

FORGOTTEN QUADRANT SURVEY

(FQS) ^{12}CO (1-0) & ^{13}CO (1-0) $220^\circ < l < 240^\circ$ - $2.5^\circ < b < 0^\circ$

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S. Molinari, L. Olmi, S. Pezzuto, K.L.J. Rygl, E. Schisano, L. Testi, A. Traficante



$^{12}\text{CO} (1-0) \text{ \& } ^{13}\text{CO} (1-0)$
 $220^\circ < l < 240^\circ \text{ } -2.5^\circ < b < 0^\circ$

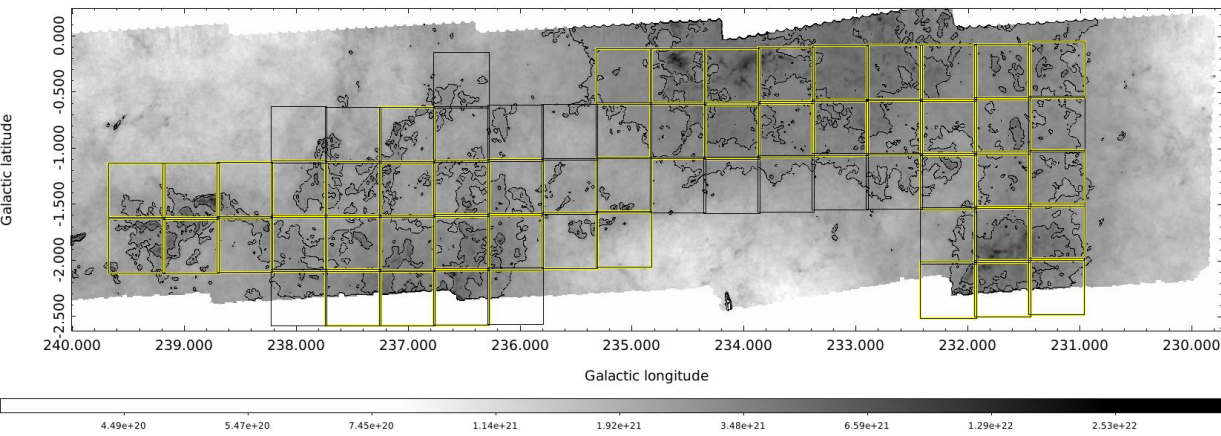
HPBW = 55''

velocity channel 0.65/0.26 km/s

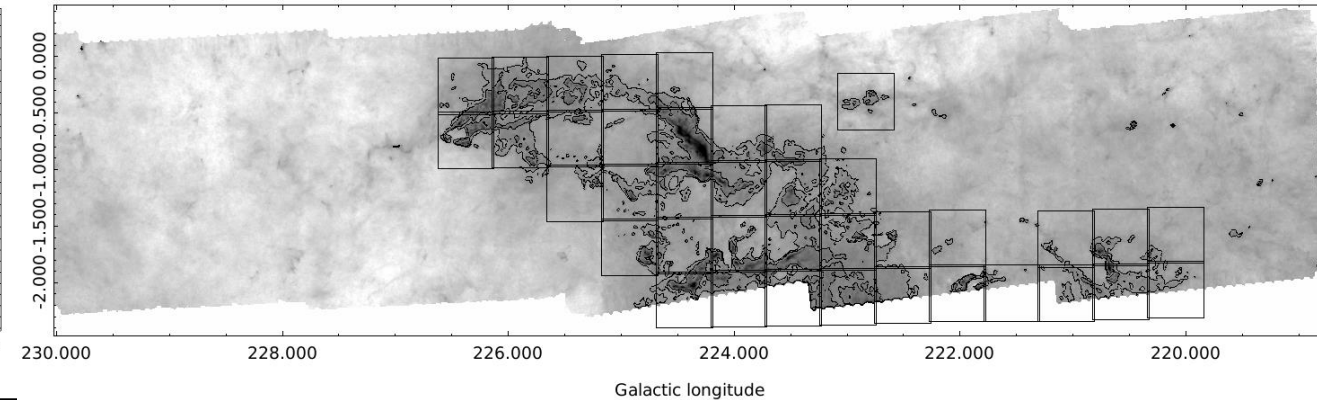
velocity band 166/66 km/s

Benedettini et al. 2020

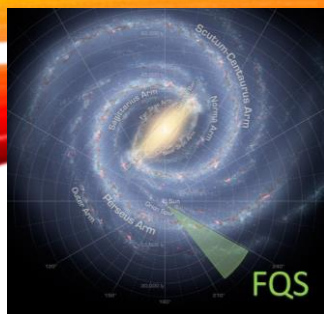
Arizona Radio Observatory 12m antenna
 November 2016 – June 2018



Grid of the observed 30' x 30' tiles over the H₂ column density image



Data available at <https://fqs.iaps.inaf.it>

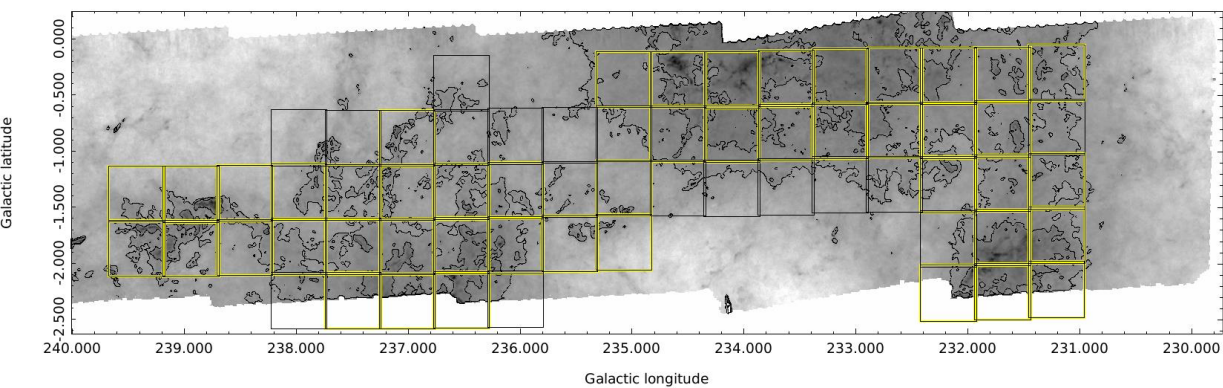


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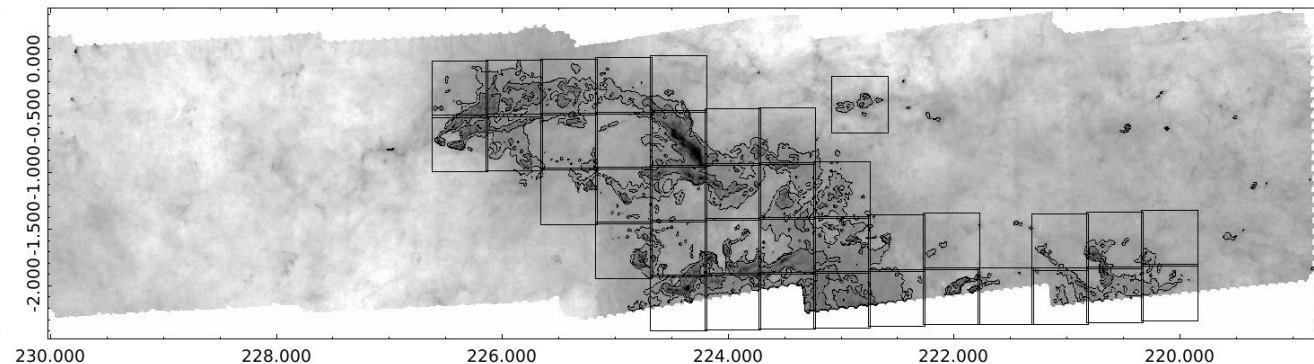
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Grid of the observed 30' x 30' tiles over the H₂ column density image



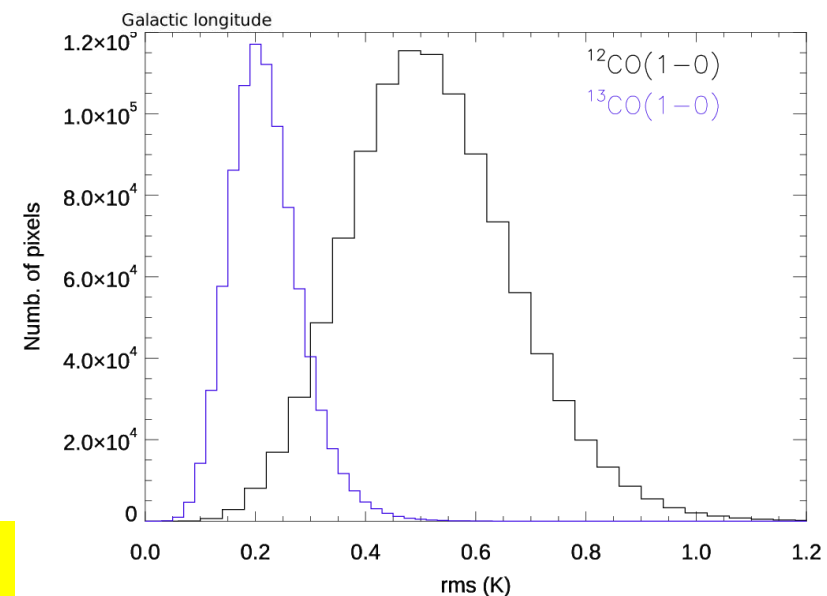
Final products:

Spectral cubes with $17''$ pixel and 1/0.3 km/s velocity channels

Following analysis done on the 1 km/s spectral cube.

