The chemistry of the Milky Way disc with the Gaia space mission

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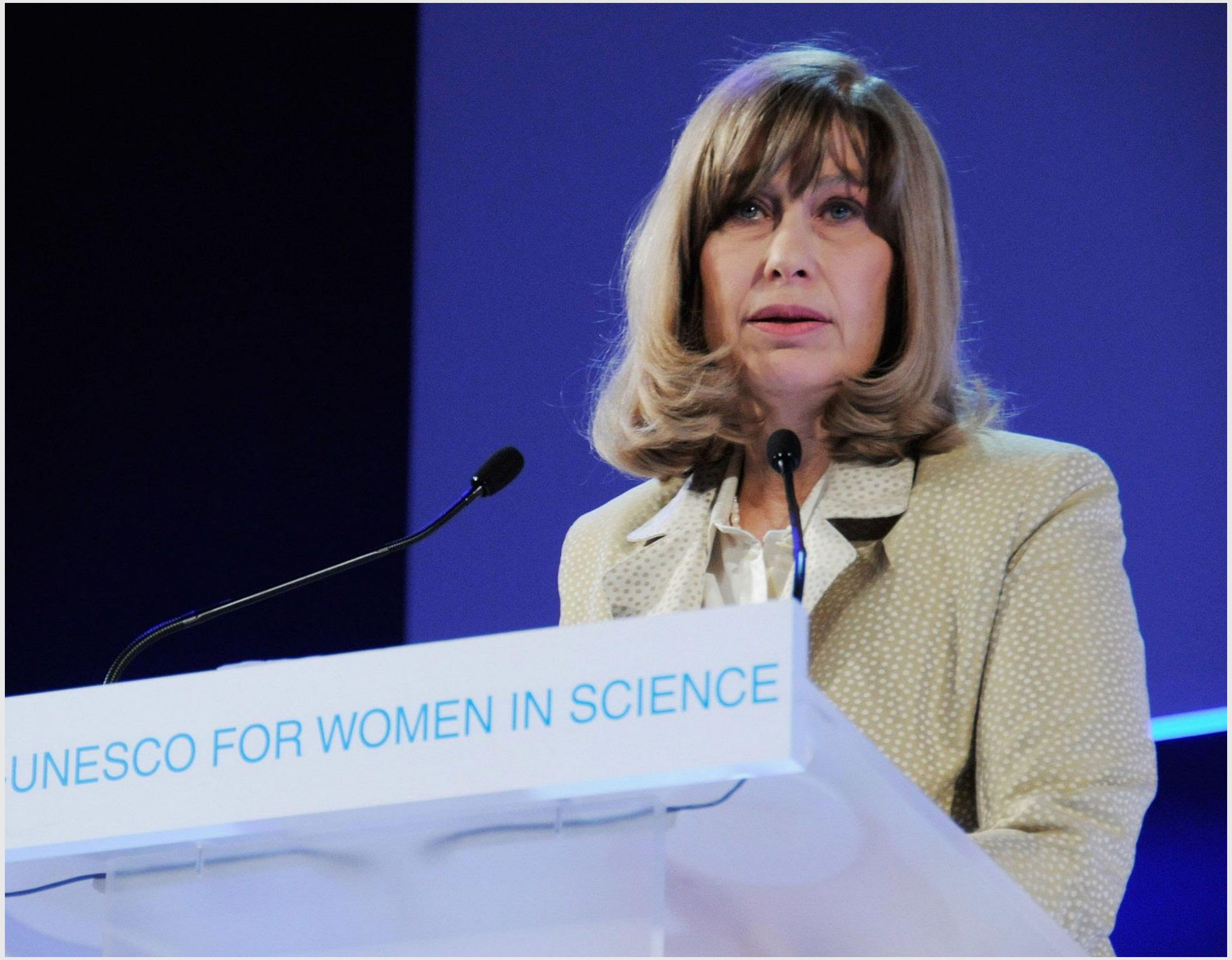
Horizon 2020 research No 101004214

Thanks Beatriz for having enlighted us the way of stellar populations and for being so inspiring!



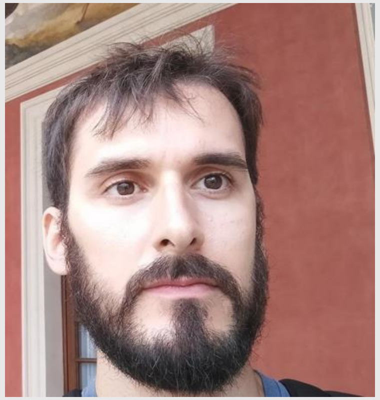
In collaboration with:

Gaia DPAC

Marie Barbillon

Camila Navarrete

Patrick de Laverny



Pedro A. Palicio

Eloisa Poggio

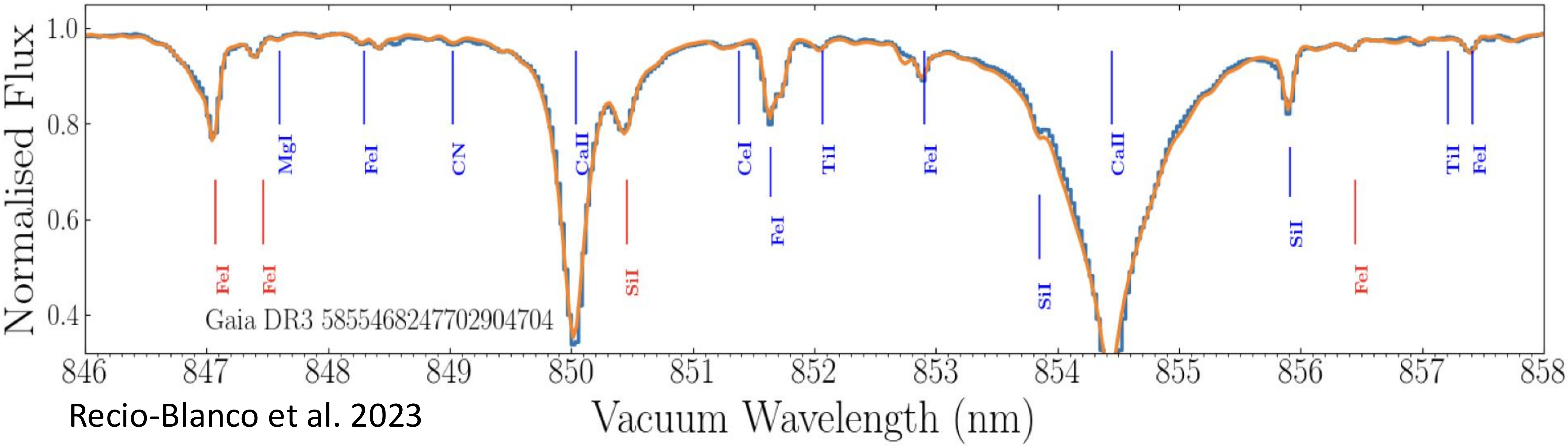
Emanuele Spitoni

Gaia GSPspec: spectral fidelity from space

Gaia/RVS is **SPACE spectroscopy** ≠ ground based spectroscopy

Continuous observations for years, no atmosphere, very good control of systematics.

Gaia RVS spectral fidelity

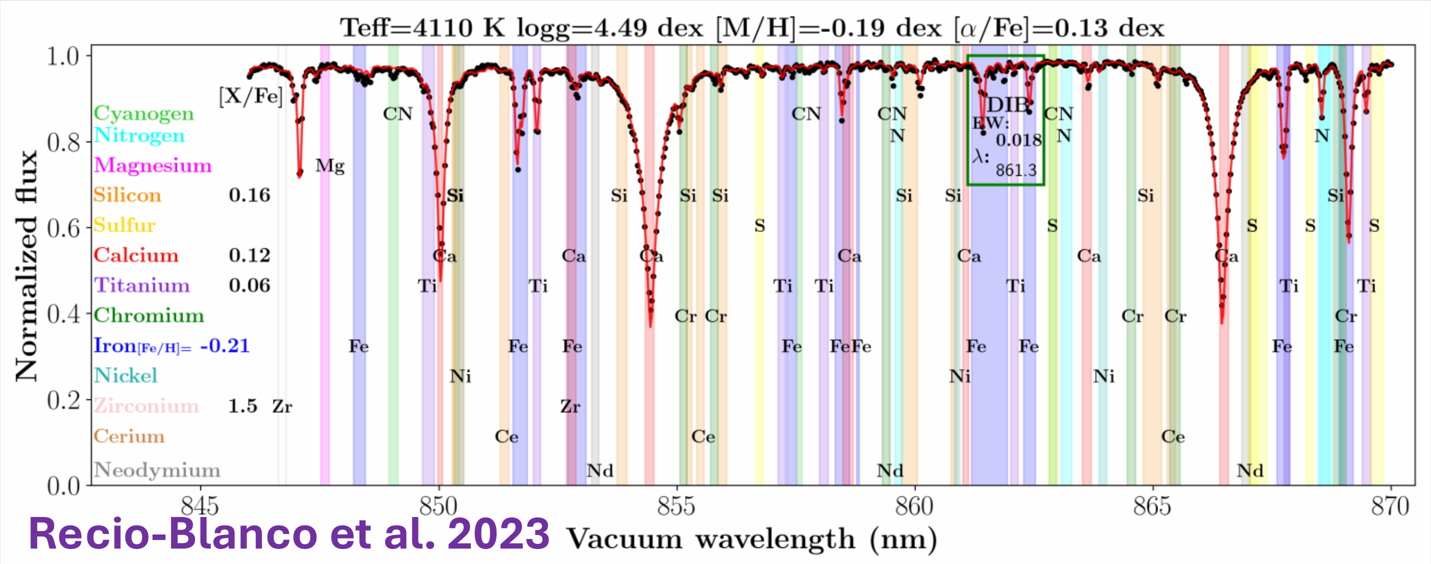


Recio-Blanco et al. 2023

Parametrization quality comparable to ground-based surveys of higher spectral resolution and wavelength coverage.

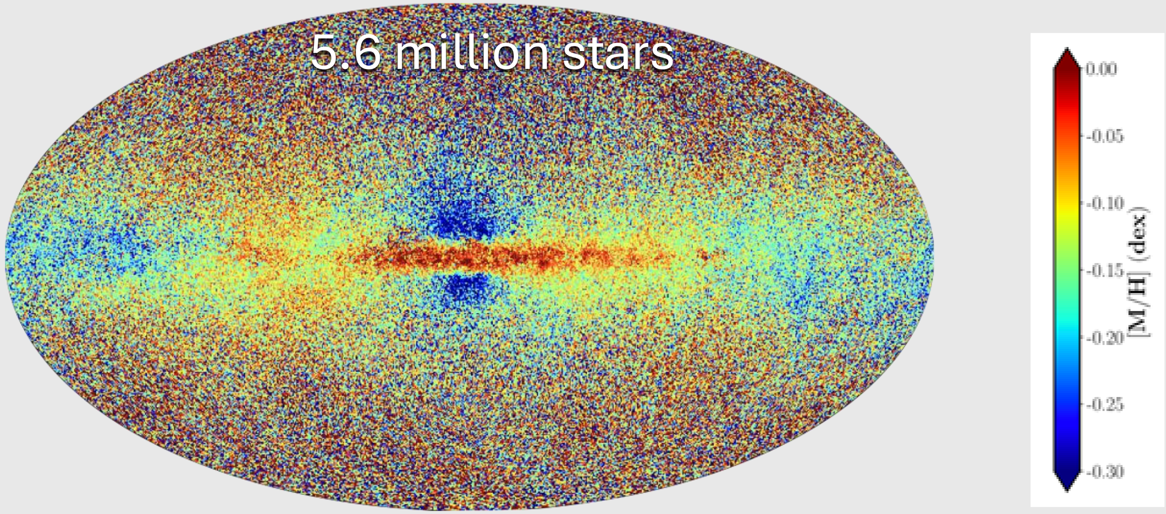
Gaia GSPspec: spectral fidelity from space

Gaia RVS R=11500 spectroscopy from space: precise chemo-physical parametrization

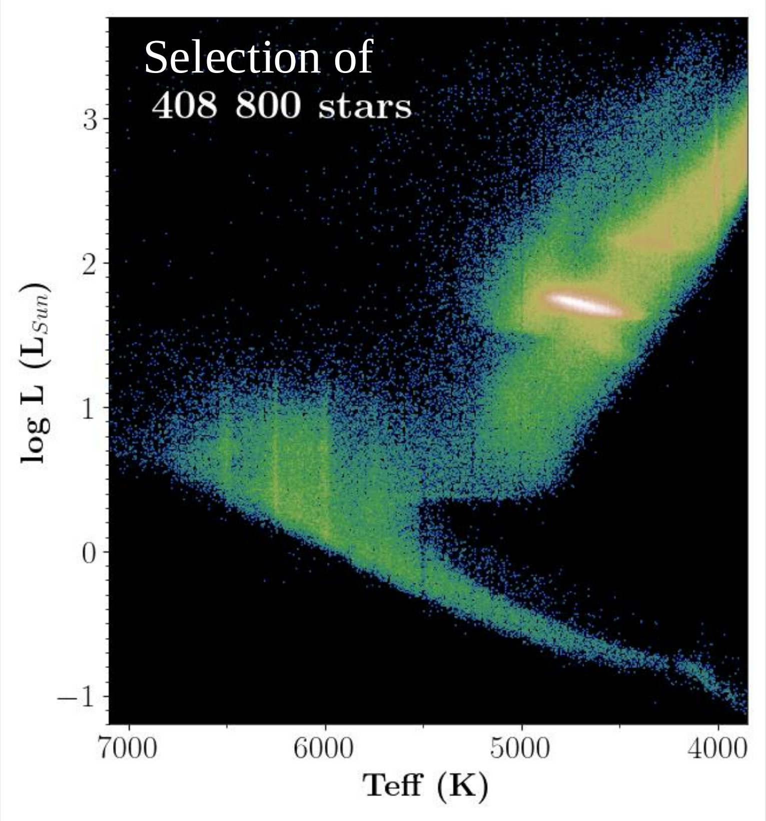


Recio-Blanco et al. 2023

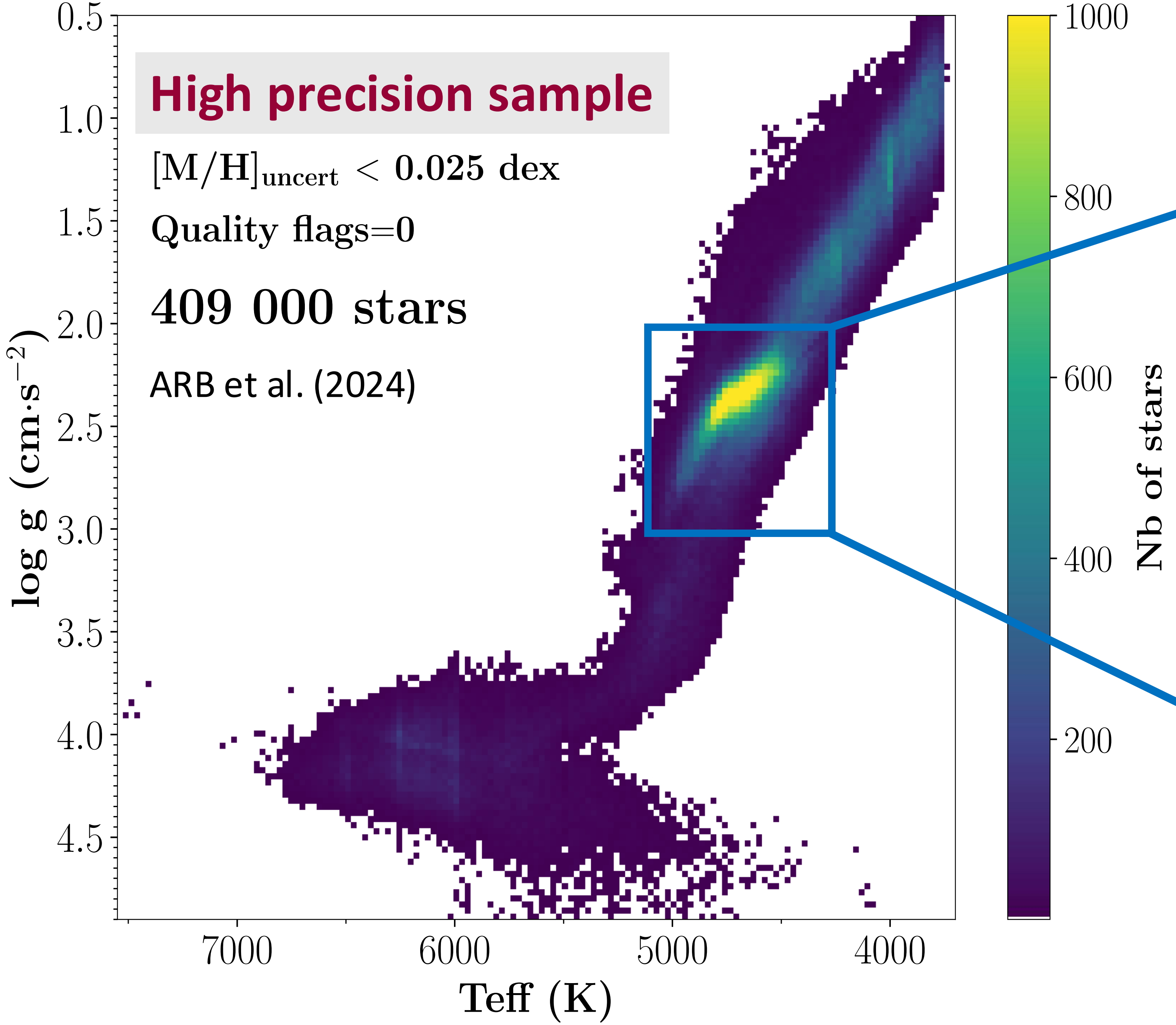
GSPspec module from DPAC APSIS pipeline : Teff, log, [M/H], [alpha/Fe], individual element abundances



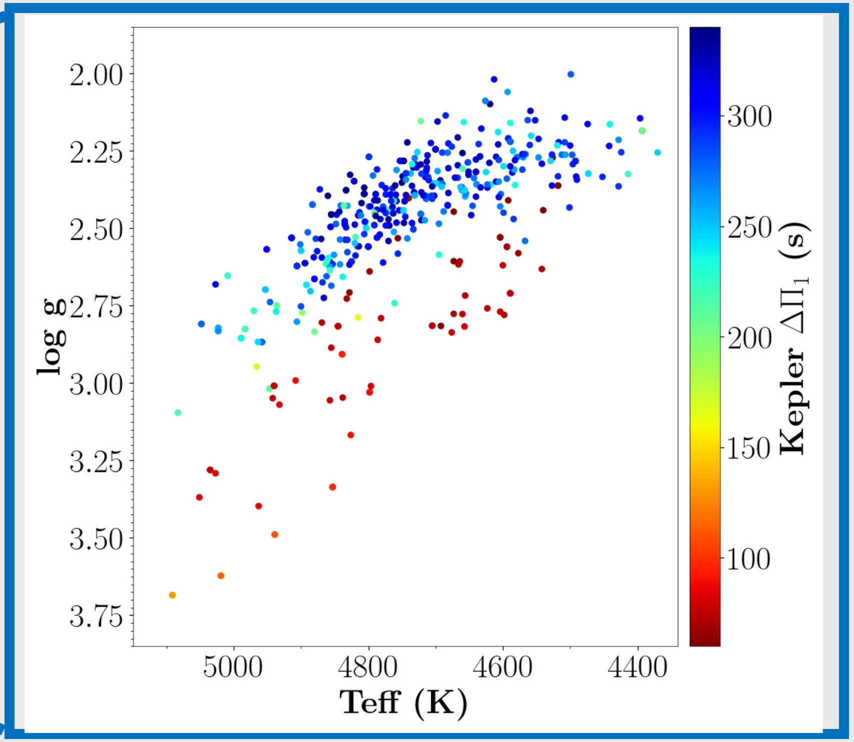
Gaia Collaboration, Recio-Blanco et al. 2023



Recio-Blanco et al. 2024



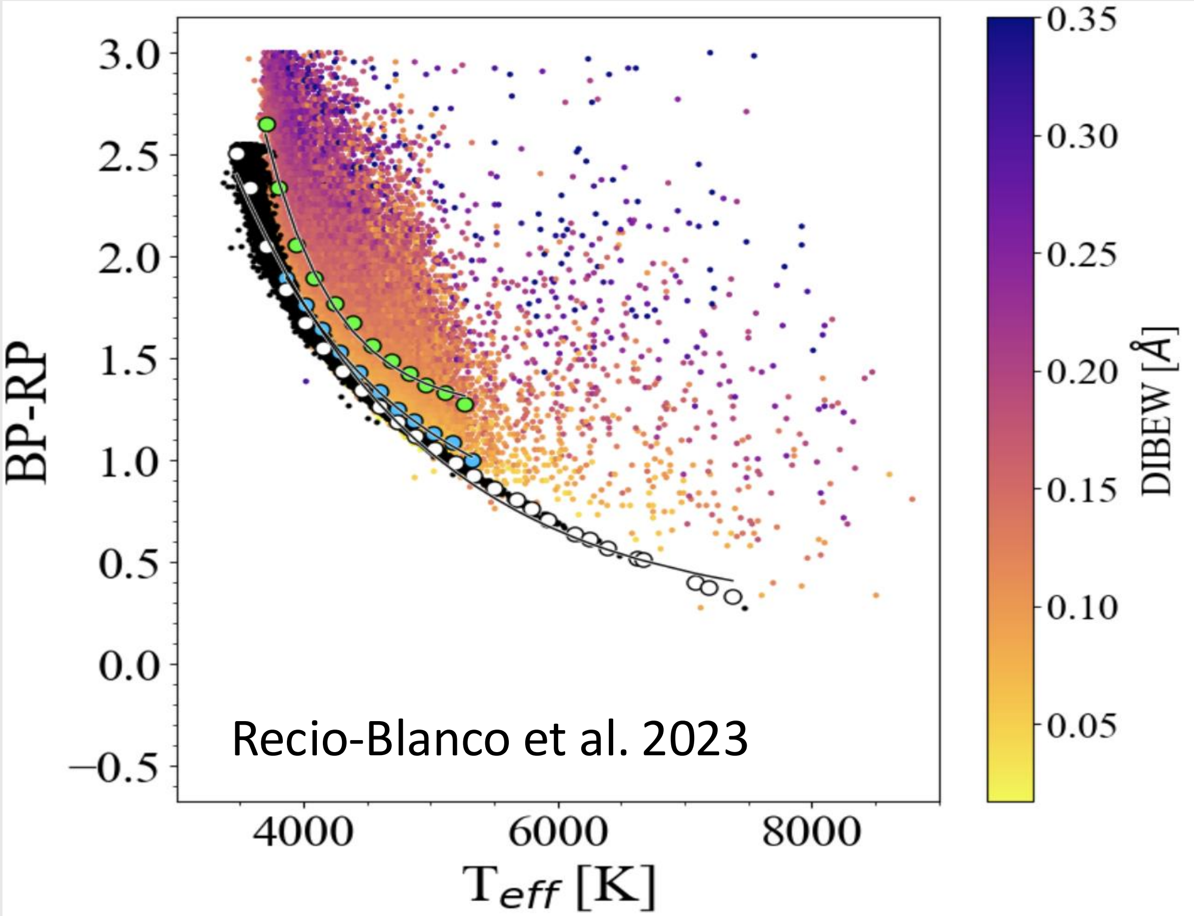
Cross-match
Gaia GSPspec - Kepler



Gaia GSPspec parameters perfectly compatible with Kepler Delta π parameter indicating evolutionary stage

