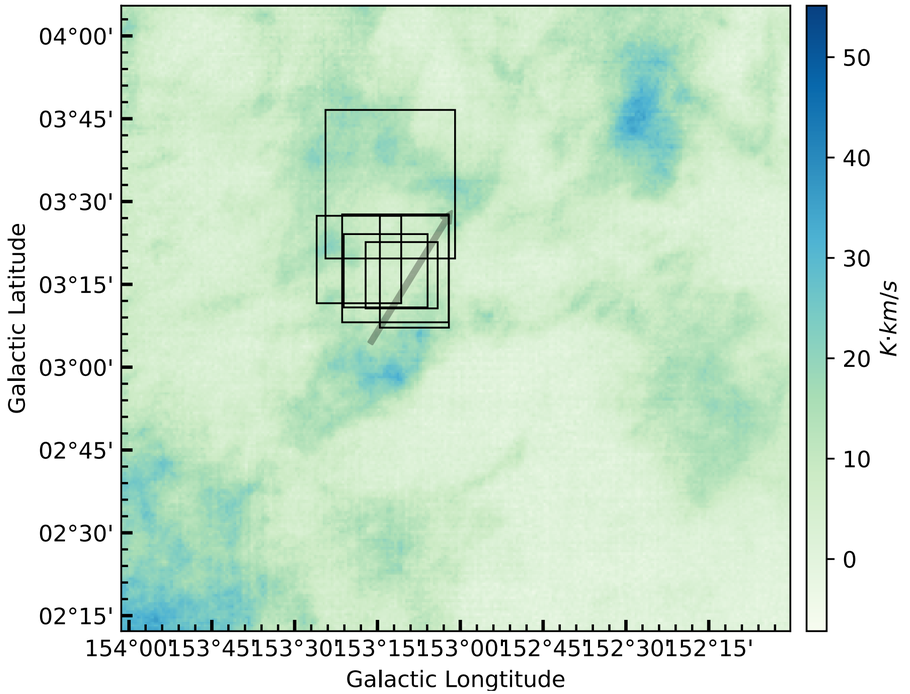


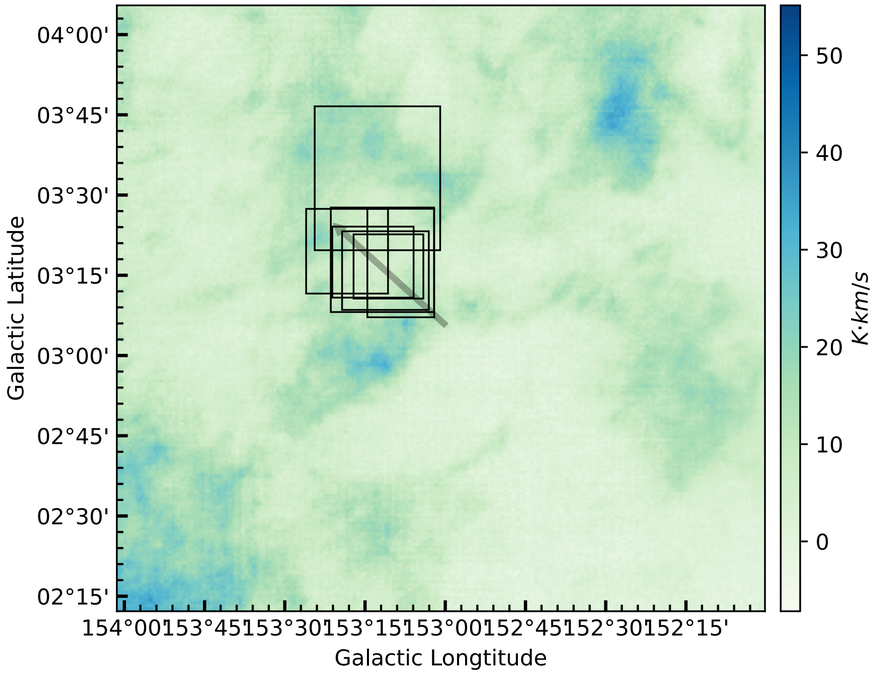


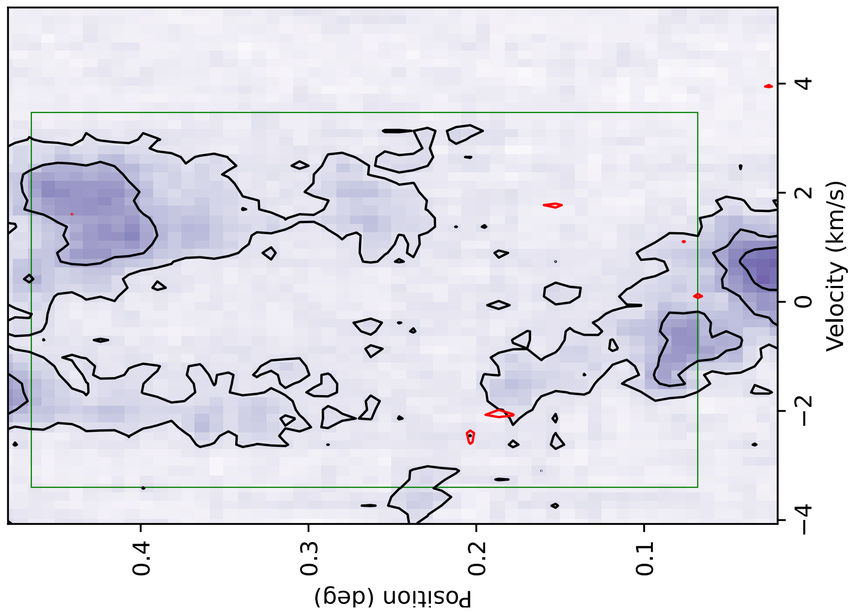
- Bubbles
  - At least 4 bubbles
  - Consistent with HI (HI4PI)
- Size
  - About 1 pc (3 of 4)

