MAPPING THE GALACTIC DISC WITH FIELD STARS AND OPEN CLUSTERS

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Marie Skłodowska-Curie Actions
Research Fellowship Programme

THE IMPORTANCE OF MAPPING THE GALACTIC DISC

- The Galactic disc contains most of the stars in our Galaxy
- Several mechanisms at work
- Internal perturbations (e.g. bar, spiral arms)
- External perturbations (e.g. satellites)
- Footprints in the spatial, kinematic and chemical properties of stars and stellar clusters

Image credits: Stefan Payne-Wardenaar

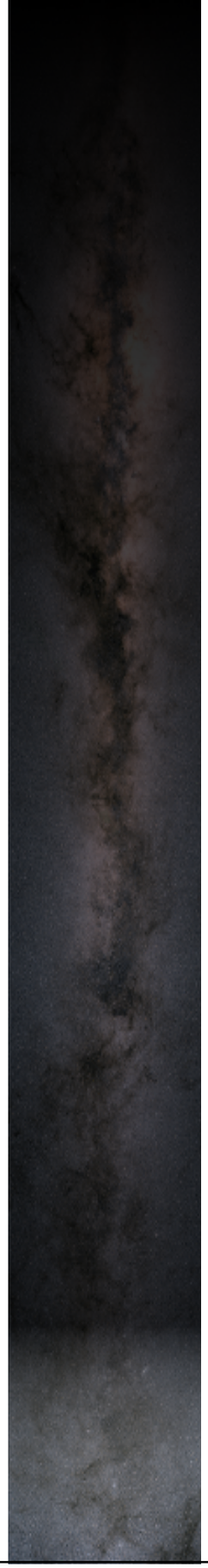
OUTLINE

SECTION 1

Field stars and open clusters (OCs) in 3-dimensional space

SECTION 2

Chemo-kinematical substructures in field stars and OCs



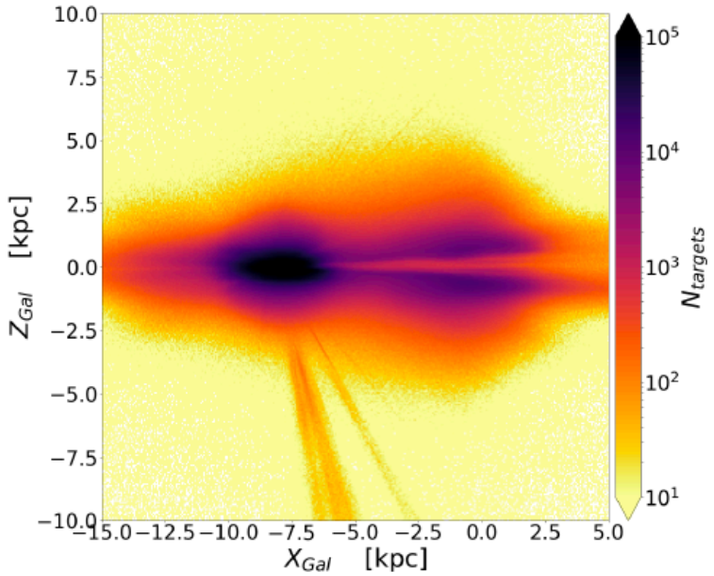
SECTION 1

Three-dimensional space

FIELD STARS: young vs. old stellar populations

SPATIAL DISTRIBUTION

Starhorse catalog



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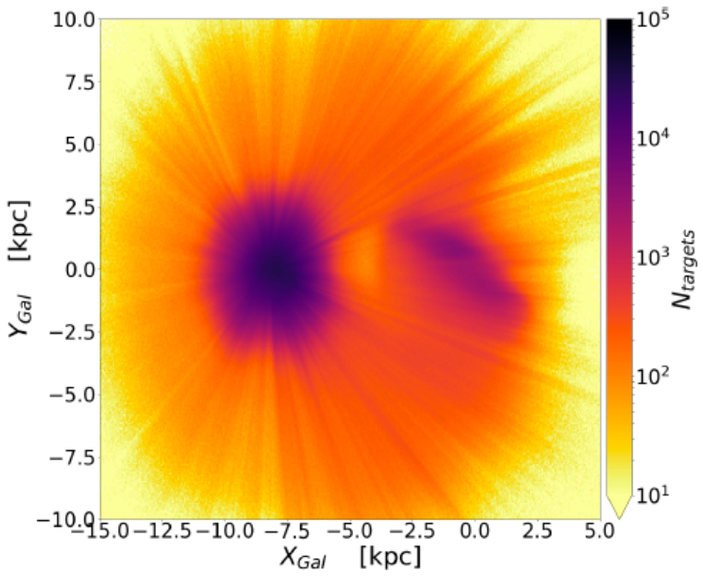

Anders et al. (2019)

FIELD STARS: young vs. old stellar populations

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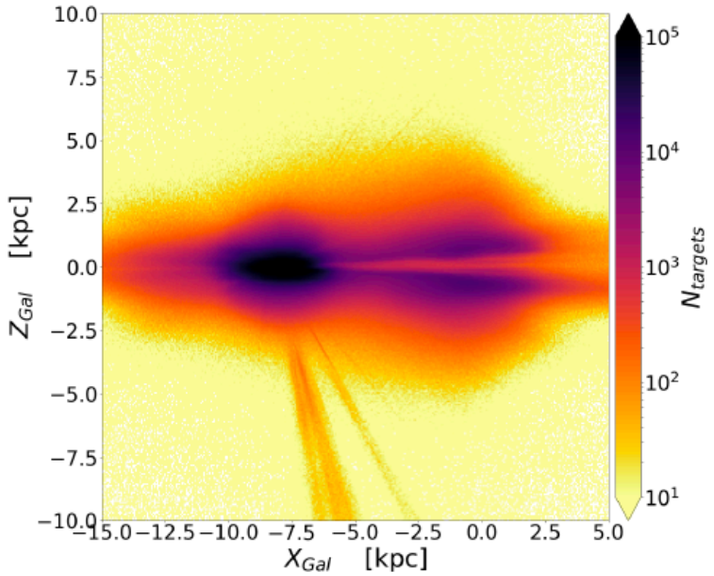

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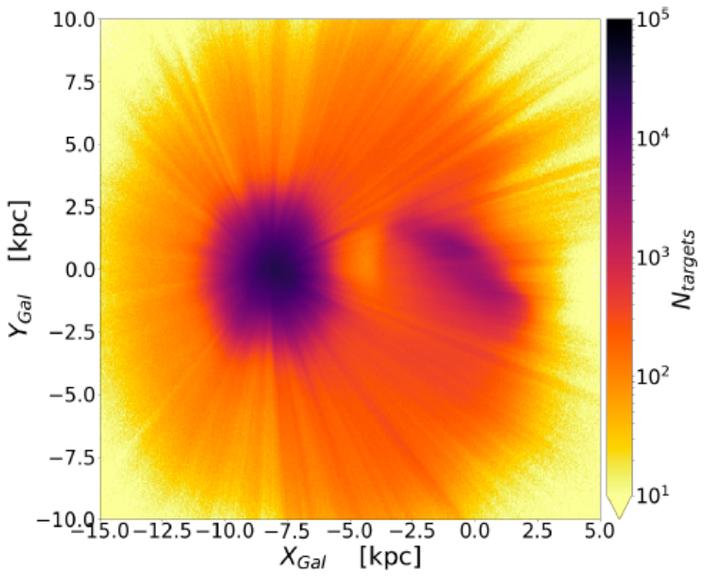
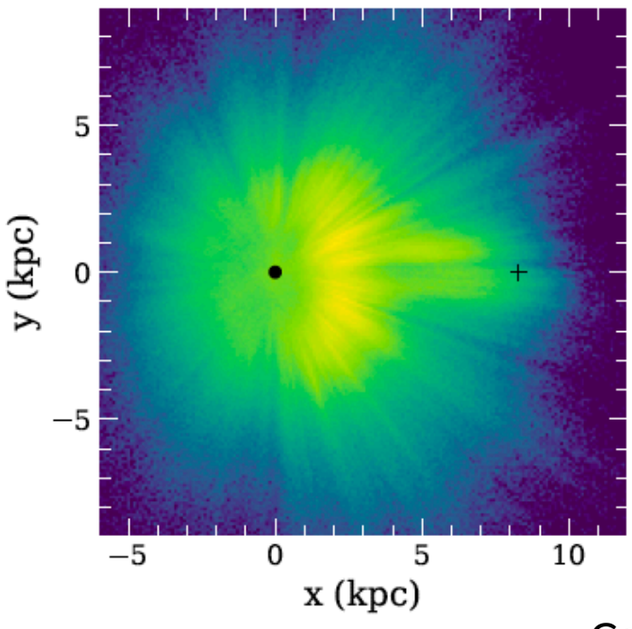


Anders et al. (2019)

Giants



Gaia Collaboration, Drimmel et al., (2022)

FIELD STARS: young vs. old stellar populations

SPATIAL DISTRIBUTION

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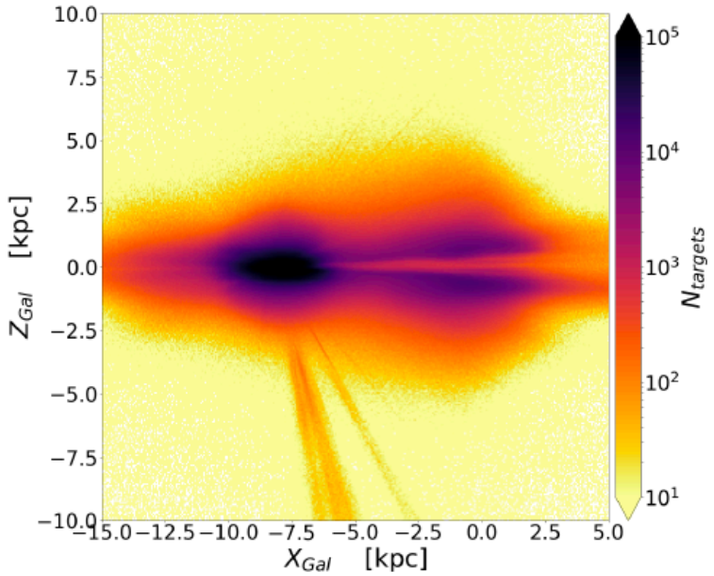
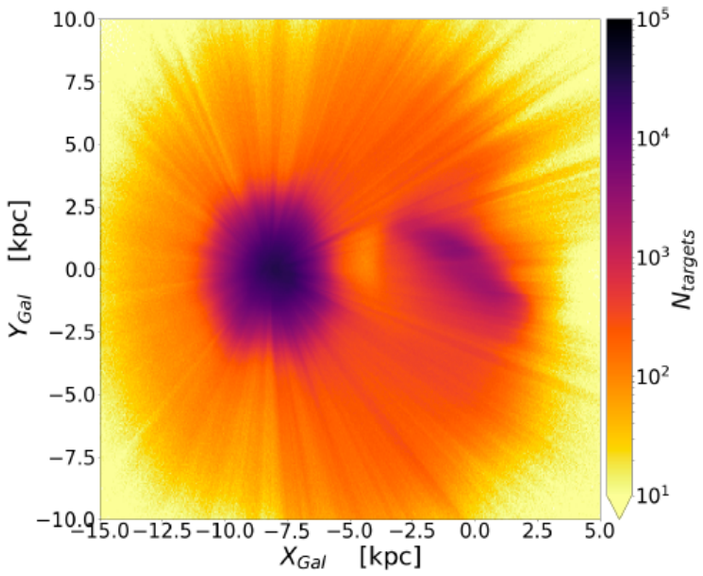
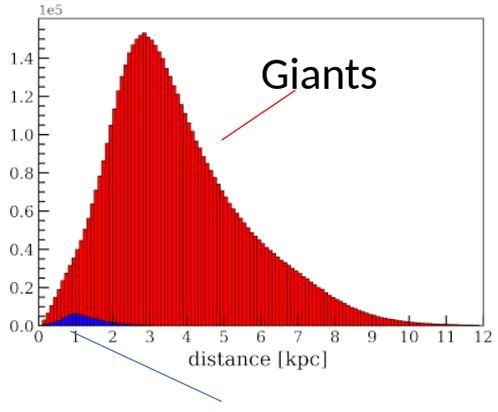


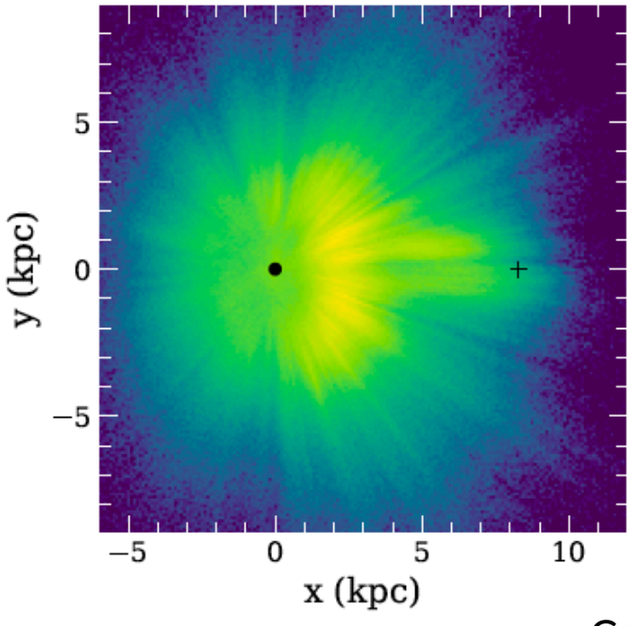
Starhorse catalog



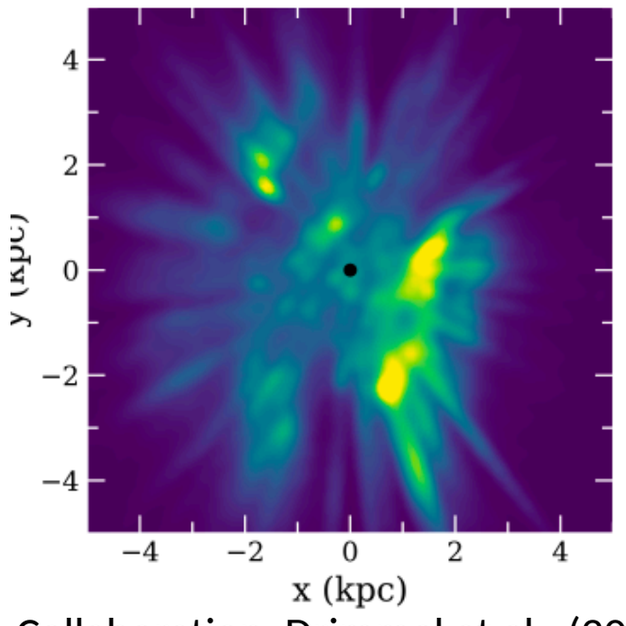
Anders et al. (2019)



