Multi-scale dynamics and magnetic fields in the high-latitude molecular cloud MBM12

Initial results from the B-FROST project

by Job Vorster

Collaborators: Mika Juvela, Julien Montillaud (PI), Dana Alina, Veli-Matti Pelkonen, Emma Mannfors, and others.

What is the B-FROST Project?

What is the B-FROST Project?

Aim: Observe many **different kinds of sources** in ^{12}CO, and ^{13}CO with the 13.7 m single dish Taeduk Radio Astronomical Observatory, and to **combine with existing observations** with Herschel and Planck (and other available data).

Finished observing LDN183, W40, G110-13, MBM12, LOri South, L Ori North, L Ori West and G358 → Varied sources.

See the next talk by Julien.

With the aim characterize their environments, identify their multi-scale dynamics, and investigate their magnetic fields using the most recent methods.

Scientific Aims - Details

For each source:

Environmental Characterization: Identify the source's larger scale context. Use line ratios, and existing Herschel observations to estimate X(^{12}CO), X(^{13}CO).

3D Radiative Transfer modelling is also being considered. N(^{12}CO) and N(^{13}CO) can be calculated if multiple transitions are available.

Multi-Scale Dynamics: Isolate kinematic components and their hierarchical structuring with dendrograms and component fitting of the cubes.

B-Fields: Use Planck polarization data to estimate the Histogram of Relative Orientations (HRO, FilDREAMS!), and to apply the velocity gradient technique (VGT).

The real fun: Look deeply into each source in the same ways, and then compare them deeply at the end.

This is the first single source study, to try to refine our methods and approach. Feedback/ideas are welcome!

Introduction to MBM12

MBM 12

MBM12 (or Lynds 1457) is a high latitude molecular cloud.

Galactic Coordinates (*l*,*b*) = (159° 21' 2.52", - 34° 19' 23.16")

MBM12 is at a distance of 278±61 pc. (GAIA extinction and others, Sun+2021)

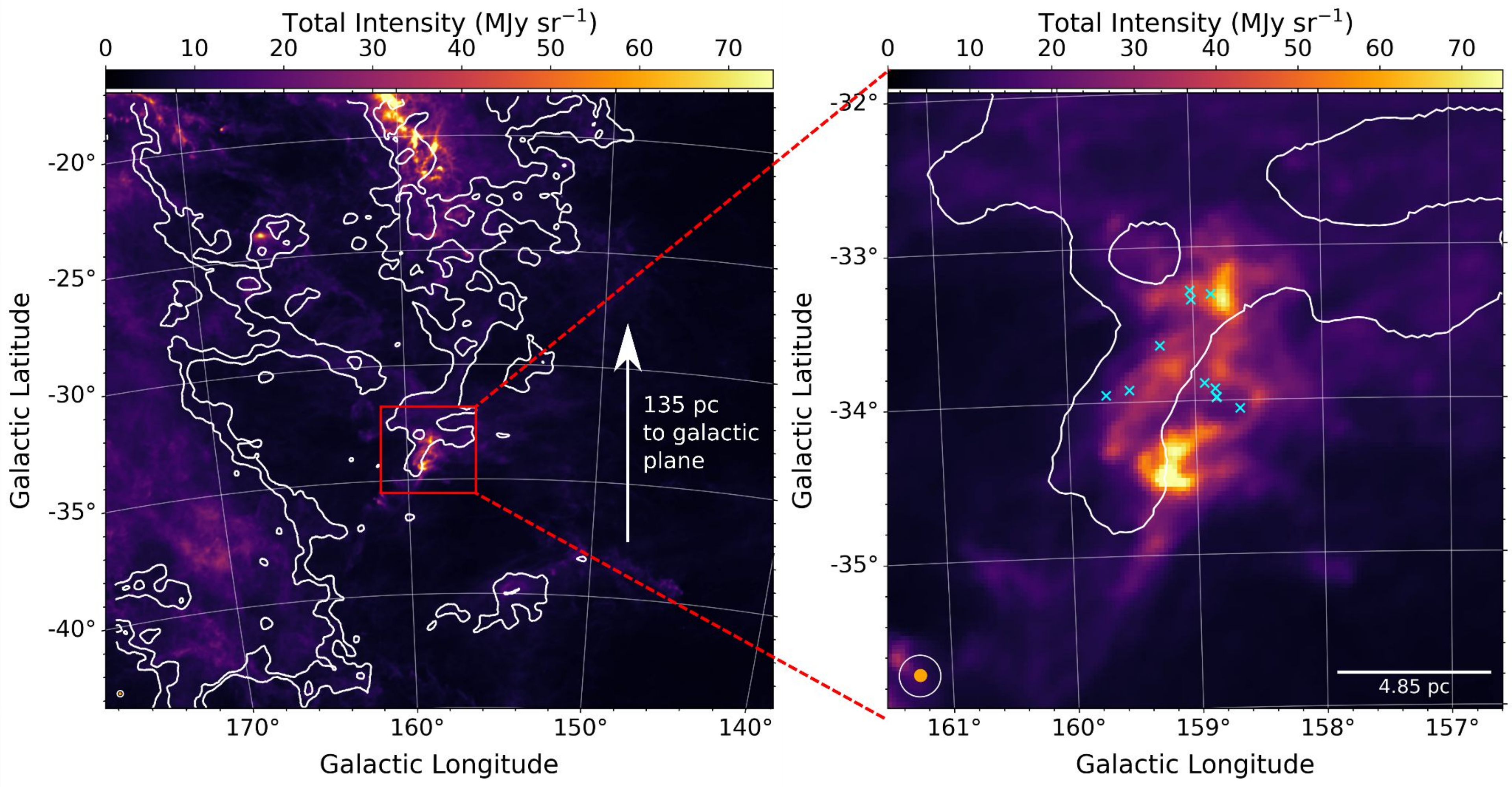
—> **~160 pc from the centre** of the galactic disk.

Contains around 15 T Tauri stars, might be slightly more evolved than the Taurus dark cloud (Luhman, 2001)

Estimated age 2 Myr from T Tauri disk frequency (Fang, van Boekel+2013)

Possibly a site of triggered star formation due to a supernova (Moriarty-Schieven+1997).

MBM 12



Colorscale: Planck 353 GHz I Stokes dust continuum. Contour: HI4PI HI column density at levels [1.04, 1.81] × 10^{21} cm^{-2}

Observations

Observations

Observed MBM12 for 65h with Taeduk Radio Astronomy Observatory 13.7 m

Toward (l,b) = (159° 21' 2.52", - 34° 19' 23.16")

Made scans with 0.6° tiles in Galactic latitude and longitude directions.

Mosaic Tiles to produce ~ 2° x 2° cubes.

^{12}CO (J=1-0) 115.2712 GHz (achieved σ = 0.30 K)

^{13}CO (J=1-0) 110.2013 GHz (achieved σ = 0.15 K)

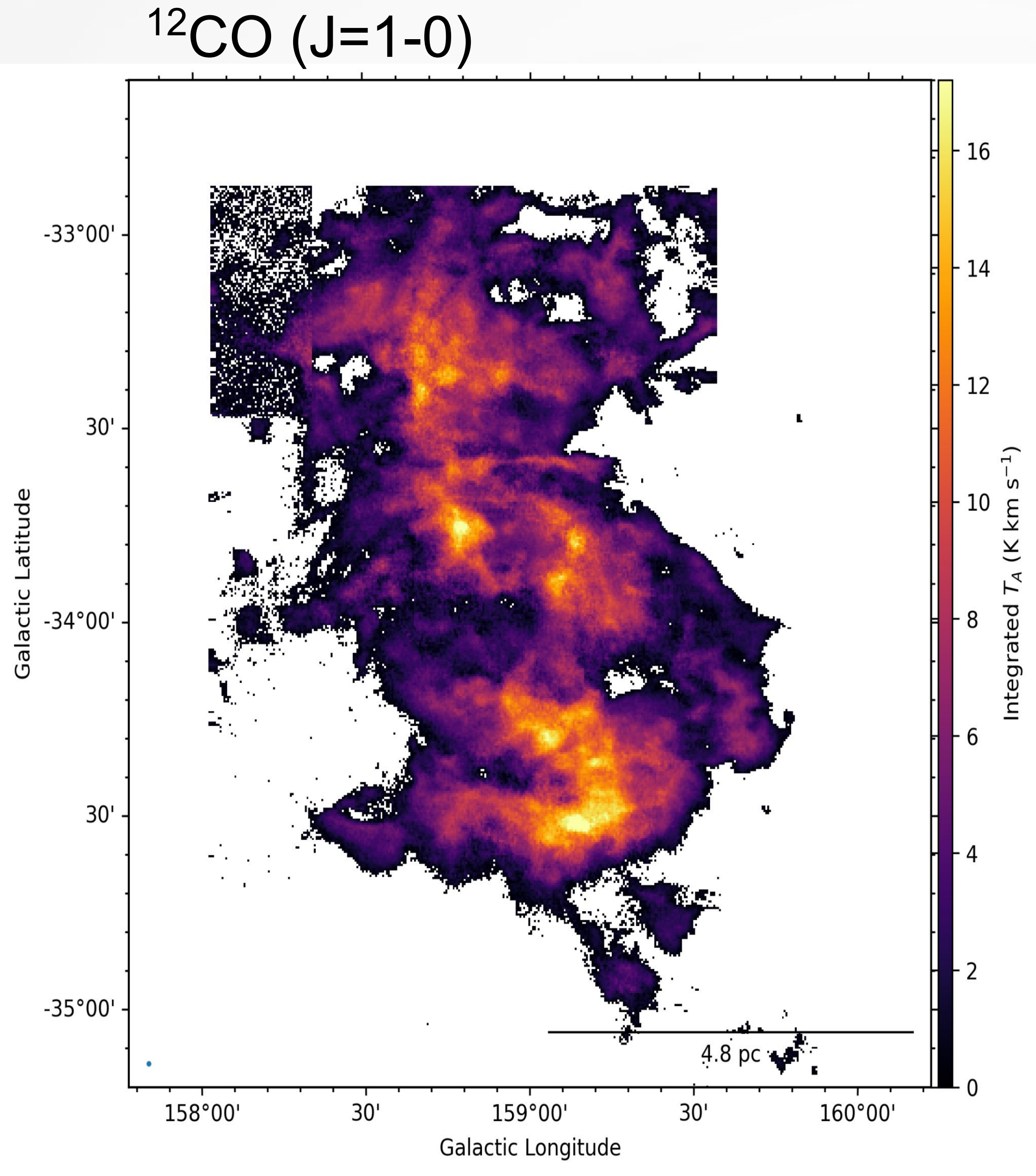
Spectral resolution = 0.2 km s^{-1}

HPBW = 45"

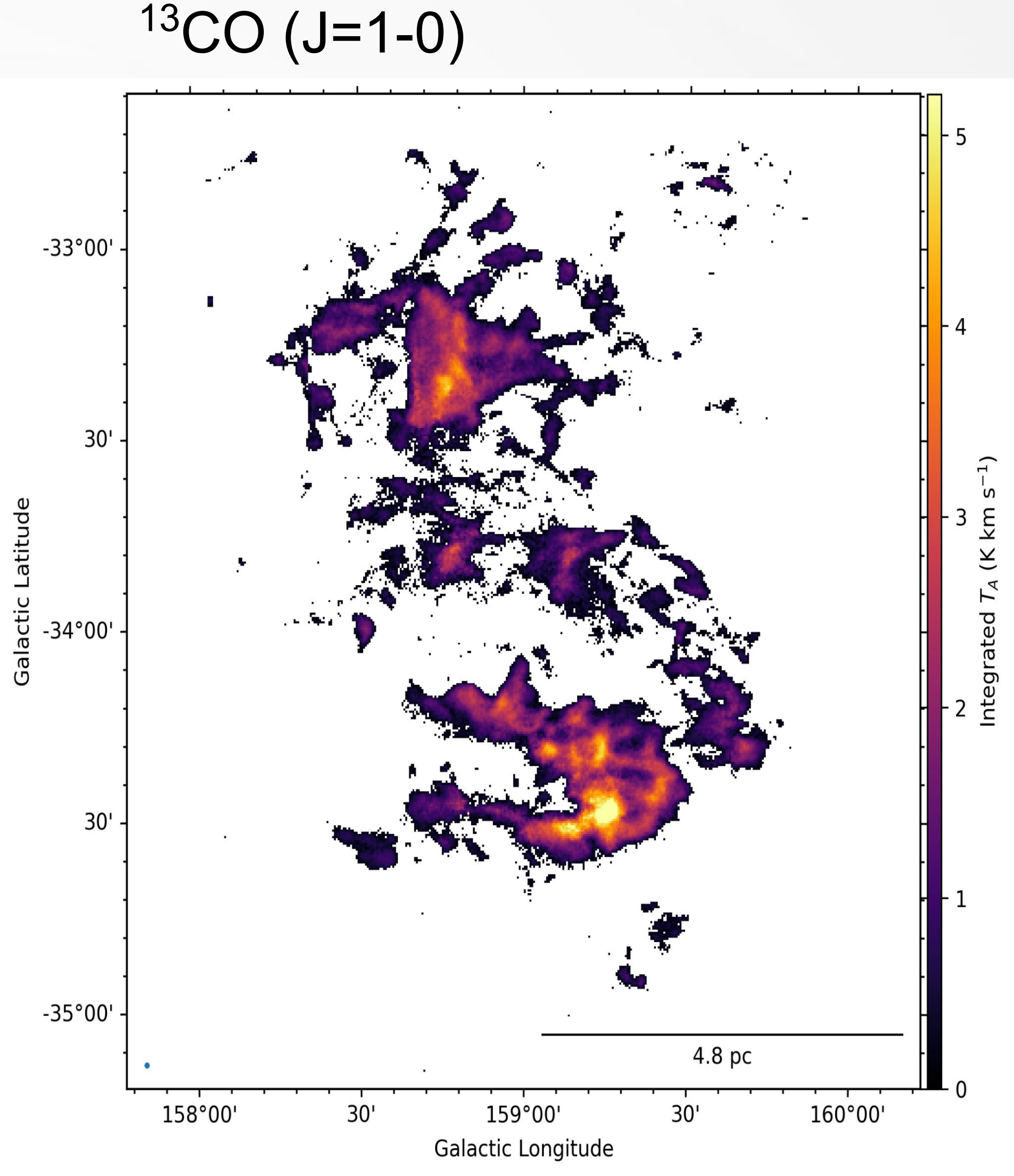
We also used archival **Herschel SPIRE maps** and **Planck 353 GHz maps** (smoothed to 7')

Results

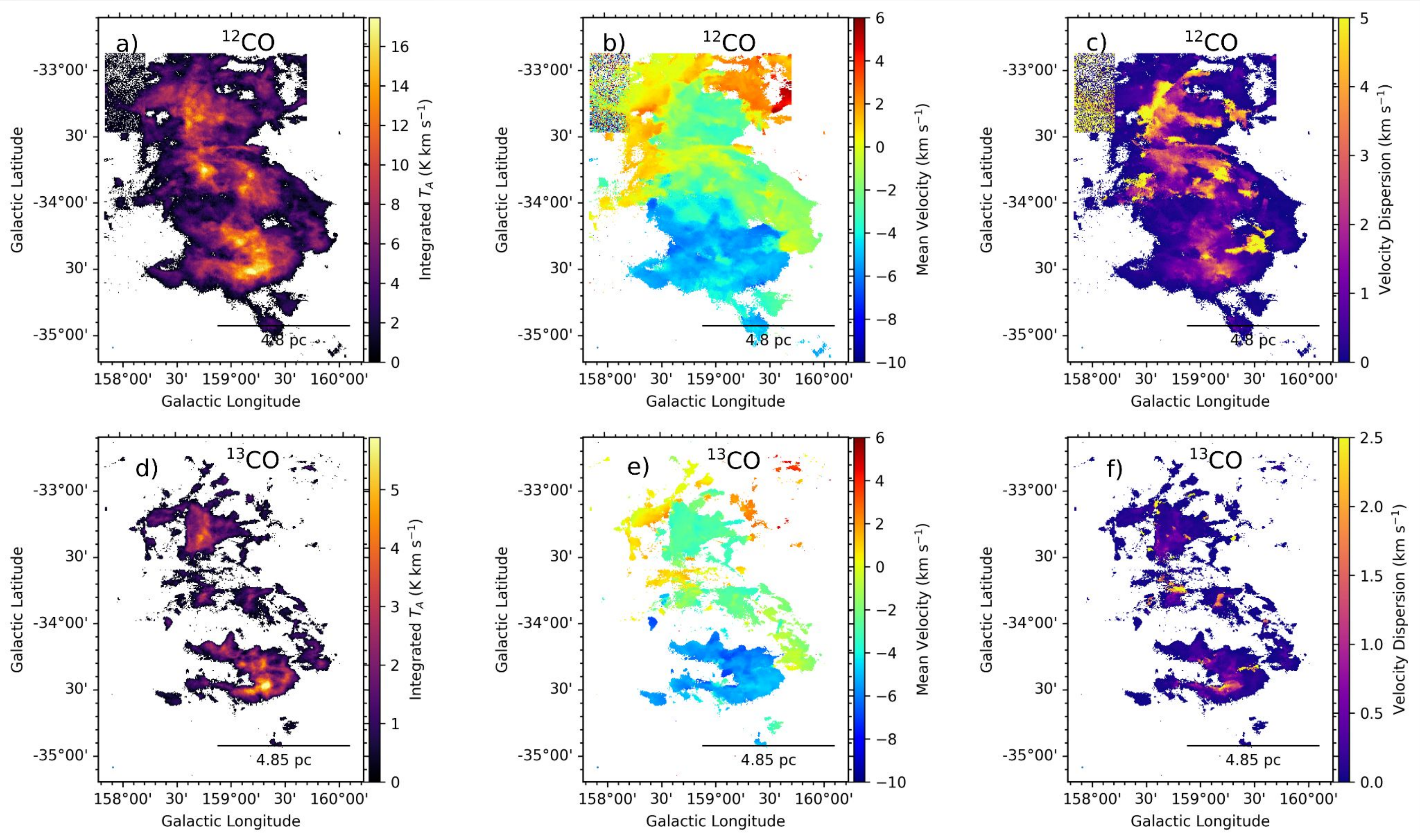
TRAO



^{12}CO (J=1-0)
-33°00'
30'
-34°00'
30'
-35°00'
Galactic Latitude
158°00'
30'
159°00'
30'
160°00'
Galactic Longitude
4.8 pc
0
2
4
6
8
10
12
14
16
Integrated T_A (K km s^{-1})



^{13}CO (J=1-0)
-33°00'
30'
-34°00'
30'
-35°00'
Galactic Latitude
158°00'
30'
159°00'
30'
160°00'
Galactic Longitude
4.8 pc
0
1
2
3
4
5
Integrated T_A (K km s^{-1})



a) ^{12}CO
b) ^{12}CO
c) ^{12}CO
d) ^{13}CO
e) ^{13}CO
f) ^{13}CO
Galactic Latitude
Galactic Longitude
-33°00'
30'
-34°00'
30'
-35°00'
158°00'
30'
159°00'
30'
160°00'
4.8 pc
4.85 pc
Integrated T_A (K km s^{-1})
Mean Velocity (km s^{-1})
Velocity Dispersion (km s^{-1})

Herschel and Planck

Observations - Archival

Archival Herschel

Herschel SPIRE 500 µm, 350 µm and 250 µm dust continuum.

