High Latitude Molecular Clouds chemodynamics using high-resolution multiline spectroscopy

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Image courtesy of Maurizio Cabibbo

Intro: what are High Latitude Molecular Clouds and why they are important

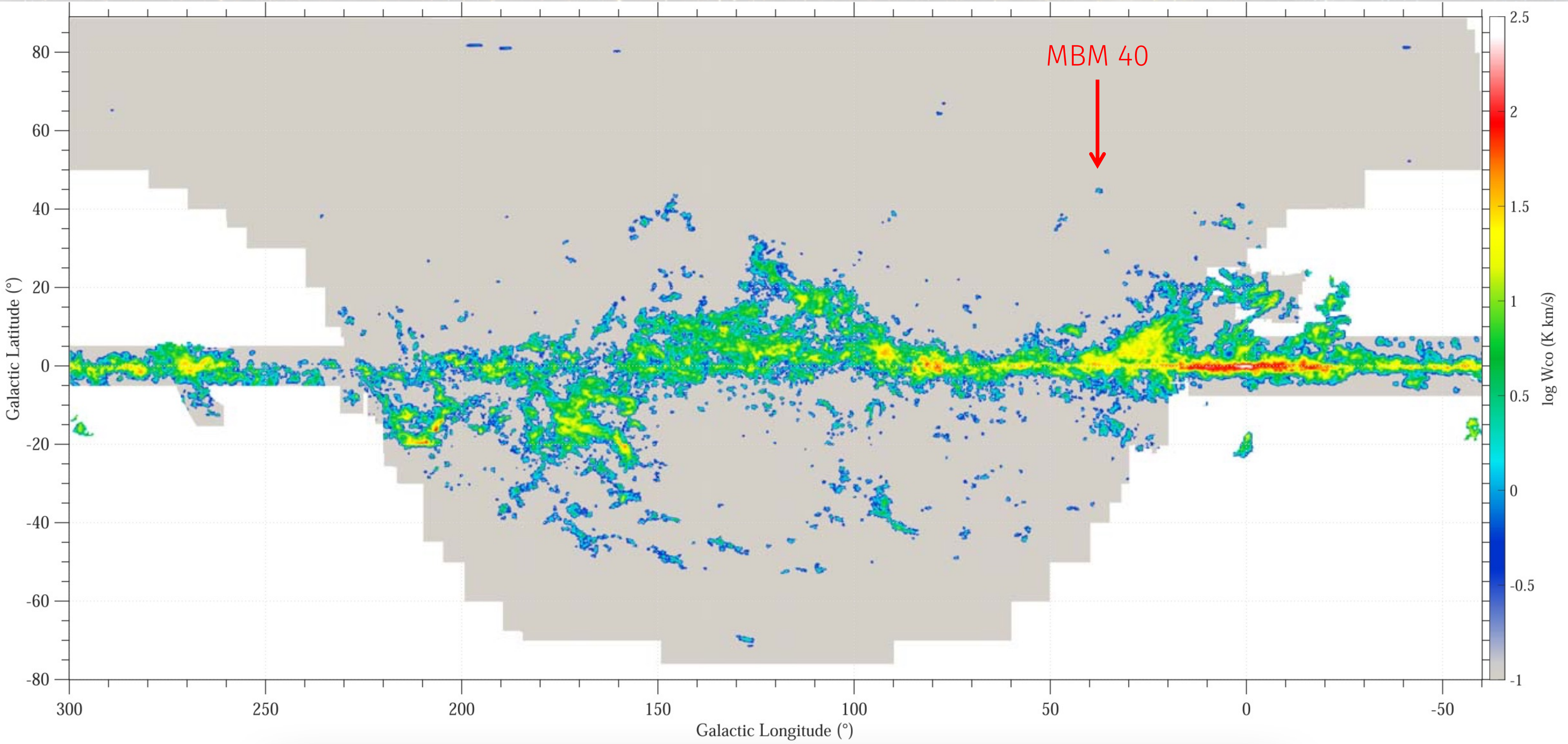
Overall features of High Latitude Molecular Clouds (HLMCs):

- High galactic latitude ($|b| \gtrsim 35°$);
- Generally close ($d \sim 100 - 200\,pc$);
- Diffuse ($A_V \sim 0.2$) or translucent ($A_V \sim 1 - 2$) with molecular cores;
- Non-star forming (not all!);
- Comparatively tranquil dynamics;
- Non-thermal linewidths and systematic velocity gradients.

Simple environments that mimic laboratory turbulent flows → excellent sites to study interstellar turbulence and testbeds against which the models can be compared.

L. Magnani, S. N. Shore, *A dirty window,* Springer (2017)

CfA ^{12}CO (1 – 0) survey. The beamsize is about 8’ and the velocity resolution is $0.65\ km\ s^{-1}$.

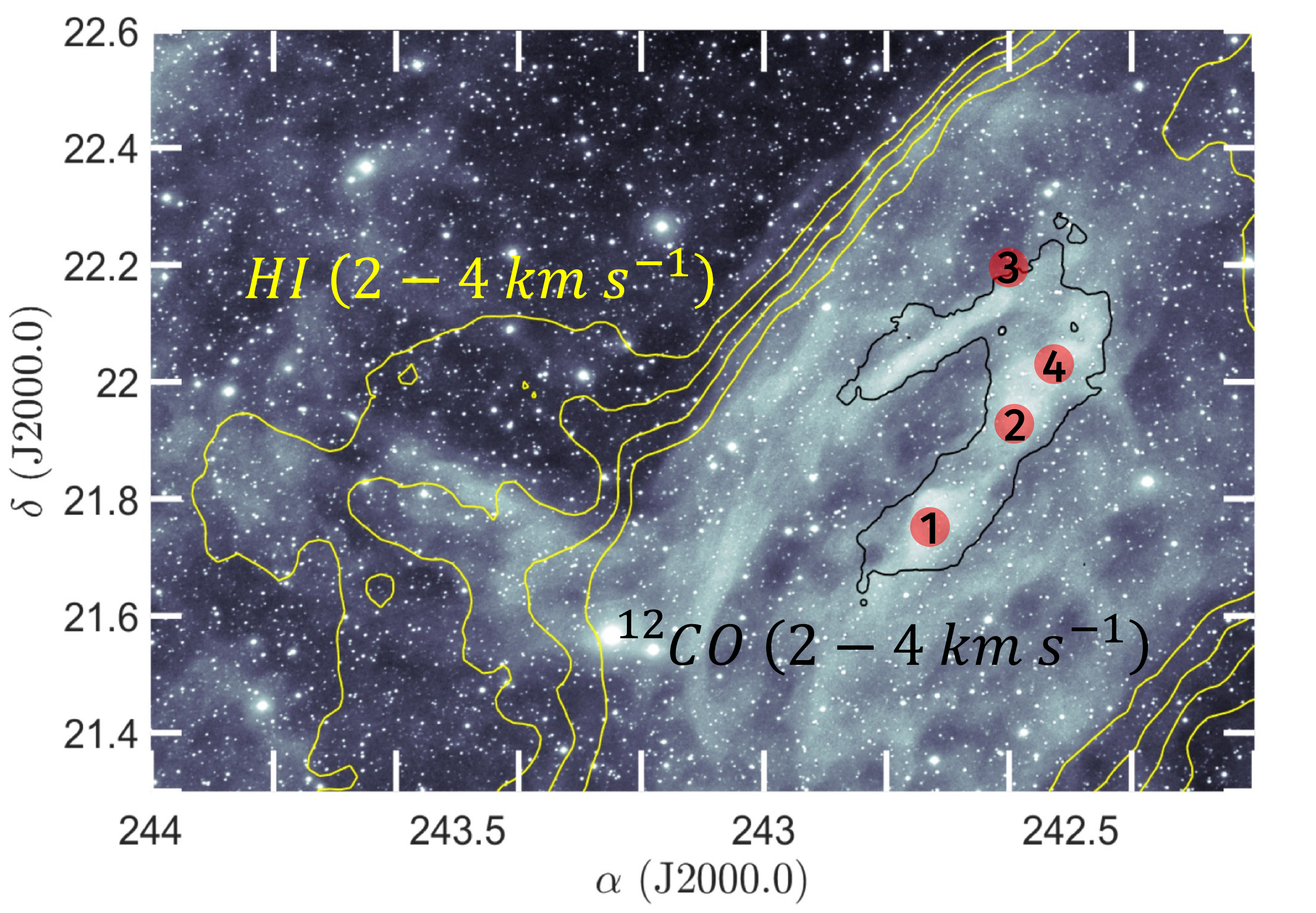


T. M. Dame and P. Thaddeus (2022)

Introducing MBM 40

MBM 40 is a low-mass $(20-40\ \mathrm{M}_\odot)$, non-star forming, near $(93^{+23}_{-20}\ pc)$, diffuse HLMC embedded in a much larger HI structure.