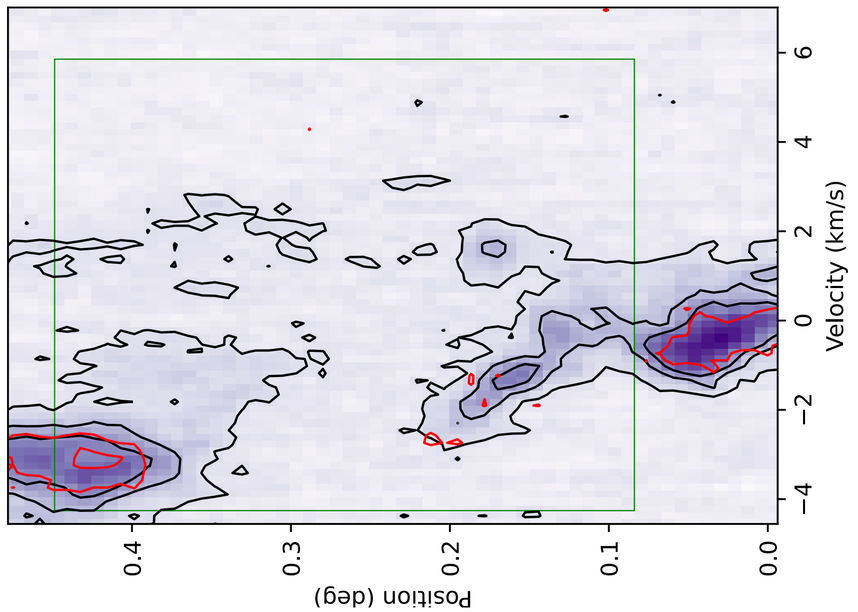










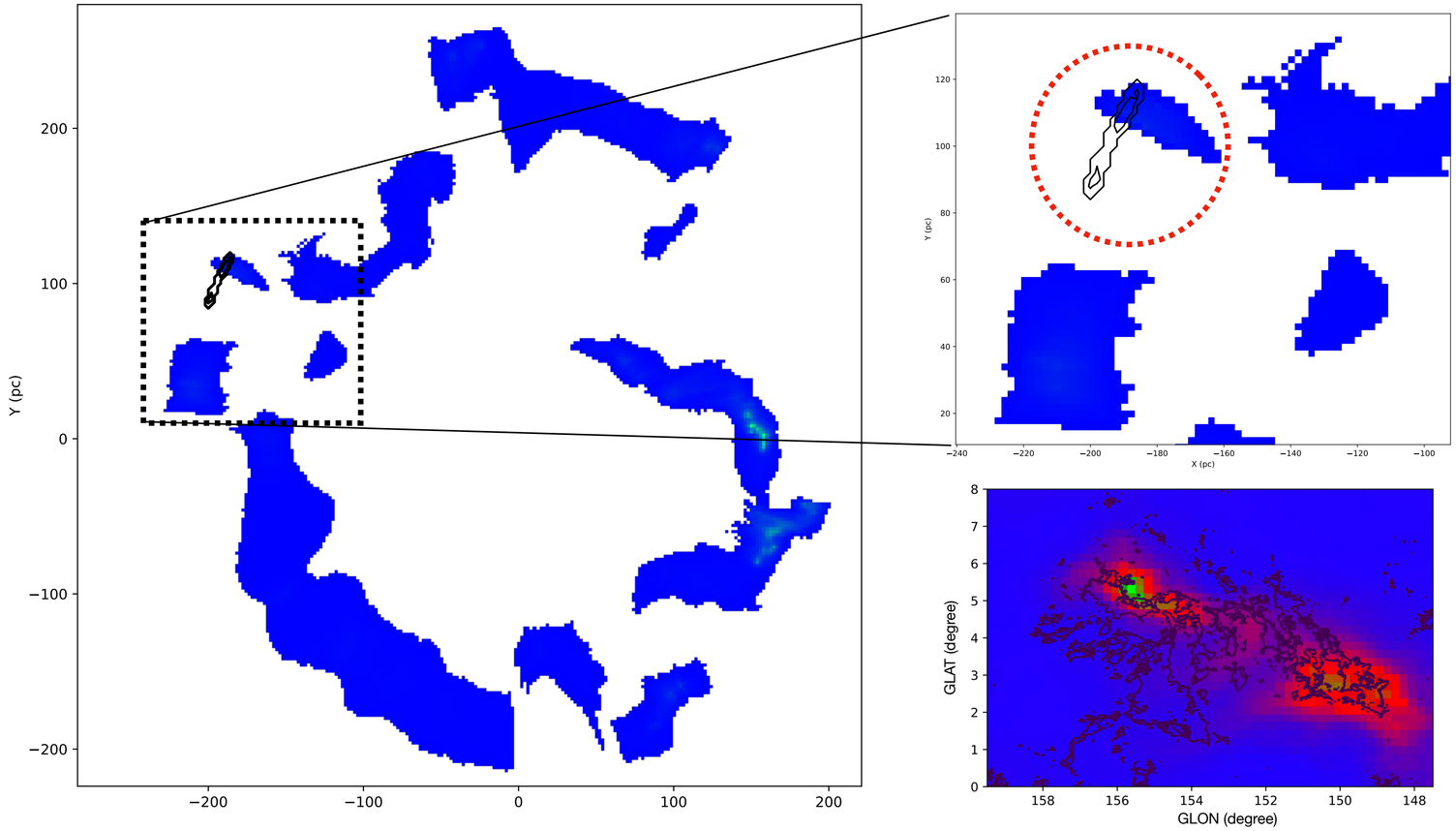


(Catalogues of Properties will be provided later)

Two Major Structures

Bow

- MCs on the Shell of the Local Bubble
  - 3D-Dust Map → associated with the Bow MCs
  - Local Bubble model from O'Neil (2024)
  - $Z \in [10, 24]\, pc$
- How did these MCs form?
  - GMC on the surface of the local bubble
    ⇒ Fragment ⇒ Late stage of Star Formation
  - GMC on the surface of the local bubble
    ⇒ YSOs not found⇒ Early stage of Star Formation
  - Others ?



