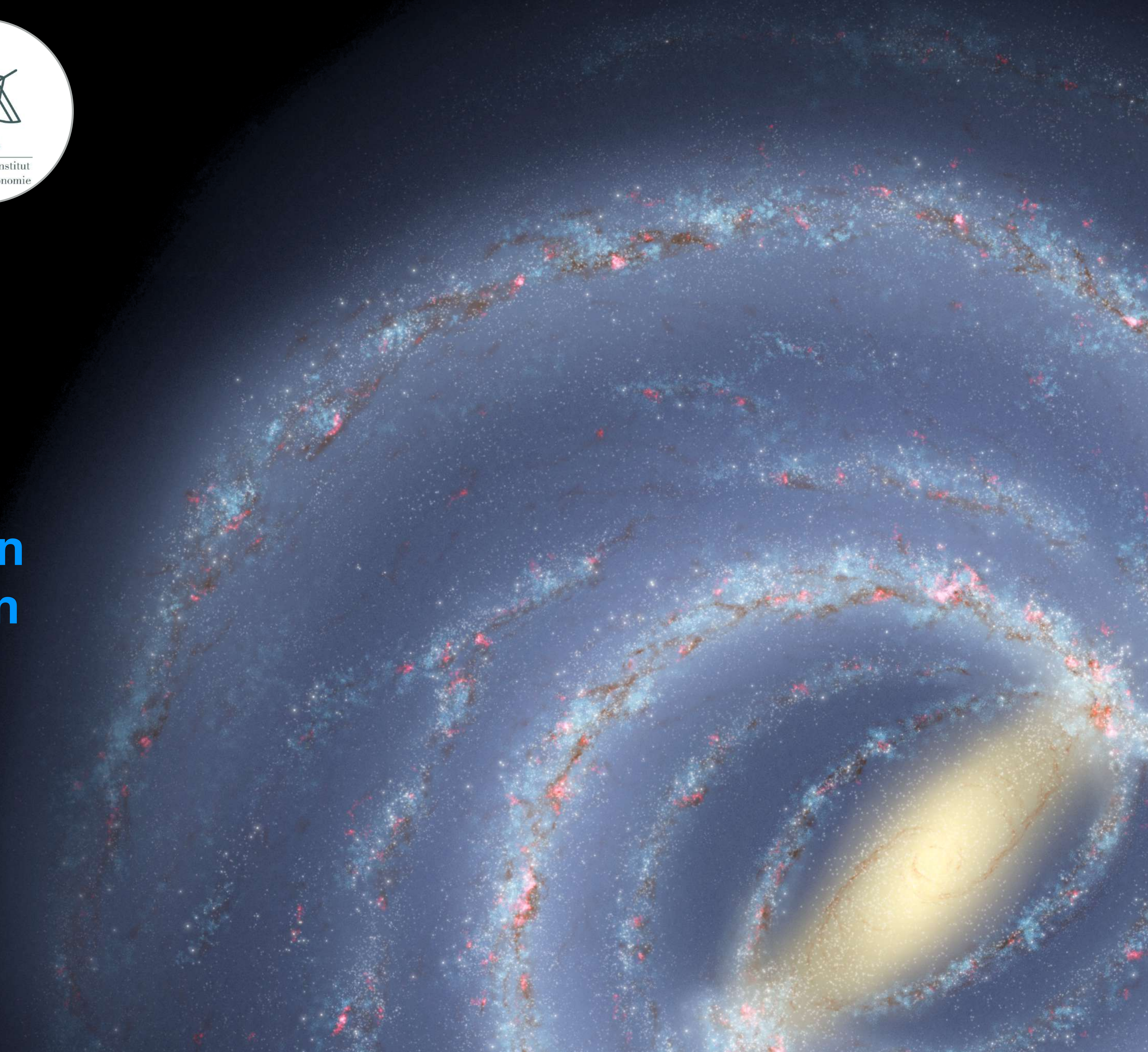
SEDIGISM workshop

the influence of spiral arms on the molecular gas distribution of the inner Milky Way



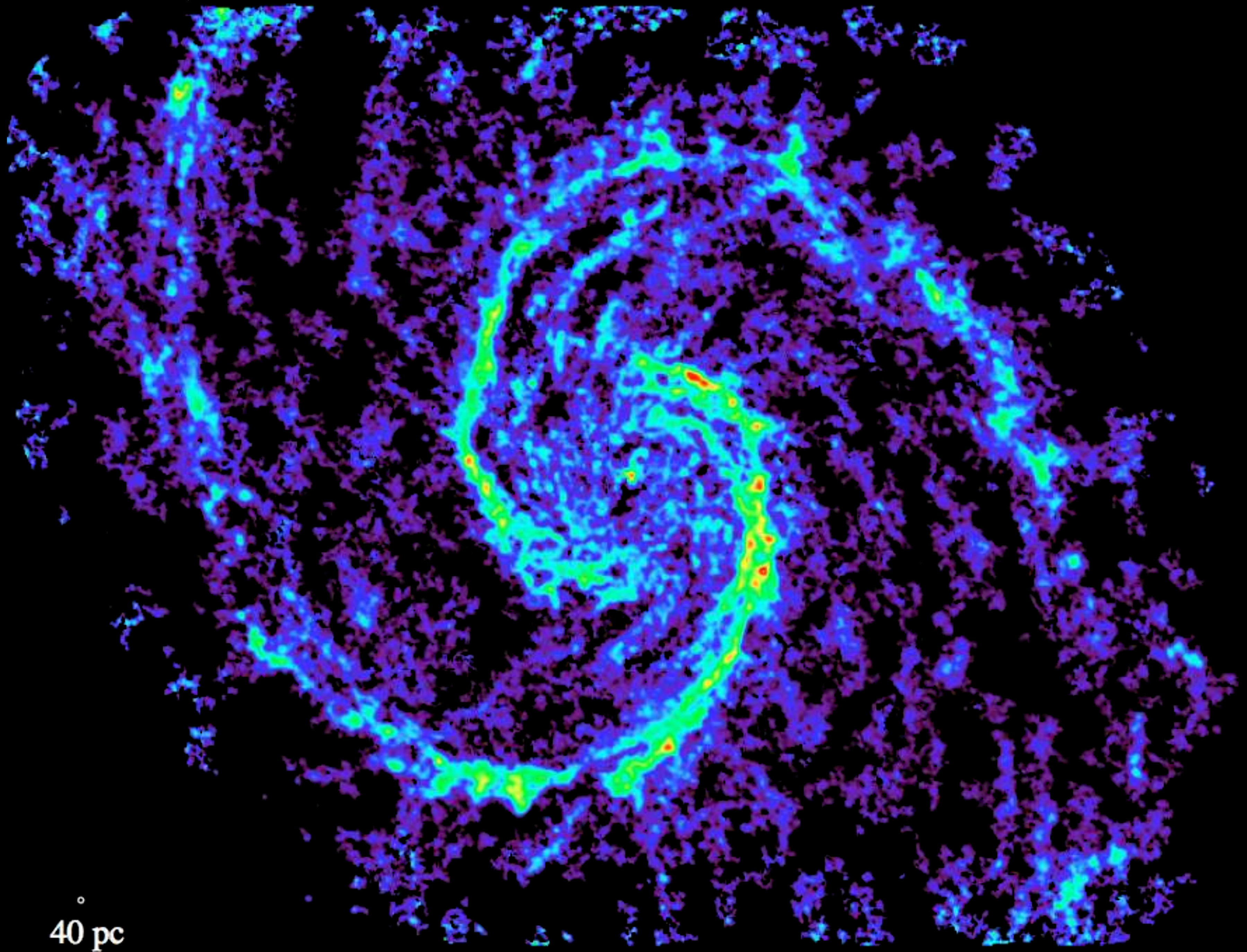
Dario Colombo

Max Planck Institute for Radio Astronomy

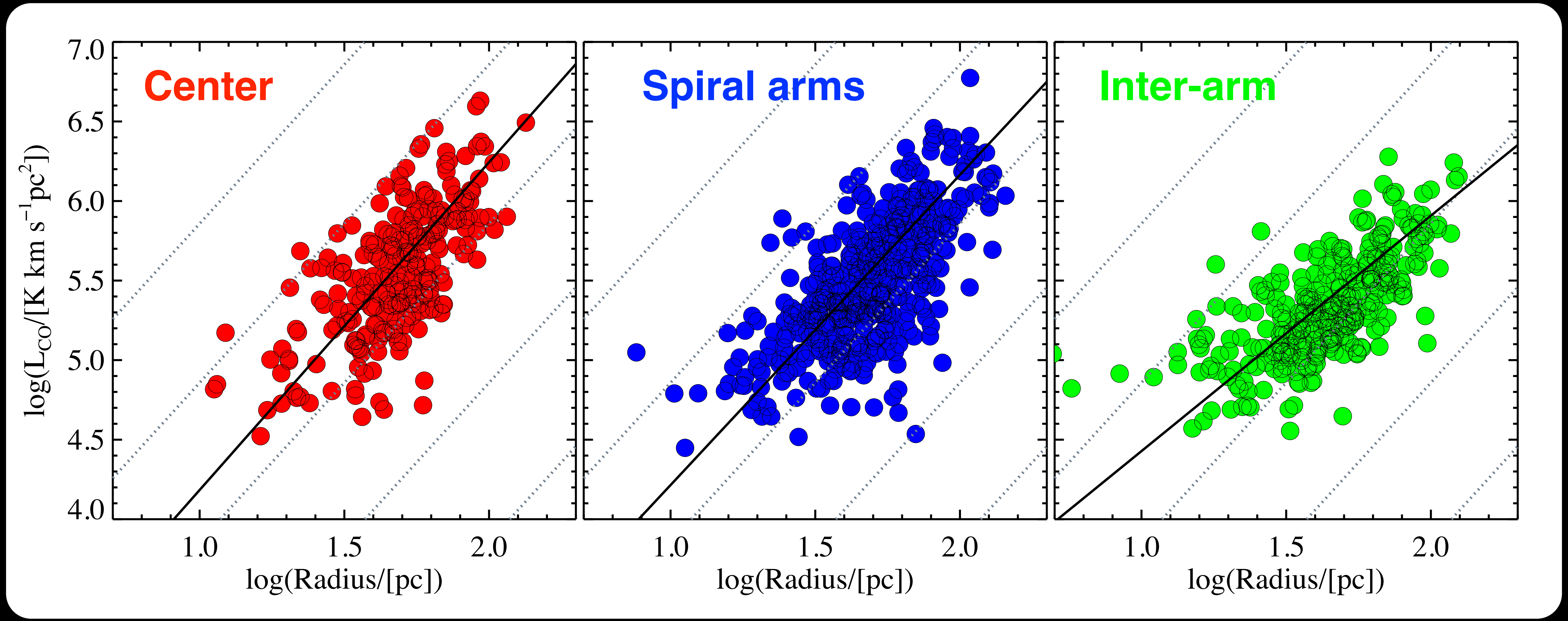
September 15th, 2021

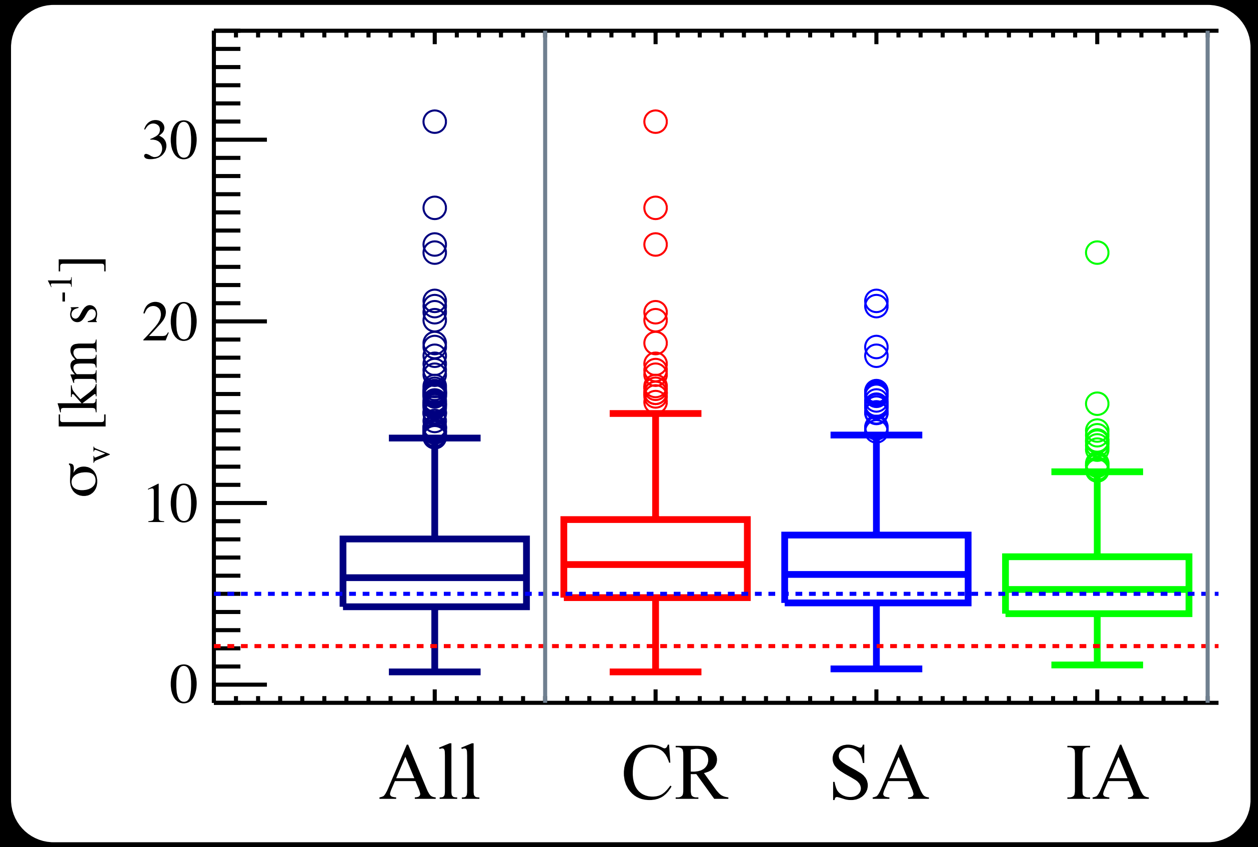
Spiral arms do influence molecular gas properties in nearby galaxies