Giants



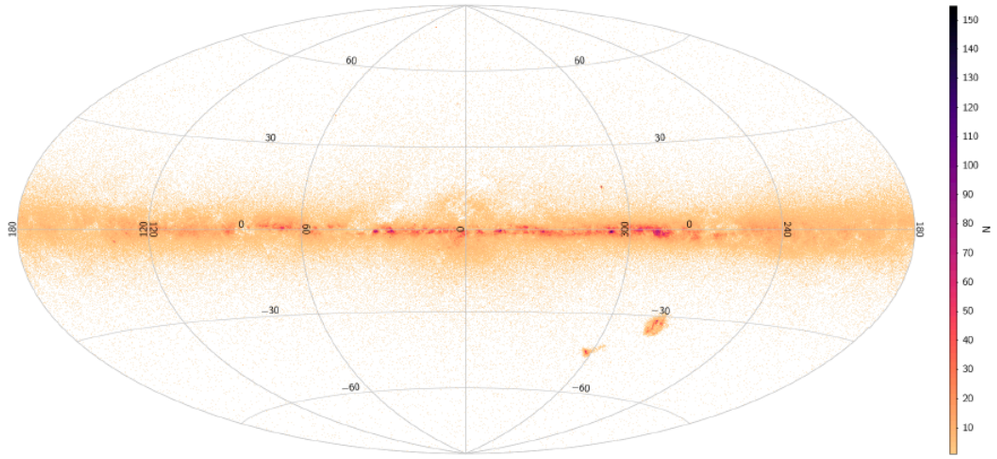
OB stars

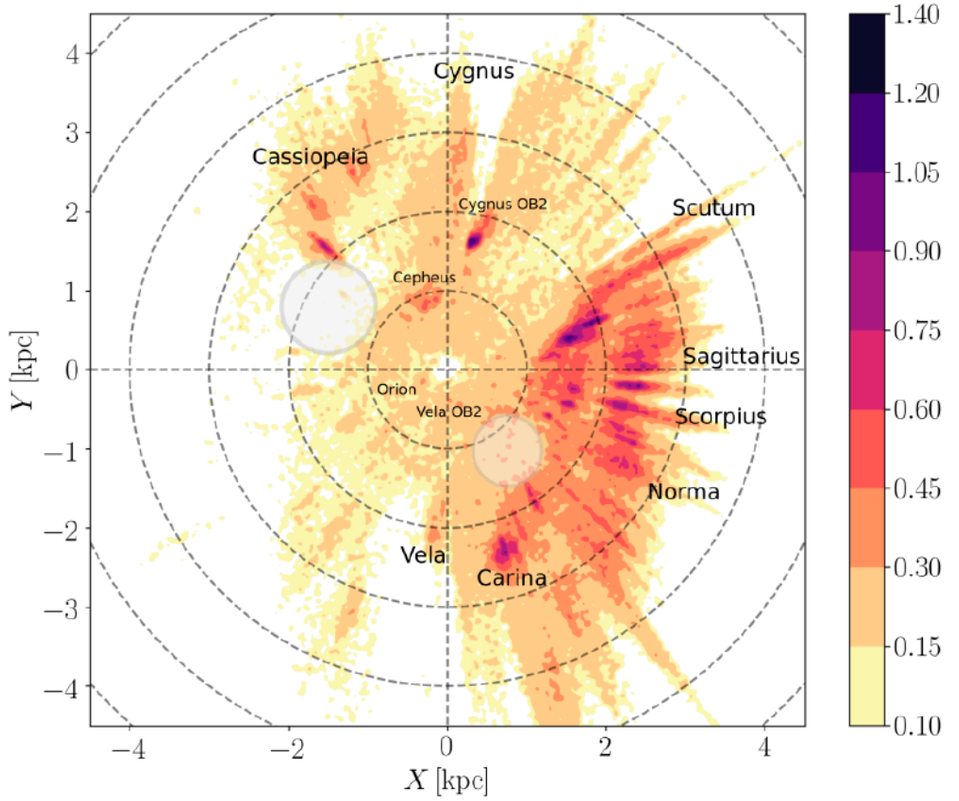


Gaia Collaboration, Drimmel et al., (2022)

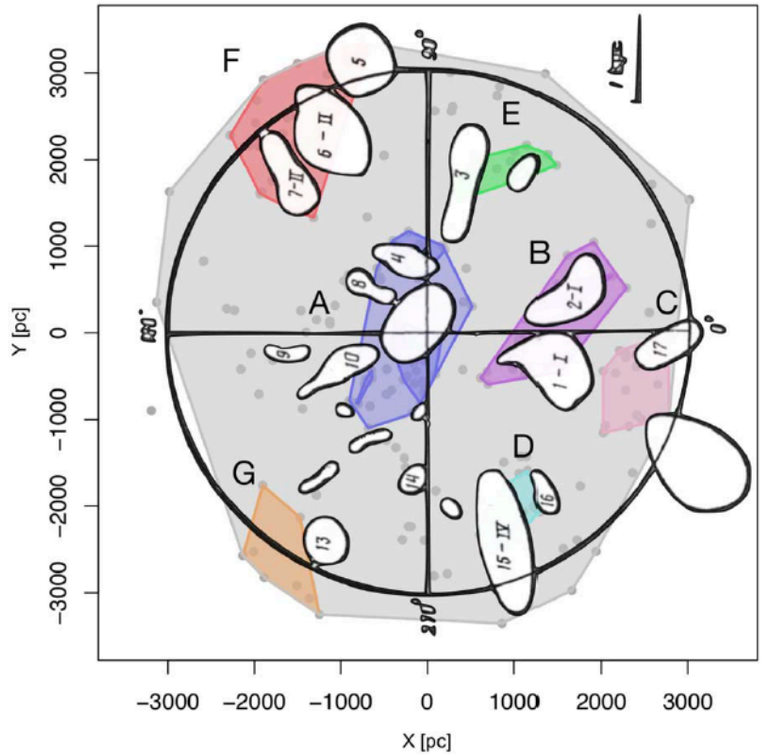
Mapping young stars with Gaia

SPATIAL DISTRIBUTION





Zari et al. (incl. EP), 2021,
following the nomenclature proposed by Kevin Jardine
(http://gruze.org/galaxymap/map_2020/)

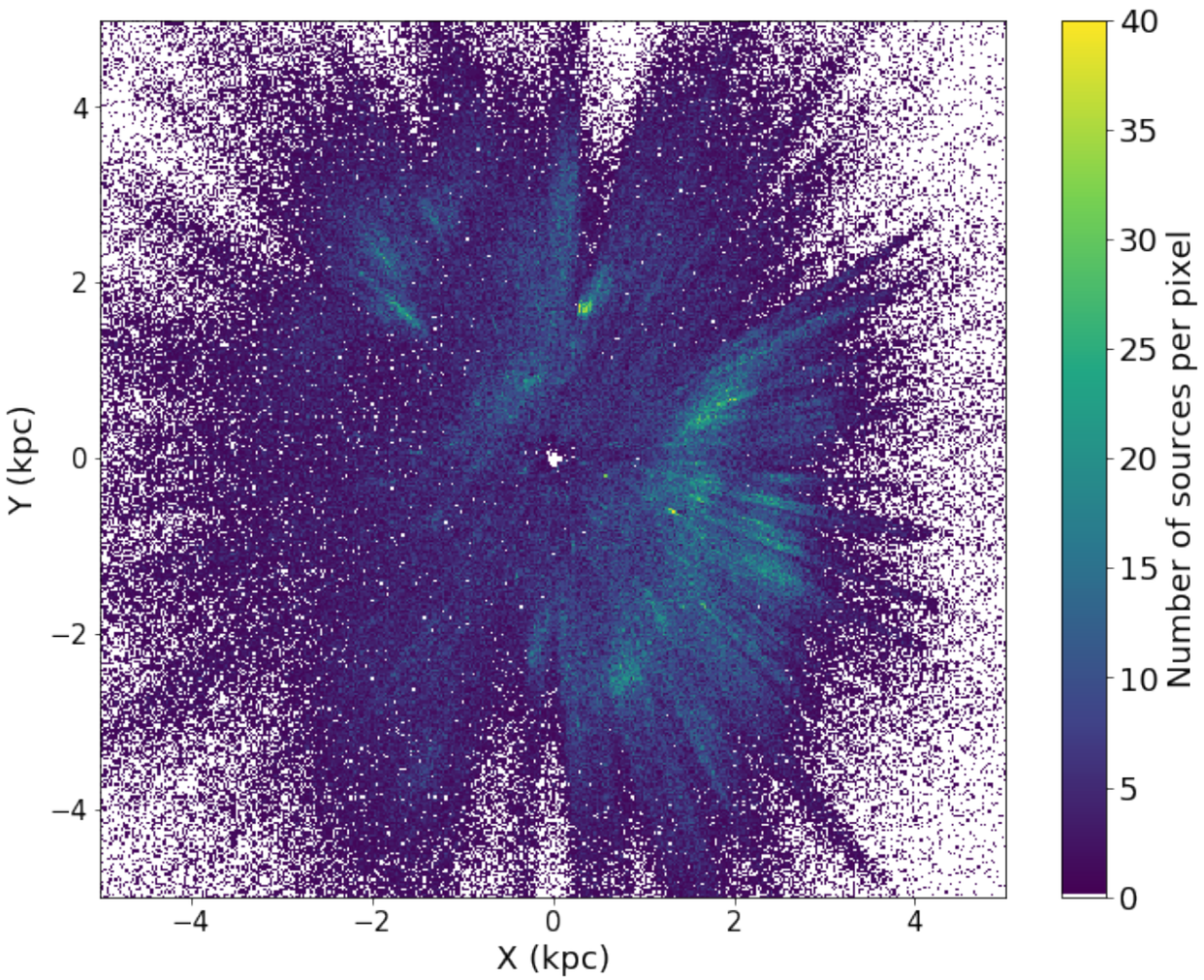


Alfaro et al. (2022)

Mapping young stars with Gaia

SPATIAL DISTRIBUTION

~600 000 Upper Main Sequence stars in Gaia EDR3



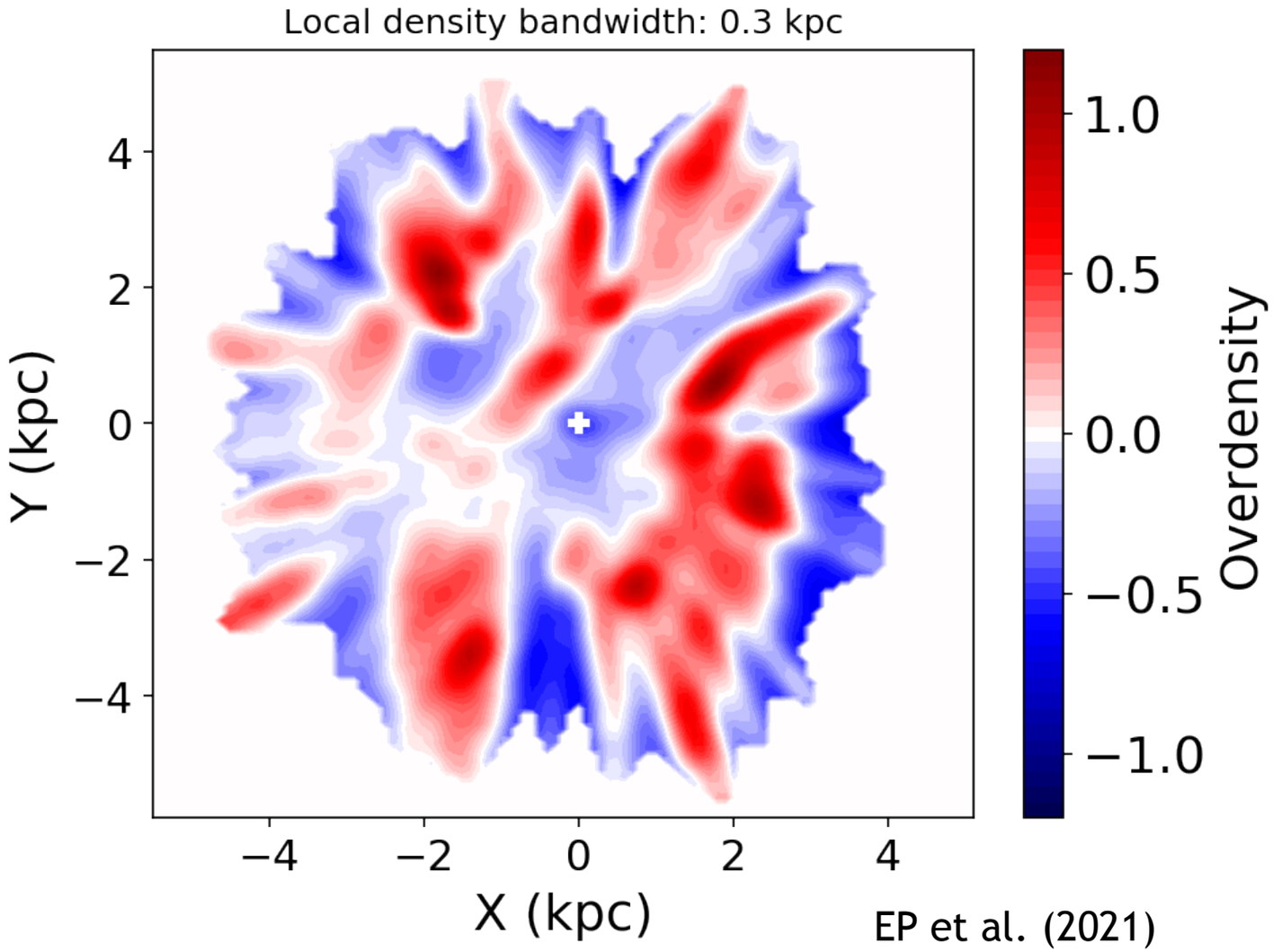
EP et al. (2021)

Mapping young stars with Gaia

SPATIAL DISTRIBUTION

~600 000 Upper Main Sequence stars in Gaia EDR3

$$\Delta_\Sigma(X,Y) = \frac{\Sigma(X,Y) - \langle \Sigma(X,Y) \rangle}{\langle \Sigma(X,Y) \rangle}$$



EP et al. (2021)

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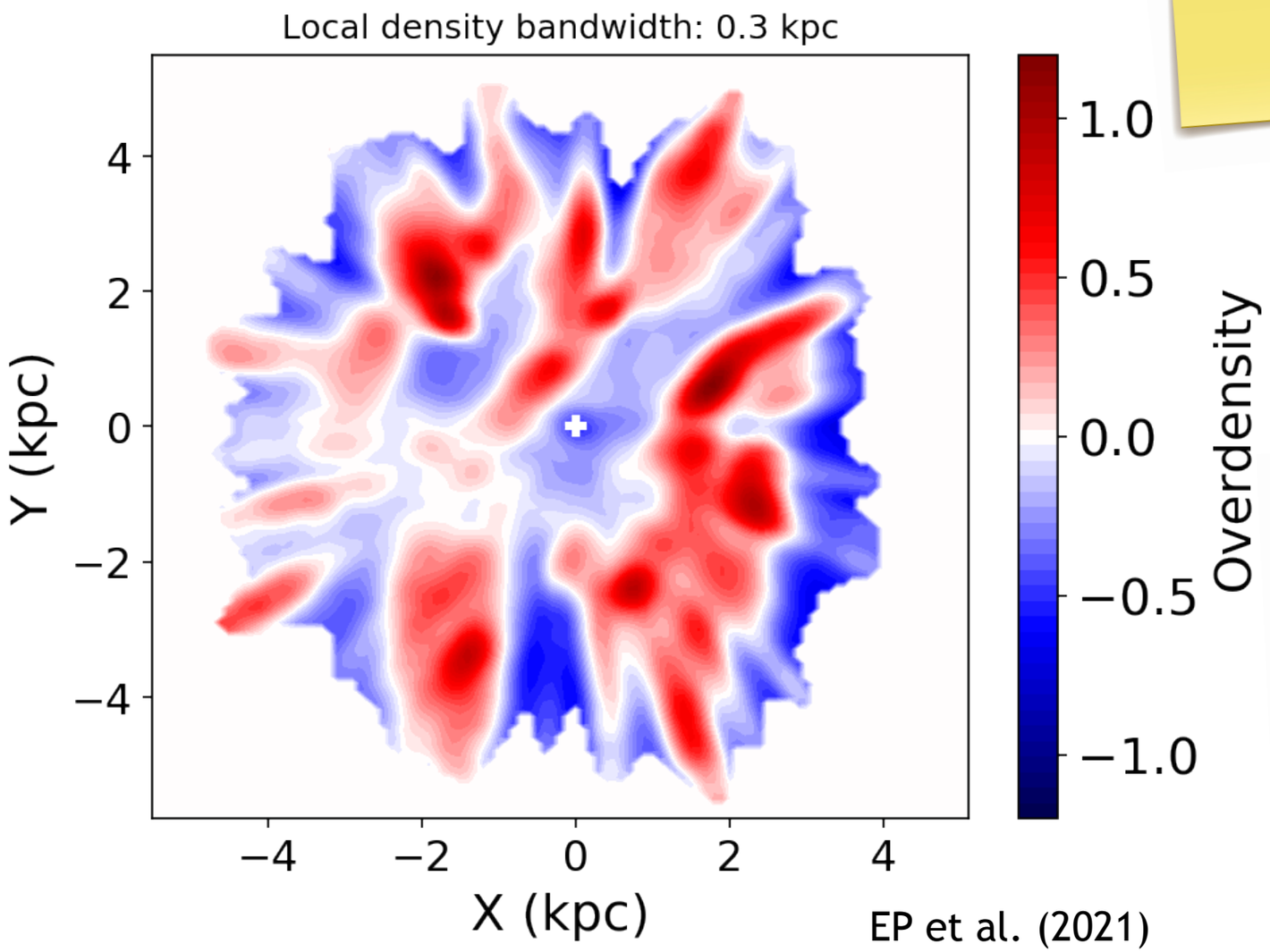


