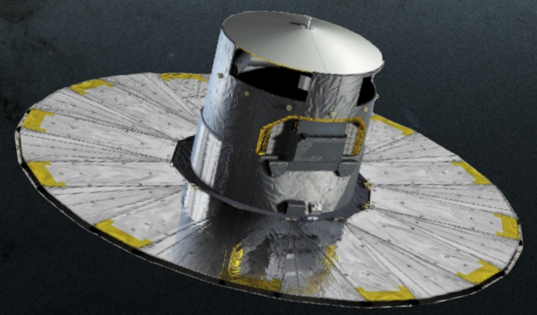
The evolution of the Galactic discs revealed by the Gaia - APOGEE - *Kepler* giant stars



Nadège Lagarde
Laboratoire d'Astrophysique de Bordeaux

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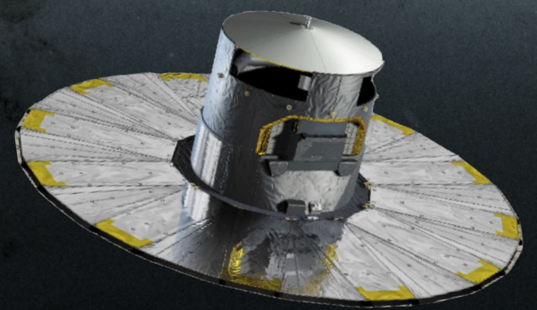

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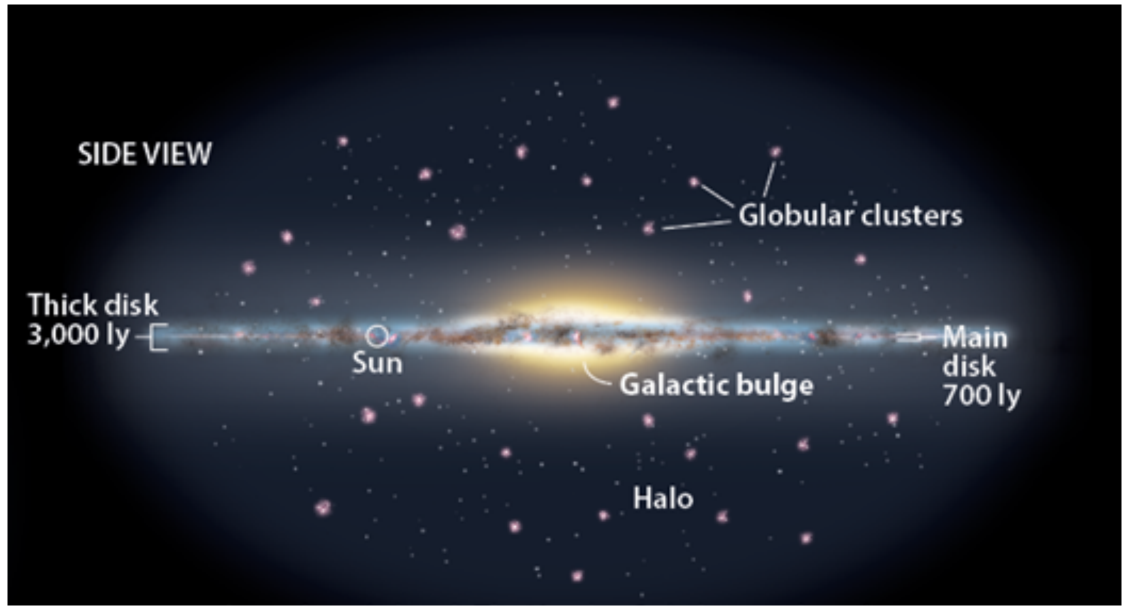
The history of our Galaxy is encoded in **the chemical properties** of stars, in their **kinematics** and **ages**



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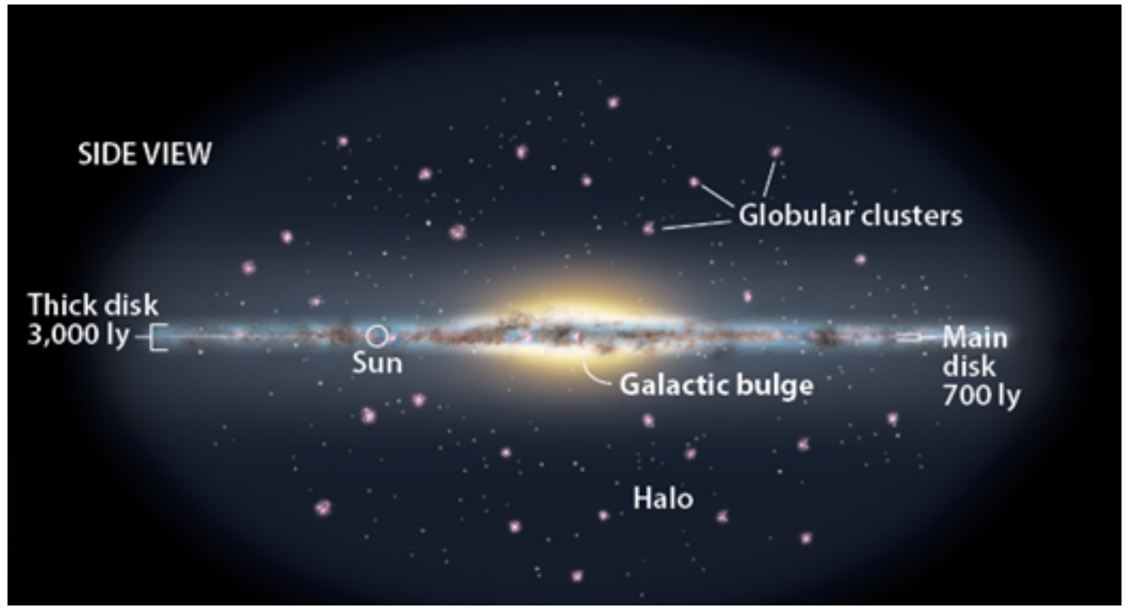
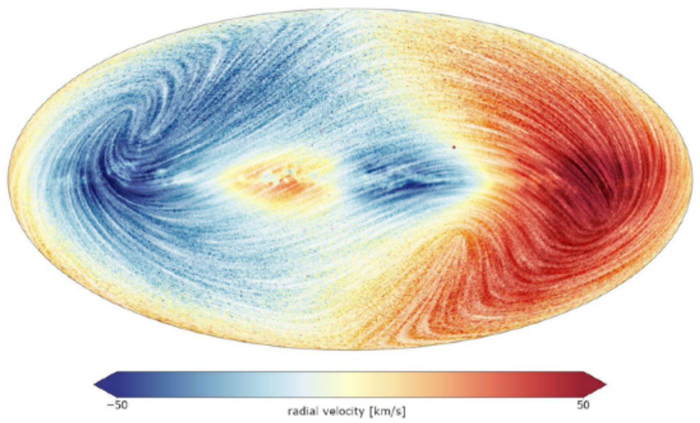


These properties reveal key insights into **star formation** and the **dynamical history of the MW**.

Gaia data

This large data set allows to discover crucial events in the evolution of the MW



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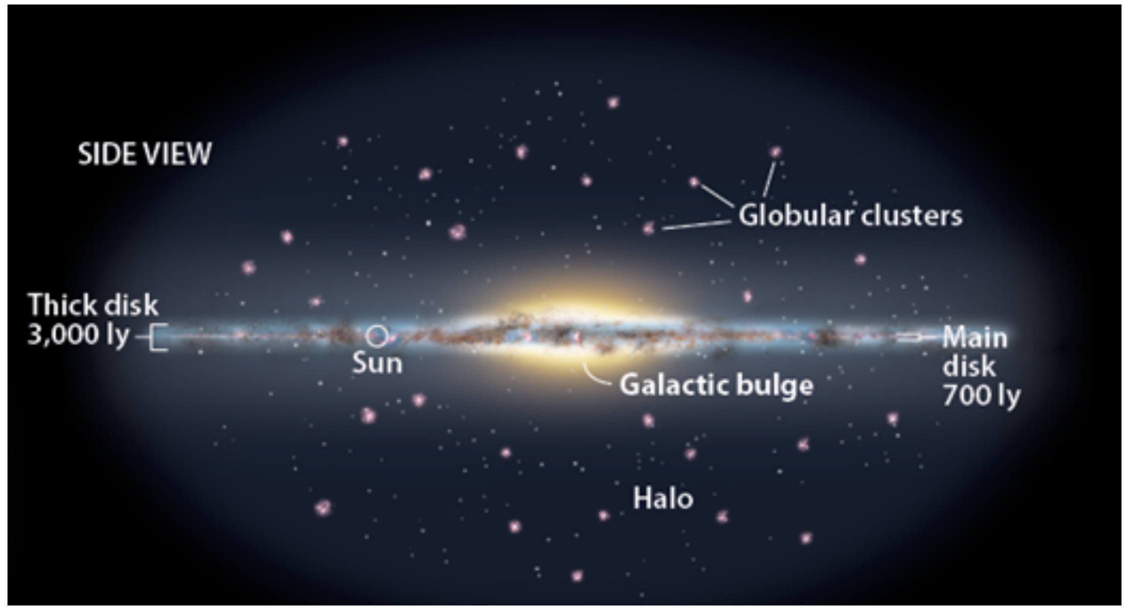

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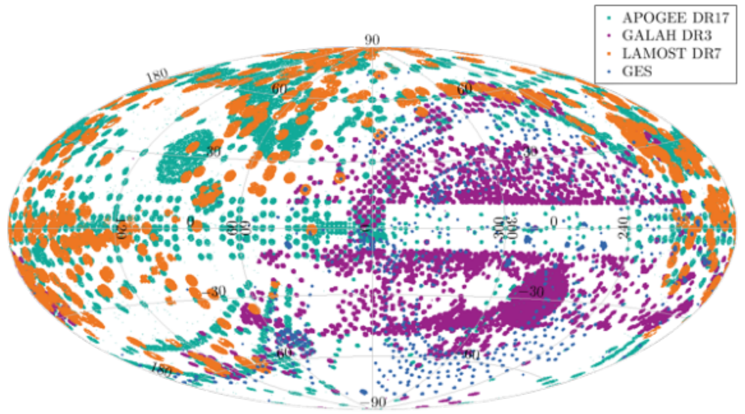

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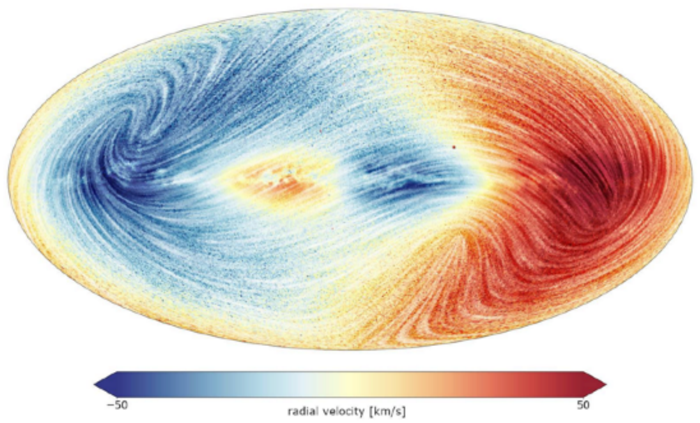

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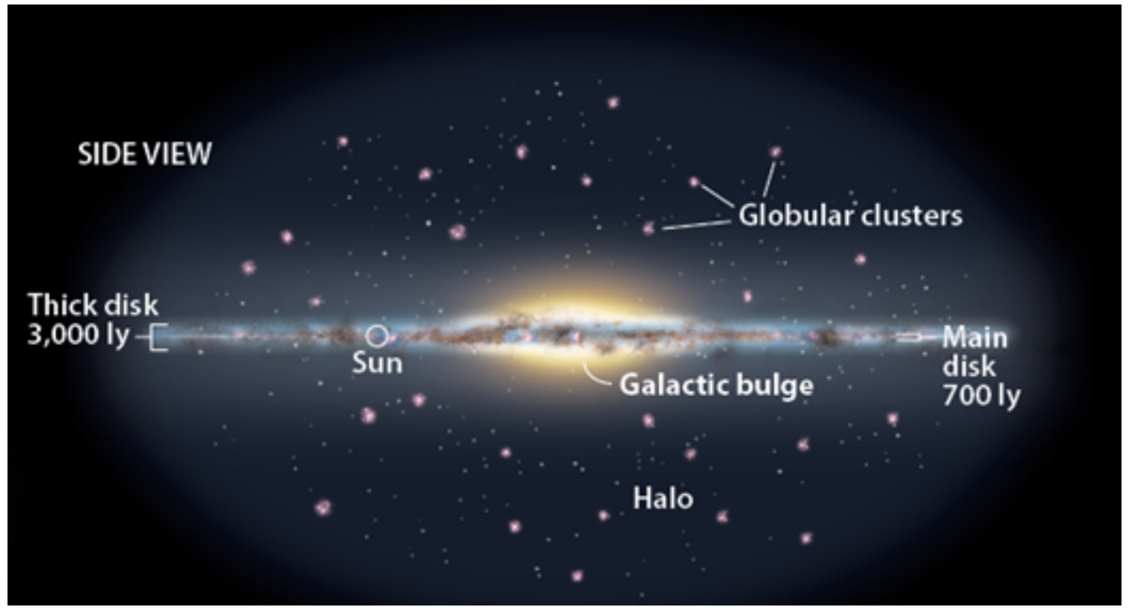

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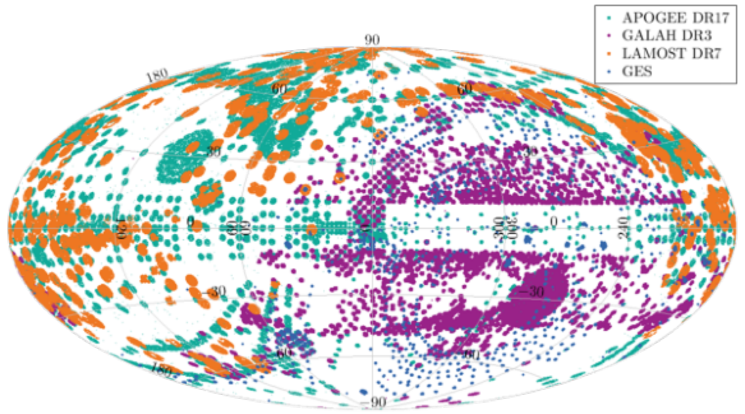

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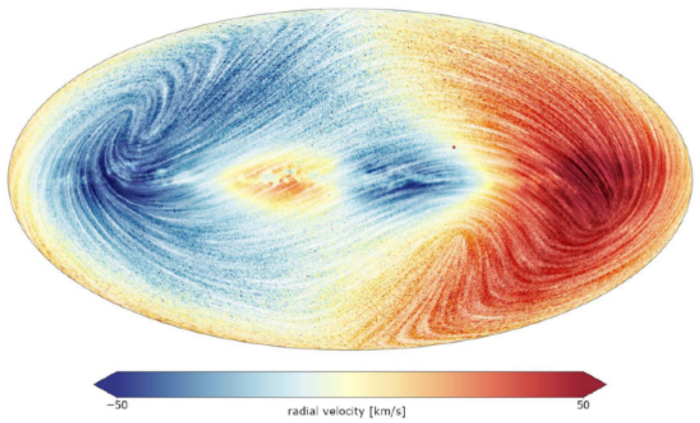