- No star formation or shocks → clean example of the turbulent dynamics and cold chemistry
- Near → good spatial resolution $(\sim 10^{-2}\ pc)$
- Well isolated in CO velocity, $[+2.5, +4.2]\ km\ s^{-1}$



Visible (unfiltered) wide field image

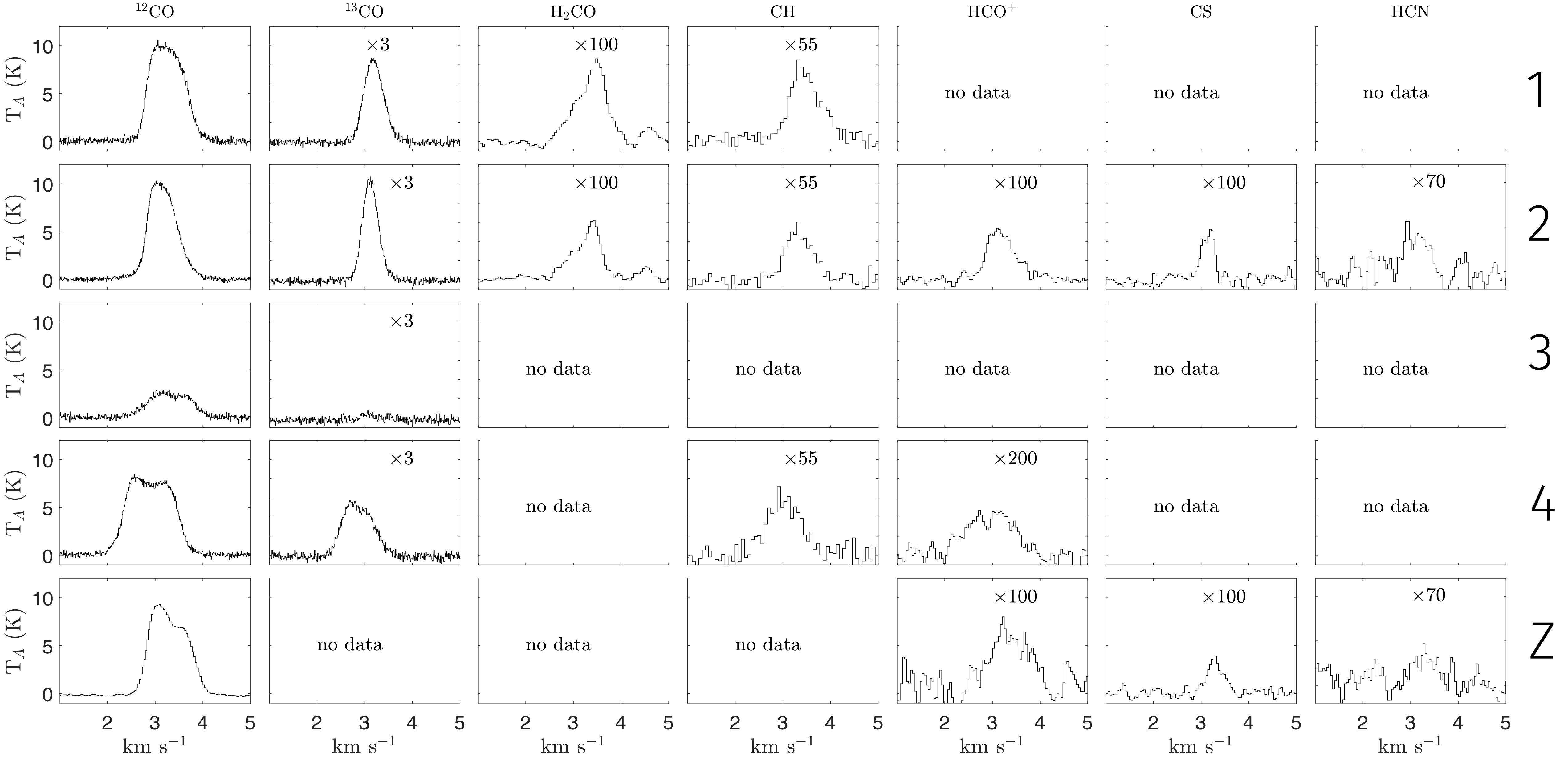
$HI = (15, 17, 19, 21)\ K\ km\ s^{-1}$

$^{12}CO = 2\ K\ km\ s^{-1}$

Dense substructures $\begin{cases} N(H_2) \sim (3-8)\times10^{20}\ \mathrm{cm}^{-2} \\ N(HI) \sim (1-2)\times10^{20}\ \mathrm{cm}^{-2} \end{cases}$

L. Magnani et al. (1996), Shore et al. (2003), Monaci et al. (2022)

Observations



Observations

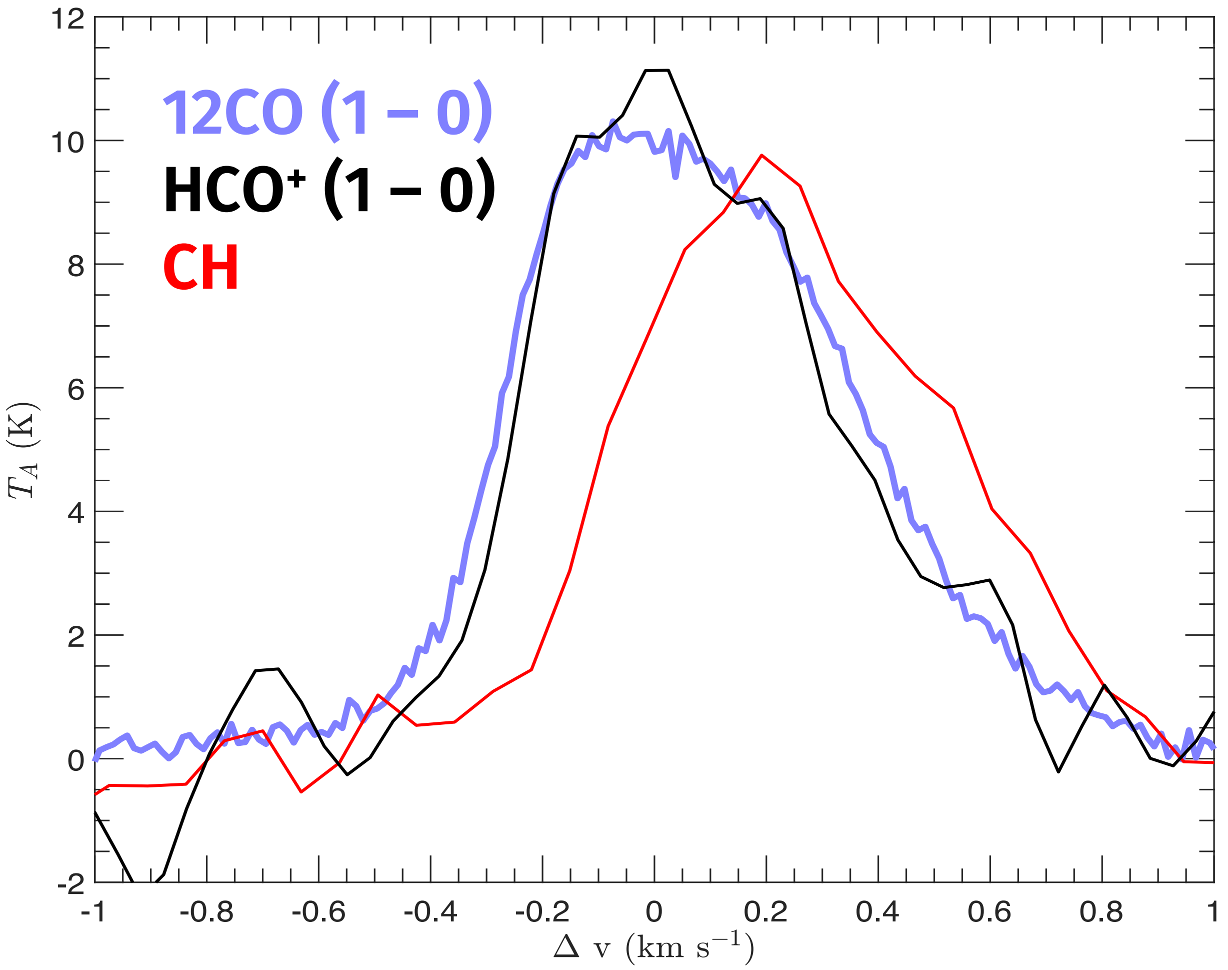
Molecule	ν (GHz)	Telescope	Location(s)	Δv (km s^{-1})	Beamsize (″)	Type
^{12}CO	115.271	FCRAO OSO	Whole cloud MAP1, 2, 3, 4	0.05 0.012	47 33	HBS FBS 9 x 9
^{13}CO	110.201	OSO ARO	MAP1, 2, 3, 4 MAP2	0.013 0.033	34 57	FBS 9 x 9 HBS 3 x 3
HCO^+	89.188	ARO	MAP2, 4	0.041	71	HBS 3 x 3
H_2CO	4.830	Arecibo	MAP1, 2	0.047	56 x 65	FBS 5 x 5
HCN	88.632	ARO	MAP2	0.041	71	Single pointing
CS	97.981	ARO	MAP2	0.037	64	HBS 3 x 3
CH	3.335	Arecibo	Whole cloud	0.069	78 x 96	FBS