EP et al. (2021)

3 (possibly 4) clumpy but coherent segments

"Shadow cones" produced by foreground extinction

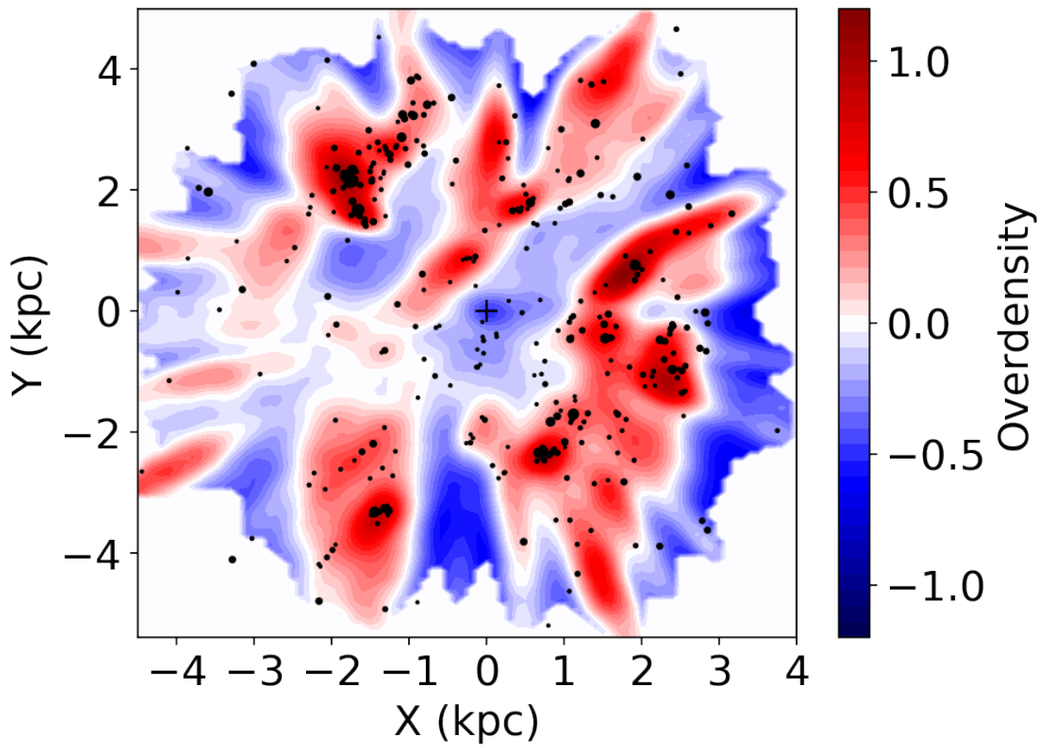
The Local arm is not so local! (at least 8 kpc!)

Comparison between UMS stars and OCs

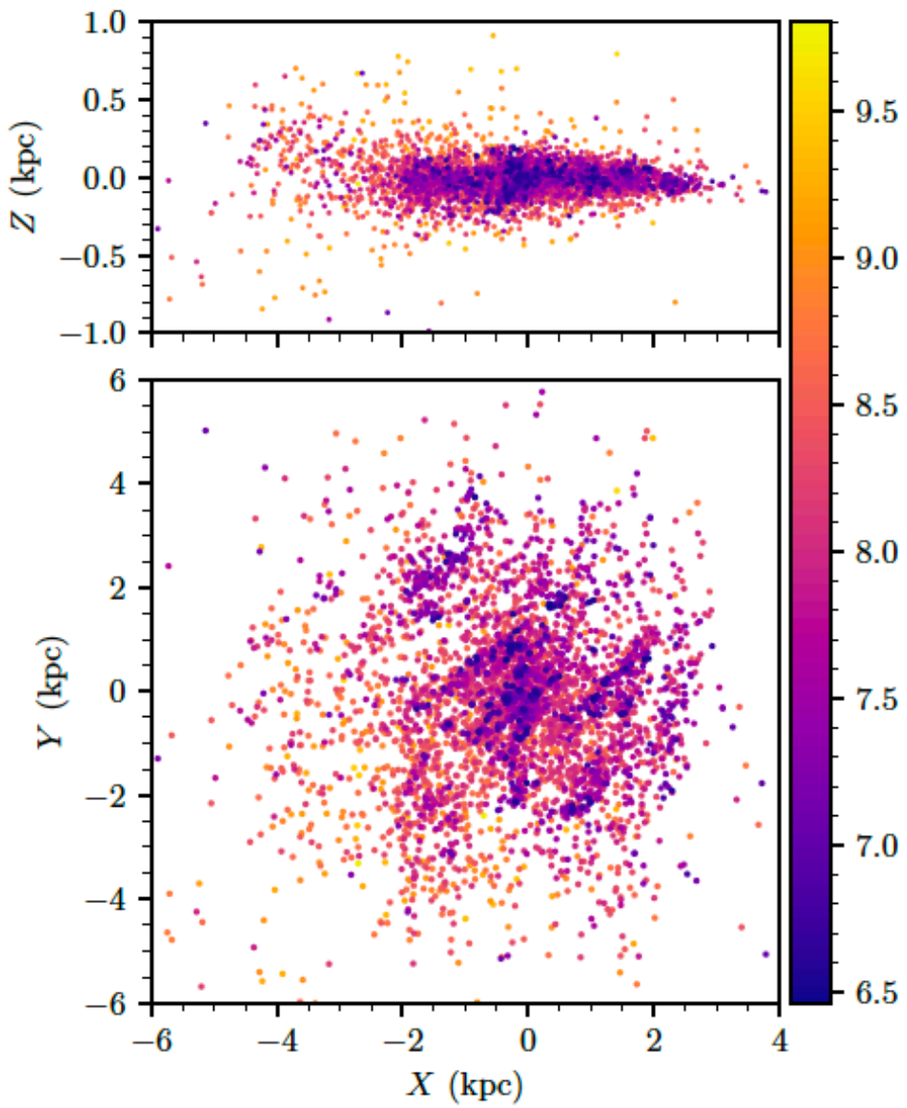
SPATIAL DISTRIBUTION

353 open clusters from Cantat-Gaudin et al. (2020) with:

- age < 100 Myr
- more than 5 members brighter than M_G=0



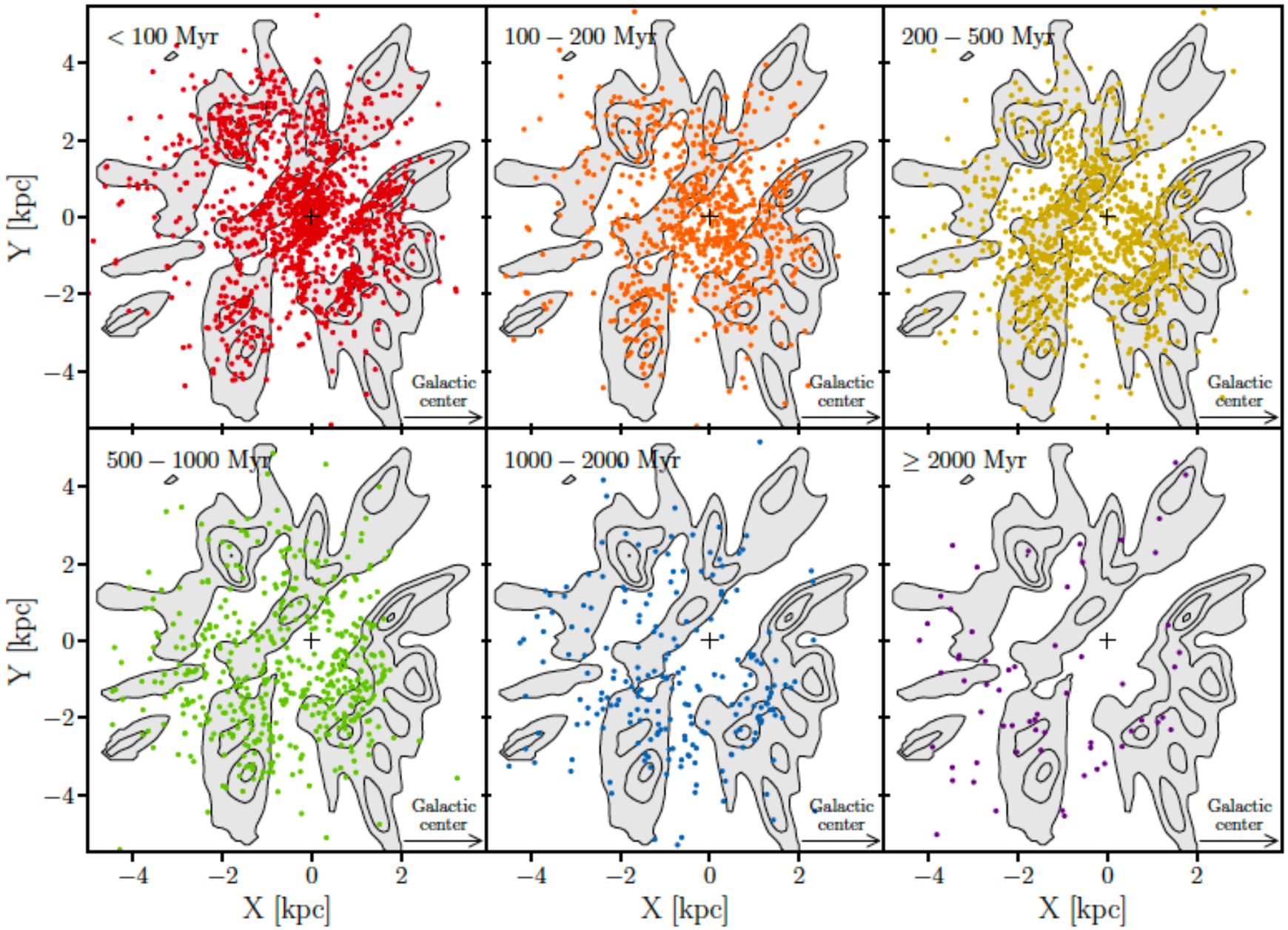
Clusters from Hunt & Reffert (2023)



Comparison between UMS stars and OCs

SPATIAL DISTRIBUTION

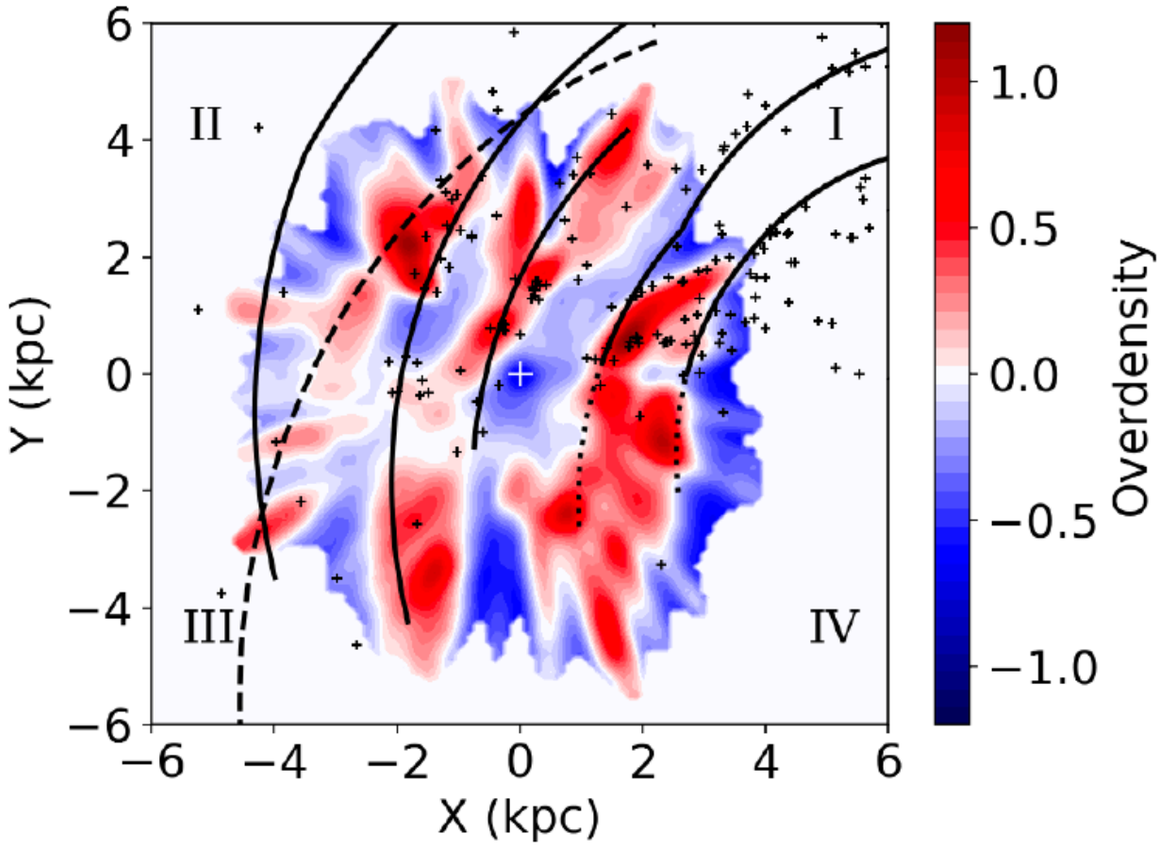
Cavallo et al. (2023)