Gaia GSPspec: spectral fidelity from space

GSPspec Teff is not affected by interstellar extinction



We first obtain E(Bp-Rp) from
Teff, logg and [M/H] from GSPspec + Teff-colour from Casagrande et al. (2021)
+ (Bp-Rp)_obs => E(Bp-Rp)

Then A_G = k * E(Bp − Rp)
with k depending on Teff, logg, [M/H] and [alpha/Fe] from the MARCS calibrations

Then absolute magnitude M_G

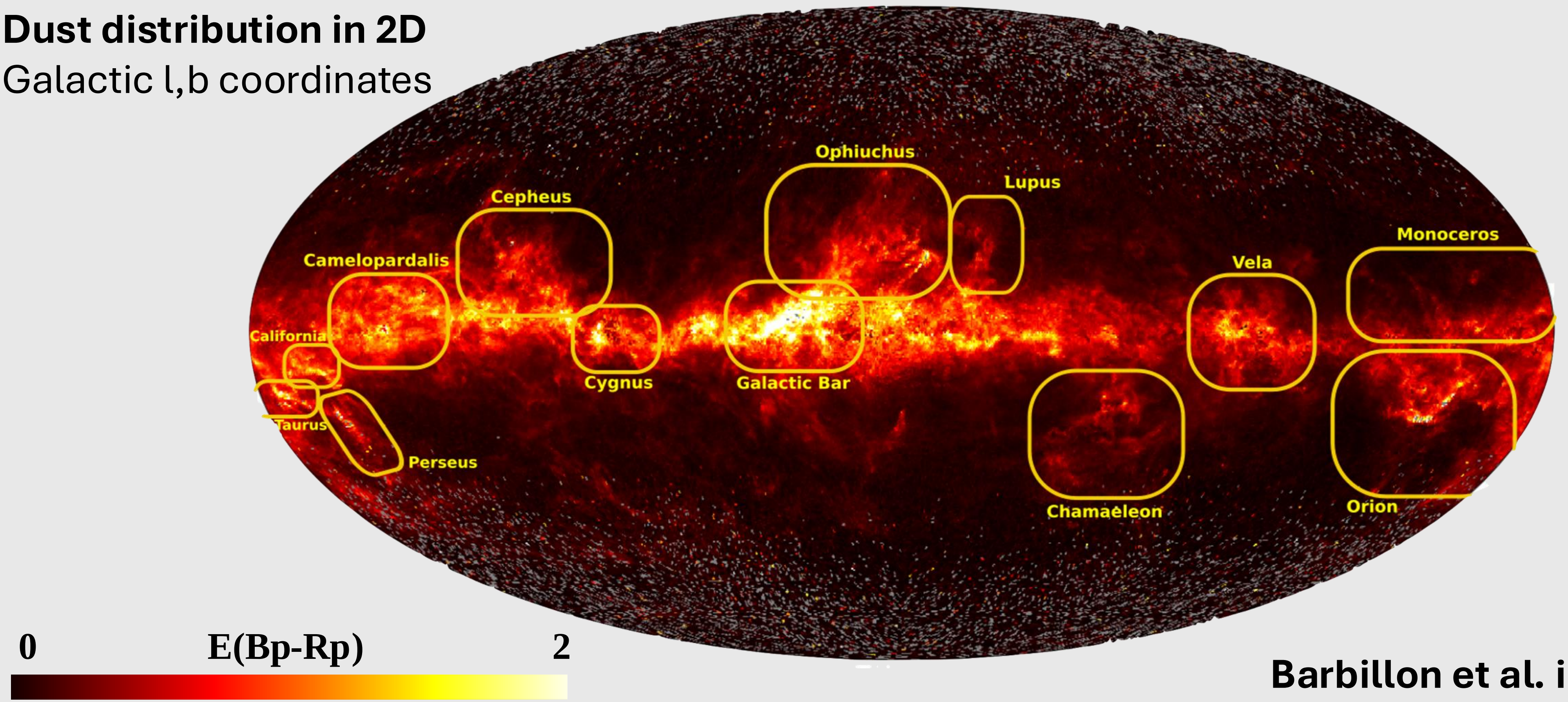
Then BC_G from Casagrande et al. (2018)

Then stellar luminosity and radius (using distance estimates)

Then stellar mass (using logg)

Gaia GSPspec: spectral fidelity from space

Dust distribution in 2D
Galactic l,b coordinates



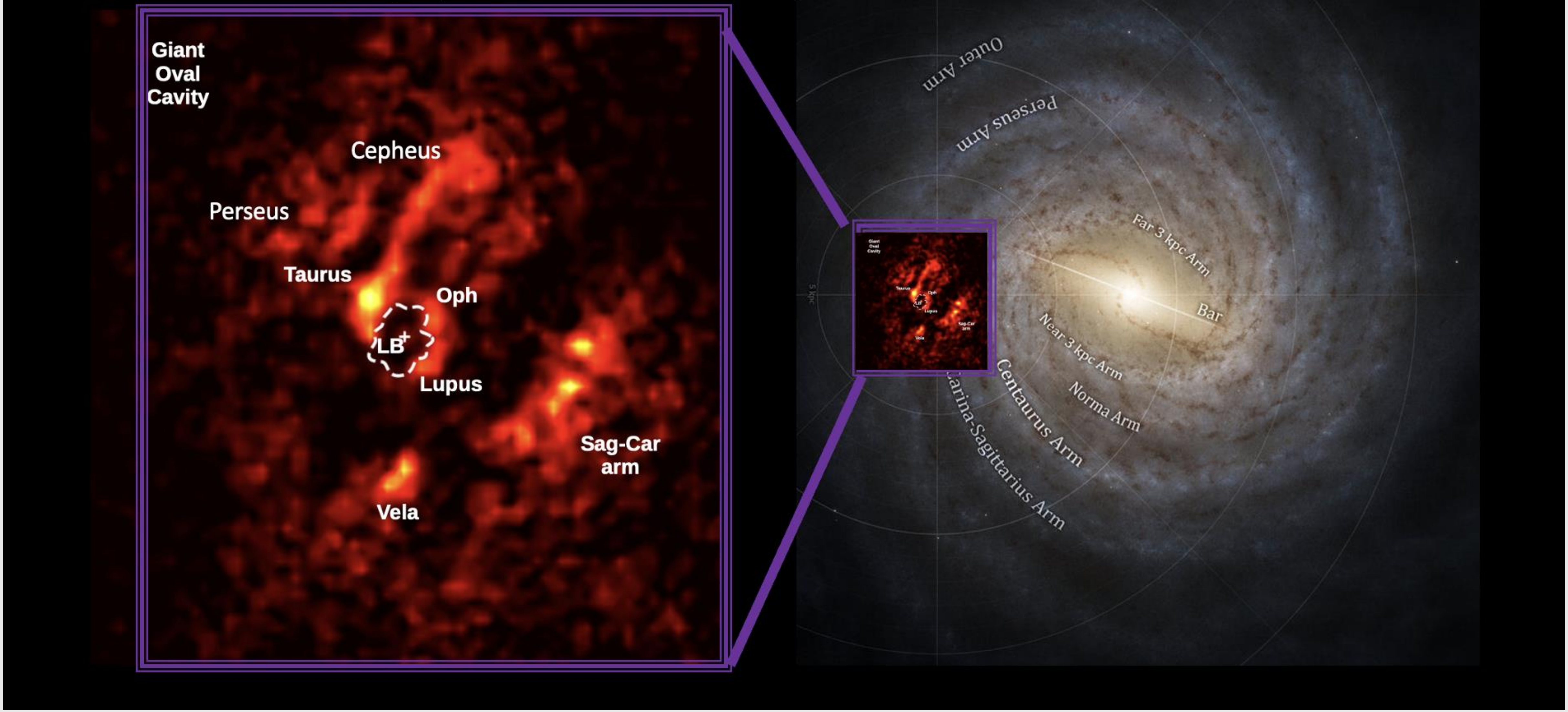
Barbillon et al. in prep.

GSPspec Teff independent of extinction.

E(Bp-Rp) from Teff, logg and [M/H] from GSPspec + Teff-colour from Casagrande et al. (2021) + $(Bp\text{-}Rp)_{obs}$
A_G = k * E(Bp − Rp) with k depending on Teff, logg, [M/H] and [alpha/Fe] from the MARCS calibrations

Gaia GSPspec: spectral fidelity from space

Dust distribution in 3D, projection in the Galactic plane

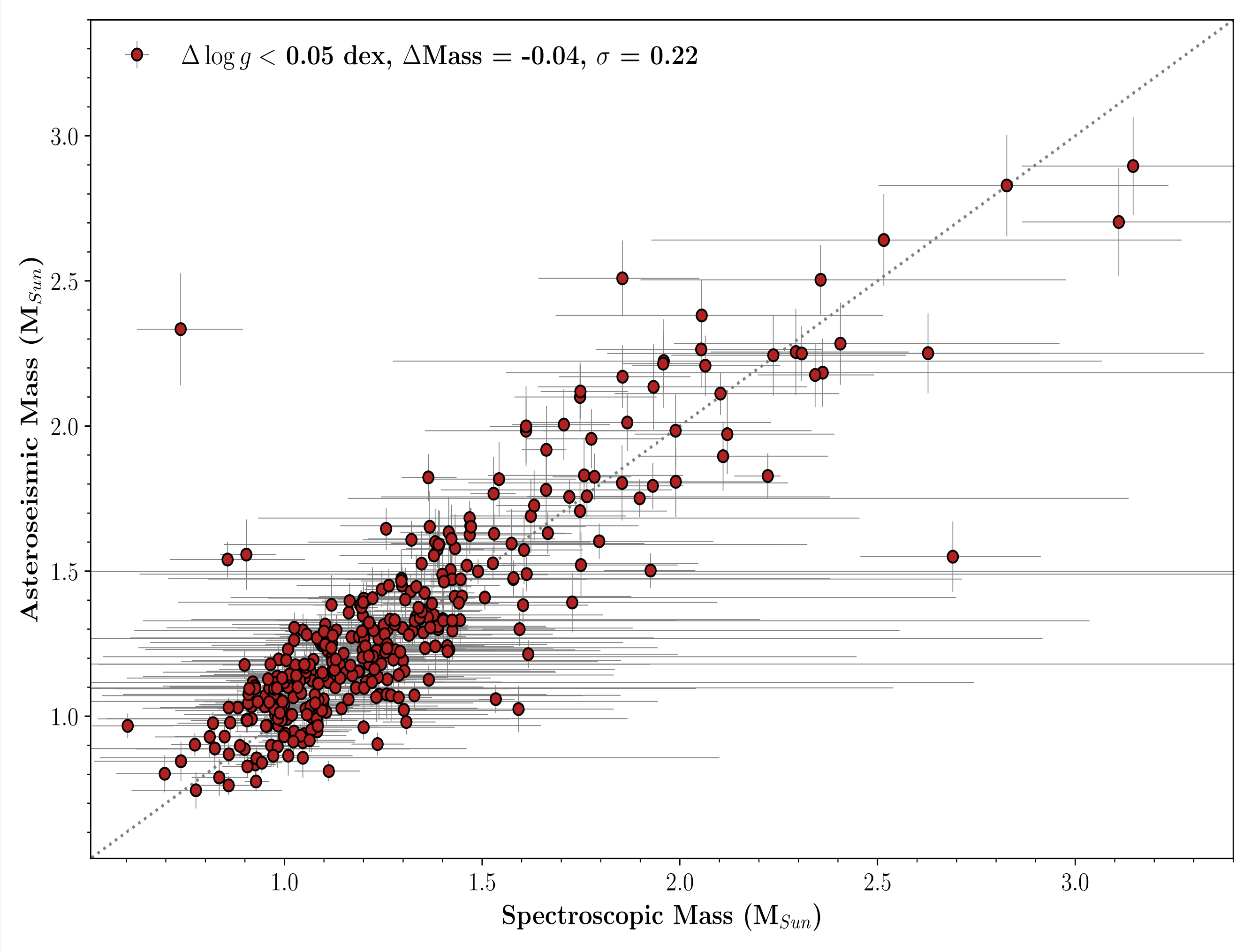


Barbillon et al. in prep.

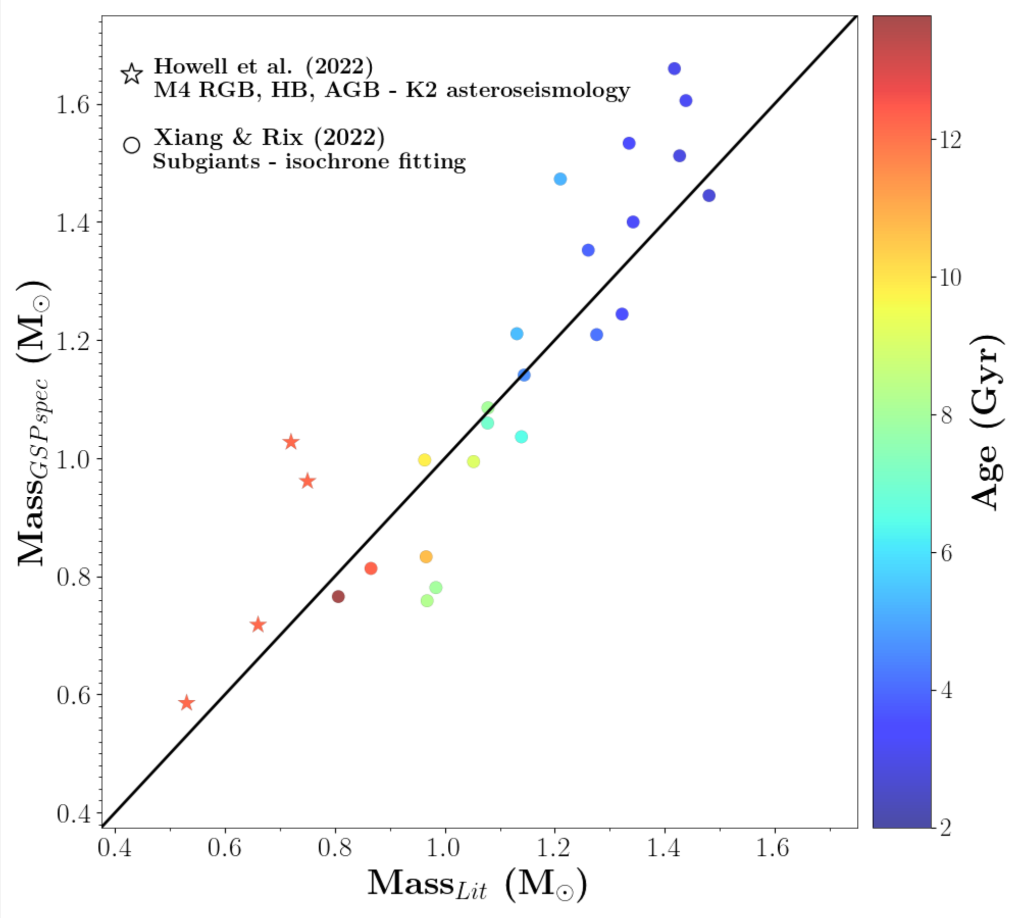
Gaia GSPspec: spectral fidelity from space

Gaia GSPspec -based stellar masses:

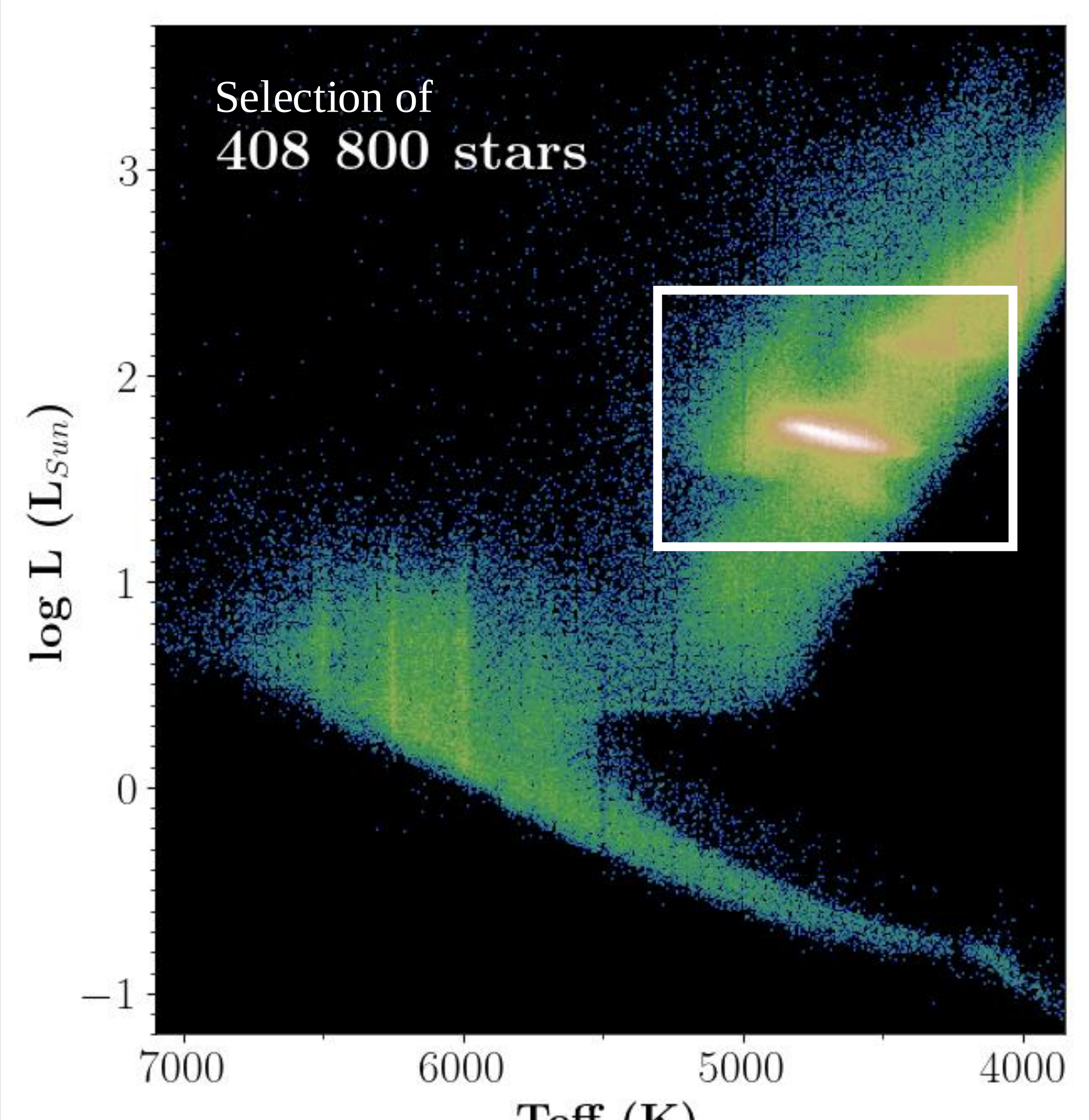
comparison with APOCASK



comparison with K2 AGB stars and Subgiant's isochrone fitting



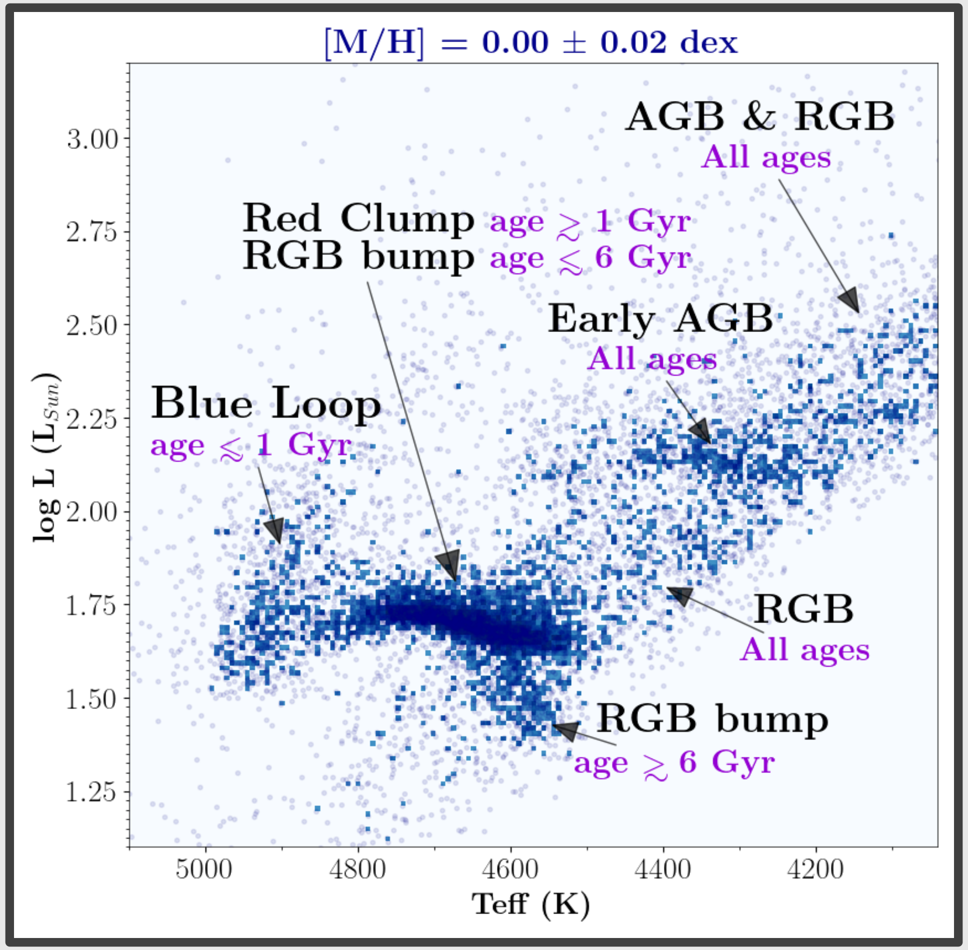
Disc bimodality from mono-abundance populations