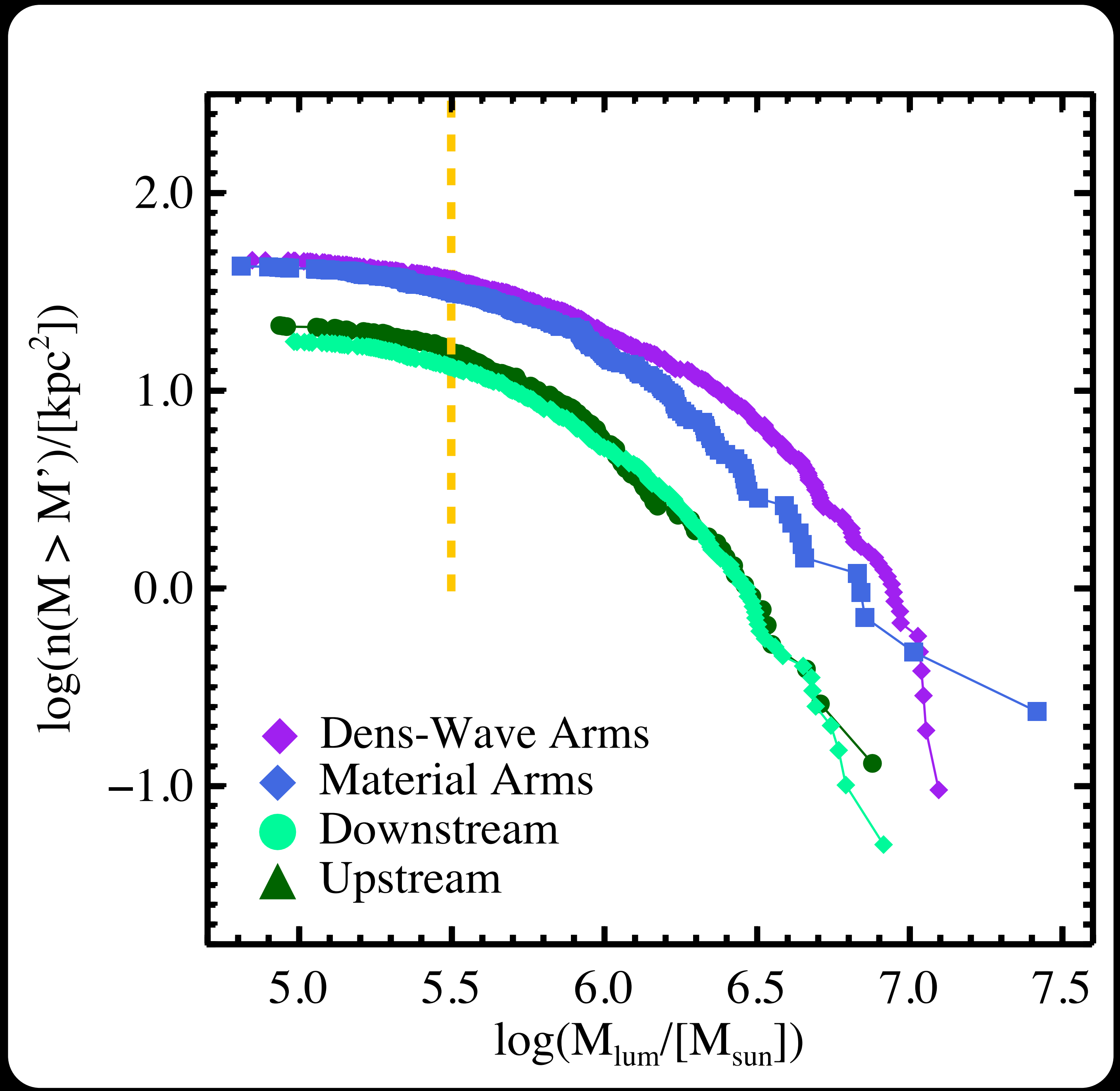
PAWS, Schinnerer+ 2013



Colombo+ 2014a

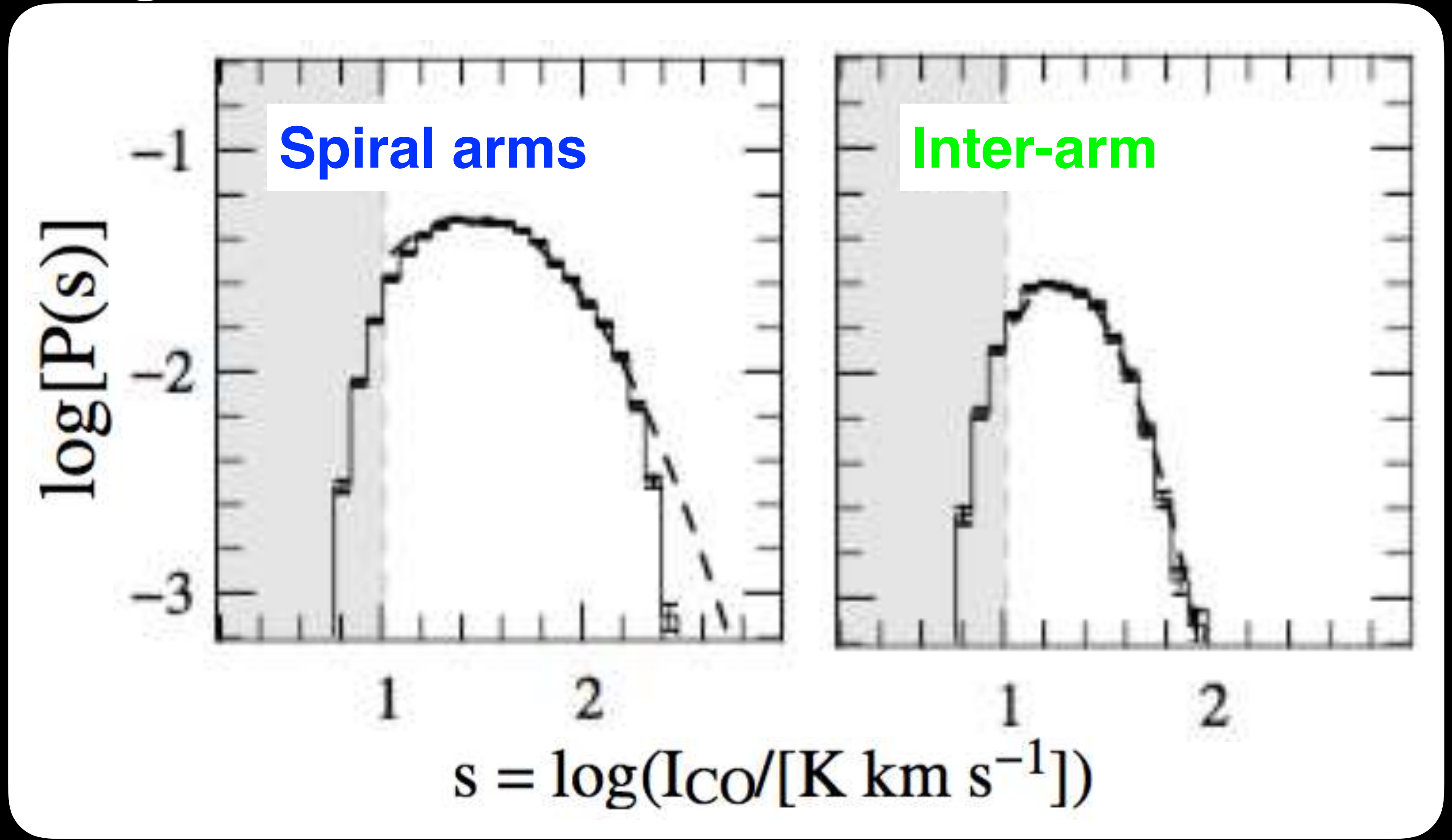






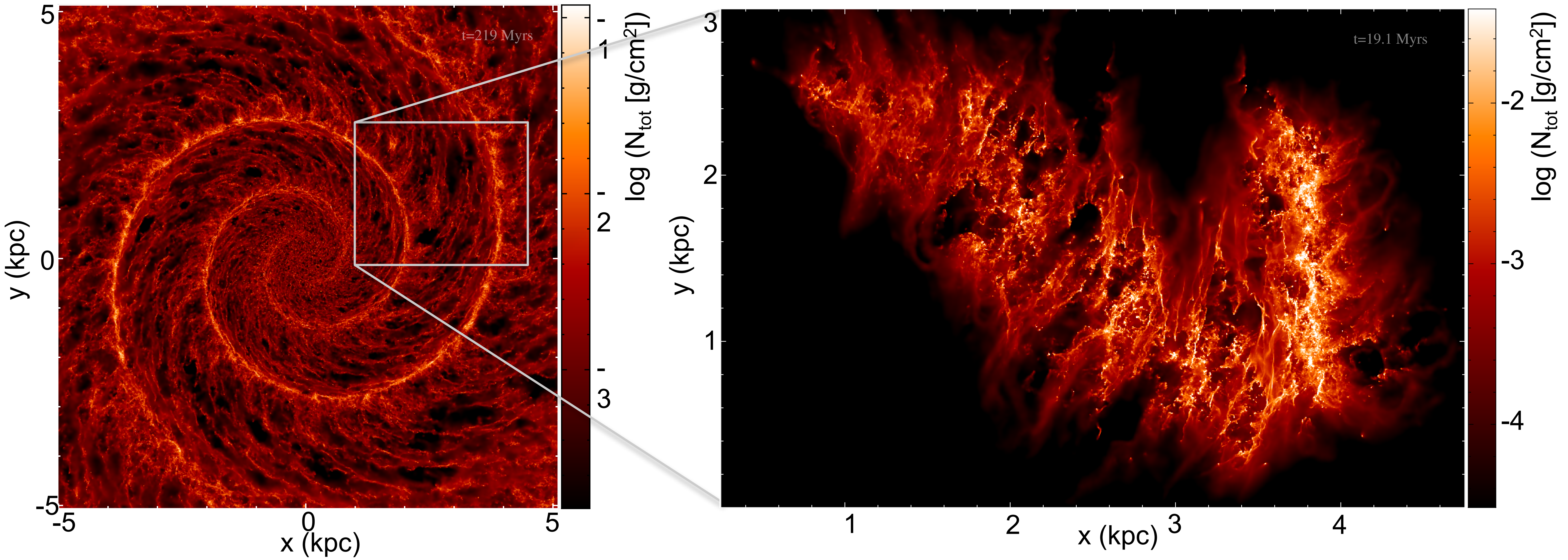
CLOUDS

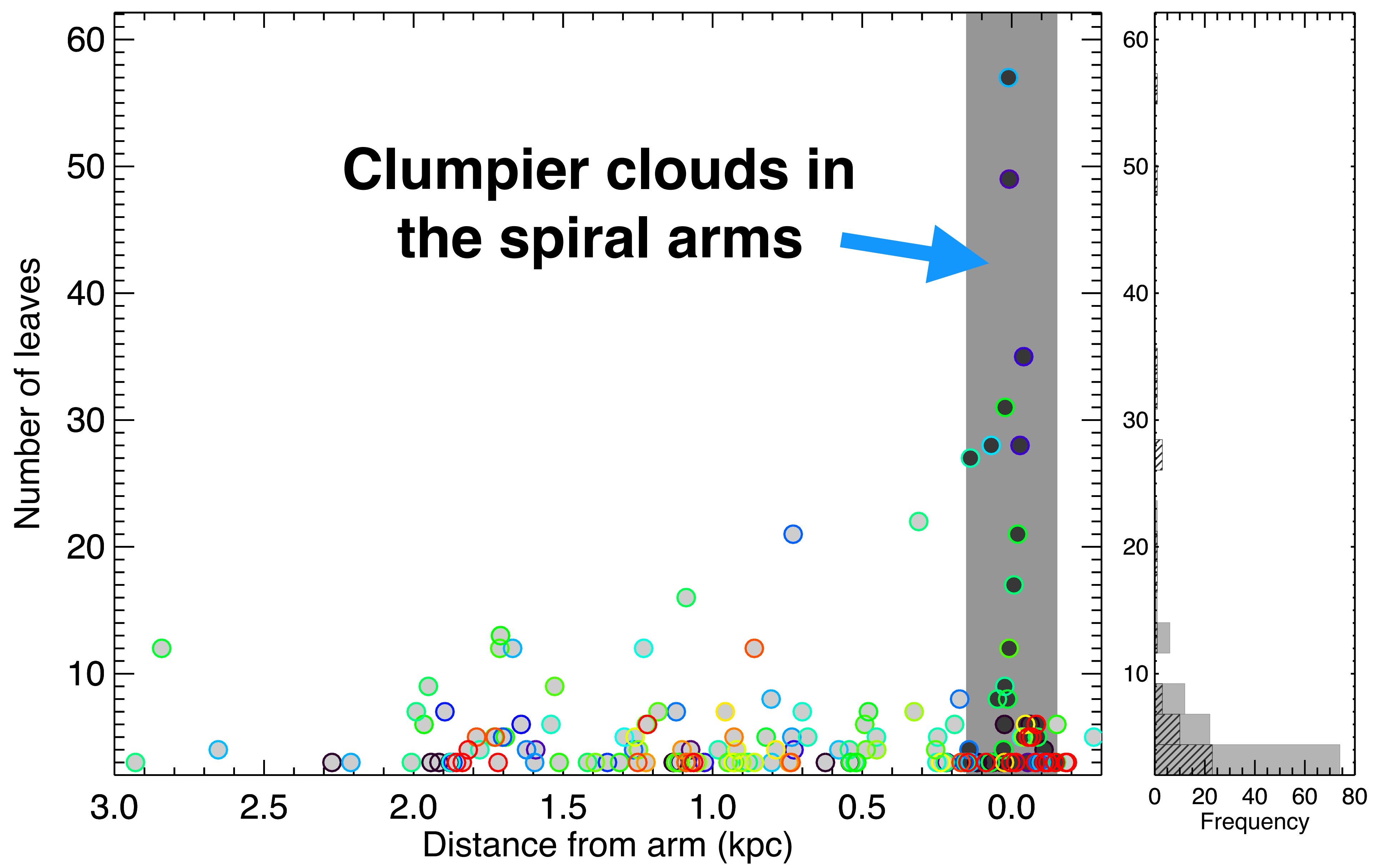
Hughes+ 2013a



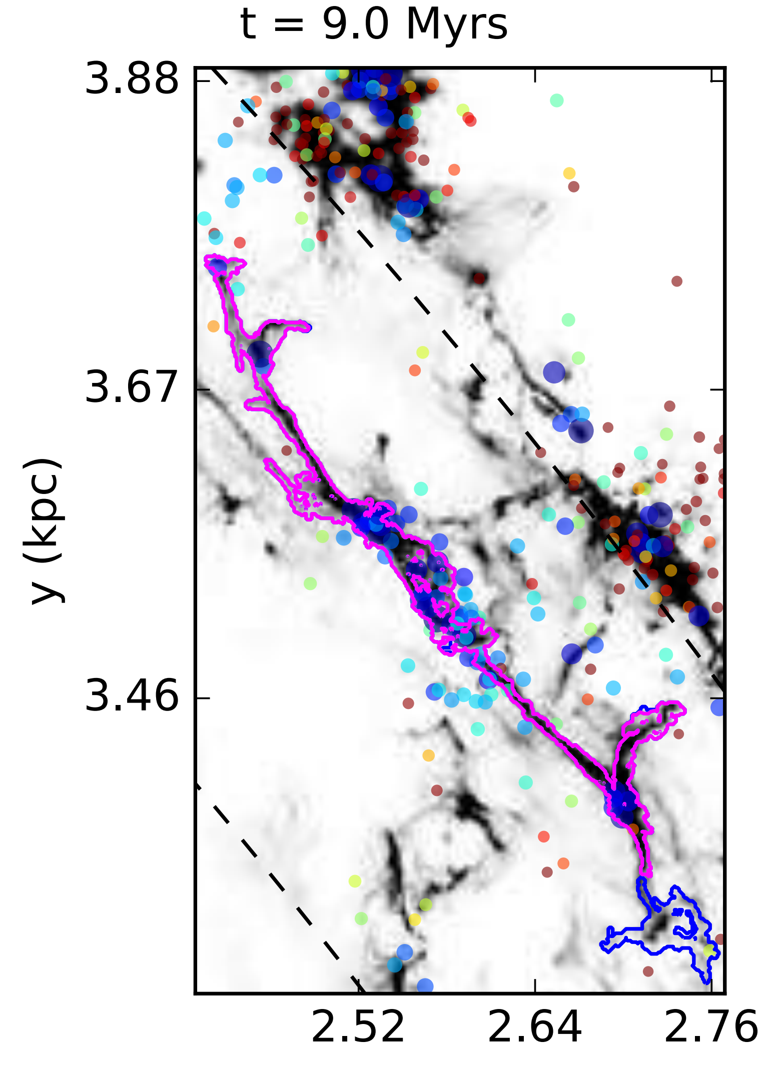
ALL GAS

Duarte-Cabral+ 2016, 2017

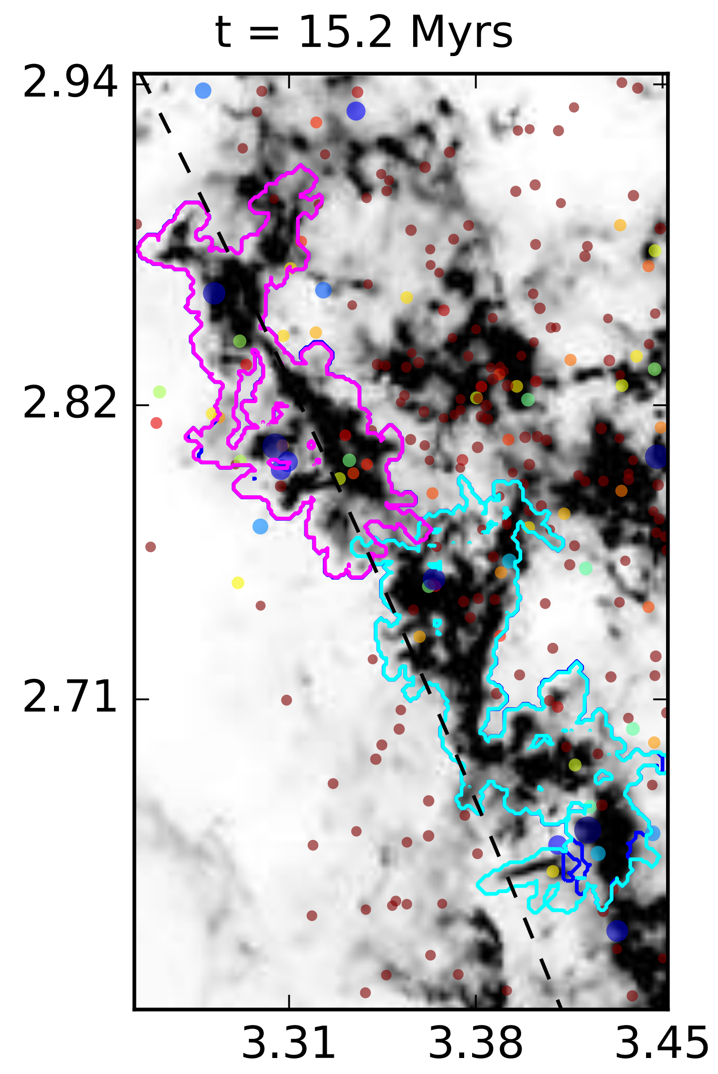




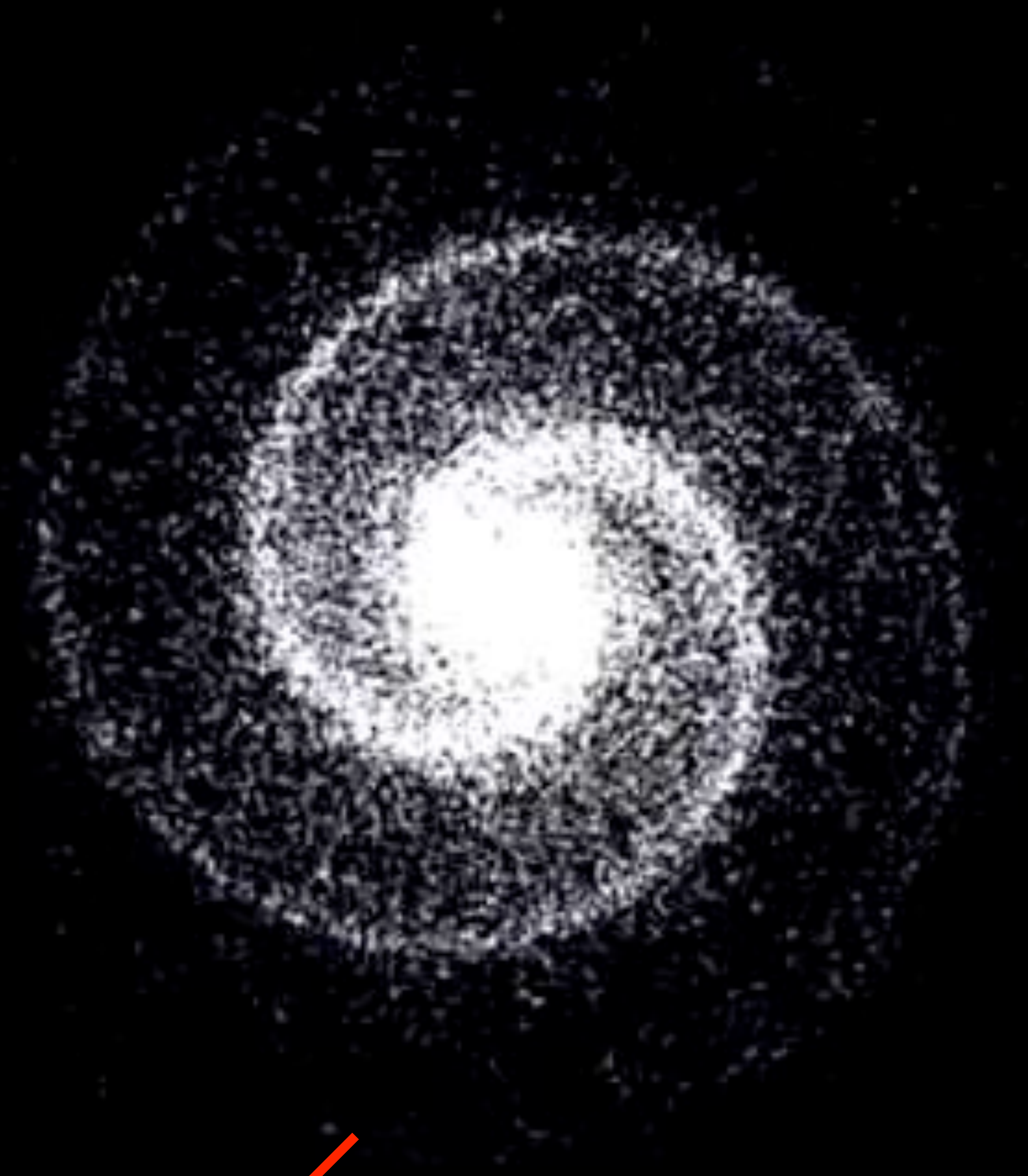
Filaments in the inter-arm region …



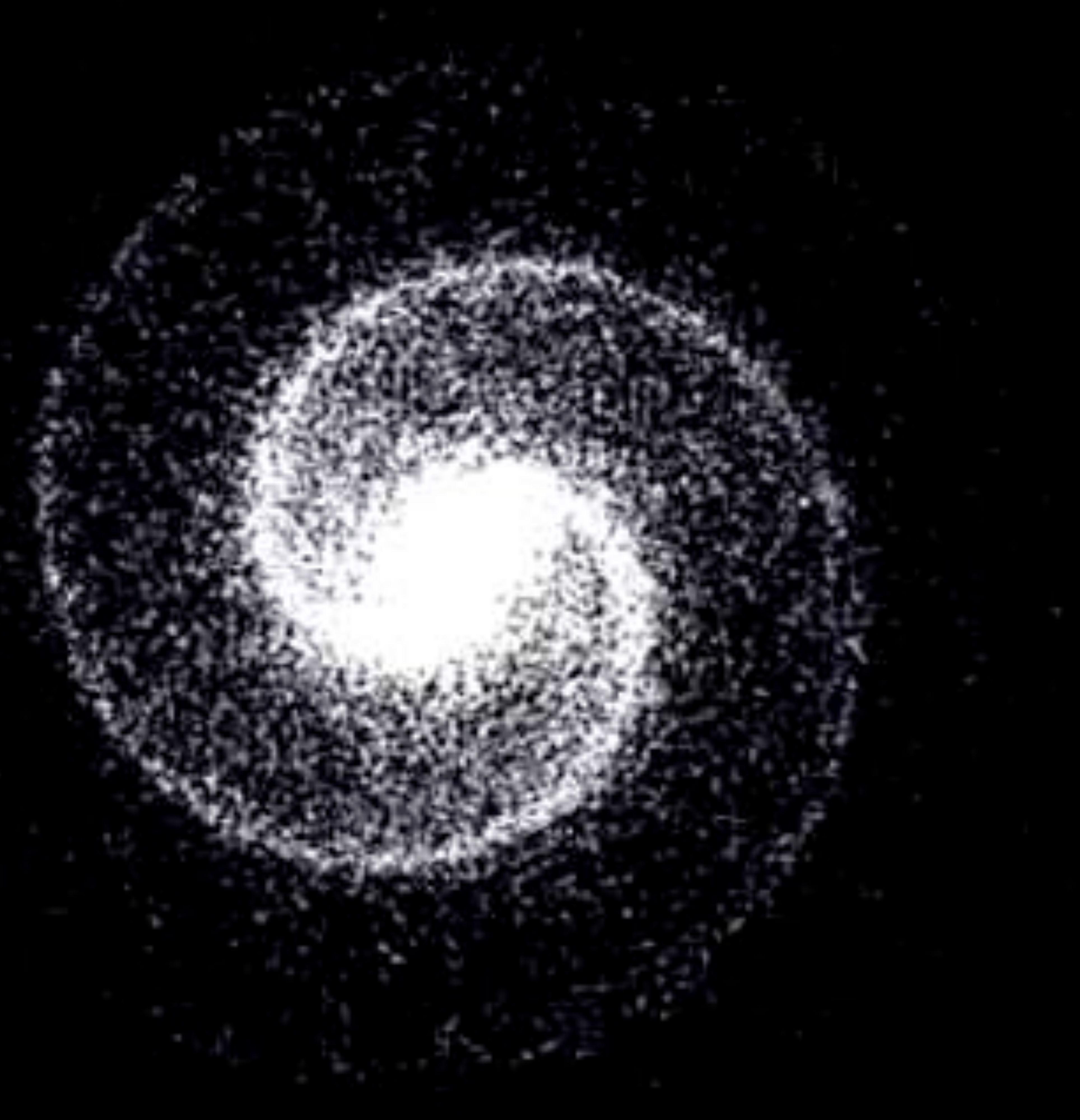