Only covered the lower half of MBM12.

Modified Black Body (MBB) fits to estimate optical depth, dust temperature and column density at 500 µm resolution. Underestimates column density at coldest regions.

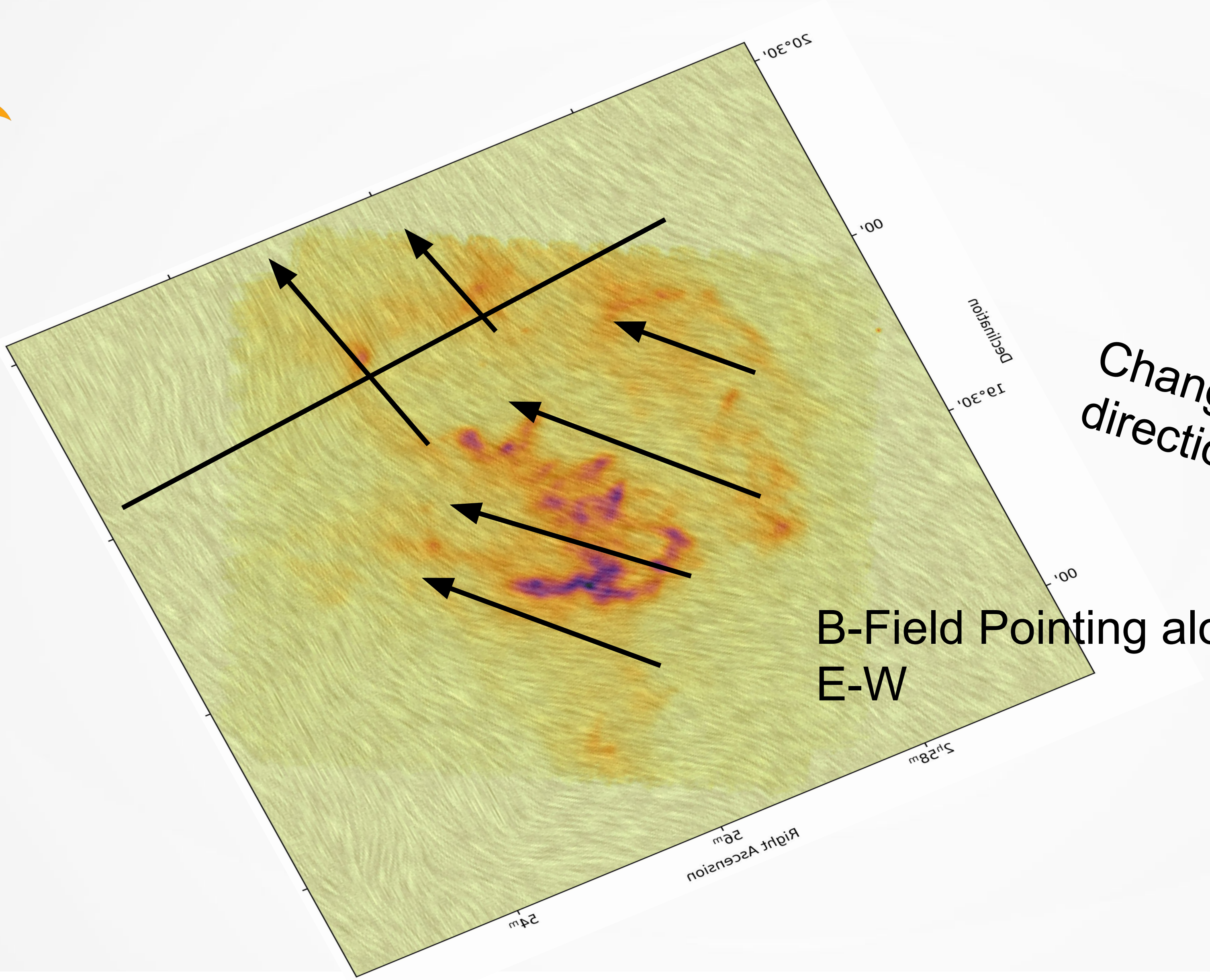
I_ν is the measured intensity in MJy sr^{-1}

$\kappa_\nu = 0.1$ cm^2 g^{-1} $(\nu$ / 1000 GHz$)^\beta$

Assumed $\beta = 2.0$

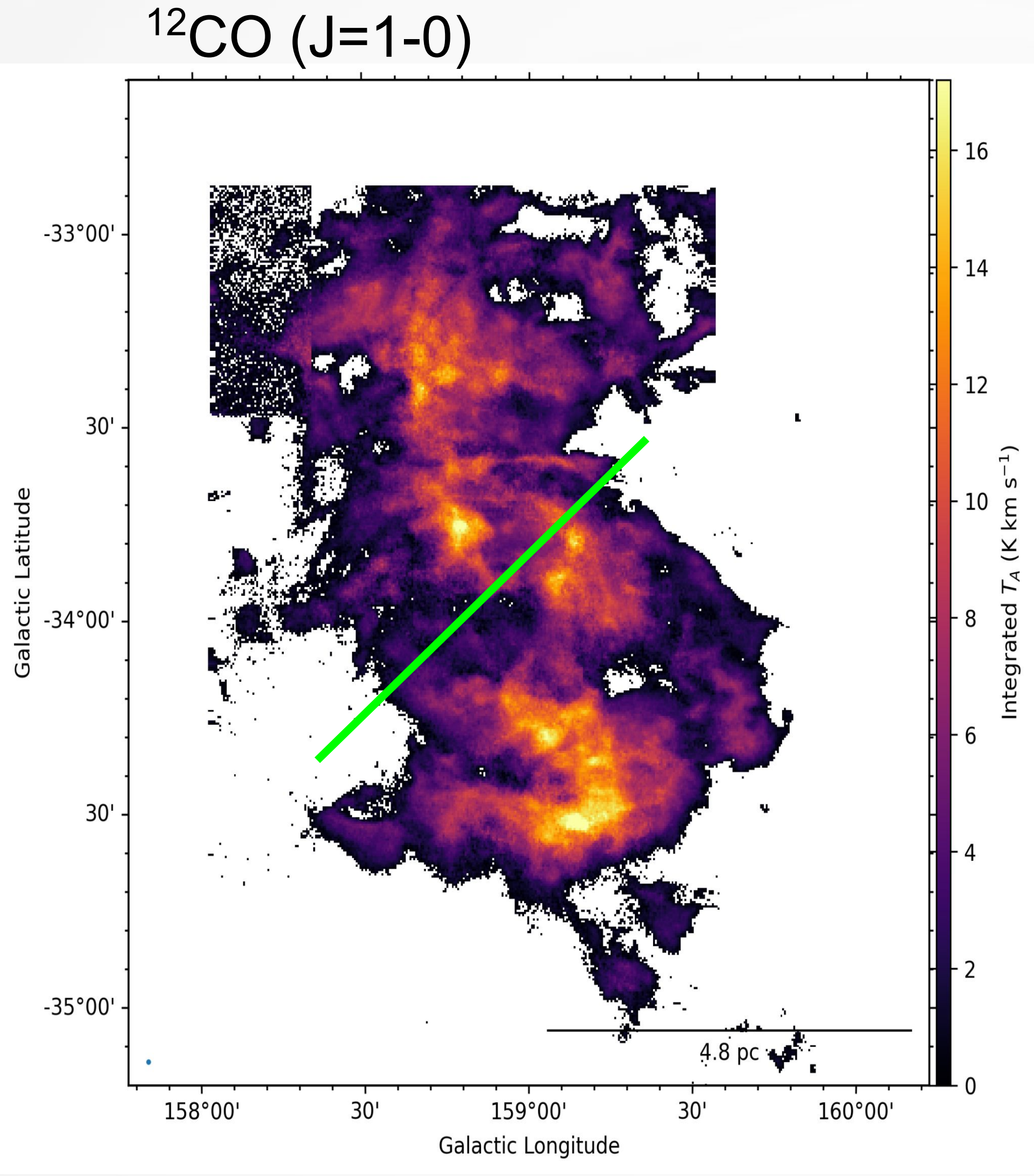
B_ν is the Planck function.

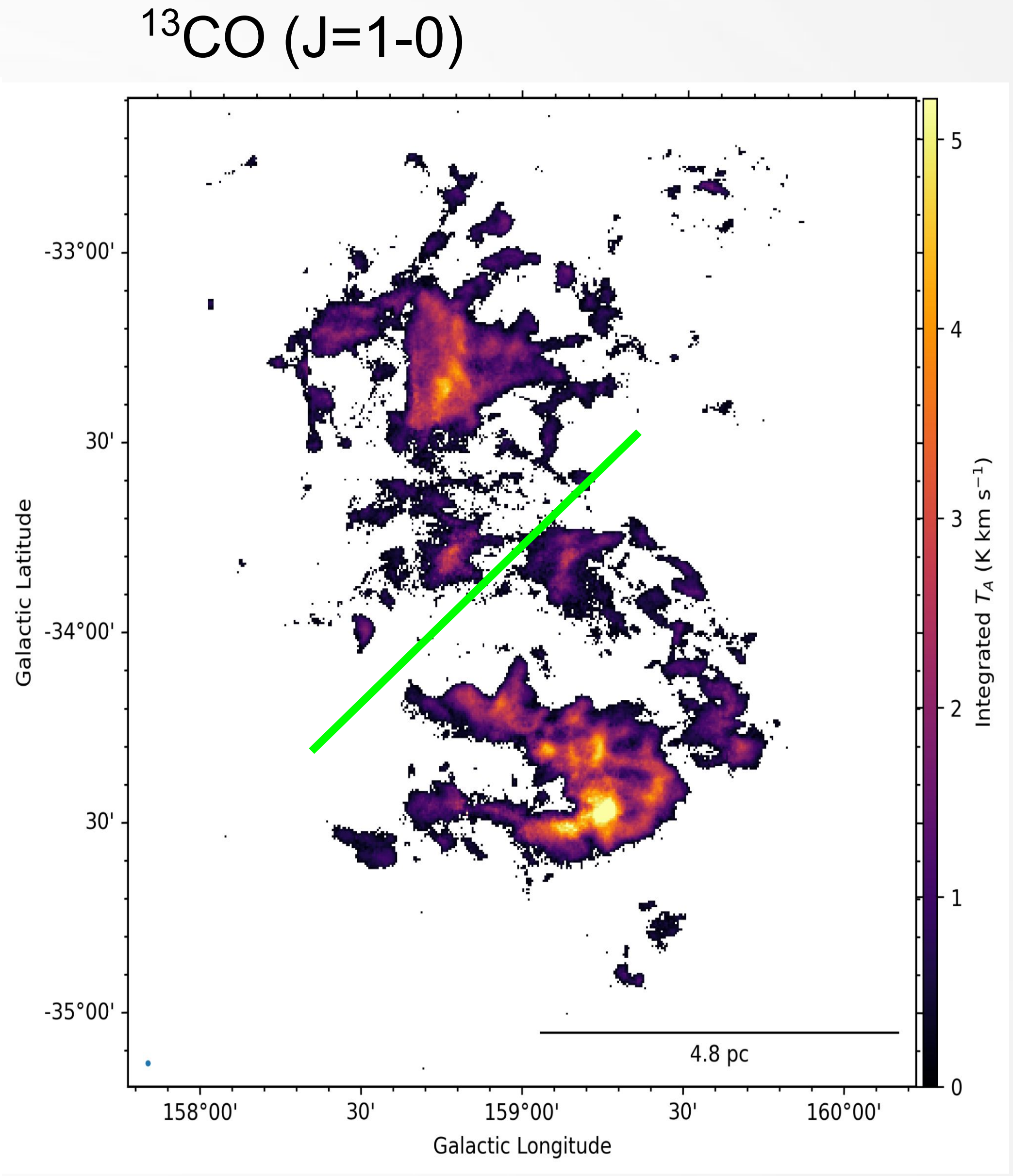
$$N(\mathrm{H_2}) = \frac{I_\nu}{B_\nu(T_{\mathrm{dust}})\kappa_\nu \mu_{\mathrm{H_2}} m_{\mathrm{H}}}$$



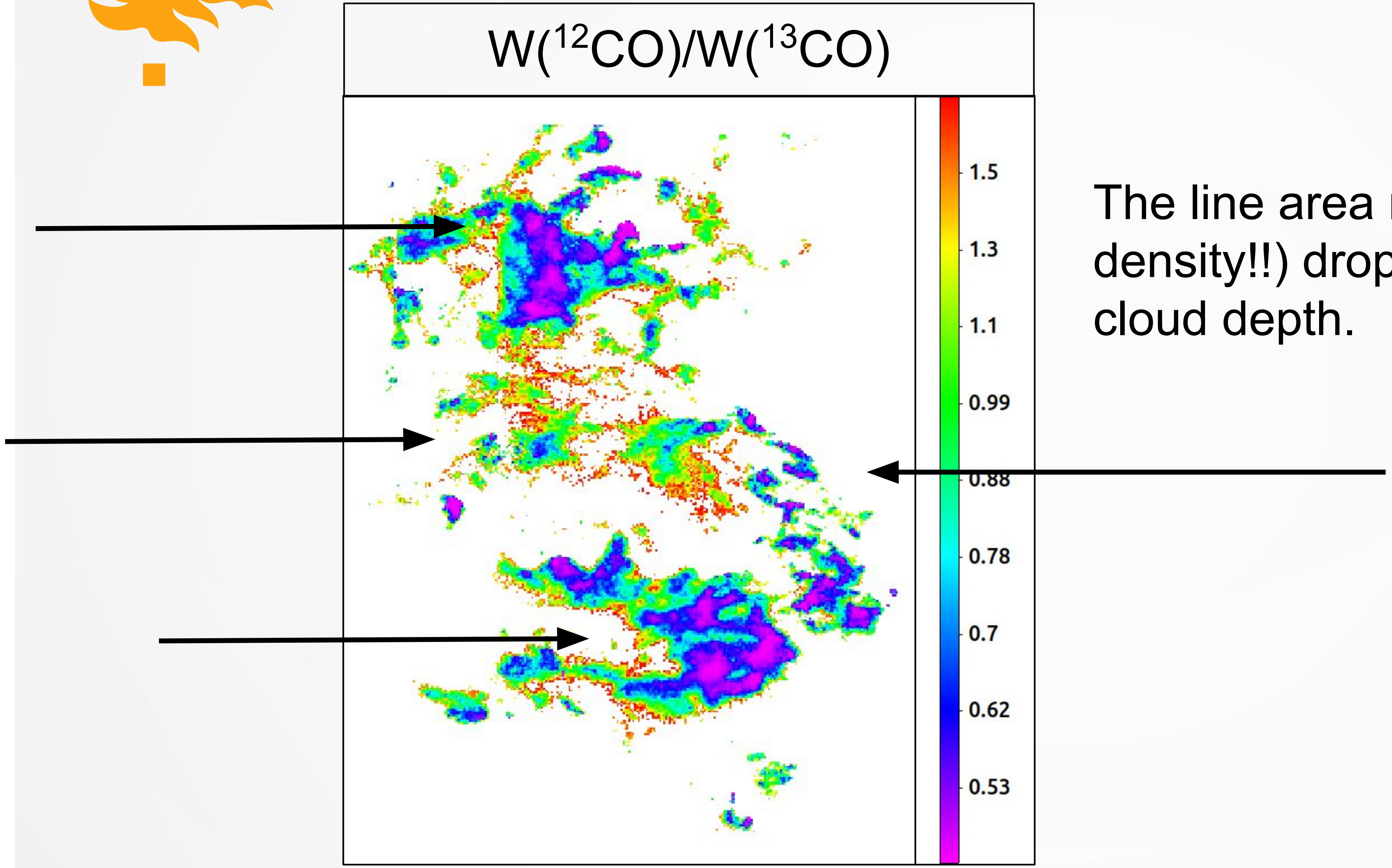
Change in direction

B-Field Pointing along galactic E-W


^{12}CO (J=1-0)
-33°00'
30'
-34°00'
30'
-35°00'
Galactic Latitude
158°00'
30'
159°00'
30'
160°00'
Galactic Longitude
4.8 pc
0
2
4
6
8
10
12
14
16
Integrated T_A (K km s^{-1})


^{13}CO (J=1-0)
-33°00'
30'
-34°00'
30'
-35°00'
Galactic Latitude
158°00'
30'
159°00'
30'
160°00'
Galactic Longitude
4.8 pc
0
1
2
3
4
5
Integrated T_A (K km s^{-1})

Results - Environmental Characterization



The line area ratio (not the column density!!) drops in every region with cloud depth.