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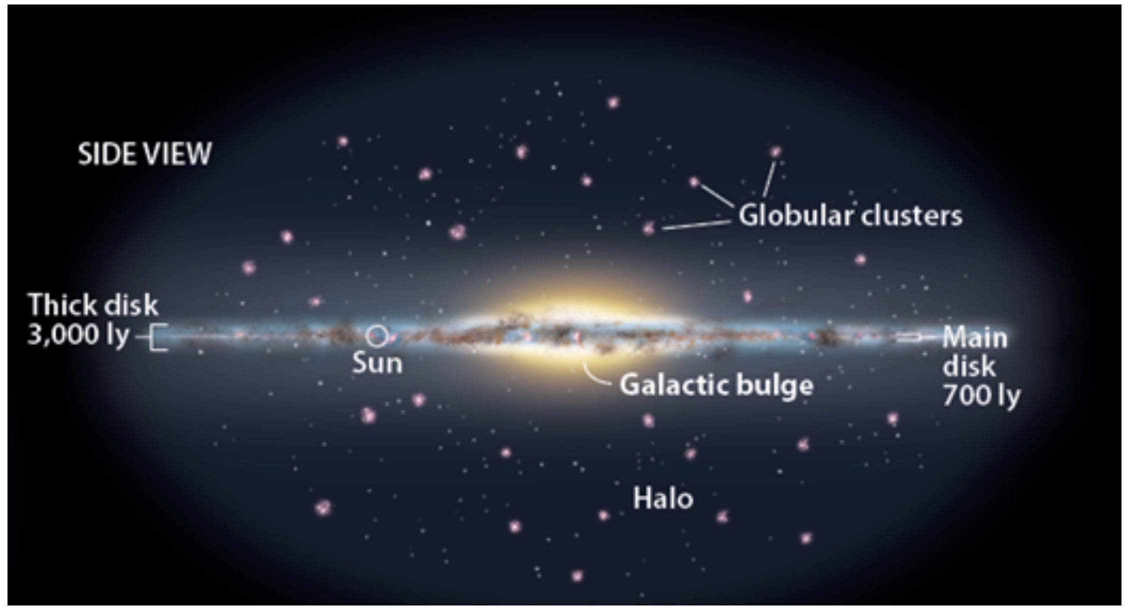

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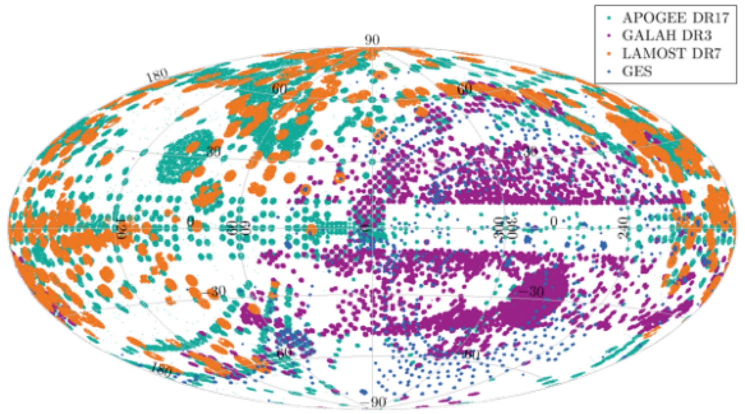
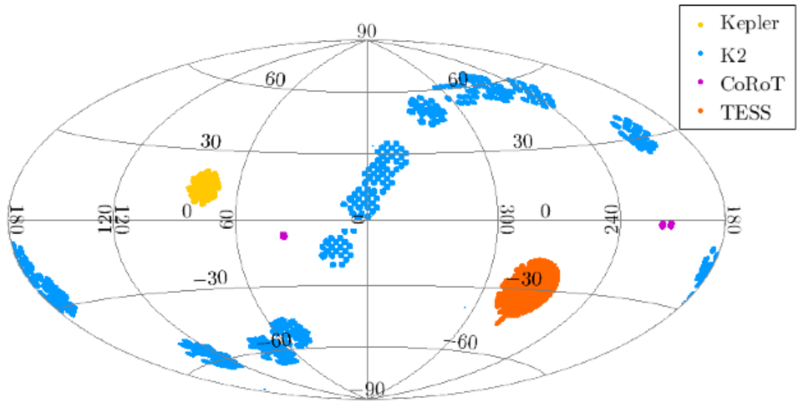


Asteroseismology



To probe stellar interiors
Chaplin & Miglio 2013
•Stellar radius, masses without being limited to surface properties
•Stellar ages with higher accuracy than isochrones fitting
Lebreton et al 2014a,b ; Miglio et al 2021

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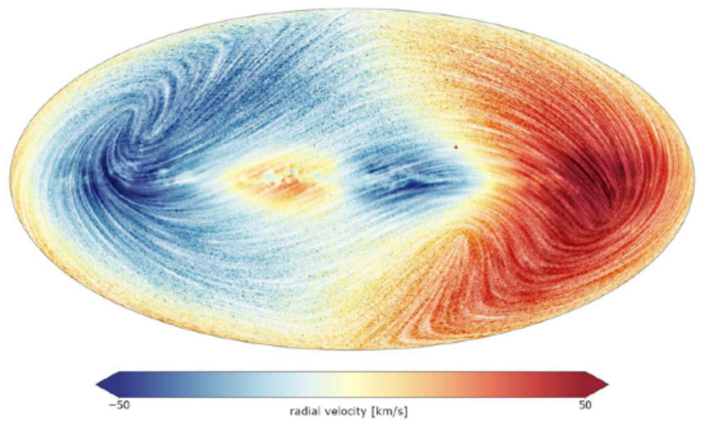

Spectroscopy

Spectroscopic parameters coming from the APOGEE DR14

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Accurate ages and masses deduced from the asteroseismic measurements

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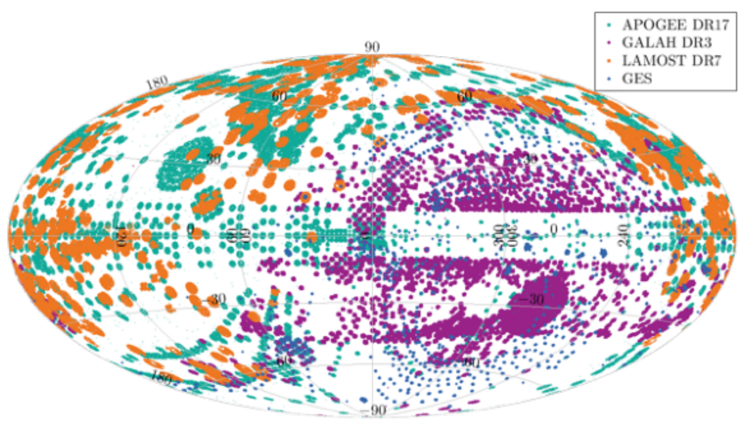

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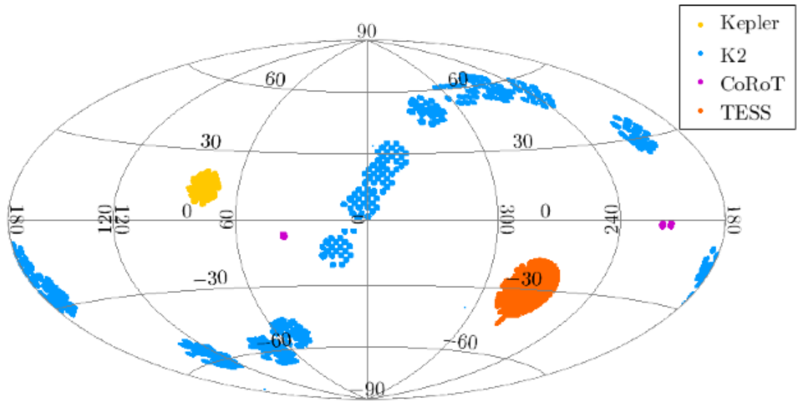

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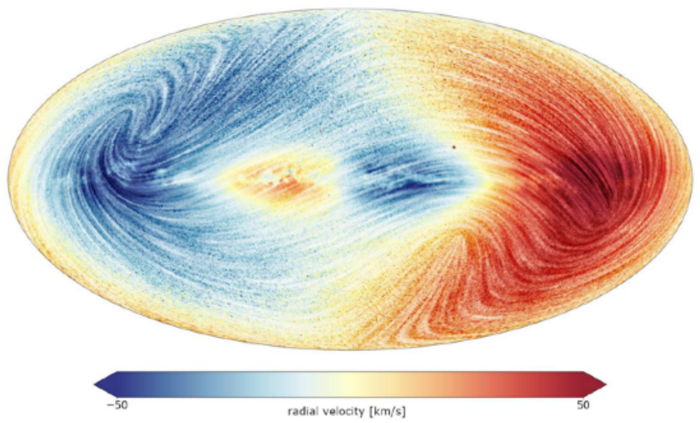

Lagarde et al. 2021

Our sample

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~5000 giant stars :

[Fe/H], [α/Fe],

Mass, Age

dist., V_R, V_φ , V_Z

Lagarde et al. 2021

APOKASC catalog
Pinsonneault et al. (2018)

Spectroscopy

APOGEE

Spectroscopic parameters coming from the APOGEE DR14

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Kepler

~5000 giant stars :

[Fe/H], [α/Fe],

Mass, Age

dist., V_R, V_φ, V_Z

Miglio et al (2021)

Gaia data

StarHorse distances from *Queiroz et al. (2020)*
Galactic velocities are computed following the method developed by *Gaia collaboration et al (2018)*

Selection criteria:

- APOKASC criteria
- the mass of clump stars, Mclump $\geq 1.2\ M_\odot$
- the radius of RGB stars, RGB $< 11R_\odot$
- Used models including microscopic diffusion.

Lagarde et al. 2021

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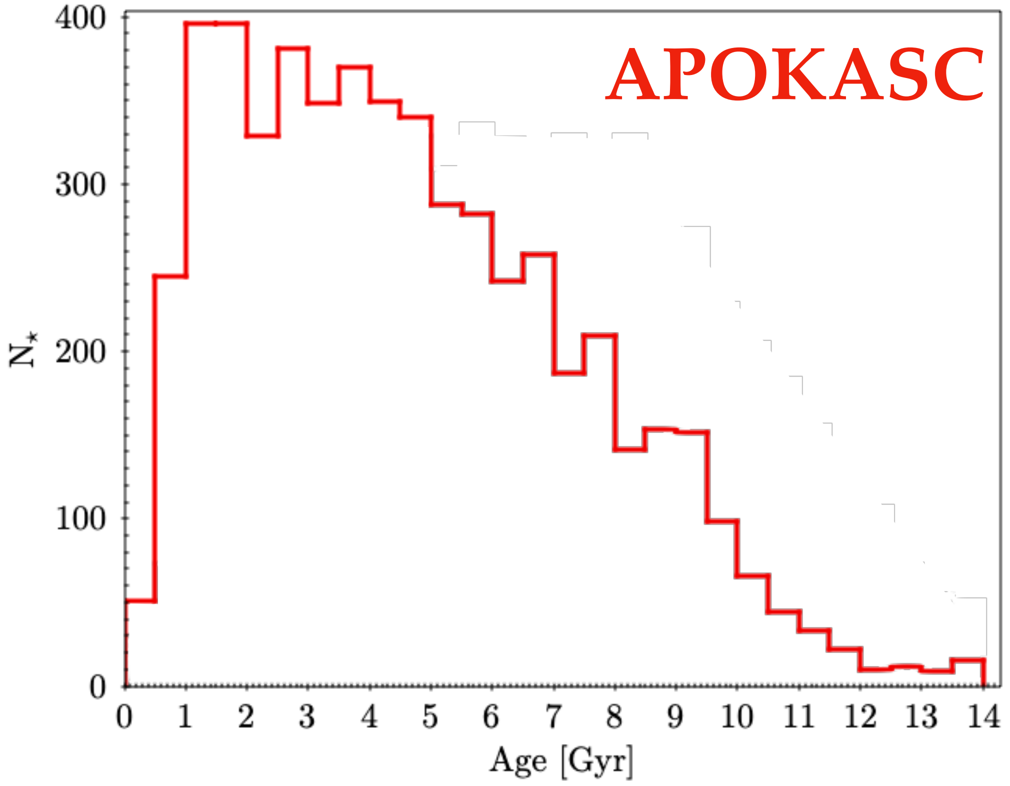

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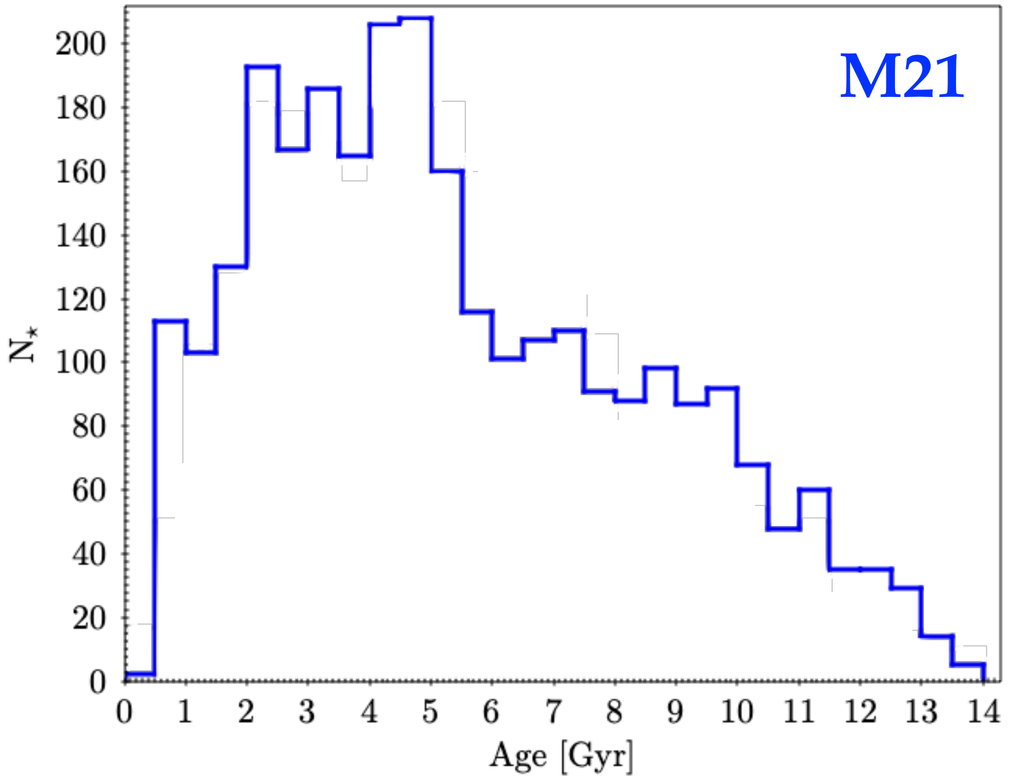