… become complexes in the spiral arms



Material arms



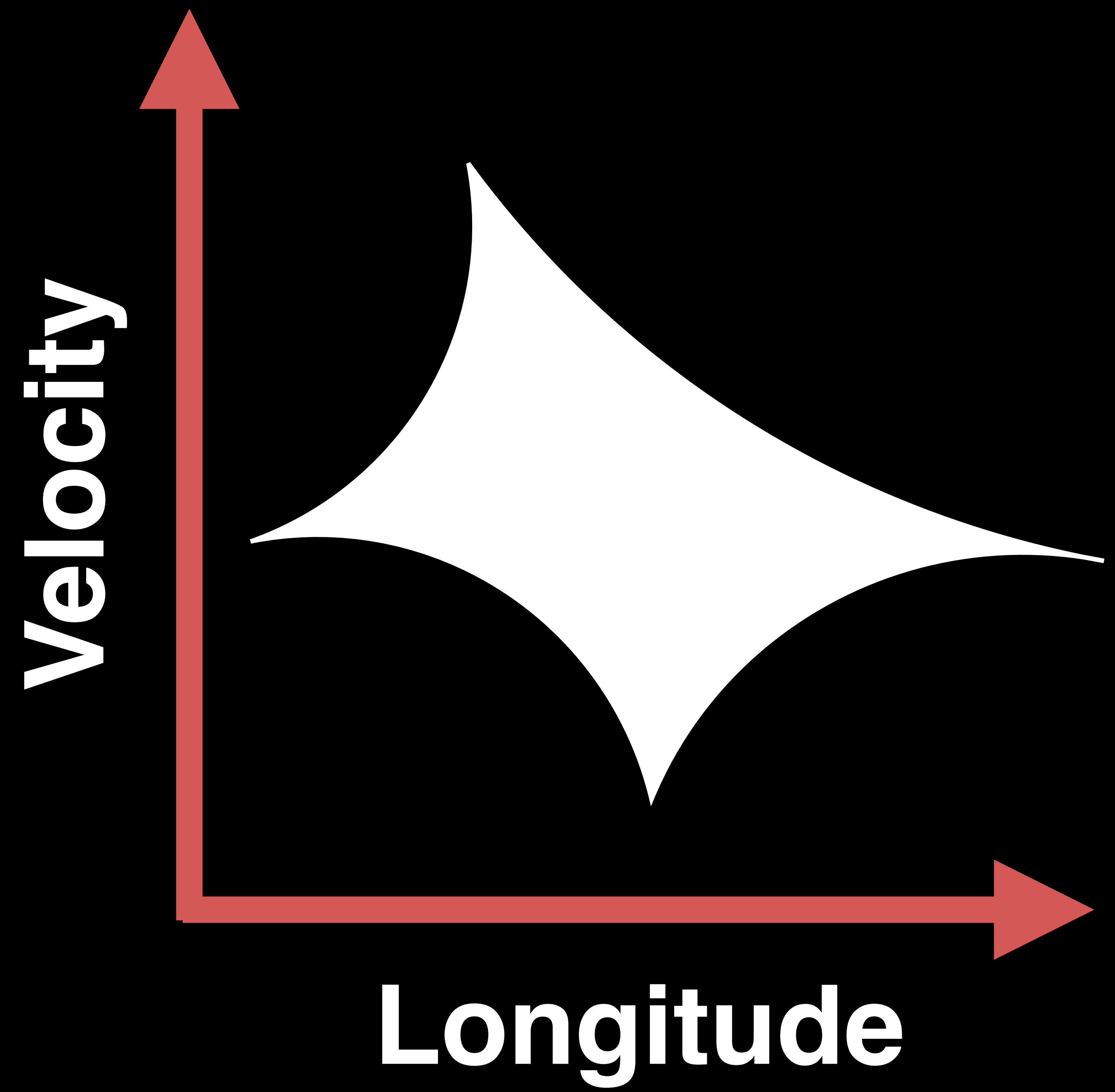
Density-wave arms



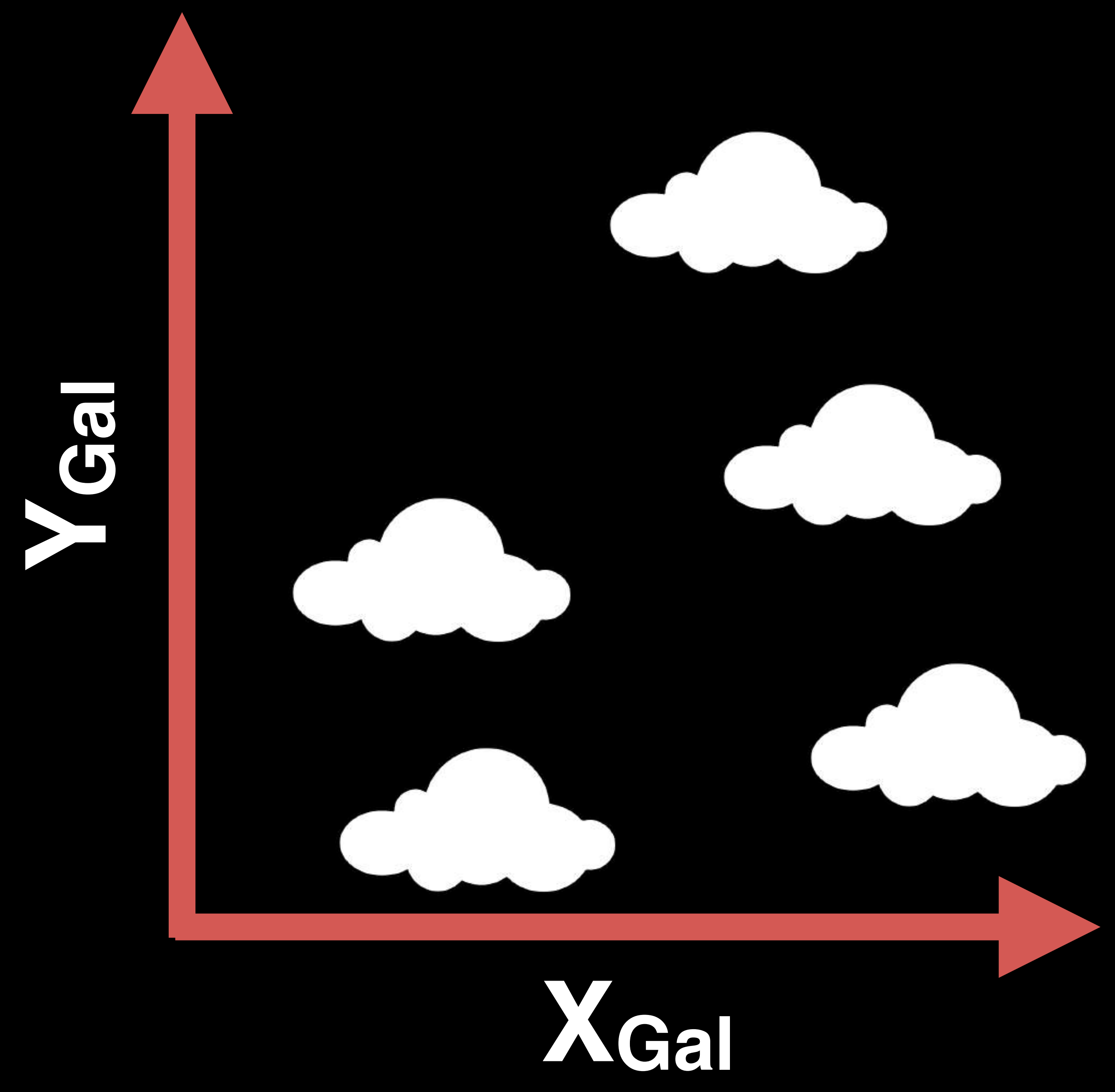
Winding problem: material arms disappear after few galactic rotations

What about the Milky Way?

Two-fold analysis



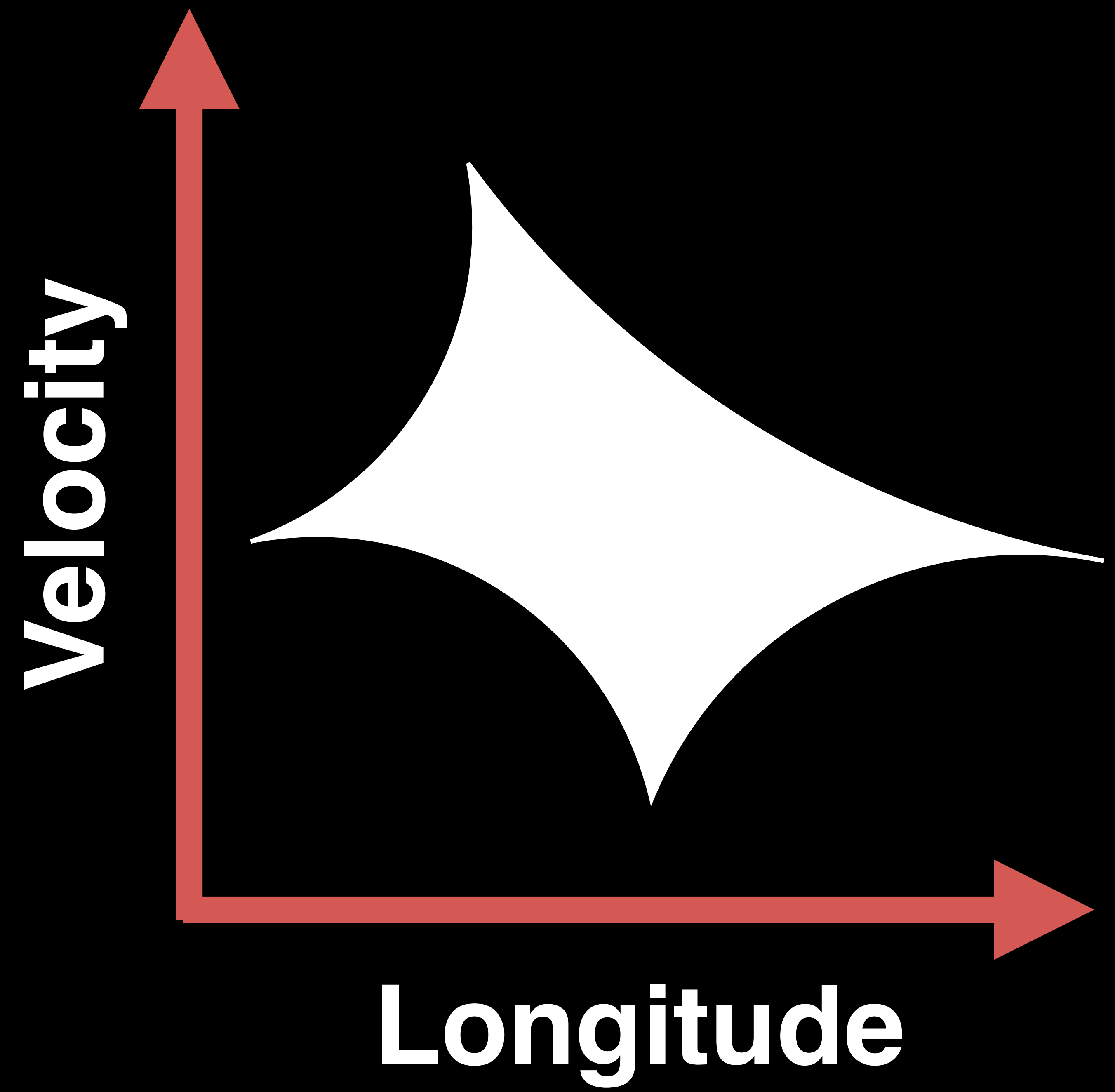
- Full gas distribution
- No physical quantities (only across the spiral arms)
- Analysis of the flux in the Galaxy centre