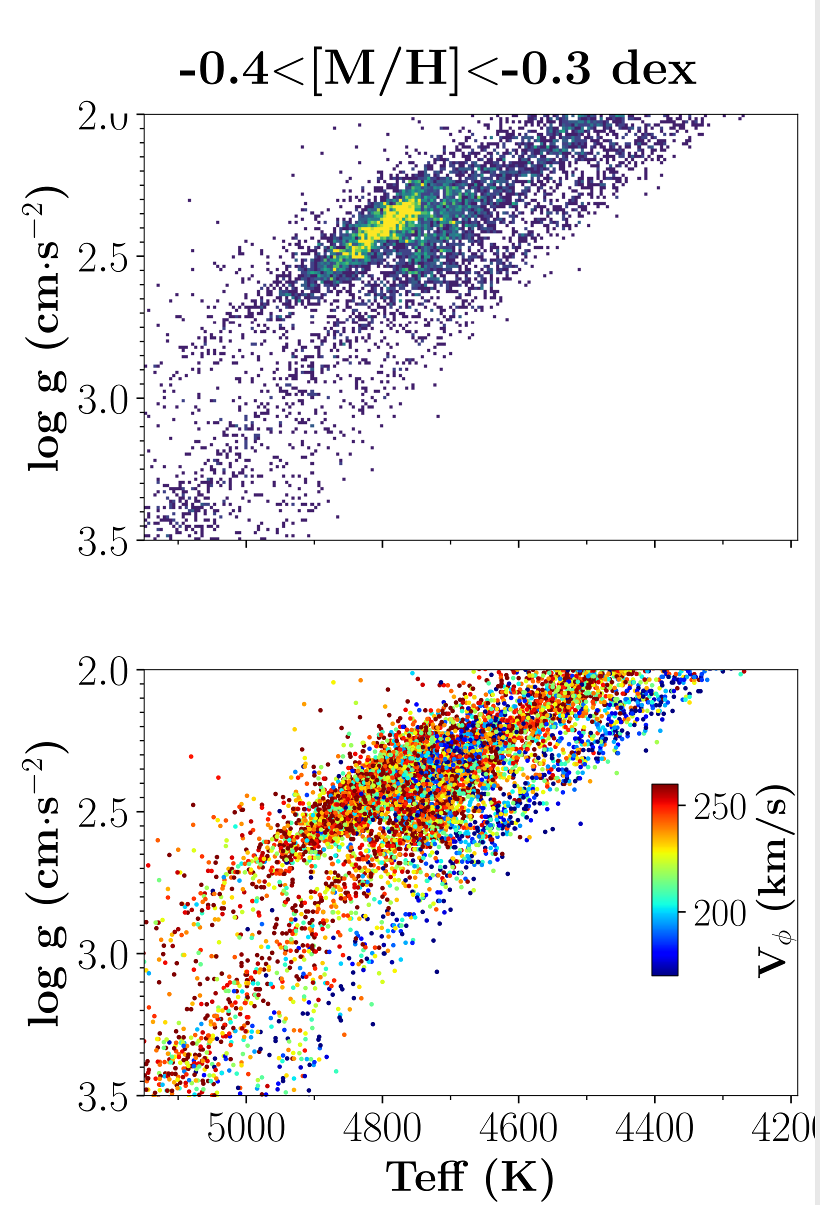
Recio-Blanco et al. 2024

Mono-metallic populations reveal:

- **Tracers of Galactic history at different epochs**



Disc bimodality from mono-abundance populations



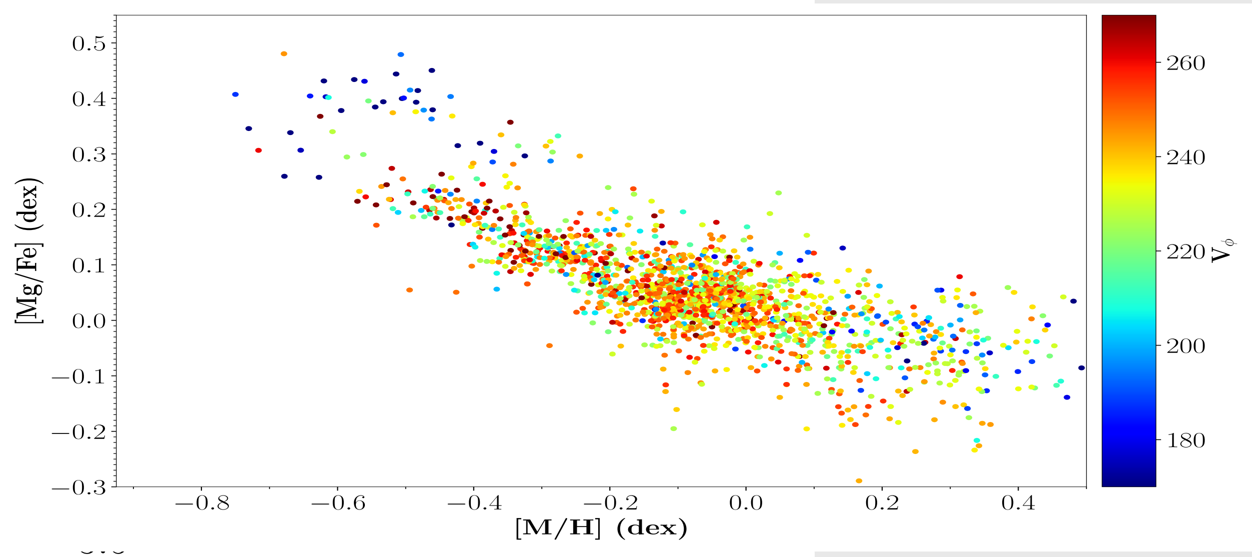
Recio-Blanco et al. 2024

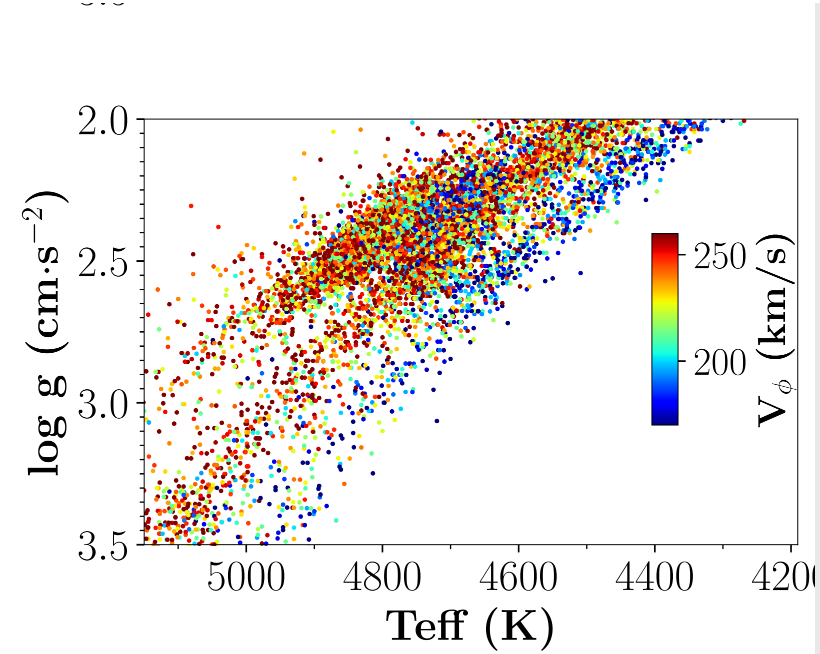
The precision in mono-metallicity populations break the age-metallicity degeneracy of giant stars and reveal double RGBs and RCs

The **"hotter" RGB** dominates at high metallicity and progressively fades as metallicity decreases and contains stars with high Vphi -> **thin disc.**

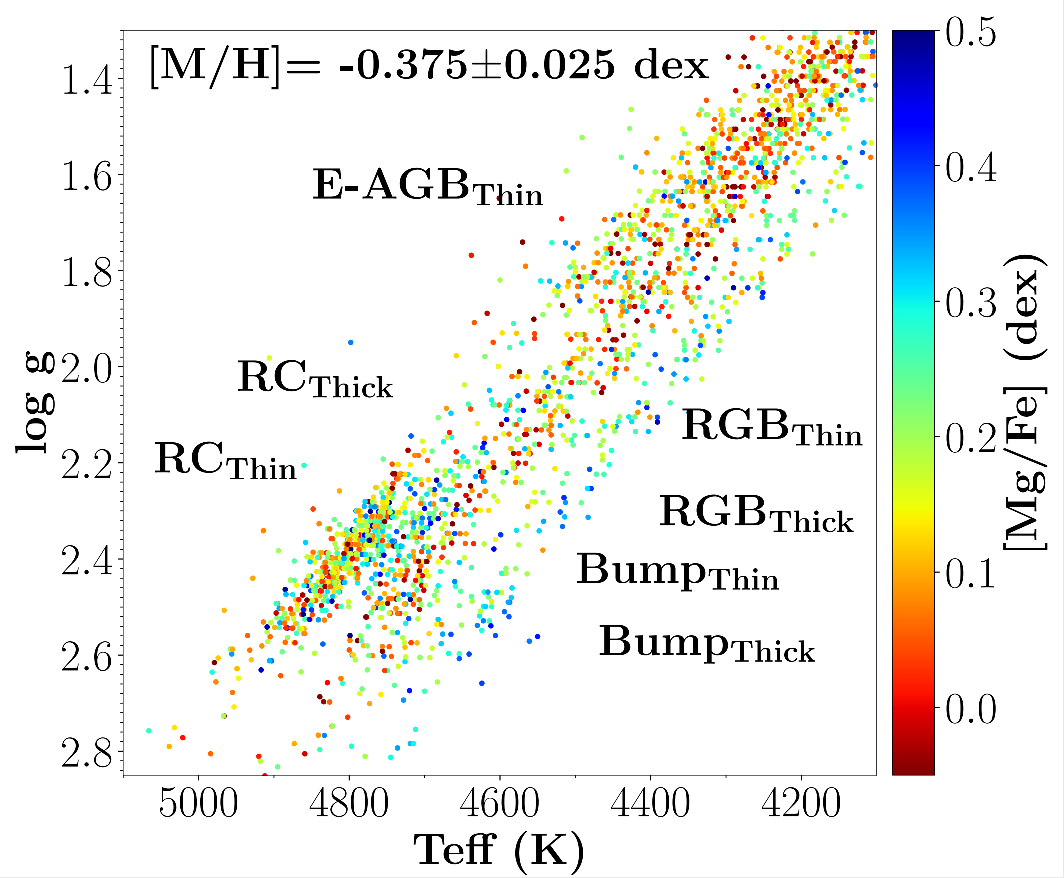
The **"cooler" RGB** is more and more visible as metallicity decreases and presents stars with lower Vphi values -> **thick disc**

Disc bimodality from mono-abundance populations





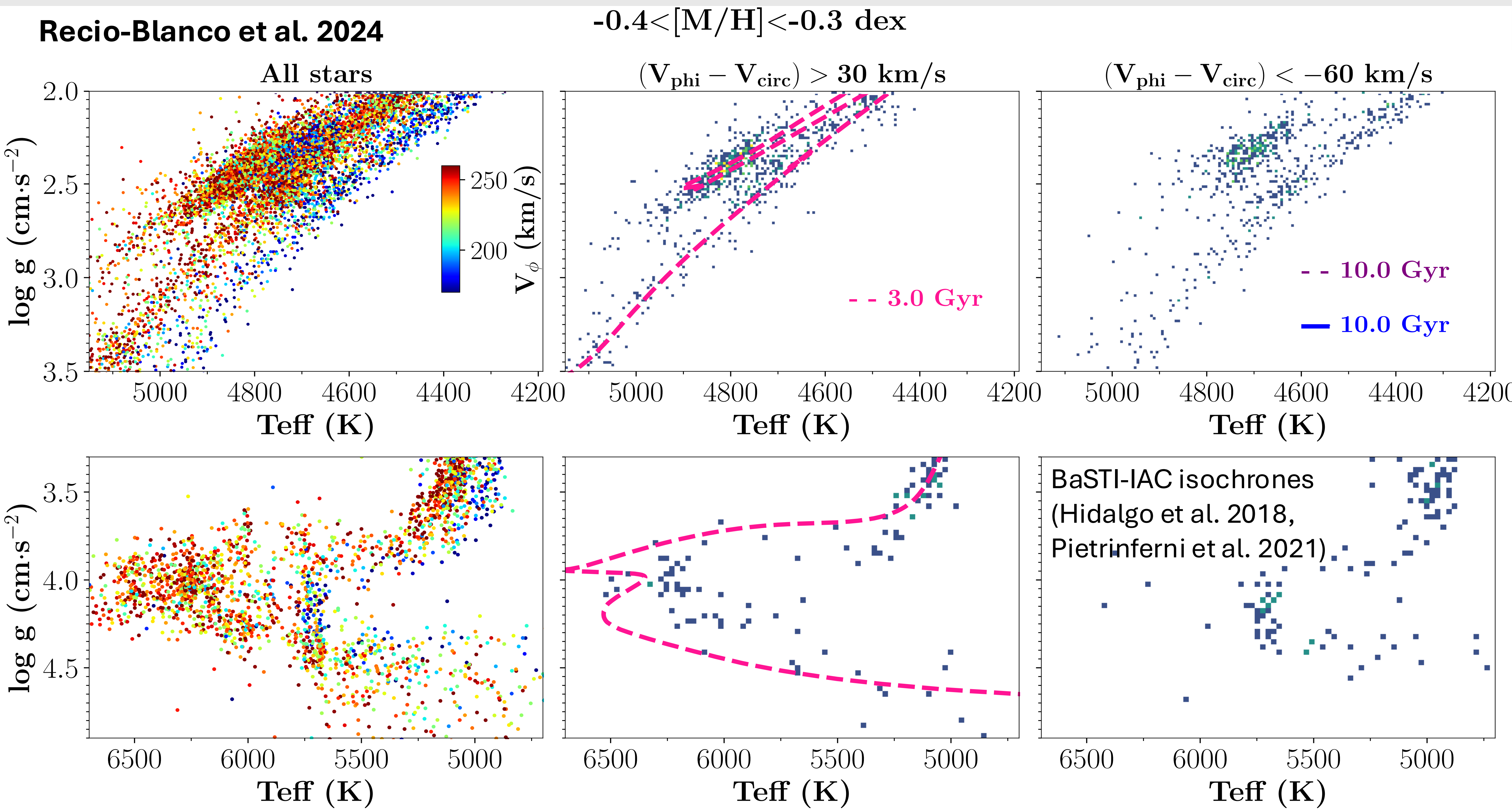
Recio-Blanco et al. 2024



Disc bimodality in:

- Kinematics and structure
- [alpha/Fe] distribution
- Stellar physical parameters -> Age distribution

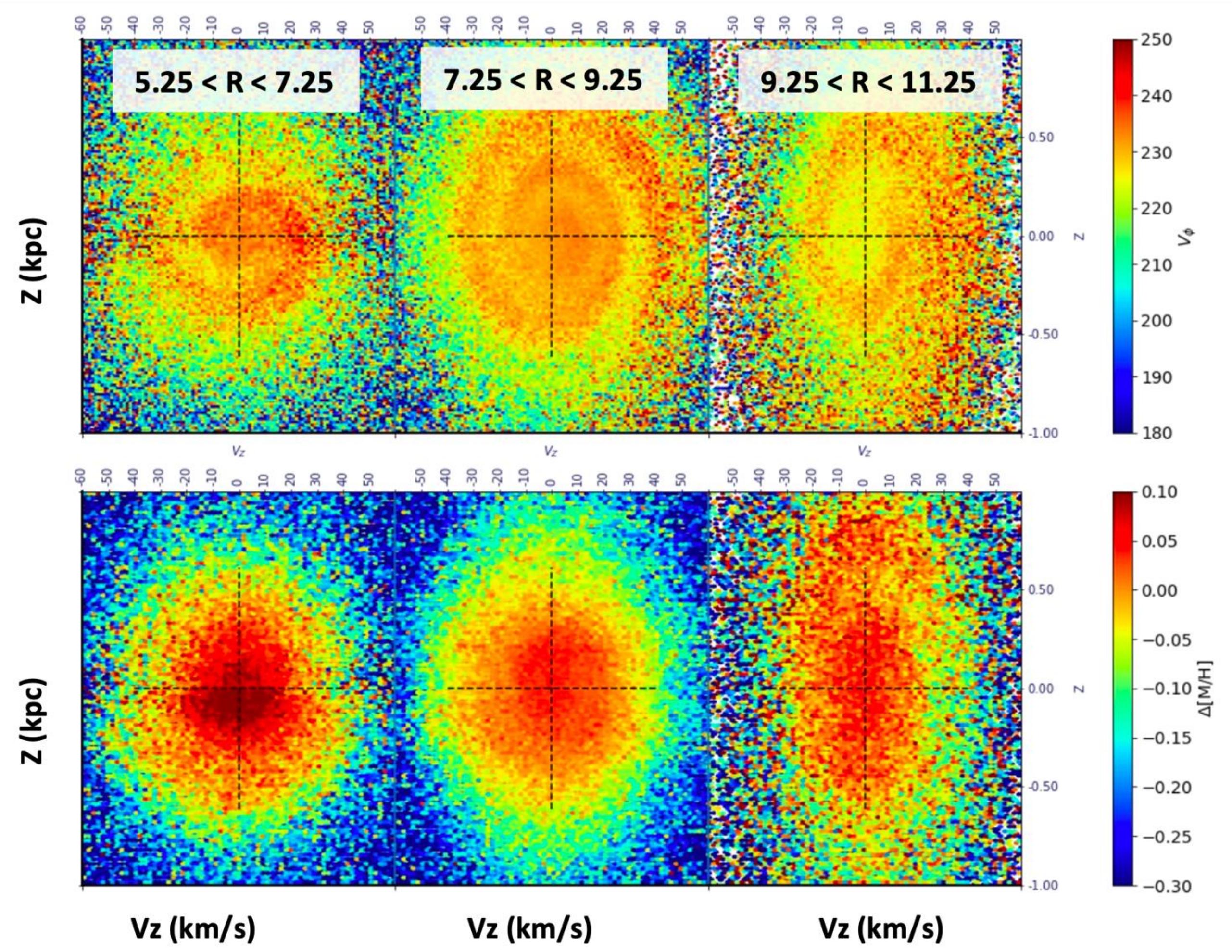
Recio-Blanco et al. 2024

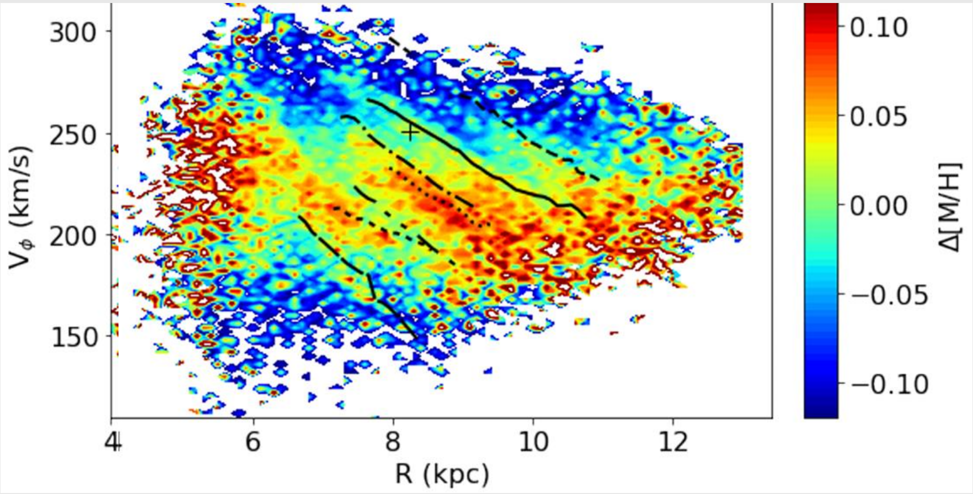


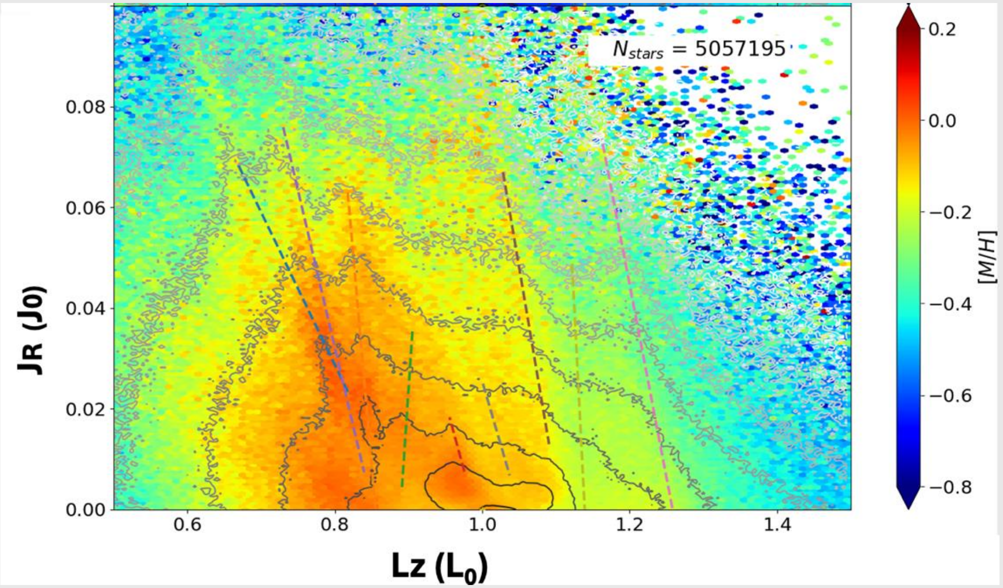
Bimodal RGB/RC age-ranges compatible with sub-giant branch ones