Lagarde et al. 2021

APOKASC catalog

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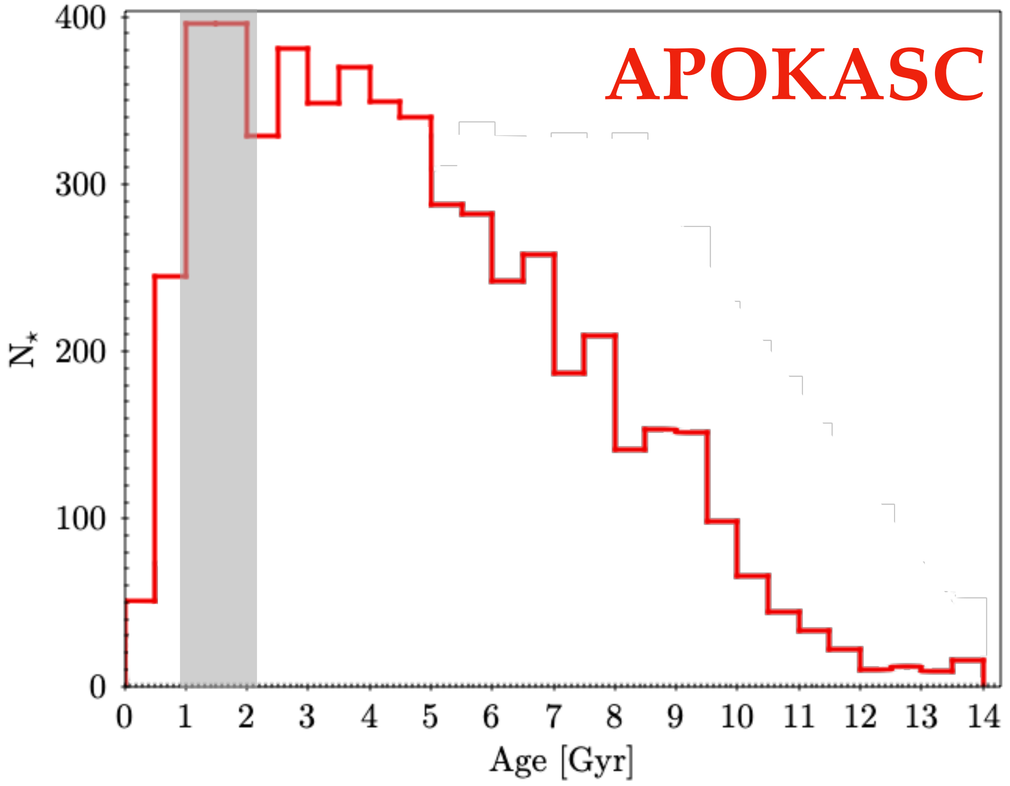
- **APOKASC** age distribution peaks around 1-2 Gyr
  => not seen in **M21 sample**



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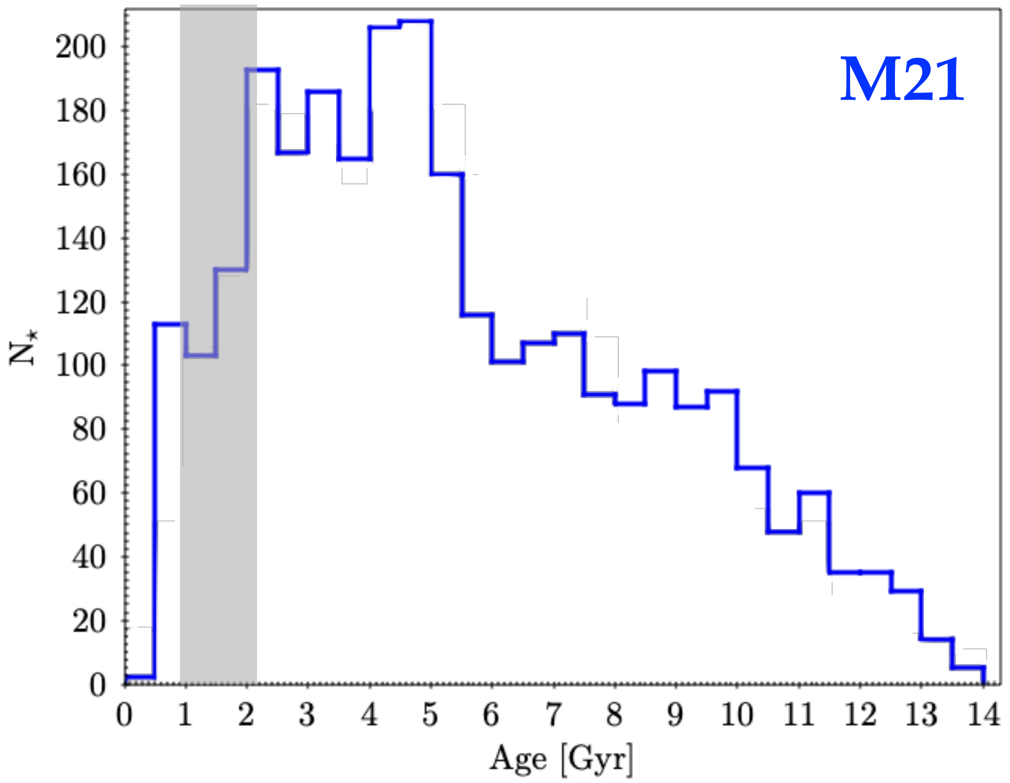

Lagarde et al. 2021

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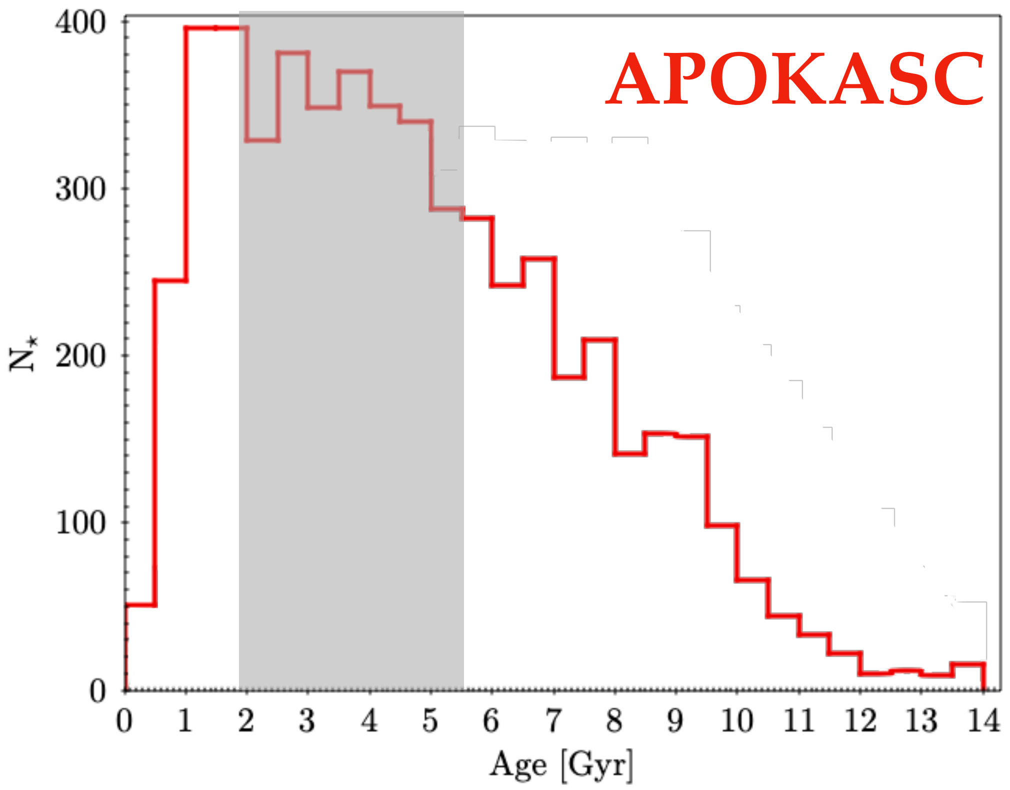


- **APOKASC** age distribution peaks around 1-2 Gyr
  => not seen in **M21 sample**

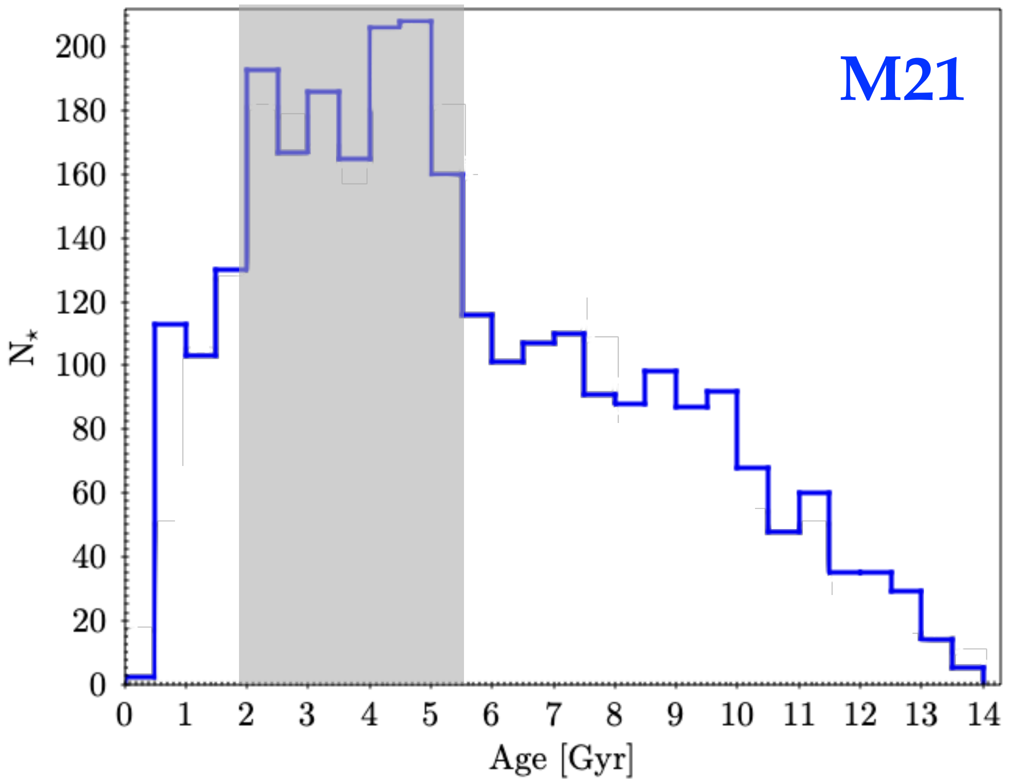
- **Both samples:**
  A small sign of SFR increase between 2 and 5.5 Gyr

  Between 2 and 3 Gyr = An increase in star formation
  (e.g., Cignoni et al 2006, Mor et al 2019, Donlon et al 2020)

  However low stellar ages are strongly dependent on hydrodynamical processes included in stellar evolution models.

=> Need to be confirmed with larger seismic sample.

Miglio et al (2021)



Lagarde et al. 2021

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~5000 giant stars :

[Fe/H], [α/Fe],

2 determinations of Mass, Age

dist., V_R, V_φ , V_Z

Main goals

1) To discuss the main chrono-chemo-kinematics relations to highlight key constraints to MW evolution

2) To highlight differences between observations and Galactic theory **using a stellar population synthesis model.**
Features not well reproduced by the mock catalog **can reveal missing physical processes** and improve our understanding of Galactic evolution..

Lagarde et al. 2021

Our sample

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Need to highlight selection bias

2) To highlight differences between observations and Galactic theory **using a stellar population synthesis model.**
Features not well reproduced by the mock catalog **can reveal missing physical processes** and improve our understanding of Galactic evolution..

Need to take into account selection function

Lagarde et al. 2021

The Besançon Galaxy Model is a stellar populations synthesis model of the Milky Way

Simulates the properties of stars in our Galaxy ***by accurately reproducing the selection biases on observables (selection functions and observed errors)****.*

Observations

Observables
Selection function
Limits and biaises of the instrument

Theories models predictions

Stellar Evolution

Galactic Formation & Evolution

The Besançon Galaxy Model is a stellar populations synthesis model of the Milky Way

Simulates the properties of stars in our Galaxy ***by accurately reproducing the selection biases on observables (selection functions and observed errors).***

Observations

Observables
Selection function
Limits and biaises of the instrument

BGM

BGM acts as a filter between observations and theories, allowing **a direct comparison of large surveys with theoretical patterns.**

Theories models predictions

Stellar Evolution

Galactic Formation & Evolution

OUTPUTS

Global properties of stars: Teff, logg, age, colors, magnitudes,…

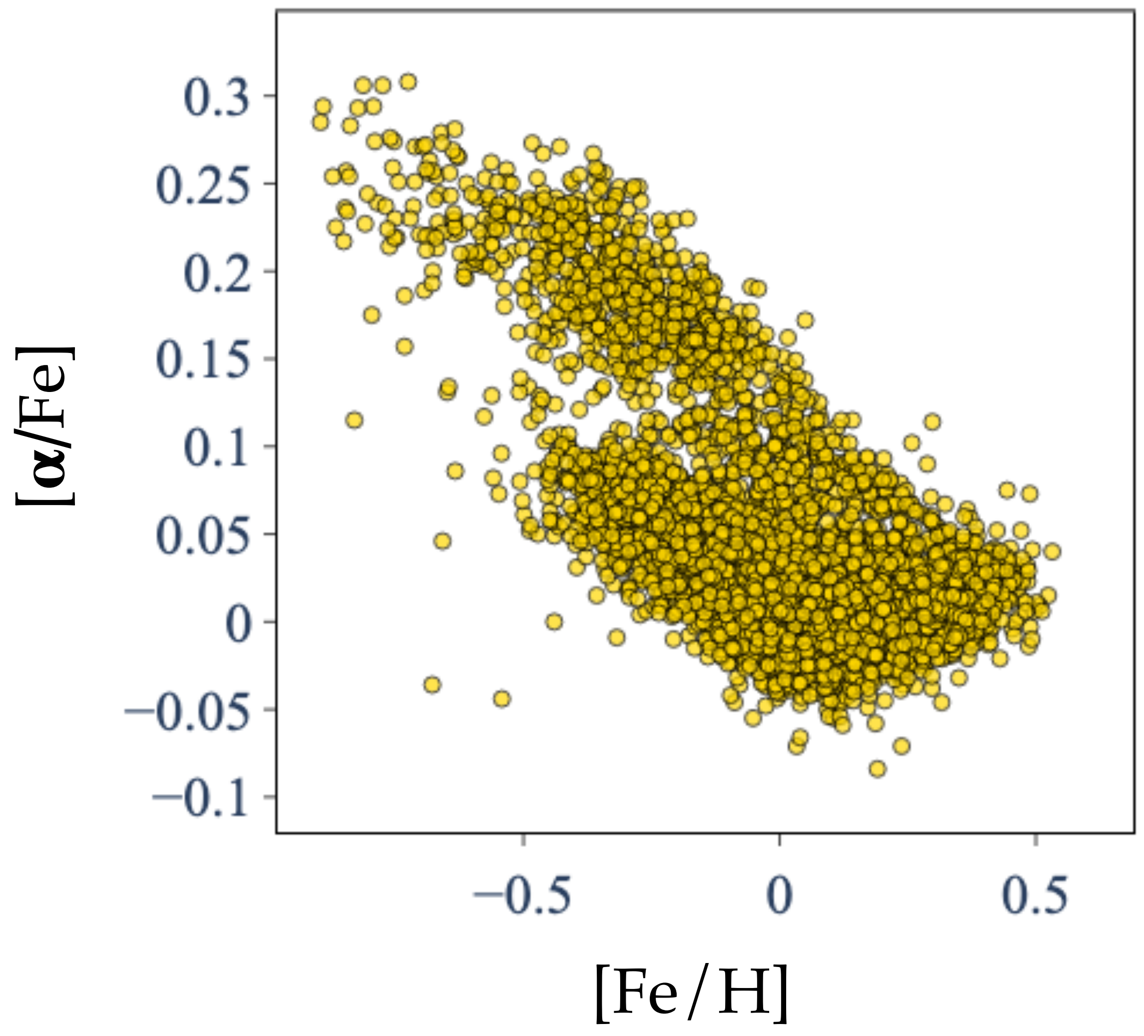
Seismic properties of stars: $\Delta\nu$, ν_{max}, $\Delta\Pi(l=1)$