Two Major Structures

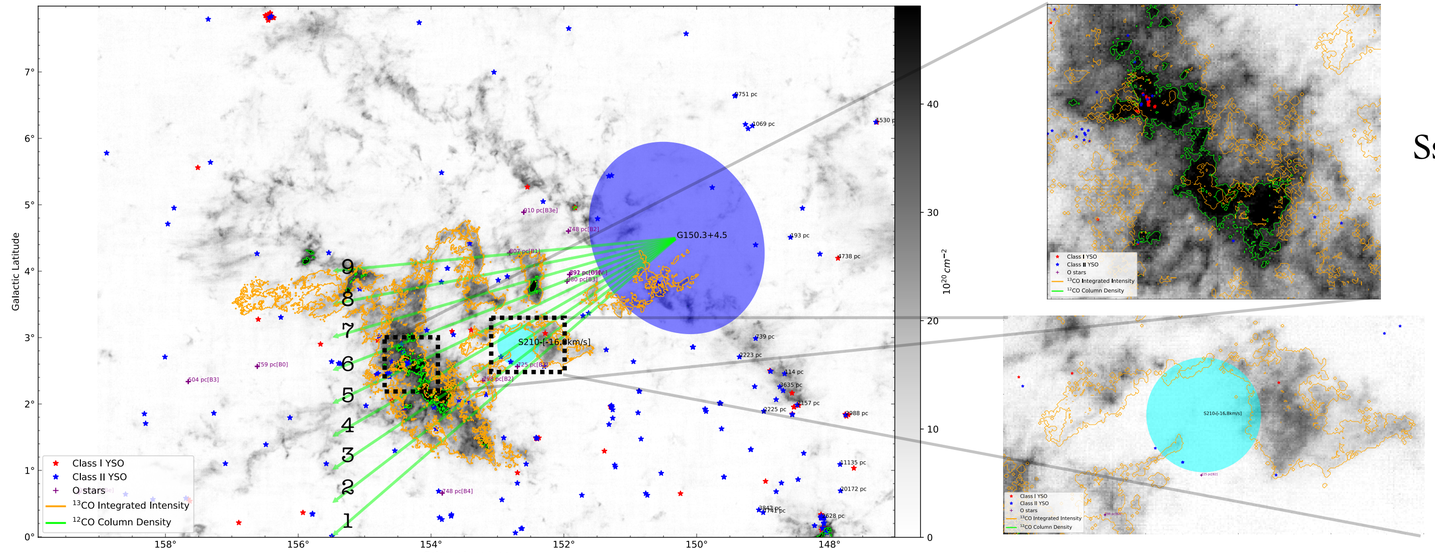
- Velocity Range
  - $v \in [-10 \sim -1]\, km/s$
- Projection Area（A）
  - $^{13}CO \rightarrow 598\, pc^2$ *or* $3.7\, deg^2$
- Distance
  - Bulk $d \approx 710\, pc$, some $d \sim 800\, pc$
- H_2 Column Density
  - $N^{12}_{Peak} \approx 7.9 \times 10^{21}\, cm^{-2}$ *or* $N^{13}_{Peak} \approx 7.6 \times 10^{21}\, cm^{-2}$
  - $N^{12}_{Mean} \approx 1.8 \times 10^{21}\, cm^{-2}$ *or* $N^{13}_{Mean} \approx 1.1 \times 10^{21}\, cm^{-2}$
- Mass（M）
  - $^{12}CO \rightarrow 27743\, M_\odot$
  - $^{13}CO \rightarrow 16181\, M_\odot$
- Shell Properties
  - $R_{sh} \approx 55\, pc$
  - $V_{sh} \approx 7.5\, km/s$