Chemical cartography of the thin disc: perturbations

Metallicity correlation with all the kinematical and dynamical signatures of disc perturbations (phase spiral - Antoja et al. 2018**, ridges and mouving groups –** Gaia Collaboration, Katz et al. 2018**)**

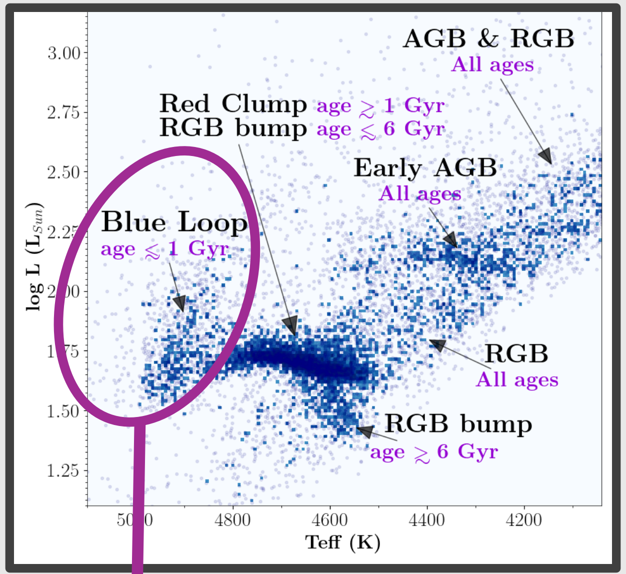






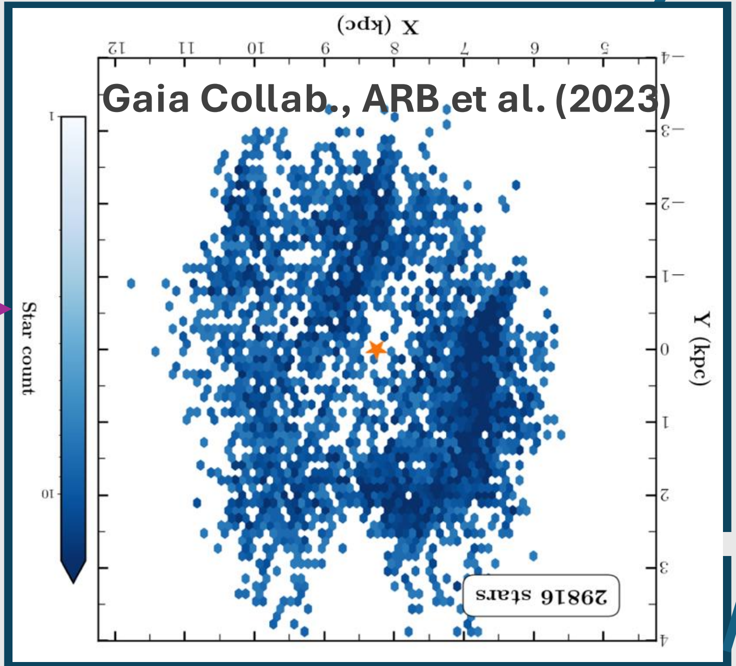
Gaia Collaboration, ARB et al. (2023)

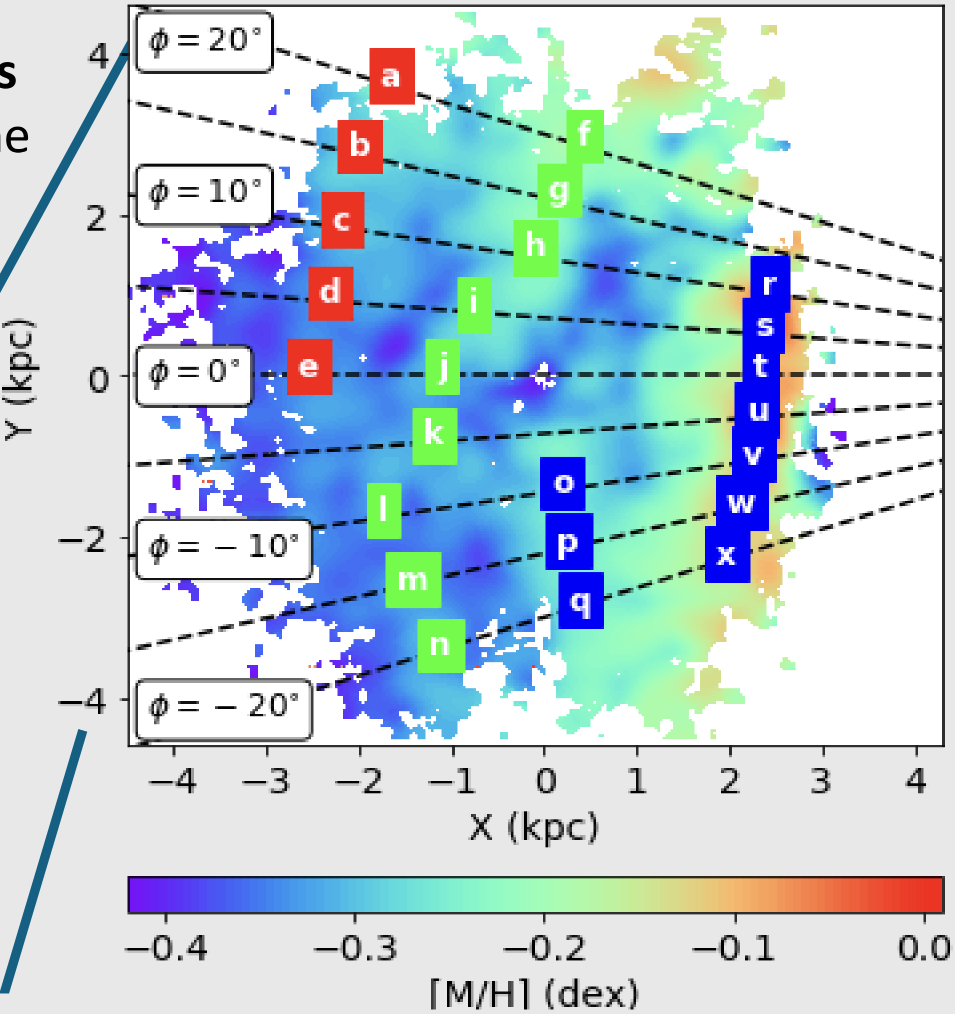
Chemical cartography of the thin disc: spiral arms

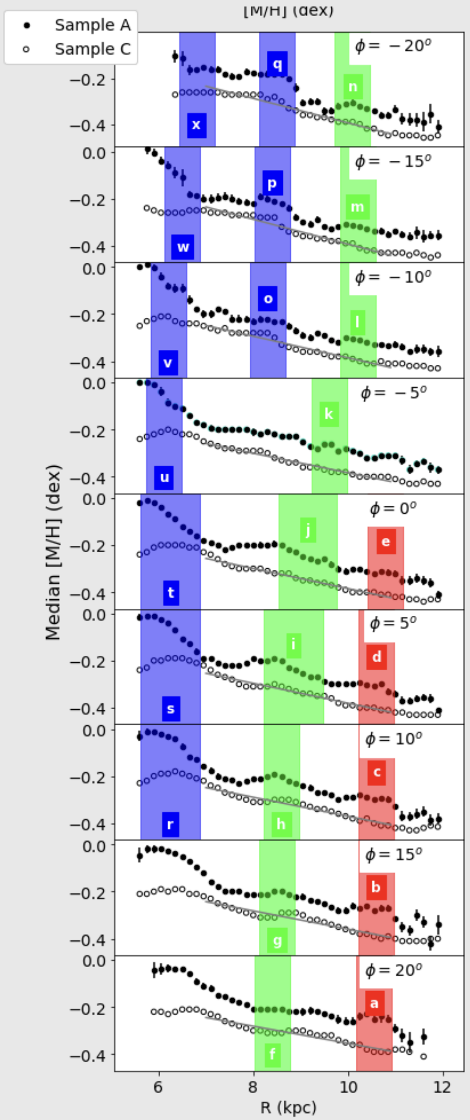


The spiral arms are [Fe/H]-enhanced with respect to inter-arm regions

Blue Loop stars
as tracers of the
Spiral arms

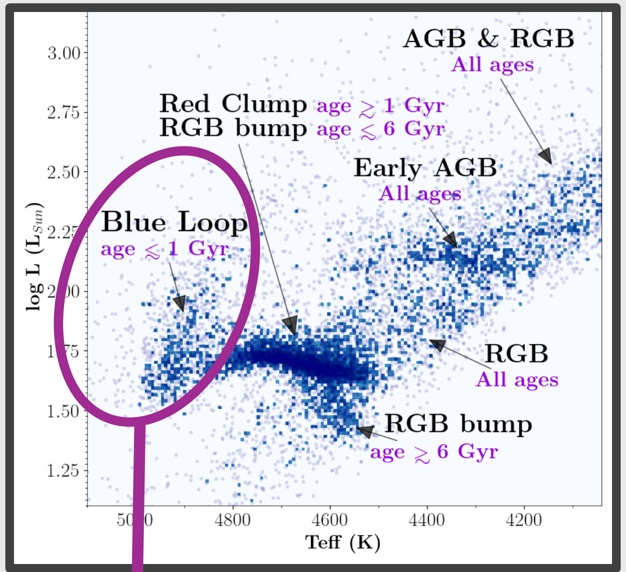






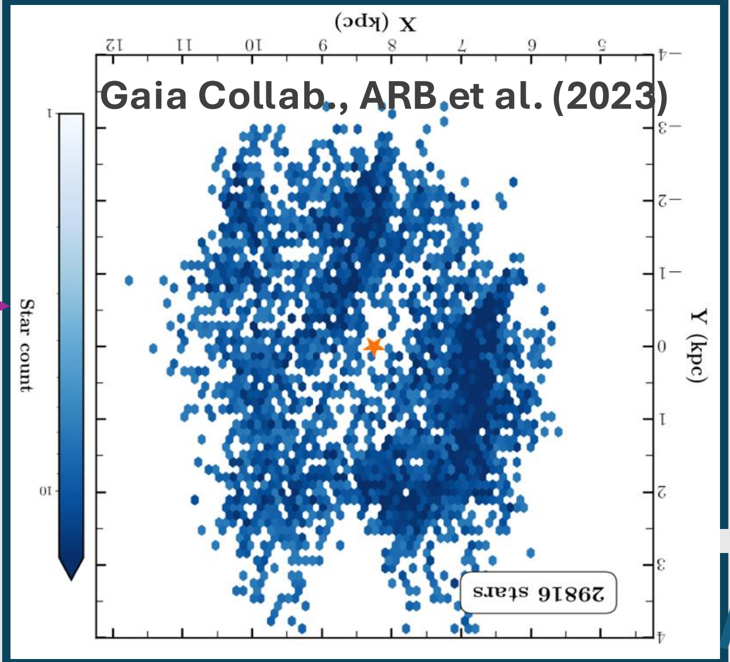
Poggio et al. (2022)

Chemical cartography of the thin disc: spiral arms

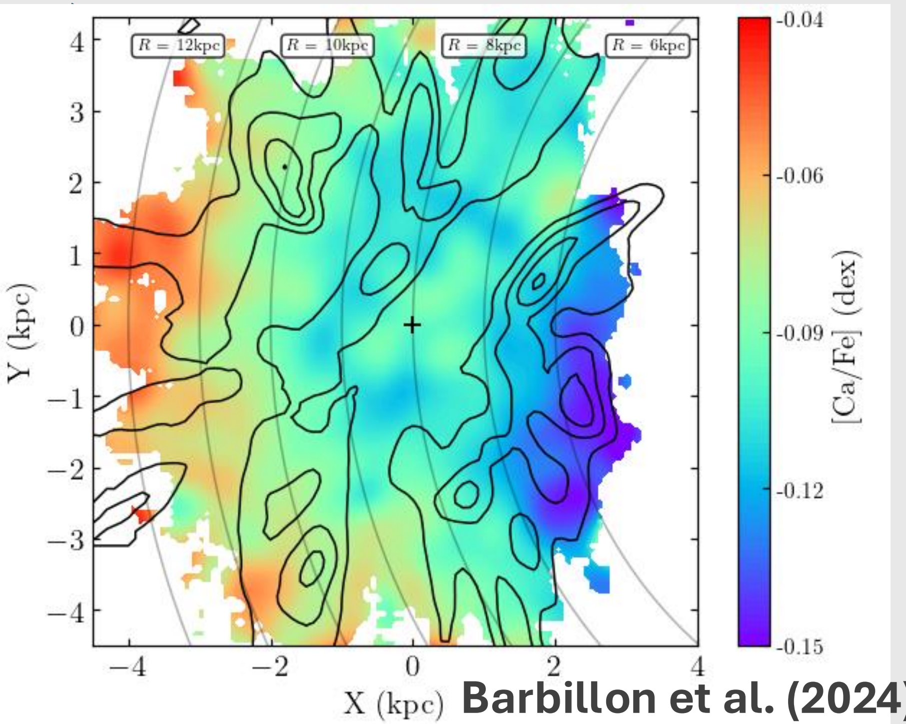


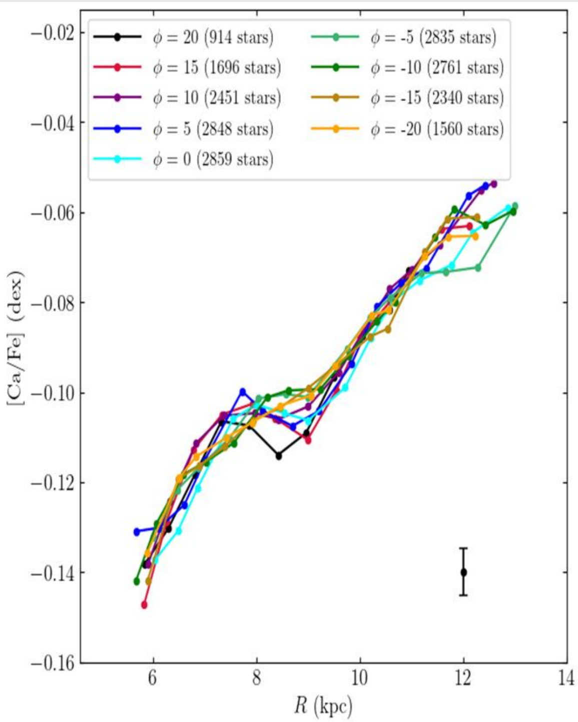
The spiral arms are [Ca/Fe]-depleted with respect to inter-arm regions

Blue Loop stars
as tracers of the
Spiral arms



Gaia Collab., ARB et al. (2023)





Barbillon et al. (2024)

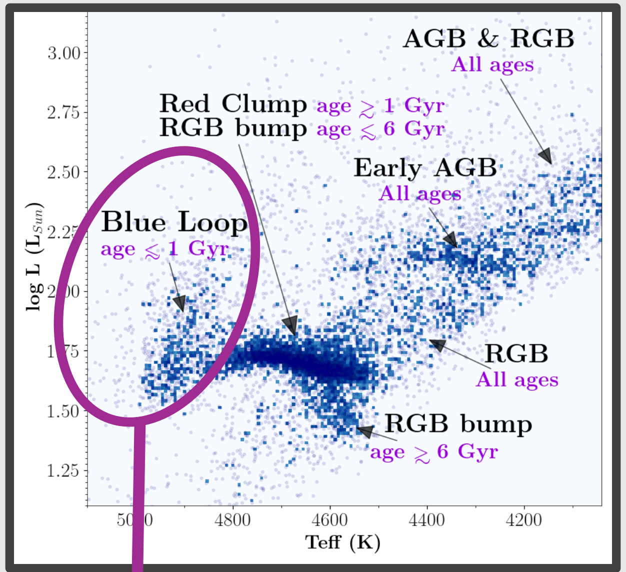
Stars within the spiral arms are:

- Enriched in [Fe/H] and [Ca/H]
- Impovered in [Ca/Fe]

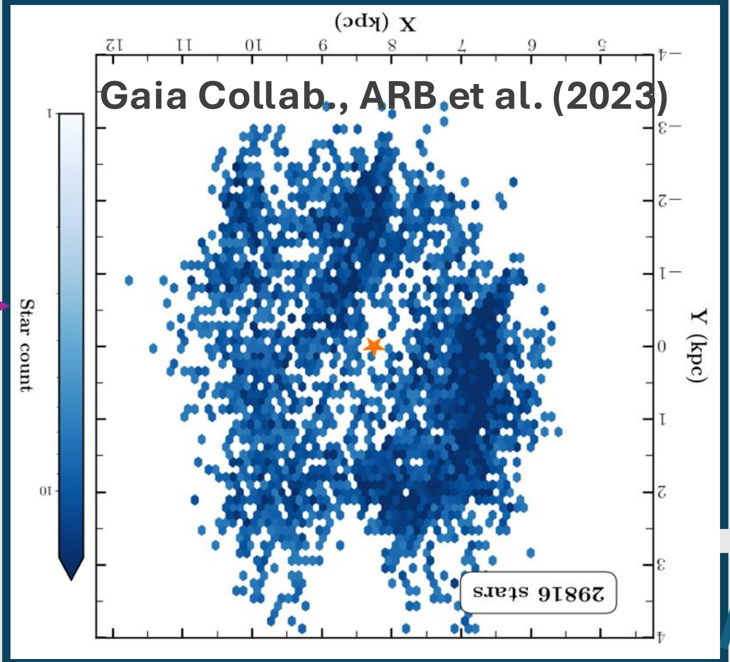
with respect to stars in inter-arm regions

Chemical cartography of the thin disc: spiral arms

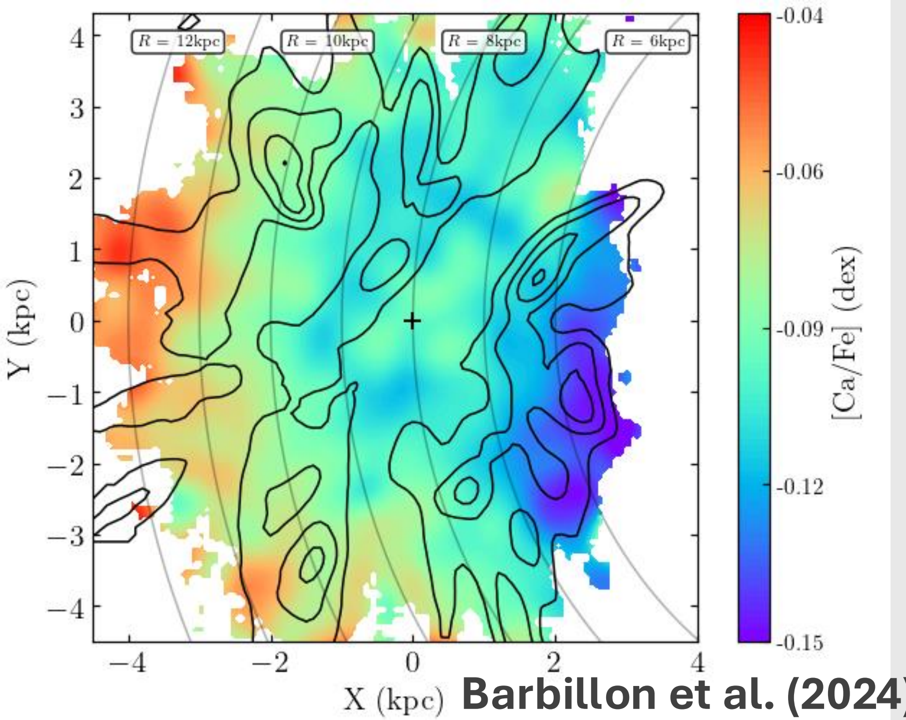
The spiral arms are [Ca/Fe]-depleted with respect to inter-arm regions



Blue Loop stars as tracers of the Spiral arms



Gaia Collab., ARB et al. (2023)



Barbillon et al. (2024)

Enrichment due to the enhanced star formation within the spiral arms, but SN type Ia > SN type II

This needs time for SN Ia to arrive

Long living spiral arms?