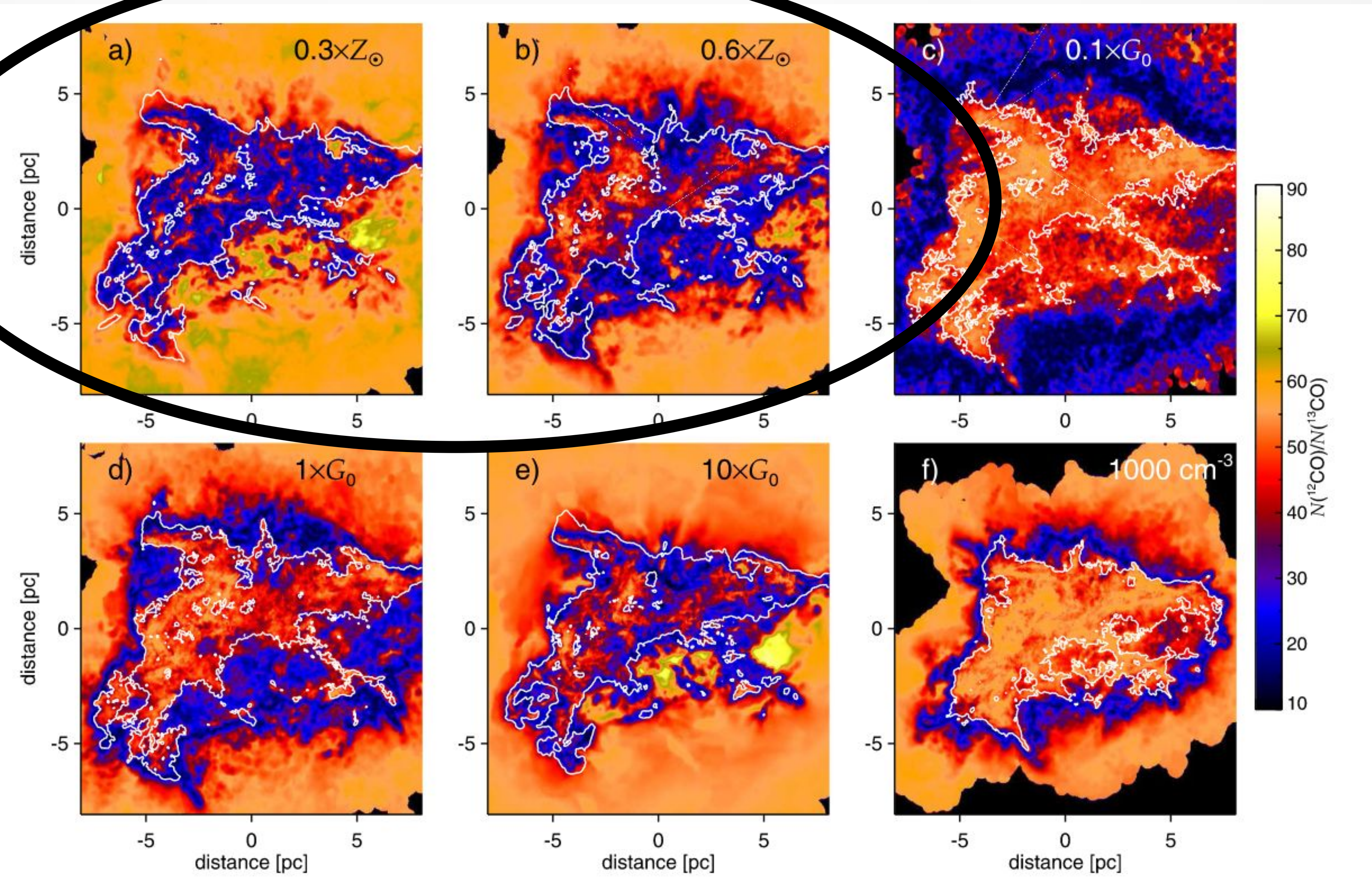
Comparison with Simulation

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **445,** 4055–4072 (2014) doi:10.1093/mnras/stu2013

The ^{12}CO/^{13}CO ratio in turbulent molecular clouds

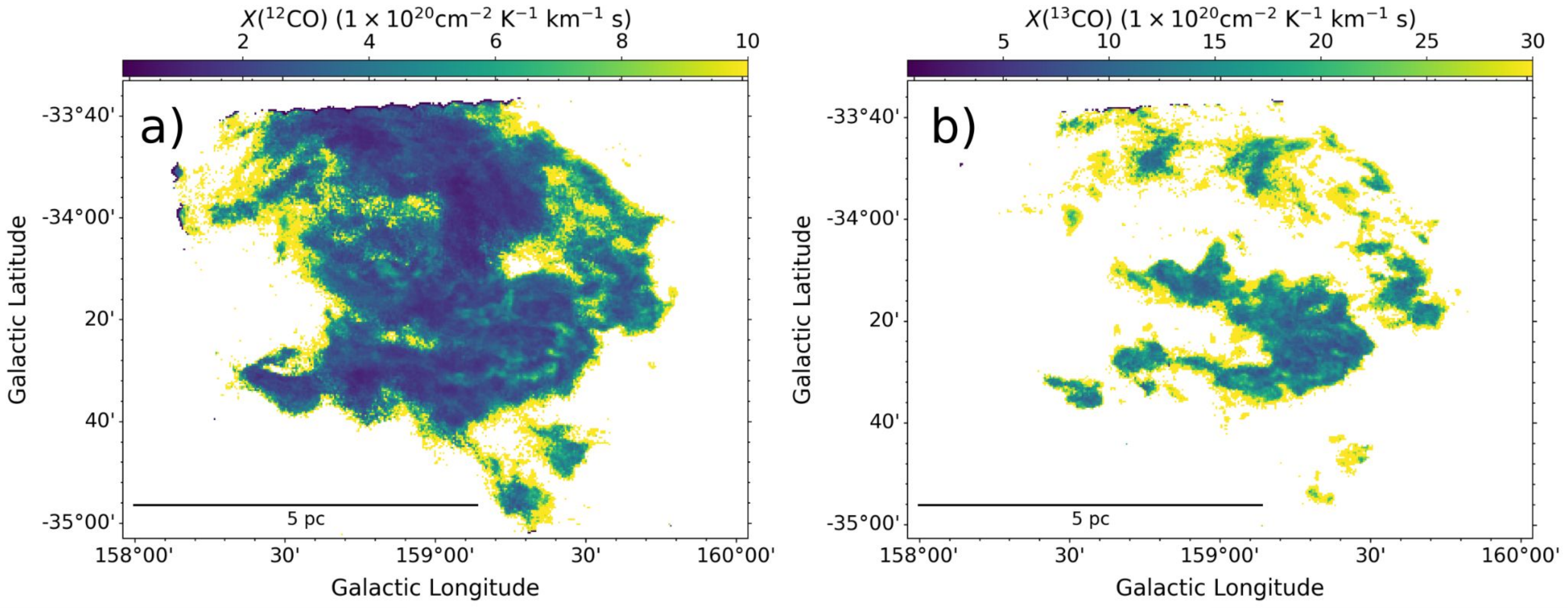
László Szűcs,★† Simon C. O. Glover and Ralf S. Klessen
Institut für Theoretische Astrophysik, Zentrum für Astronomie, Universität Heidelberg, Albert-Ueberle-Str. 2, D-69120 Heidelberg, Germany

Comparison with Simulation

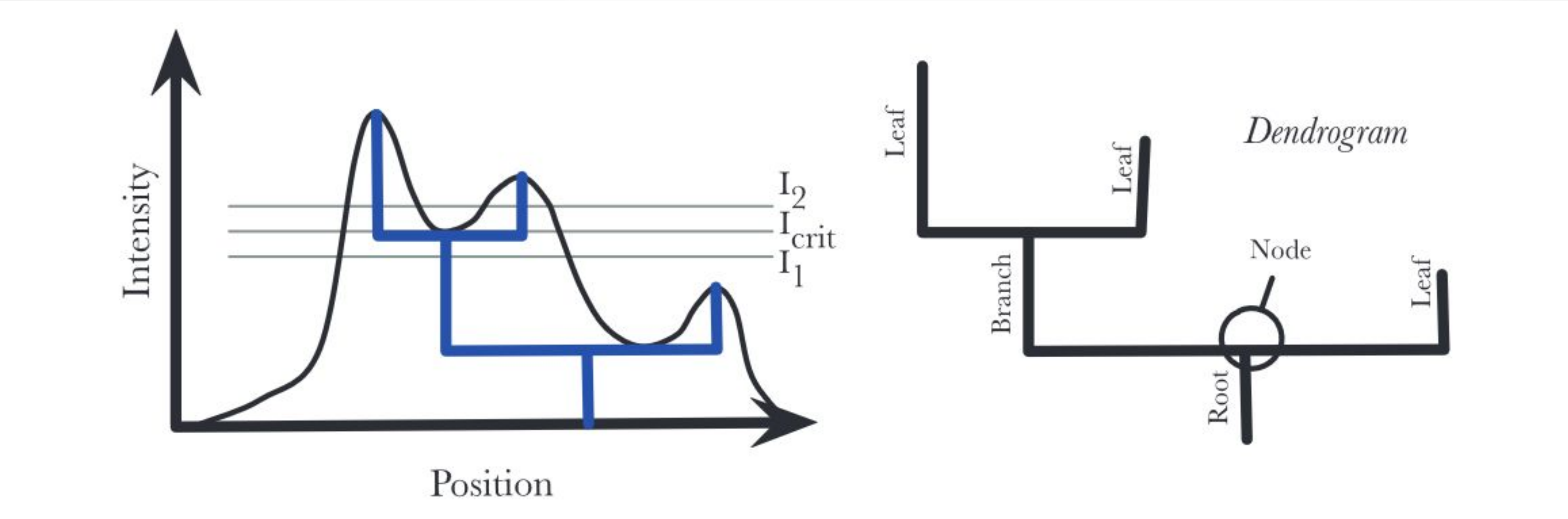


If the line area ratio is a good tracer of the column density ratio (??), then MBM12 is consistent with a cloud in a lower radiation field.