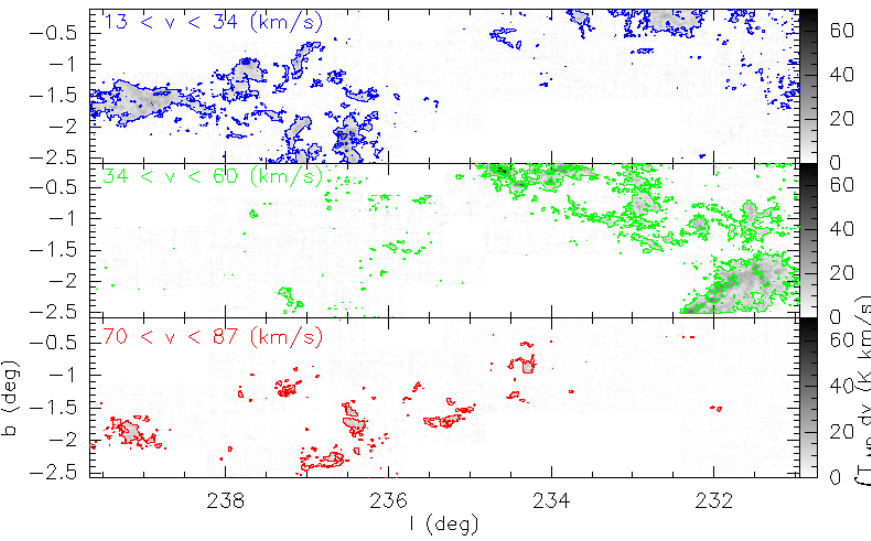
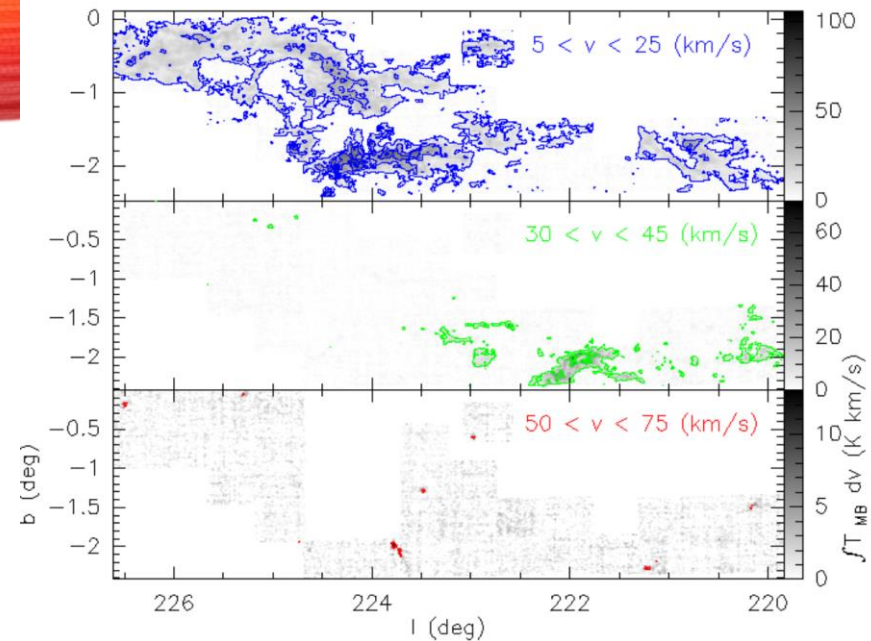
median[rms($^{12}\text{CO} (1-0)$)] = 0.53 K

median[rms($^{13}\text{CO} (1-0)$)] = 0.22 K

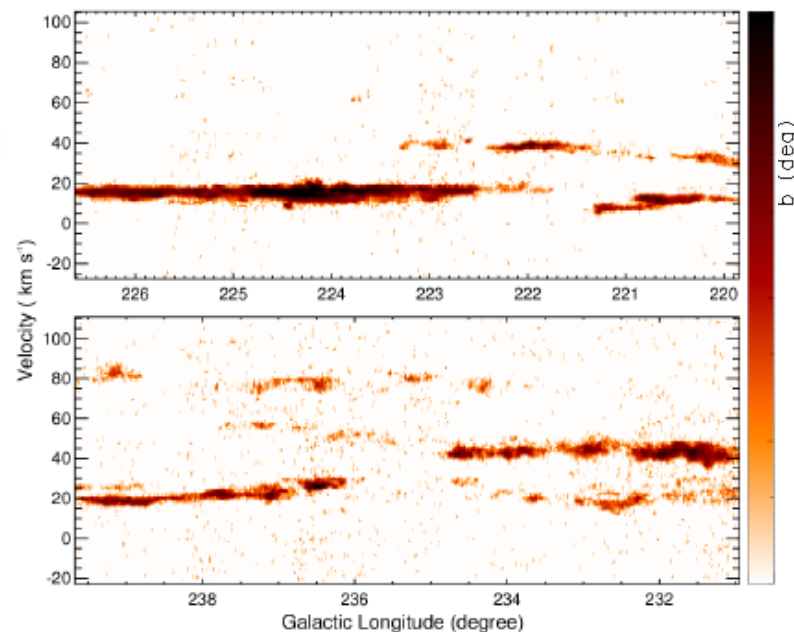


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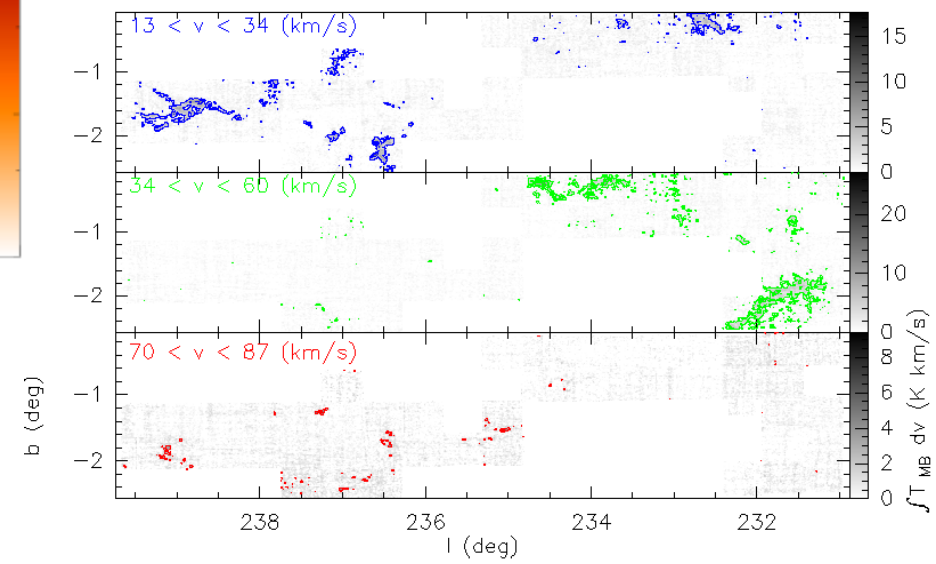
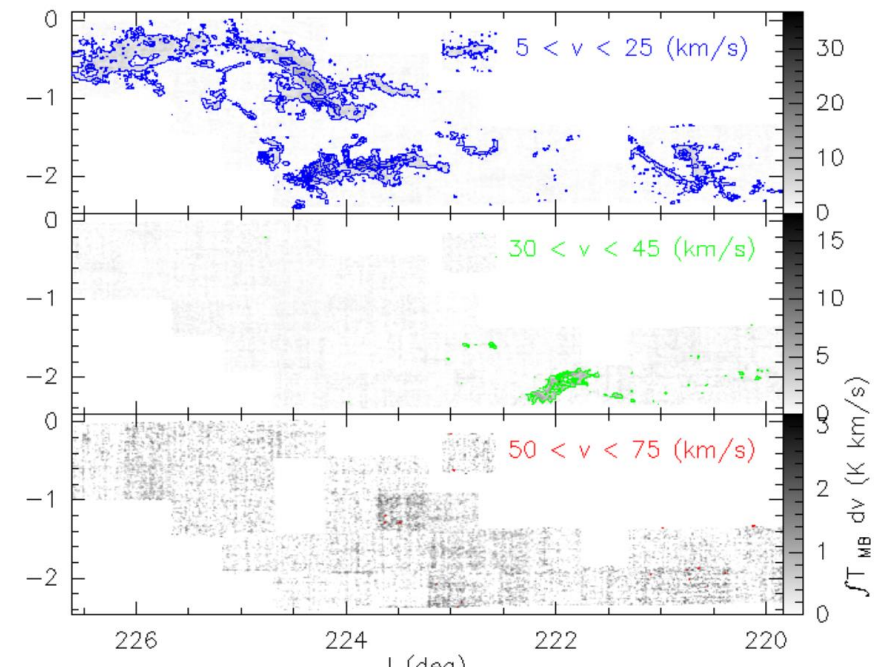
^{12}CO (1-0)