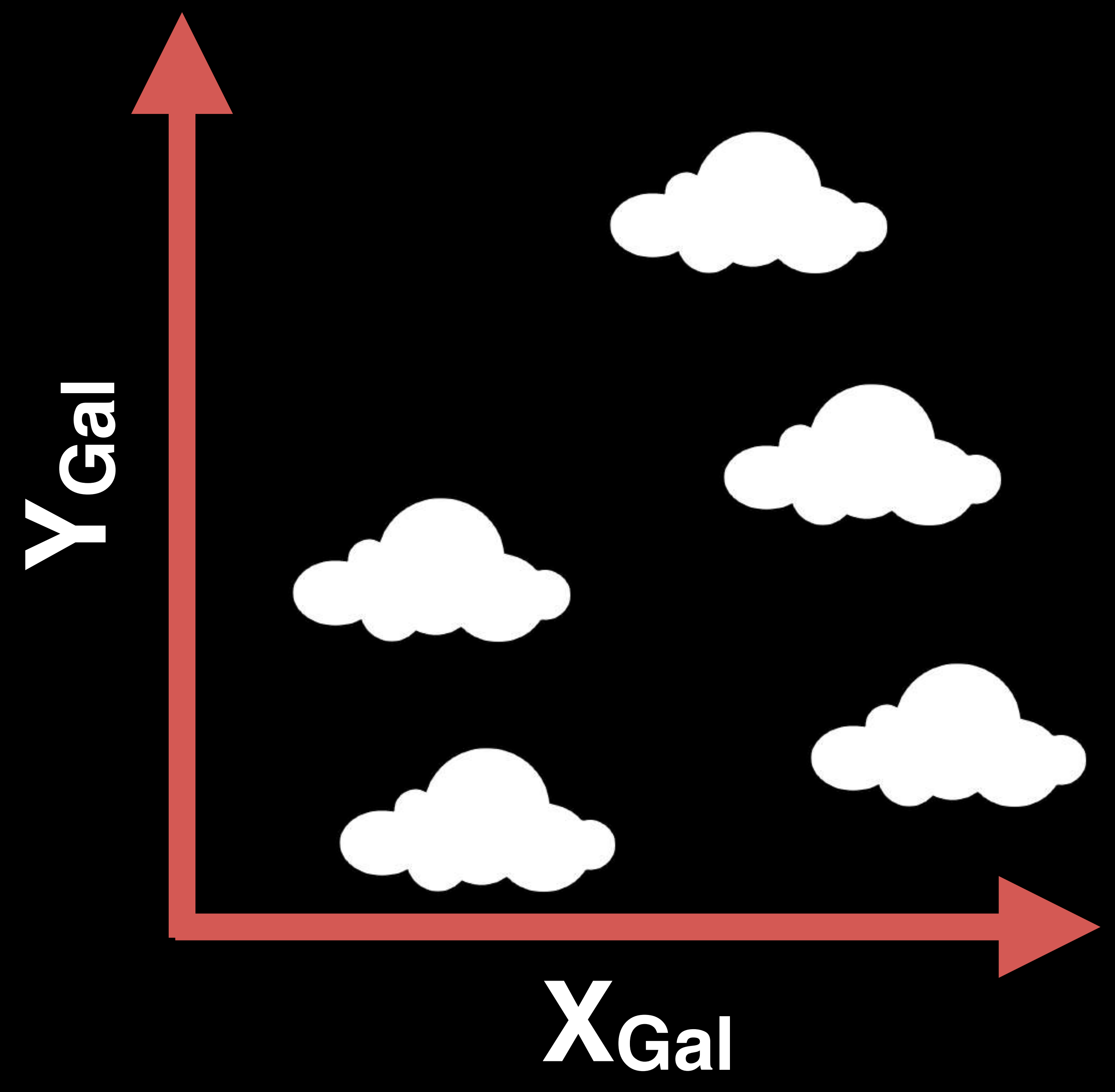


- Only gas in clouds
- Physical quantities
- Distance and segmentation method biases
- No Galaxy centre

Colombo+ 2021, subm.

Two-fold analysis





- Full
- No p
  acro
- Anal
  Gala

Astronomy & Astrophysics manuscript no. output
September 15, 2021

The SEDIGISM survey: the influence of spiral arms on the molecular gas distribution of the inner Milky Way

D. Colombo[1★], A. Duarte-Cabral[2], A. R. Pettitt[3], J. S. Urquhart[4], F. Wyrowski[1], T. Csengeri[5], K. R. Neralwar[1], F. Schuller[1,6], K. M. Menten[1], L. Anderson[7,8,9], P. Barnes[10,11,12], H. Beuther[13], L. Bronfman[14], D. Eden[15], A. Ginsburg[16], T. Henning[13], C. König[1], M.-Y. Lee[17], M. Mattern[18], S. Medina[1], S. E. Ragan[2], A. J. Rigby[2], Á. Sánchez-Monge[19], A. Traficante[20], A. Y. Yang[1], M. Wienen[1]

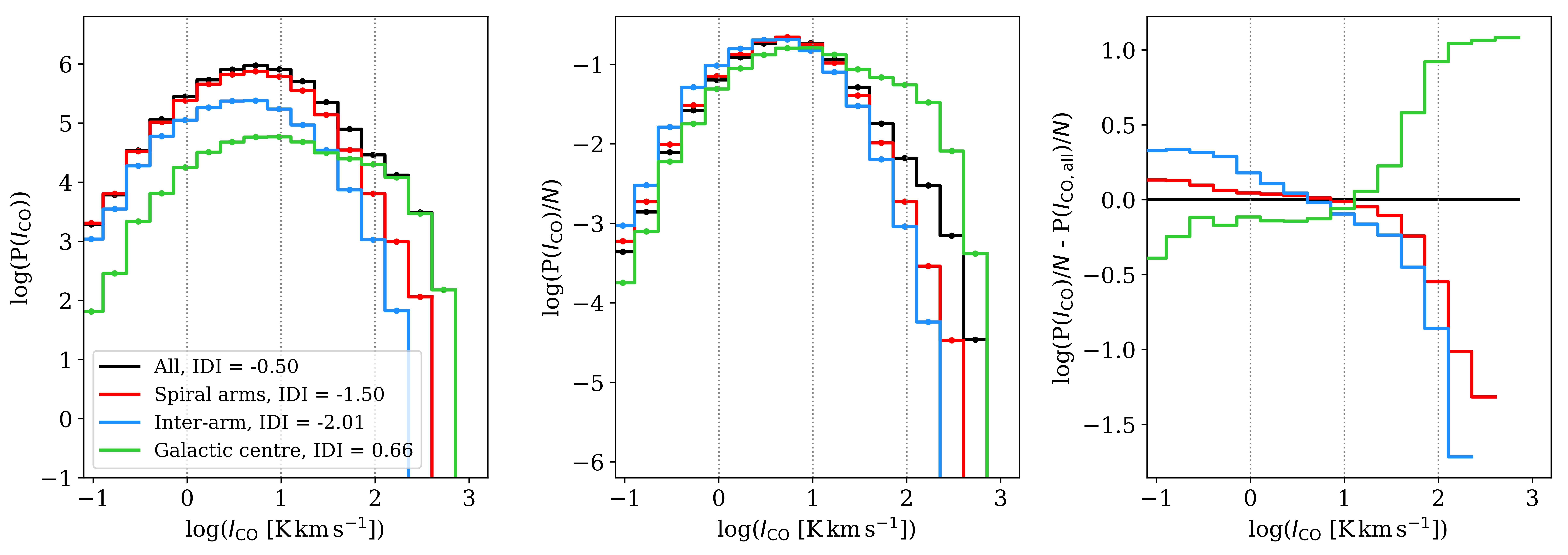
Galactic centre region
-2 < l < 2 deg

Spiral arm non-overlapping regions in shades

Models from Taylor & Cordes 1993, adopted by Schuller et al. 2021 and reproduced by A. Pettitt

Spiral arm region on the lv-map defined with velocity offset from spiral arm, ΔV < 10 km/s

INTENSITY PDFs FROM LV-MAP



in ***M51*** **(Hughes+ 2013b):**

All, IDI = 0.40

Spiral arm, IDI = 0.12, 0.54

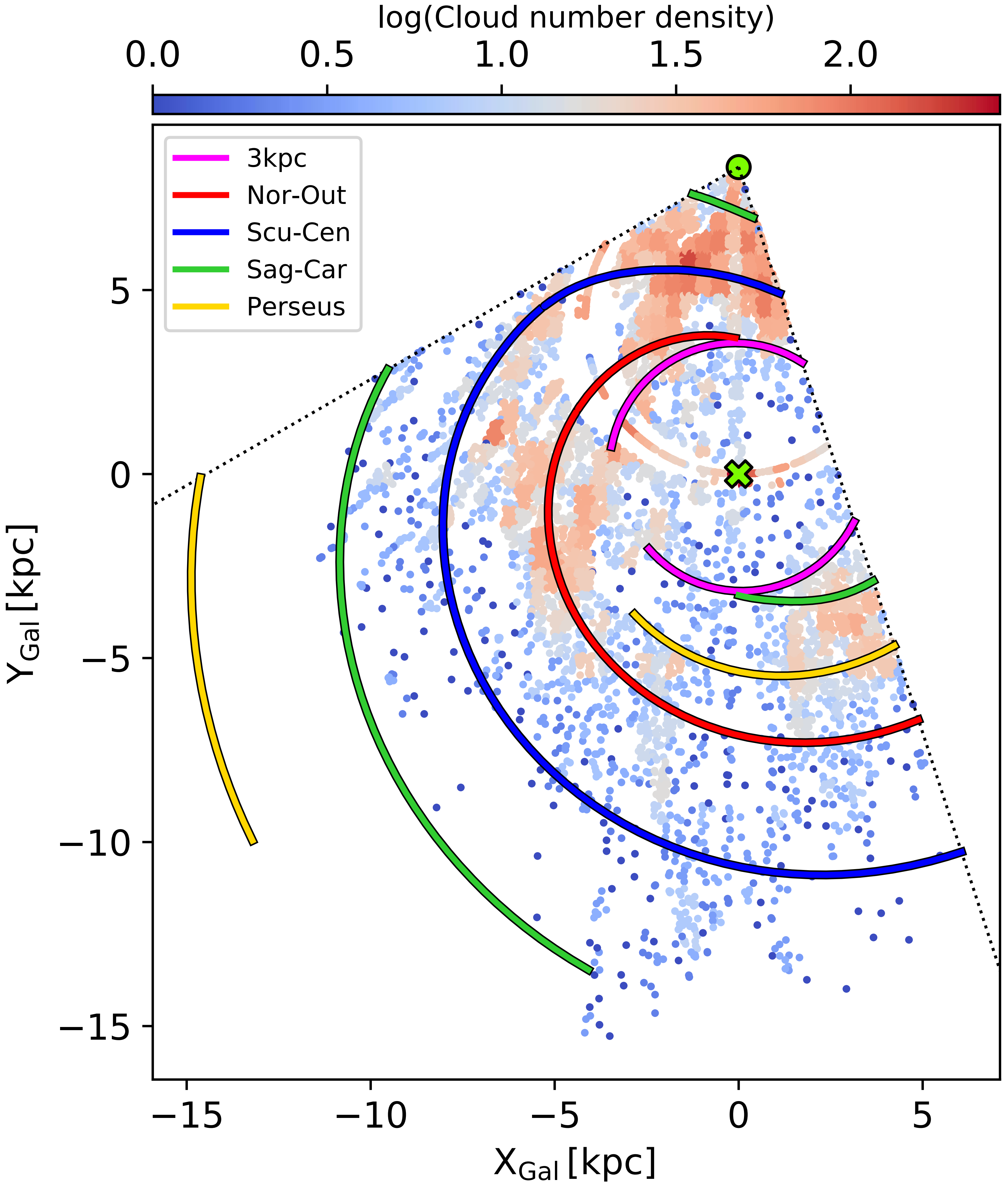
Inter-arm, IDI = -0.95, -0.65

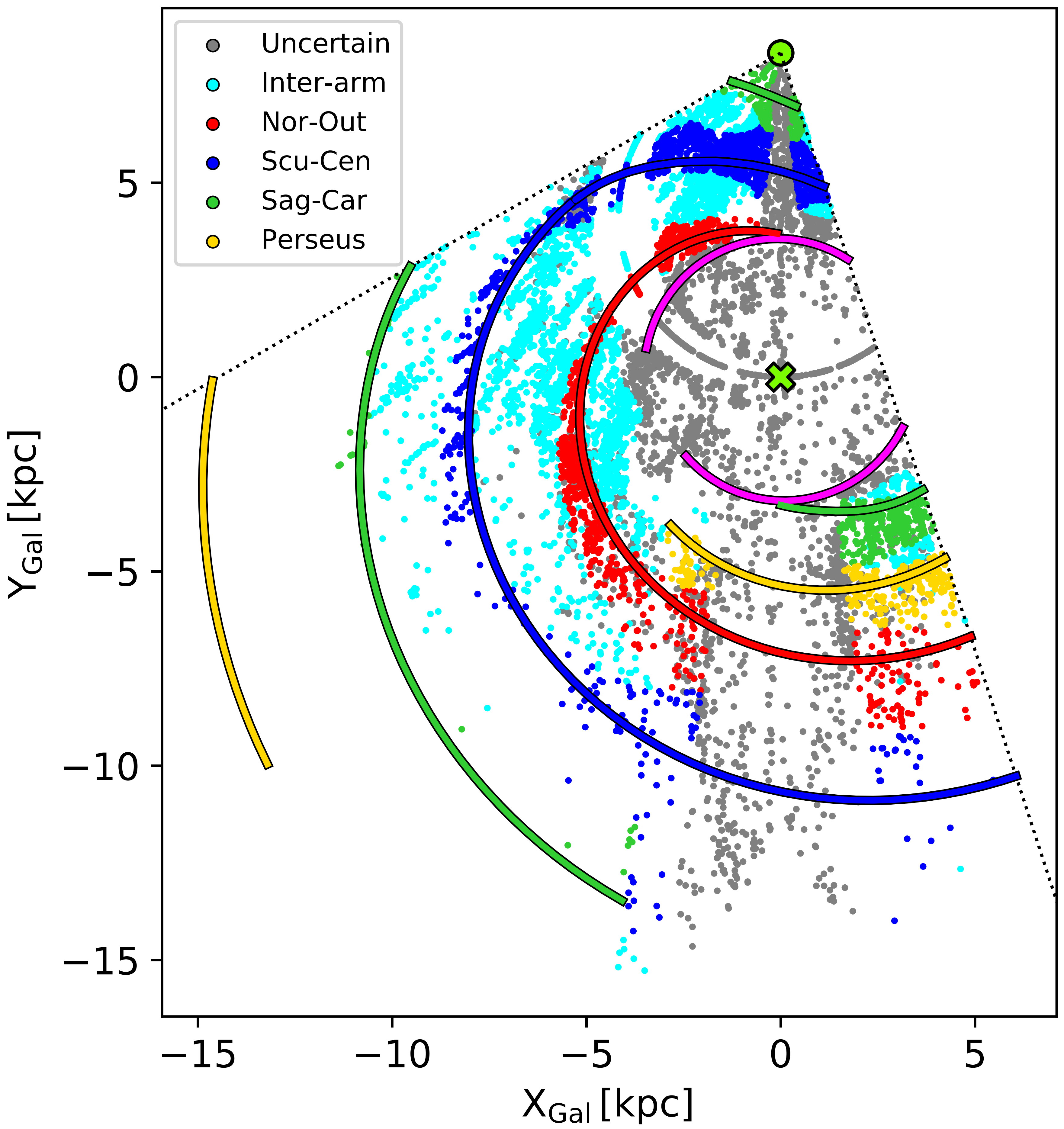
Galactic centre, IDI = 0.76, 1.08

Intensity distribution index

$$IDI = \log\left(\frac{\sum_{I_2 < I_{\mathrm{CO}} < I_3} I_{\mathrm{CO,i}}}{\sum_{I_1 < I_{\mathrm{CO}} < I_0} I_{\mathrm{CO,i}}}\right),$$

$$(I_0,\ I_1,\ I_2,\ I_3) = (1, 10, 100, \infty)\ \mathrm{K\,km\,s^{-1}}$$





Association of clouds to spiral arms

$$\chi^2 = \frac{(d_{\rm cloud} - d_{\rm arm})^2}{\sigma_d^2} + \frac{(l_{\rm cloud} - l_{\rm arm})^2}{\sigma_l^2},$$