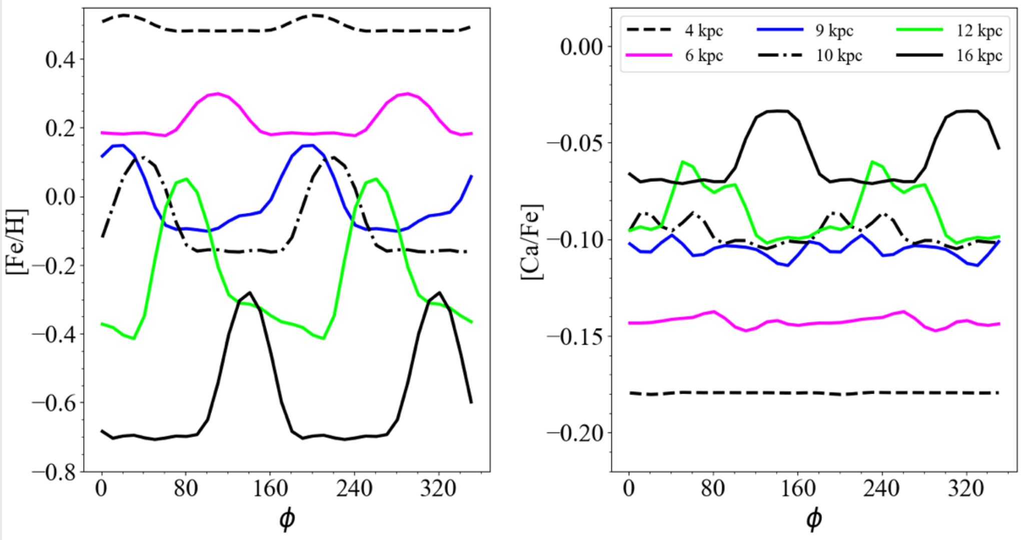
Stars within the spiral arms are:

- Enriched in [Fe/H] and [Ca/H]
- Impovered in [Ca/Fe]

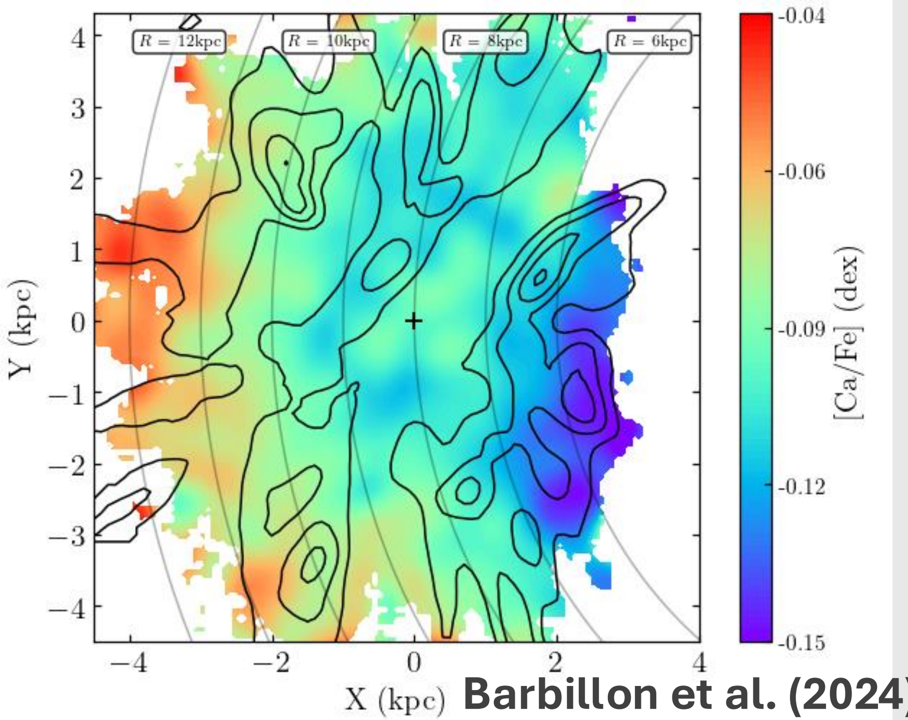
with respect to stars in inter-arm regions

Chemical cartography of the thin disc: spiral arms

The spiral arms are [Ca/Fe]-depleted with respect to inter-arm regions



Spitoni et al. (2023) 2D chemical evolution
Multiple spiral-arm modes with different pattern speeds



Barbillon et al. (2024)

Enrichment due to the enhanced star formation within the spiral arms, but
SN type Ia > SN type II

This needs time for SN Ia to arrive

Long living spiral arms?

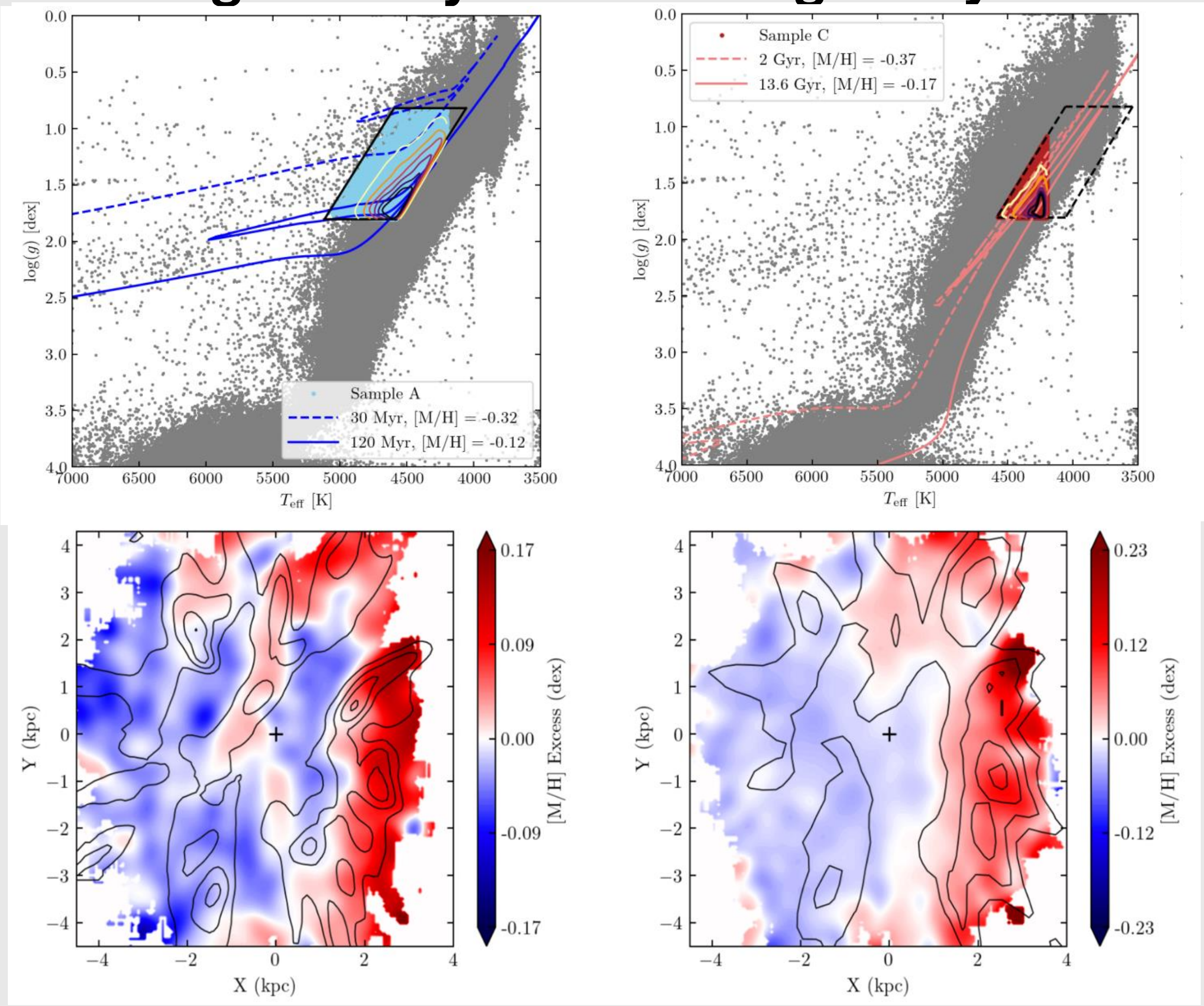
[Ca/Fe] impoverishment obtained if co-rotation lasts > 2 Gyr

Super-position of transient spiral modes? (Selwood & Calberg 2014)

Instable configuration? (Quillen et al. 2011)

Chemical cartography of the thin disc: spiral arms

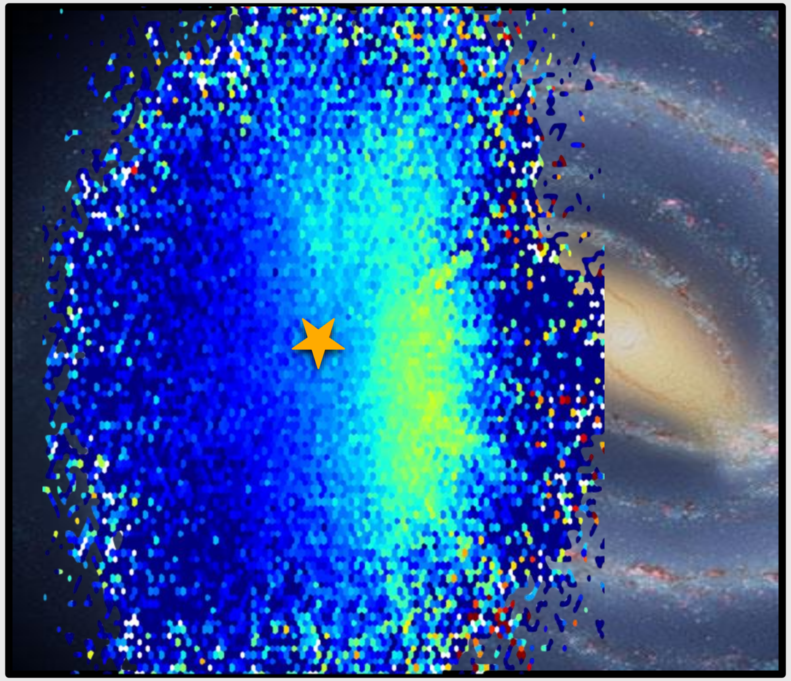
Age<0.5 Gyr **Age>2Gyr**



Poggio et al. (2022); Barbillon et al. 2024

Metallicity signatures of the spiral arms (Poggio et al. 2022, young tracers).

The old population presents also clear azimuthal variations.



Gaia Collaboration, ARB et al. (2023)

Chemical cartography of the thin disc: spiral arms

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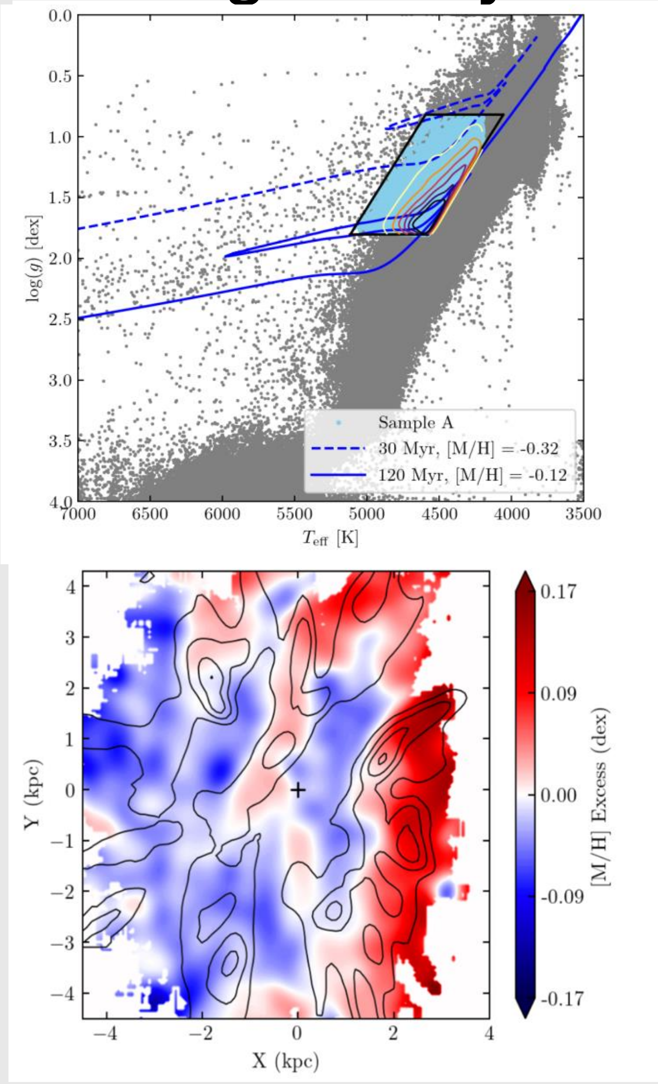

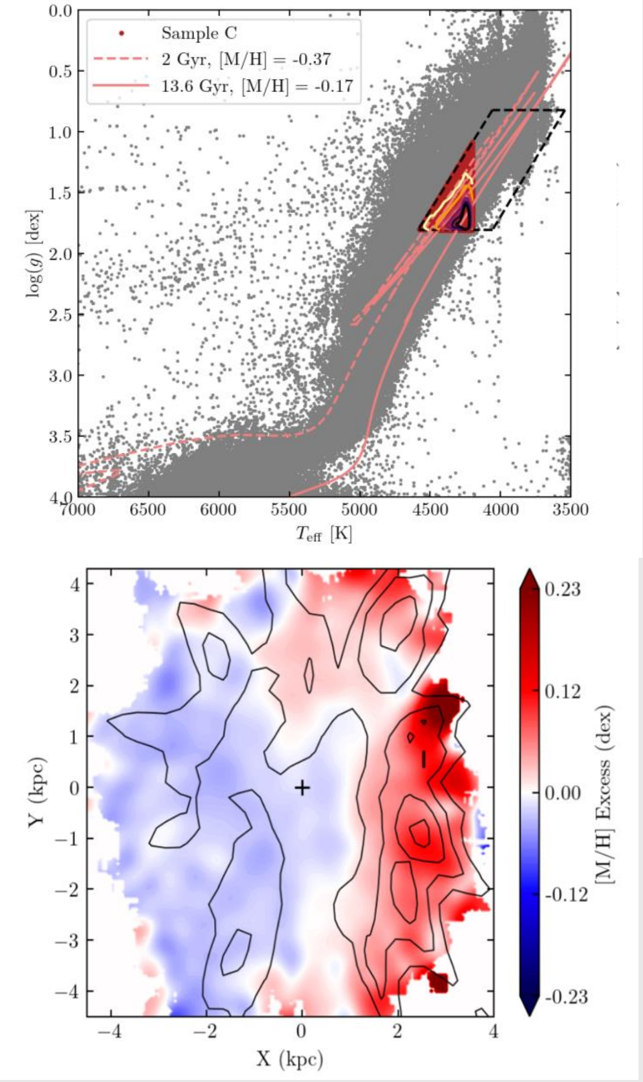

Poggio et al. (2022)

Barbillon et al. (2024)

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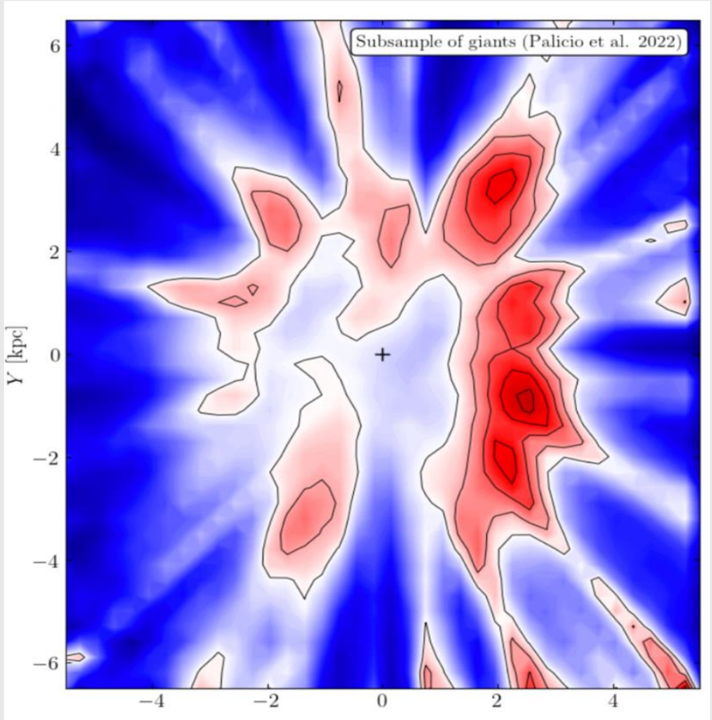
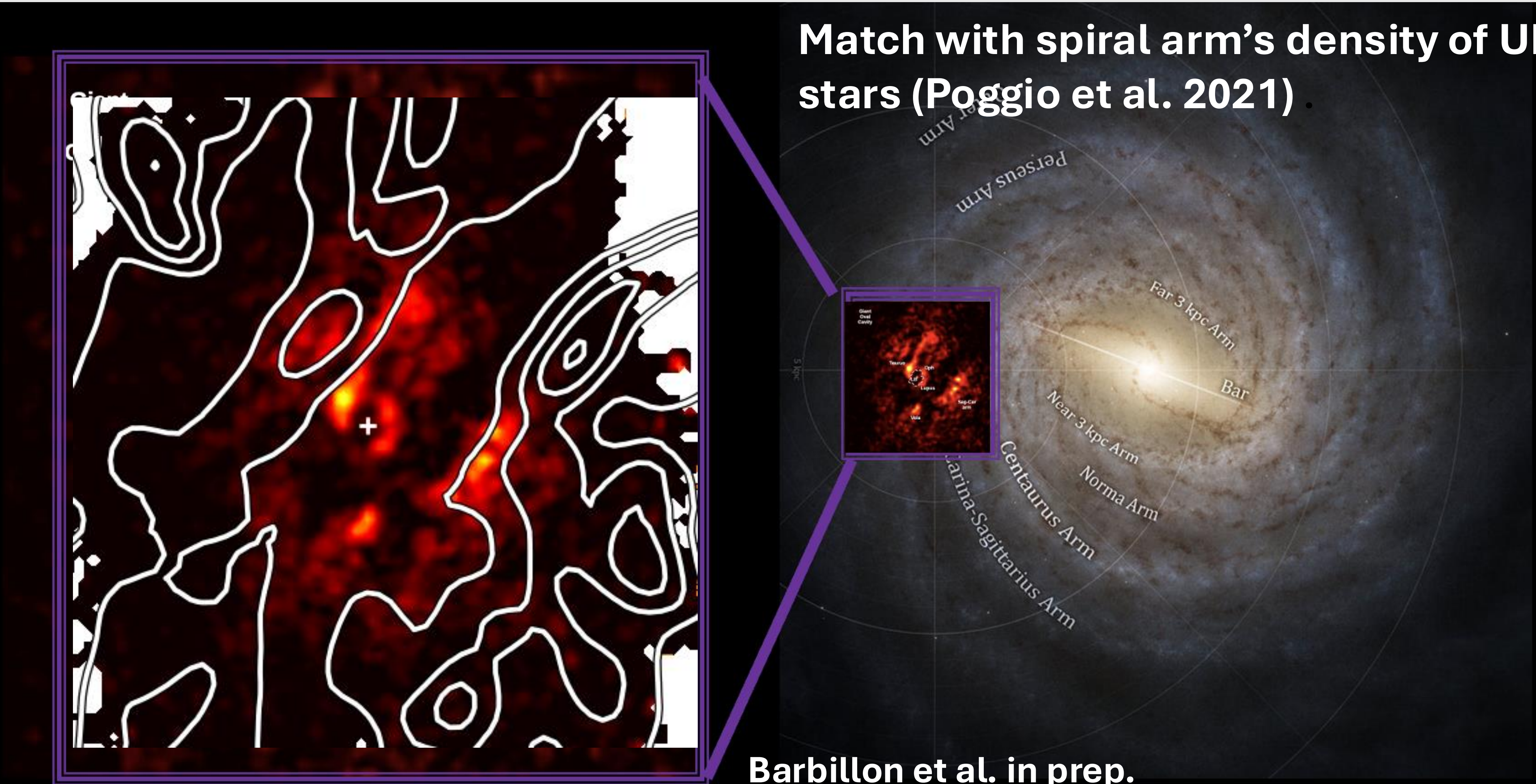


Palicio et al. (2023a)

Spiral features in density for a giant sample photometric selection.
See also Khana et al. 2024

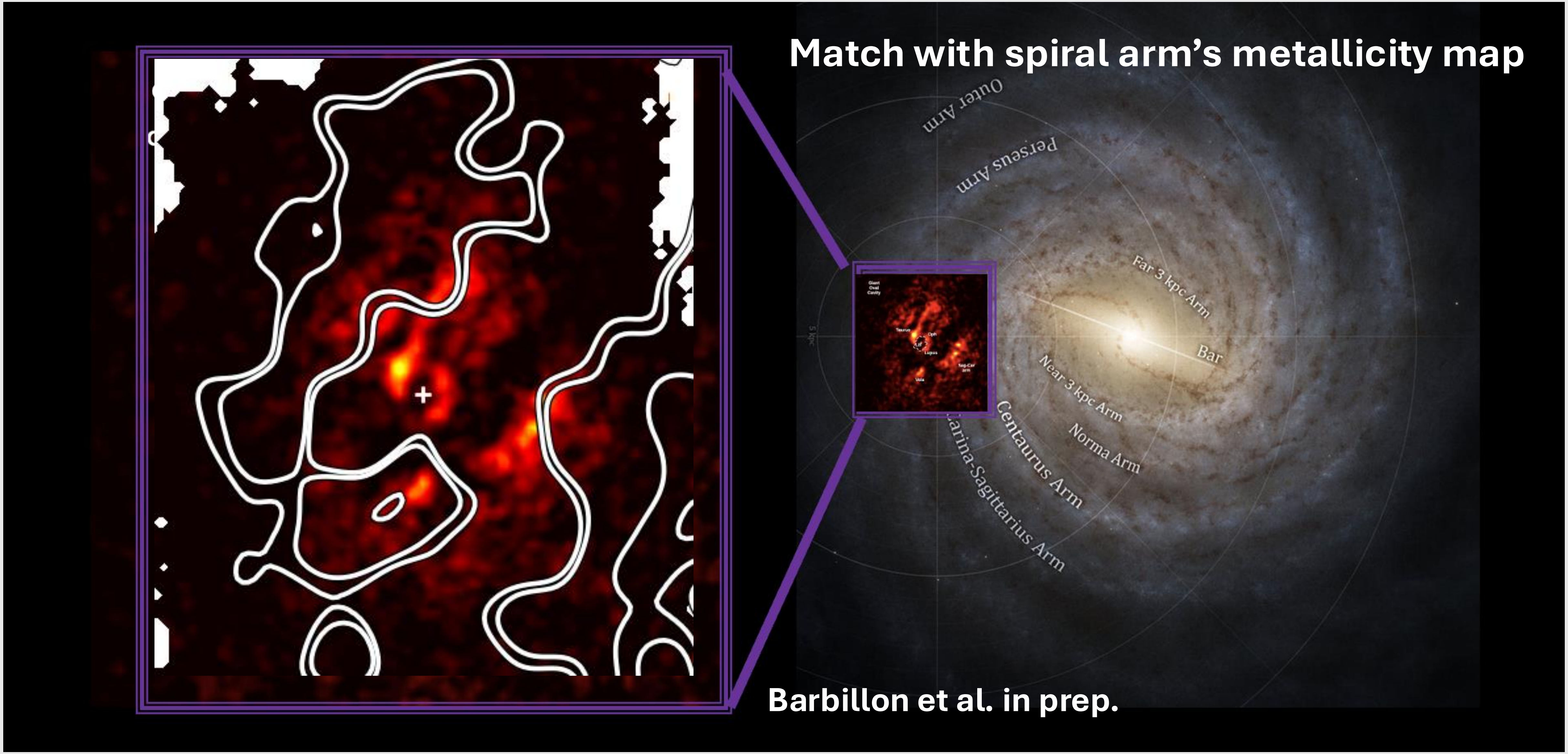
Chemical cartography of the thin disc: spiral arms