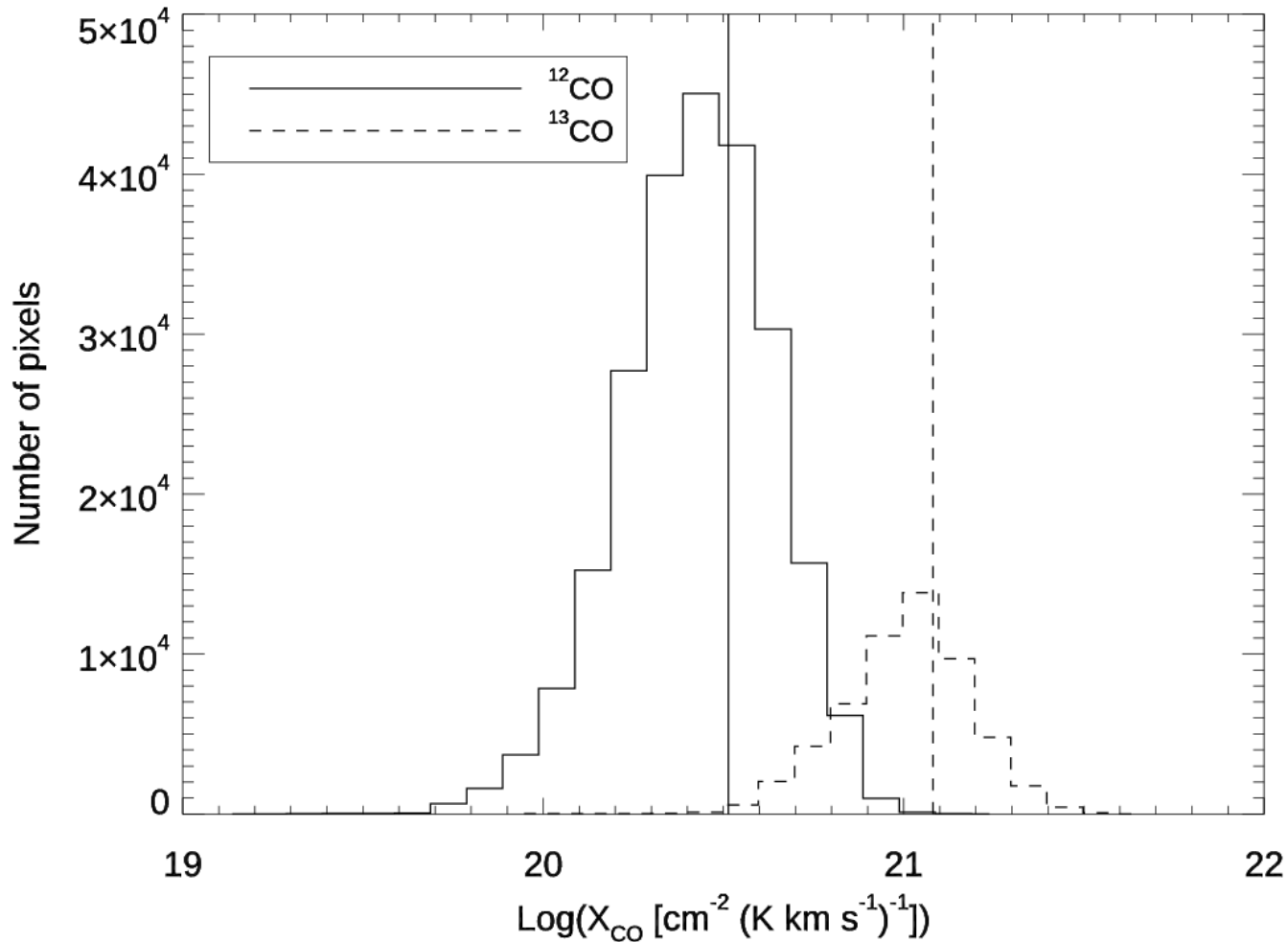
^{12}CO (1-0)



^{13}CO (1-0)



CO-TO-H2 CONVERSION FACTOR



$$N(\text{H}_2) = X(\text{CO}) I(\text{CO})$$

$N(\text{H}_2)$ from Herschel HiGal (Schisano et al. 2020)
 $I(\text{CO})$ from FQS

$$X(^{12}\text{CO}) = (3.3 \pm 1.4) \times 10^{20} \text{ cm}^{-2} (\text{K km s}^{-1})^{-1}$$

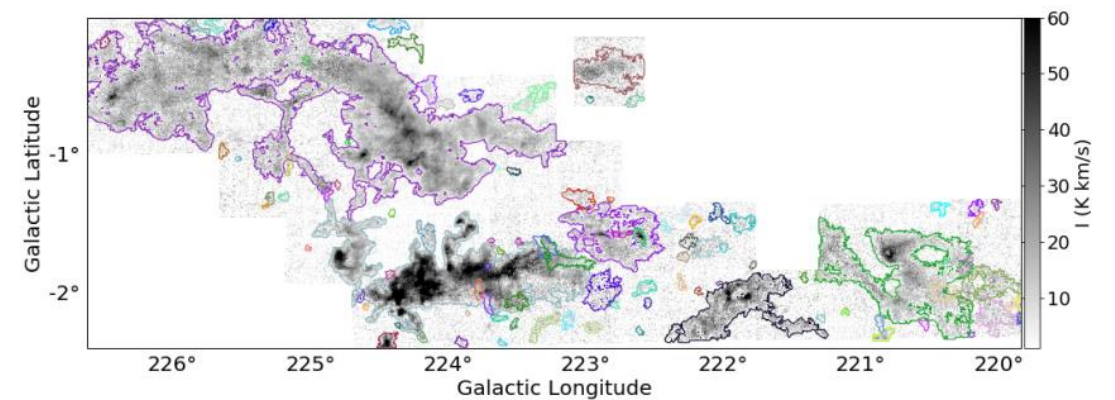
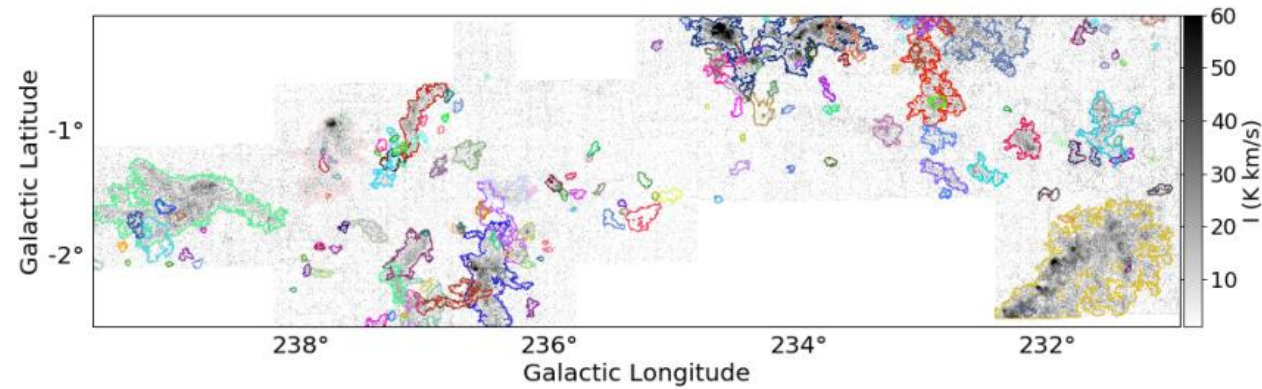
$$X(^{13}\text{CO}) = (1.2 \pm 0.4) \times 10^{21} \text{ cm}^{-2} (\text{K km s}^{-1})^{-1}$$

Benedettini et al. 2021

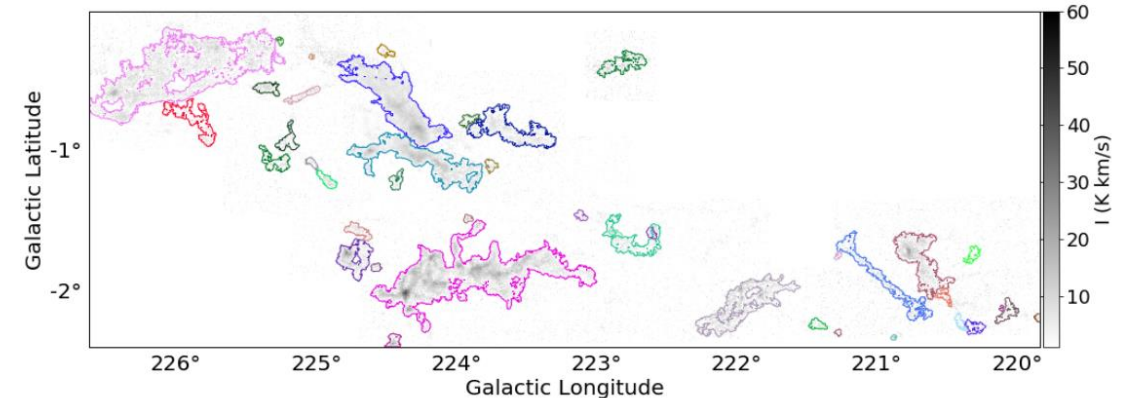
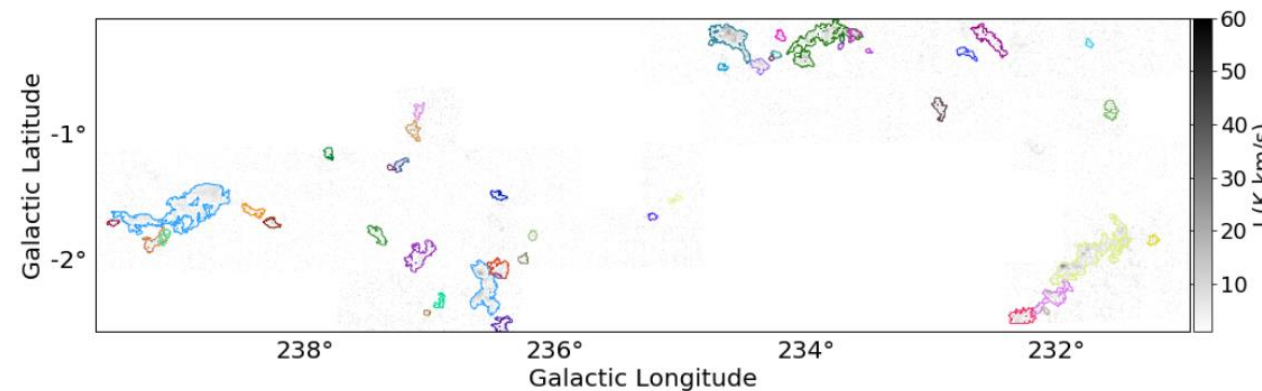
MOLECULAR CLOUDS