Shell

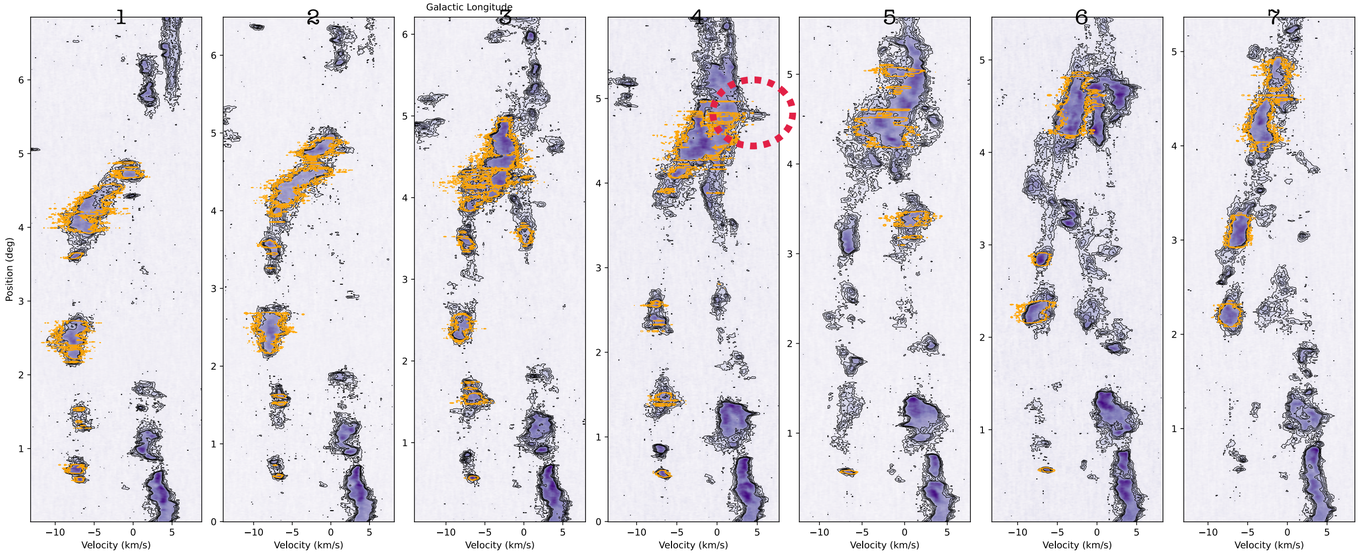
- How to determine the ^{13}CO boundary?
  - MCs whose distances are within $[650, 850]\, pc$ and projected spatially to form a Shell shape
  - $v \in [-10, -1]\, km/s$ not measurable in distance and form a Shell in projected space
- How to determine the expanding velocity?
  - From $PV - diagram$
- How to estimate properties? (Rough estimation)
  - Timescale（$t_{sh} = R_{sh}/V_{sh}$）
  - Kinetic Energy（$E_{sh} = \frac{1}{2} M V^2_{sh}$）
  - Total Energy（$E_{Total} = E_{sh} \times \frac{4\pi R^2_{sh}}{A}$）

Two Major Structures

Shell



Ss2



- Expanding Velocity
  - $V_{sh} \approx 7.5\,km/s$
- Timescale
  - $t_{sh} \approx 7.2\,Myr$
- Mass
  - $M = 16181\,M_{\odot}$
- Total energy of the Shell
  - $E_{sh} \approx 9.1 \times 10^{48}\,erg$
- Energy required from Stars
  - $E_{Total} \approx 5.6 \times 10^{50}\,erg$
- How much energy can star offer ? (Need Further Investigation)
  - $E_{Star} \in [10^{50}\,erg \sim 10^{52}\,erg] \Rightarrow E_{Total} \in E_{cluster}$
- Distribution of YSOs
  - There are some YSOs in Ss2 region
  - ClassI $(t_{typical,I} \approx [0.1\,Myr \sim 1\,Myr])$
  - ClassII $(t_{typical,II} \approx [1\,Myr \sim 10\,Myr])$ $\Rightarrow t_{sh} \in t_{typical,II}$
- Properties of Clumps
  - Mass $(M_{med} = 15.4\,M_{\odot})$
  - Velocity Dispersion $(\sigma_{med} = 0.36\,km/s)$
  - Virial Parameter $(\alpha_{med} = 0.56)$