Match with spiral arm's density of UMS stars (Poggio et al. 2021)



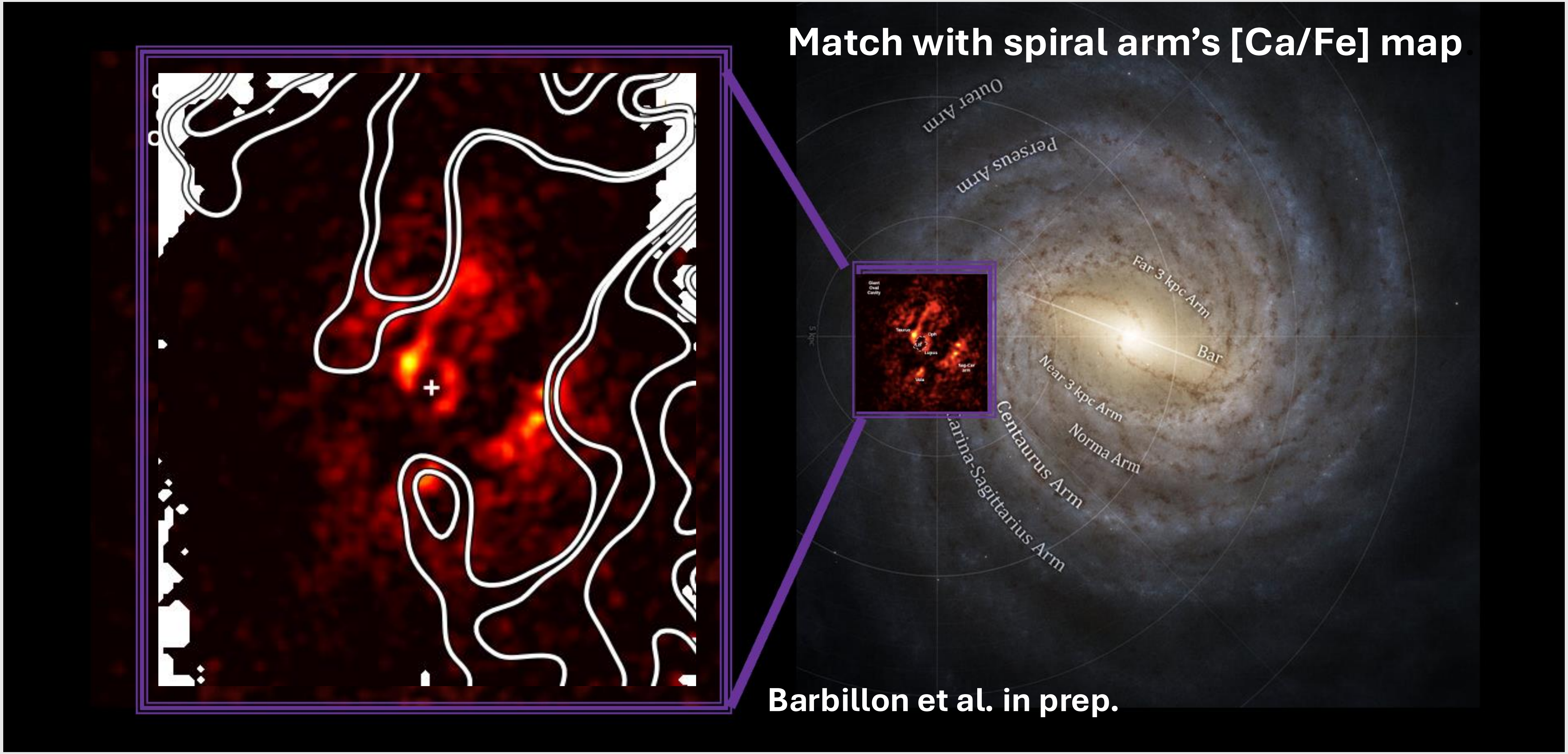
Barbillon et al. in prep.

Chemical cartography of the thin disc: spiral arms



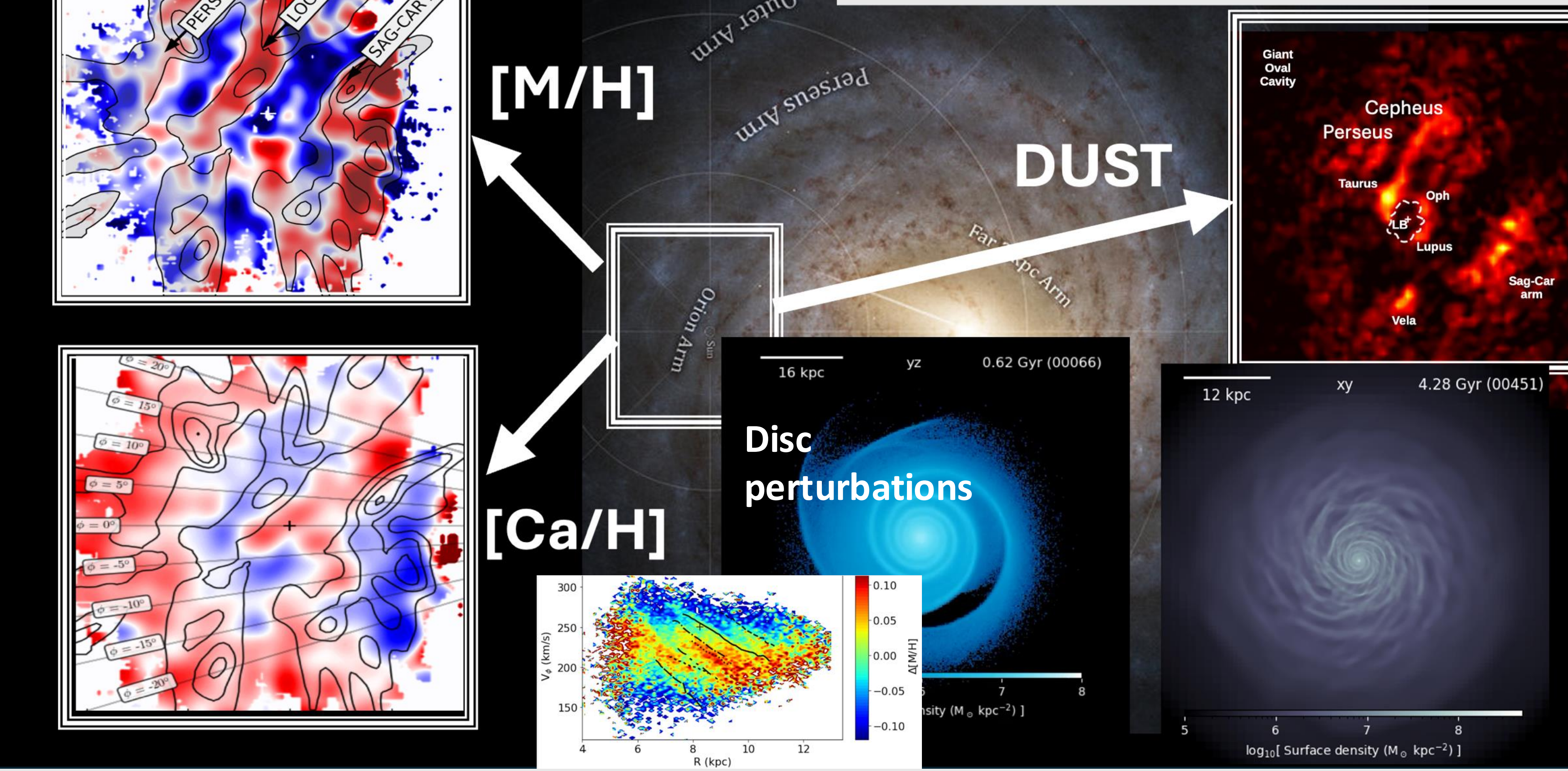
Chemical cartography of the thin disc: spiral arms

Match with spiral arm's [Ca/Fe] map



Barbillon et al. in prep.

Interpretation of this complex physics interplay through the NEXUS simulations (Tepper-Garcia et al. 2024) on going.



Credits:
T. Tepper-García &
Joss Bland-Hawthorn

Conclusions

- Gaia RVS reveals the diversity of stellar populations with high precision and high number statistics in the bright magnitude domain

75% of Gaia observations not published yet !
Next data releases: higher SNR on RVS data -> tenths of millions of stars with GSPspec parameters

- The disc bimodality is visible on the RGB and RC morphology of mono-abundance populations

- The disc chemical cartography has imprinted its kinematical perturbations and non-axisymmetric structures.

- The [alpha/Fe] abundance of spiral arms suggests a duration (co-rotation with the disc) for at least 2 Gyr of at least part of the spiral structure.

Vincent Van Gogh
(1888)

13 Boo
Gaia DR3 1511173389717021312

Gaia GSPspec: an all sky spectroscopic survey with high number statistics.... stars everywhere!

Gaia GSPspec

Teff = 3760K

log g = 0.41 cm/s^2

[M/H] = -0.66 dex

[α/Fe] = 0.14 dex

[Ca/Fe] = 0.19 dex

[Nd/Fe] = 0.59 dex

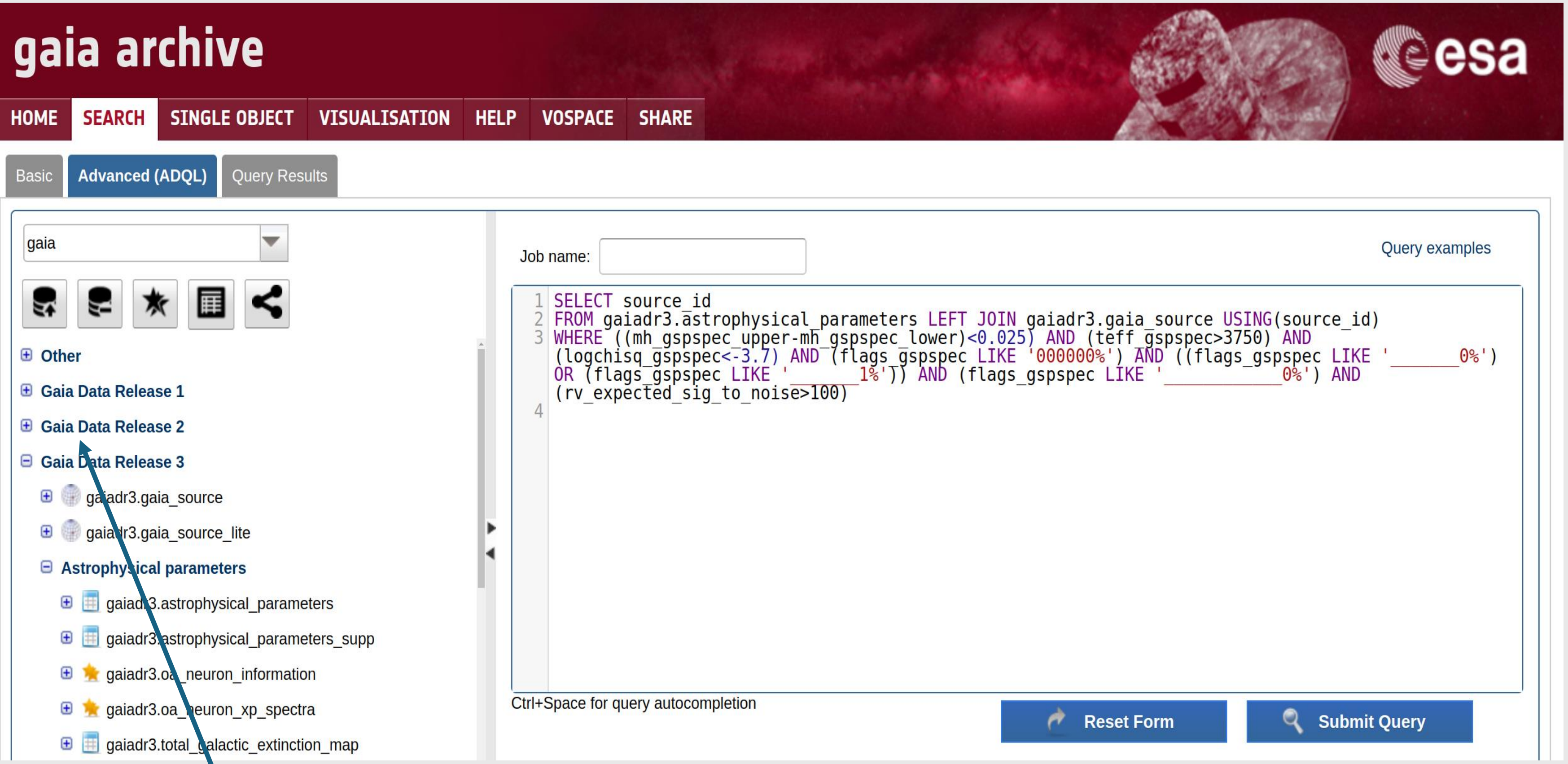
[Cr/Fe] = 0.3 dex

[Ce/Fe] = 0.34 dex

Gaia DPAC

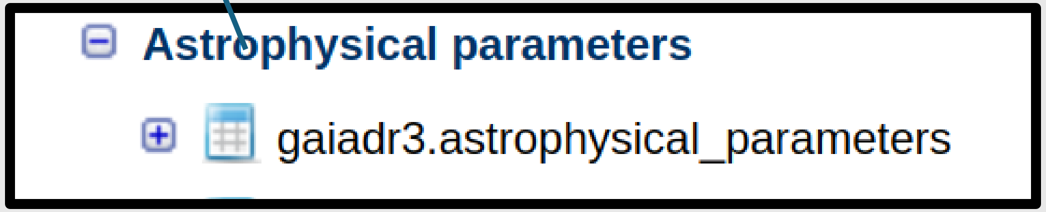
Diversity and evolution: GSPspec parameters

CU8/GSPspec: The chemical composition of 5.6 million stars



The Gaia DR3 archive contains many different tables.

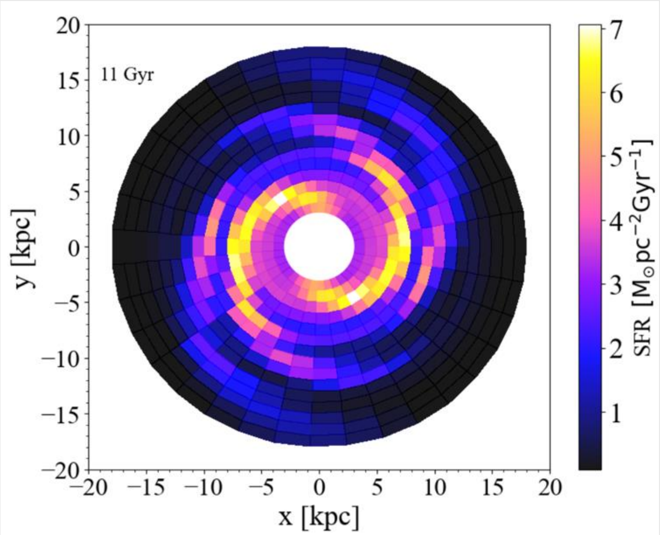
Most of the data are NOT on the on the main one (gaia.source)

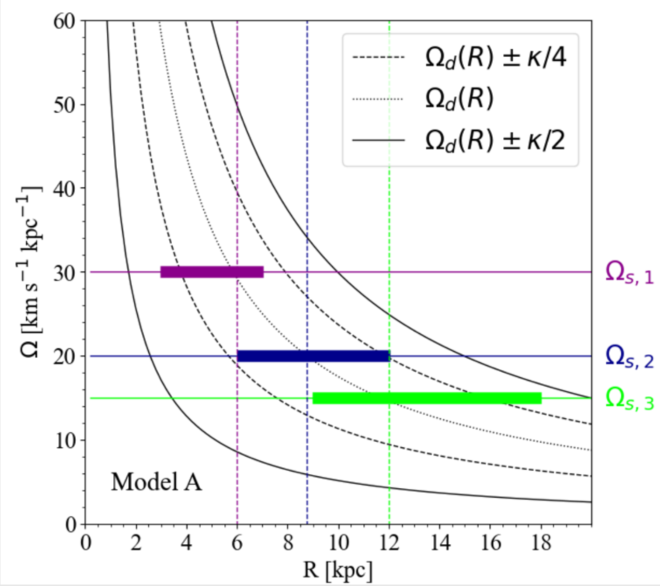


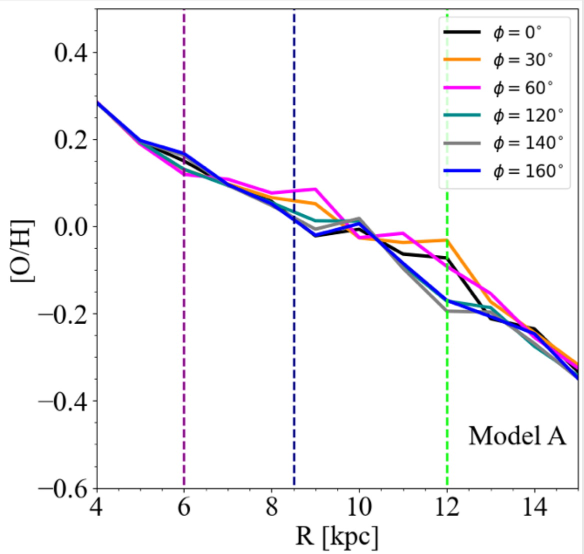
GSPspec chemophysical parameters are on the **gaiadr3.astrophysical_parameters table**

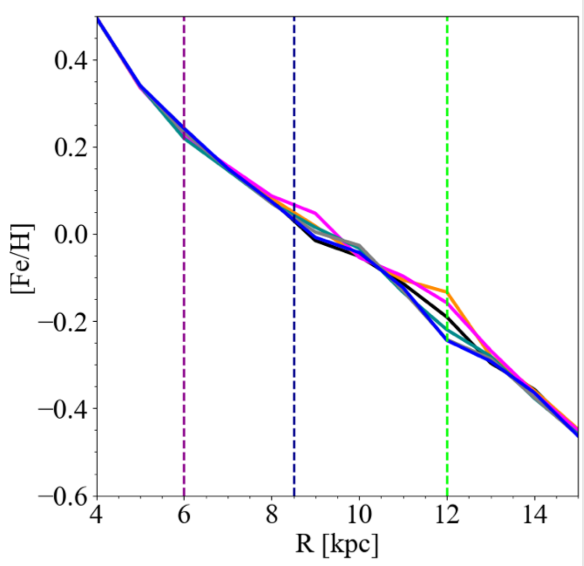
Resilience & stochasticity: spiral arms

Interpretation through a 2D chemical evolution model (Spitoni et al. 2023b)









Multiple spiral-arm modes with different pattern speeds

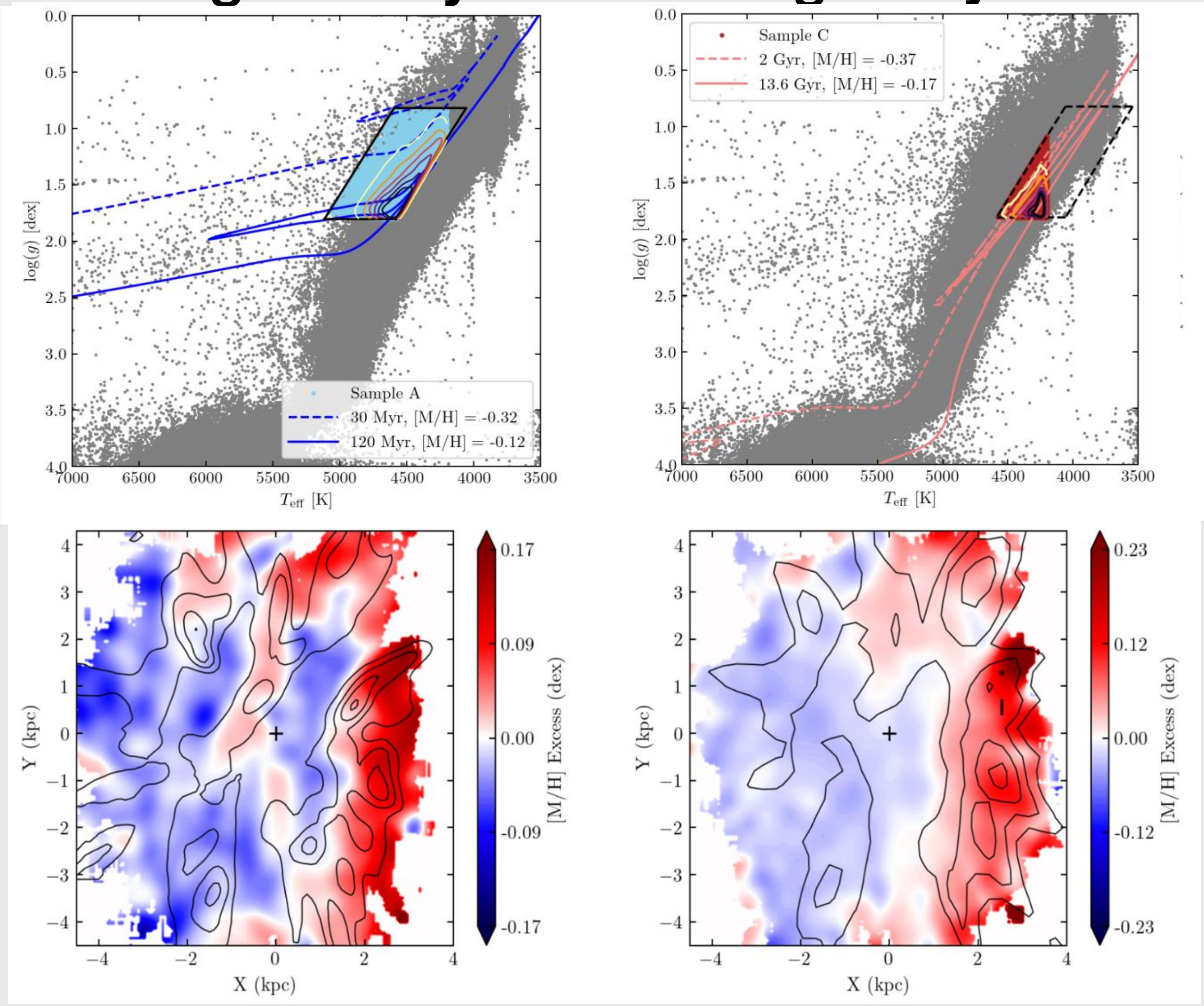
Iron is enhanced in spiral arms populations.