Results - Environmental Characterization

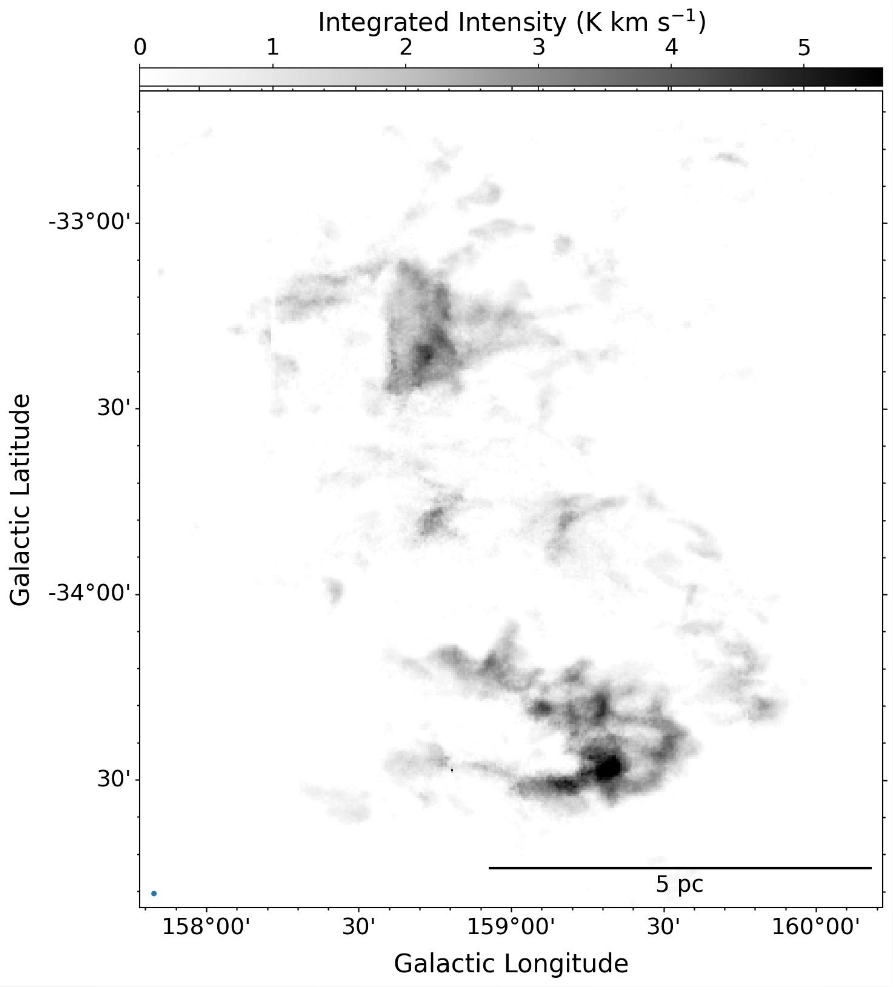


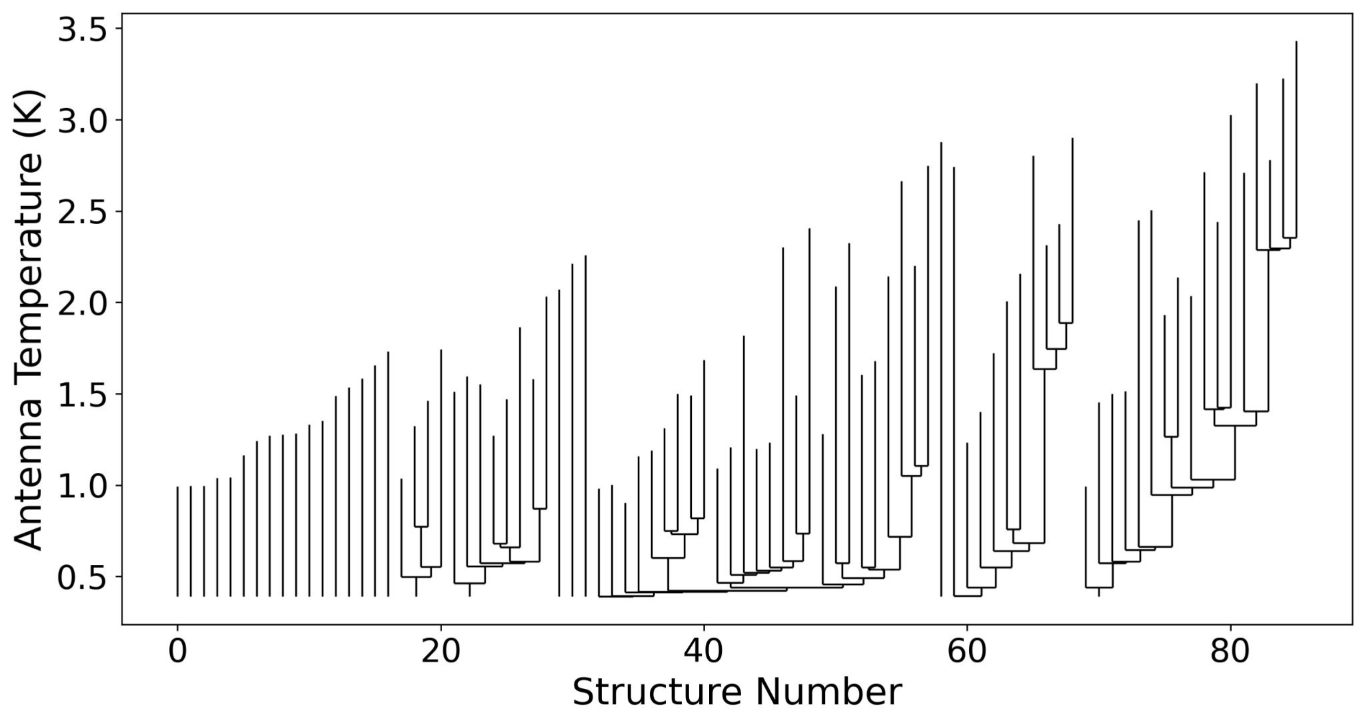
Results - Multi-Scale Dynamics



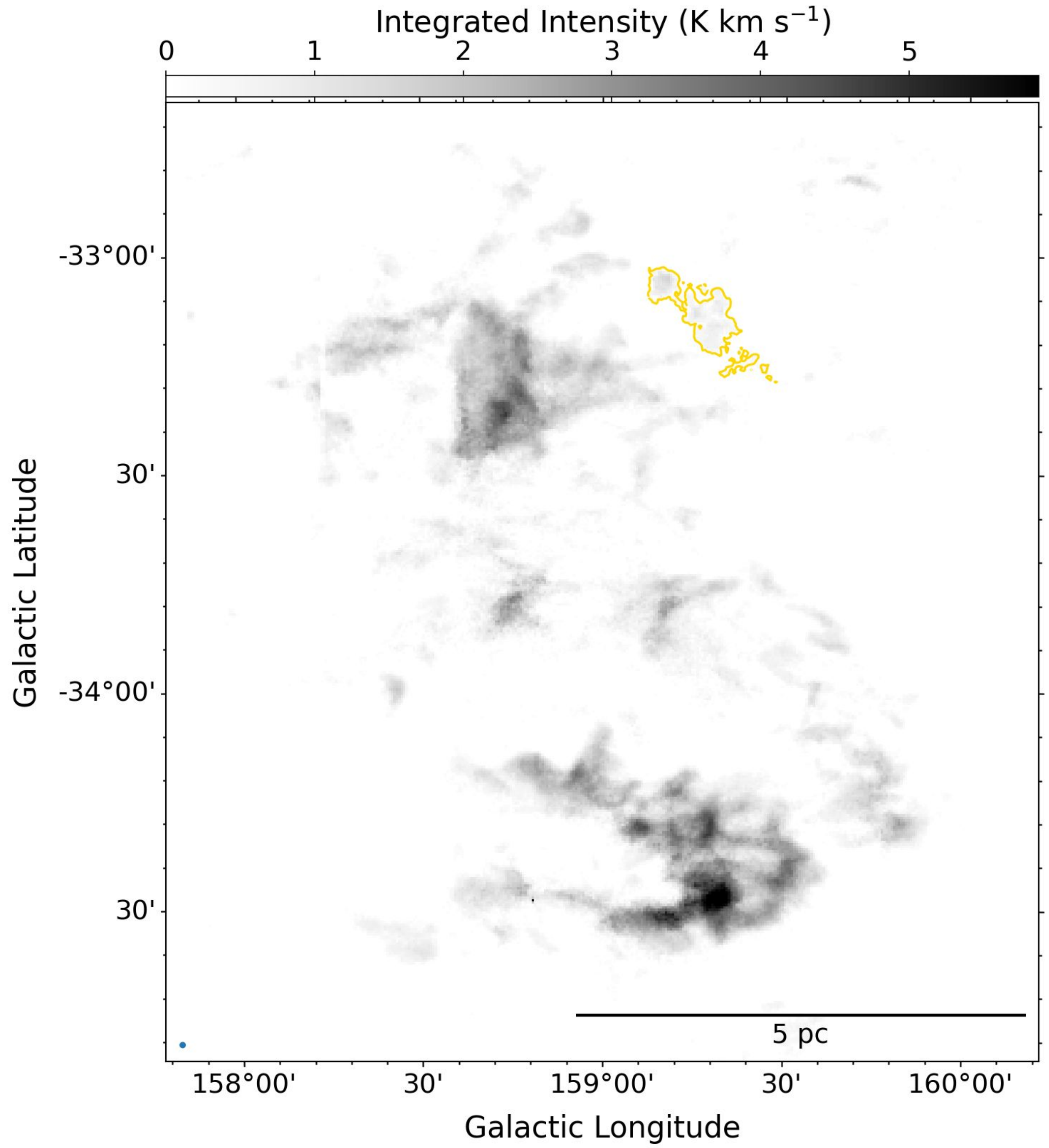
From Rosolowski+2008

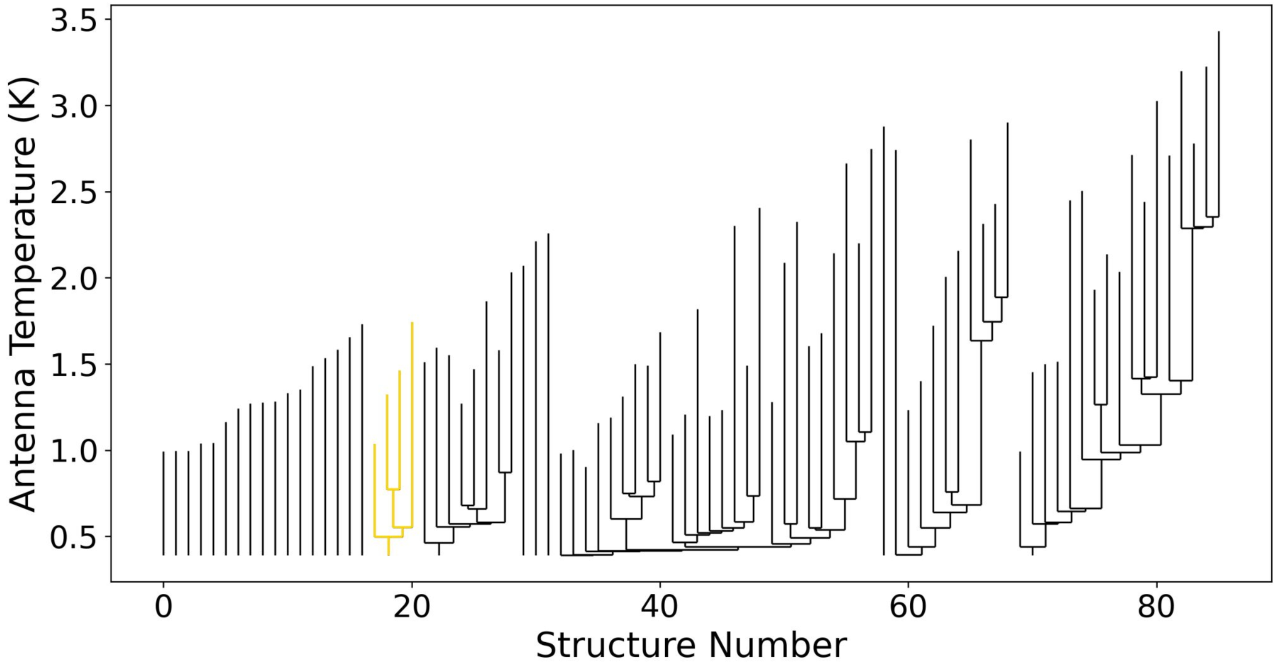
Results - Multi-Scale Dynamics

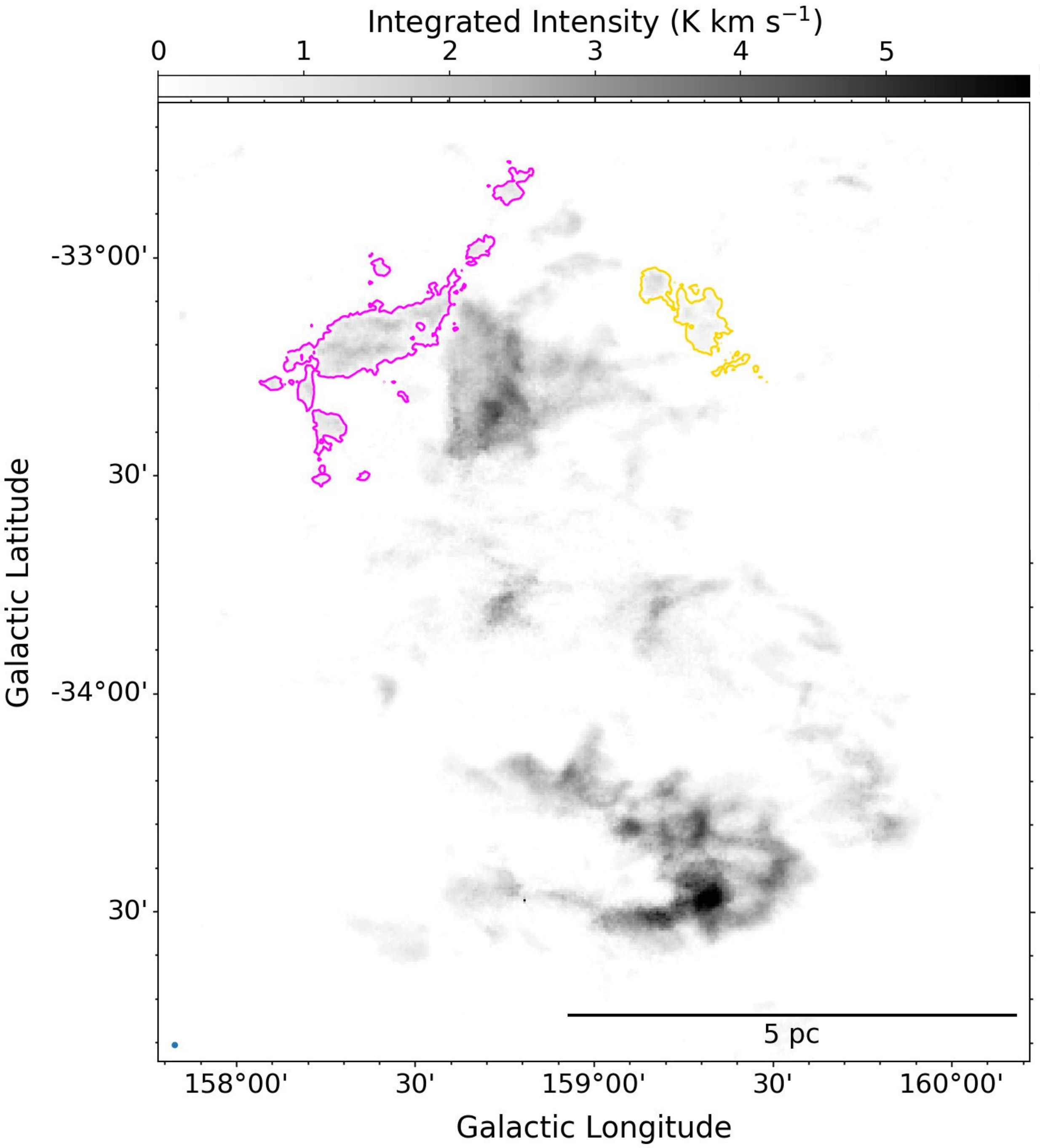


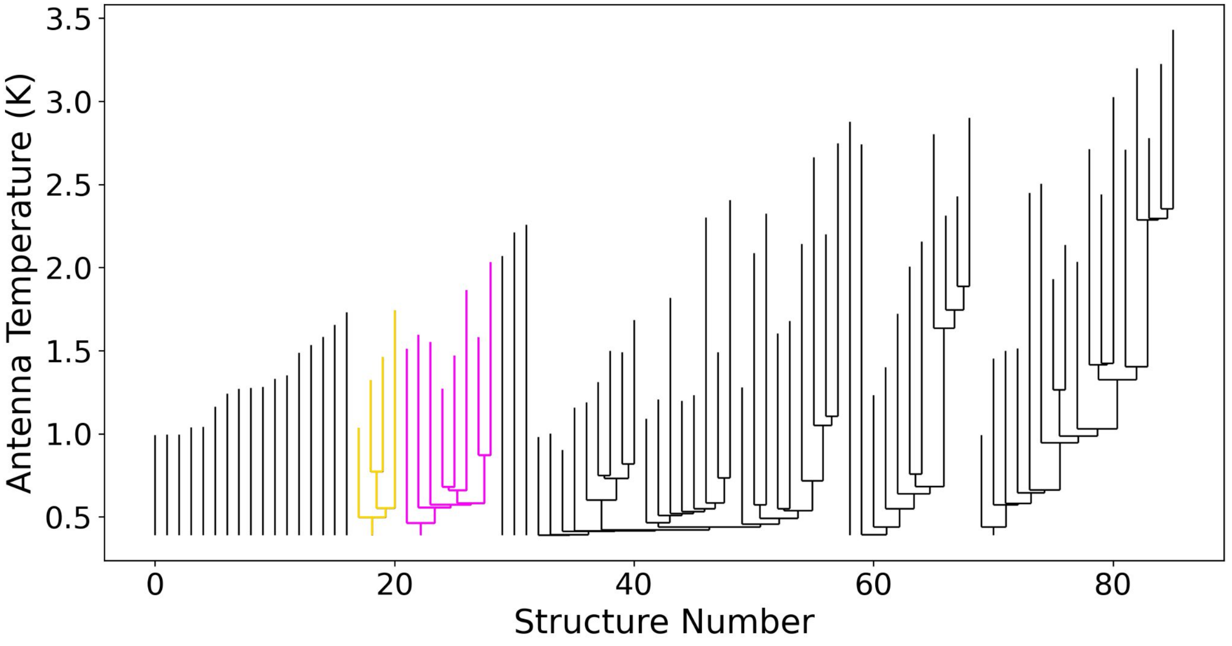


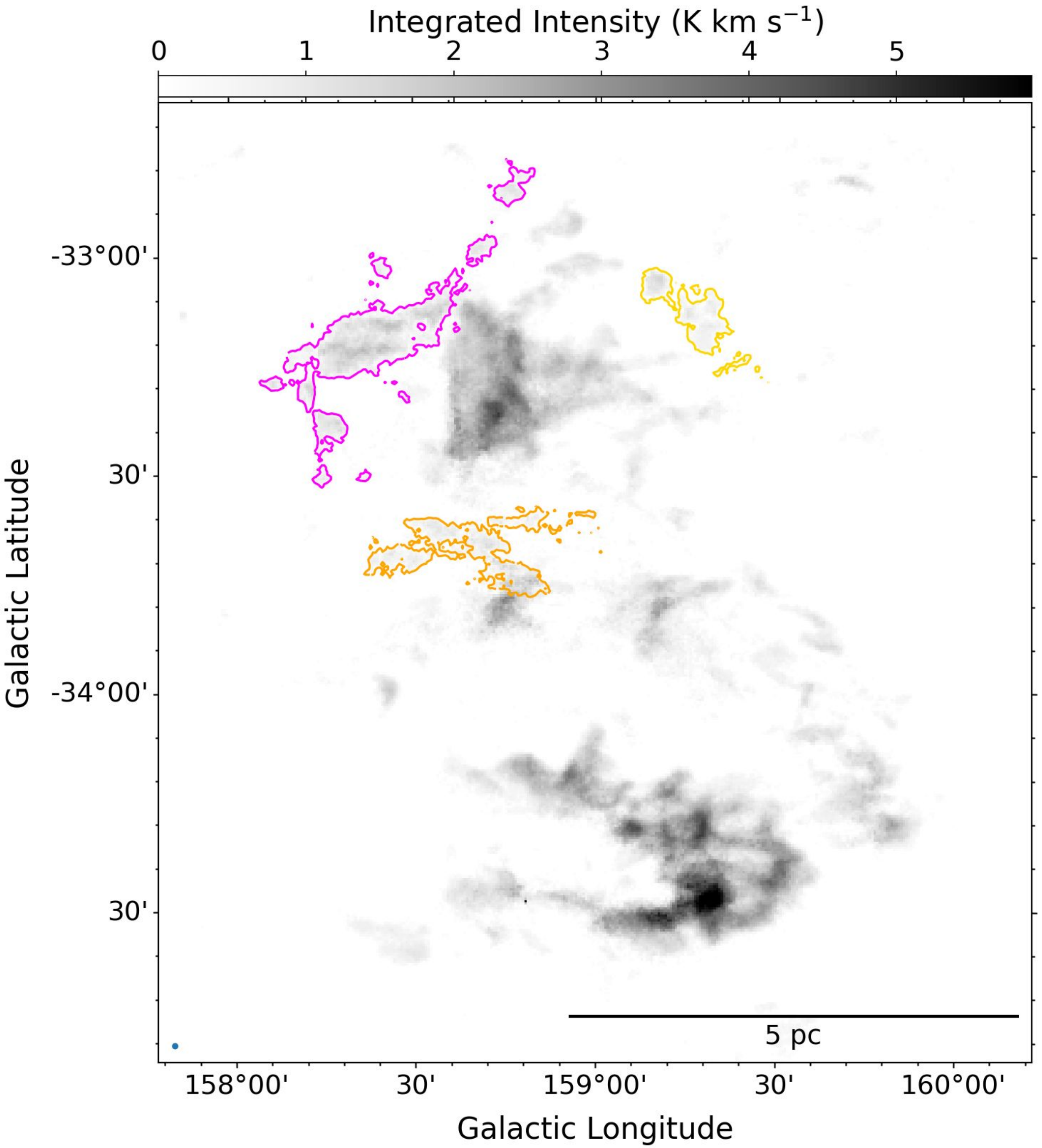
HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

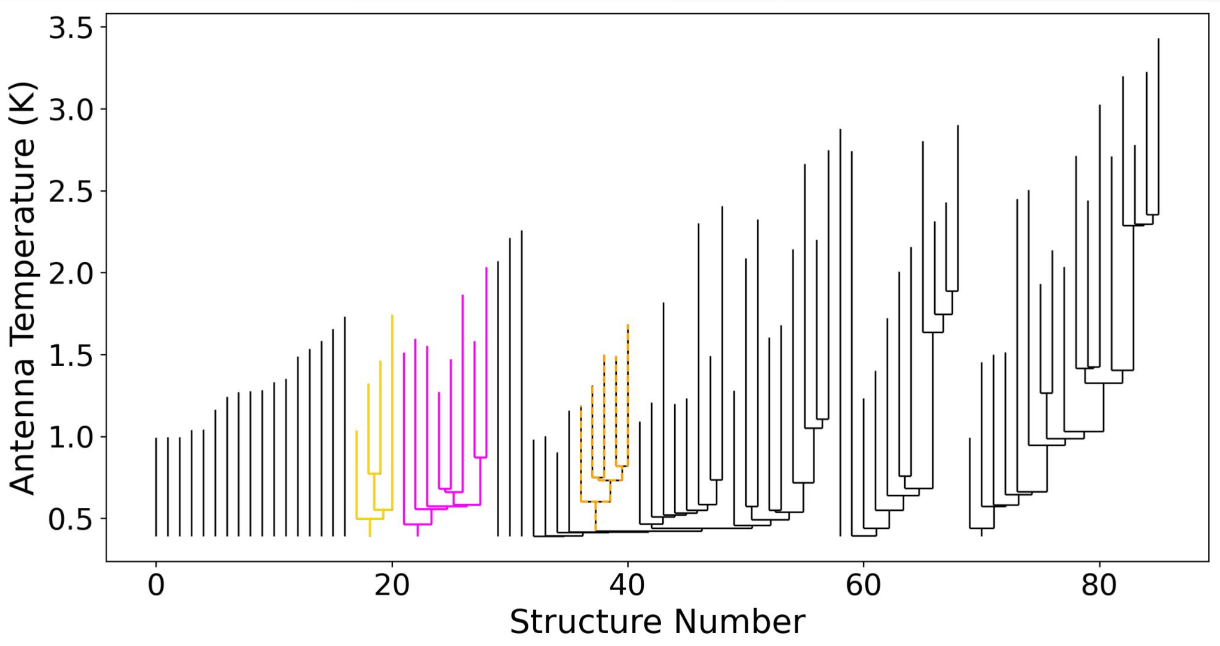

Integrated Intensity (K km s^{-1})
0
1
2
3
4
5
-33°00'
30'
-34°00'
30'
Galactic Latitude
5 pc
158°00'
30'
159°00'
30'
160°00'
Galactic Longitude