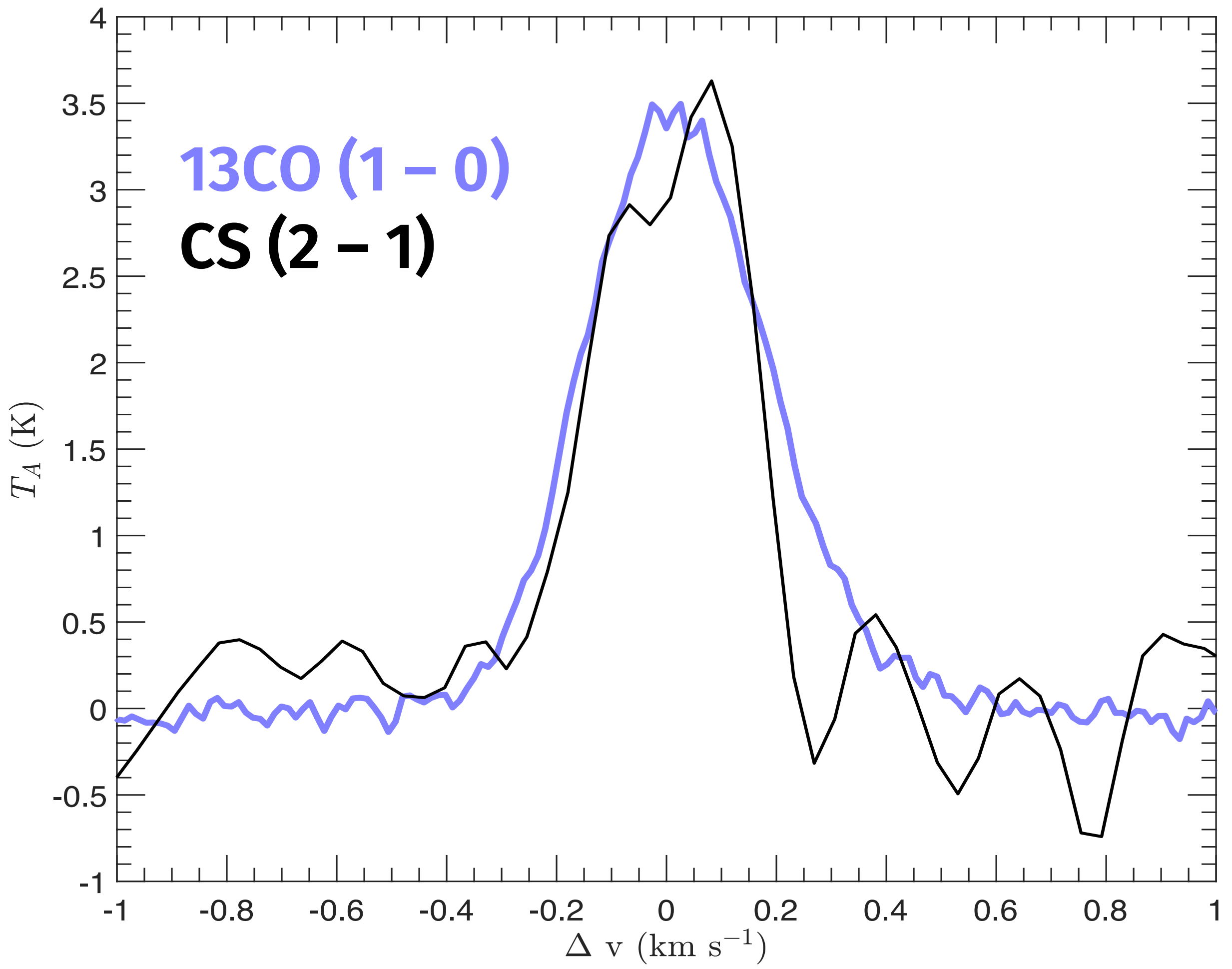
HBS = half-beam spacing; FBS = full-beam spacing

Mapping diffuse and dense gas: different tracers

Diffuse

Dense





Monaci et al. (2023, A&A, in press)

And the formaldehyde?

The 4.830 GHz is actually formed by six different components → **The profile analysis is more complicated, i.e. a satellite line might easily mimic a secondary velocity component.**

If we assume that the H_2CO and CO are well mixed, the ^{12}CO and ^{13}CO line profiles – interpreted as probability distribution functions of the velocity fluctuations – provide convolution kernels that can be used with theoretical profiles of H_2CO based on laboratory intensities of the hyperfine components.

The theoretical profile is created from theoretical optical depth:

$$\tau_{H_2CO} = \sum \tau_{(0,n)} e^{-\left(\frac{v - v_{0,n}}{2\sigma}\right)^2}$$

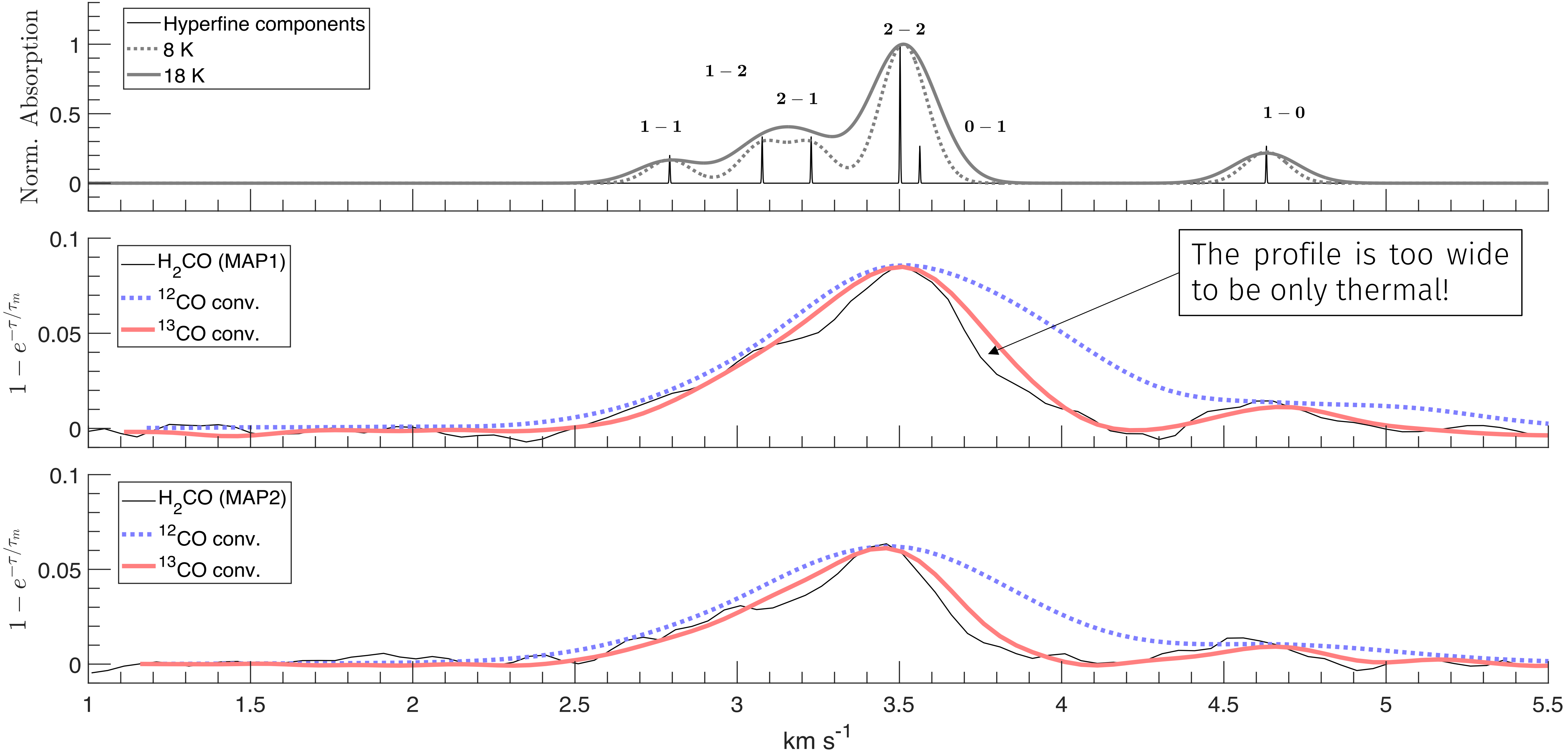
Convolved with normalized profile from ^{12}CO or ^{13}CO:

$$\phi(v)_{theo} \propto \exp\left[-\Phi * \left(\frac{\tau_{H_2CO}}{\tau_m}\right)\right]$$

F – F'	Rel. Intensity	Frequency (MHz)
2 - 2	15	4829.659
1 - 1	3	4829.671
2 - 1	5	4829.664
1 - 2	5	4829.666
1 - 0	4	4829.641
0 - 1	4	4829.658

Tucker et al. (1970)

And the formaldehyde?



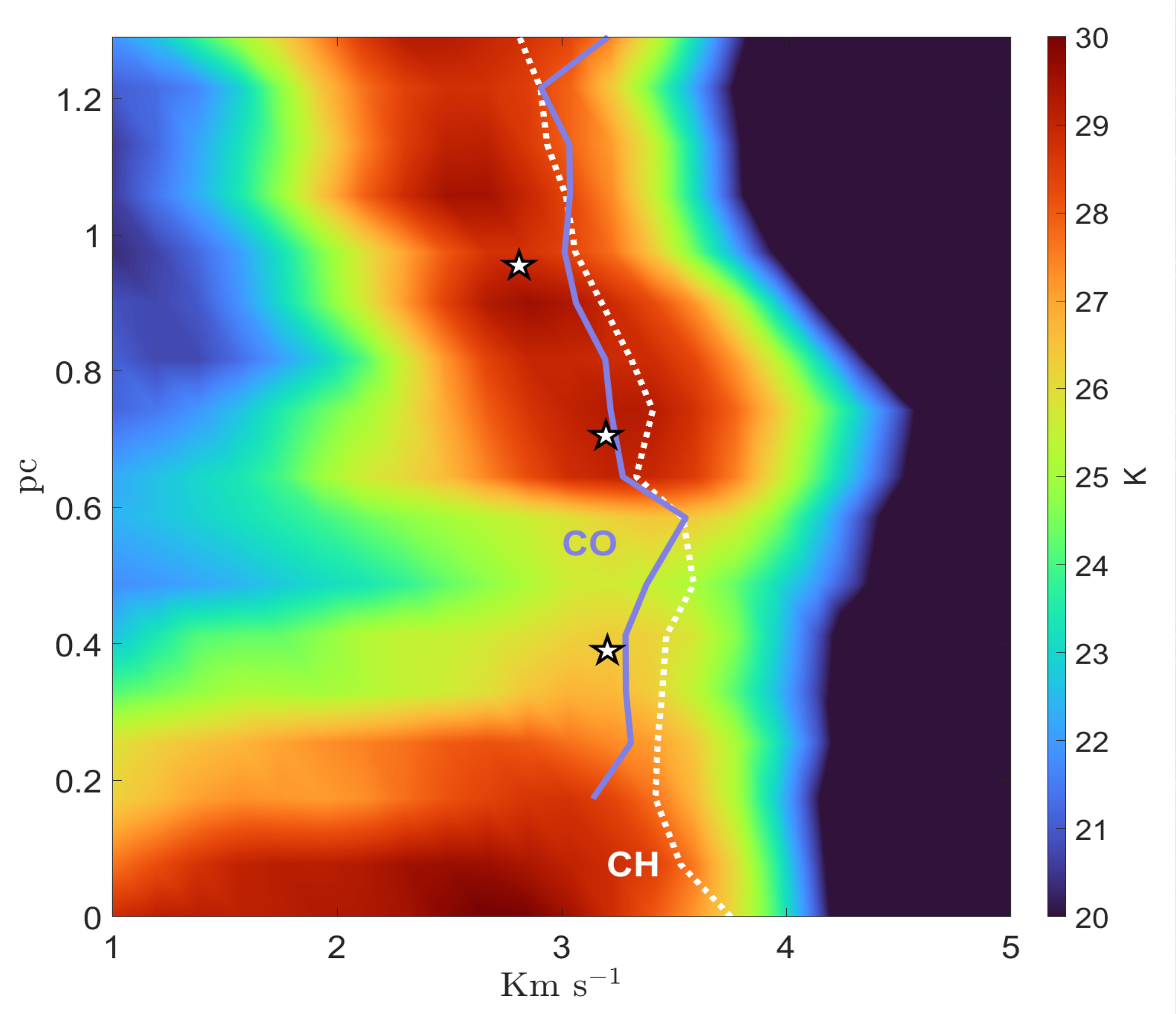
A shear flow over 1 pc

Turbulence decays faster than the lifetime of the clouds, so a continuous source of kinetic energy is necessary. In MBM 40 (or where is no star formation) this source must be external.