Stellar abundances: from ^{1}H to ^{37}Cl

Kinematics properties: Velocities

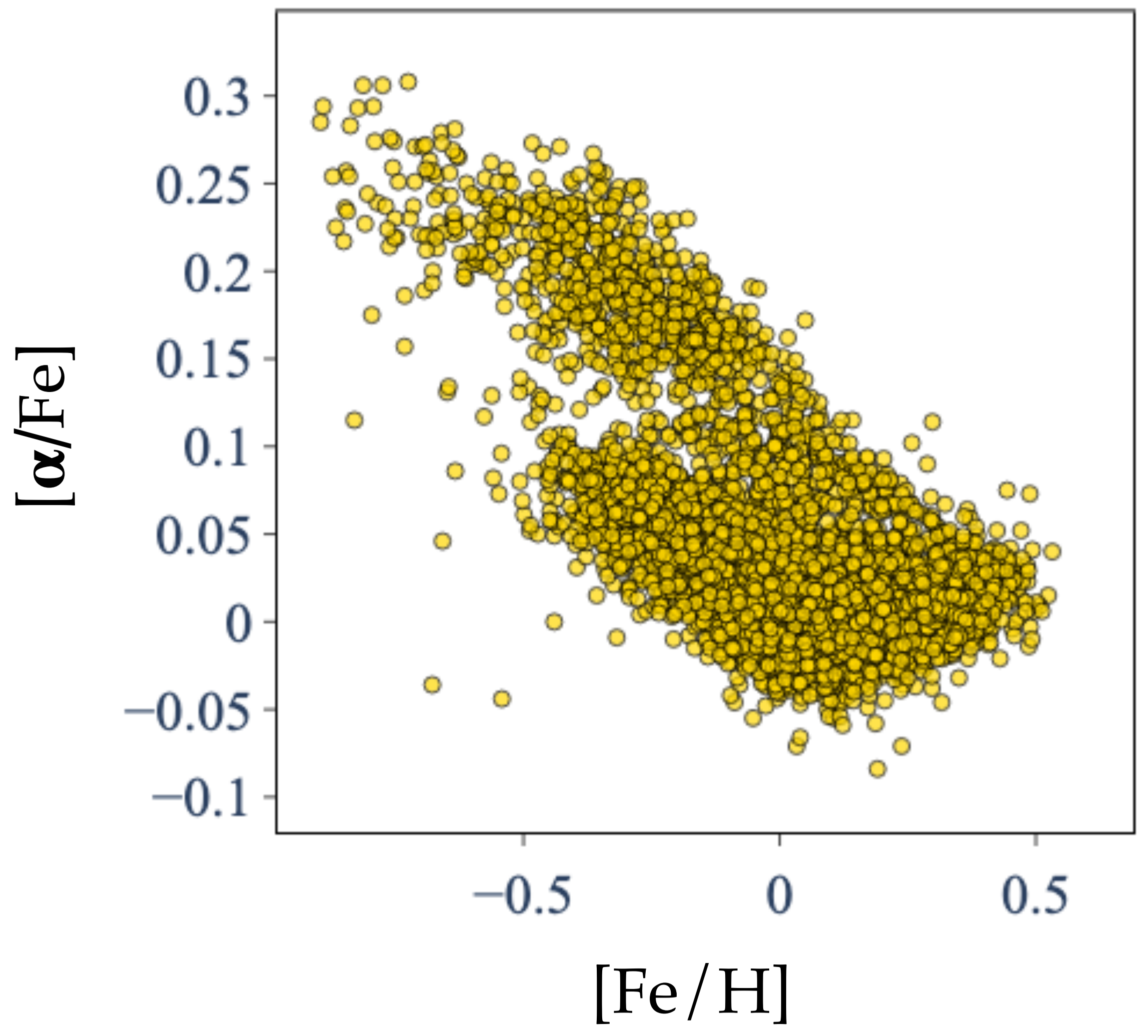
Lagarde et al. 2017, 2019

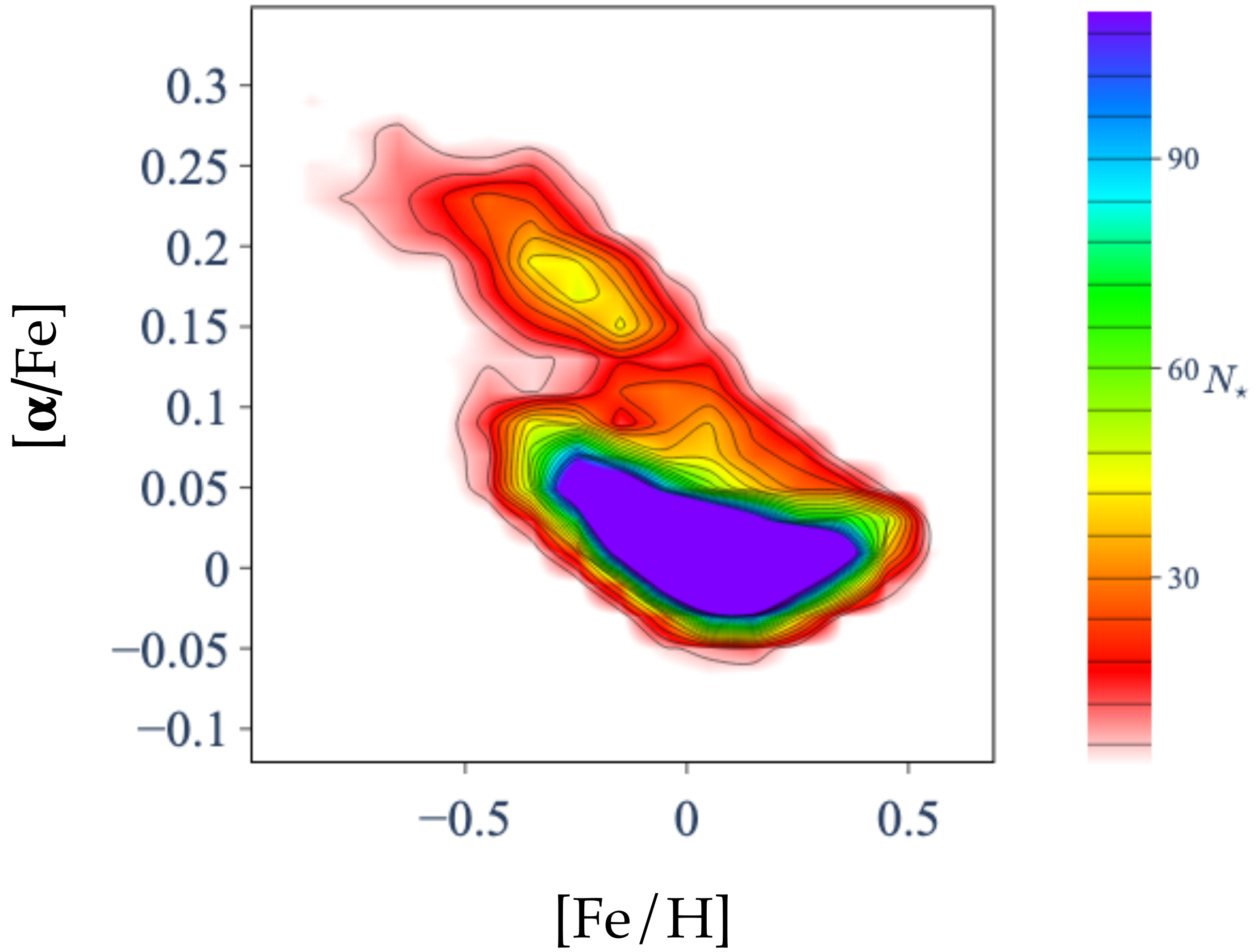
- Chemical properties are used to identify stellar populations of our sample



Lagarde et al. 2021

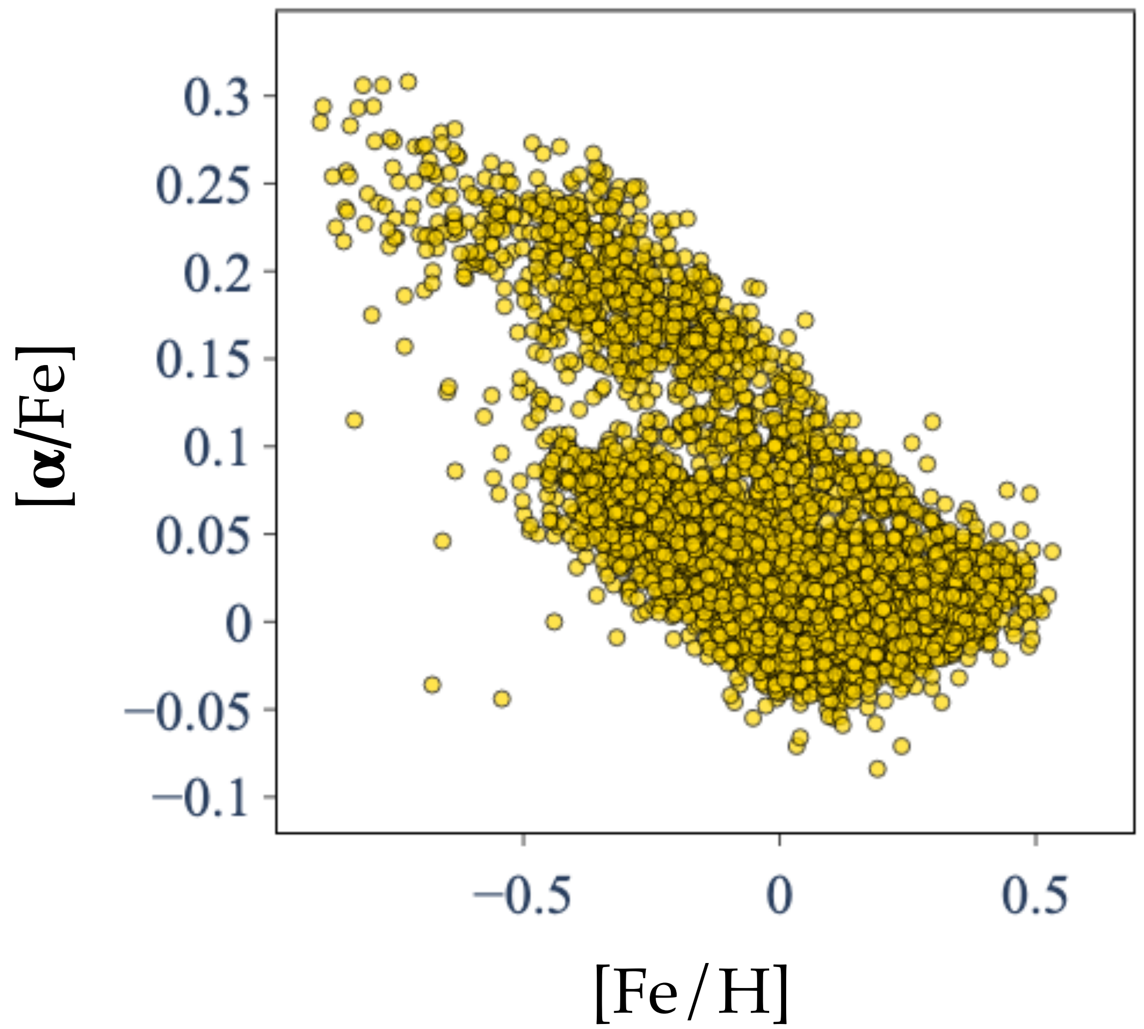
- Chemical properties are used to identify stellar populations of our sample
- **The thin disc** is easily identifiable

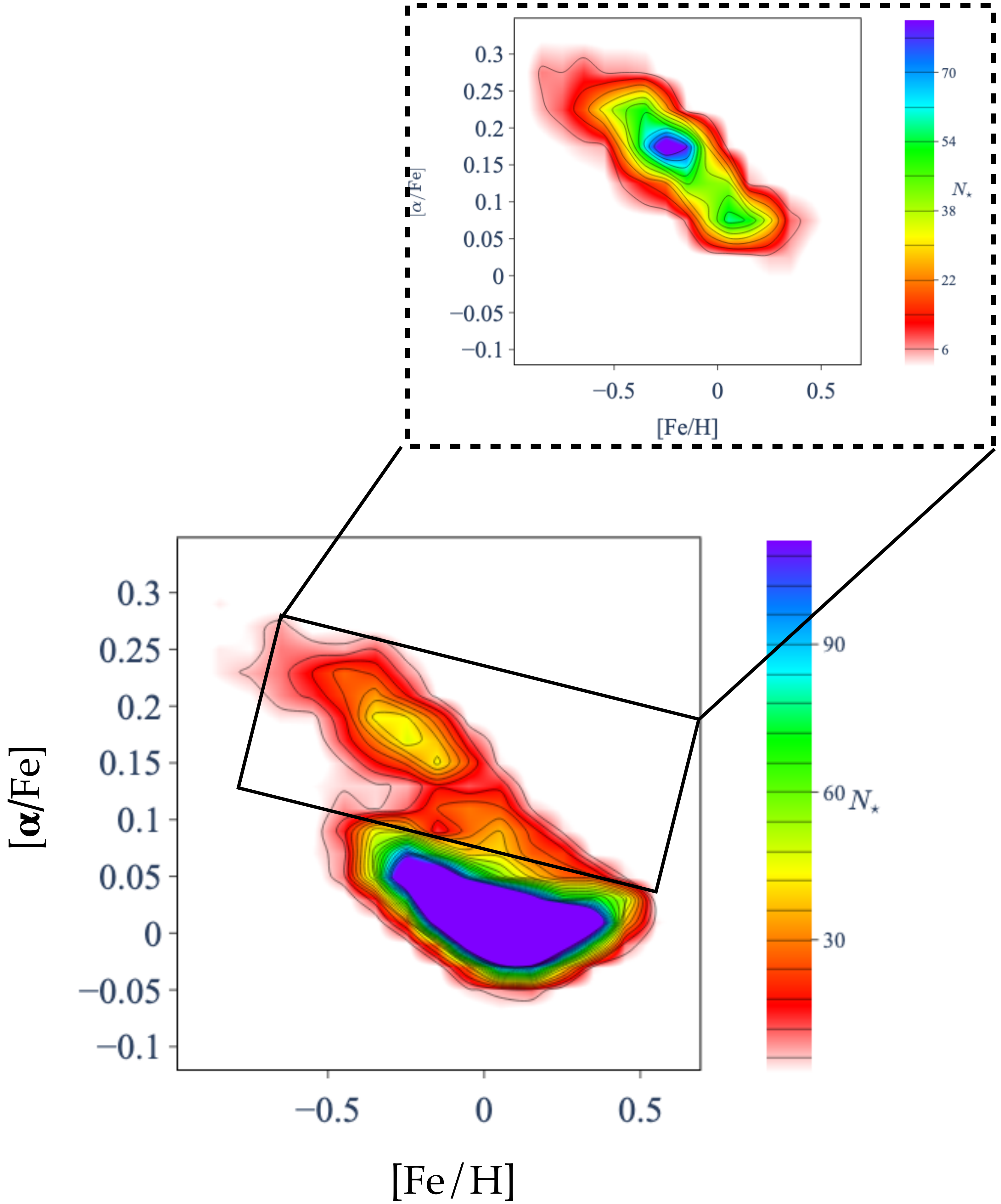




Lagarde et al. 2021

- Isolating « common » thick disc, two density peaks appears. Already mentioned by *Adibekyan et al (2013) and Anders et al (2018)*