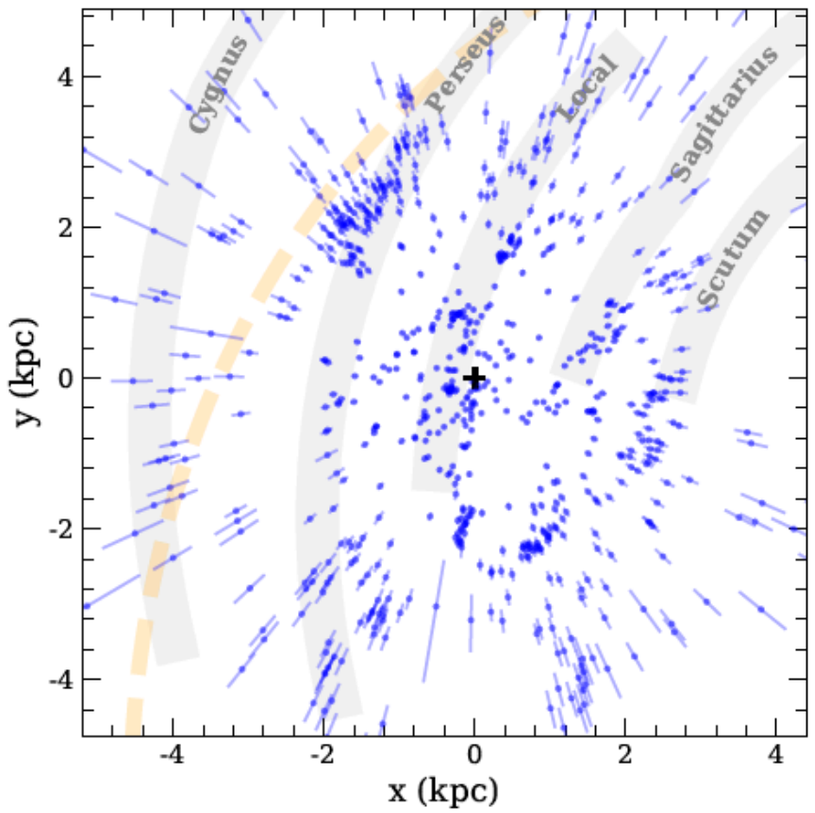
Comparison with Reid et al. (2019)

SPATIAL DISTRIBUTION

UMS + Masers from Reid et al. (2019)



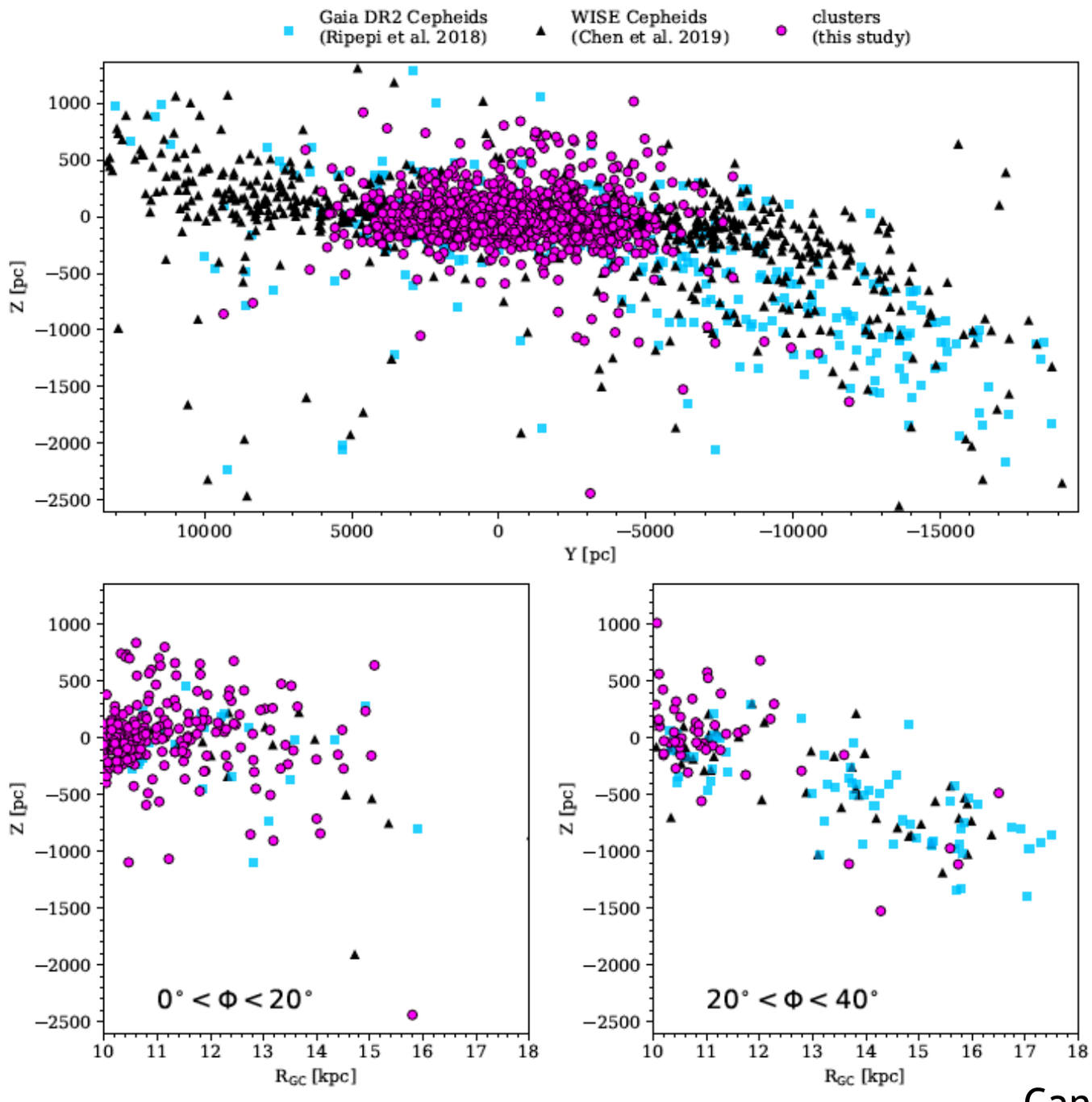
OCs from Gaia Coll. Drimmel et al. (2023) + model from Reid et al. (2019)



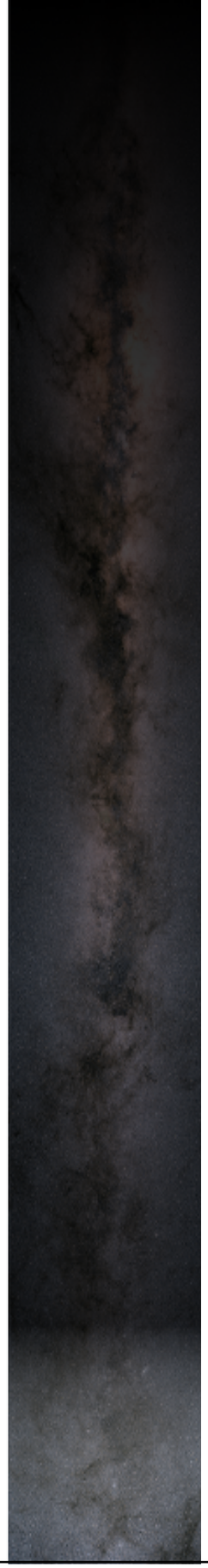
See discussion in Cantat-Gaudin et al. (2020)

Z-dimension: the Galactic warp

SPATIAL DISTRIBUTION



Cantat-Gaudin et al. (2020)

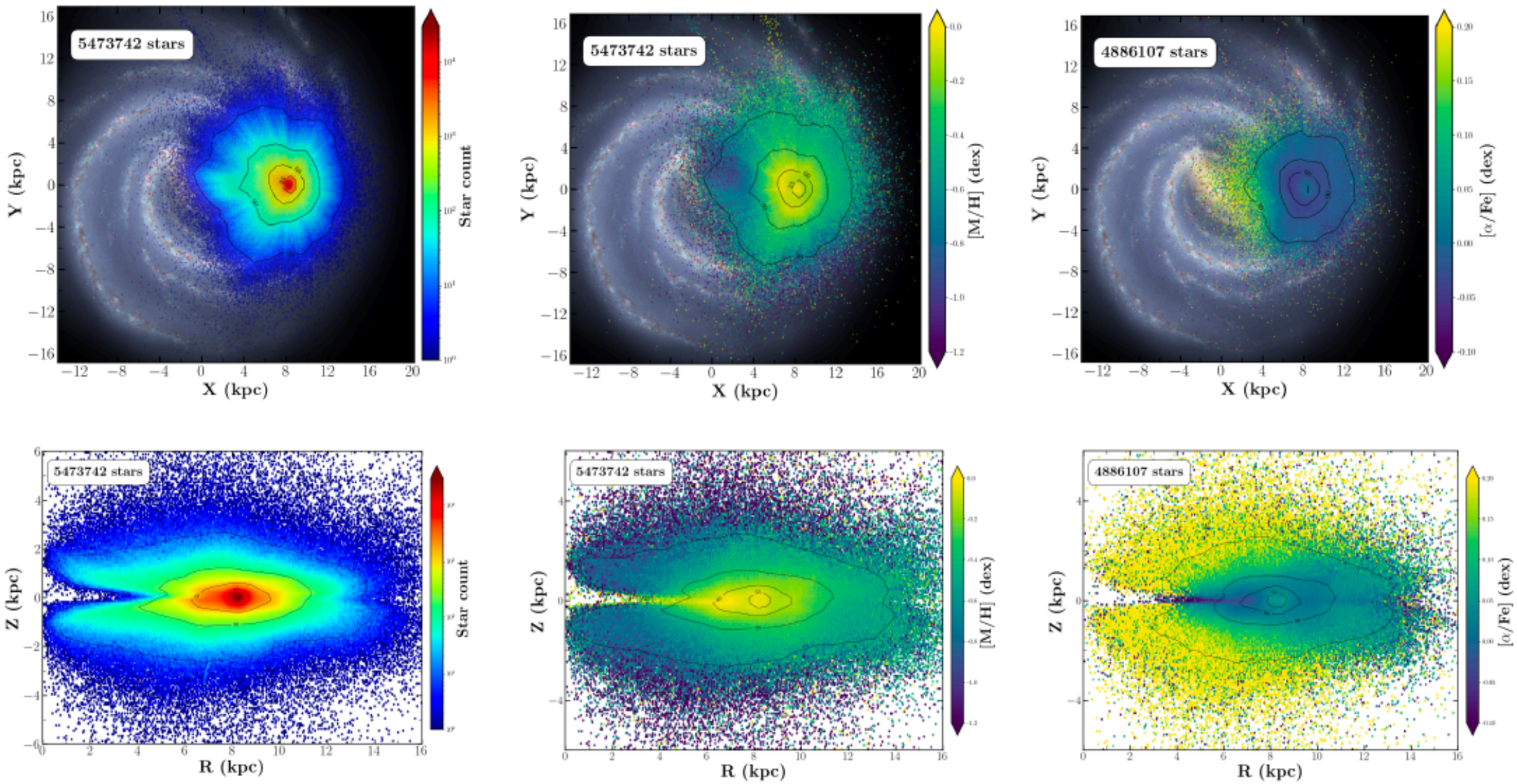


SECTION 2

Chemo-kinematical substructures

Chemical cartography

CHEMO-KINEMATIC SUBSTRUCTURES

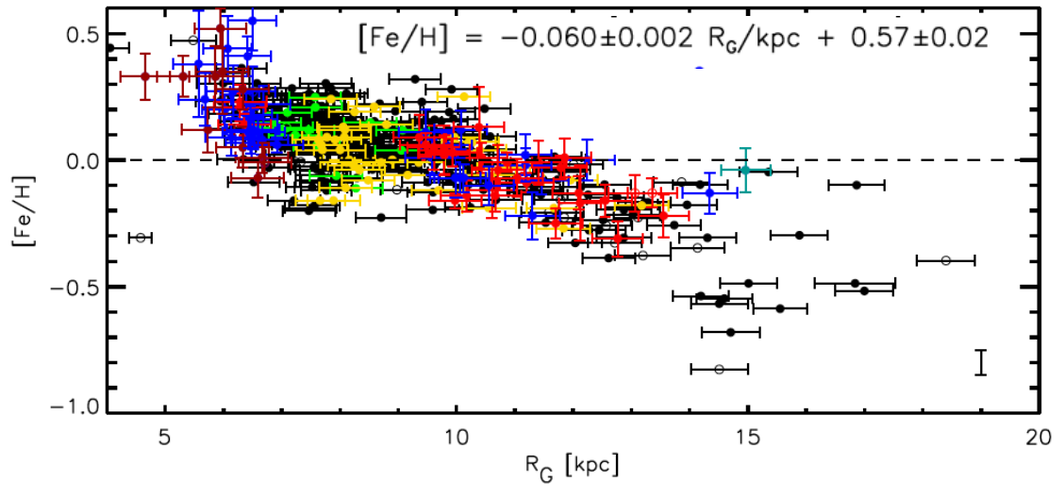


Gaia Collaboration, Recio-Blanco et al. (2023)