Evidence for large shear flow that runs through western filament.

Caveat: visible in HI, but masked by diffuse external gas. *Driven* profile decomposition using ^{12}CO velocity informations.

Reynolds decomposition is in general problematic → here seems to be possible.



Pseudocolor → HI over west ridge
Solid/dashed lines → centroid velocities of ^{12}CO and CH
Stars → ^{13}CO centroid velocity in MAP1, 2 and 4

Kleiner and Dickman (1985), Dickman and Kleiner (1985)

Intermittency and single line profile as Probability Distribution Function (PDF)

Intermittency: large deviations in velocity that are rare events occurring with a higher frequency than in an uncorrelated process.

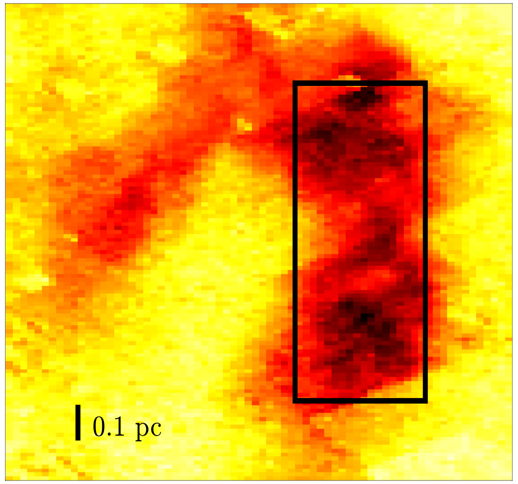
PDF computed as the histogram of:

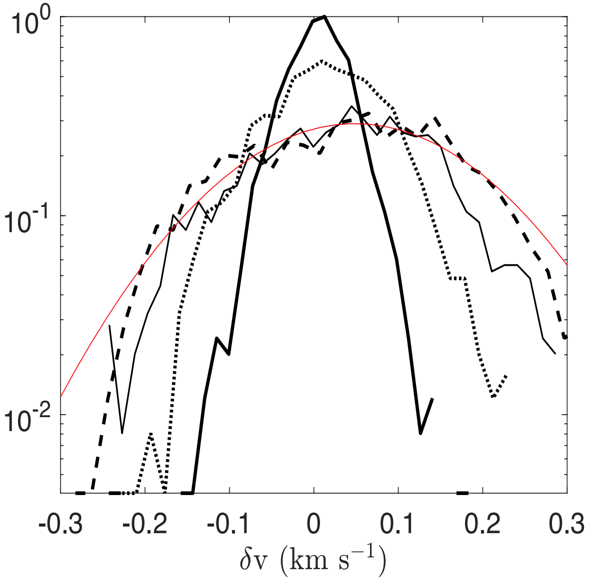
$$\delta\mathrm{v}(\mathbf{r},\delta\mathbf{r}) = u_c(\mathbf{r}) - u_c(\mathbf{r}+\delta\mathbf{r})$$

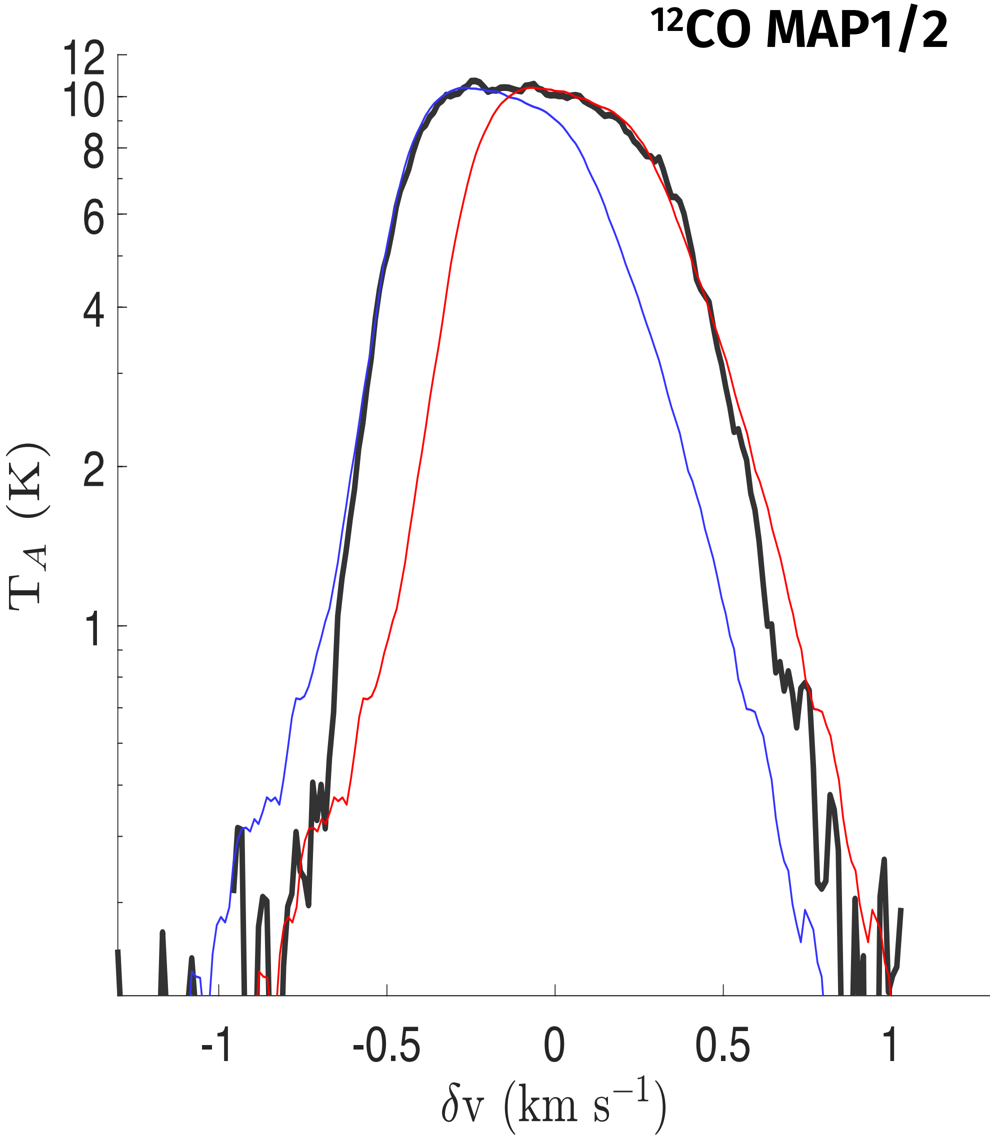
u_c velocity centroid:

$$u_c = \frac{\int_{line} T_A(u)\, u\, du}{\int_{line} T_A(u)\, du}$$

Large scale velocity correlation **can** mask turbulence → **detrending is crucial.**