$$\sigma_l = \sigma_{\rm maj}\cos(pa),$$

$\sigma_{\rm d}$, **distance uncertainty**

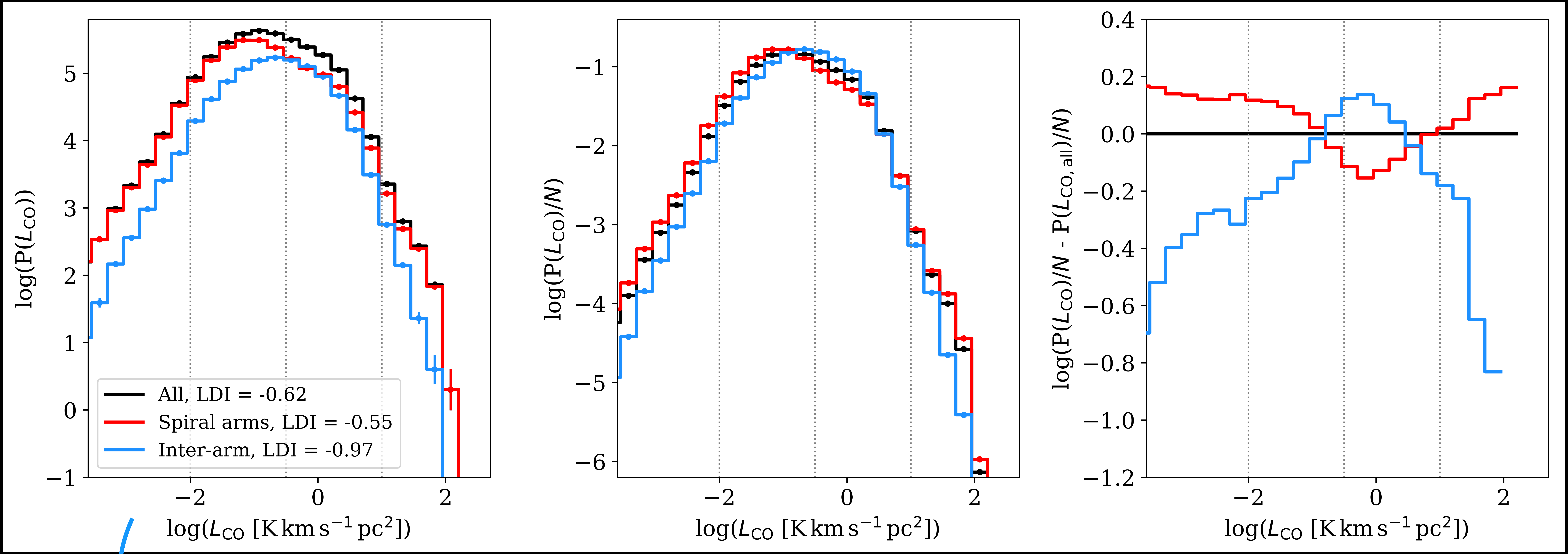
p-value > 0.05, ΔV < 10 km/s

Uncertain: **clouds with unreliable distance attribution, cloud associated with the 3 kpc arm on the *xy* plane**

7889 / 10,300 (77% of total sample) attributed to spiral arms


+0.5
b
-0.5
8
l
10
Scutum
Centaurus
Sagittarius
Carina
Norma
Outer
Perseus
3 kpc
Inter-arm
region

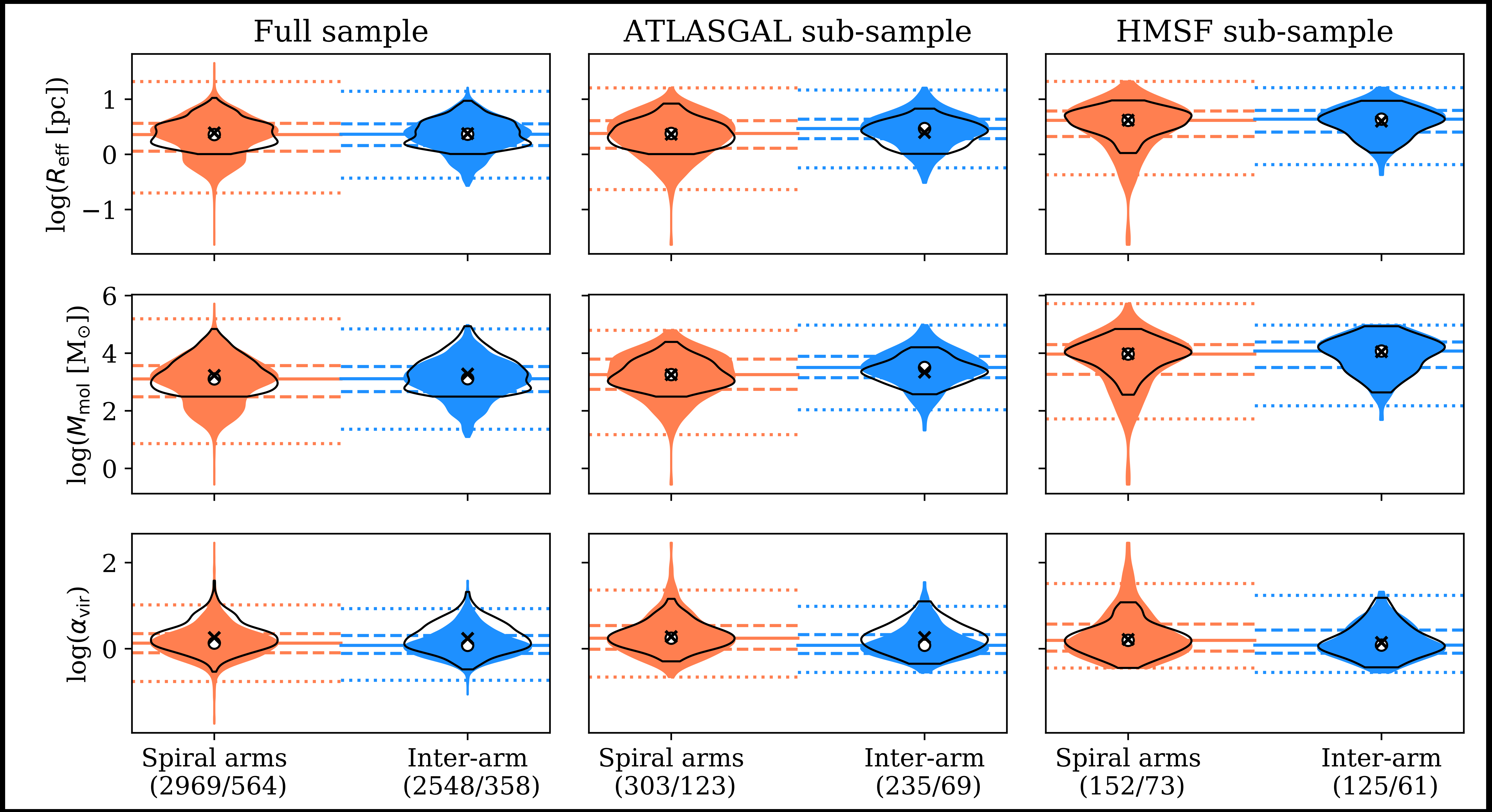
Luminosity PDFs from clouds



Luminosity from each pixels in the clouds considering their distance

I_{CO} PDF IDI	L_{CO} PDF LDI
All = -0.50	All = -0.62
SA = -1.50	SA = -0.55
IA = -2.01	IA = -0.97

Properties of clouds within and outside spiral arms



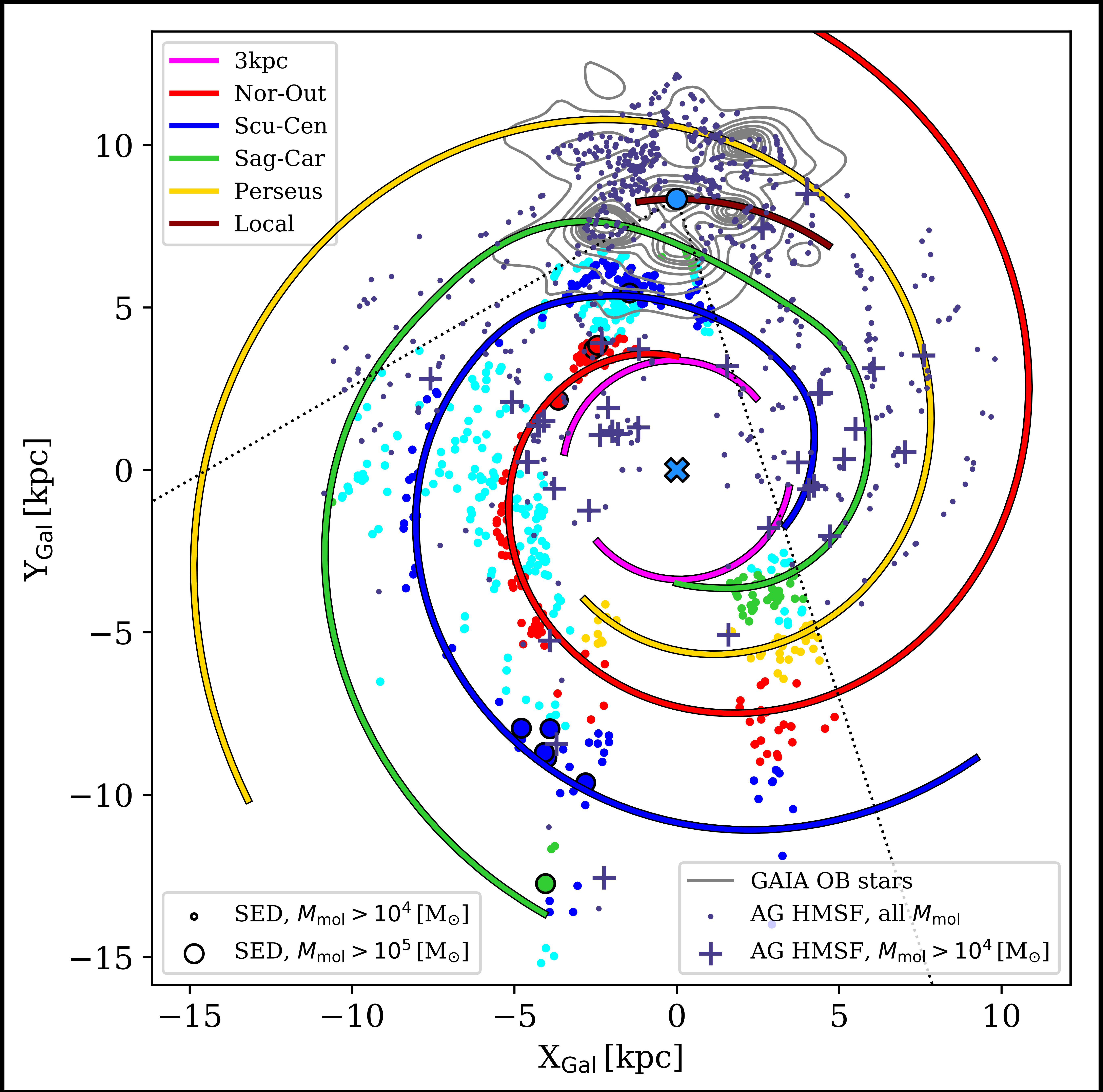
- **Distribution differences seem to be driven by a distance bias; tentative differences from distance-independent parameters (e.g. *AR*, Σ_{mol})**
- **Spiral arms do not seem to influence properties of clouds with HMSF**

Science:
no edge, reliable dist,
area > $3\Omega_{beam}$

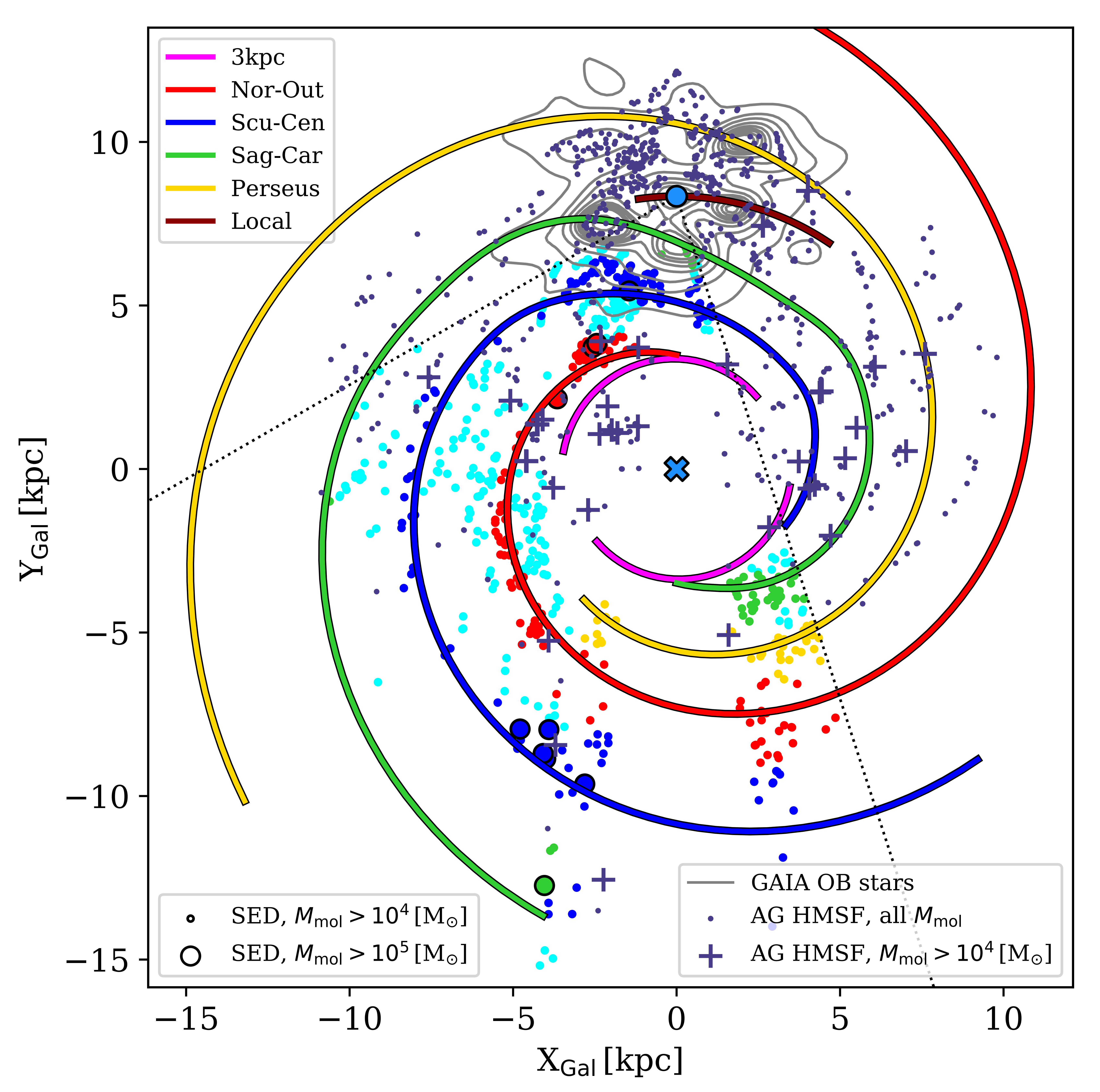
Complete-distance limited:
d=2.5-5 kpc,
$M_{mol} > 3.1\times10^2\ M_{sol}$, $R_{eff} > 1$ pc

***p*-value**	**Full**	**ATLASGAL**	**HMSF**
R_{eff}	<0.0001 0.7	0.0008 0.8	0.2 0.8
M_{mol}	<0.0001 0.4	<0.0001 0.09	0.2 0.8
α_{vir}	<0.0001 <0.0001	<0.0001 0.1	0.4 0.6