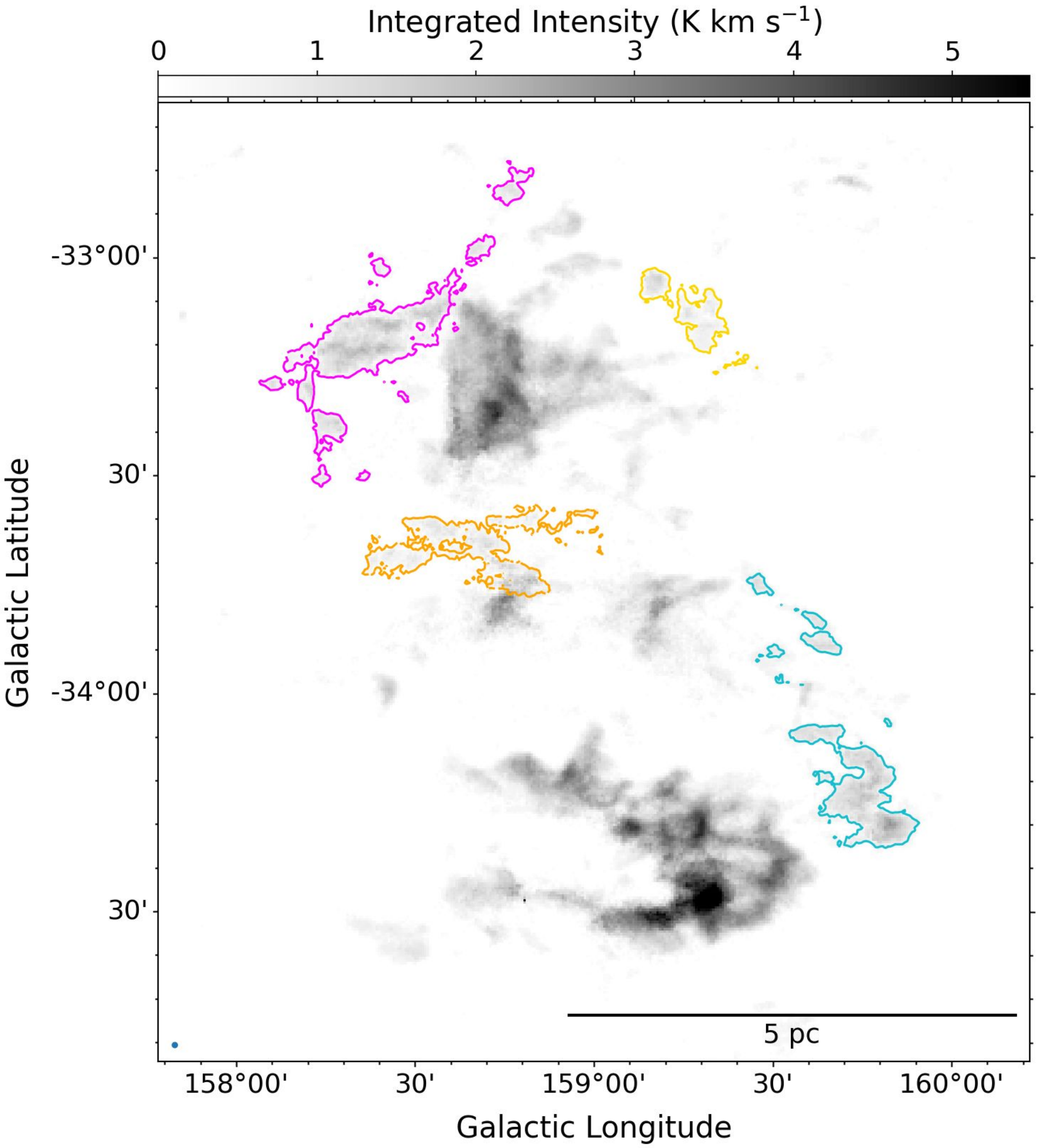

Antenna Temperature (K)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
20
40
60
80
Structure Number

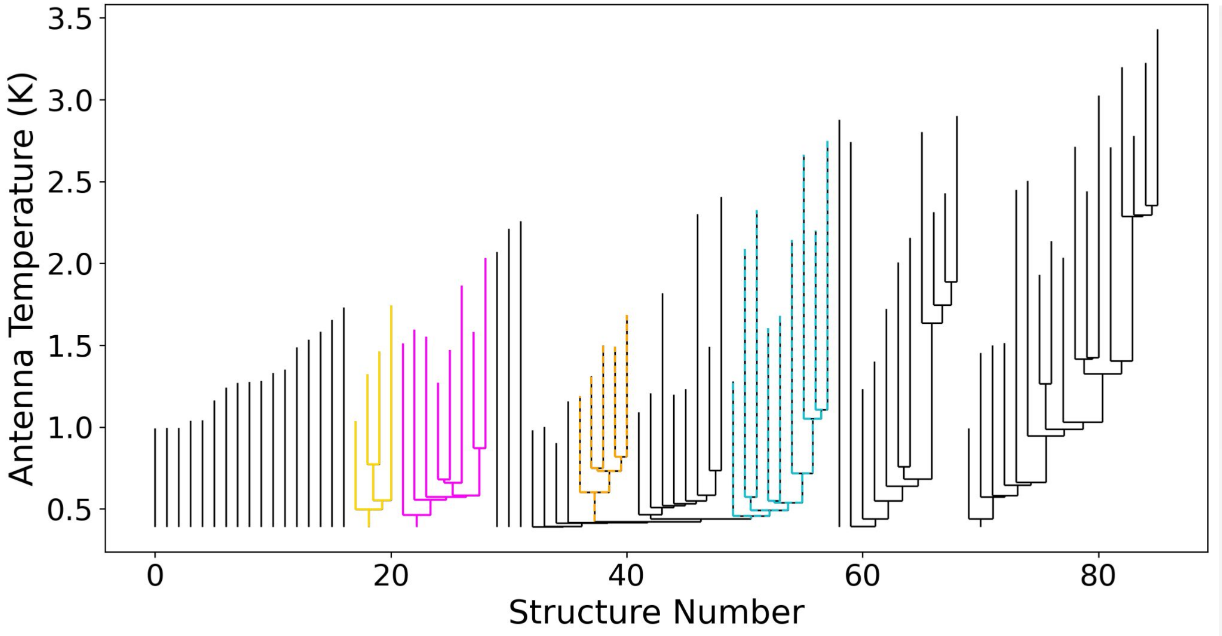

Integrated Intensity (K km s^{-1})
0
1
2
3
4
5
-33°00'
30'
-34°00'
30'
Galactic Latitude
5 pc
158°00'
30'
159°00'
30'
160°00'
Galactic Longitude

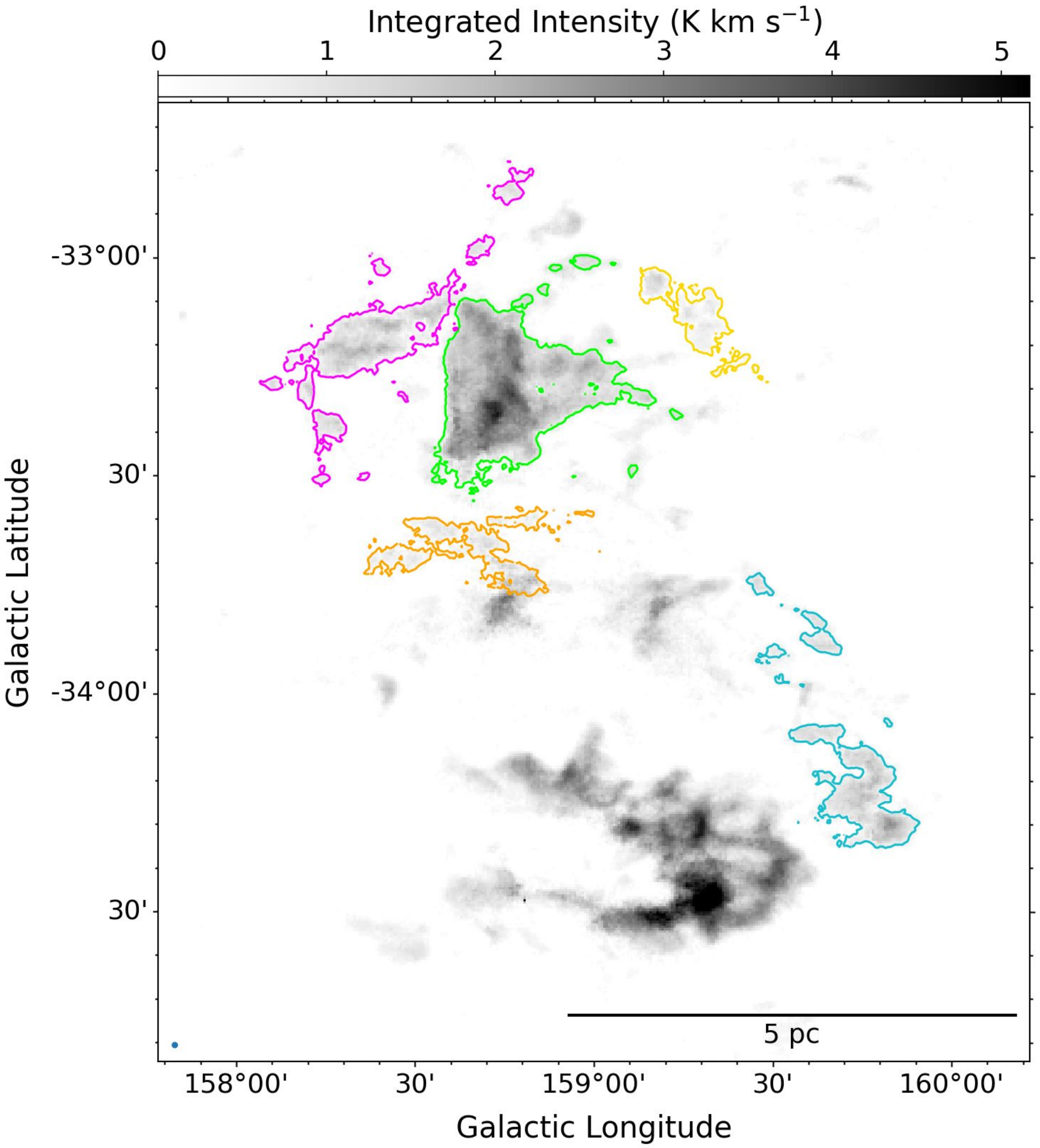

3.5
3.0
2.5
2.0
1.5
1.0
0.5
Antenna Temperature (K)
0
20
40
60
80
Structure Number

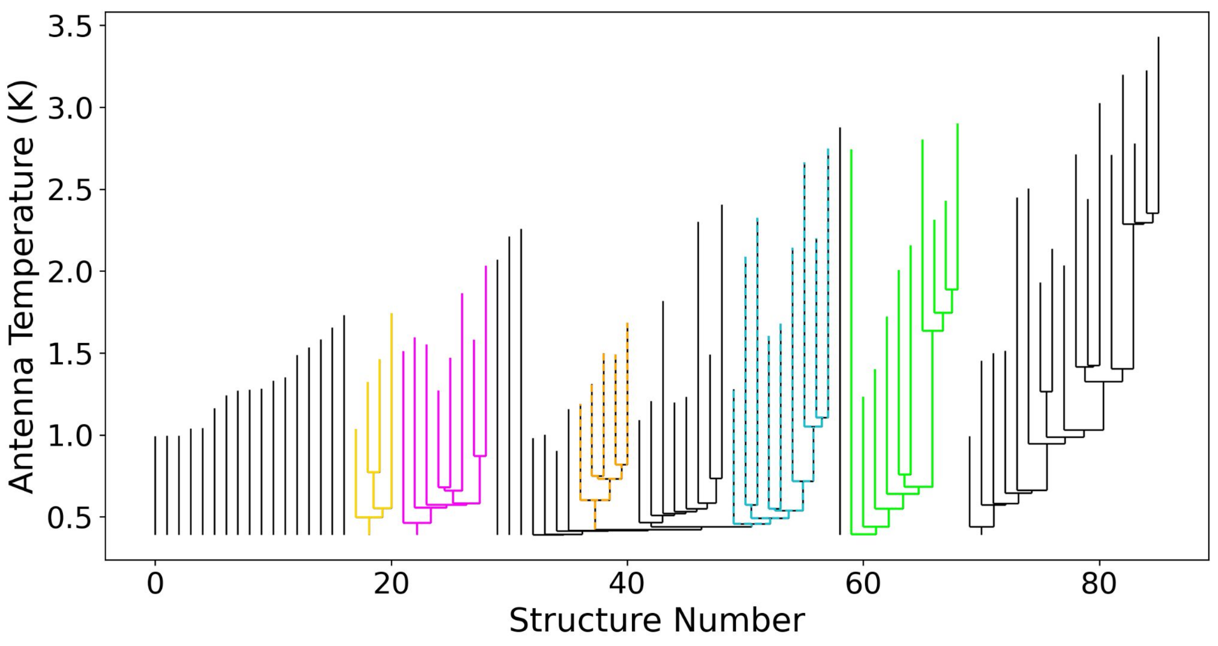

Integrated Intensity (K km s^{-1})
0
1
2
3
4
5
-33°00'
30'
-34°00'
30'
Galactic Latitude
158°00'
30'
159°00'
30'
160°00'
Galactic Longitude
5 pc

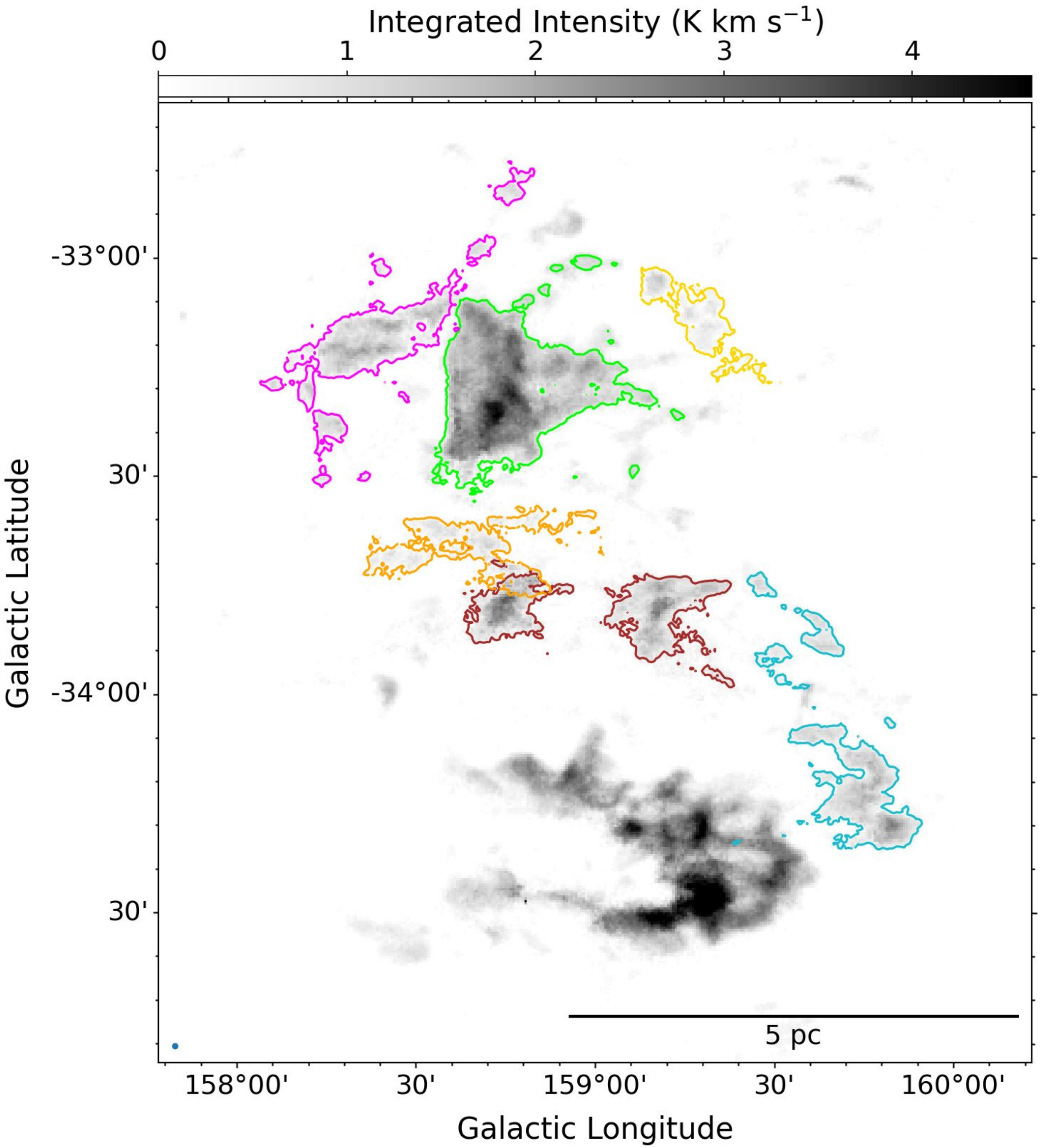

Antenna Temperature (K)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
20
40
60
80
Structure Number

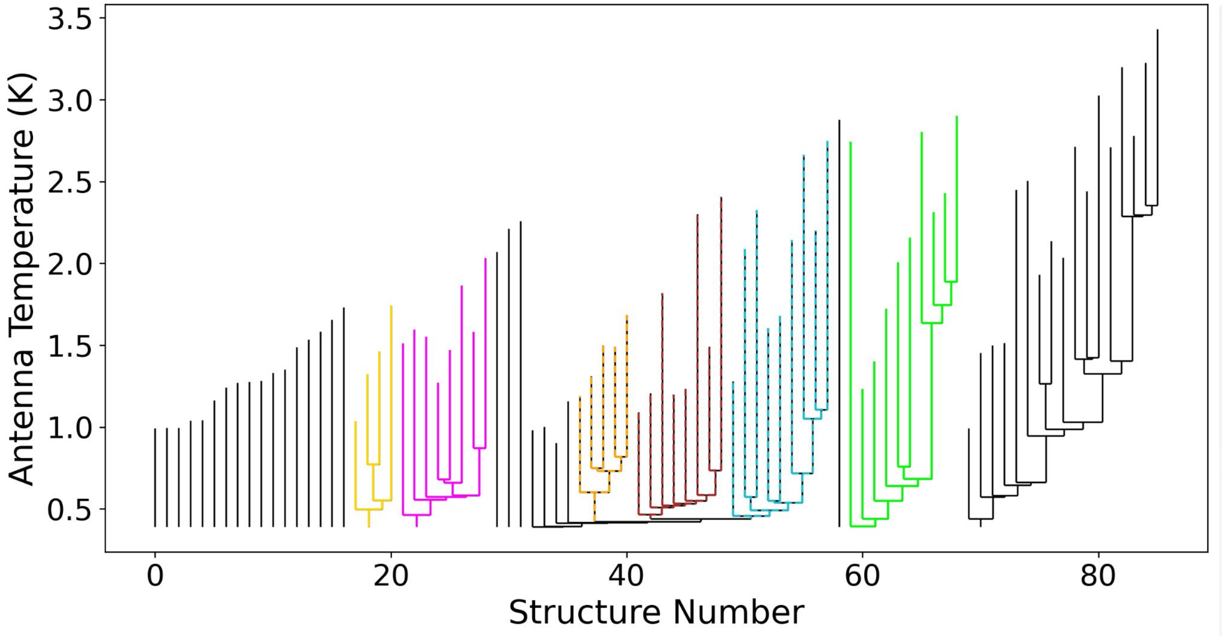

Integrated Intensity (K km s^{-1})
0 1 2 3 4 5
-33°00'
30'
-34°00'
30'
Galactic Latitude
5 pc
158°00' 30' 159°00' 30' 160°00'
Galactic Longitude