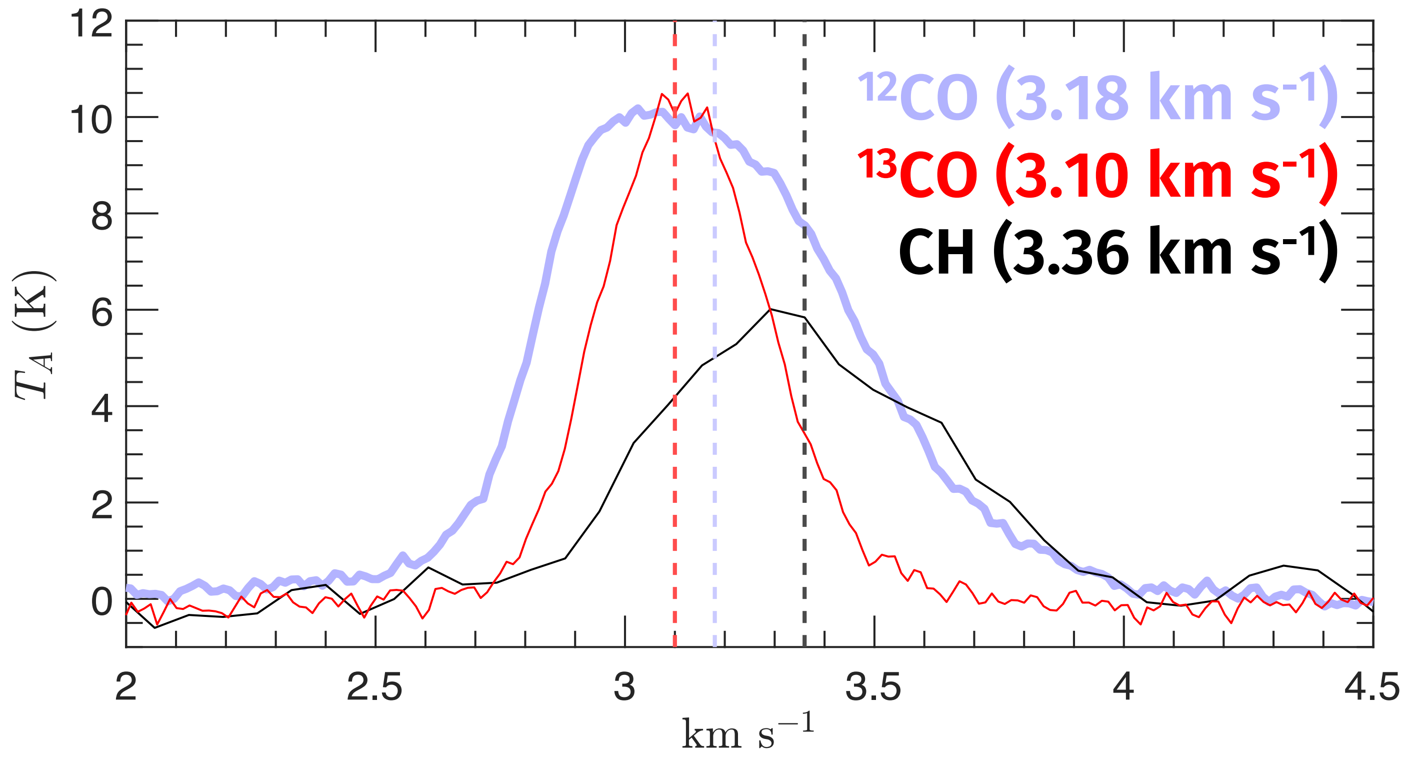


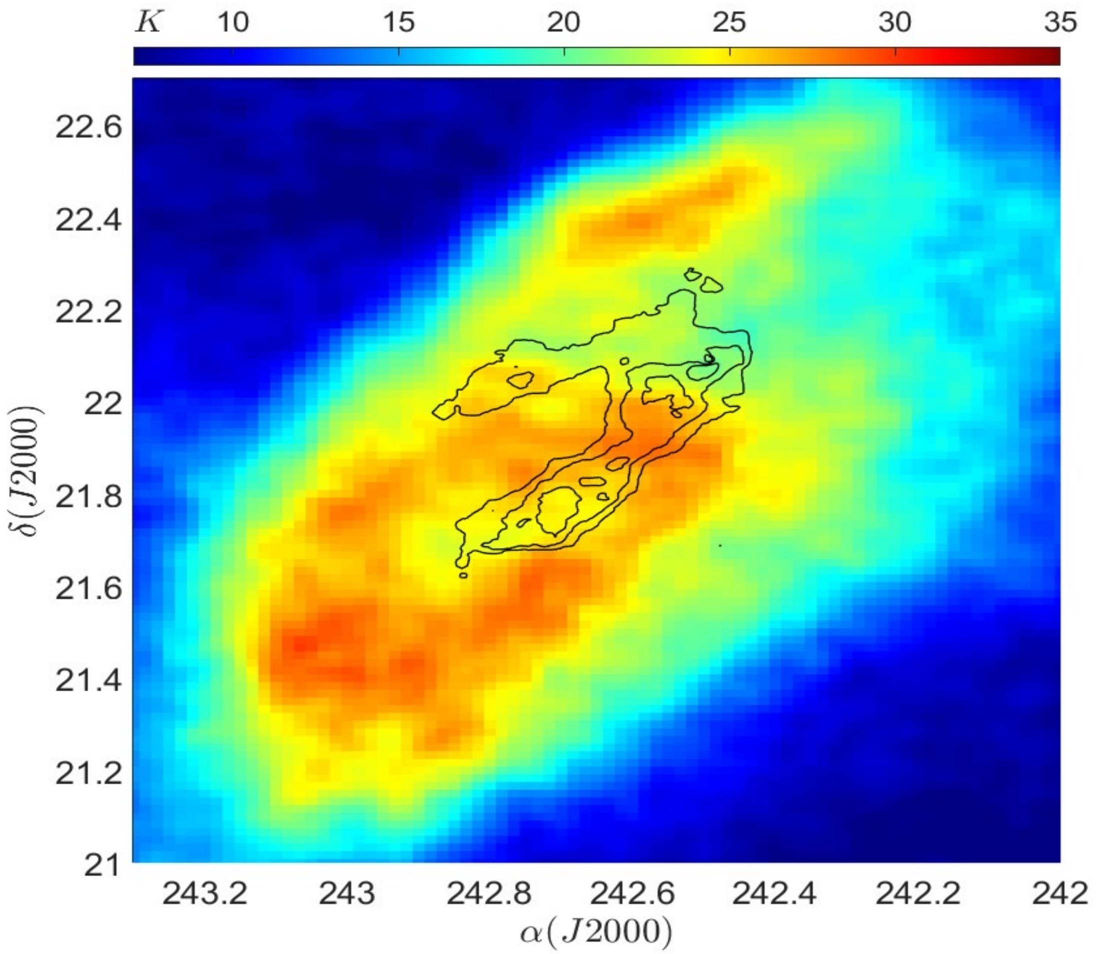


Possible structure of the *longitudinal* shear

Chastain et al. (2010) points out a systematic offset between CH and CO gas

Different gas regimes. ^{13}CO (denser, axial interior), CH (less dense, outer envelope)





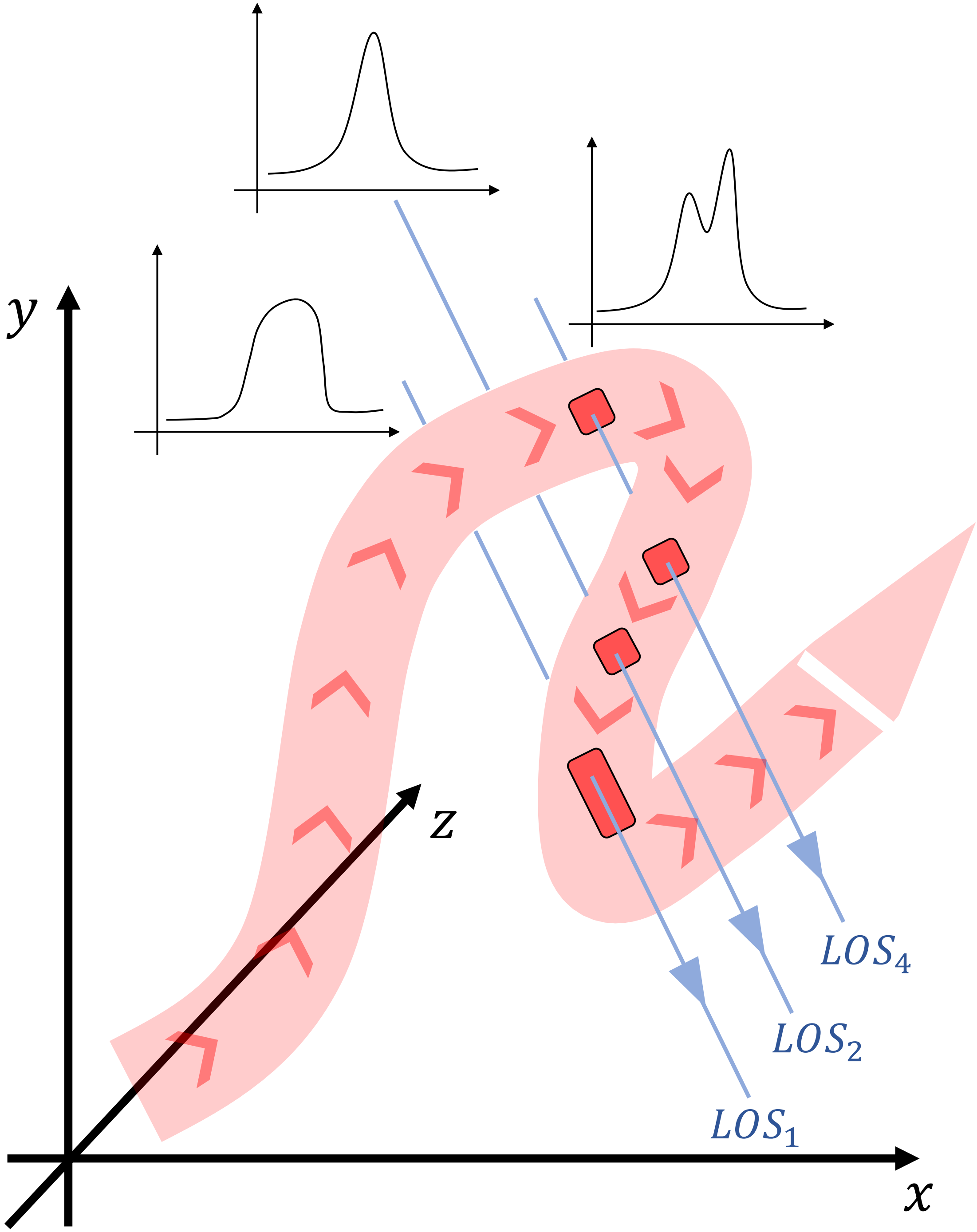
Colors: HI brightness temperature at 3.4 km s^{-1}
Contours: Integrated line ^{12}CO intensity (2, 3, 4 K km s^{-1})
Monaci et al. (2022), A&A, 668, L9

A reconstruction of the topological structure of MBM 40

Common picture: complex profiles arise from multiple superposed flows or velocity components.

Linewidths can be continuously and physically consistently reconstructed with the combined contributions of a twisted flow and turbulent broadening

Simple picture → we see skew in single line profiles that cover a much smaller, spatially unresolved, region.