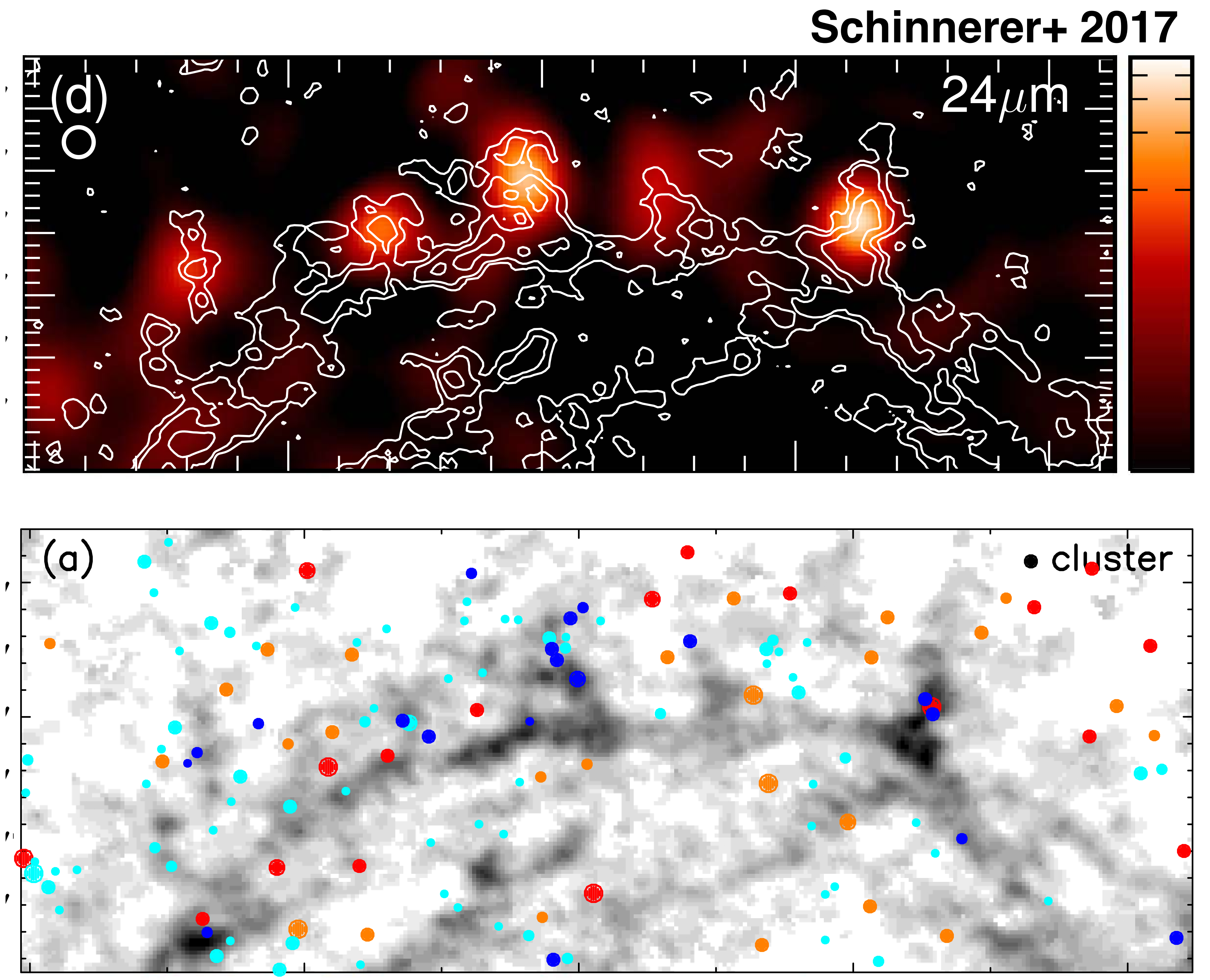
MILKY WAY SPIRAL ARMS AND STAR FORMATION



- Most massive SEDIGISM clouds are tightly associated with spiral arms
- ATLASGAL HMSFs are not clearly associated with the arms
- Distribution of OB stars from GAIA peak along spiral arms, but OB stars are observed everywhere



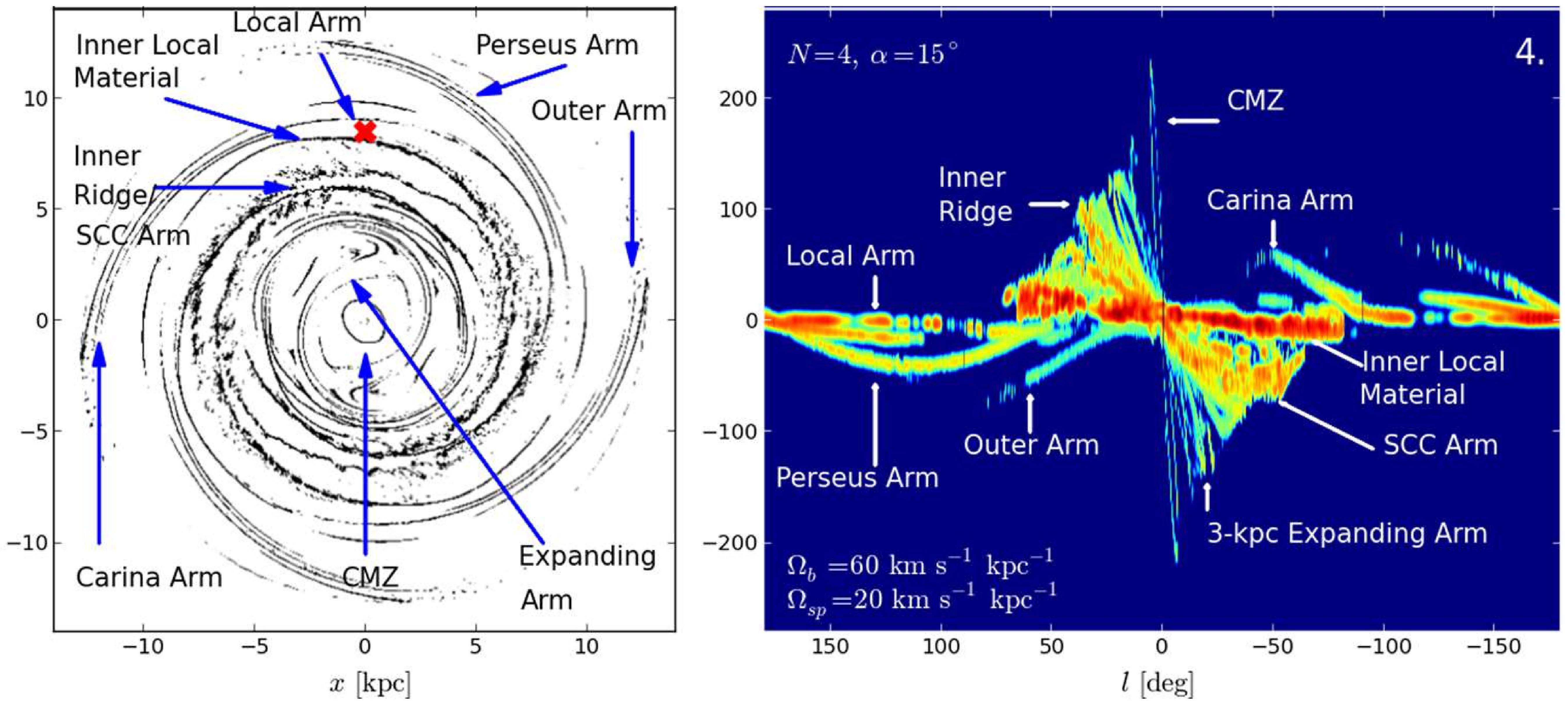
MILKY WAY SPIRAL ARMS AND STAR FORMATION



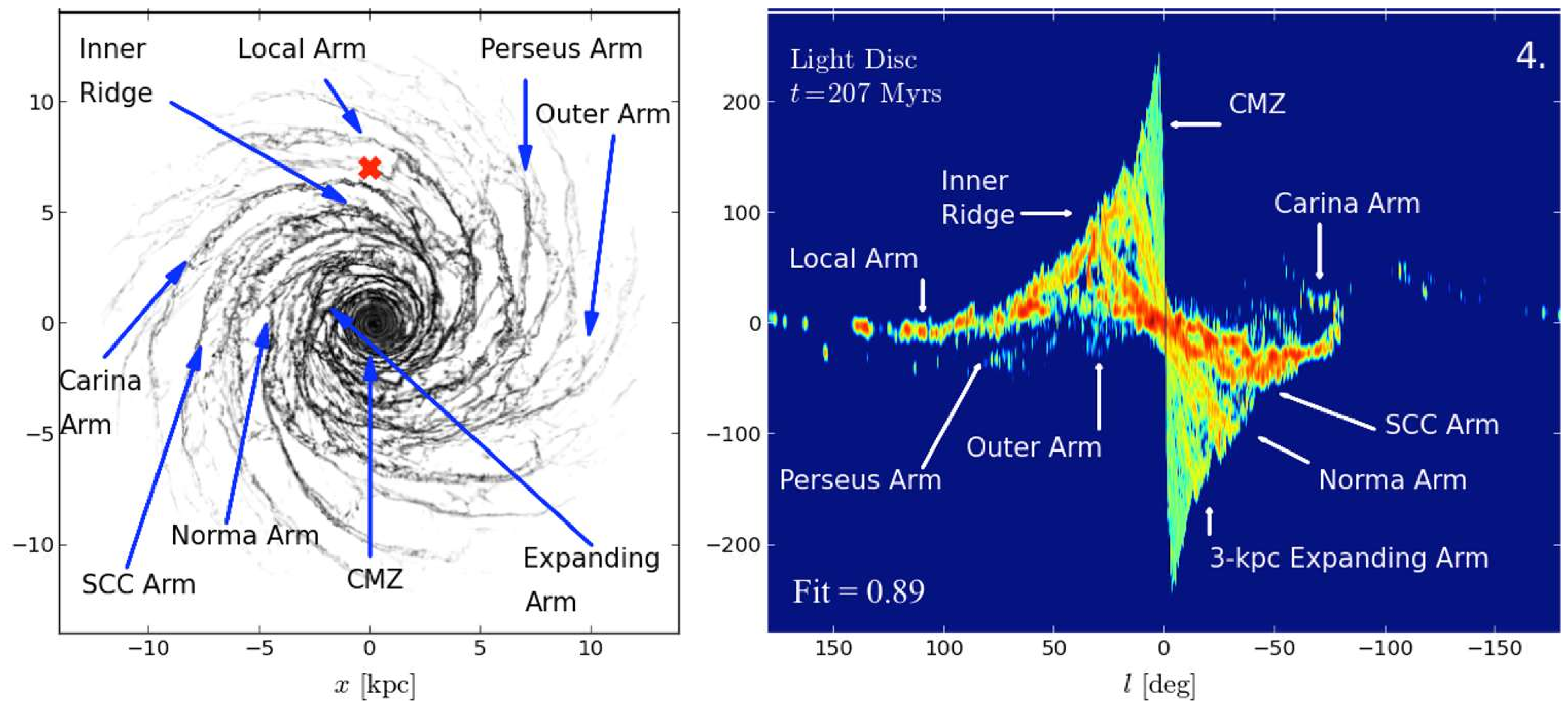
- Star formation happens outside spiral arms in M51 (in the spurs)
- No age gradient observed across the spurs of the star clusters: star formation happens in situ

Pettitt+ 2014, 2015

Fixed potential (Density-wave arms)

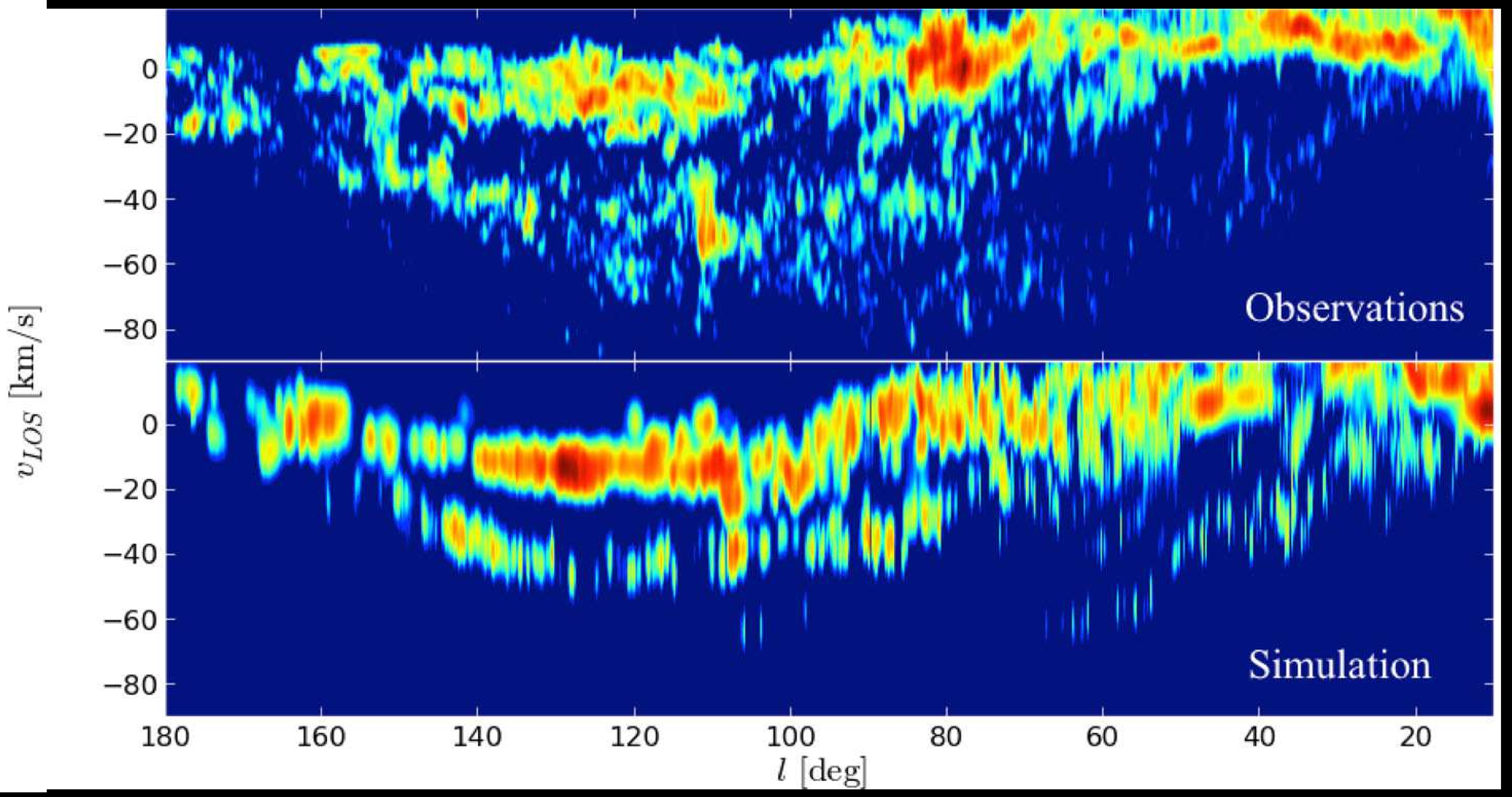


Live-stellar potential (Material arms)



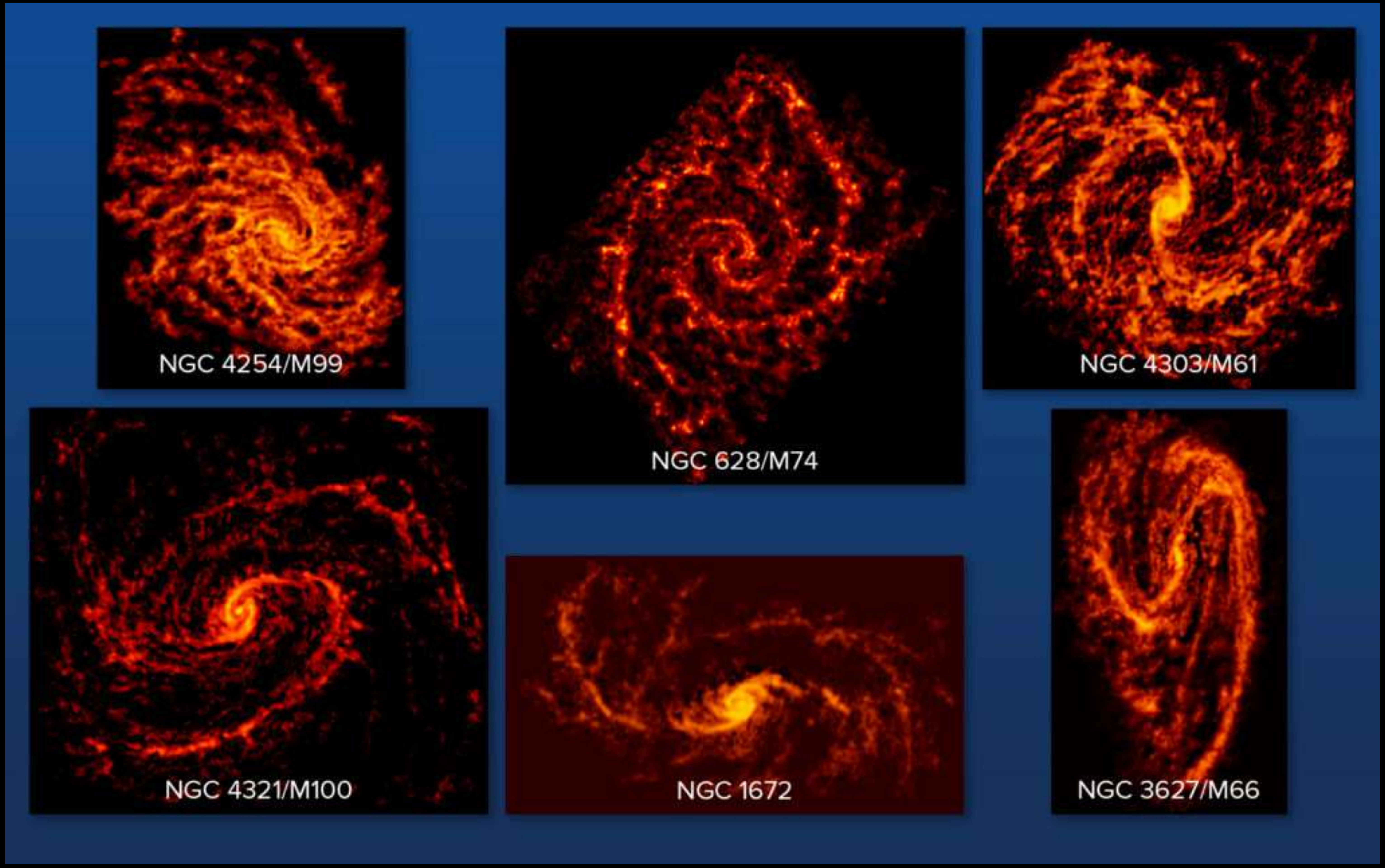
Milky Way simulations

- Both models best predict a 4-armed spiral structure
- However, some structures like the Carina arm and the Inner ridge are impossible to reproduce with fixed potential