The radial metallicity gradient

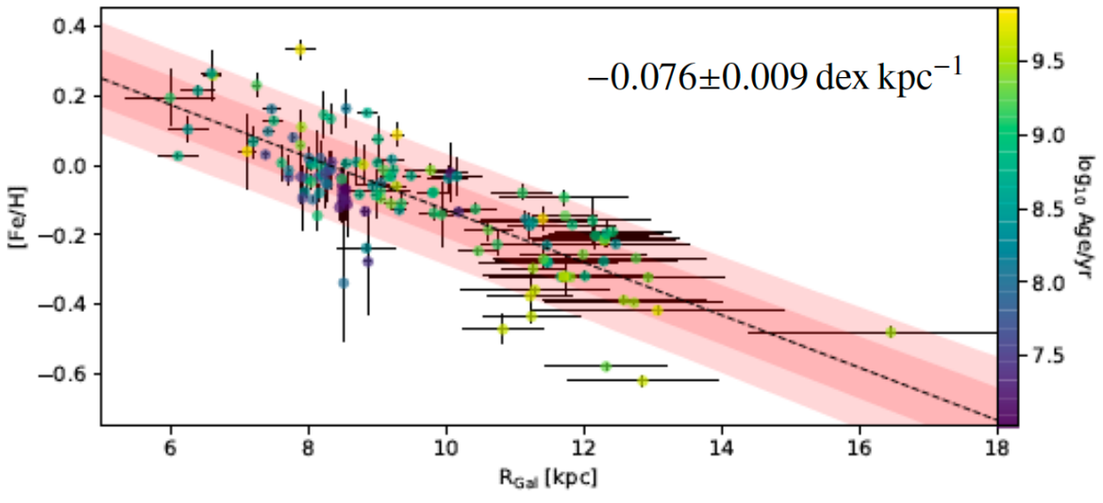
CHEMO-KINEMATIC SUBSTRUCTURES

Cepheids

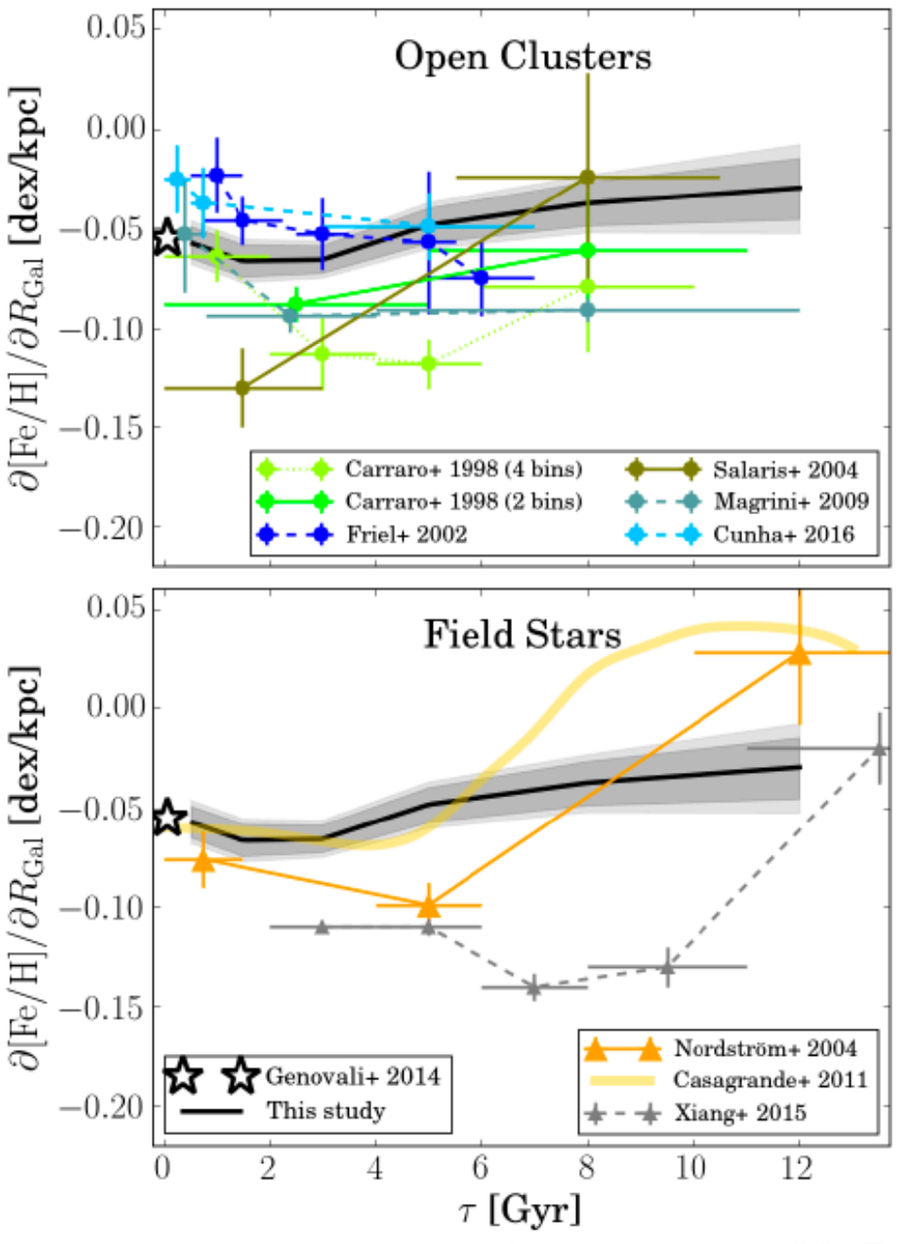


Genovali et al. (2014)

Open Clusters



Spina et al. (2020)

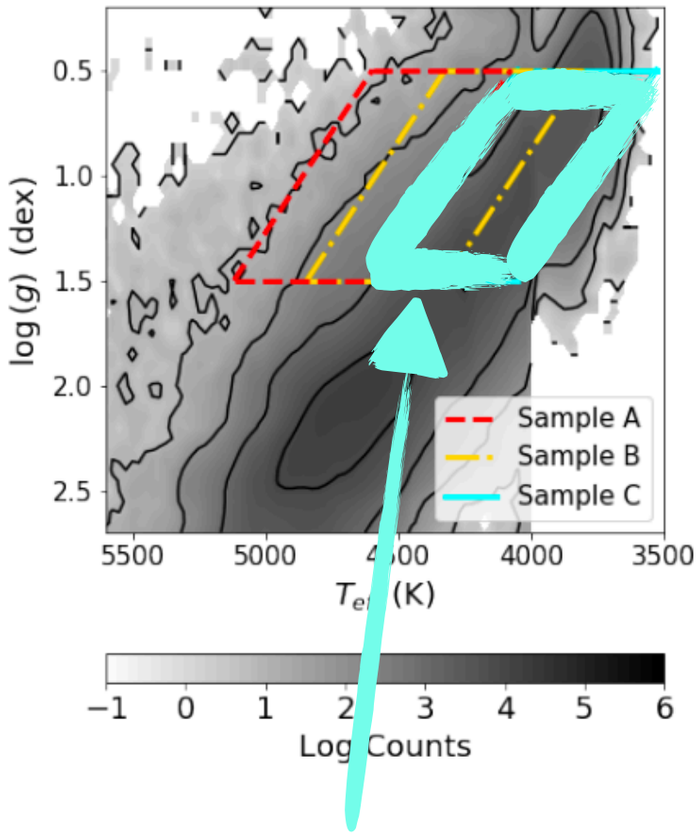


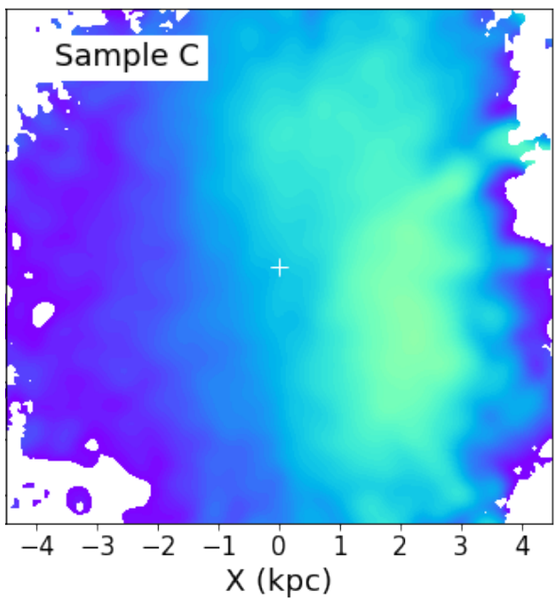
Anders et al. (2017)

See also Magrini et al. 2023, Hayden et al. 2015, Bergemann et al. 2014, and others

Azimuthal dependency of the radial metallicity gradient

CHEMO-KINEMATIC SUBSTRUCTURES





ϕ (deg)	Slope (dex kpc^{-1})	Intercept (dex)
-20 ± 5	-0.054 ± 0.002	0.15 ± 0.02
-15 ± 5	-0.053 ± 0.002	0.13 ± 0.02
-10 ± 5	-0.046 ± 0.002	0.07 ± 0.02
-5 ± 5	-0.041 ± 0.002	0.03 ± 0.01
0 ± 5	-0.043 ± 0.002	0.04 ± 0.01
5 ± 5	-0.042 ± 0.002	0.04 ± 0.02
10 ± 5	-0.040 ± 0.002	0.03 ± 0.02
15 ± 5	-0.039 ± 0.002	0.03 ± 0.02
20 ± 5	-0.036 ± 0.002	0.01 ± 0.02

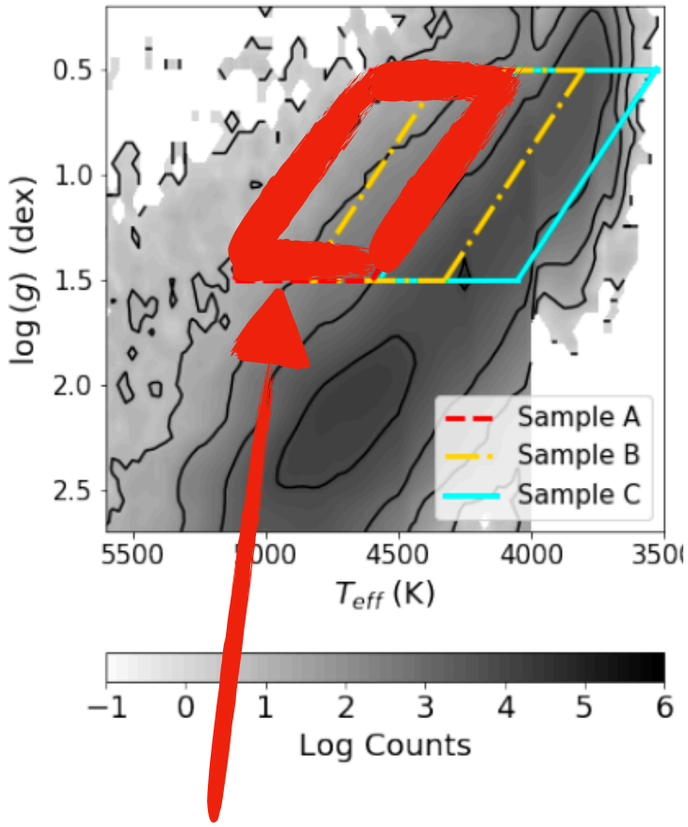
EP et al. (2022)

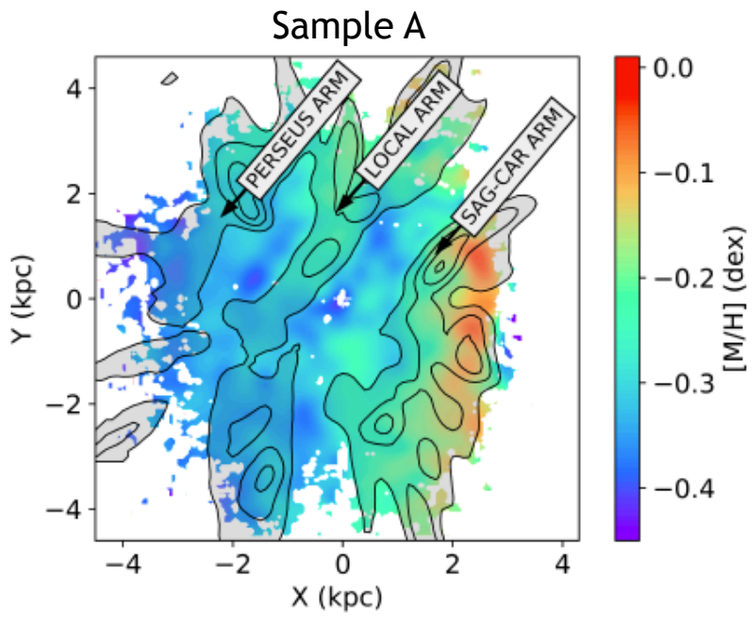
Gaia DR3 GSP-spec data:
- Giants
- Older than >1 Gyr

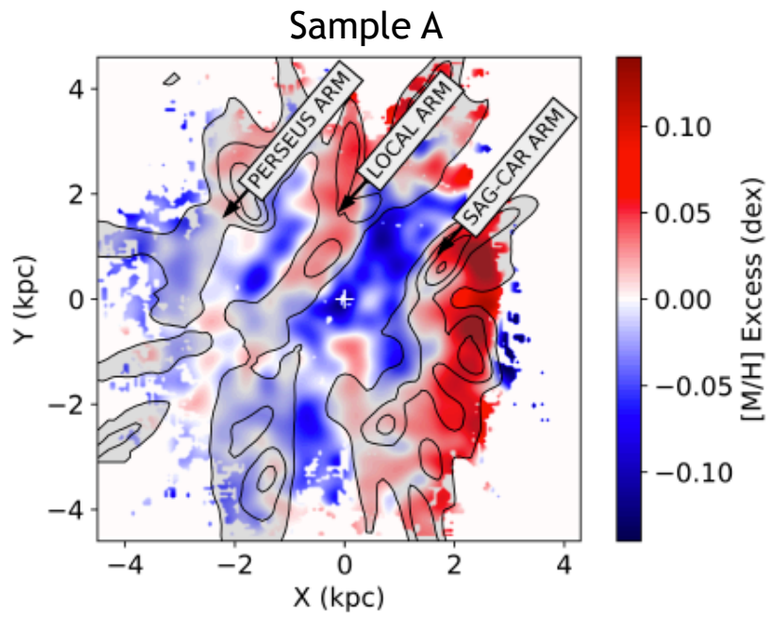
Azimuthal variation
of the radial metallicity gradient

Azimuthal dependency of the radial metallicity gradient

CHEMO-KINEMATIC SUBSTRUCTURES

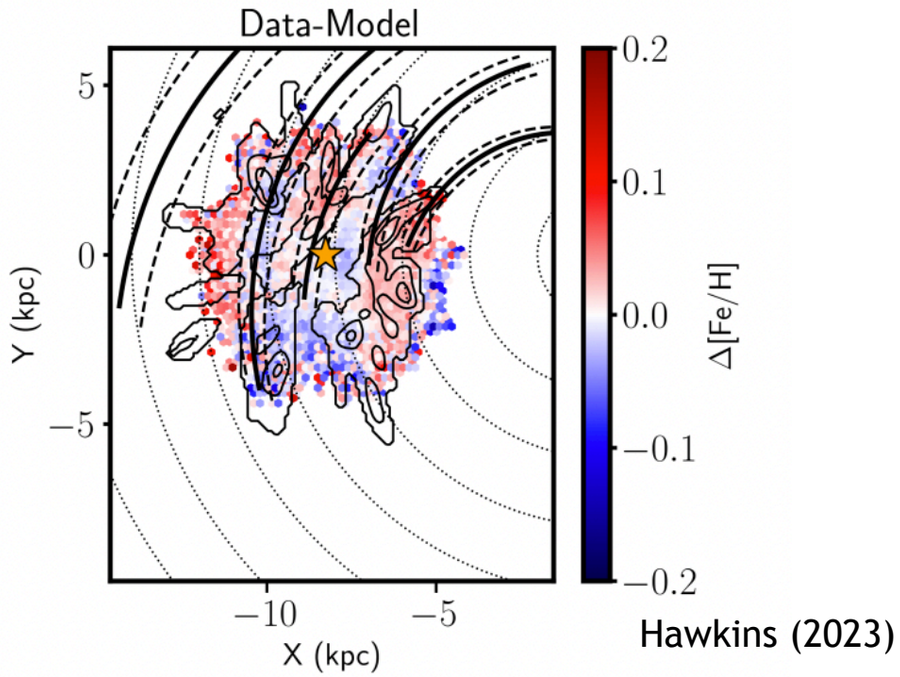






EP et al. (2022)

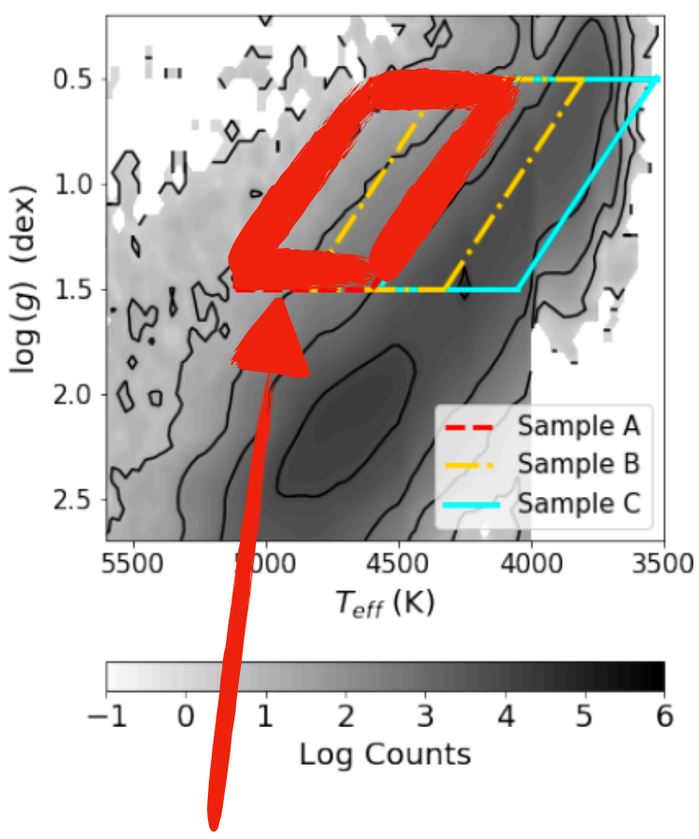
Gaia DR3 GSP-spec data:
- Giants
- ~20-200 Myr



Hawkins (2023)