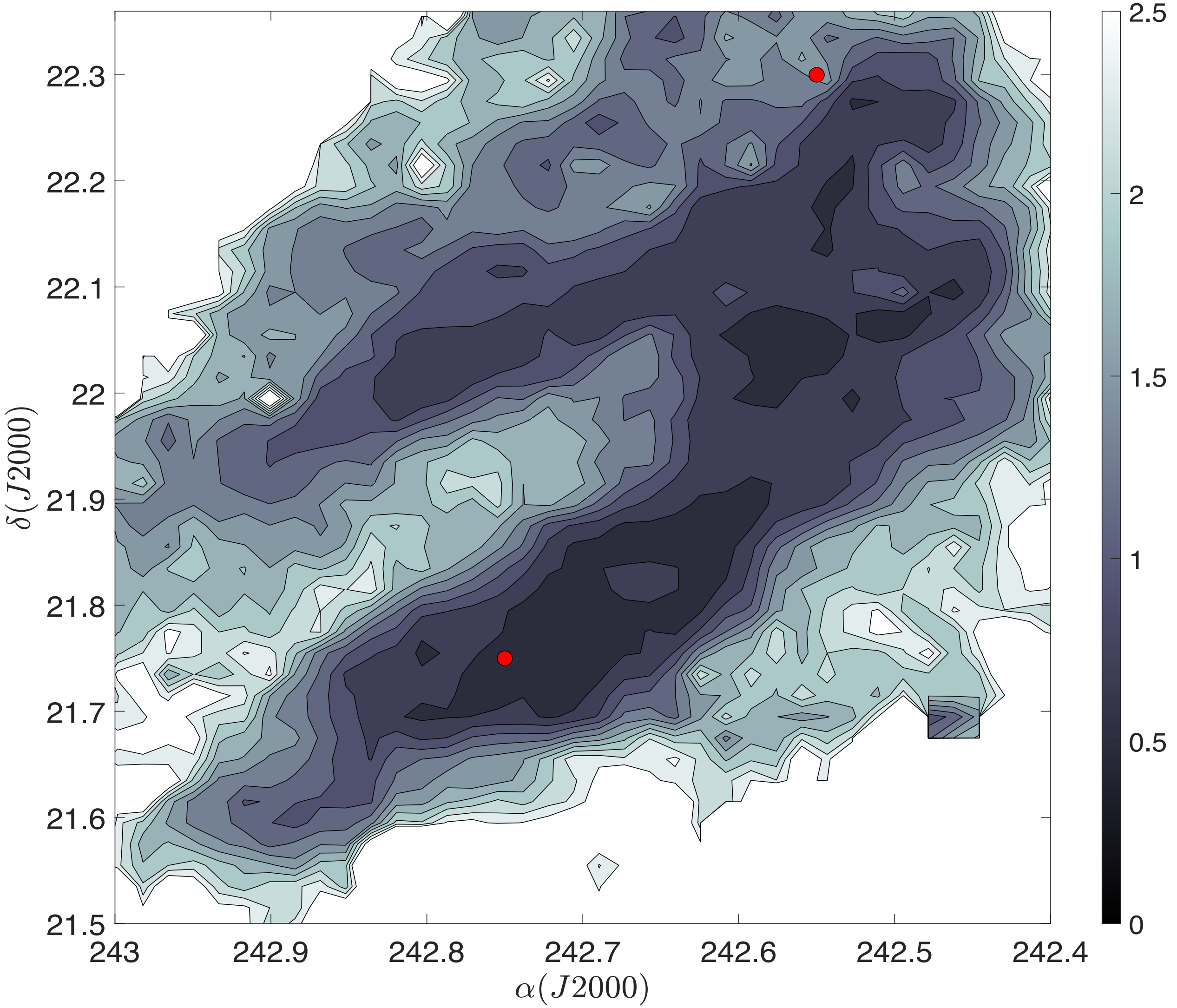
References

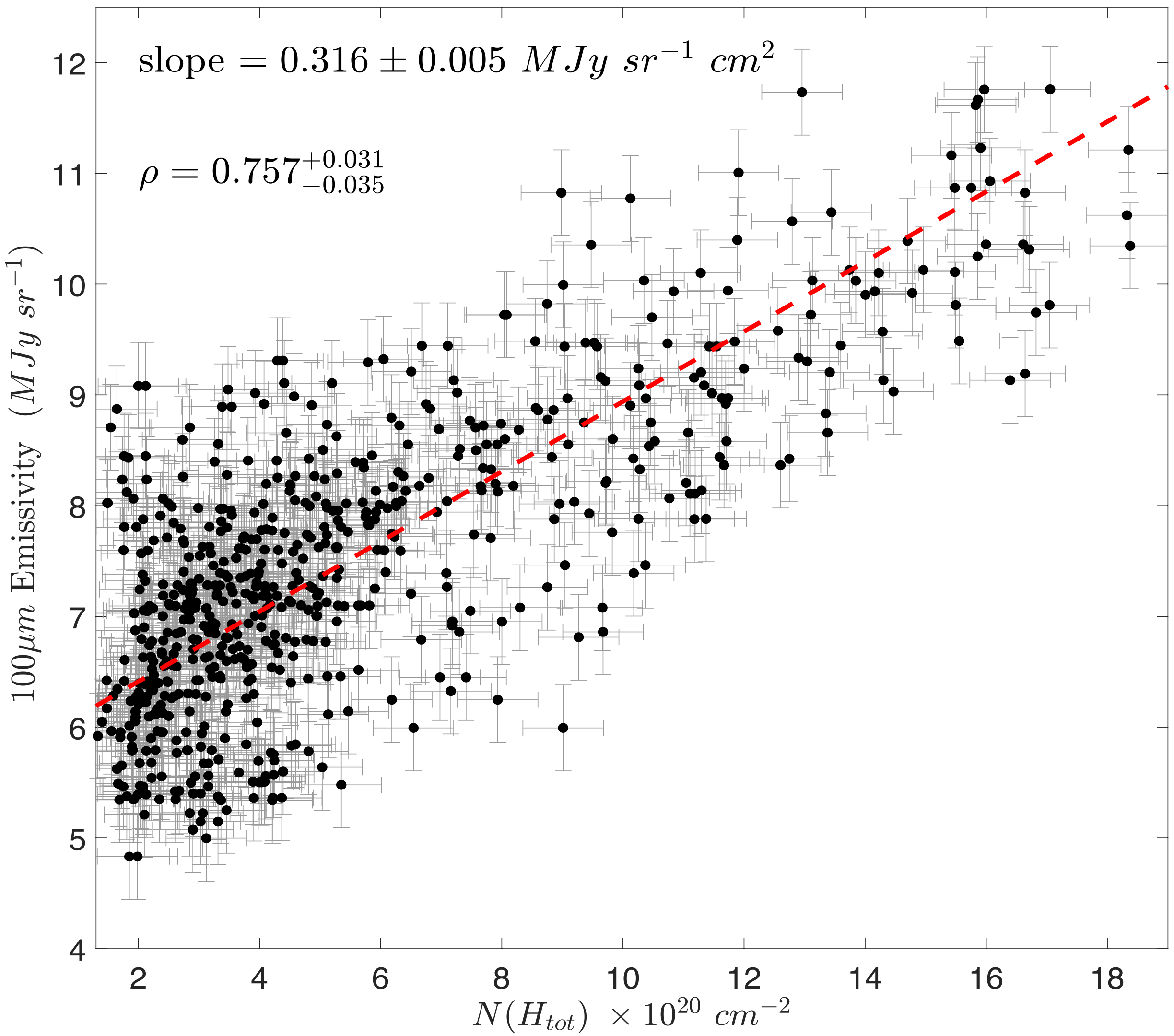
The mixing of dust and gas in the high latitude translucent cloud MBM 40
M. Monaci, L. Magnani and S. N. Shore
A&A, 668 (2022) L9

Shear, writhe and filaments: turbulence in the high latitude molecular cloud MBM 40
M. Monaci, L. Magnani, S. N. Shore, H. Olofsson and M. R. Joy
Accepted for publication in A&A (2023)

Backup slides

Dust to gas mass ratio (DGMR)