Clouds extractor in the ppv space: SCIMES (Colombo et al. 2015)

^{12}CO (1-0) catalog, 263 clouds Benedettini et al. 2020



^{13}CO (1-0) catalog, 87 clouds Benedettini et al. 2021



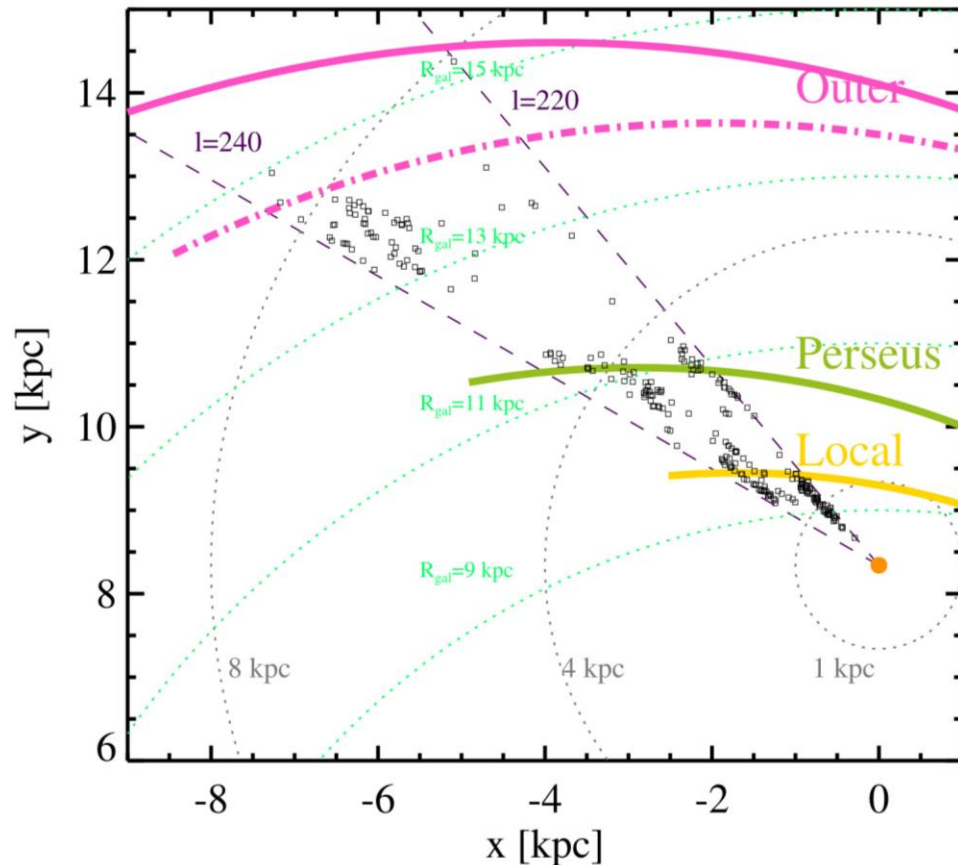
POSITION IN THE MILKY WAY

Kinematical distances derived from Galaxy rotation model of Reid et al. 2014

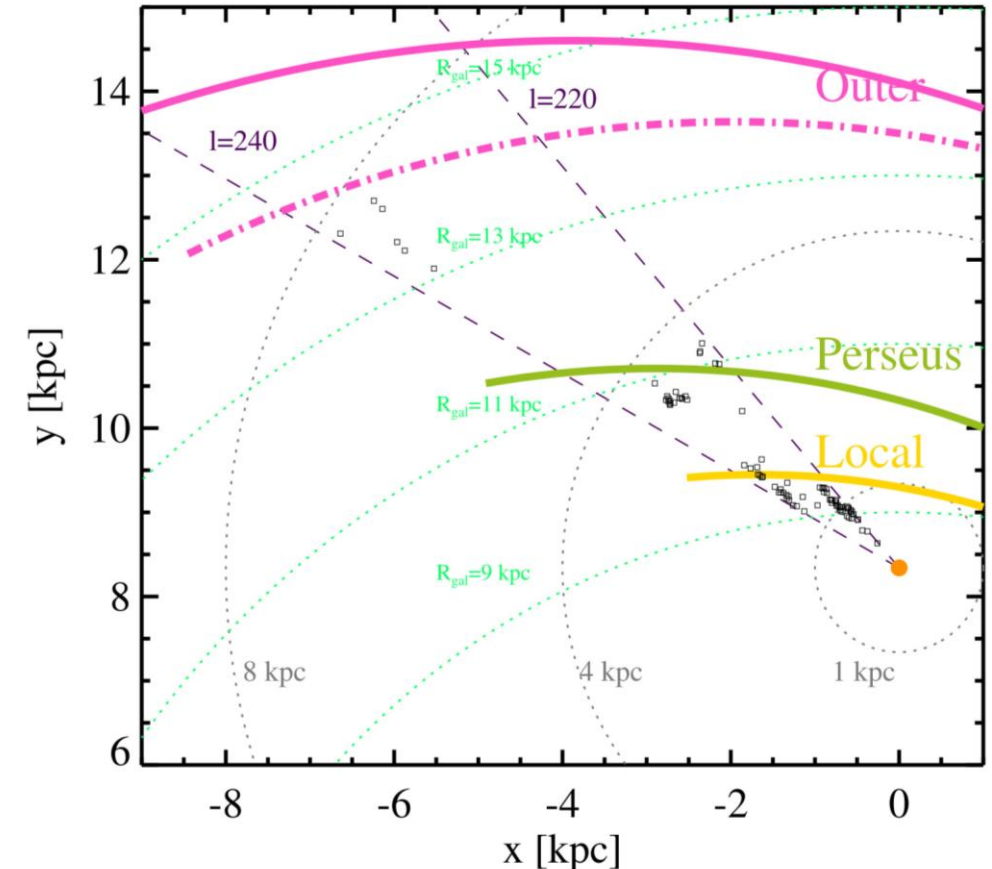
Spiral arm parameters from the BeSSeL project.

Continuous lines: Xu et al. 2013, Choi et al. 2014, Hachisuka et al. 2015 dot-dash line: Hou & Ham 2014