Lagarde et al. 2021

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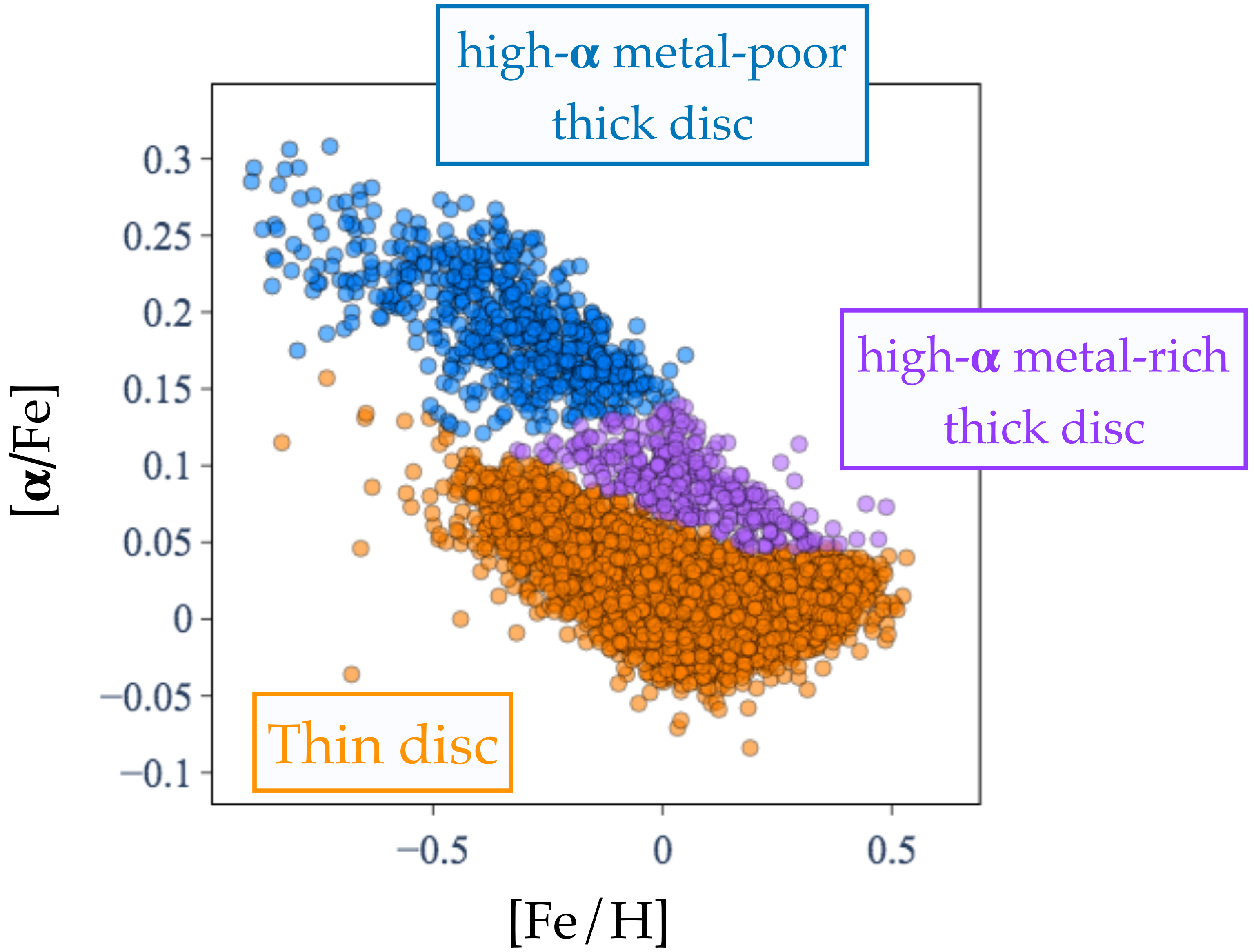
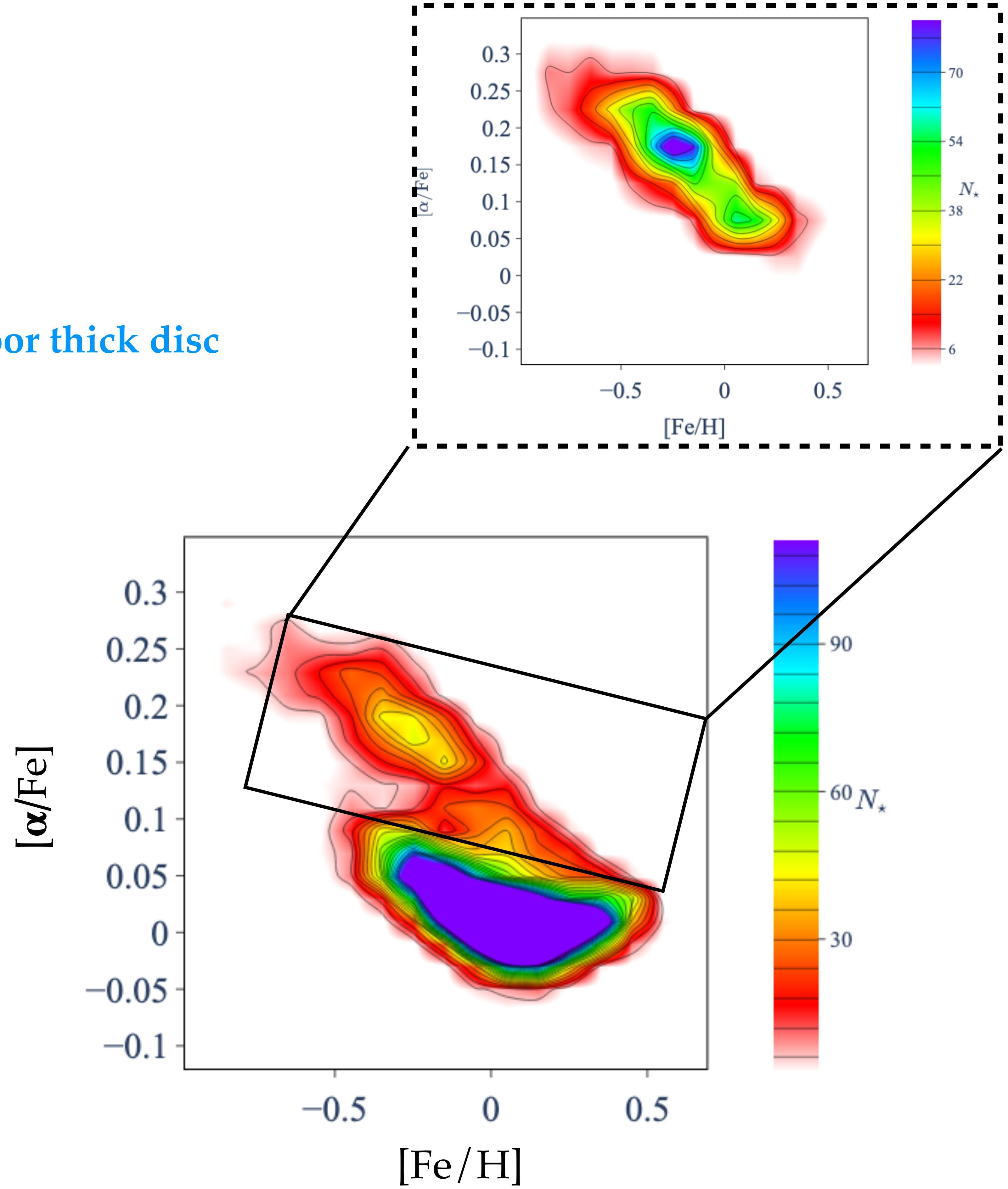
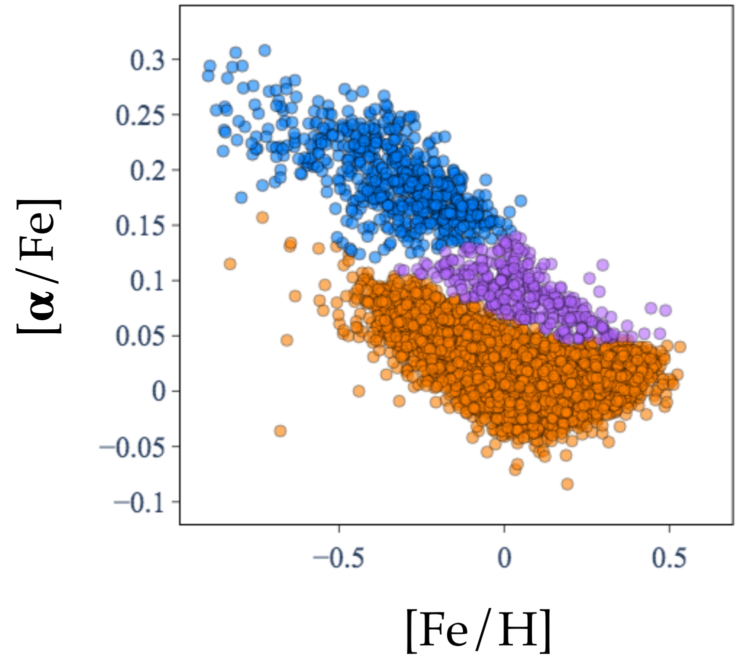
For our study, we consider 3 stellar populations :
the thin disc ; the high-α metal-rich thick disc ; the high-α metal-poor thick disc