Azimuthal dependency of the radial metallicity gradient

CHEMO-KINEMATIC SUBSTRUCTURES



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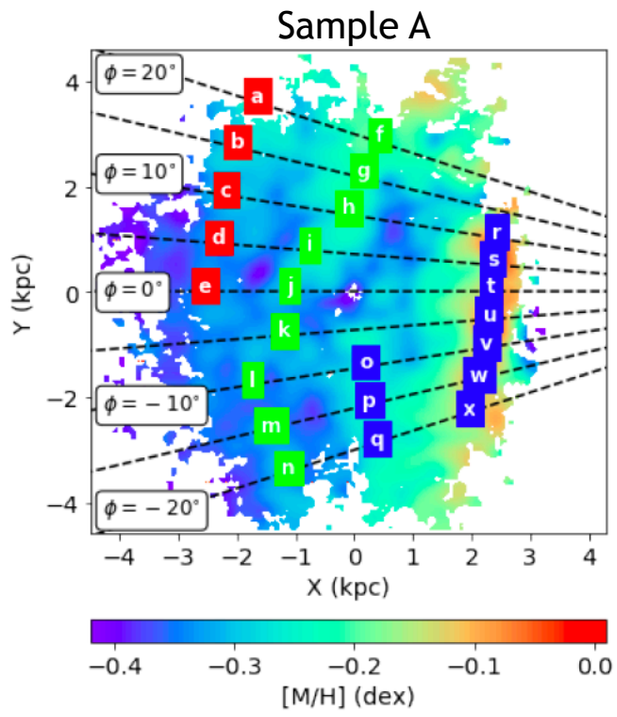
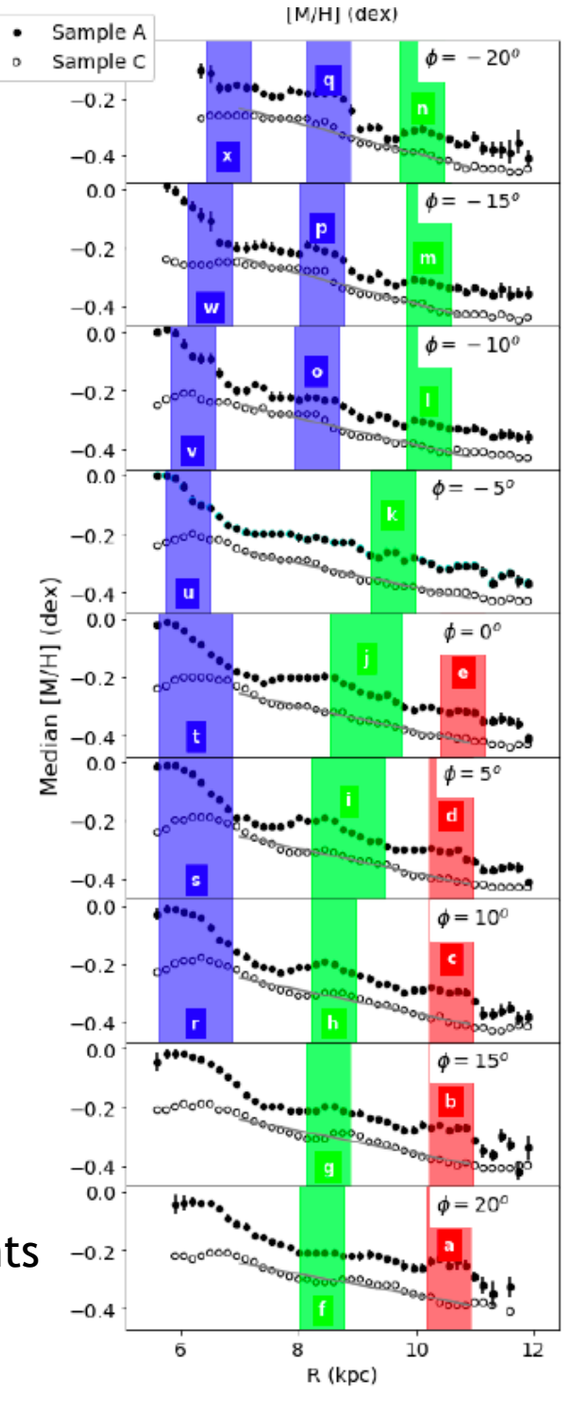




statistically significant bumps
with amplitudes up to 0.05-0.1 dex
on top of the observed radial metallicity gradients

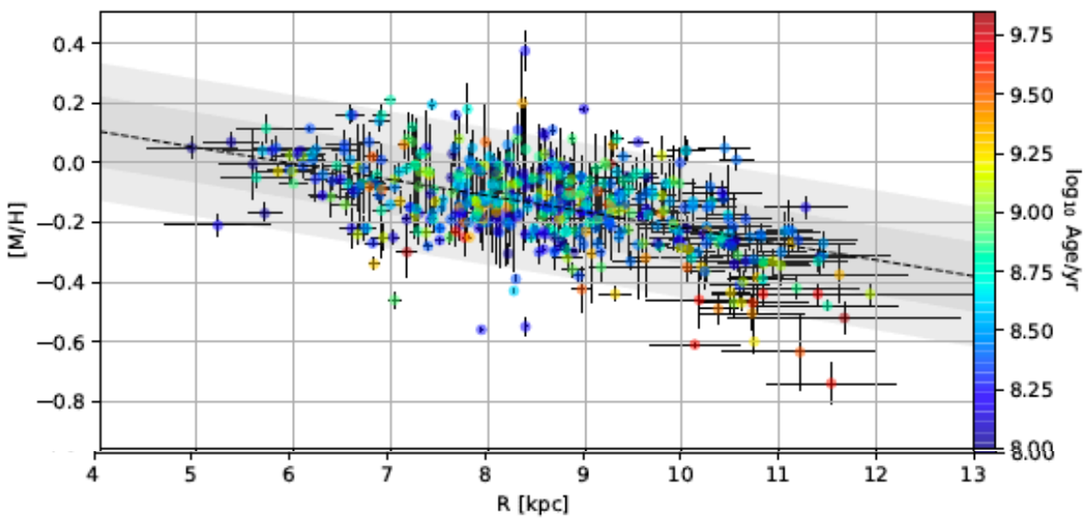
Open clusters: metallicity substructures?

CHEMO-KINEMATIC SUBSTRUCTURES

OCs:

[M/H] versus R

Parameter	Mean	σ	95% C.I.
α [dex kpc^{-1}]	−0.054	0.008	−0.062–−0.046
β [dex]	0.32	0.07	0.25–0.39
ϵ [dex]	0.116	0.008	0.108–0.124



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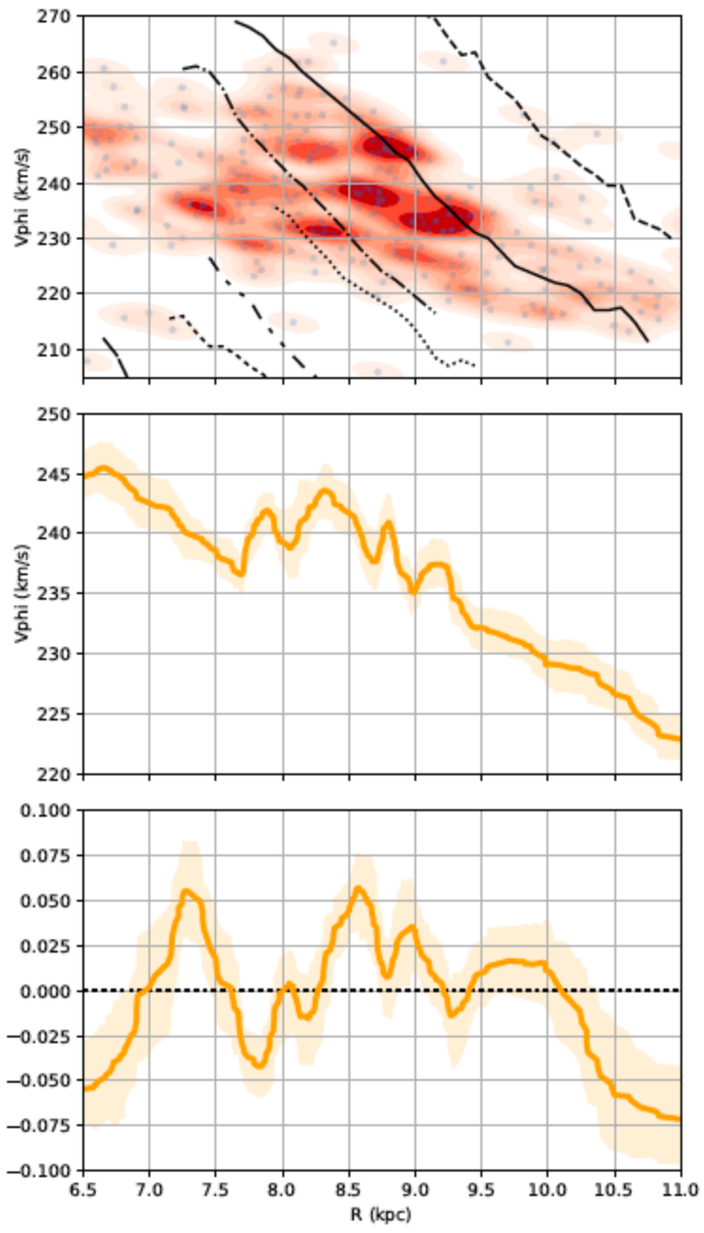
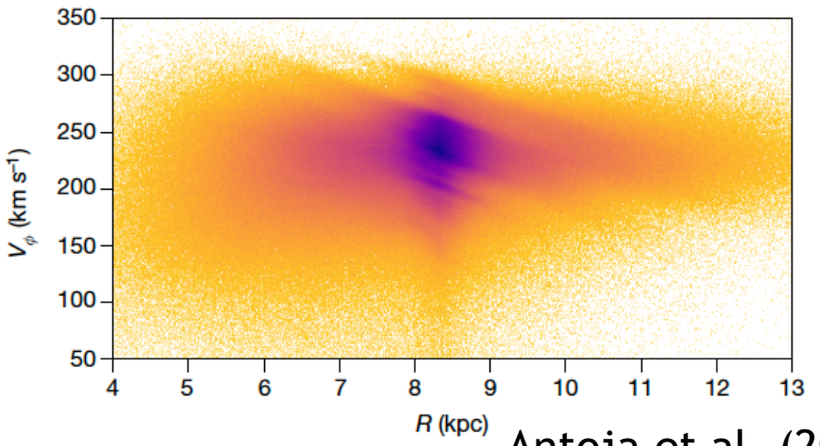


Gaia Collaboration, Recio-Blanco et al. (2023)

Ridges in Vphi vs R: field stars vs. OCs

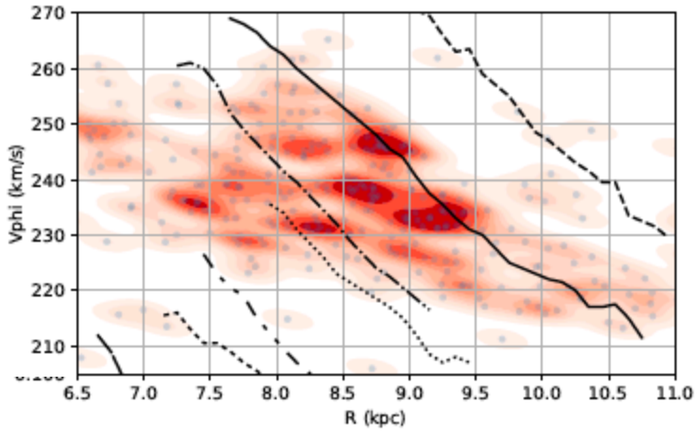
CHEMO-KINEMATIC SUBSTRUCTURES

FIELD STARS:

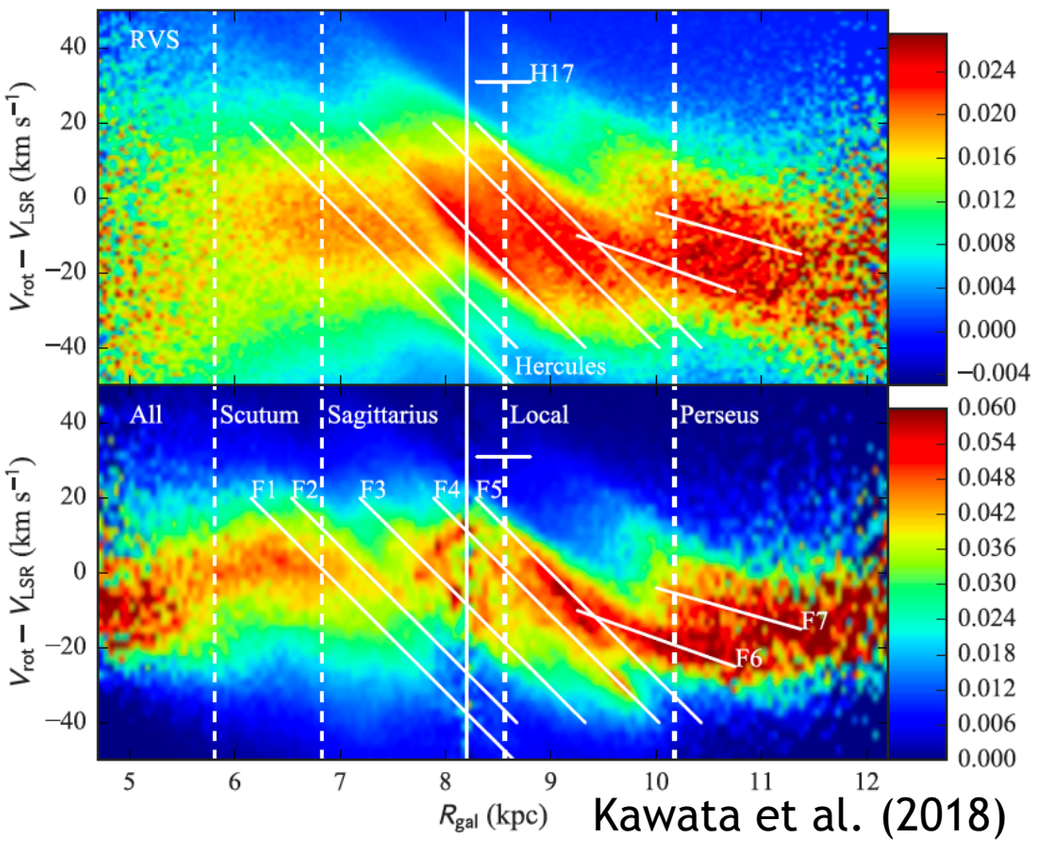


Antoja et al. (2018)

OCs:

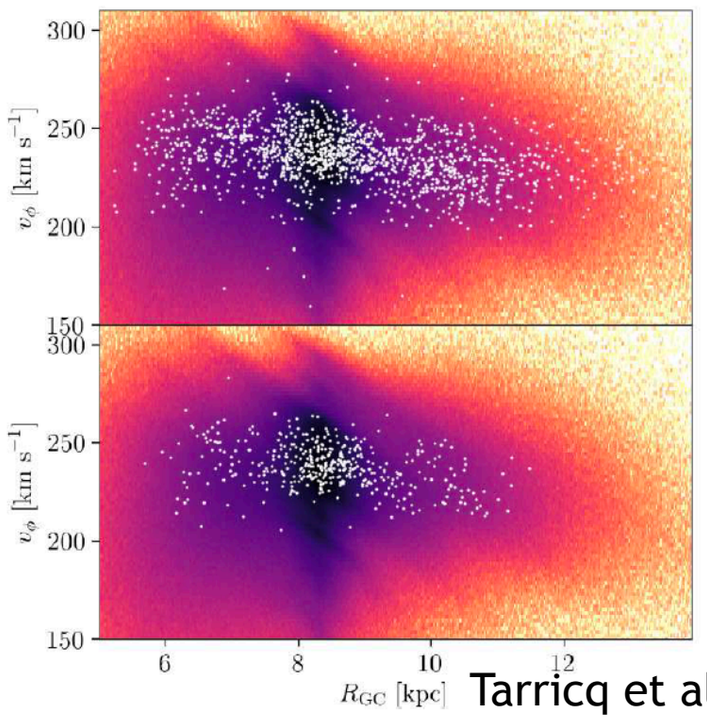


Gaia Collaboration, Recio-Blanco et al. (2023)