^{12}CO (1-0) catalog



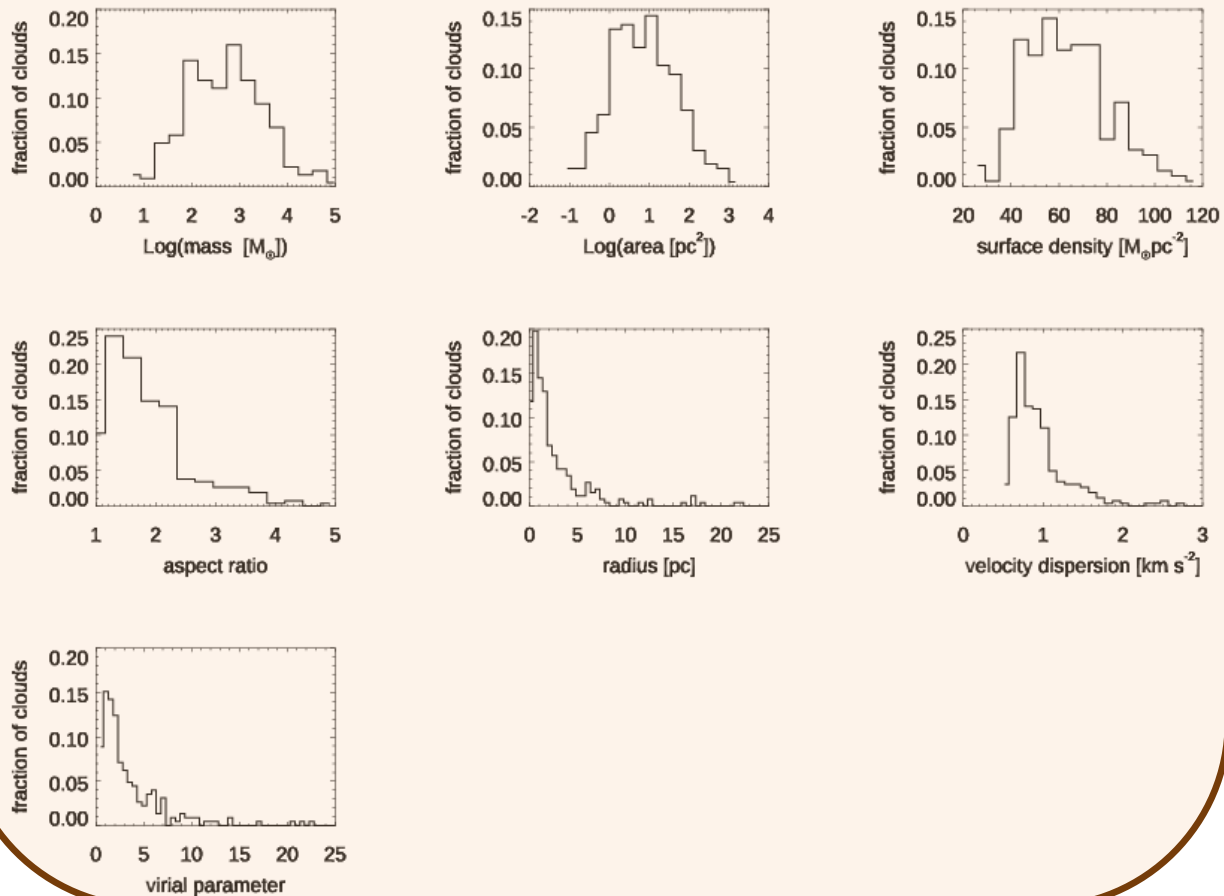
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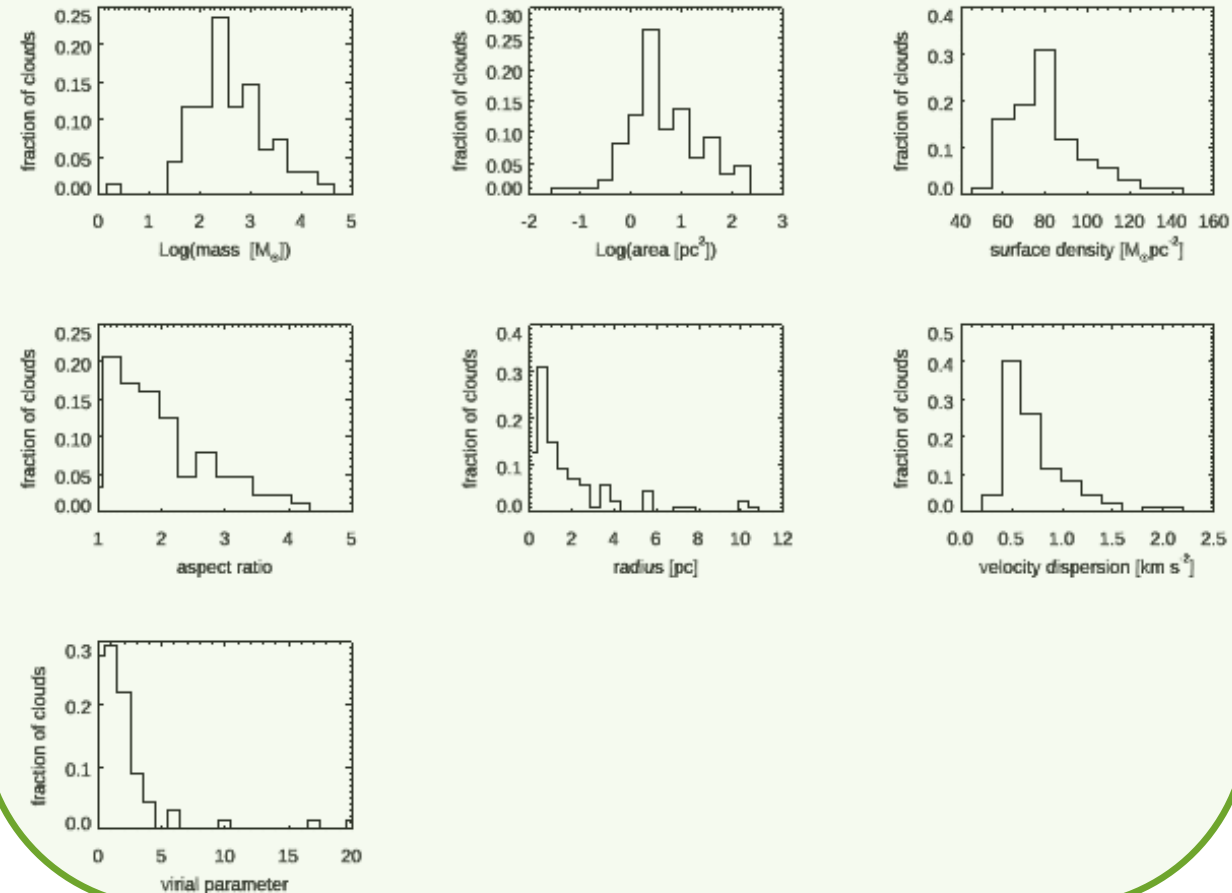
MOLECULAR CLOUDS

Physical properties

^{12}CO (1-0) catalog, 263 clouds
Benedettini et al. 2020



^{13}CO (1-0) catalog, 87 clouds
Benedettini et al. in 2021



MOLECULAR CLOUDS

Physical properties

^{12}CO (1-0) catalog, 263 clouds
Benedettini et al. 2020

	Median	Mode
Mass ($M_{\odot}$)	759	760
Area (pc^2)	9.6	11.3
Surface density ($M_{\odot} \text{pc}^{-2}$)	65	56
Aspect ratio	1.8	1.3
Equivalent spherical radius (pc)	1.8	0.6
Velocity dispersion (km s^{-1})	0.9	0.7
Virial parameter	2.51	1.06

^{13}CO (1-0) catalog, 87 clouds
Benedettini et al. in 2021

	Median	Mode
Mass _{dust} ($M_{\odot}$)	443	251
Area (pc^2)	4.7	2.5
Surface density ($M_{\odot} \text{pc}^{-2}$)	86	80
Aspect ratio	2.0	1.2
Equivalent spherical radius (pc)	1.4	0.6
Velocity dispersion (km s^{-1})	0.7	0.5
Virial parameter	1.87	1.00
Heliocentric distance (kpc)	1.57	0.89
Galactocentric radius (kpc)	9.33	9.00

MOLECULAR CLOUDS

Physical properties

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The structures traced by the ^{13}CO (1–0) line are the brightest and densest parts of the ^{12}CO (1–0) structures, while low-brightness regions in ^{12}CO (1–0) (less dense) are mostly undetected in ^{13}CO (1–0).

MOLECULAR CLOUDS

Mass estimate comparison

Mass from $X(^{12}\text{CO})$ (gas)

Mass from $N(^{13}\text{CO})$ (gas)

Mass from $N(\text{H}_2)$ from Herschel (dust)

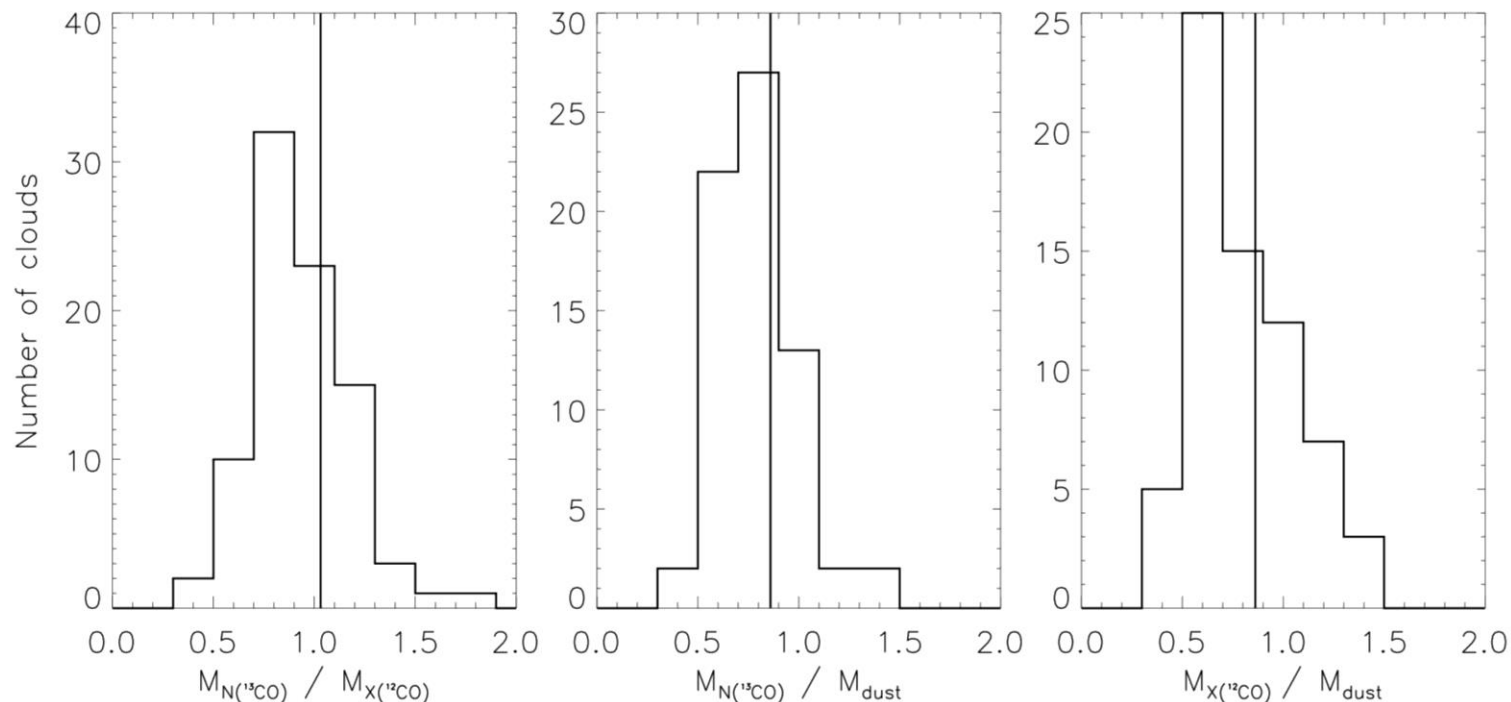
MOLECULAR CLOUDS

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Mass from $N(^{13}\text{CO})$ (gas)