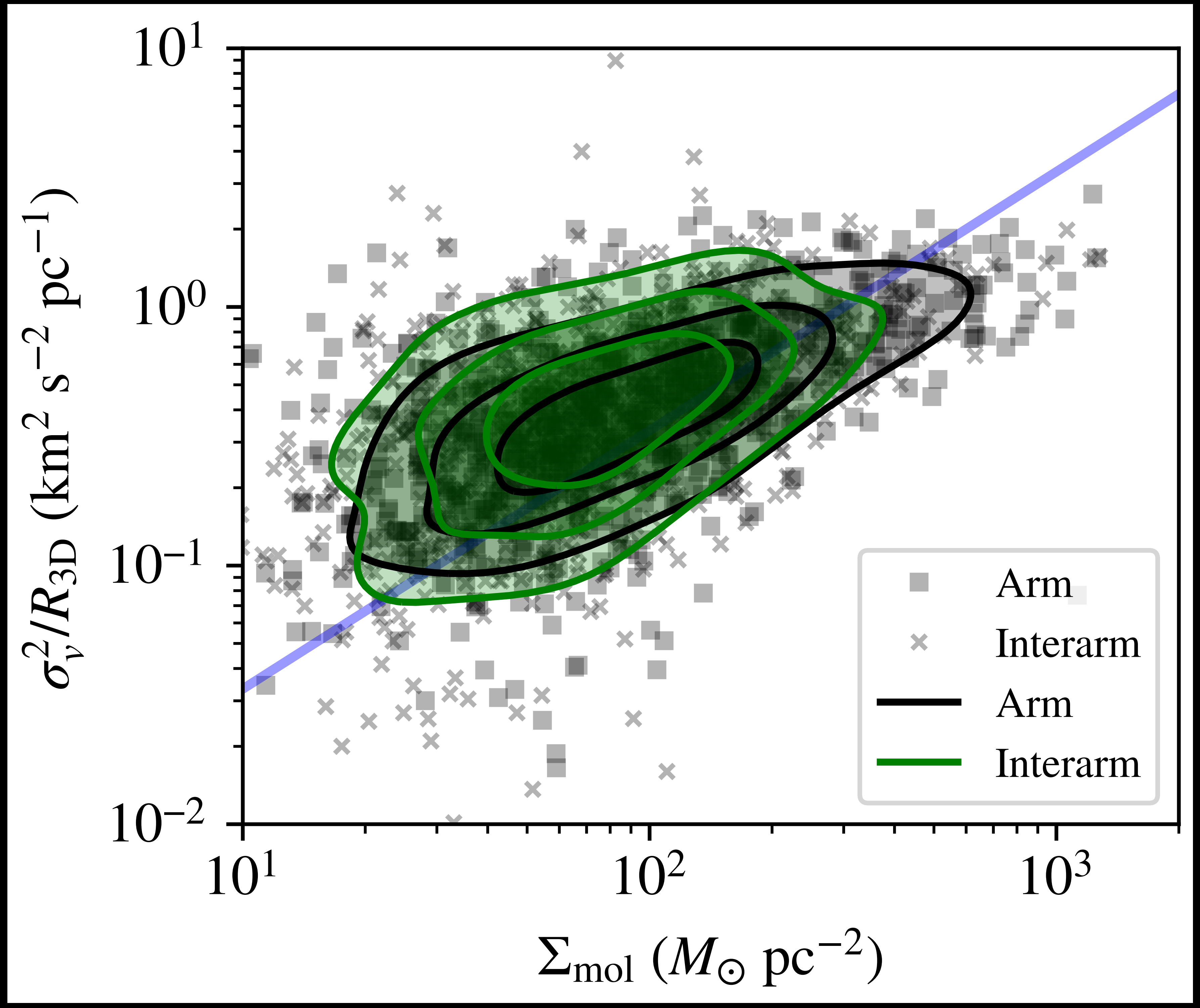


Rosolowsky+ 2021

Is the Milky Way morphology common?

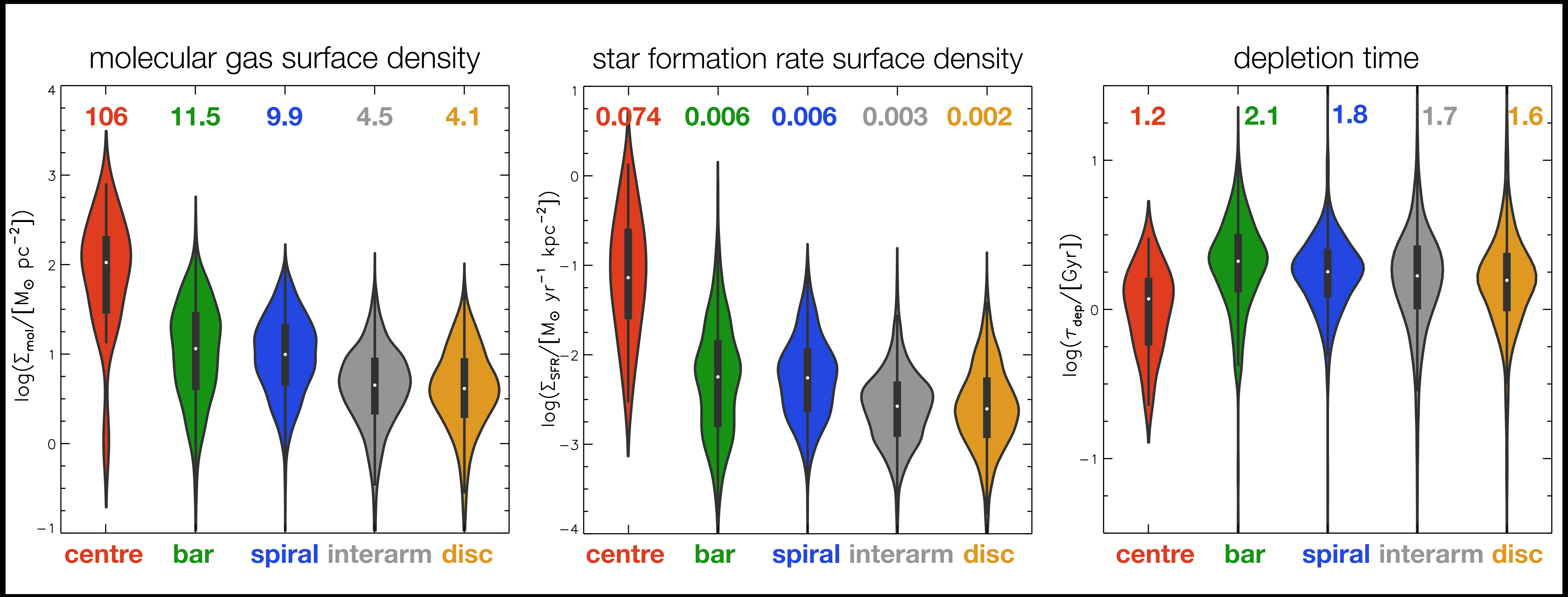


PHANGS galaxies



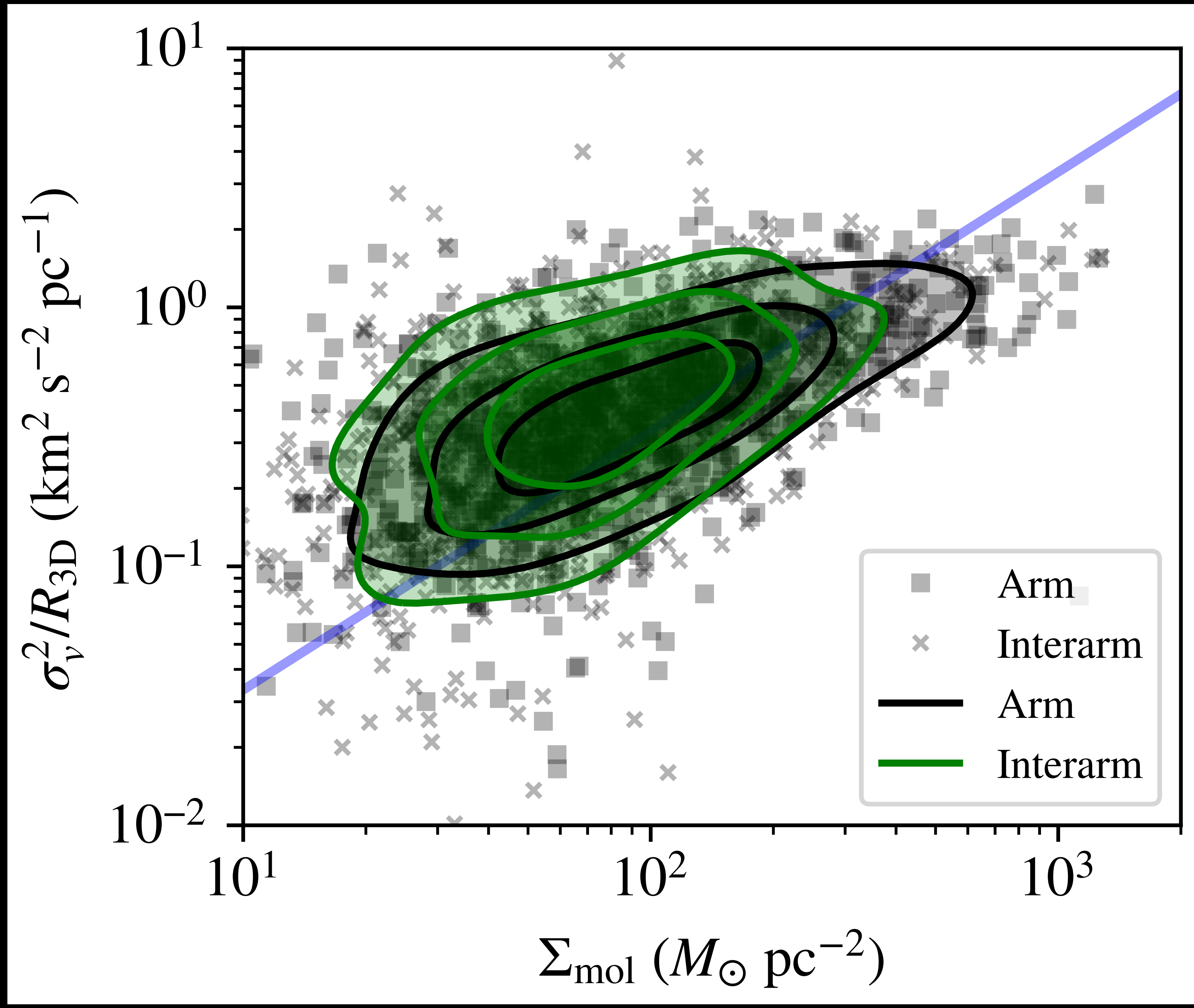
- 4986 clouds in 10 galaxies
- Slightly higher amount of massive and dense clouds in the spiral arms compared to the inter-arm regions
- Median virial parameter slightly lower in spiral arms compared to inter-arm

Is the Milky Way morphology common?



Querejeta+ 2021

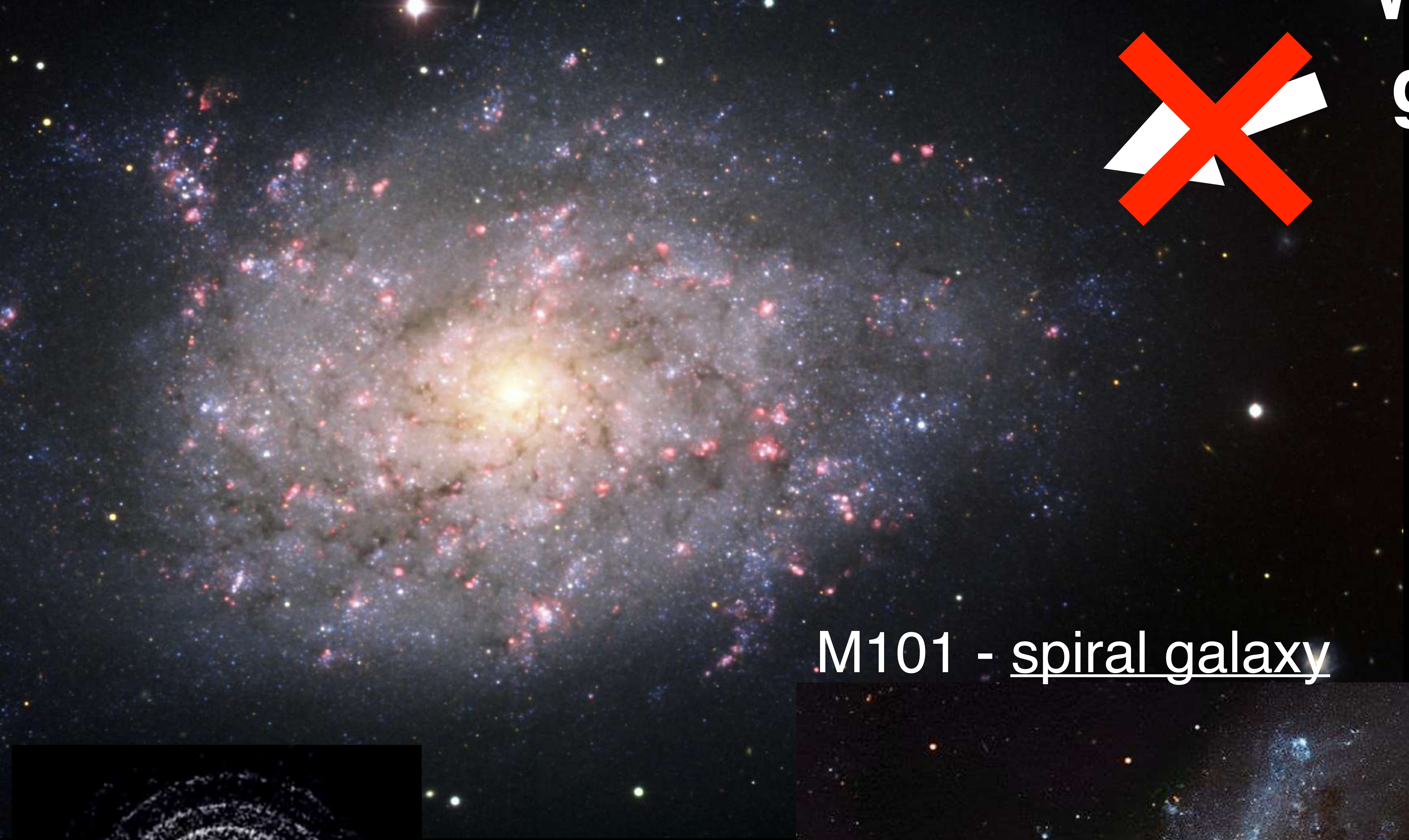
Rosolowsky+ 2021

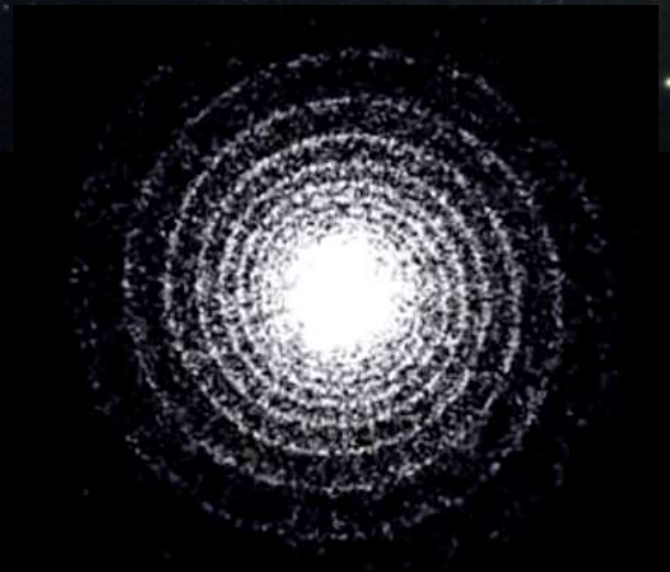


- 4986 clouds in 10 galaxies
- Slightly higher amount of massive and dense clouds in the spiral arms compared to the inter-arm regions
- Median virial parameter slightly lower in spiral arms compared to inter-arm

Which type of galaxy is the Milky Way?