Elements synthesised on short time scales (i.e., oxygen and europium) exhibit larger abundance fluctuations.

Agreement with Gaia observations if at most recent times the spiral arm structure is co-rotating with the disc.

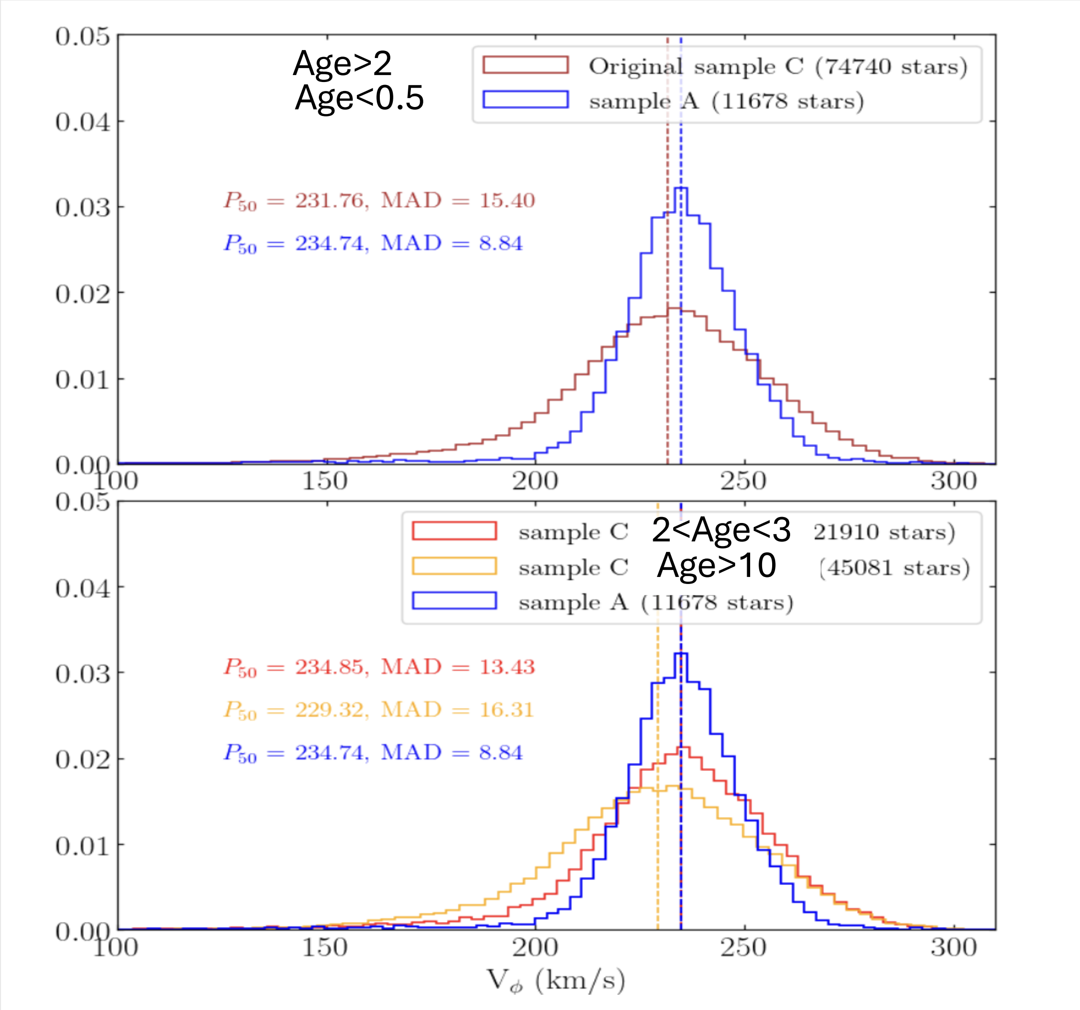
Resilience & stochasticity: spiral arms

Age<0.5 Gyr **Age>2Gyr**



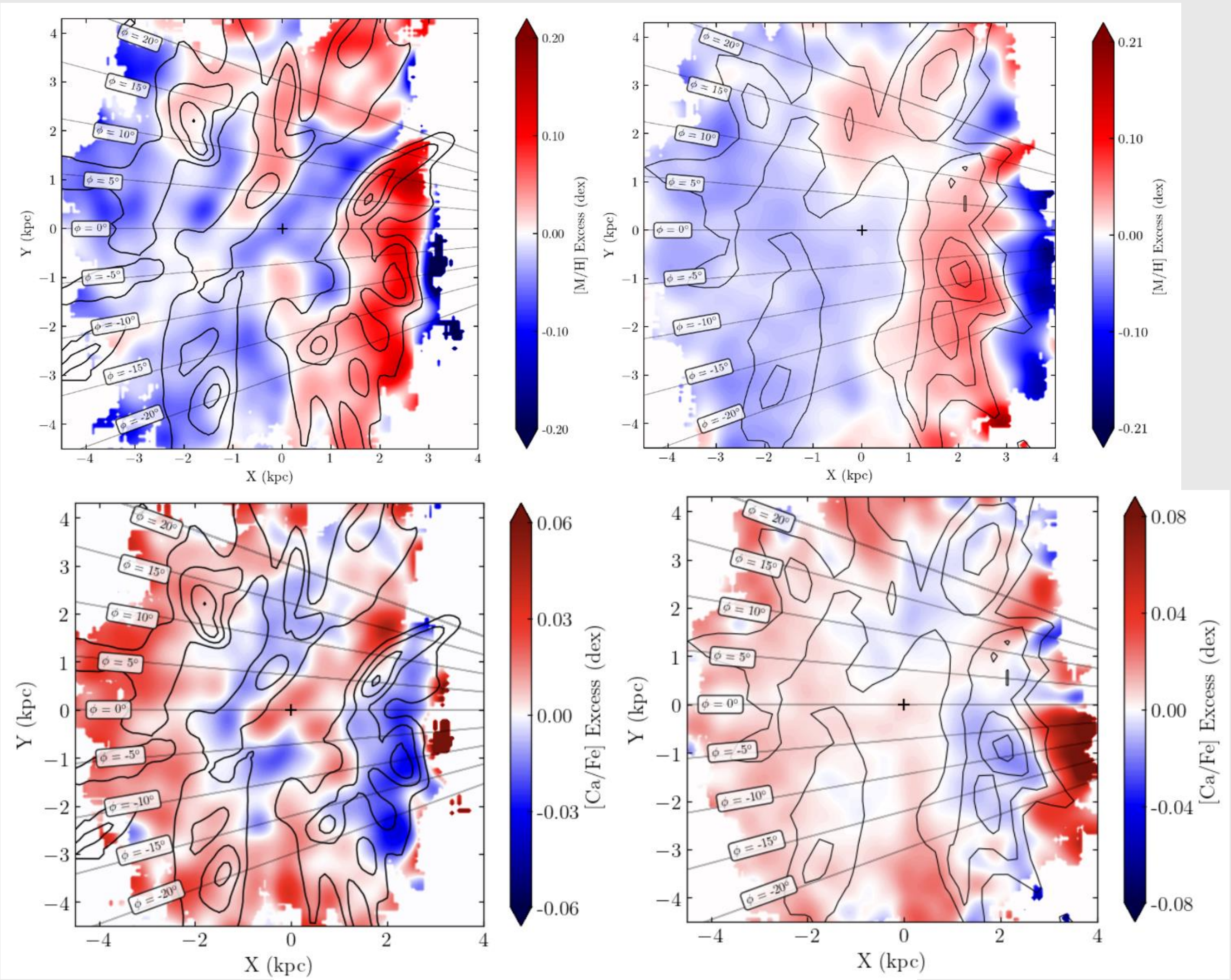
Poggio et al. (2022); Barbillon et al., subm.

Vphi dispersion for older populations
selected using isochrones and the GSPspec Kiel diagram



Resilience & stochasticity: spiral arms

Age<0.5 Gyr **Age>2Gyr**



Barbillon et al. (2024)

Metallicity signatures of the spiral arms both **in the young** (Poggio et al. 2023) **and the old population**

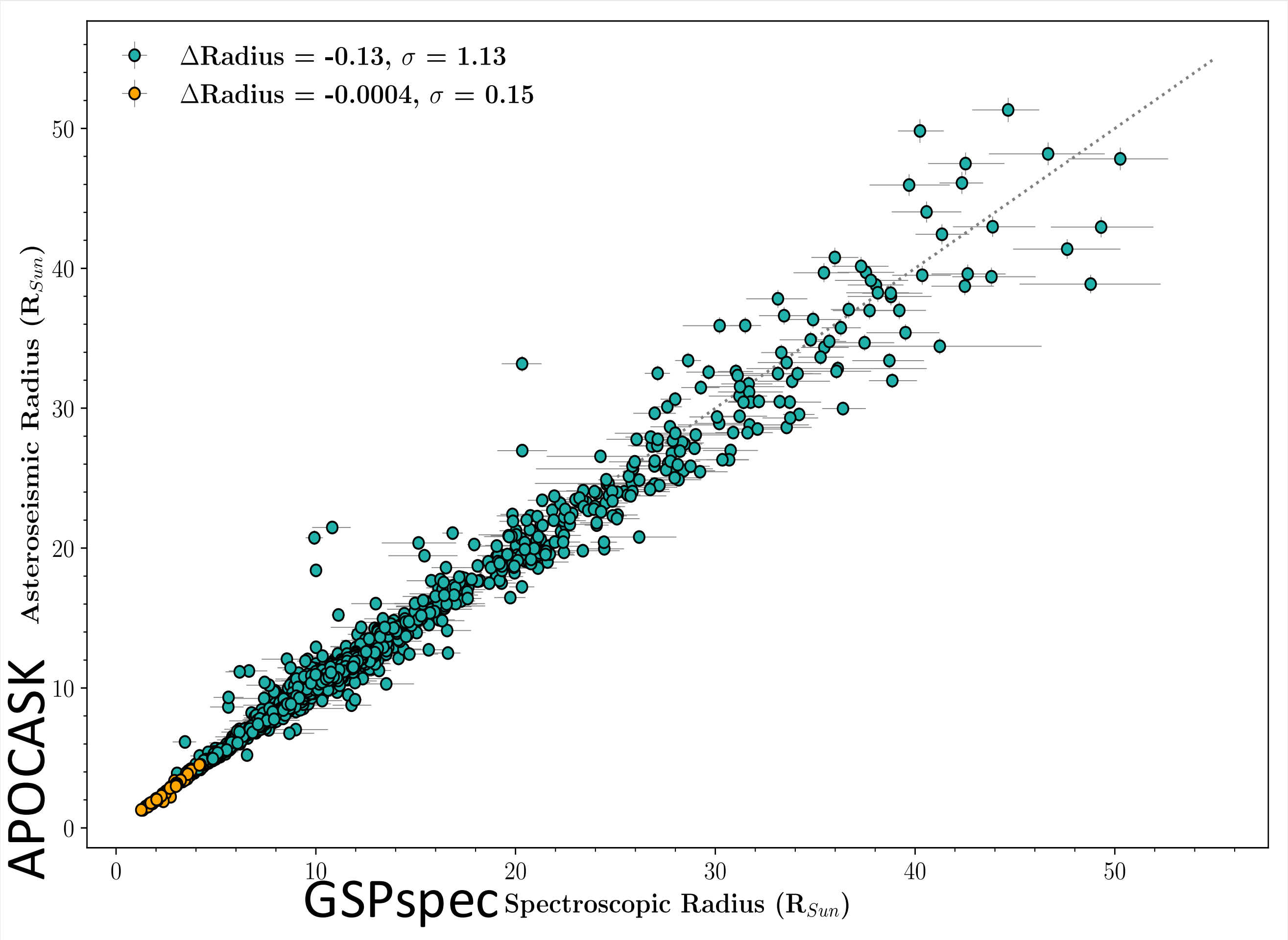
$[\alpha/\mathrm{Fe}]$ signatures in the young and the old populations
(Barbillon et al., 2024)

The fluctuation in α-elements is higher than in iron, as expected, in the old populations.

Diversity and evolution: stellar radius

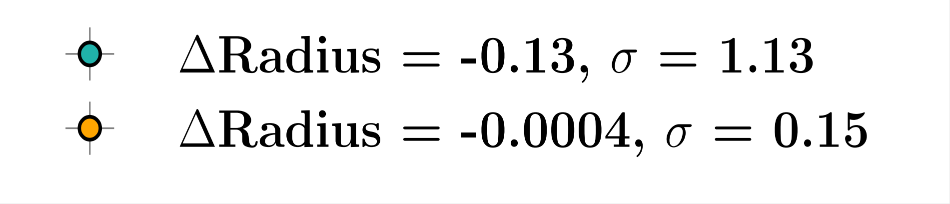
Gaia GSPspec -based stellar radius:

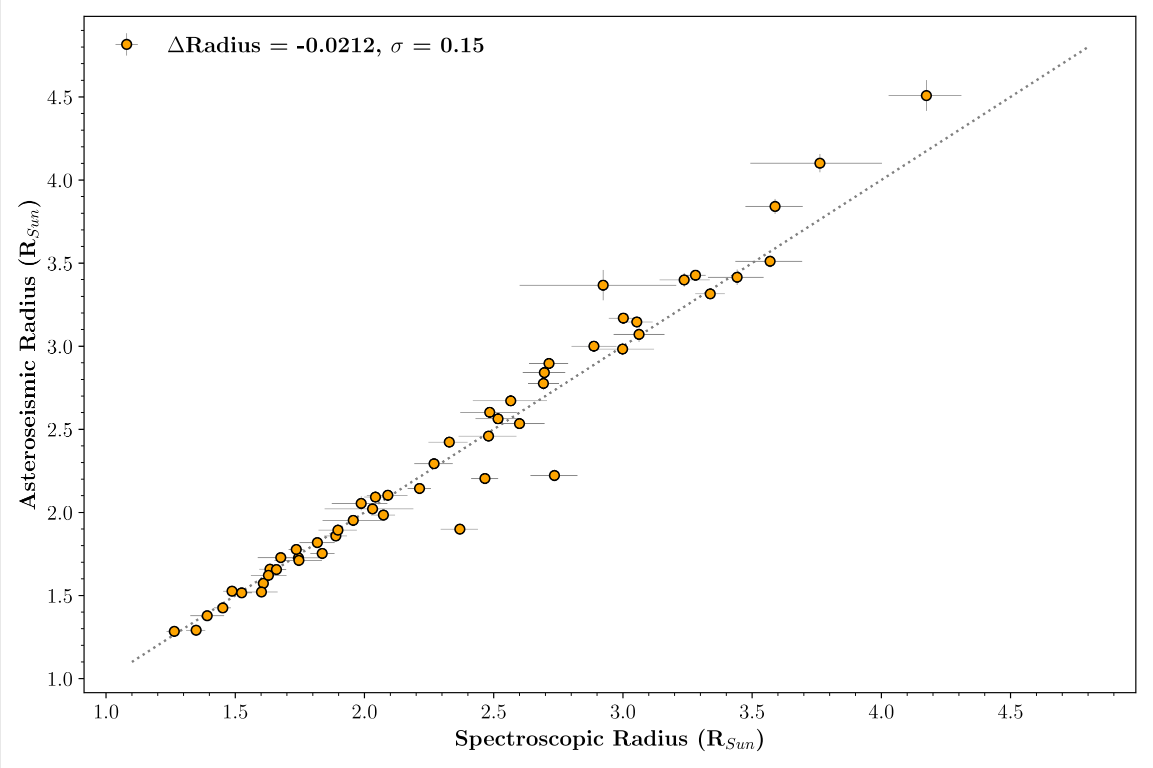
comparison with APOCASK Silva-Aguirre et al. (2015), Serenelli et al. (2017)



Giants

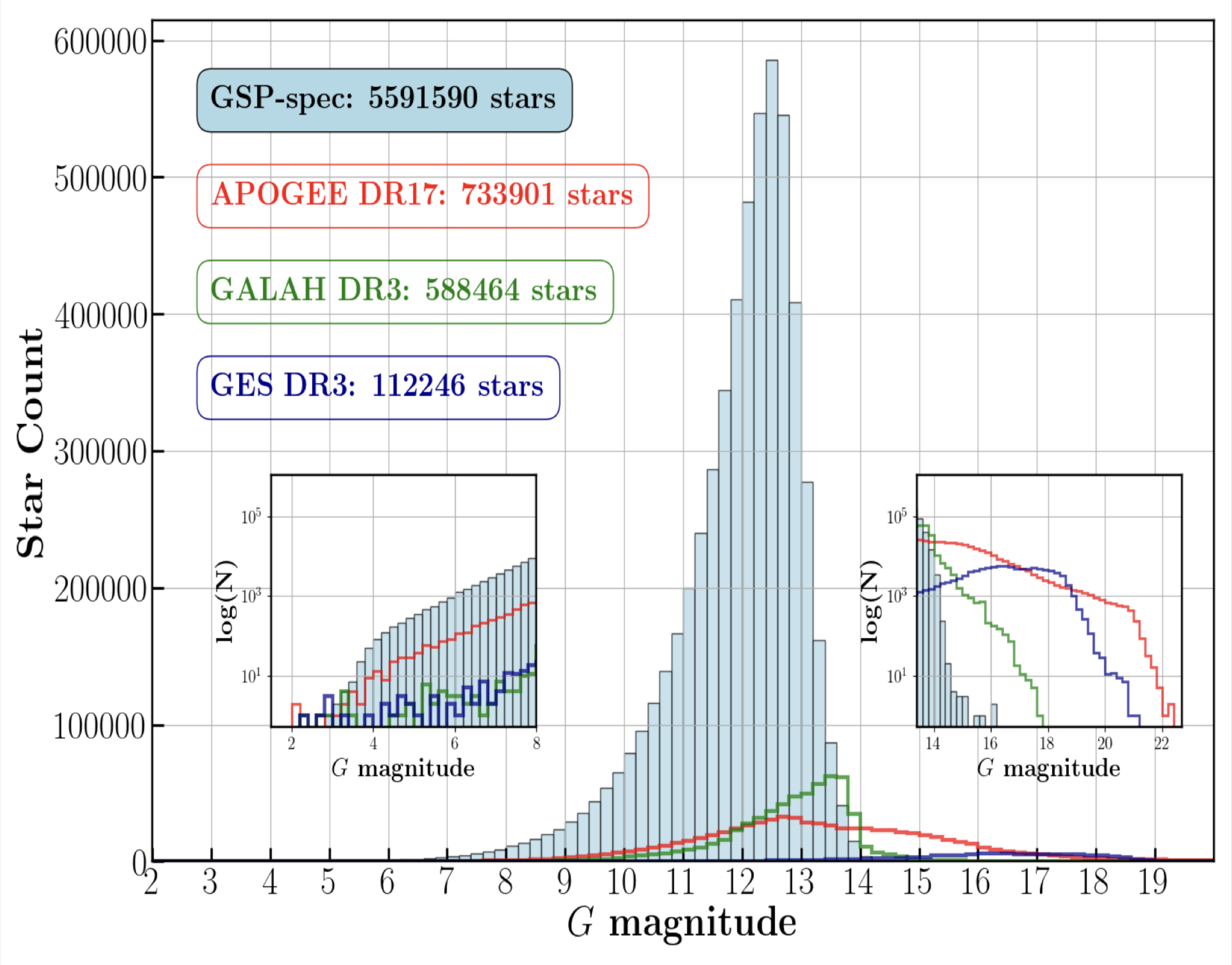
Dwarfs





Diversity and evolution: GSPspec parameters

CU8/GSPspec: The chemical composition of **5.6 million stars**



About 2.5 times more stars than ground-based high resolution spectroscopic surveys taken altogether (and nb will increase!)