Mass from $N(\text{H}_2)$ from Herschel (dust)



mass ratio	median	10 th percentile	90 th percentile
$M_{N(^{13}\text{CO})} / M_{X(^{12}\text{CO})}$	0.99	0.76	1.36
$M_{N(^{13}\text{CO})} / M_{\text{dust}}$	0.86	0.66	1.15
$M_{X(^{12}\text{CO})} / M_{\text{dust}}$	0.86	0.61	1.34

MOLECULAR CLOUDS

Mass estimate comparison

Mass from $X(^{12}\text{CO})$ (gas)

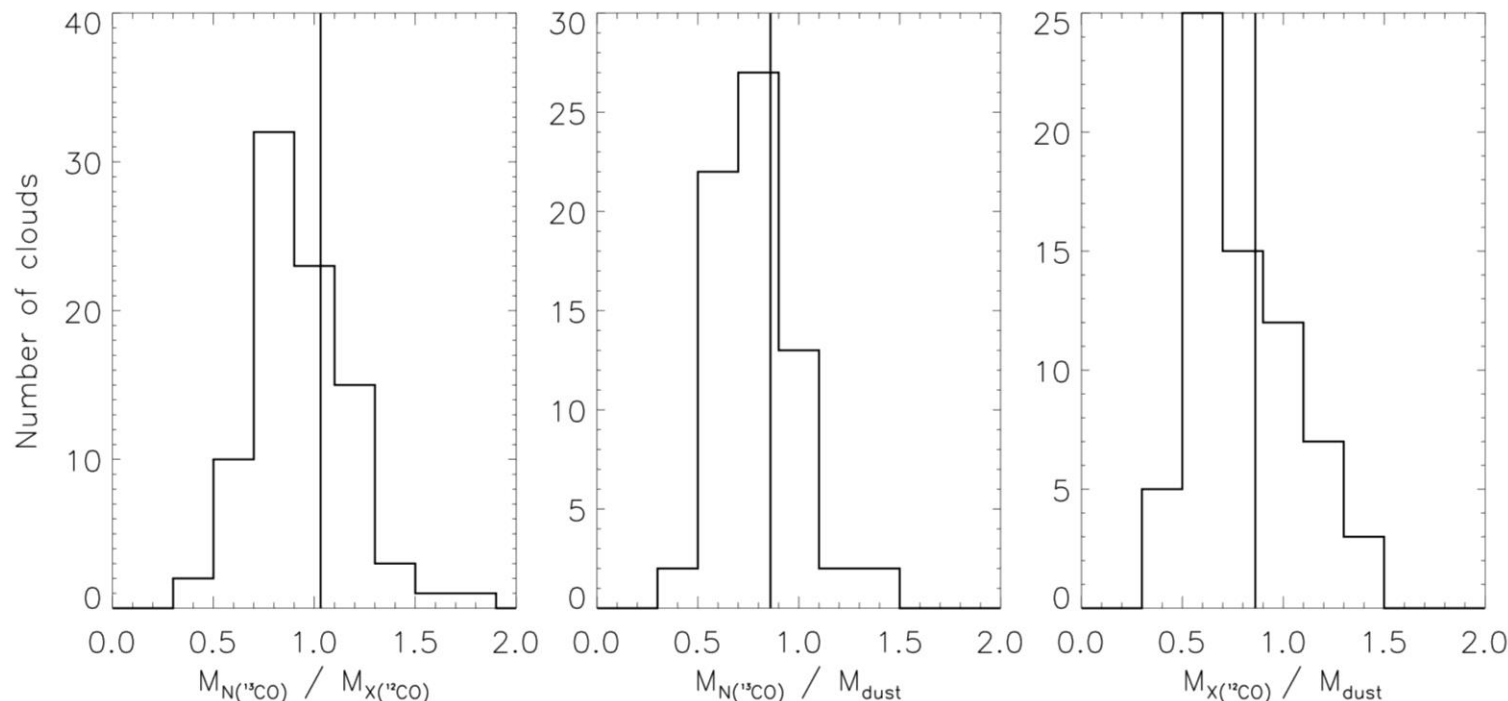
Mass from $N(^{13}\text{CO})$ (gas)

Mass from $N(\text{H}_2)$ from Herschel (dust)

^{12}CO and ^{13}CO trace a similar column of gas

Dust is really optical thin tracer

CO becomes optically thick in the densest regions as clumps/cores

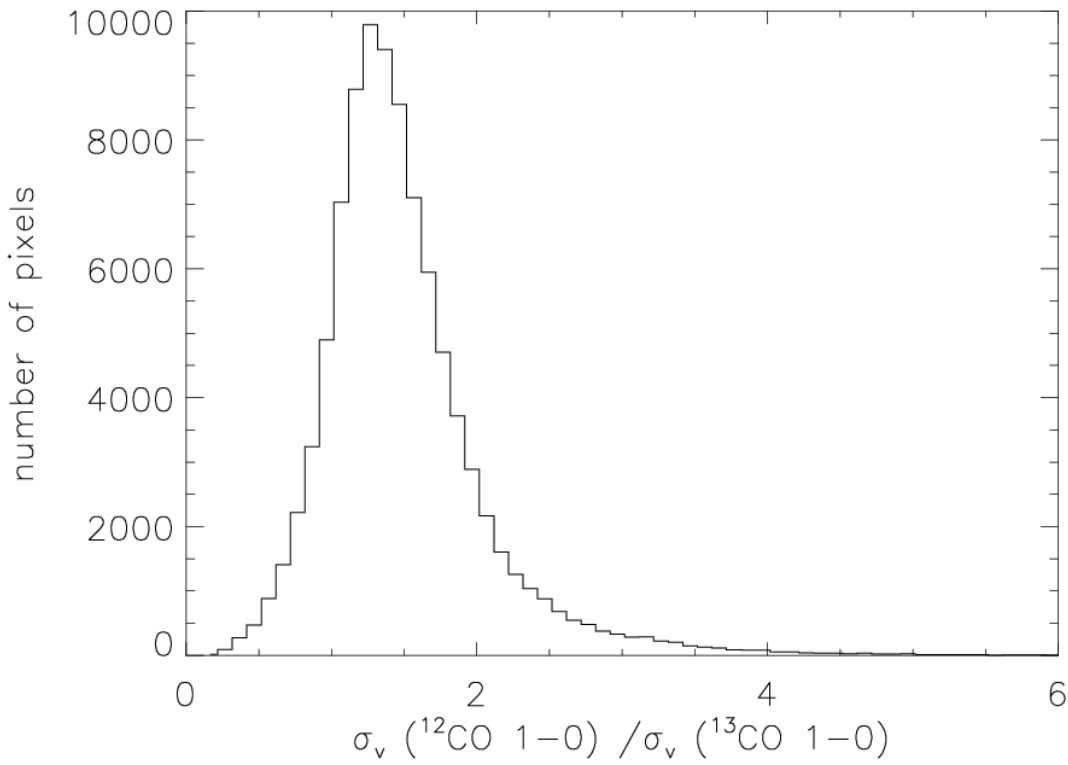


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MOLECULAR CLOUDS

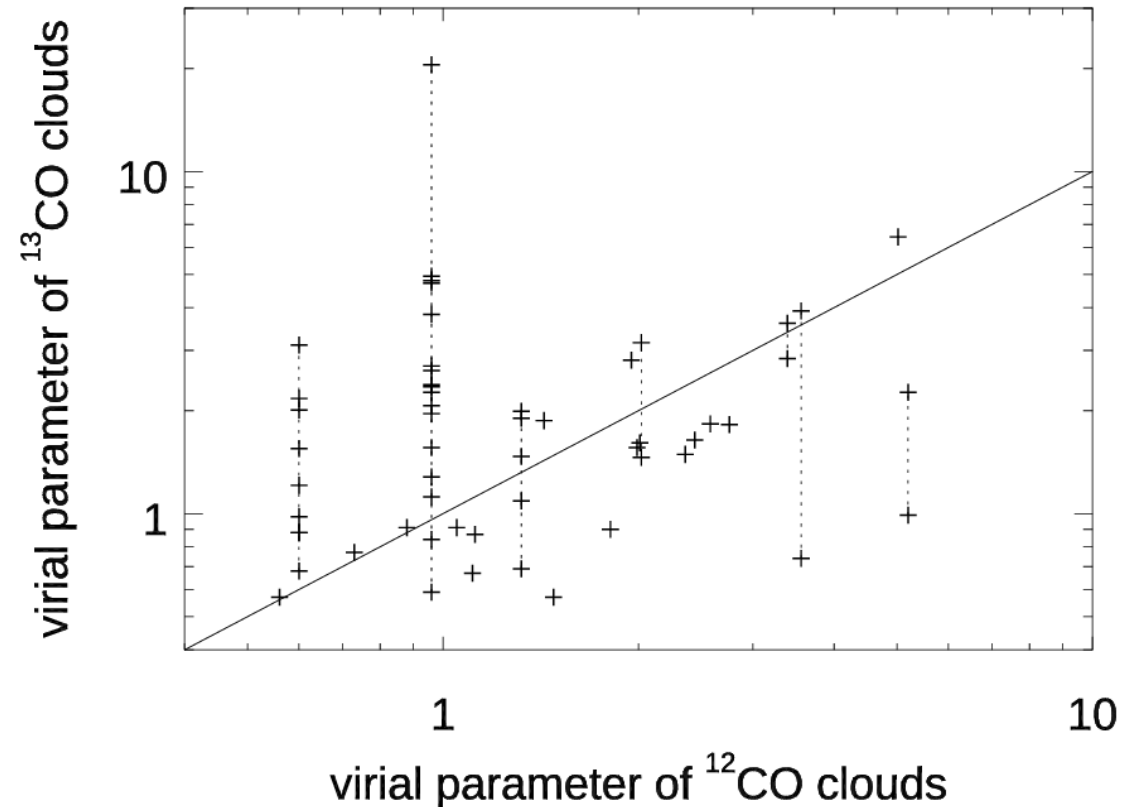
Physical properties comparison

Velocity dispersion



$$\langle \sigma_v (^{12}\text{CO } 1-0) / \sigma_v (^{13}\text{CO } 1-0) \rangle > 1.4$$