NGC7793 - flocculent galaxy

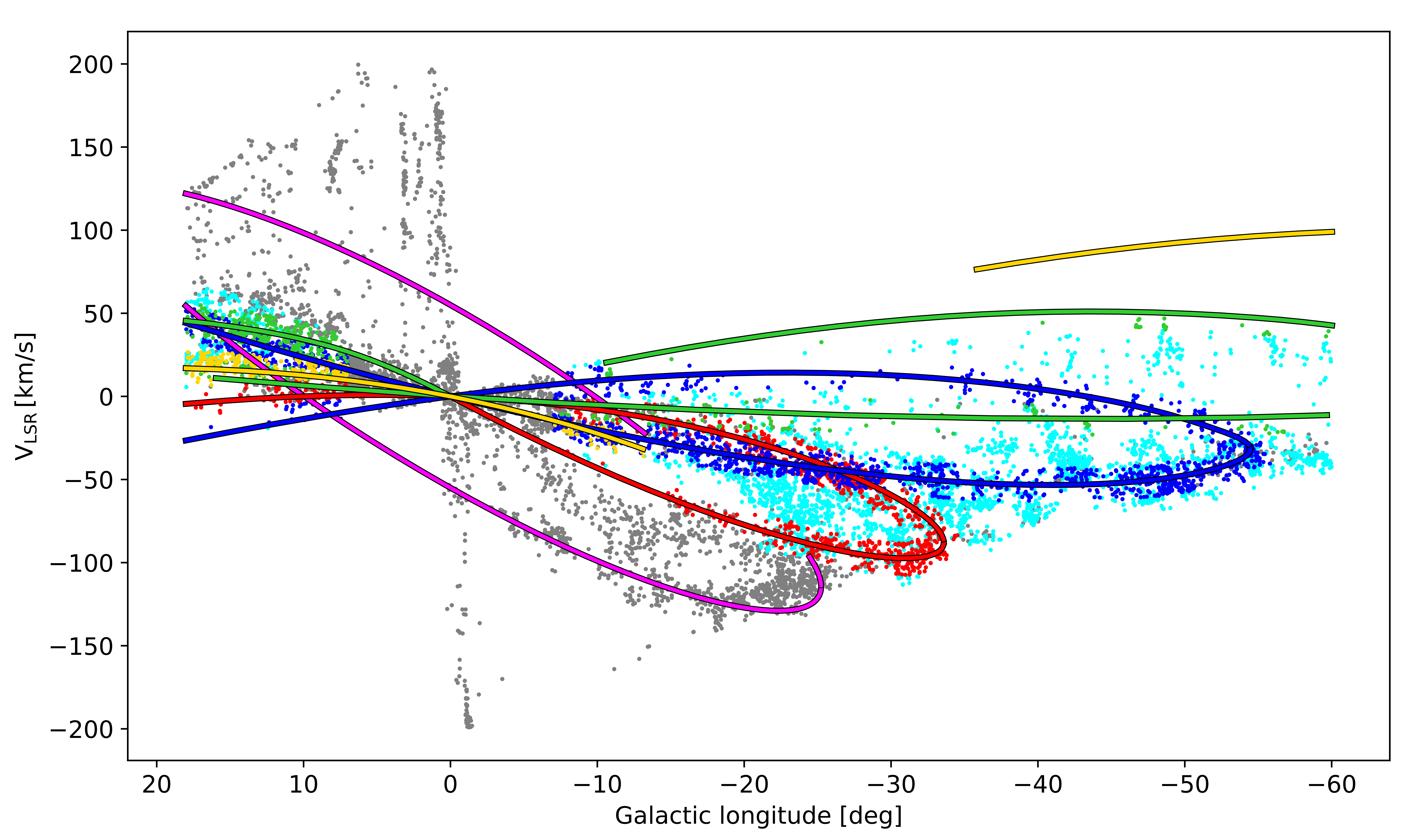




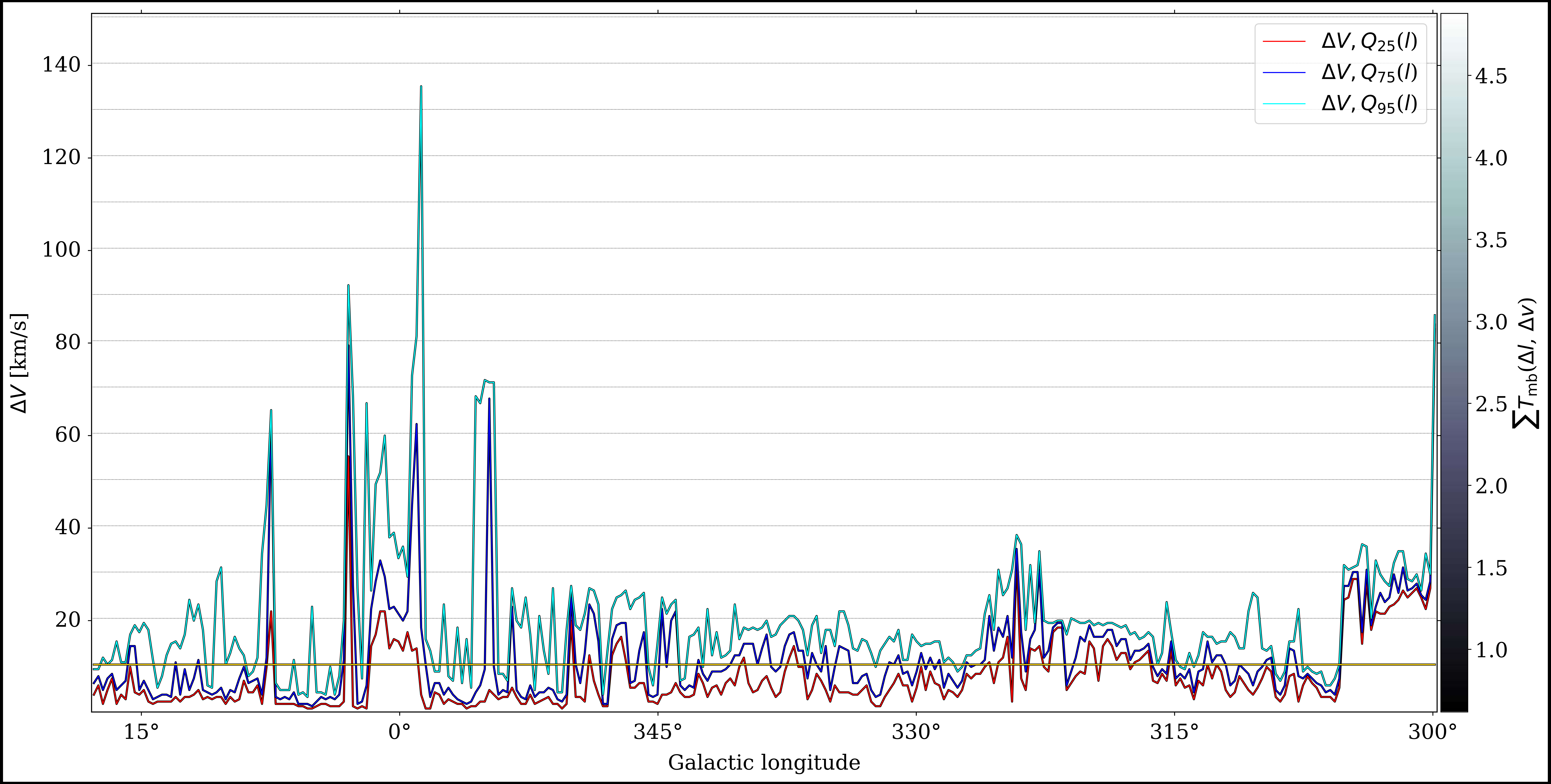
M101 - spiral galaxy

M51 - grand design spiral galaxy

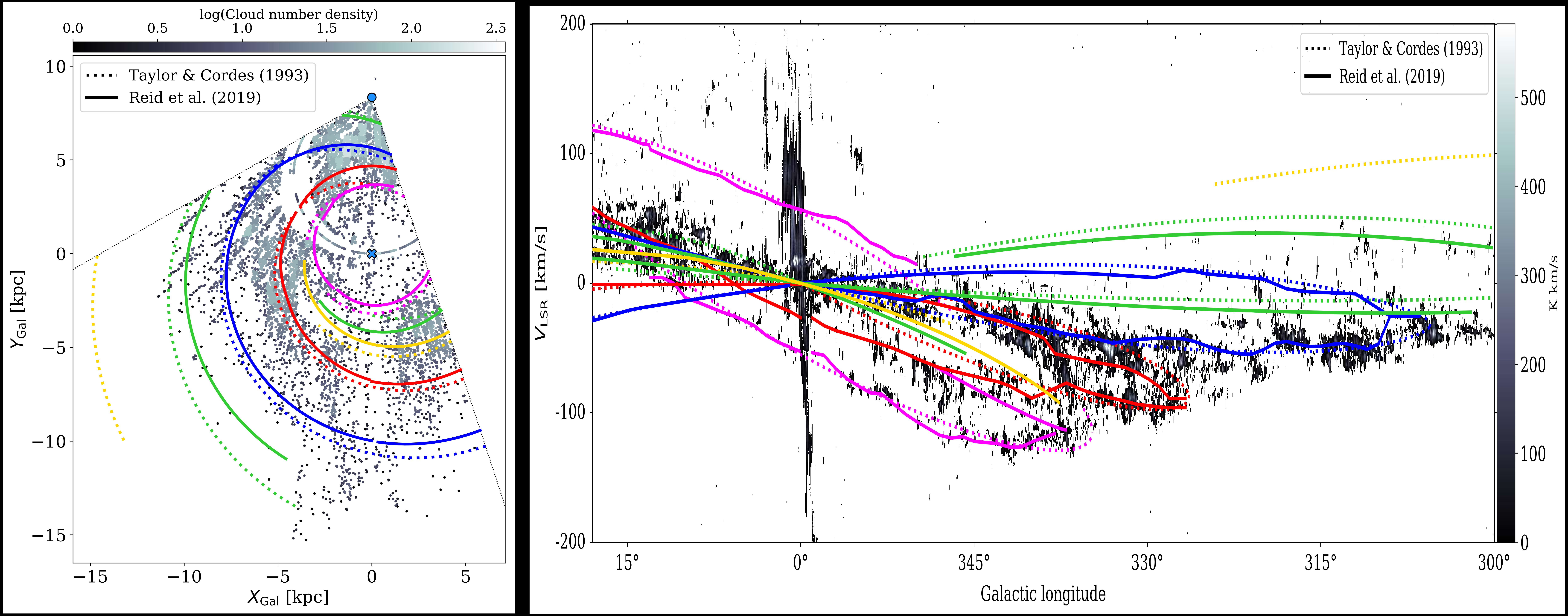
Considering molecular gas properties, the Milky Way is more similar to a flocculent rather than a grand-design spiral galaxy



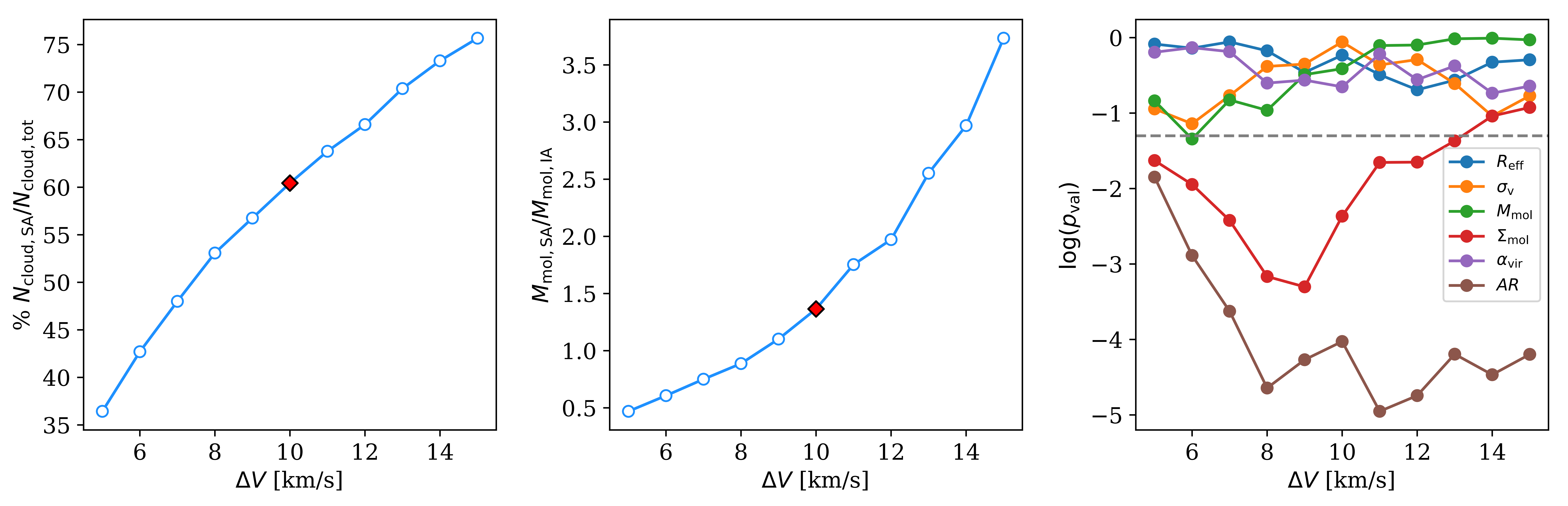
200
150
100
50
0
−50
−100
−150
−200
V_LSR [km/s]
20
10
0
−10
−20
−30
−40
−50
−60
Galactic longitude [deg]



$\Delta V, Q_{25}(l)$
$\Delta V, Q_{75}(l)$
$\Delta V, Q_{95}(l)$
140
120
100
80
60
40
20
ΔV [km/s]
15°
0°
345°
330°
315°
300°
Galactic longitude
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
$\sum T_{\mathrm{mb}}(\Delta l, \Delta v)$


log(Cloud number density)
0.0
0.5
1.0
1.5
2.0
2.5
Taylor & Cordes (1993)
Reid et al. (2019)
$Y_{\rm Gal}$ [kpc]
$X_{\rm Gal}$ [kpc]
10
5
0
−5
−10
−15
Taylor & Cordes (1993)
Reid et al. (2019)
$V_{\rm LSR}$ [km/s]
200
100
0
-100
-200
15°
0°
345°
330°
315°
300°
Galactic longitude
K km/s
500
400
300
200
100
0

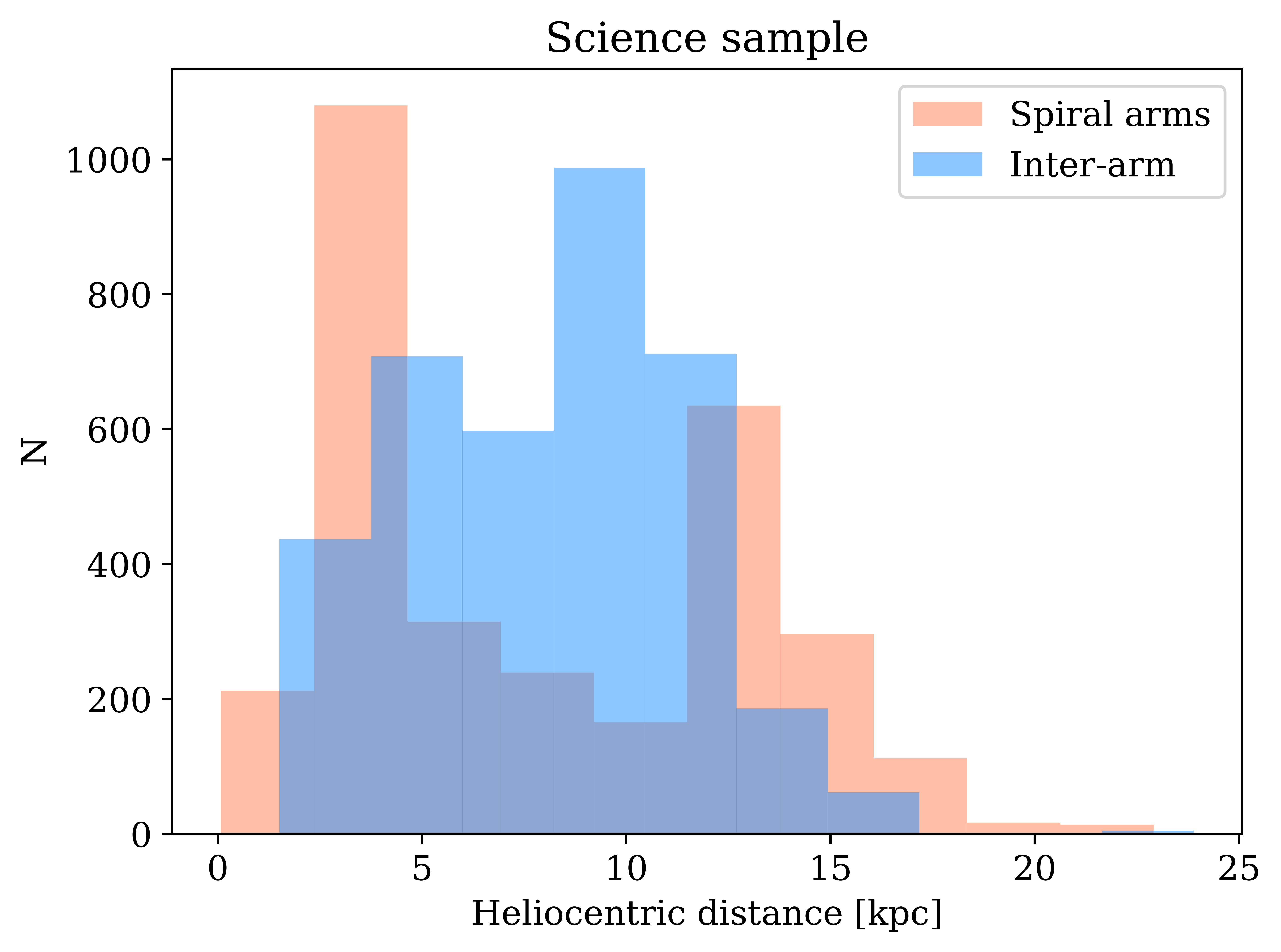
Choice of ΔV



Percentage of number of clouds in spiral arms w.r.t. total number of clouds

Mass contrast of clouds in the spiral arms with respect to inter-arm region

p-values from property distributions of clouds in spiral arms and inter-arm region


Science sample
Spiral arms
Inter-arm
N
0
200
400
600
800
1000
0
5
10
15
20
25
Heliocentric distance [kpc]