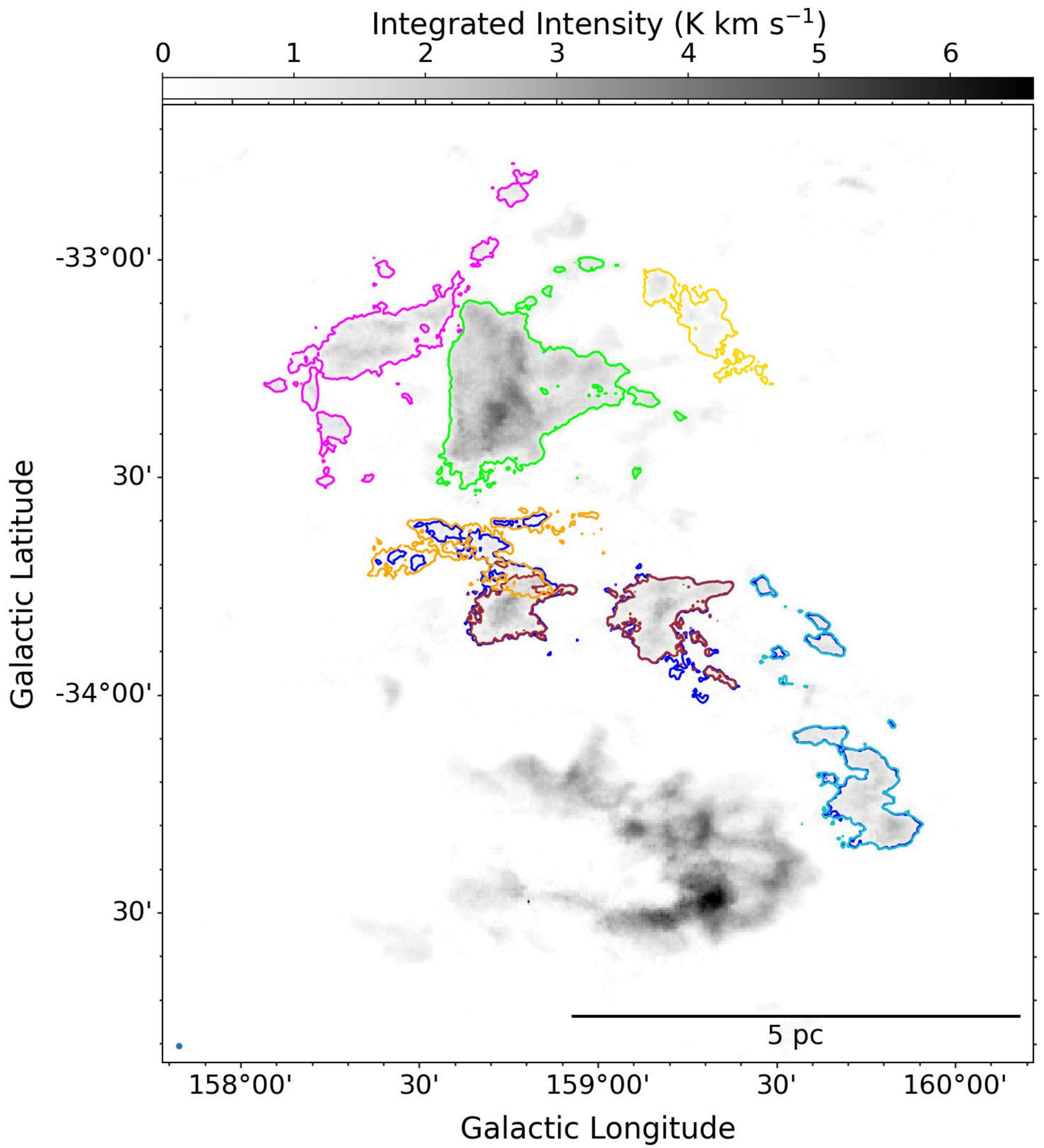

Antenna Temperature (K)
3.5 3.0 2.5 2.0 1.5 1.0 0.5
0 20 40 60 80
Structure Number

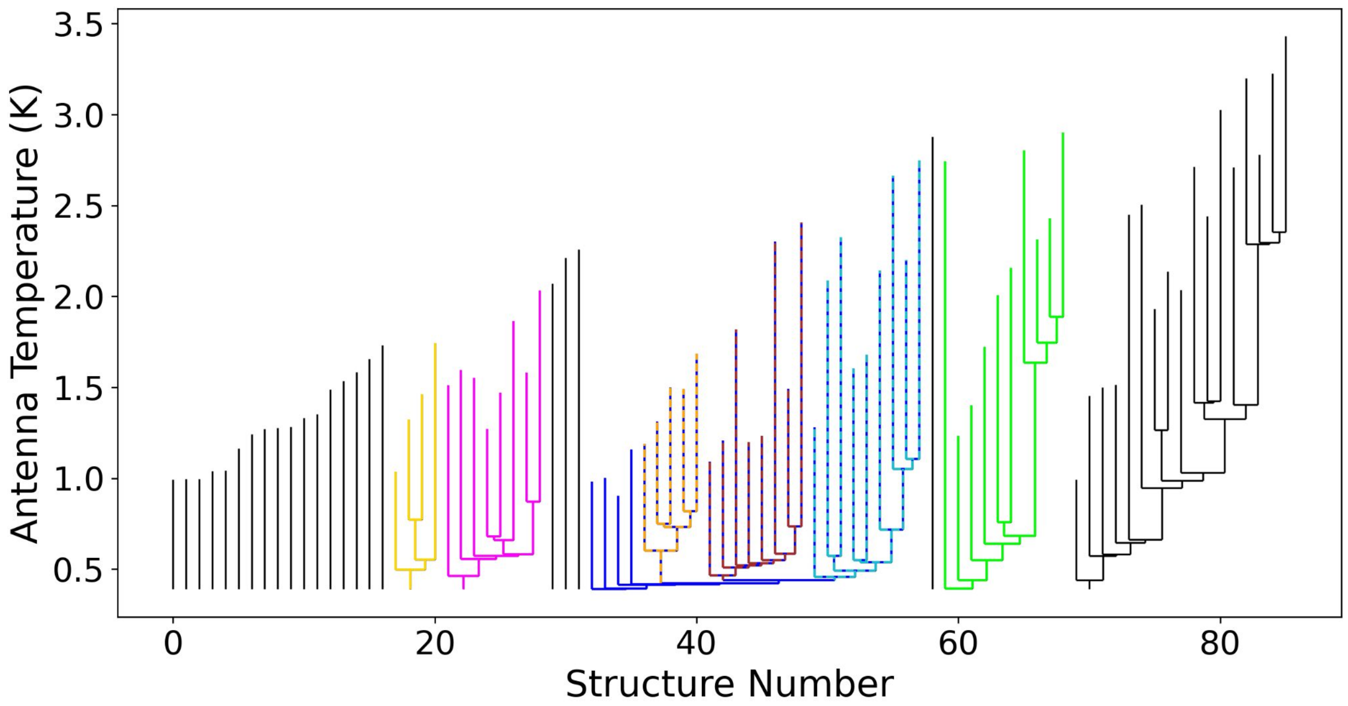

Integrated Intensity (K km s^{-1})
0
1
2
3
4
5
-33°00'
30'
-34°00'
30'
Galactic Latitude
158°00'
30'
159°00'
30'
160°00'
Galactic Longitude
5 pc


Antenna Temperature (K)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
20
40
60
80
Structure Number

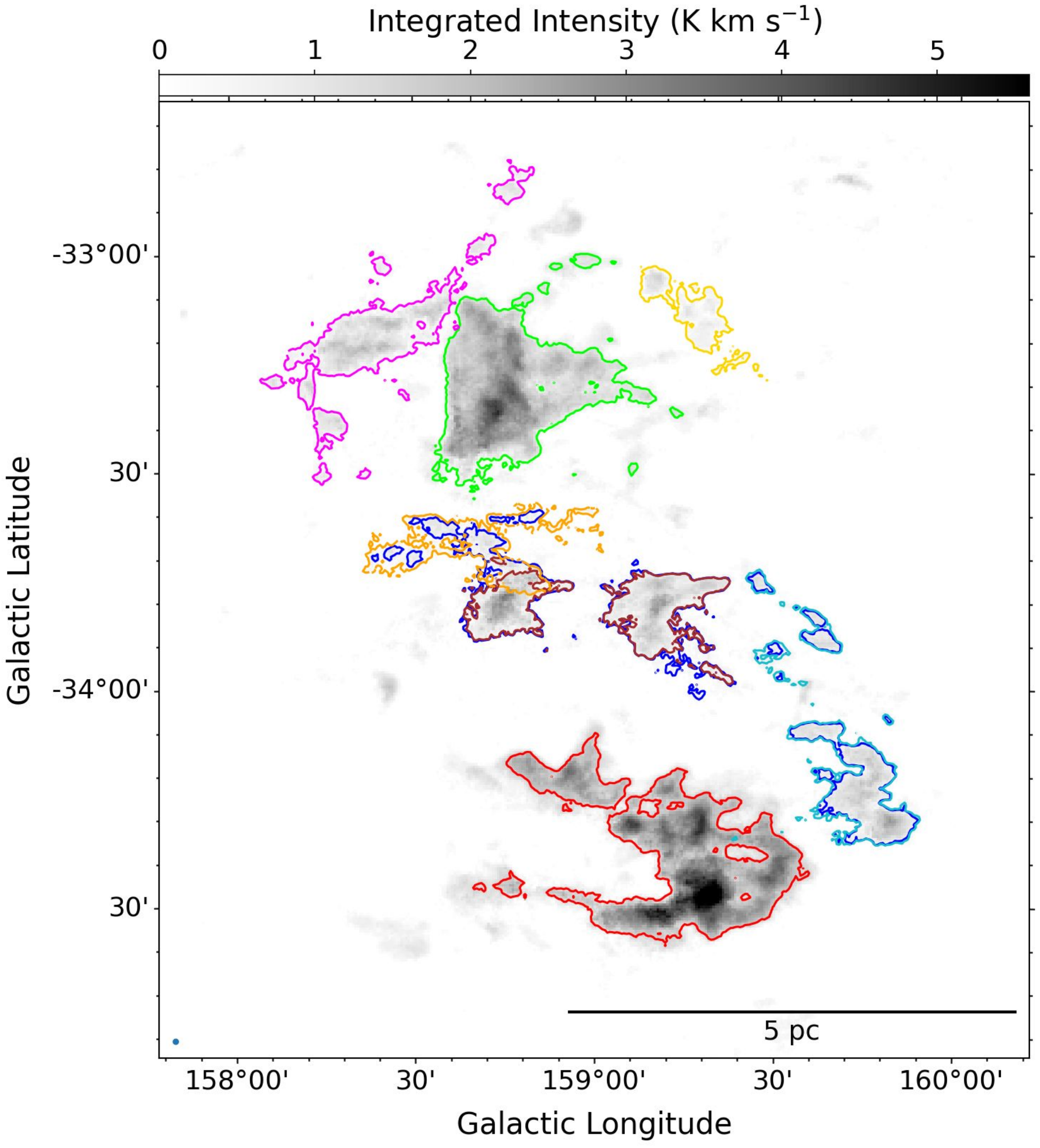

Integrated Intensity (K km s^{-1})
0
1
2
3
4
-33°00'
30'
-34°00'
30'
Galactic Latitude
5 pc
158°00'
30'
159°00'
30'
160°00'
Galactic Longitude

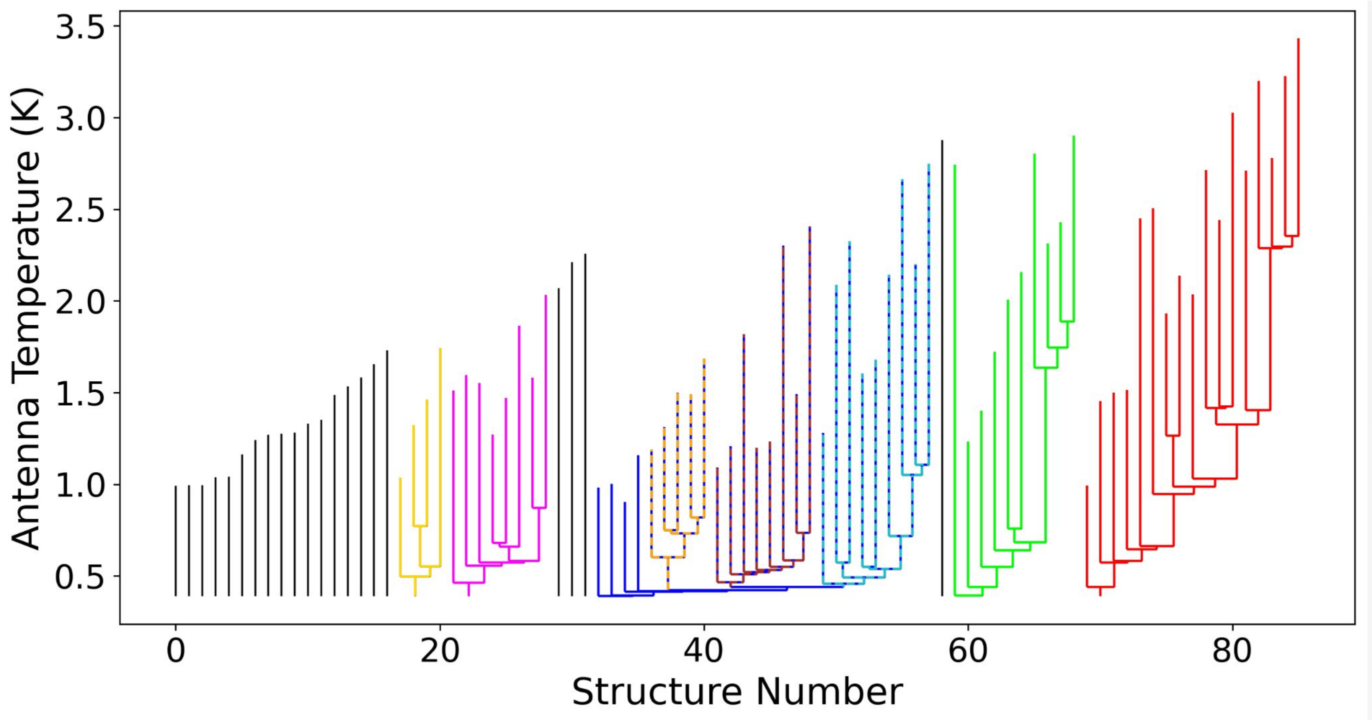

Antenna Temperature (K)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
20
40
60
80
Structure Number

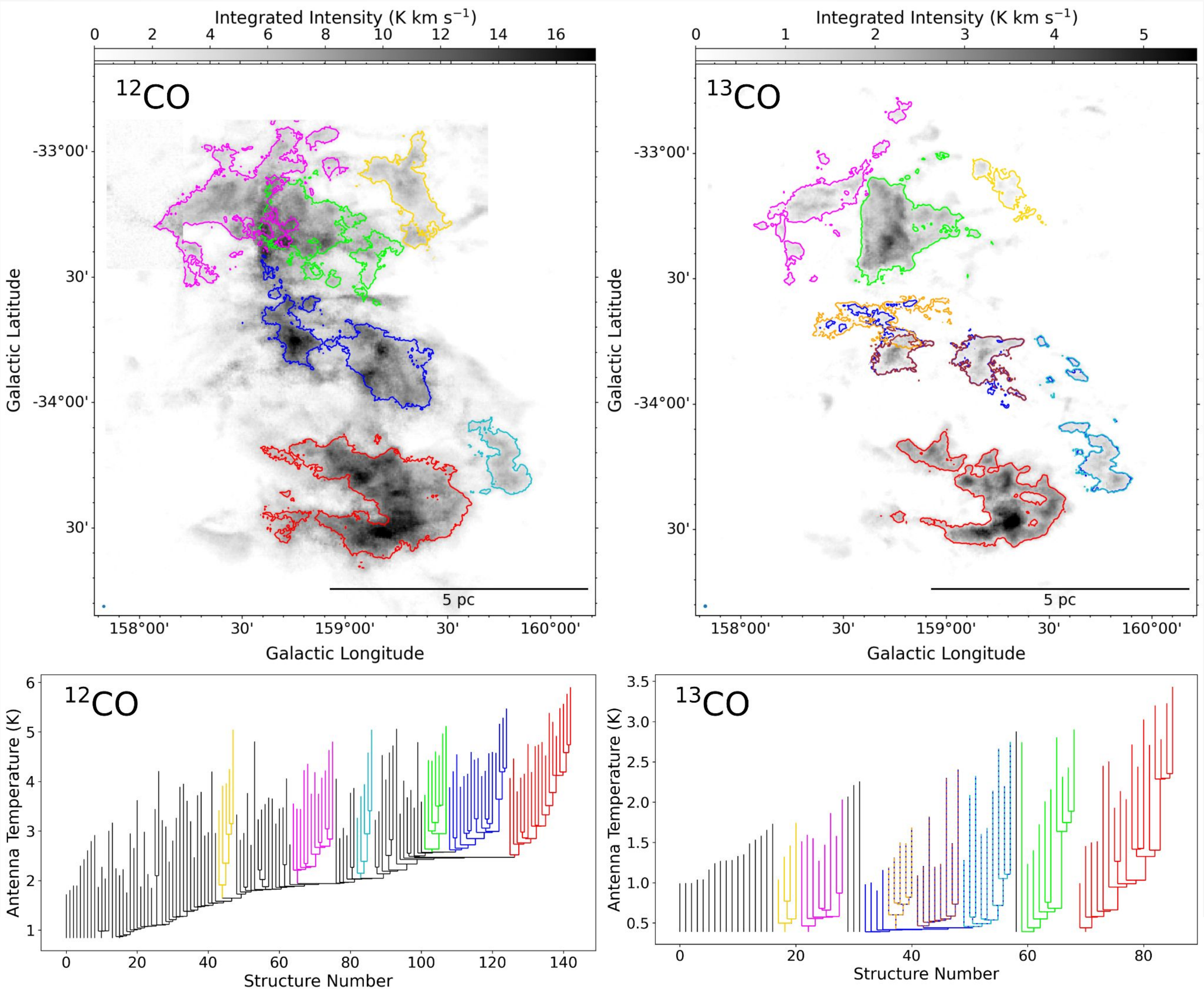




HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI


Integrated Intensity (K km s^{-1})
0
1
2
3
4
5
-33°00'
30'
-34°00'
30'
Galactic Latitude
158°00'
30'
159°00'
30'
160°00'
Galactic Longitude
5 pc