All sky coverage

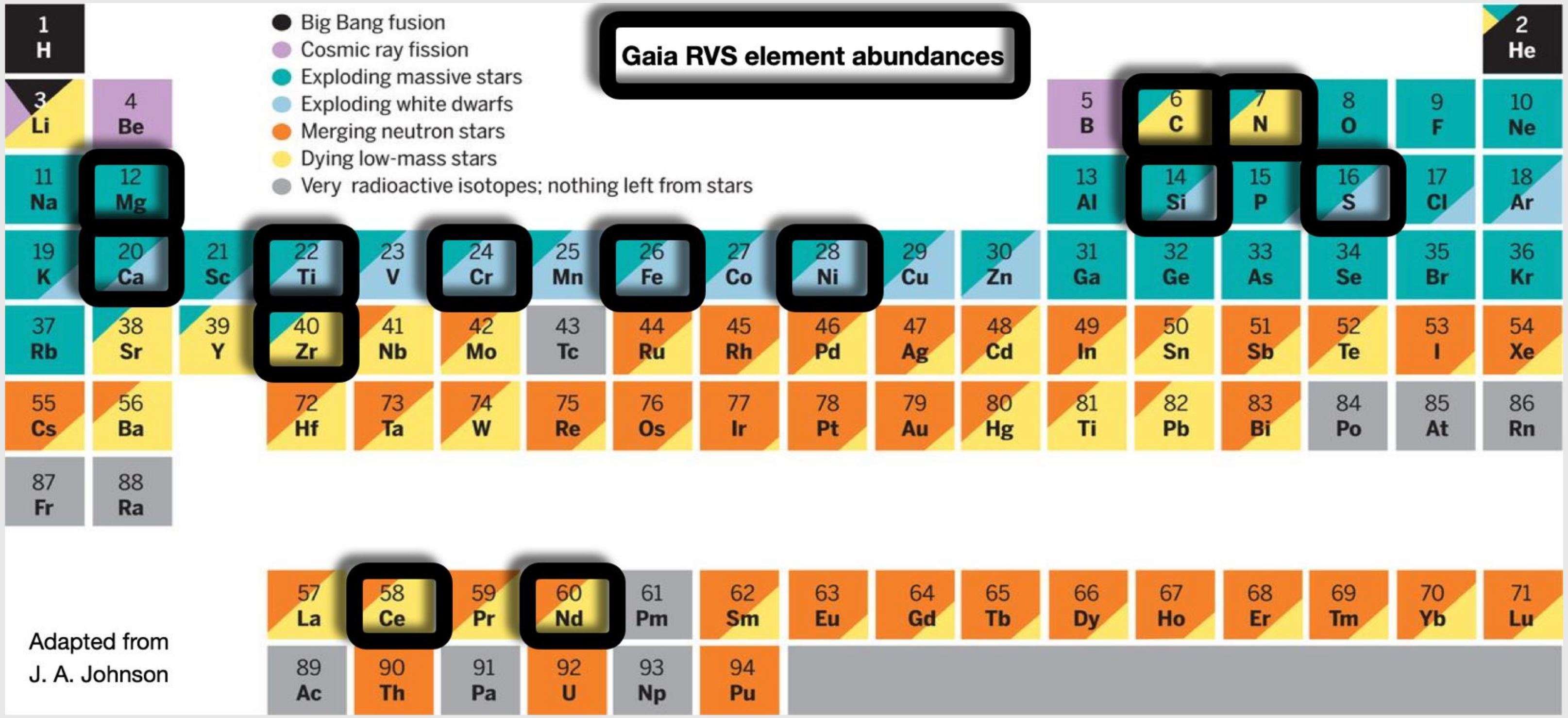
Homogeneous data

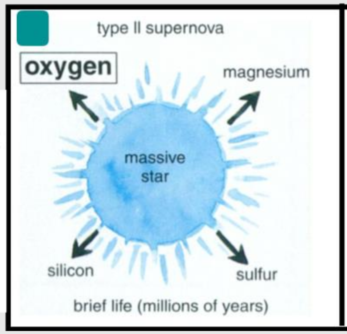
Different selection function than ground-based data

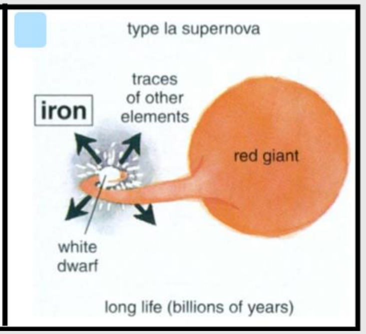
No input catalogue

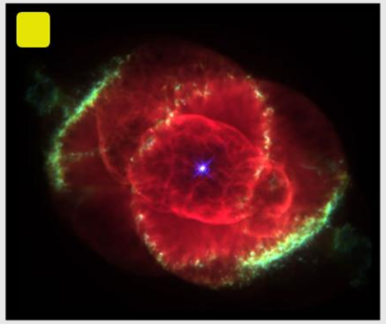
GSPspec individual element abundances

Different nucleosynthetic channels

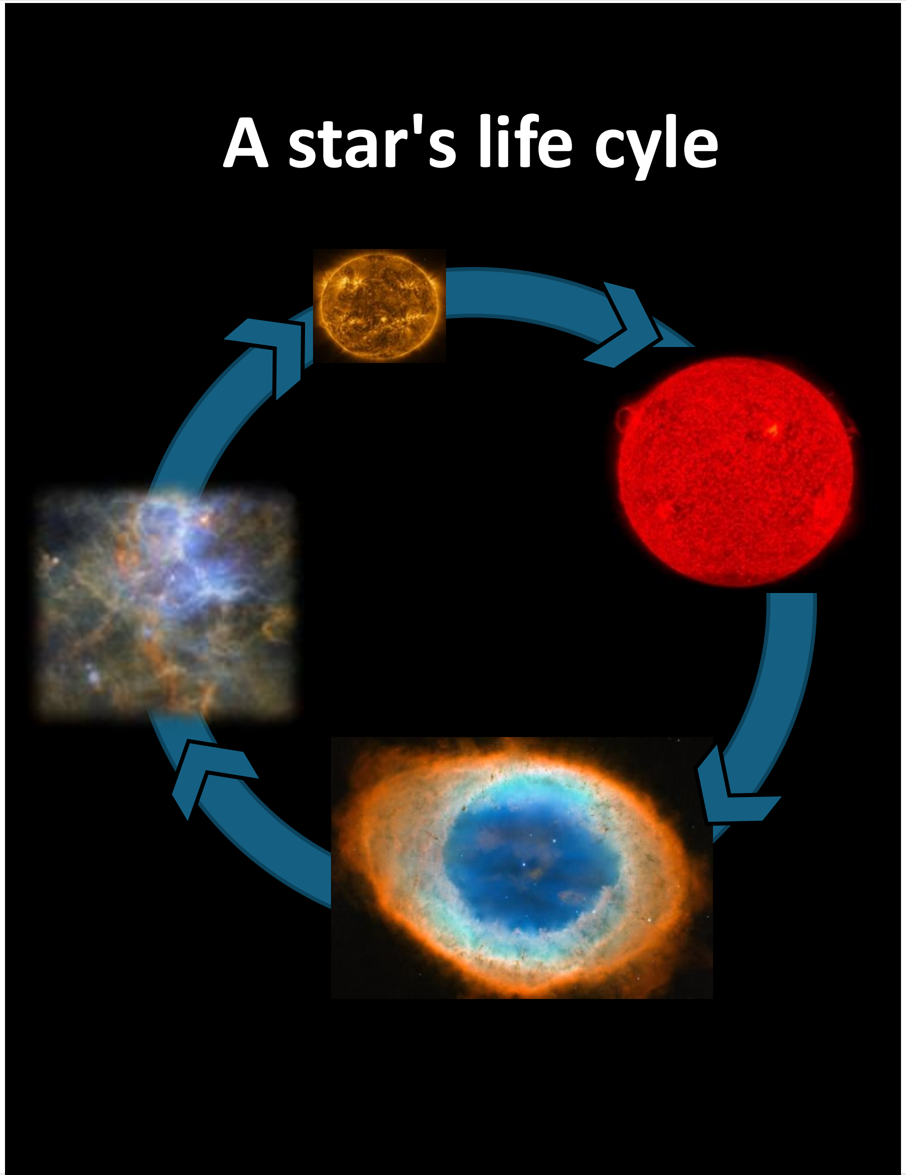






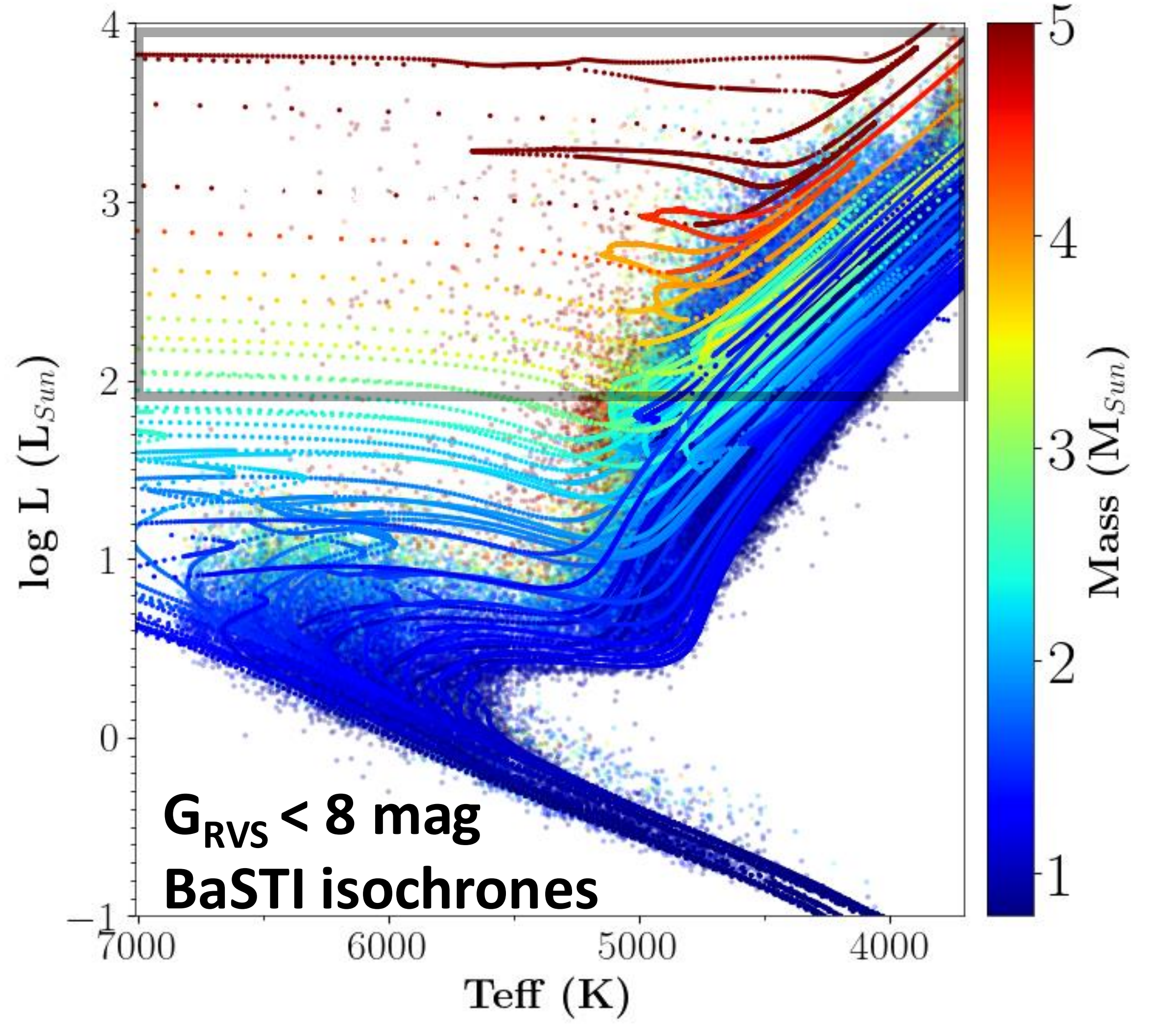


credits C. Chiappini



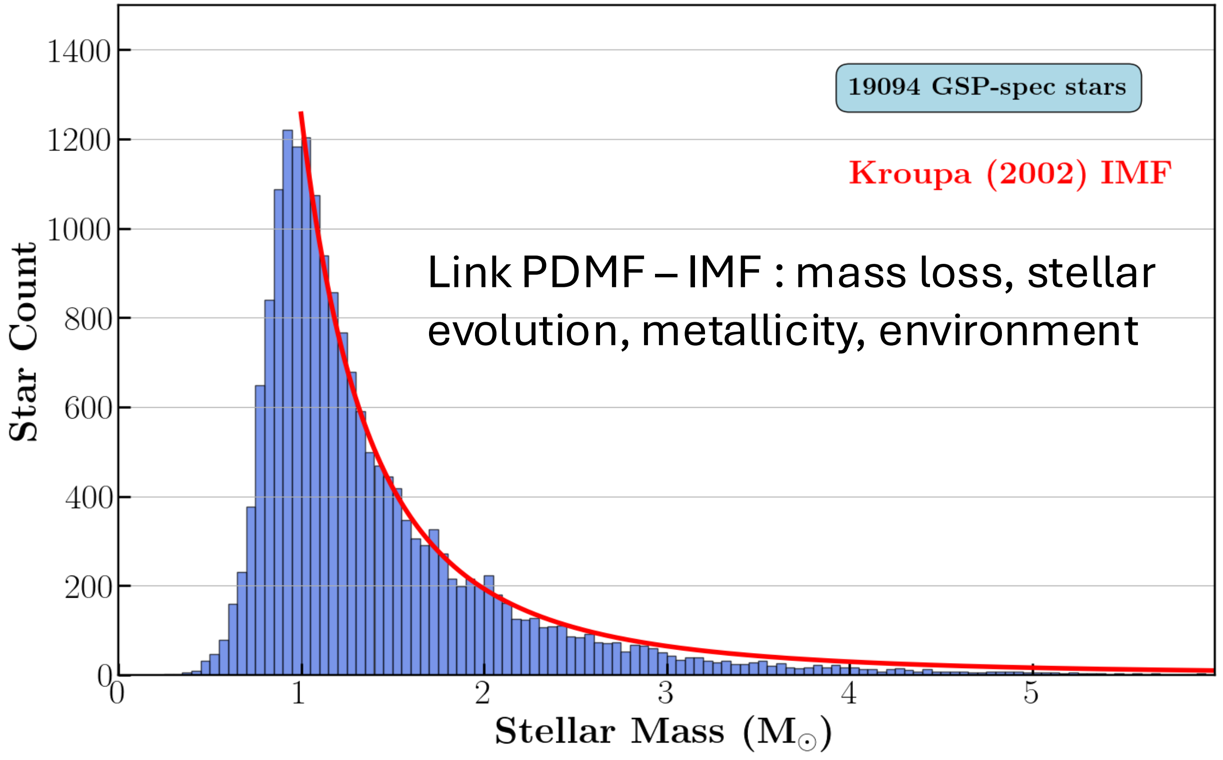
Diversity and evolution: stellar present day mass function

Selection of bright stars to enhance completeness & giant stars to reduce selection effects



Very good agreement with Kroupa IMF in the 1-4 M_{sun} regime

Assesment of completeness needed (GaiaUnlimited)

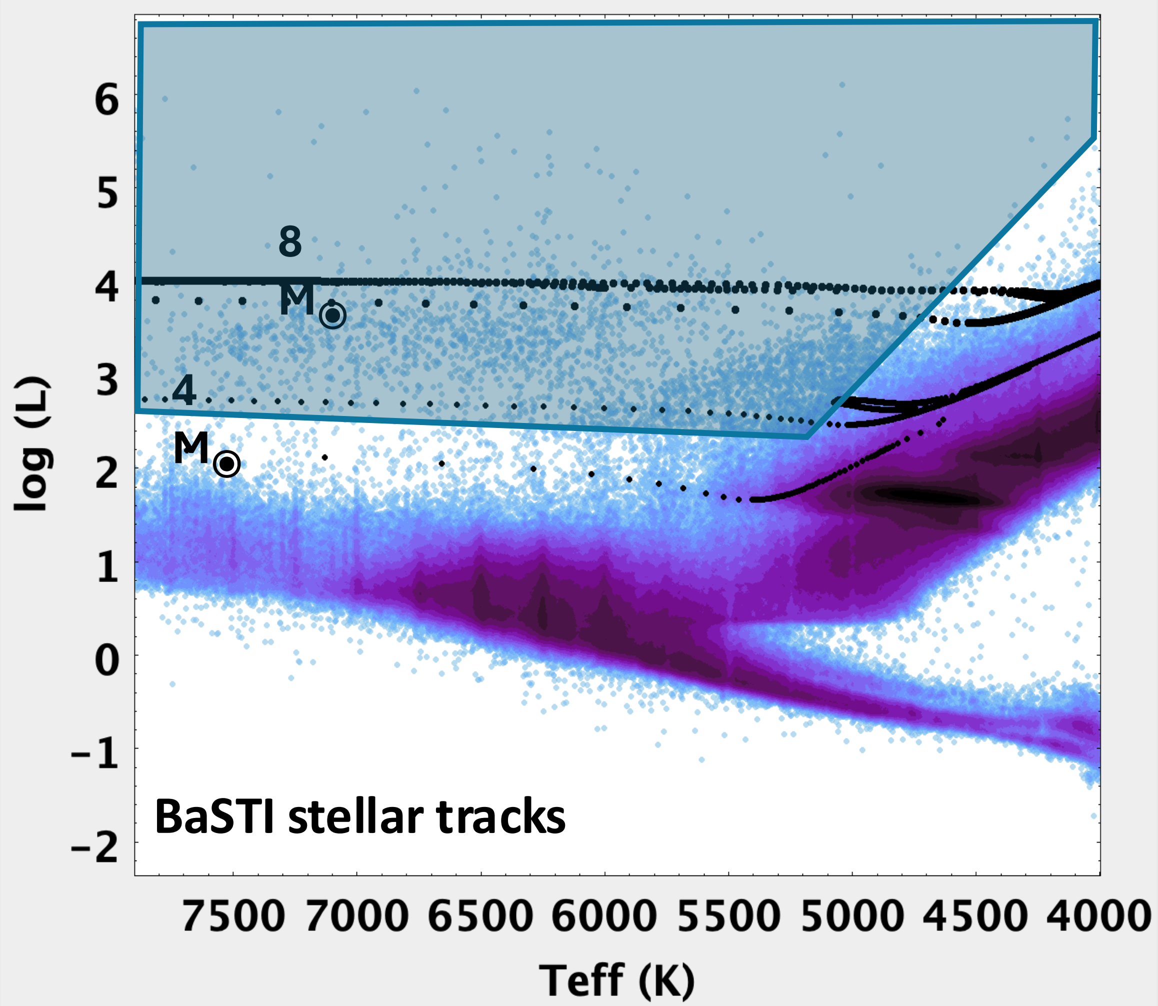


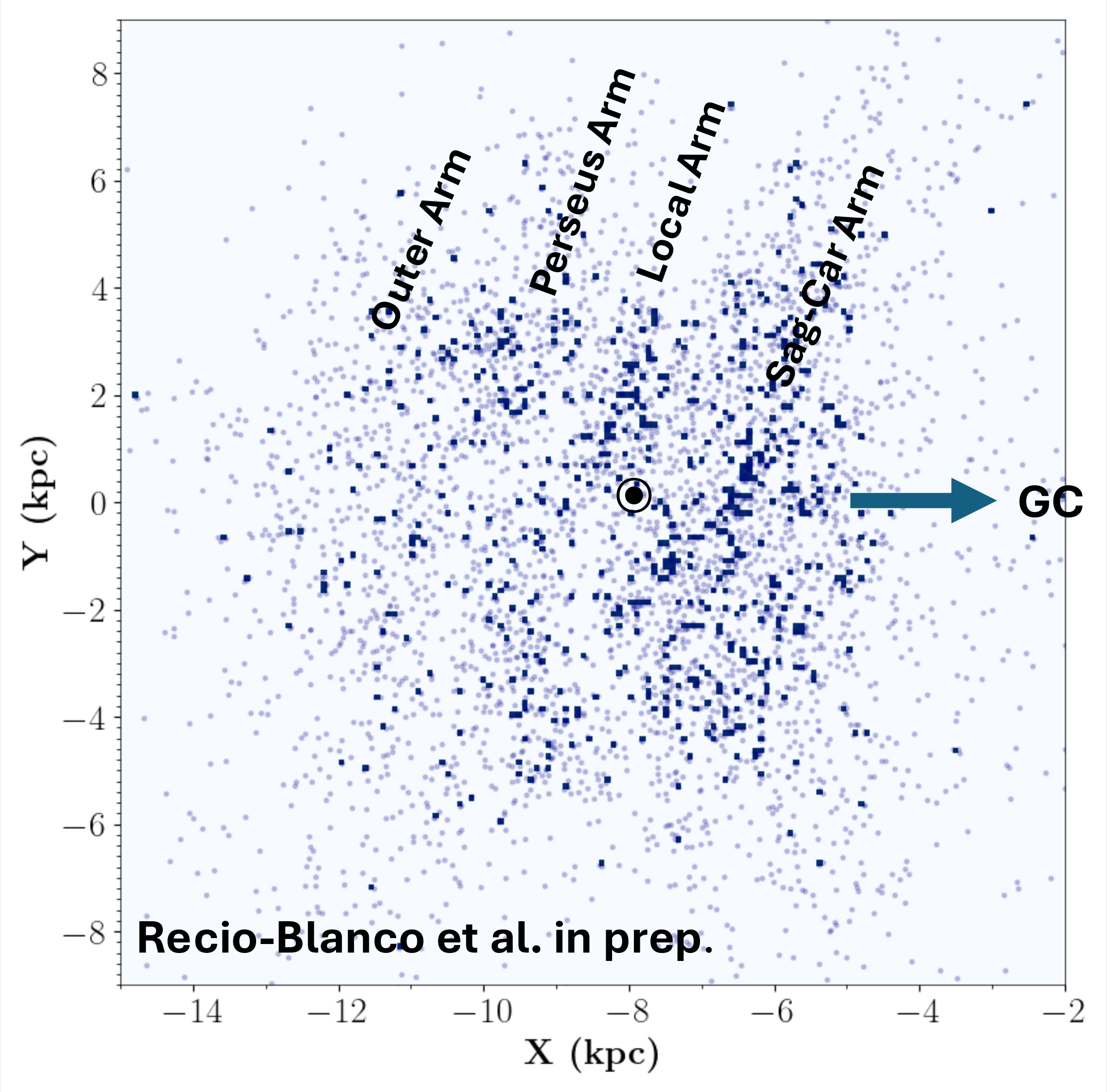
Link PDMF – IMF : mass loss, stellar evolution, metallicity, environment

de Laverny et al. in prep.

Diversity and evolution: Super Novae precursors

Characterisation of cool massive stars, including SN Type II progenitors





See Drimmel et al. 2024 for comparison with Cepheids