Virial parameter



$$\langle \alpha_{\text{vir}} [^{12}\text{CO}(1-0)] / \alpha_{\text{vir}} [^{13}\text{CO}(1-0)] \rangle = 1.3$$

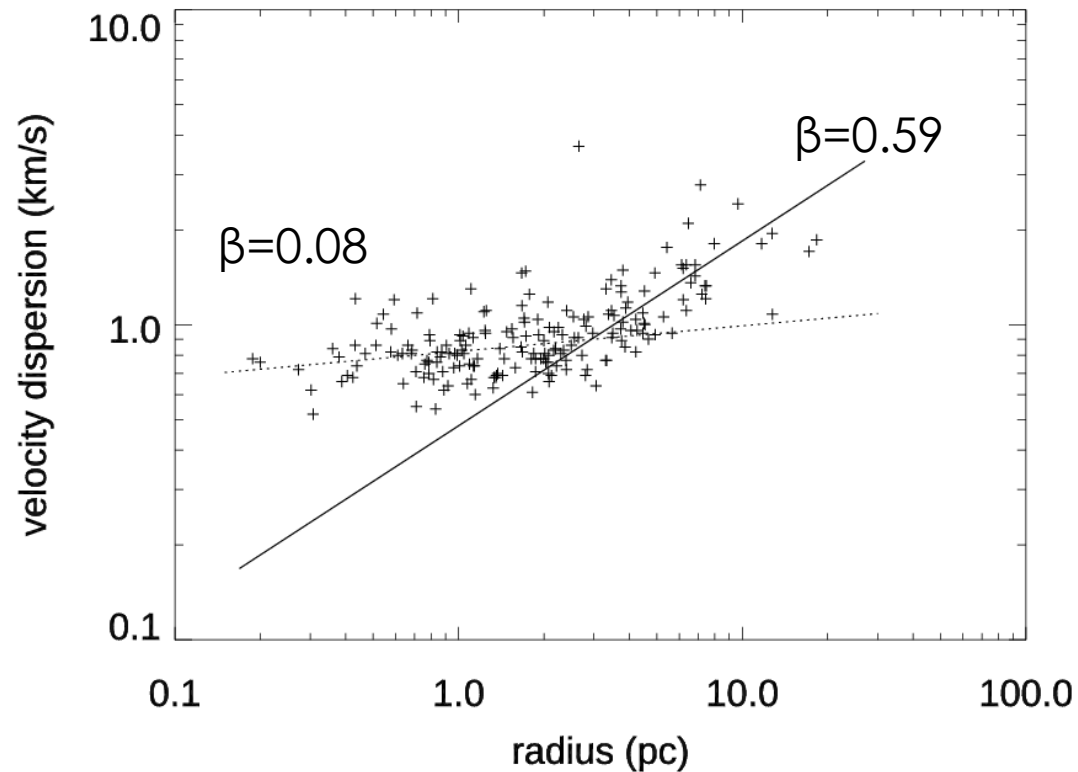
MOLECULAR CLOUDS

Physical properties

Supersonic turbulence $\beta=0.5$

$$\sigma_v \propto R^\beta$$

^{12}CO (1-0) catalog, 263 clouds
Benedettini et al. 2020



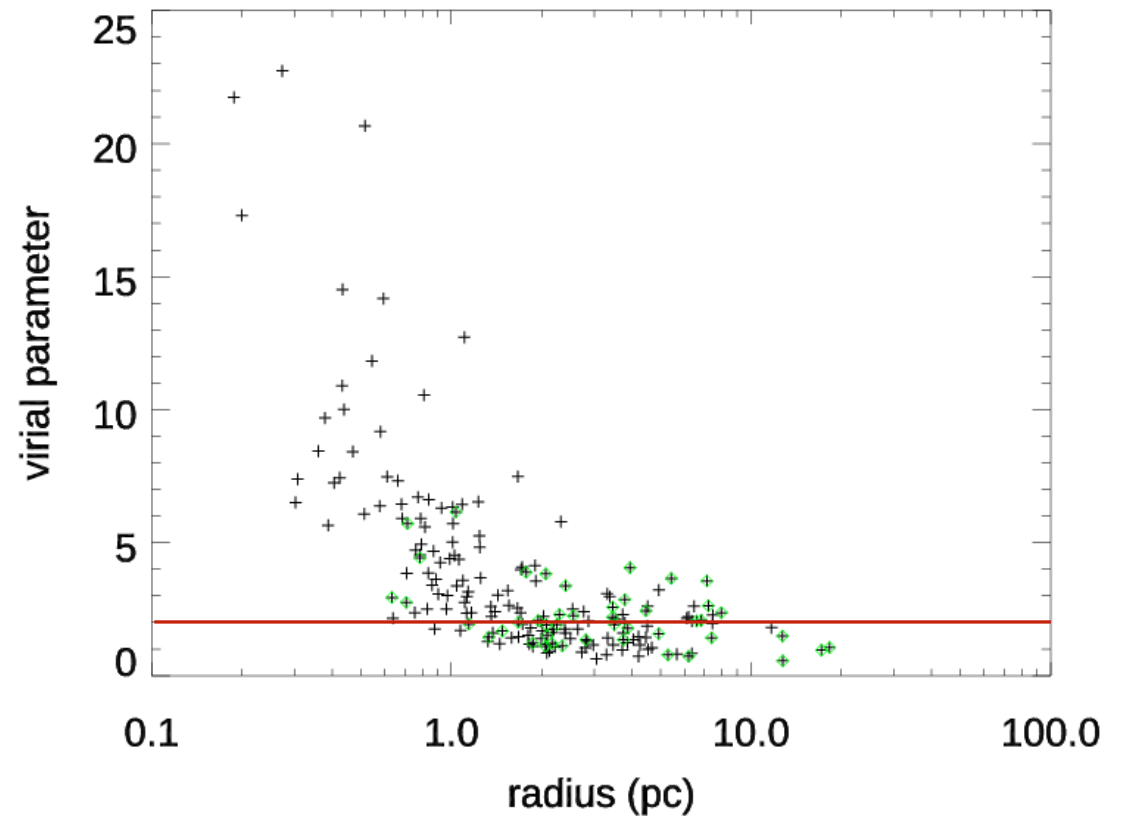
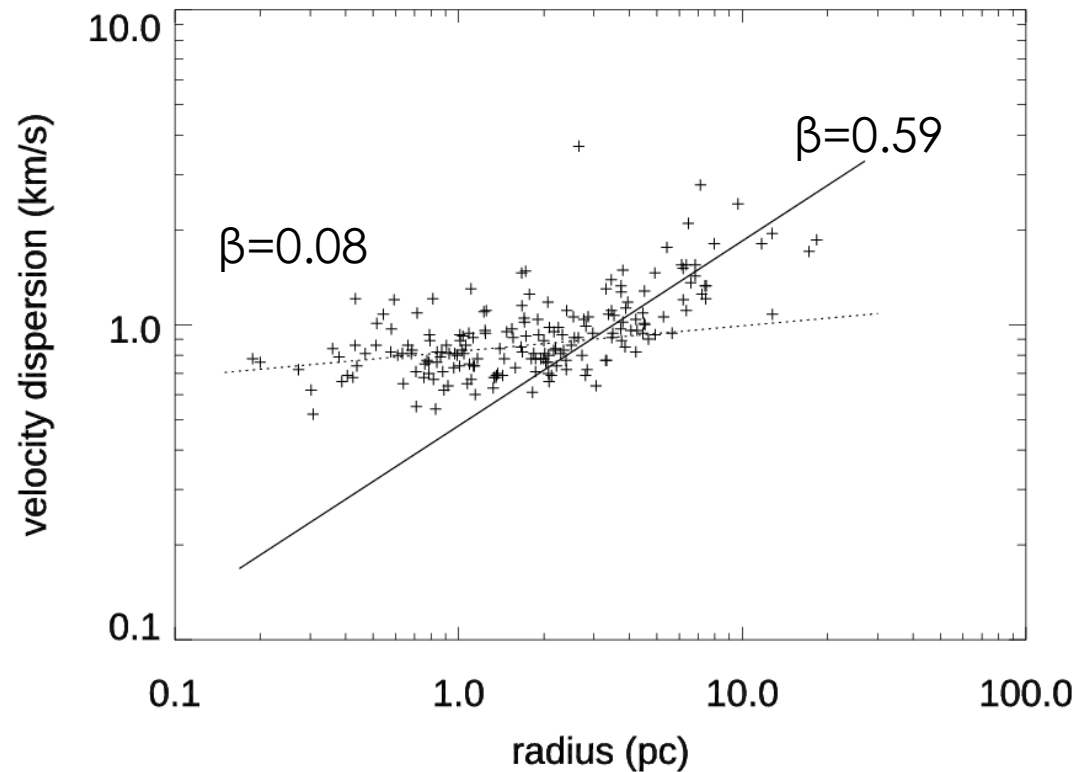
MOLECULAR CLOUDS