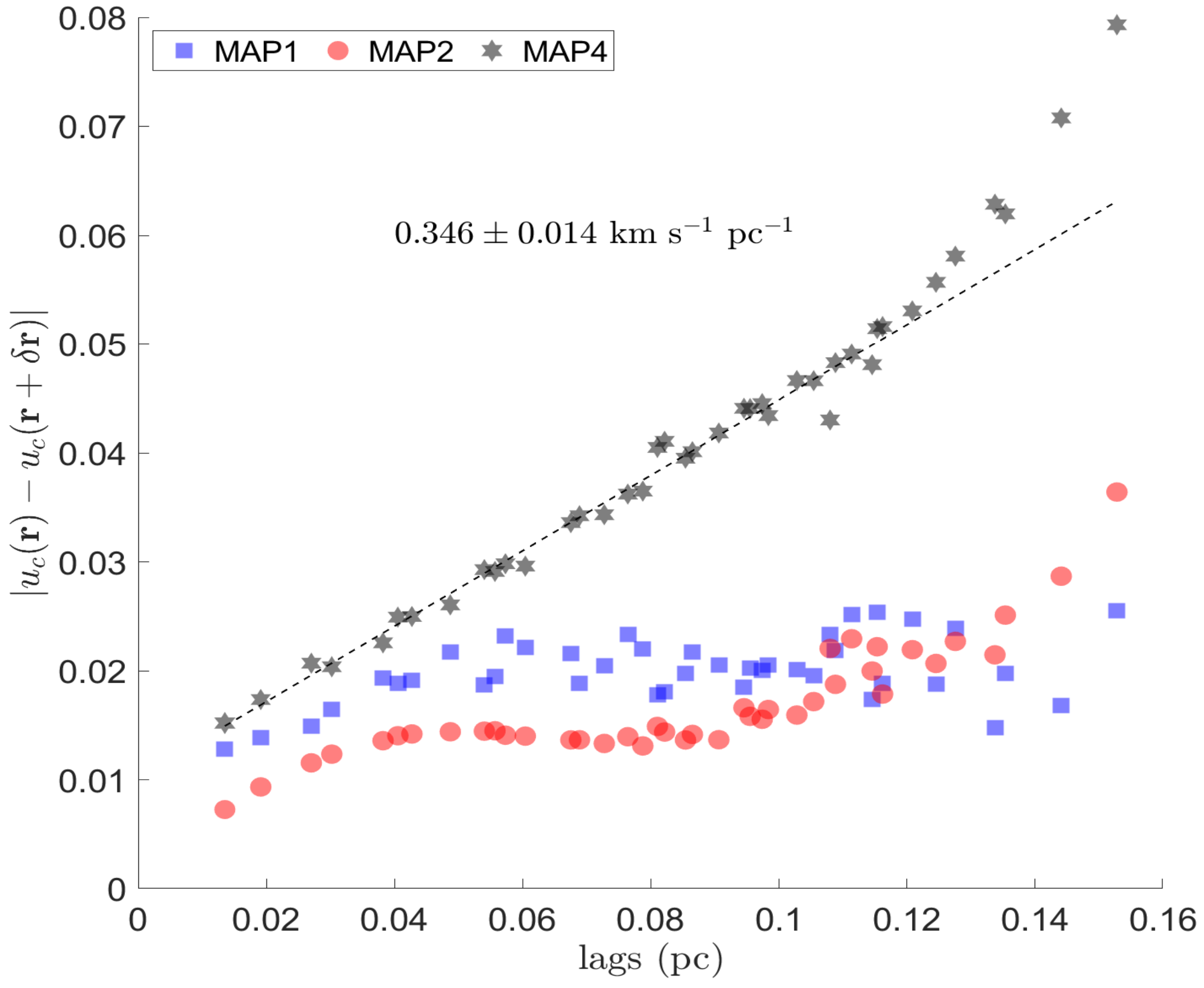


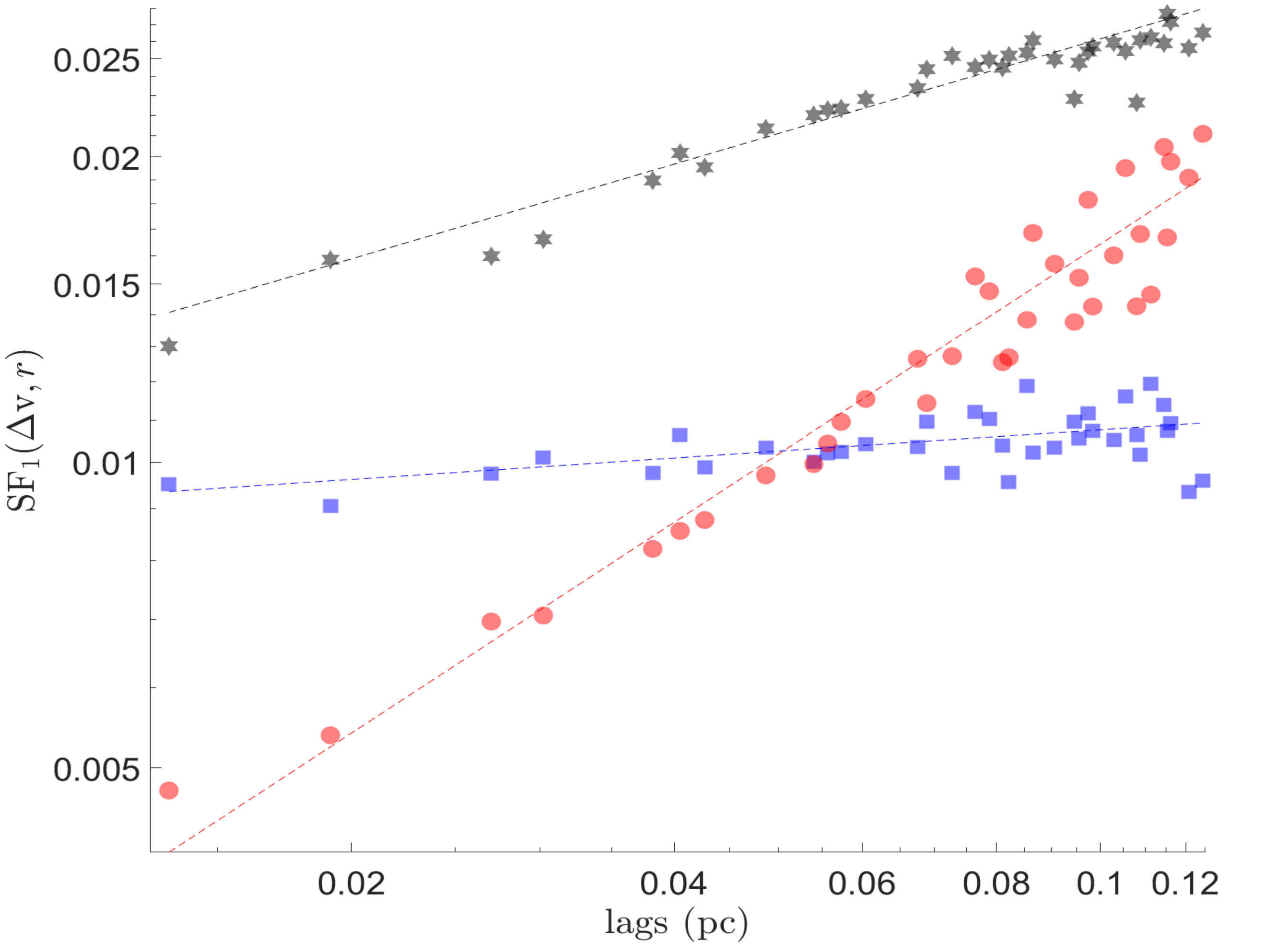


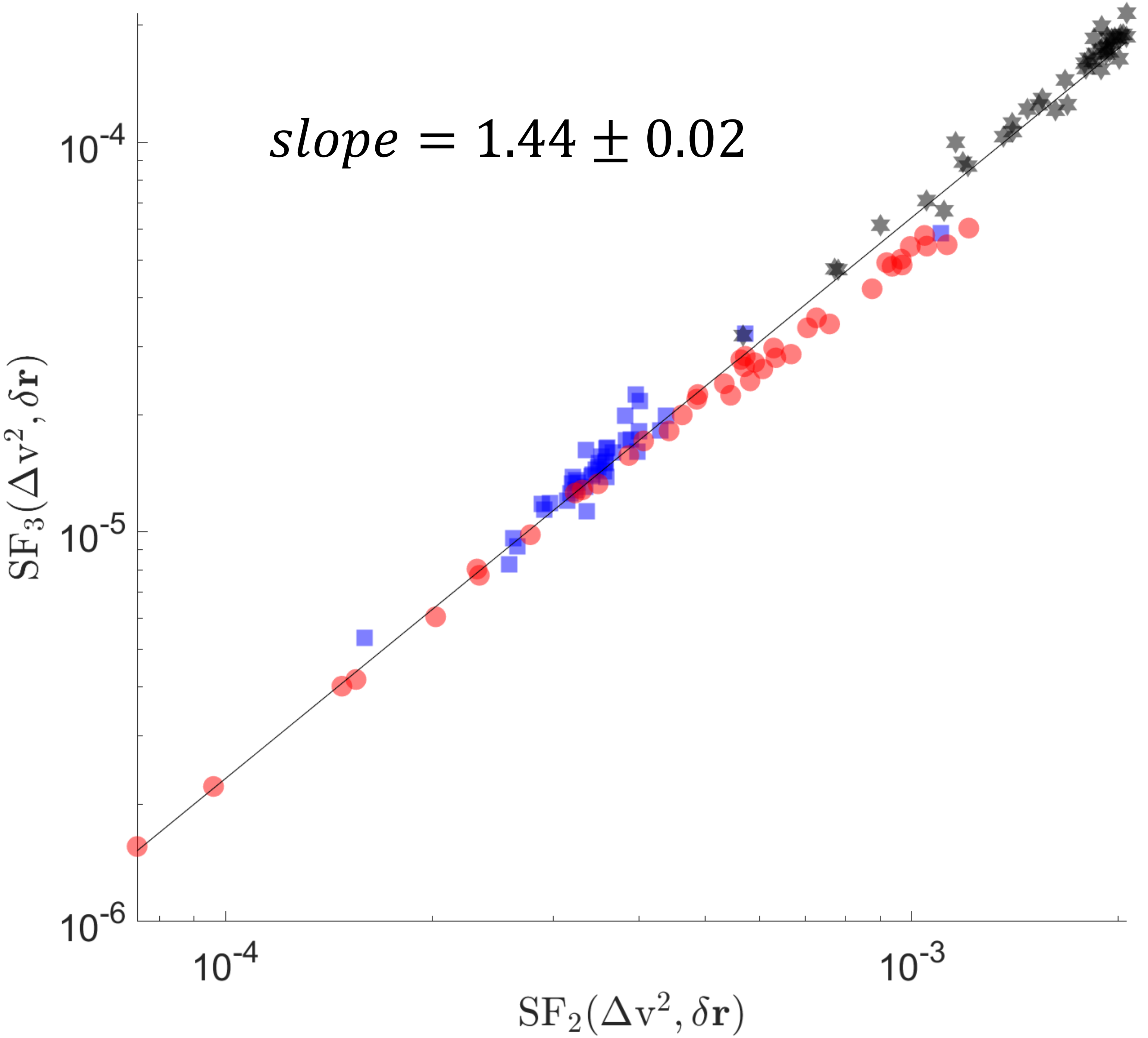
Monaci et al. (2022)

Structure Functions (SFs)