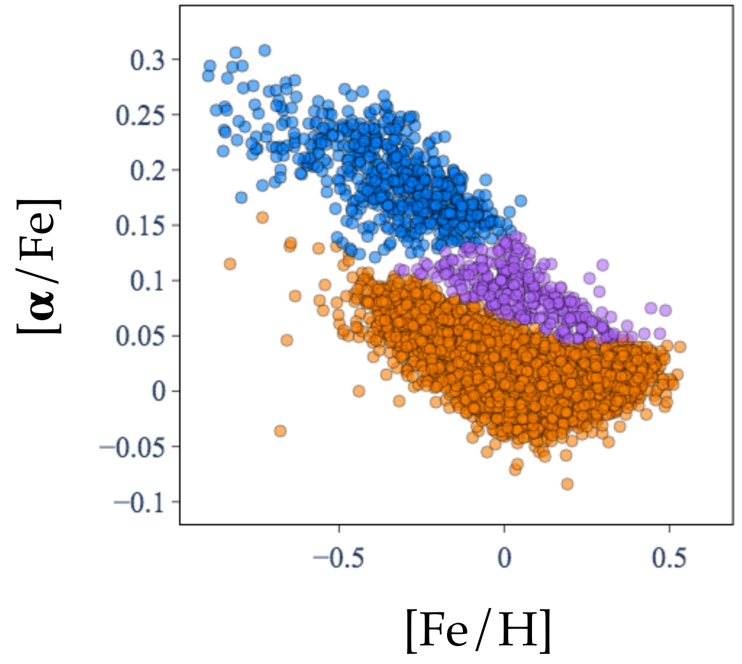


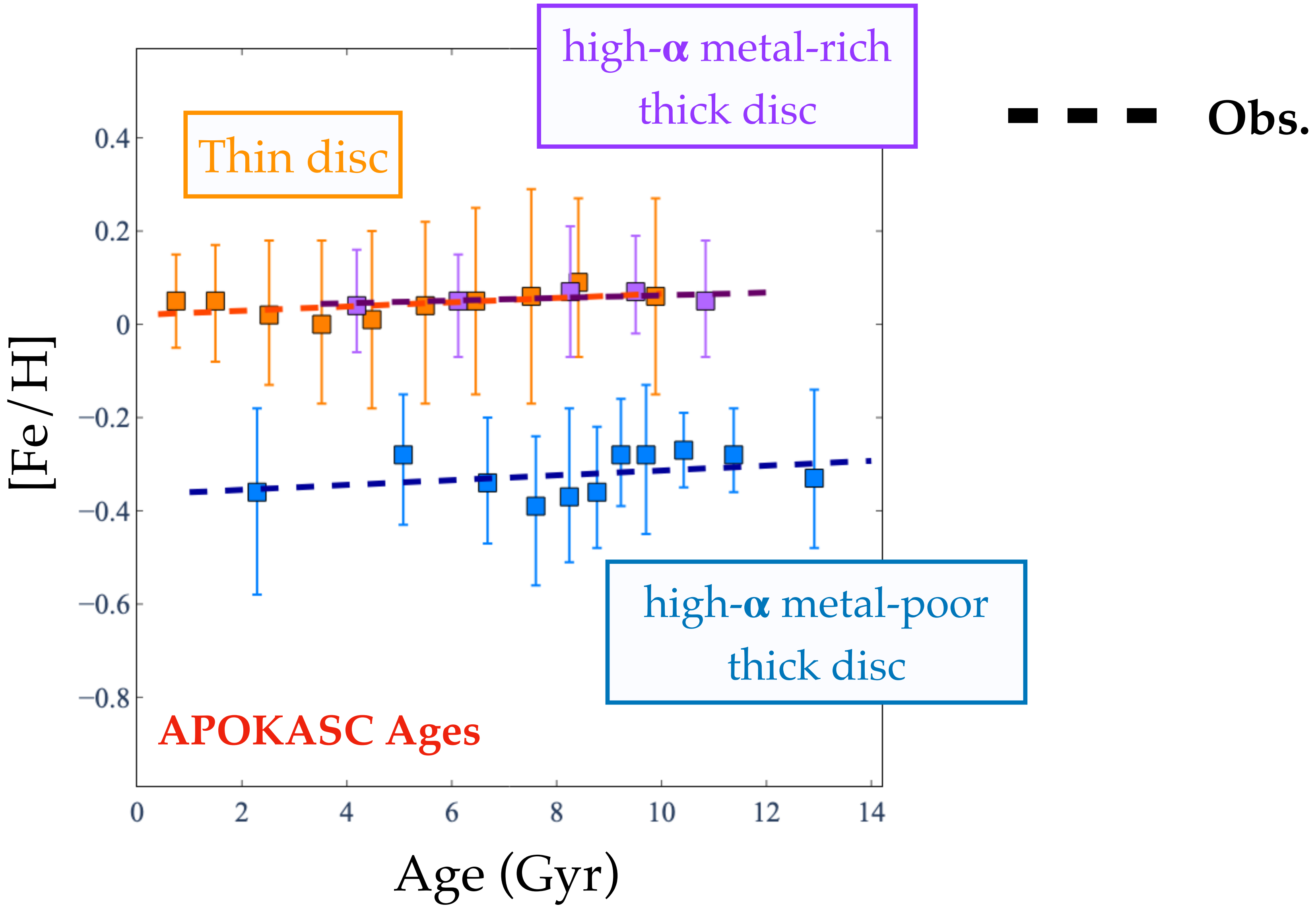


Lagarde et al. 2021

Age-metallicity relations







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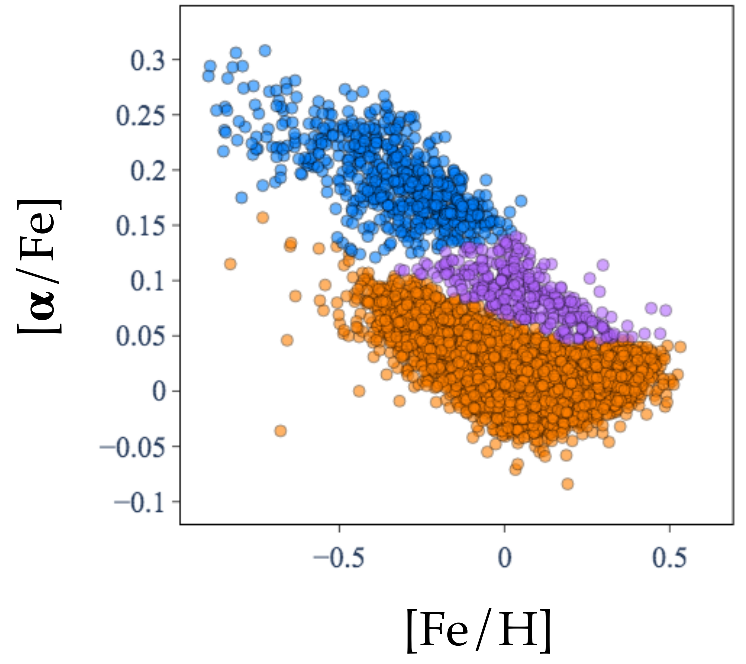
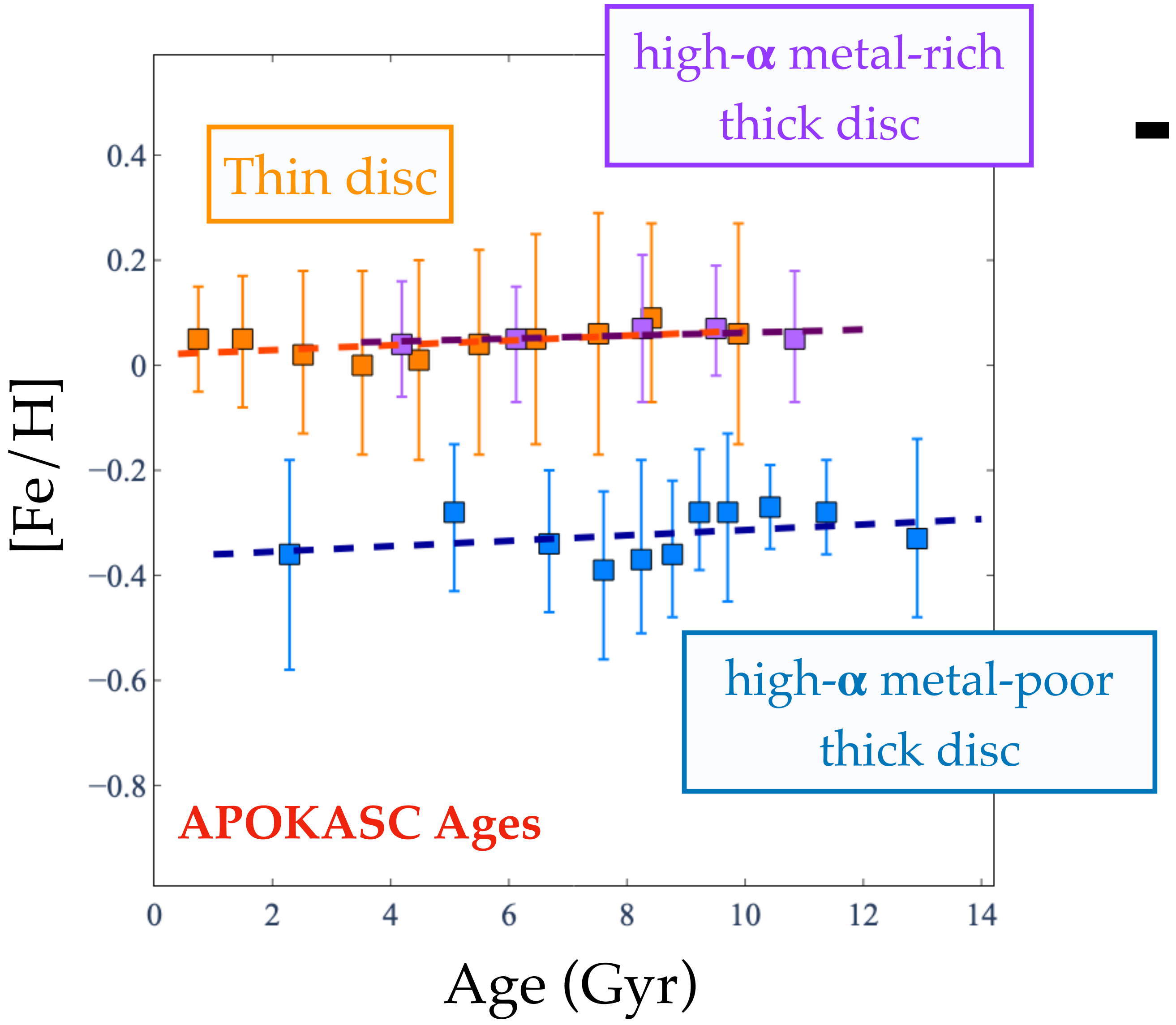
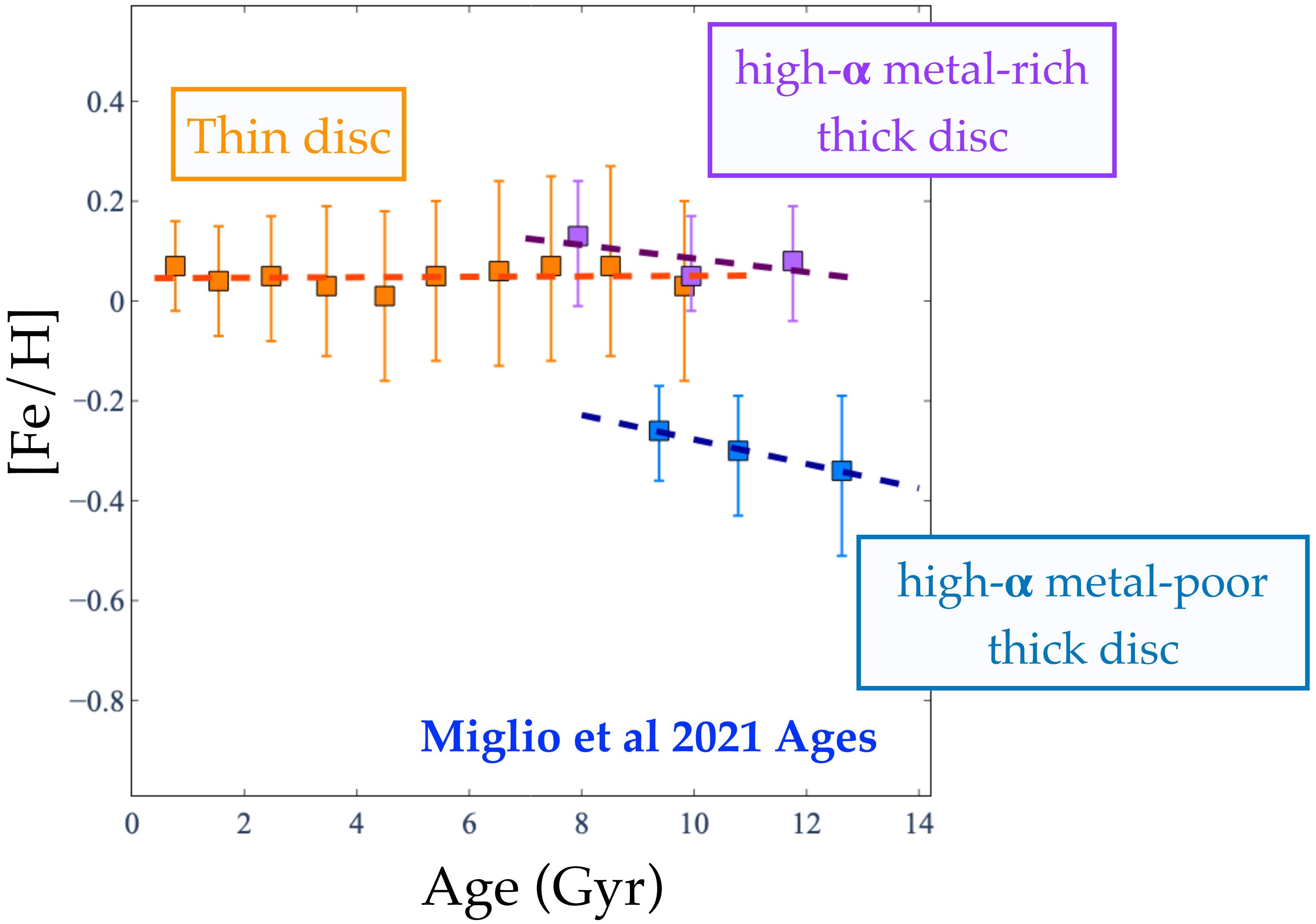


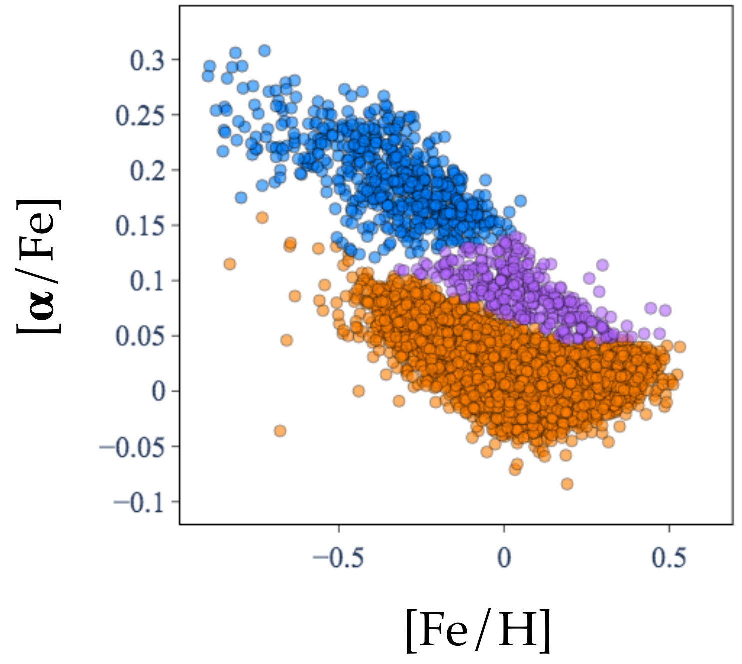


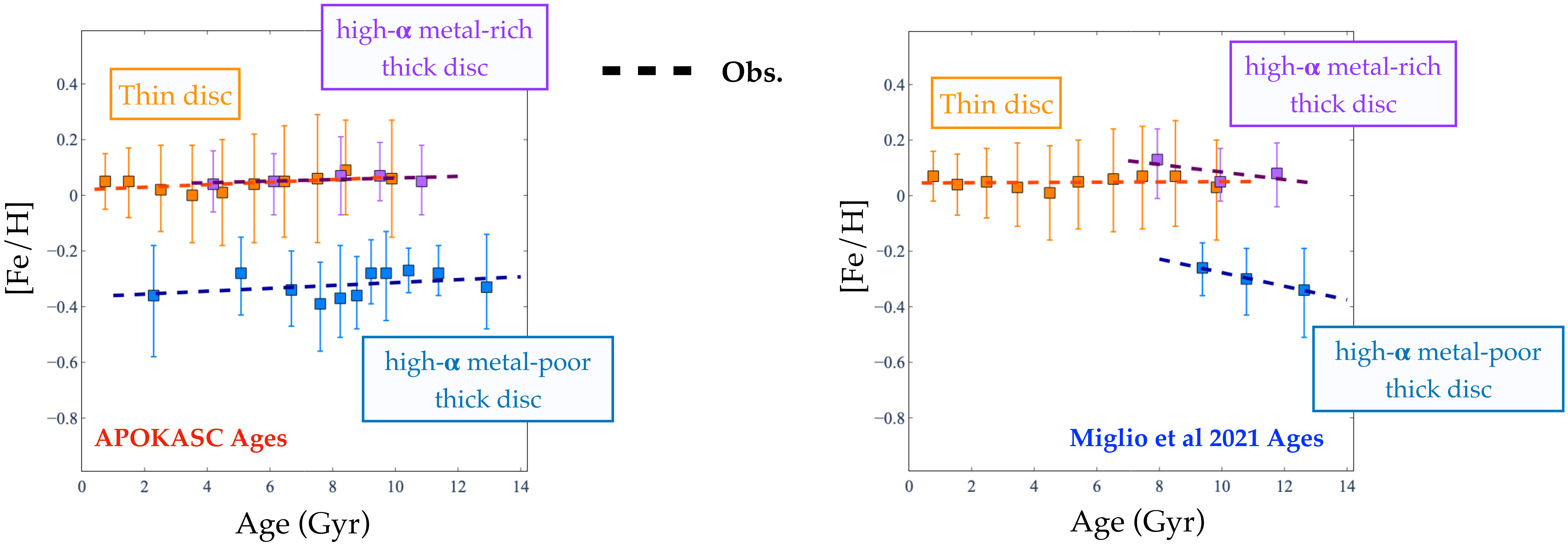
- - - Obs.



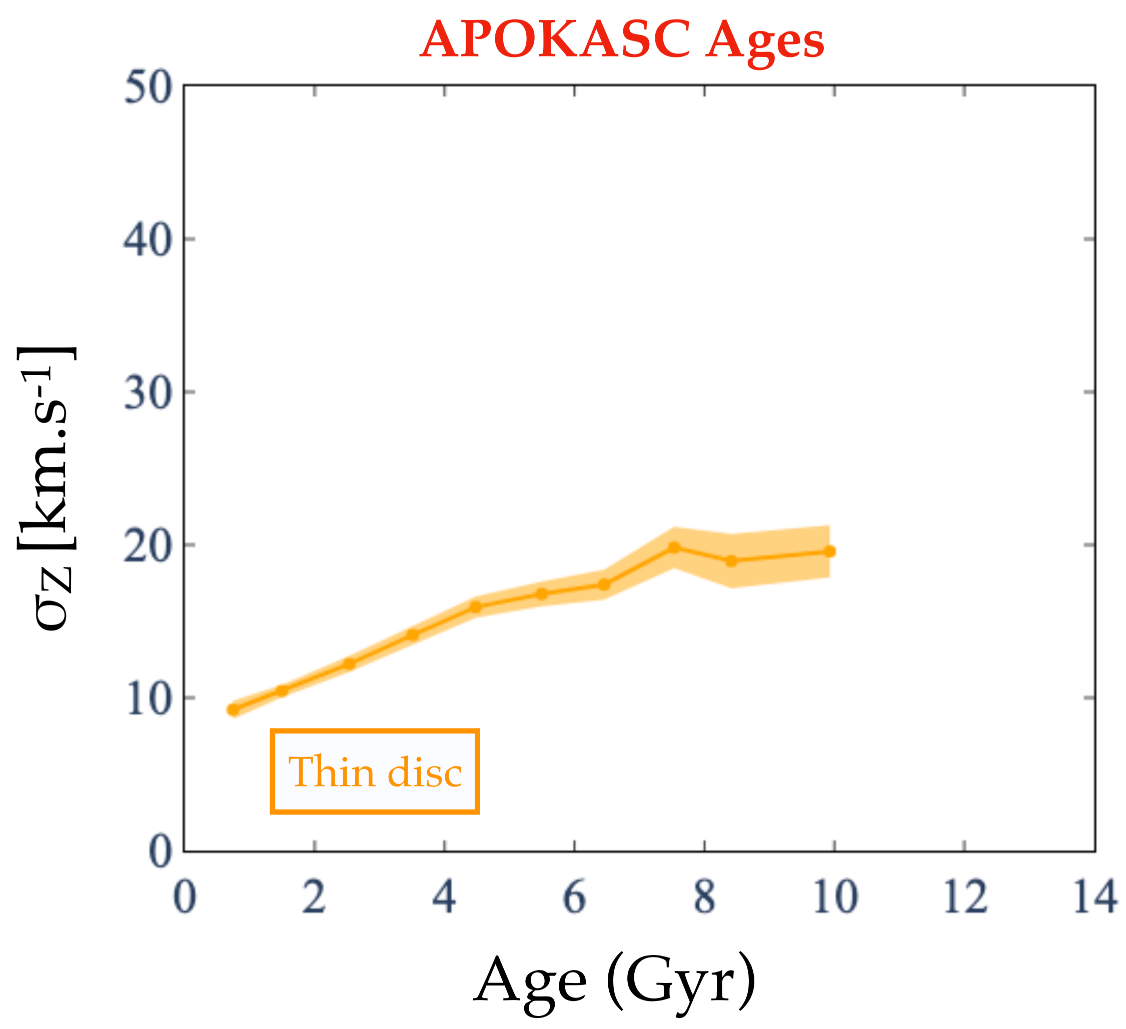
Lagarde et al. 2021

- **Thin disc** both samples show a flat age-metallicity relation
- **hαmr thick disc** No correlation between the stellar age and metallicity
- **hαmp thick disc** While for the age-metallicity relation is **flat for the APOKASC** sample, the M21 sample shows **a negative gradient.**