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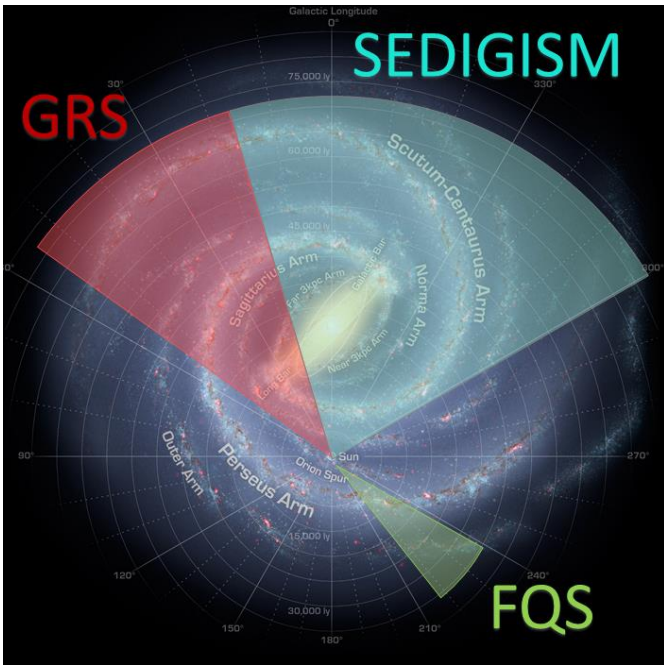
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MASS SURFACE DENSITY OF MOLECULAR CLOUDS



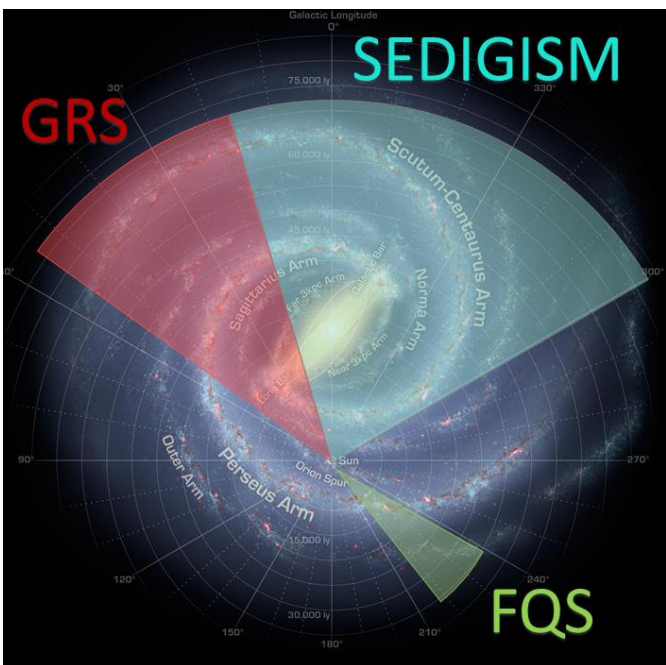
SEDIGISM catalog: ^{13}CO (2-1) SCIMES
Duarte-Cabral et al 2021

GRS catalog: ^{13}CO (1-0) CLUMPFIND
Roman-Duval et al. 2010

FQS ^{12}CO catalog: ^{12}CO (1-0) SCIMES
Benedettini et al 2020

FQS ^{13}CO catalog: ^{13}CO (1-0) SCIMES
Benedettini et al. 2021

MASS SURFACE DENSITY OF MOLECULAR CLOUDS

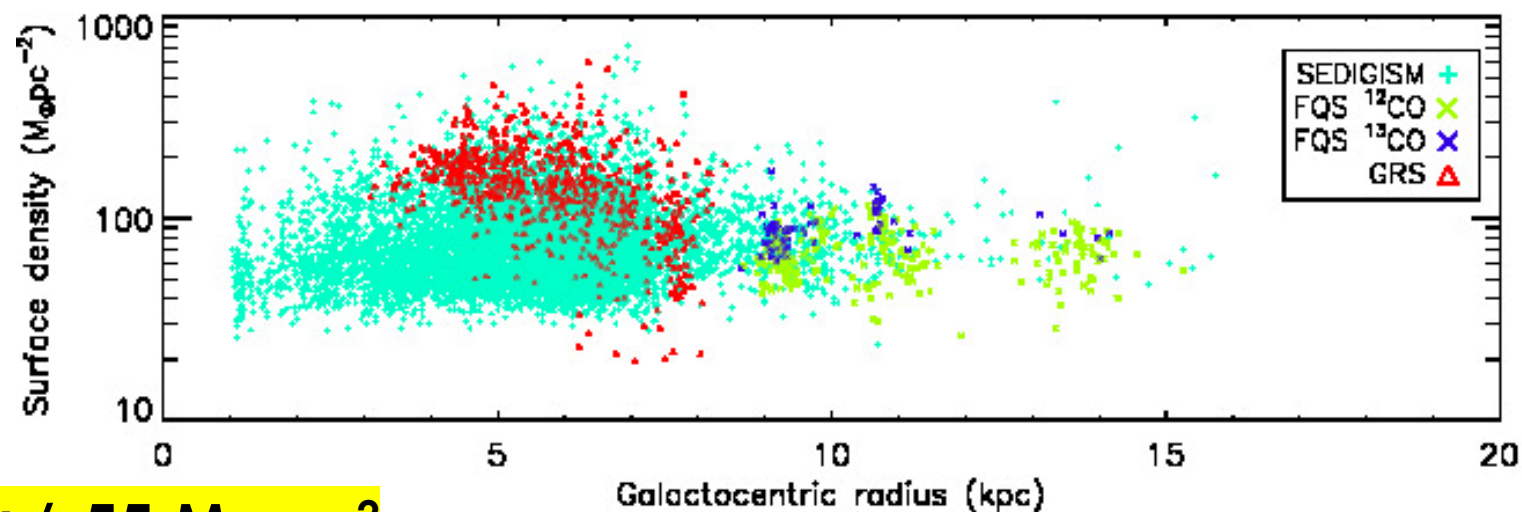


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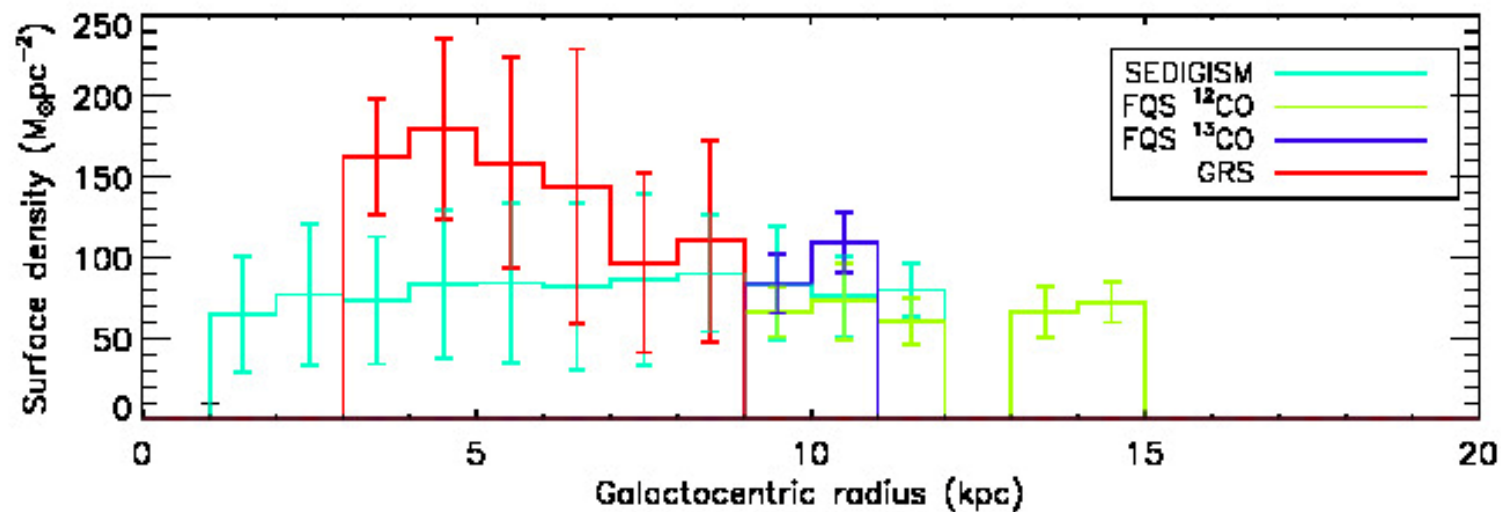
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FQS ^{12}CO catalog: ^{12}CO (1-0) SCIMES
Benedettini et al 2020

FQS ^{13}CO catalog: ^{13}CO (1-0) SCIMES
Benedettini et al. 2021



$$\Sigma = 87 \pm 55 \text{ M}_{\odot} \text{ pc}^{-2}$$



SUMMARY

- FQS: ^{12}CO (1-0) & ^{13}CO (1-0) survey of Galactic Plane in the range $220^\circ < l < 240^\circ$ $-2.5^\circ < b < 0^\circ$
- First self-consistent catalogs of physical properties of molecular clouds of the Outer Galaxy ($R_{\text{gal}} = 8 - 15$ kpc) at sub-parsec spatial resolution. Several products are public.
- The structures traced by the ^{13}CO (1-0) line are the brightest and densest parts of the ^{12}CO (1-0) structures, while low-brightness regions in ^{12}CO (1-0) are mostly undetected in ^{13}CO (1-0).
- Total mass, velocity dispersion and the virial parameter of clouds estimated with the two tracers are similar, likely due to the fact that in the surveyed portion of the Galactic plane, the H_2 column density is not particularly high, leading to a CO emission with a not very high optical depth.
- We observe a change in the behaviour of some properties of the identified structures at an equivalent radius of ~ 1 pc.
- The mean mass surface density of clouds is almost constant across the galactocentric radius and is affected by local conditions.