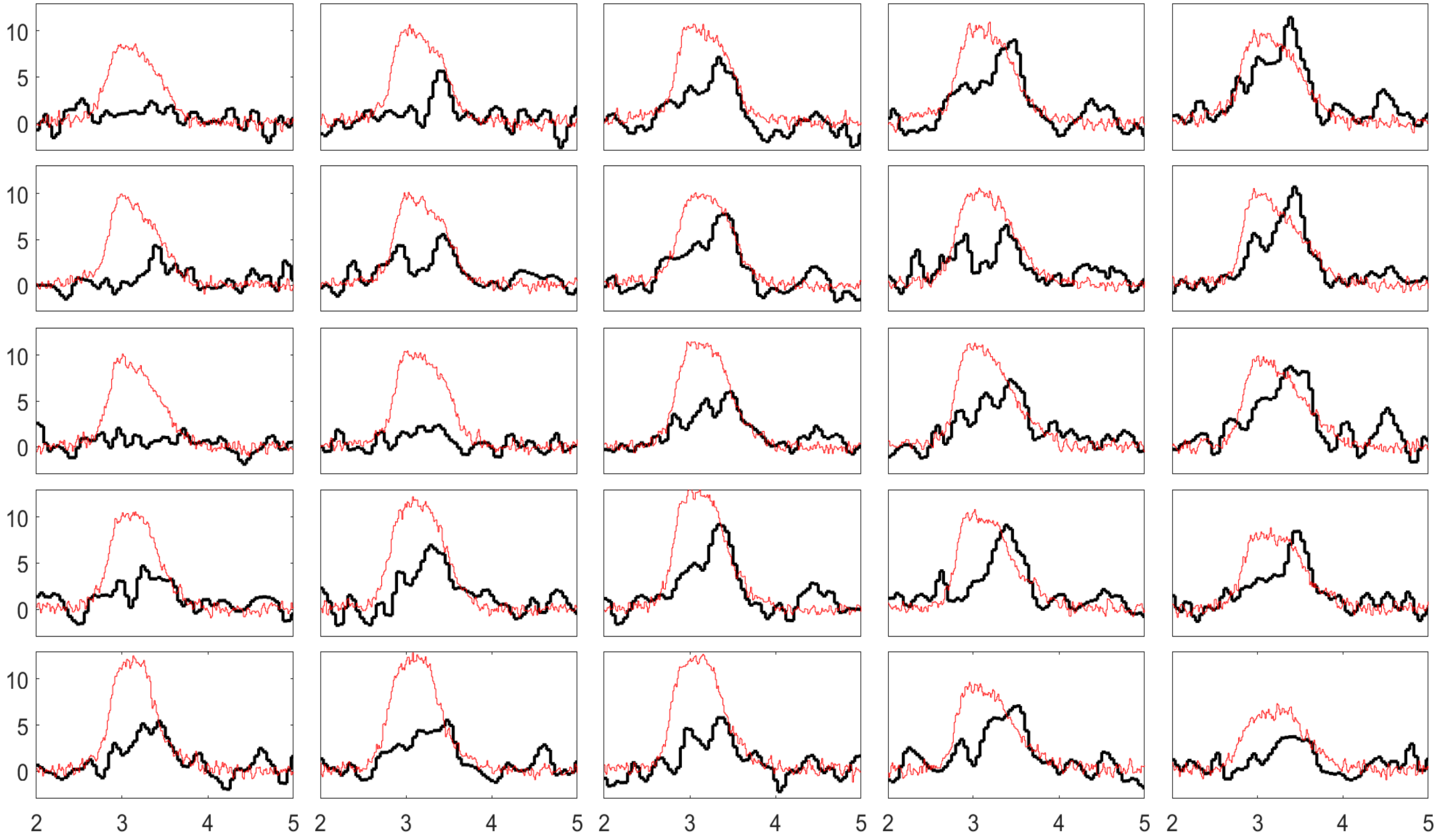
$$S_p = \langle |A(\boldsymbol{r}) - A(\boldsymbol{r} + \delta\boldsymbol{r})|^p \rangle$$



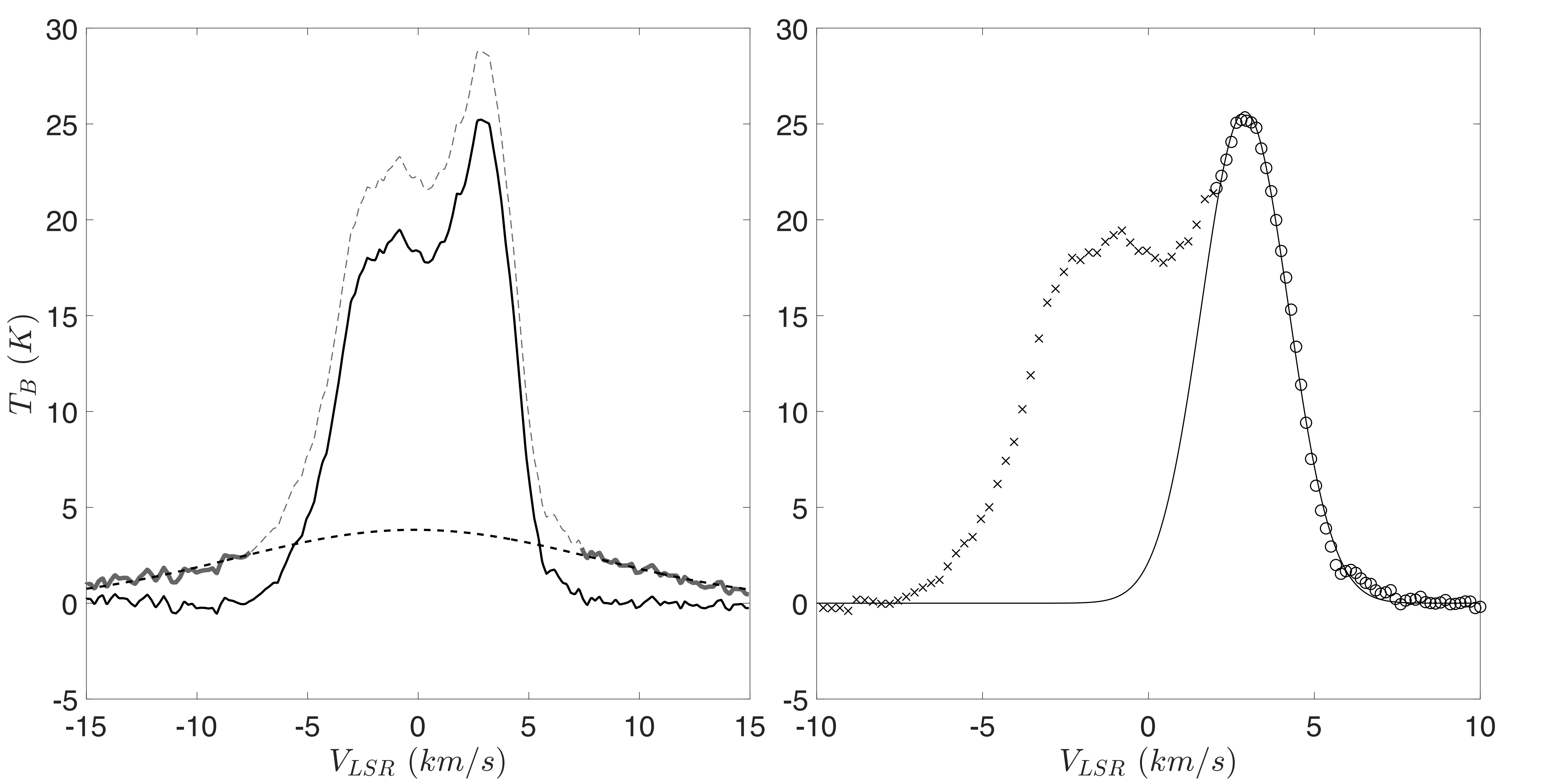



$slope = 1.44 \pm 0.02$
10^{-4}
10^{-5}
10^{-6}
10^{-4}
10^{-3}
$\mathrm{SF}_3(\Delta \mathrm{v}^2, \delta \mathbf{r})$
$\mathrm{SF}_2(\Delta \mathrm{v}^2, \delta \mathbf{r})$

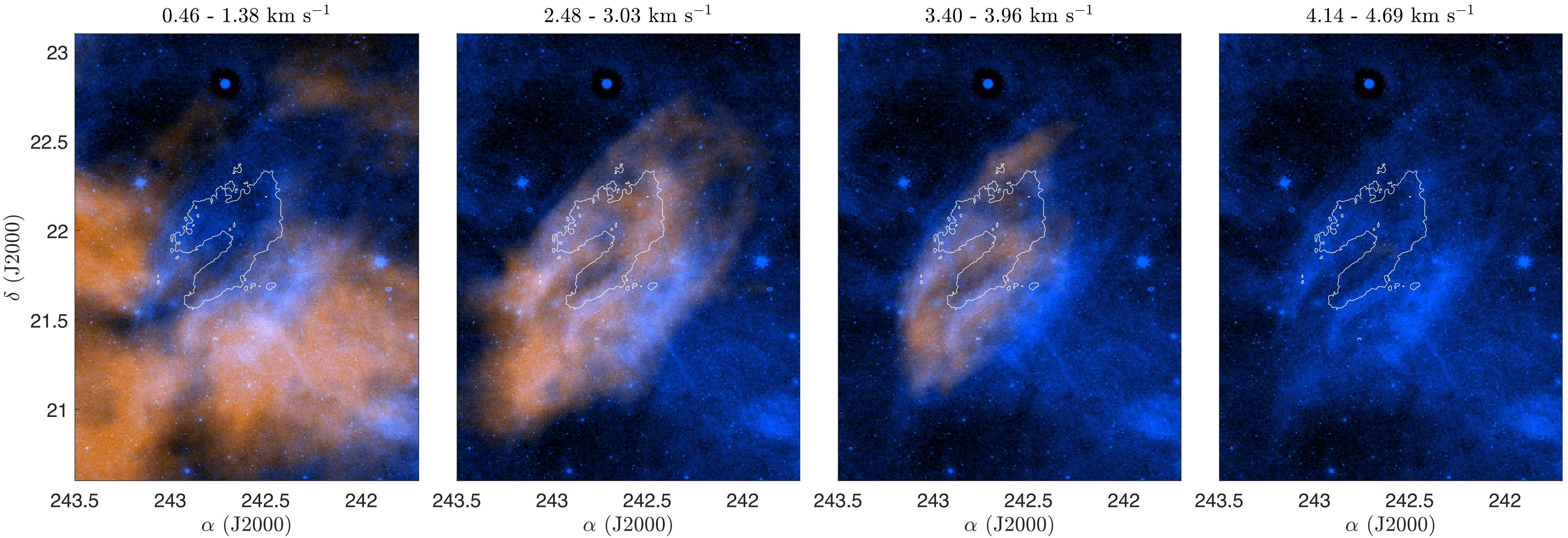
^{12}CO and H_2CO in MAP2



Driven decomposition of HI profiles



Dust and gas relation



Blue: WISE 12 μm image that traces mainly PAHs. The cloud shape is invisible in this channel → cloud optically thick to UV radiation.

Orange: HI velocity channels. Note that the external envelope is traced by both HI and PAHs.

MAP2

MAPZ