Thin disc : The older the thin disc population, the higher velocity dispersion
=> **Secular evolution in the disc** *(e.g., Spitzer & Schwarzschild 1951;Sellwood 2014)*



Lagarde et al. 2021

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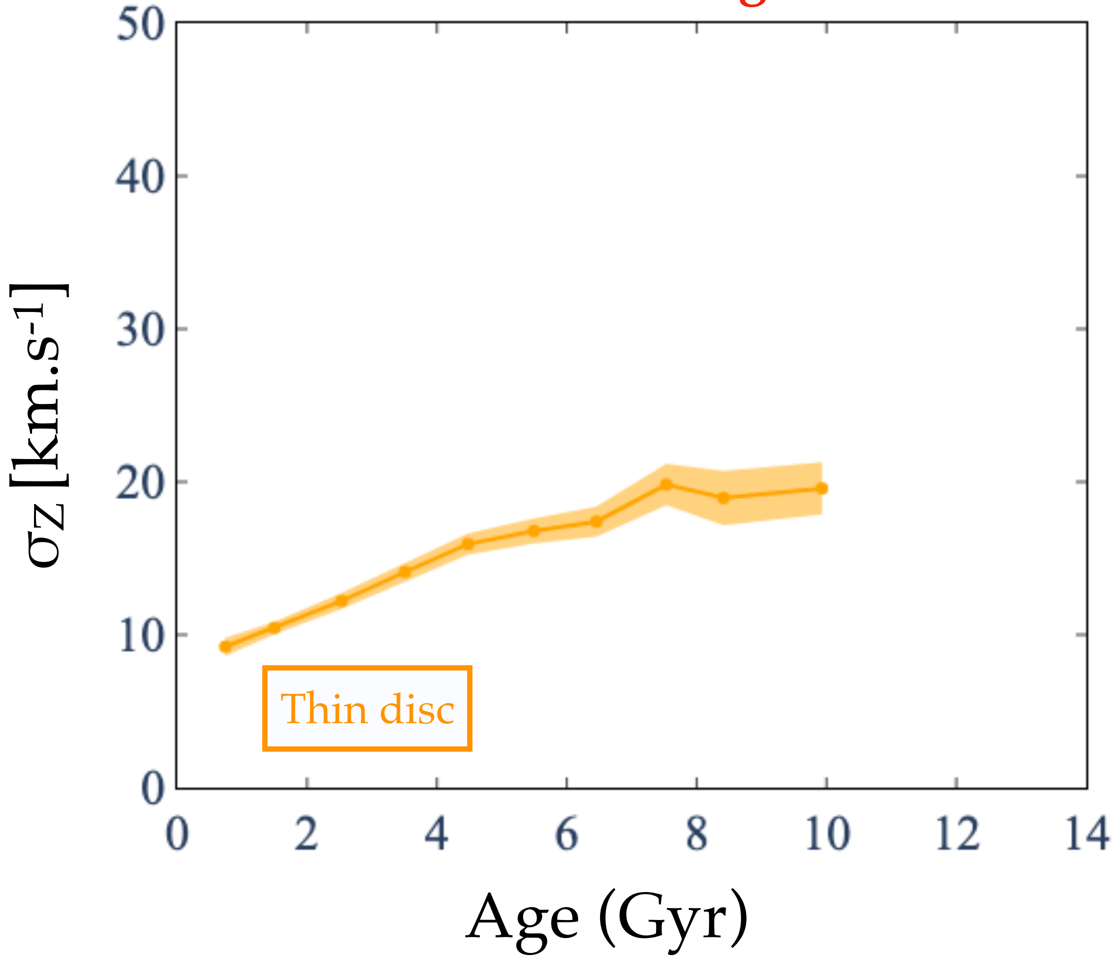
Inputs

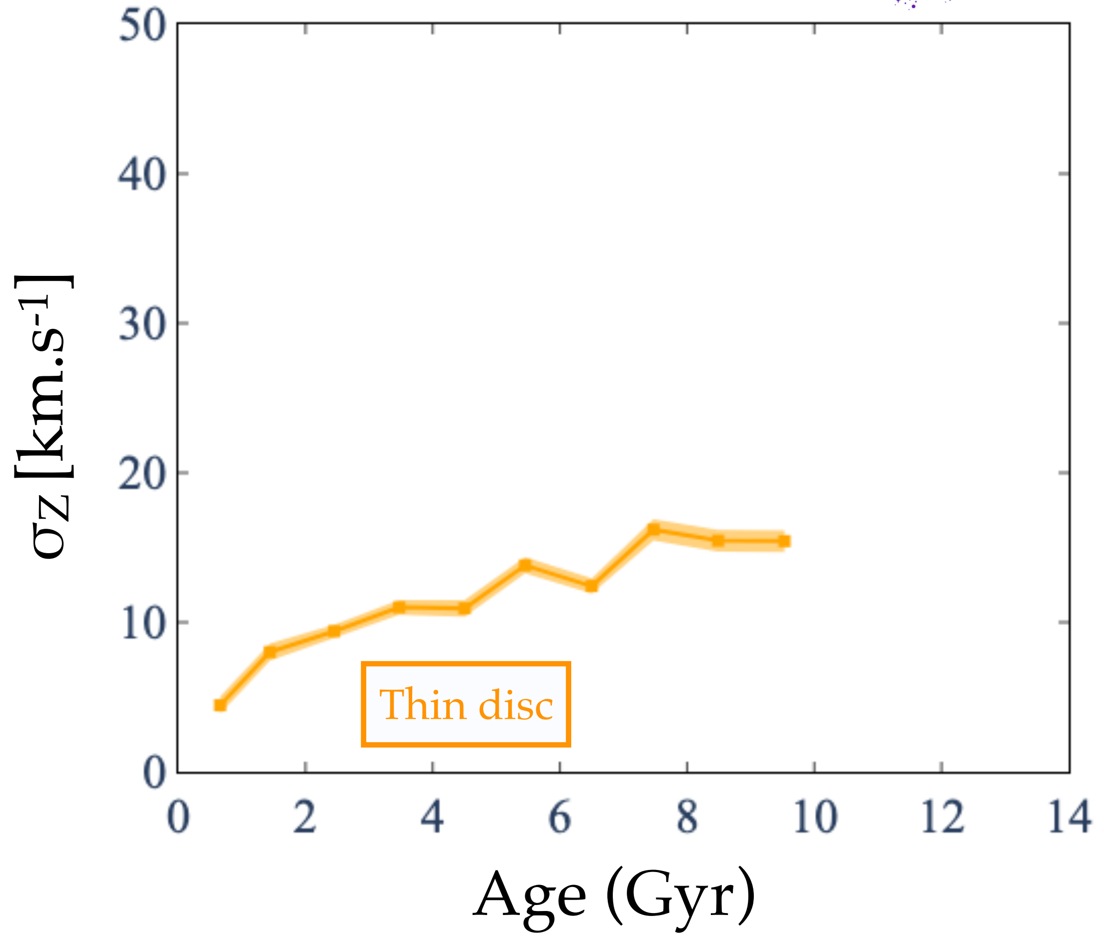
σ_Z vs Age

constrained with RAVE survey *(Kordopatis et al 2013a)*
More details *Robin et al. 2017*

No merger and radial migration is included

APOKASC Ages





Lagarde et al. 2021

At given age, σ_Z is **higher** in hαmp thick disc compared to the thin disc with the hαmr thick disc in between

- thin disc / hαmp thick disc => **a different history imprinted in their kinematics** *(e.g., Minchev et al 2013; Miglio et al 2021).*

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More details *Robin et al. 2017*

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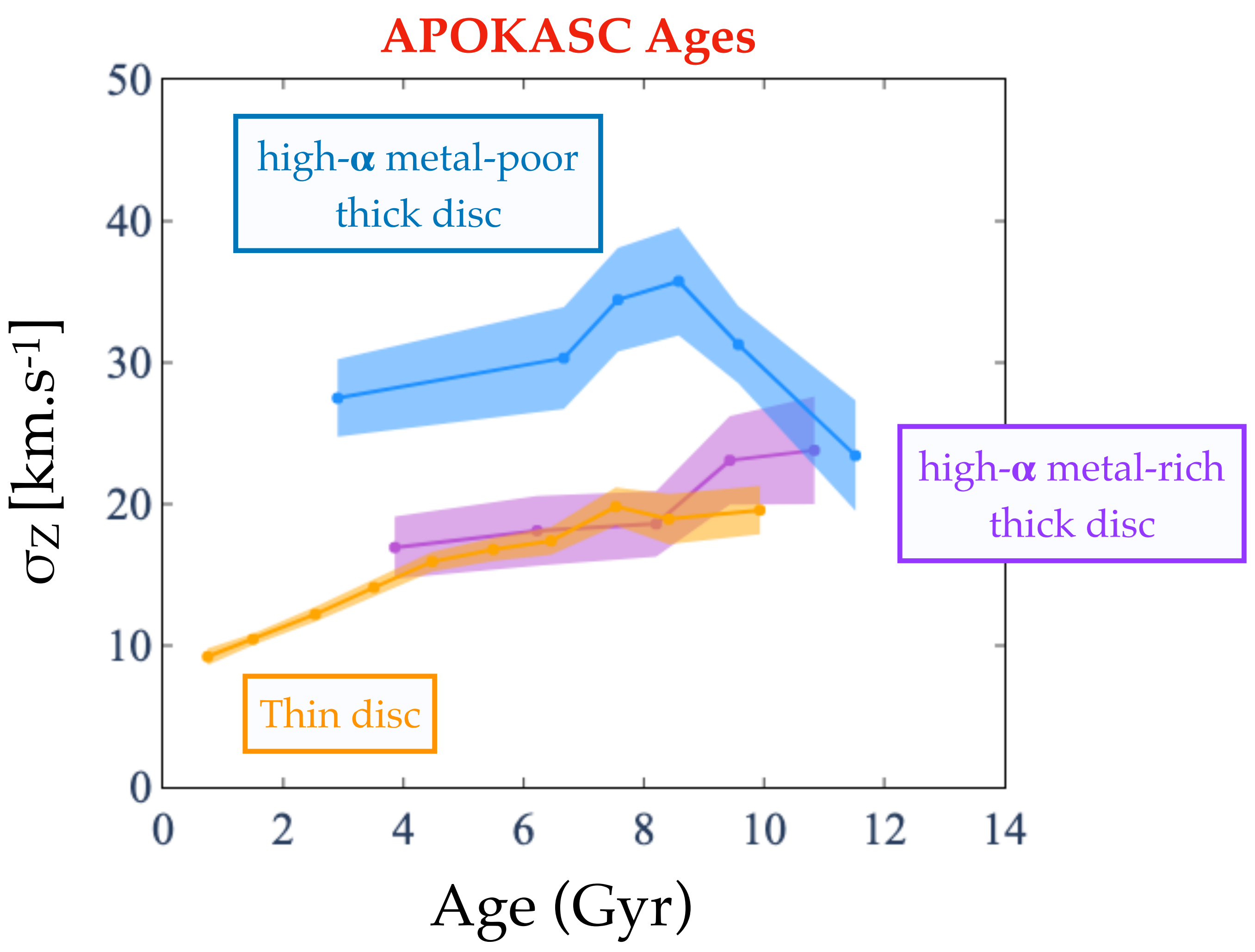

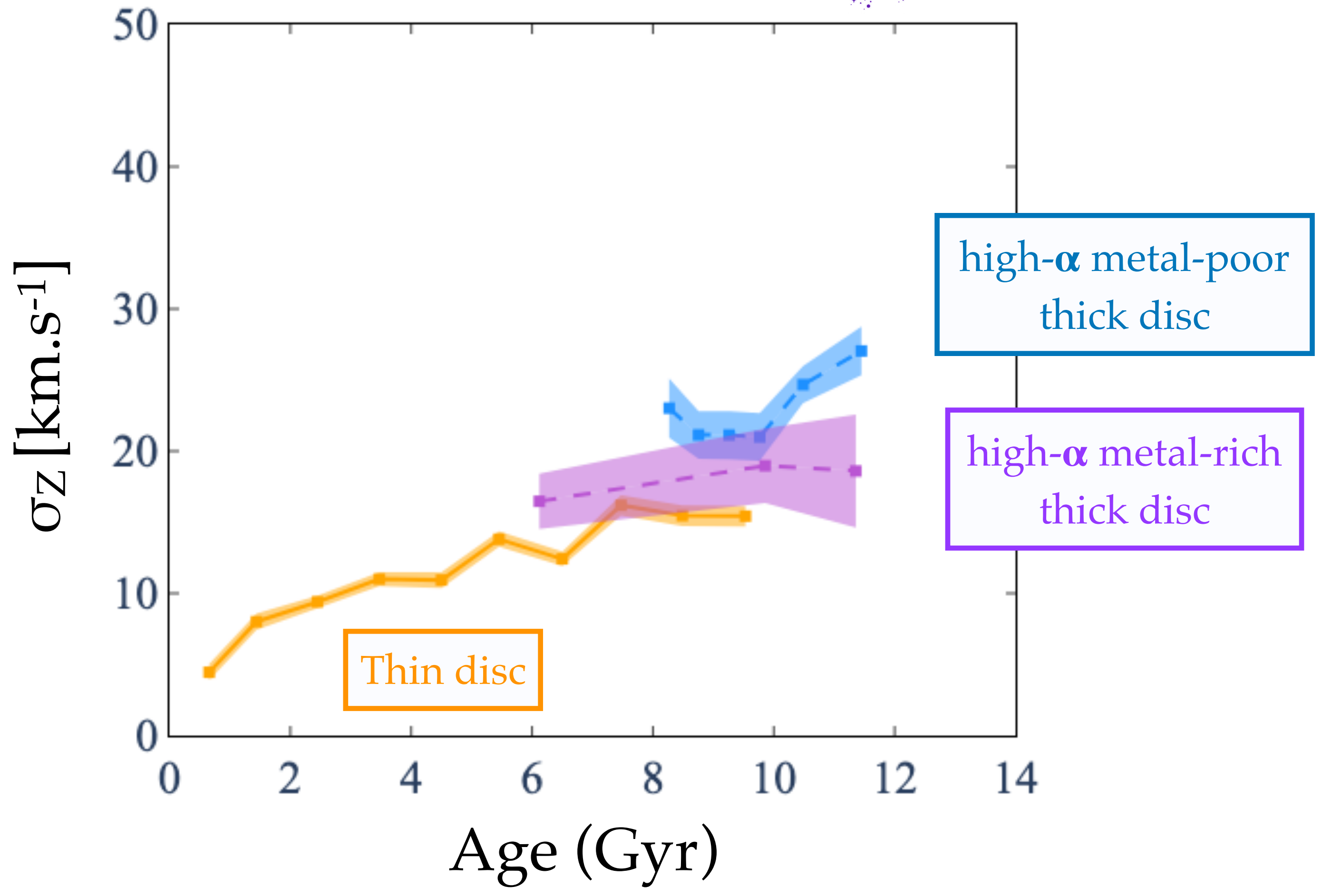

Lagarde et al. 2021

hαmp thick disc : max in the σ_Z behavior at ~8 Gyrs not predicted by the BGM
=> not induced by sample selection