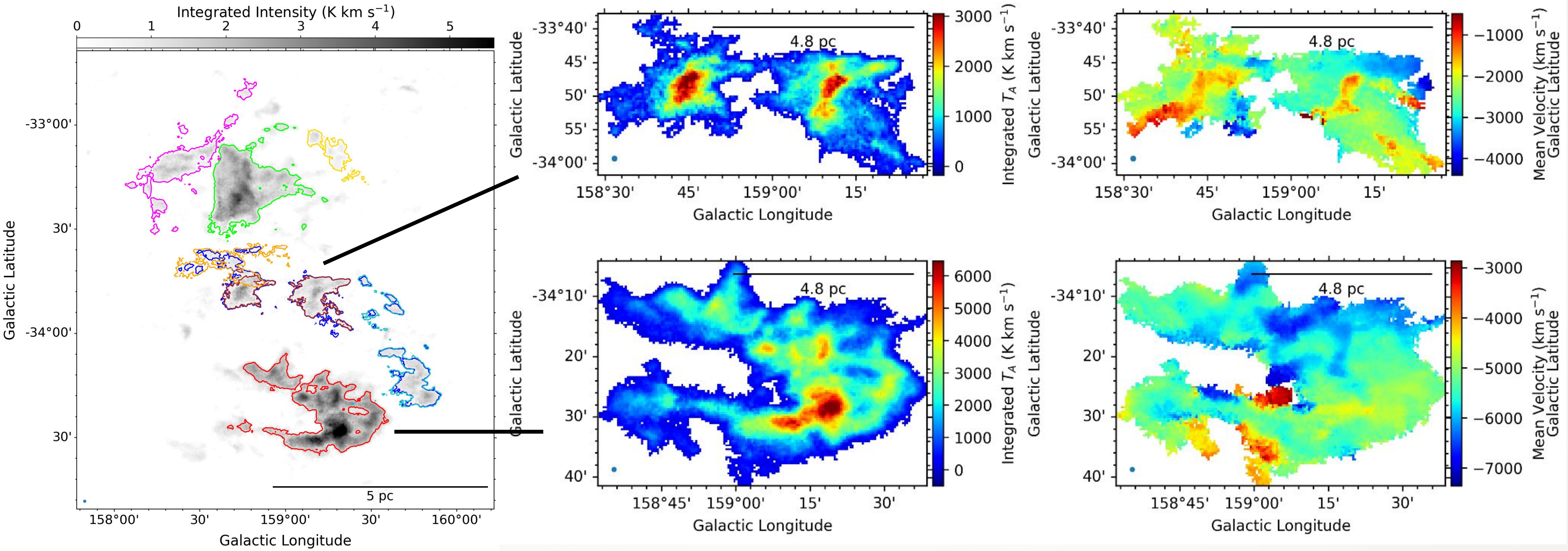

Antenna Temperature (K)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
20
40
60
80
Structure Number



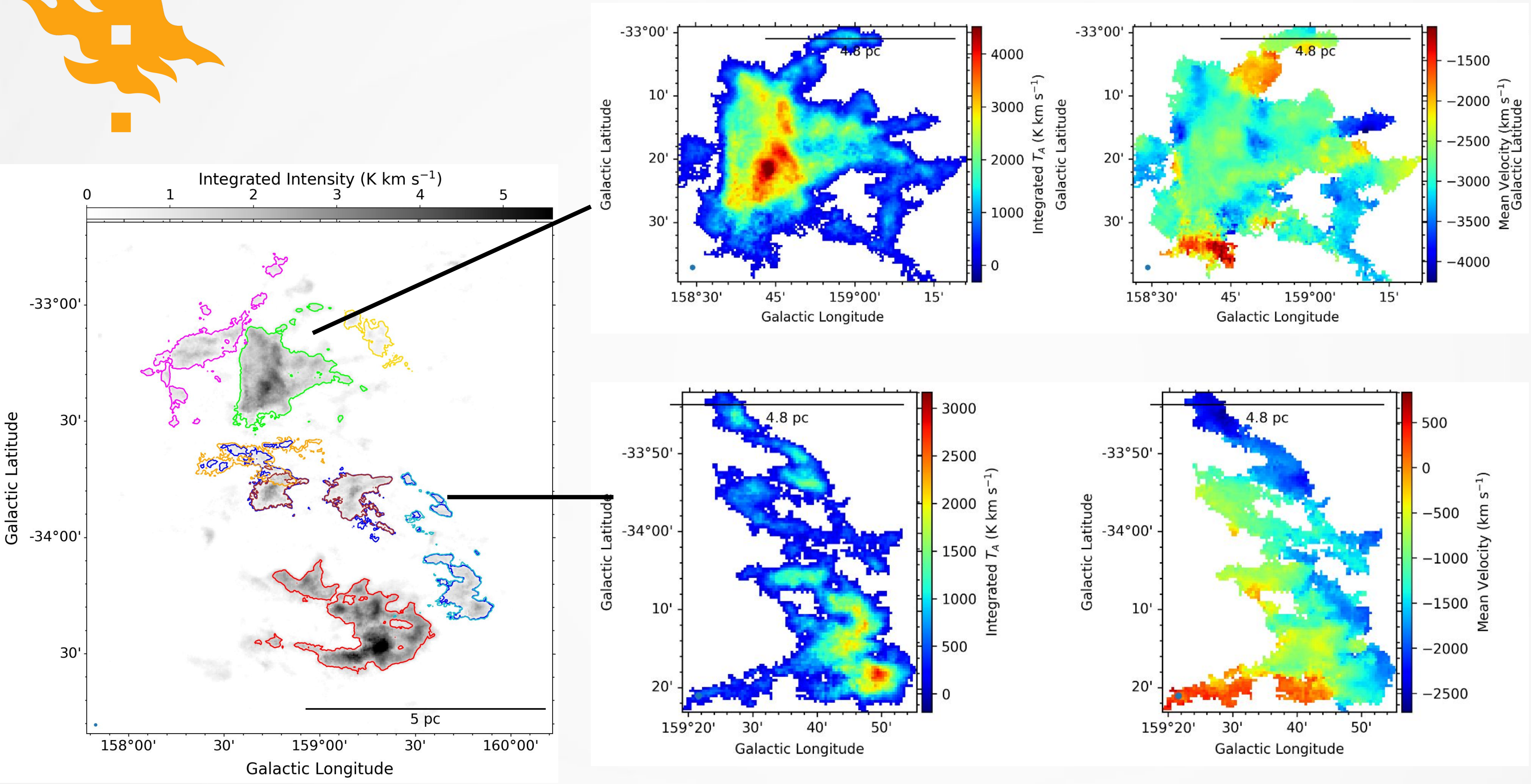
Integrated Intensity (K km s^{-1})
^{12}CO
^{13}CO
Galactic Latitude
Galactic Longitude
5 pc
Antenna Temperature (K)
Structure Number

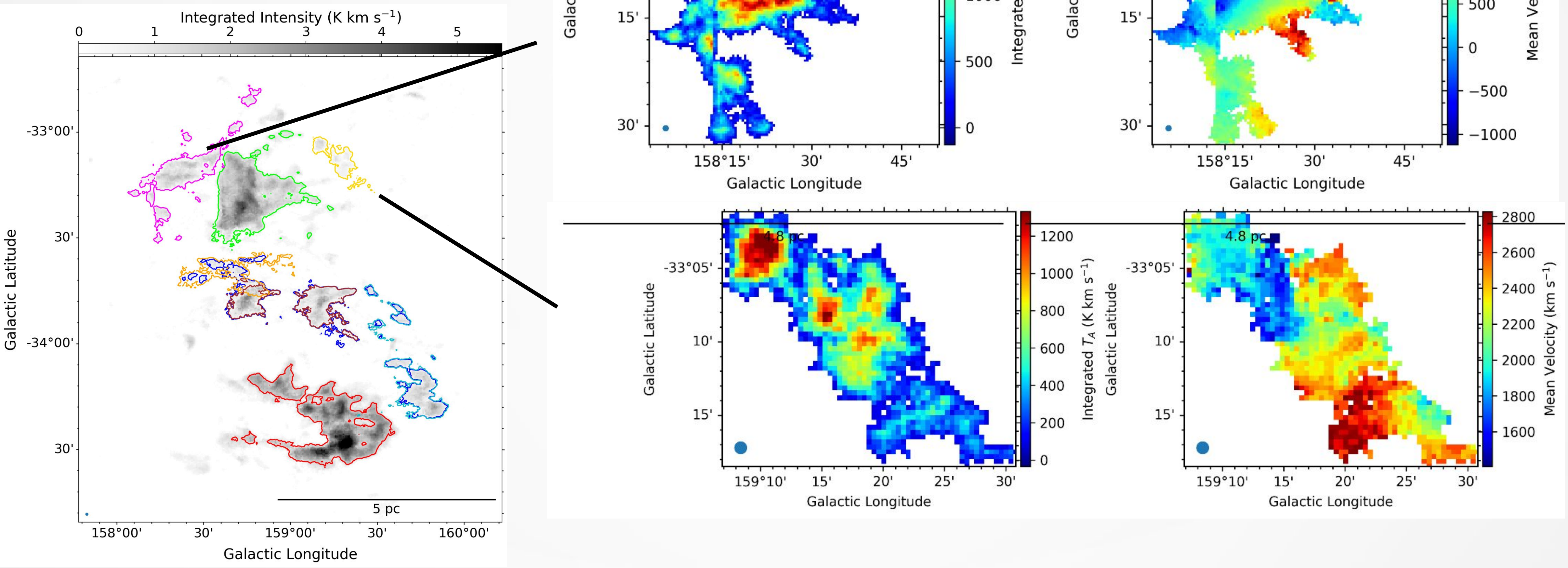
Large Scales Characteristics

ID	Color	l (deg)	b (deg)	Area (deg^2)	V_{centre} (km s^{-1})	σ_V (km s^{-1})	$\int I_\nu d\Omega$ (K km s^{-1} ster)
				^{12}CO			
d12−0	Red	158.63829	−33.90387	0.334	−5.35	0.37	1655.91
d12−1	Blue	159.22761	−34.01887	0.217	−1.73	0.45	790.86
d12−2	Green	159.69893	−34.14108	0.170	−2.95	0.11	474.86
d12−3	Cyan	158.78332	−33.40851	0.065	−1.07	0.12	164.61
d12−4	Magenta	159.82709	−34.43976	0.265	0.84	0.17	736.32
d12−5	Yellow	159.86356	−33.78141	0.100	2.07	0.16	271.15
				^{13}CO			
d13−0	Red	158.33149	−33.58953	0.317	−5.40	0.30	499.66
d13−1	Blue	158.80287	−33.58306	0.368	−1.28	0.27	240.92
d13−2	Brown	158.89374	−33.73655	0.145	−2.38	0.21	107.32
d13−3	Green	159.40054	−33.91040	0.245	−2.82	0.18	292.94
d13−4	Cyan	158.56908	−33.16841	0.126	−1.14	0.06	76.46
d13−5	Orange	159.04508	−34.01026	0.069	0.72	0.06	31.20
d13−6	Magenta	159.53525	−34.22116	0.133	0.57	0.10	88.24
d13−7	Yellow	159.57708	−33.50824	0.036	2.22	0.05	16.53



Integrated Intensity (K km s^{-1})
0 1 2 3 4 5
-33°00'
30'
-34°00'
30'
Galactic Latitude
5 pc
158°00' 30' 159°00' 30' 160°00'
Galactic Longitude
-33°40' 45' 50' 55' -34°00'
4.8 pc
158°30' 45' 159°00' 15'
Galactic Longitude
Galactic Latitude
Integrated T_A (K km s^{-1})
3000 2000 1000 0
Mean Velocity (km s^{-1})
−1000 −2000 −3000 −4000
-34°10' 20' 30' 40'
158°45' 159°00' 15' 30'
6000 5000 4000 3000 2000 1000 0
−3000 −4000 −5000 −6000 −7000


Integrated Intensity (K km s^{-1})
0
1
2
3
4
5
-33°00'
30'
-34°00'
30'
Galactic Latitude
5 pc
158°00'
30'
159°00'
30'
160°00'
Galactic Longitude
-33°00'
10'
20'
30'
4.8 pc
158°30'
45'
159°00'
15'
Galactic Longitude
Galactic Latitude
Integrated T_A (K km s^{-1})
4000
3000
2000
1000
0
Mean Velocity (km s^{-1})
−1500
−2000
−2500
−3000
−3500
−4000
-33°50'
-34°00'
10'
20'
159°20'
30'
40'
50'
3000
2500
2000
1500
1000
500
0
500
0
−500
−1000
−1500
−2000
−2500



Integrated Intensity (K km s^{-1})
0 1 2 3 4 5
-33°00'
30'
-34°00'
30'
Galactic Latitude
5 pc
158°00' 30' 159°00' 30' 160°00'
Galactic Longitude
4.8 pc
-33°00'
15'
30'
158°15' 30' 45'
Galactic Longitude
Galactic Latitude
Integrated T_A (K km s^{-1})
2000 1500 1000 500 0
Mean Velocity (km s^{-1})
2500 2000 1500 1000 500 0 −500 −1000
-33°05'
10'
15'
159°10' 15' 20' 25' 30'
1200 1000 800 600 400 200 0
2800 2600 2400 2200 2000 1800 1600

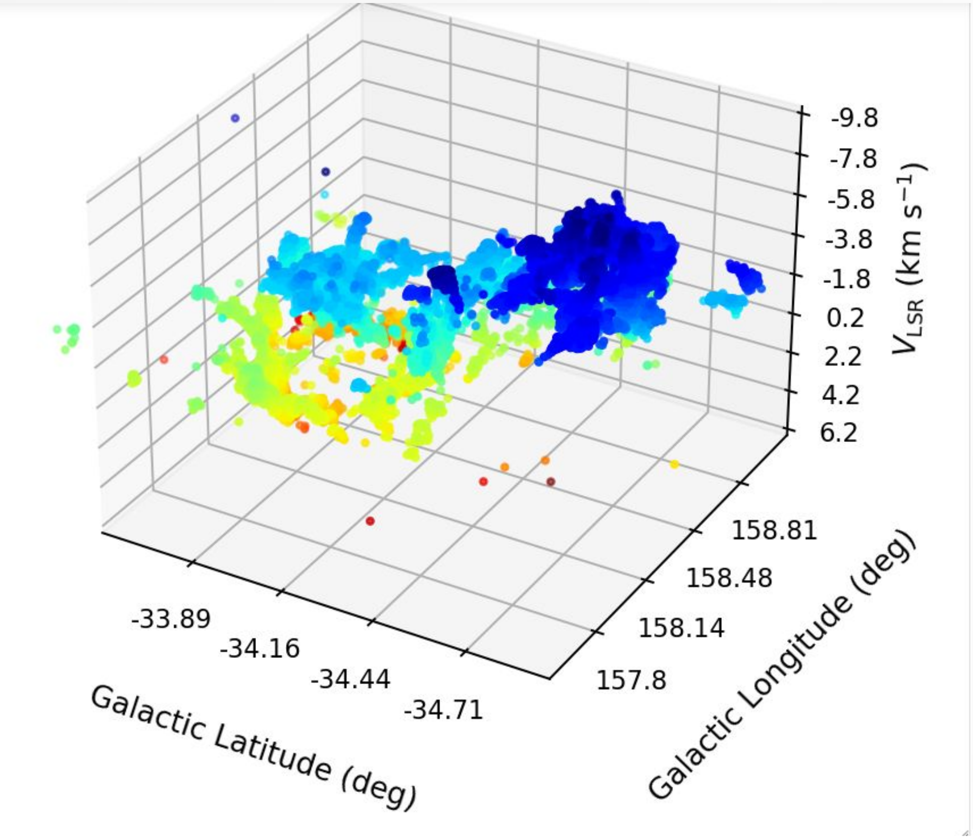
There is still a lot to do with dendrograms.