Kawata et al. (2018)

FIELD STARS + OCs:

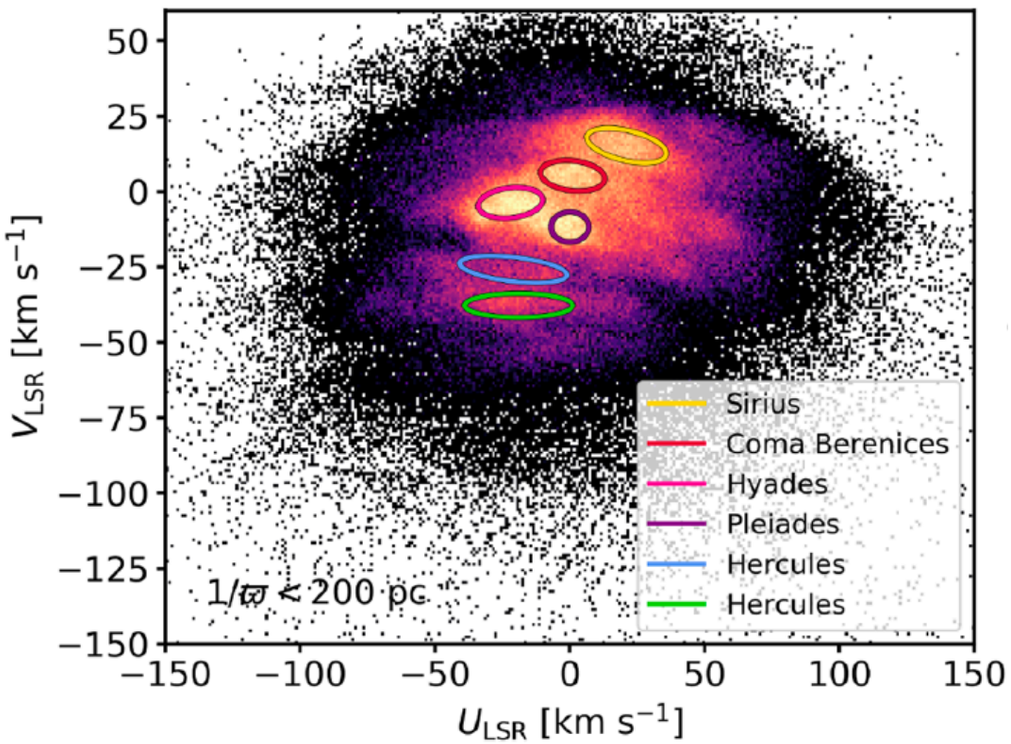


Tarricq et al. (2021)

Moving groups: field stars vs. open clusters

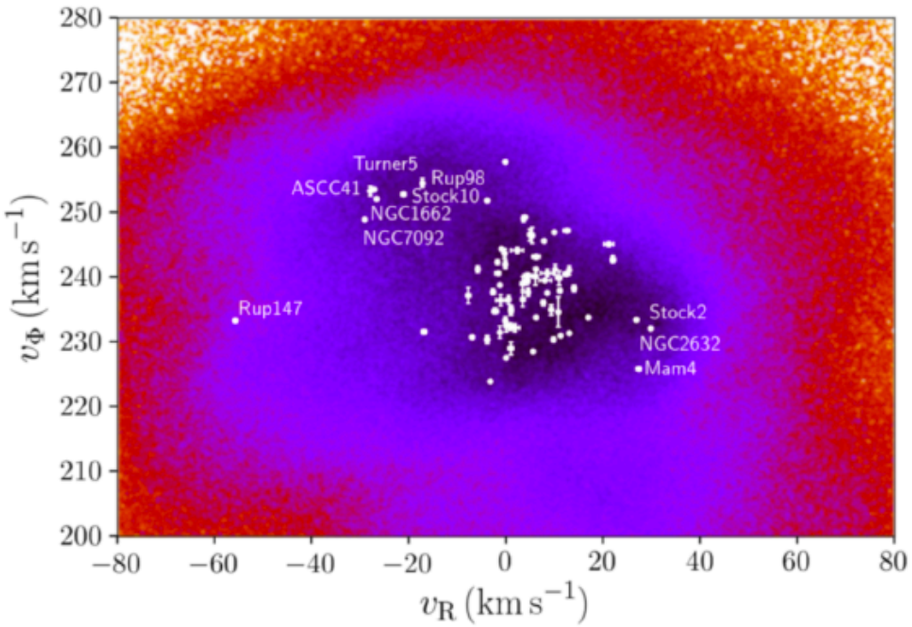
CHEMO-KINEMATIC SUBSTRUCTURES

FIELD STARS:

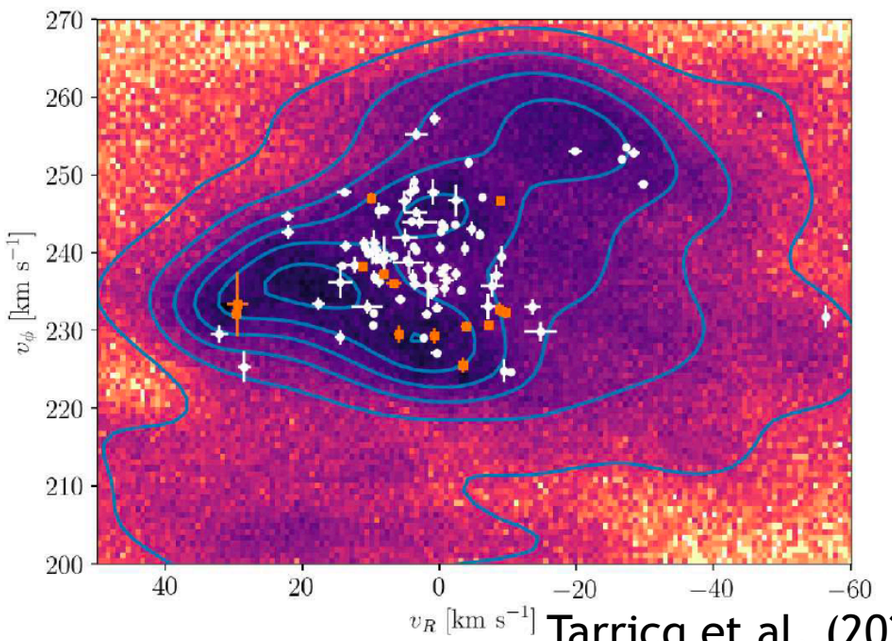


Trick et al. (2018)

FIELD STARS + OCs:



Soubiran et al. (2018)



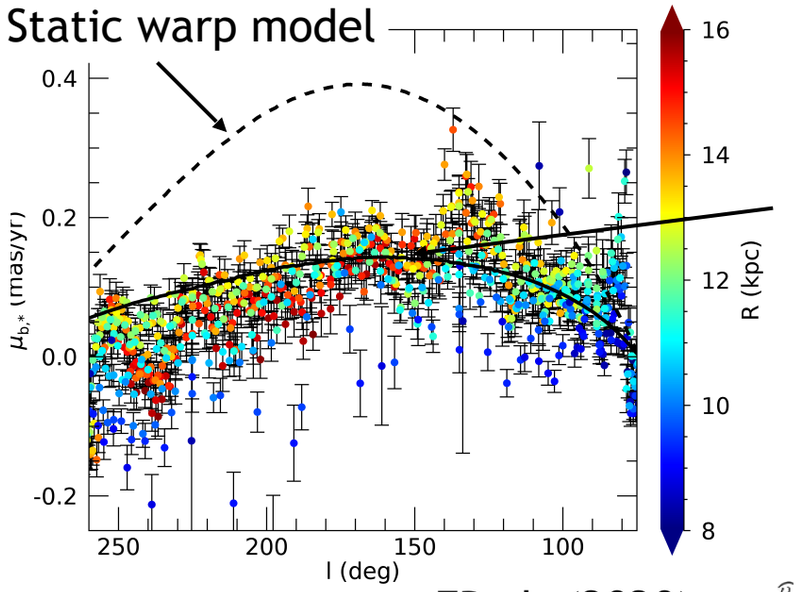
Tarricq et al. (2021)

Warp precession

CHEMO-KINEMATIC SUBSTRUCTURES

Giants:

Static warp model

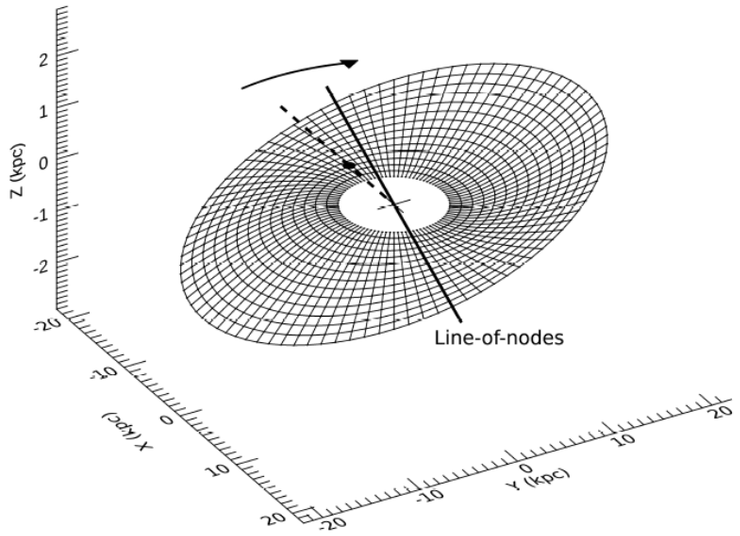


EP al. (2020)

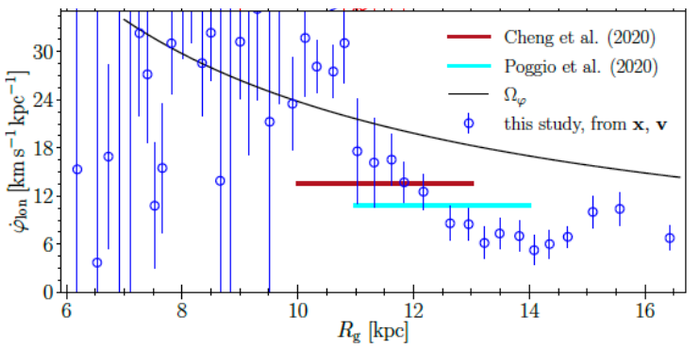
Warp precession rate:

10.86 ± 0.03 (statistical) ± 3.20 (systematic) km s^{-1} kpc^{-1}

Precessing warp model

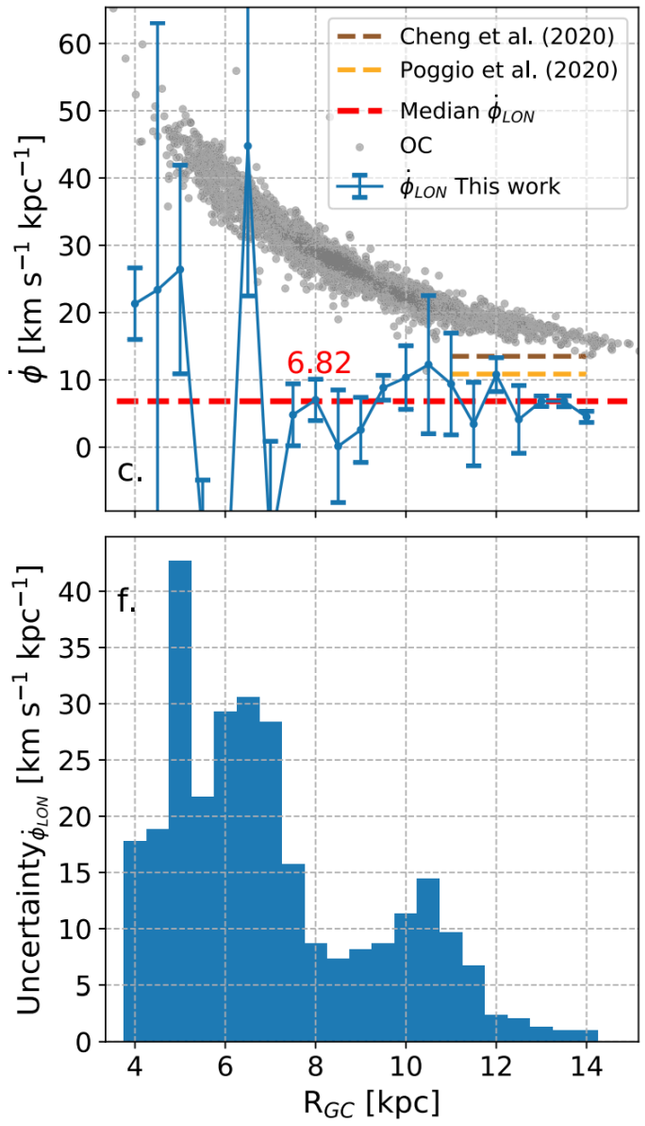


Cepheids:



Dehnen al. (2023)

OCs:



He (2023)

Summary

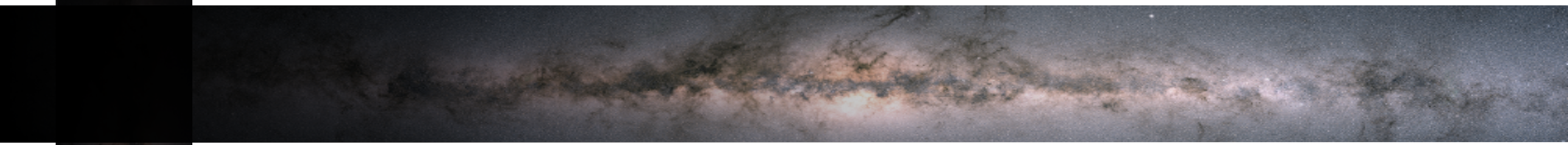
CONCLUSION

SPATIAL DISTRIBUTION:

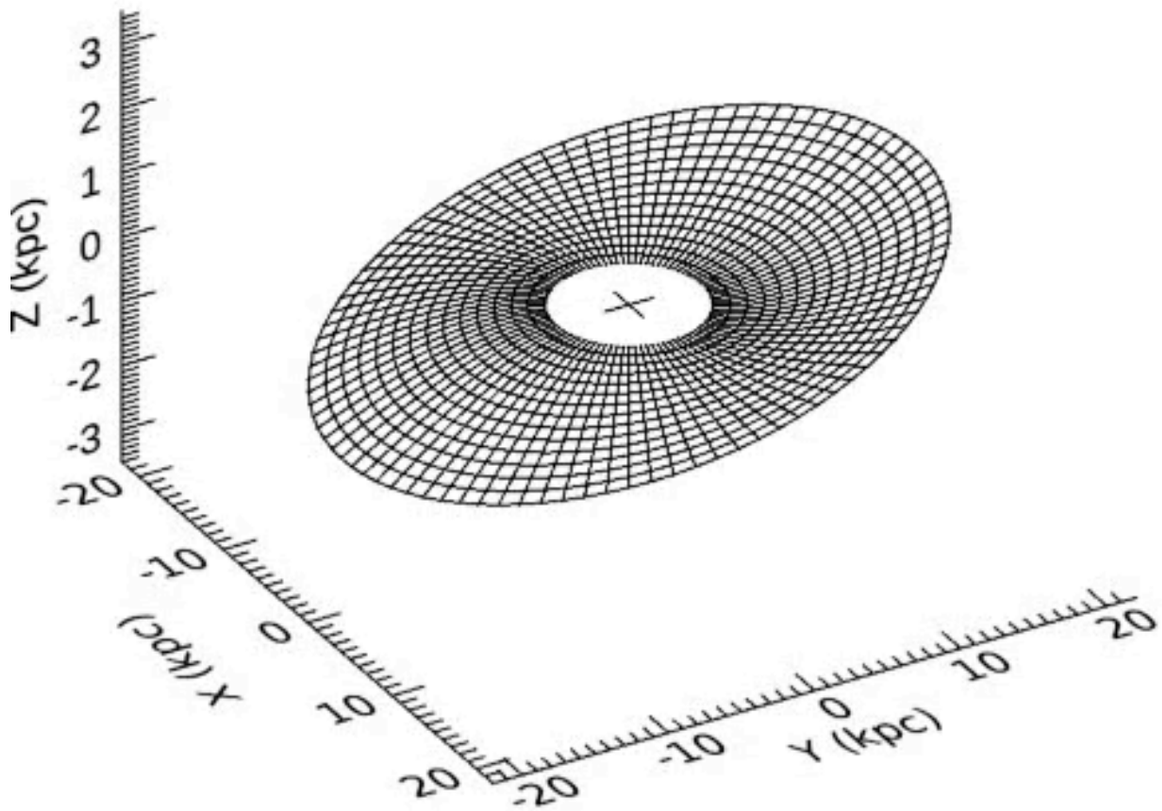
- Old field populations: smooth distribution (exponential disk + selection function)
- Young field populations: segments of the nearest spiral arms out to ~5 kpc (UMS stars)
- Young open clusters (<100-200 Myr): good agreement with young stars

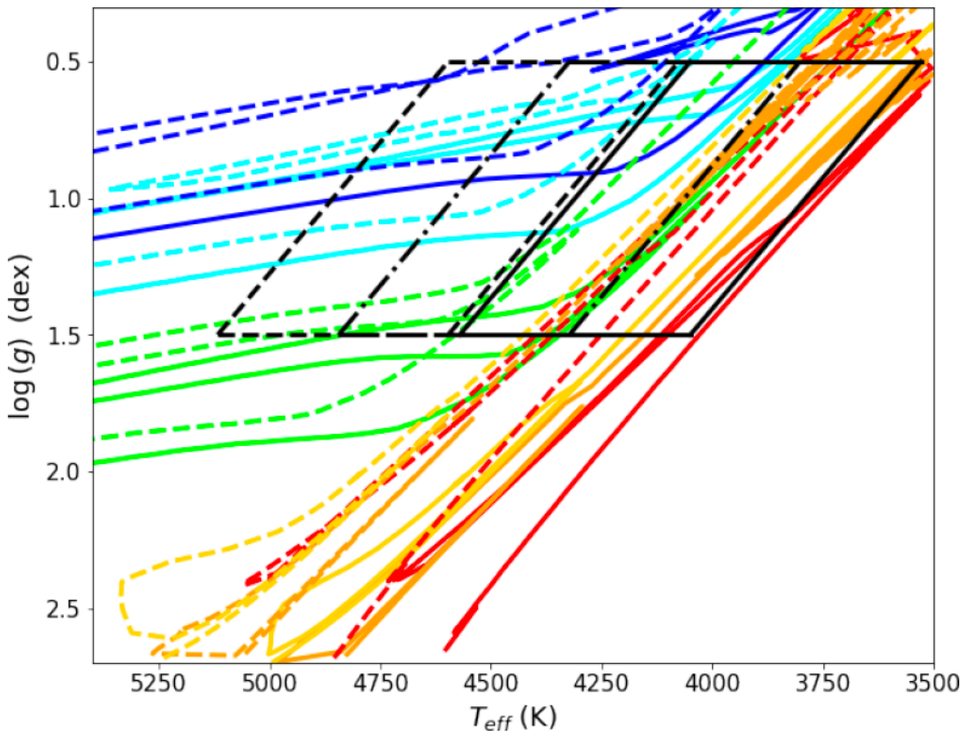
CHEMO-KINEMATICAL SUBSTRUCTURES:

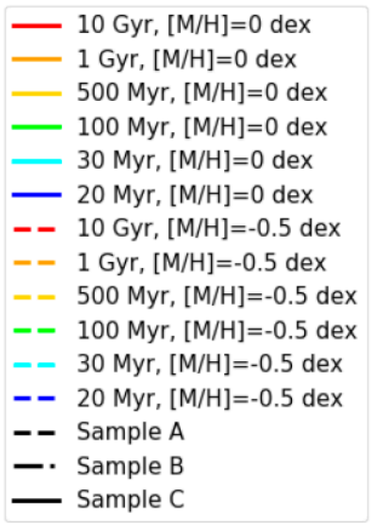
- Old field stars: azimuthal dependence of the slope
- Young field stars: signature of the spiral arms apparent as metallicity fluctuations
- Open clusters: metallicity fluctuations, possibly related to Vphi structures
- Open clusters: kinematic substructures detected - but not clear whether they follow the same kinematic substructures of field stars

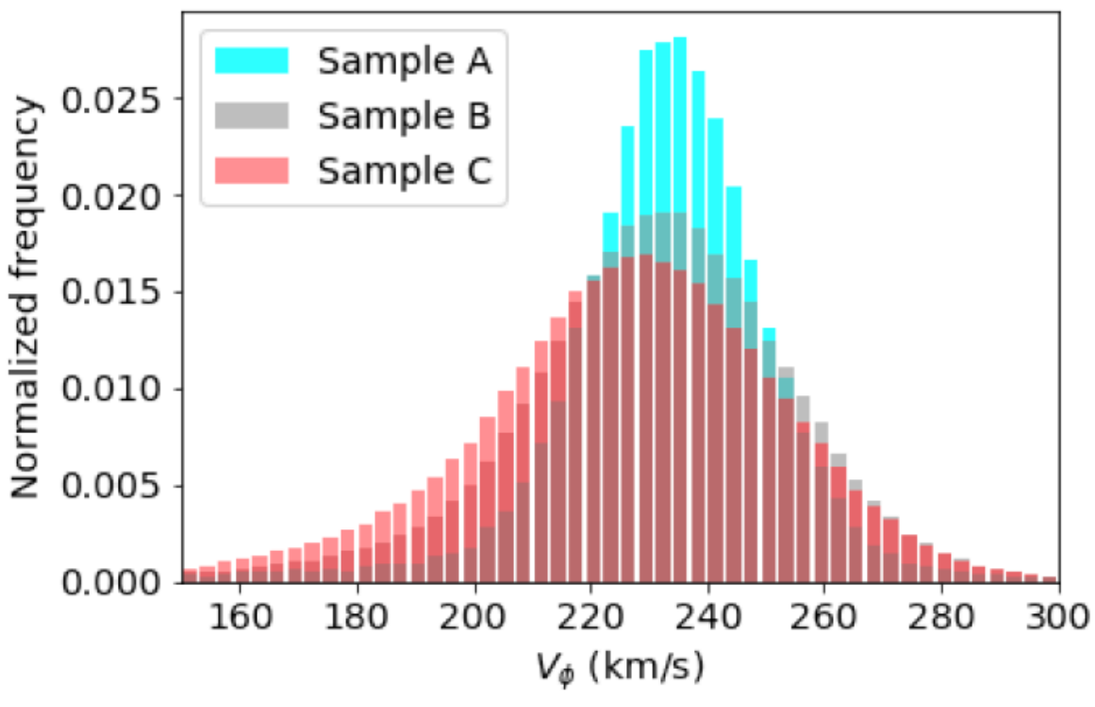


Precessing warp model:



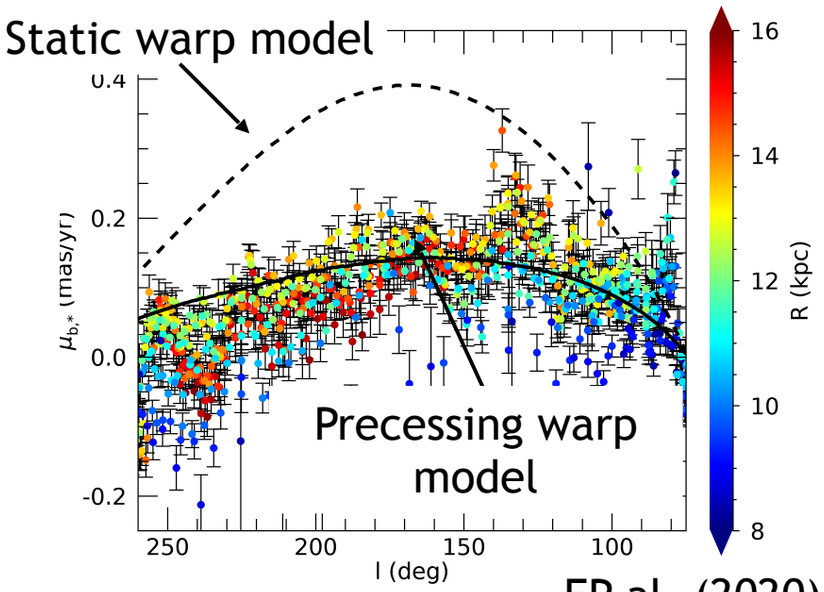

0.5
1.0
1.5
2.0
2.5
log (g) (dex)
5250
5000
4750
4500
4250
4000
3750
3500
T_{eff} (K)


10 Gyr, [M/H]=0 dex
1 Gyr, [M/H]=0 dex
500 Myr, [M/H]=0 dex
100 Myr, [M/H]=0 dex
30 Myr, [M/H]=0 dex
20 Myr, [M/H]=0 dex
10 Gyr, [M/H]=-0.5 dex
1 Gyr, [M/H]=-0.5 dex
500 Myr, [M/H]=-0.5 dex
100 Myr, [M/H]=-0.5 dex
30 Myr, [M/H]=-0.5 dex
20 Myr, [M/H]=-0.5 dex
Sample A
Sample B
Sample C


Sample A
Sample B
Sample C
Normalized frequency
0.025
0.020
0.015
0.010
0.005
0.000
160
180
200
220
240
260
280
300
V_ϕ (km/s)

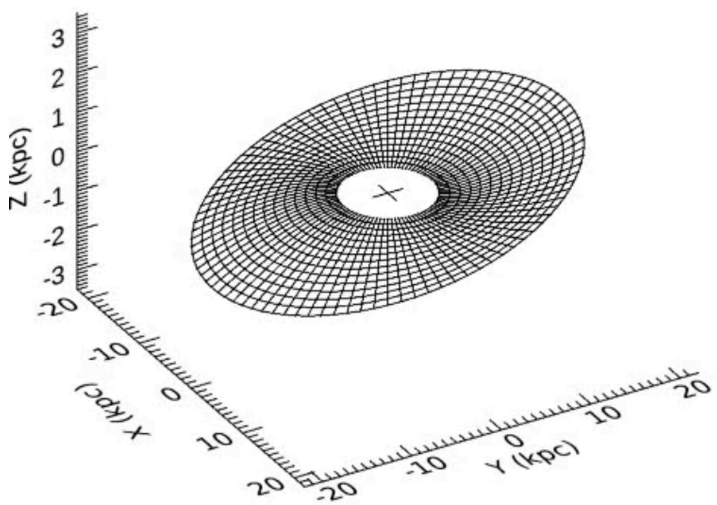
Warp precession

Field stars:

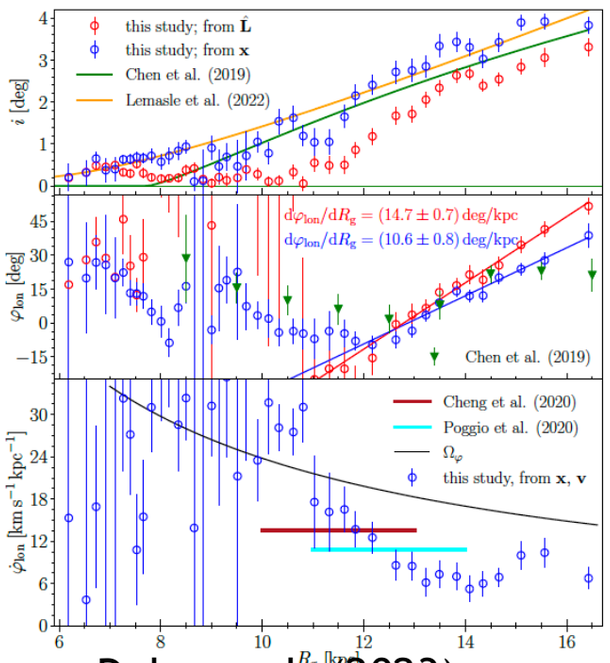


EP al. (2020)

Precessing warp model:

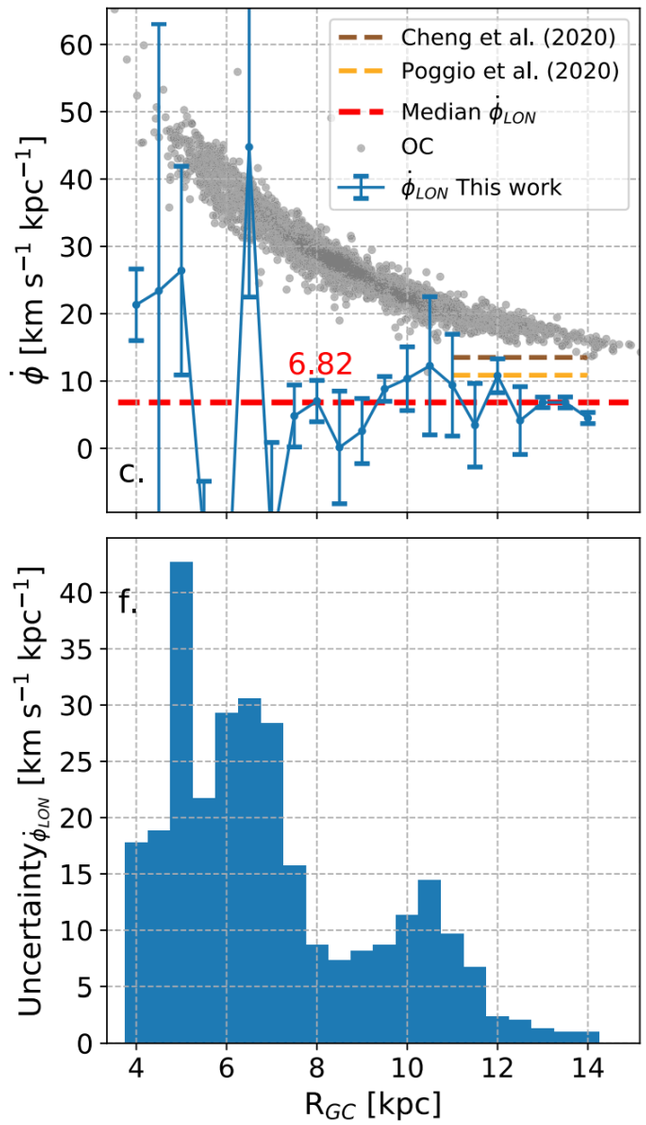


Cepheids:



Dehnen al. (2023)

OCs:



He (2023)