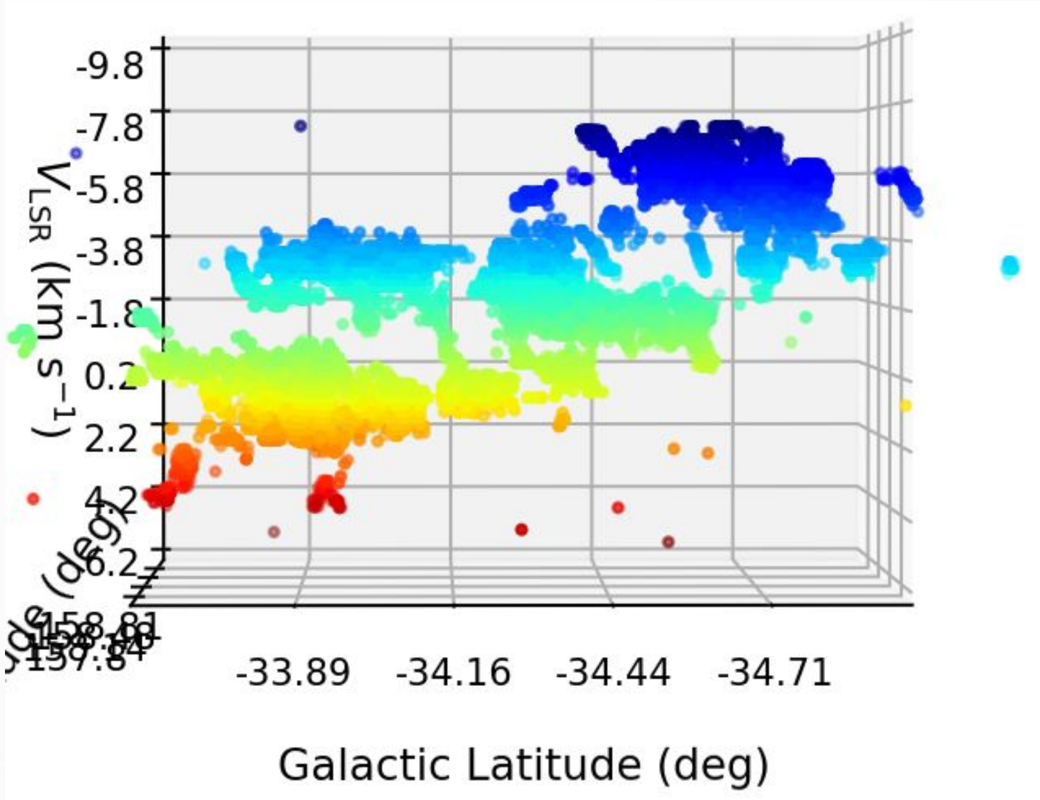
One can look at the characteristics by scale.

Ideas are welcome!

Gaussian Fitting First Try

BTS (Behind the Spectrum) Clarke et al. 2018, MNRAS, 479, 1722

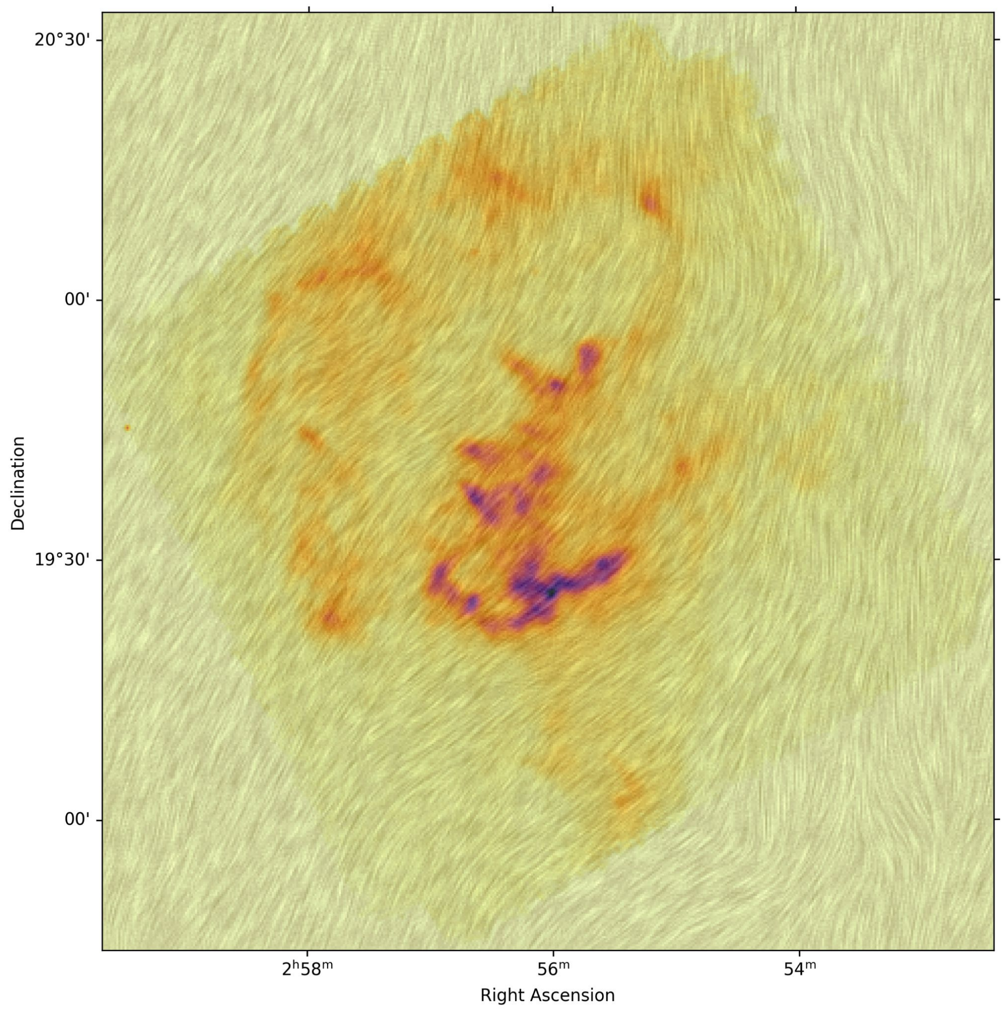


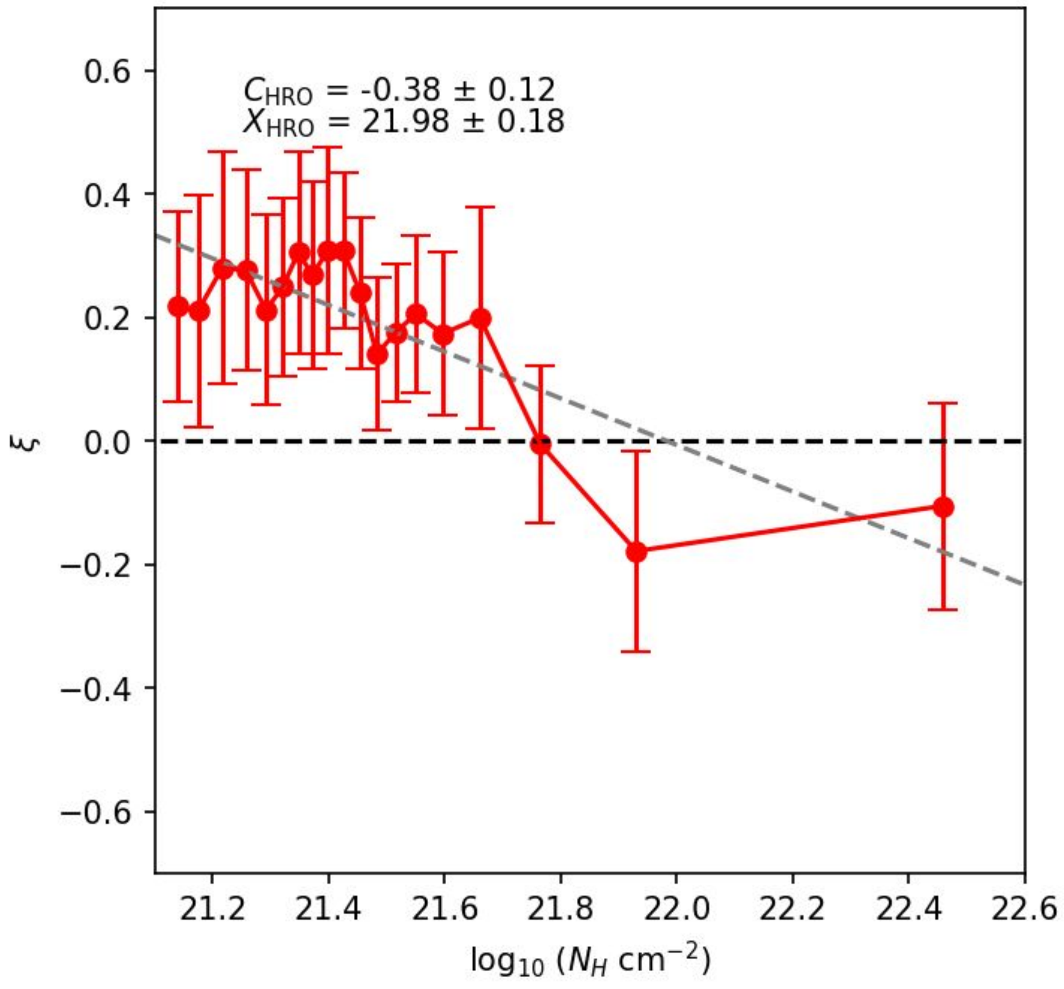


Results - B-Fields

HRO Analysis - Sobel GRAD Method

Followed Sobel 2019 for this cloud.





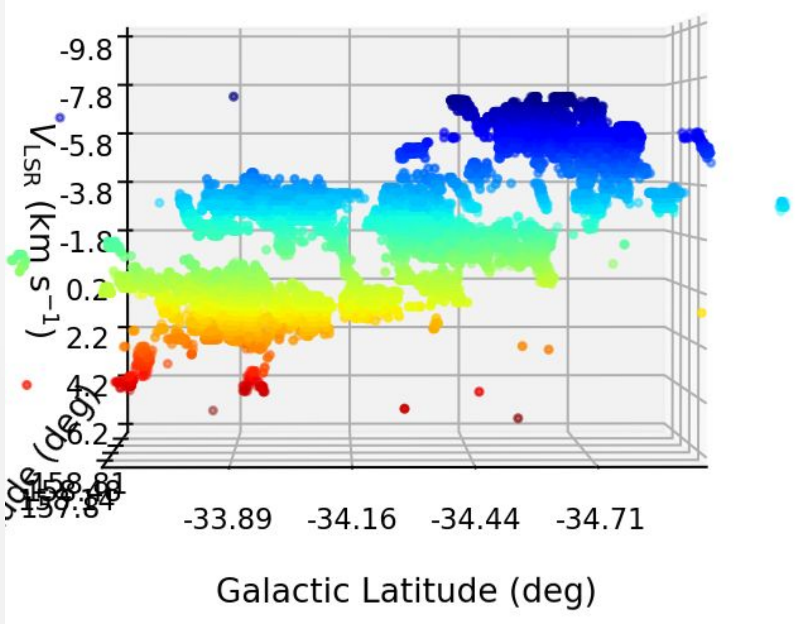
HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

We can rather use the (slightly modified) FilDreams results.

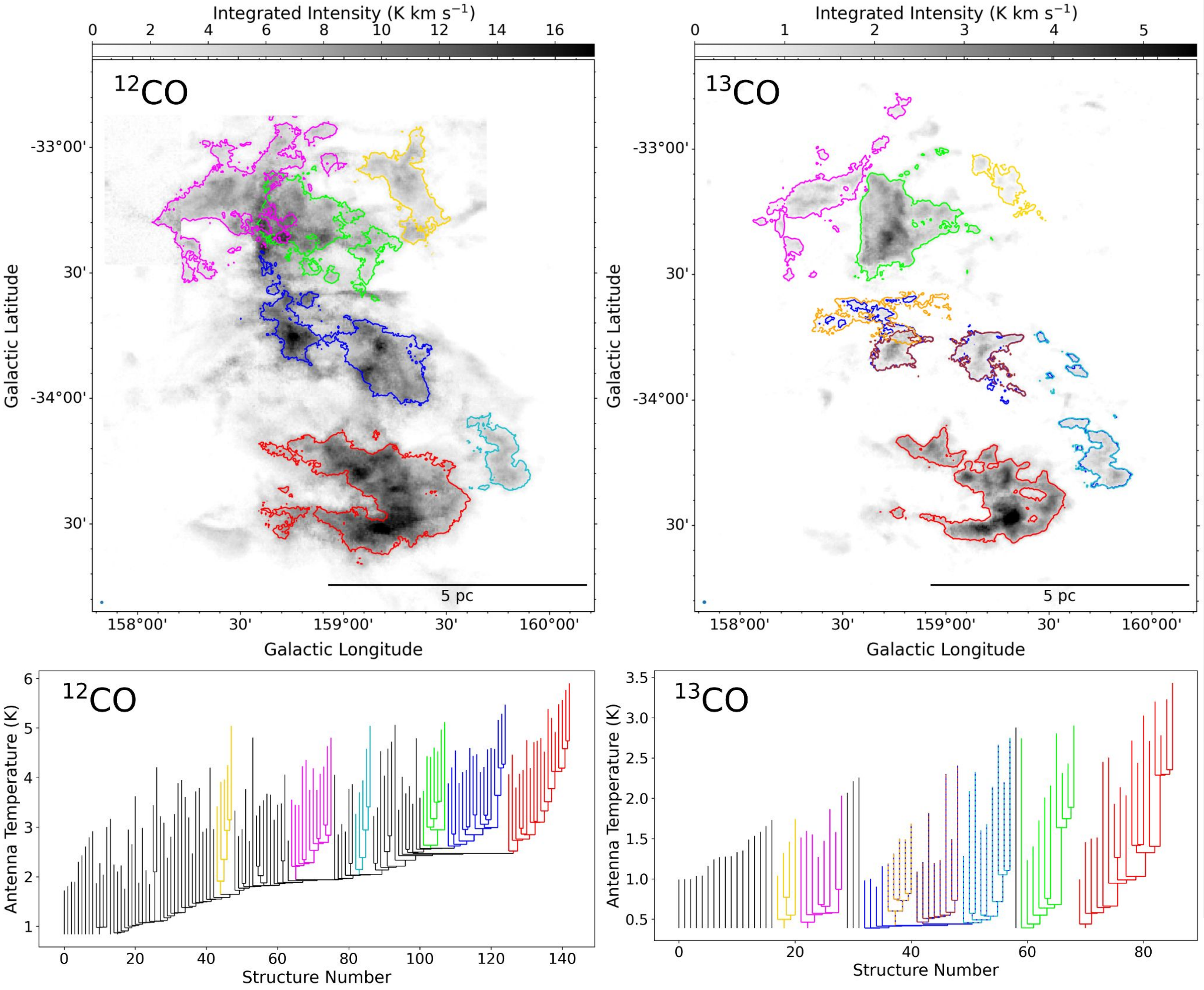
Already done.
More thorough.
See Jonathan's talk.

Velocity gradient technique

Taking line overlap into account!

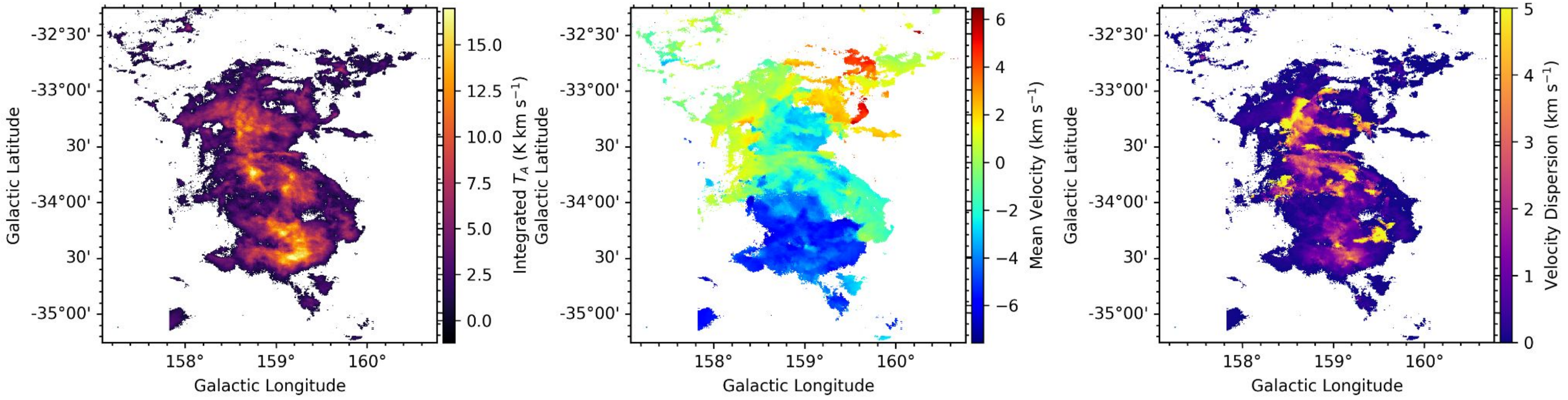


-9.8
-7.8
-5.8
-3.8
-1.8
0.2
2.2
4.2
6.2
V_{LSR} (km s^{-1})
-33.89
-34.16
-34.44
-34.71
Galactic Latitude (deg)



Integrated Intensity (K km s^{-1})
0 2 4 6 8 10 12 14 16
^{12}CO
-33°00'
30'
-34°00'
30'
Galactic Latitude
5 pc
158°00' 30' 159°00' 30' 160°00'
Galactic Longitude
Integrated Intensity (K km s^{-1})
0 1 2 3 4 5
^{13}CO
-33°00'
30'
-34°00'
30'
Galactic Latitude
5 pc
158°00' 30' 159°00' 30' 160°00'
Galactic Longitude
^{12}CO
Antenna Temperature (K)
1 2 3 4 5 6
0 20 40 60 80 100 120 140
Structure Number
^{13}CO
Antenna Temperature (K)
0.5 1.0 1.5 2.0 2.5 3.0 3.5
0 20 40 60 80
Structure Number

Future Work



-32°30'
-33°00'
30'
-34°00'
30'
-35°00'
Galactic Latitude
158°
159°
160°
Galactic Longitude
Integrated T_A (K km s^{-1})
15.0
12.5
10.0
7.5
5.0
2.5
0.0
Mean Velocity (km s^{-1})
6
4
2
0
−2
−4
−6
Velocity Dispersion (km s^{-1})
5
4
3
2
1
0

Future Work

- $N(^{12}CO)$ and $N(^{13}CO)$ estimation - possibly maps of more transitions of the source.
- Looking deeper in the hierarchical structure + virial parameters for scale size.
- Include FilDreams HRO - look at B-Field orientation as a function of structure size.
- Implement VGT.
- (Possibly) 3D Radiative Transfer Modelling.
- Put it all together into a coherent story.
- Do it for the seven or so other sources!