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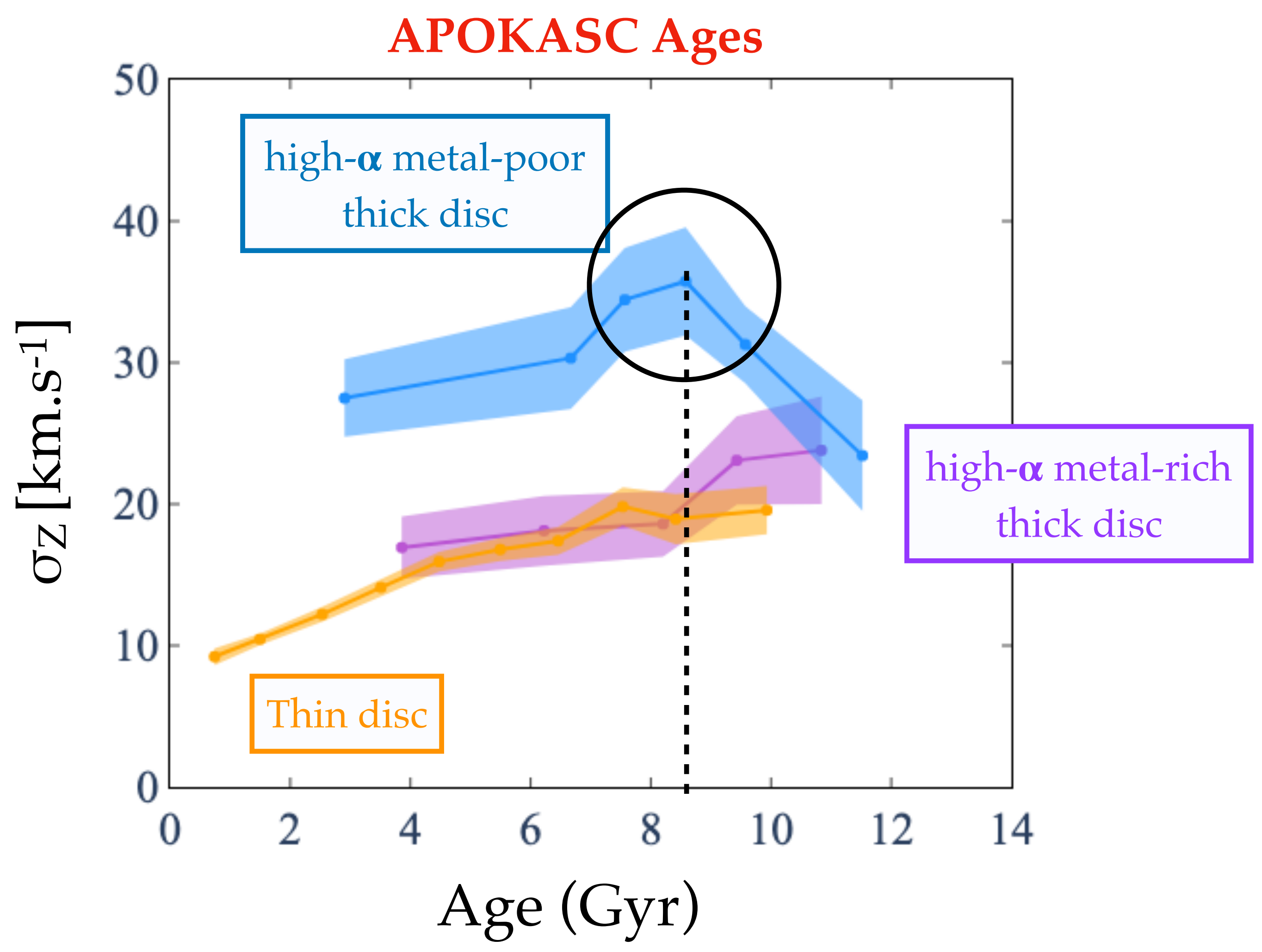

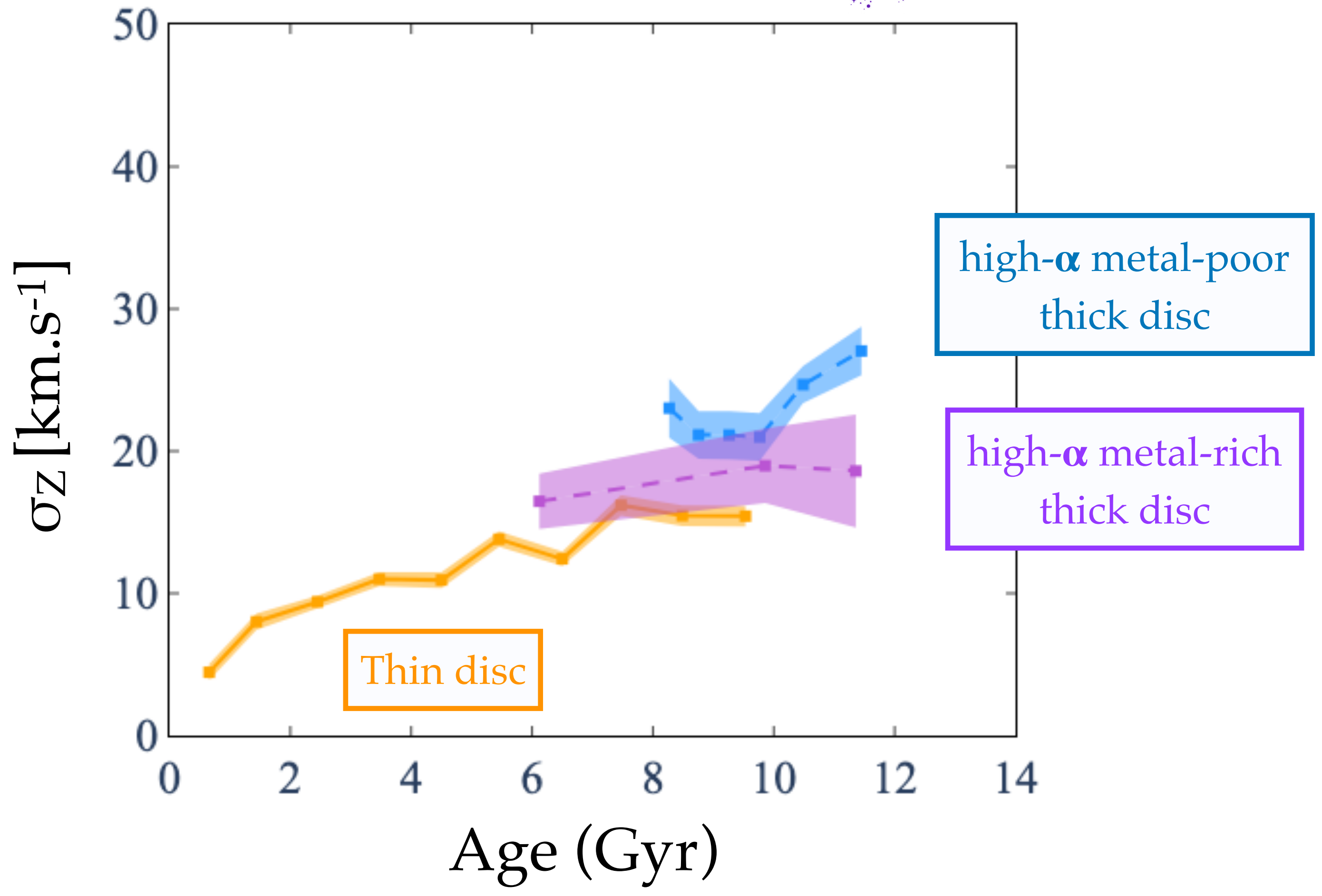

Lagarde et al. 2021

Age-velocities dispersion relations

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σ_Z vs Age

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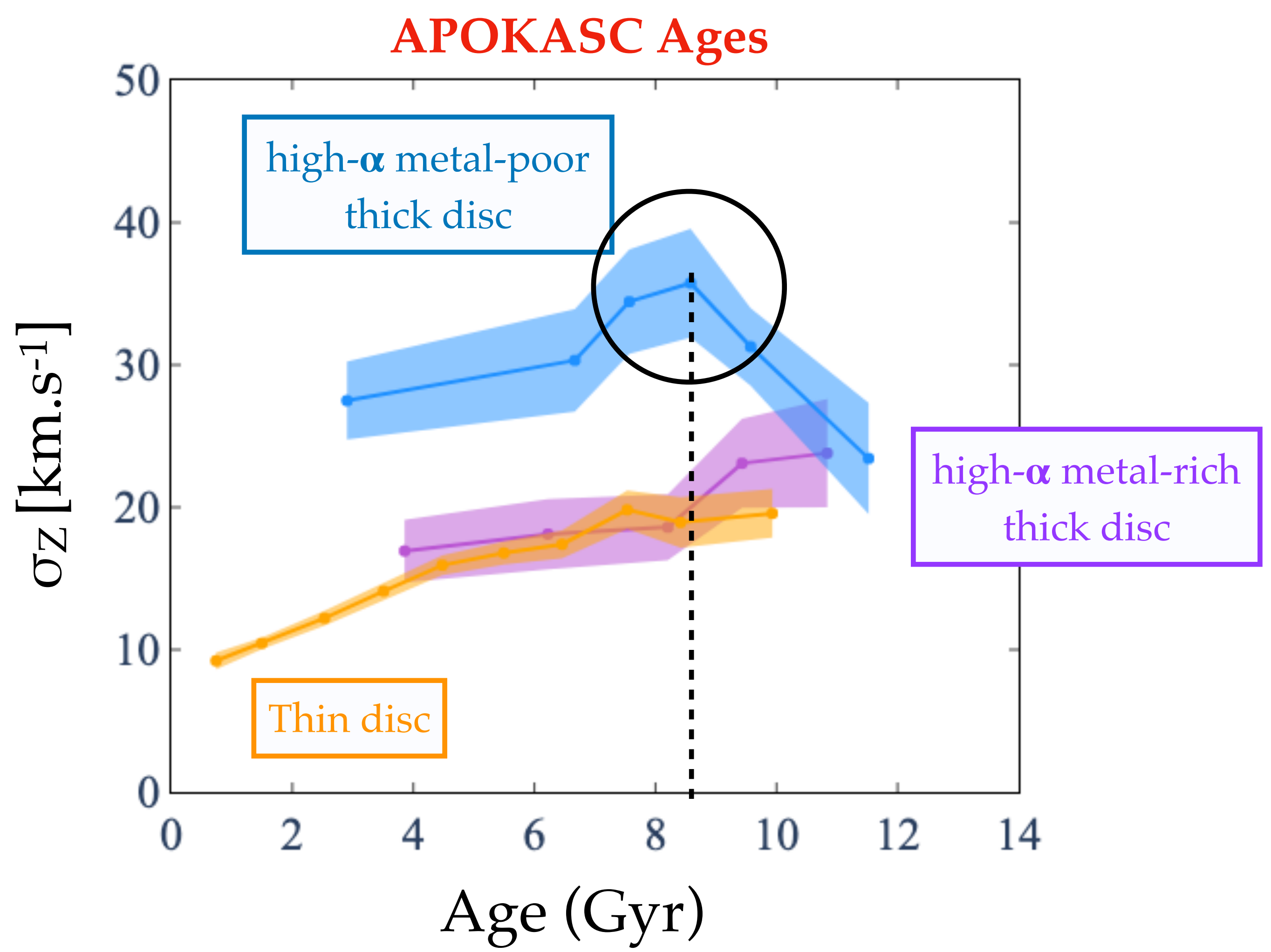
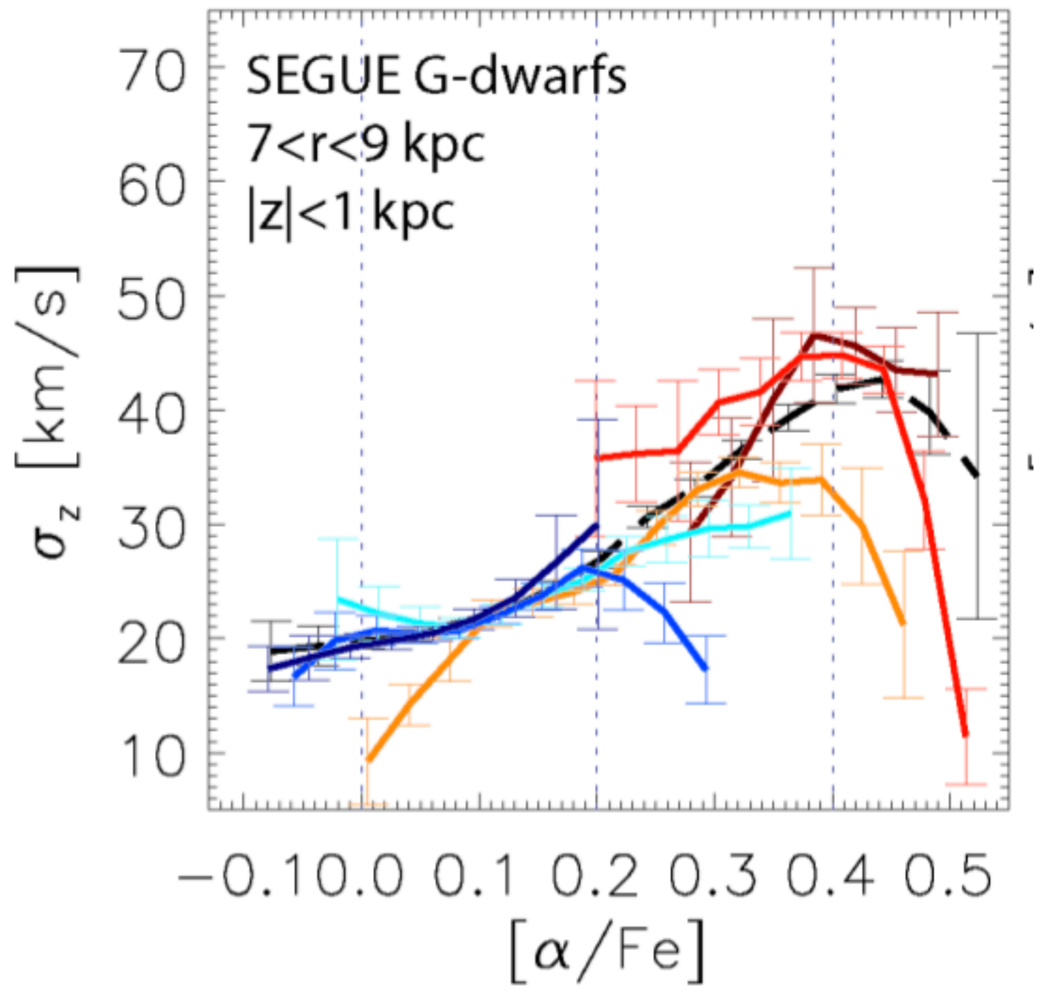
More details *Robin et al. 2017*

No merger and radial migration is included

hαmp thick disc : max in the σ_Z behavior at ~8 Gyrs not predicted by the BGM
=> not induced by sample selection
=> could suggest a more complex chemo-dynamical scheme (mergers and radial migration effects, see *Minchev et al 2013, 2014a, b*)





Lagarde et al. 2021

Lagarde et al. 2024

Spectroscopy

Spectroscopic atmospheric parameters

Abundances $^{12}C/^{13}C$

C, N, O

Asteroseismology

Accurate ages and masses deduced from the asteroseismic measurements

Evolutionary stages with $\Delta\Pi_{l=1}$

Gaia data

Luminosity, Spectroscopy, Kinematics

Lagarde et al. 2024

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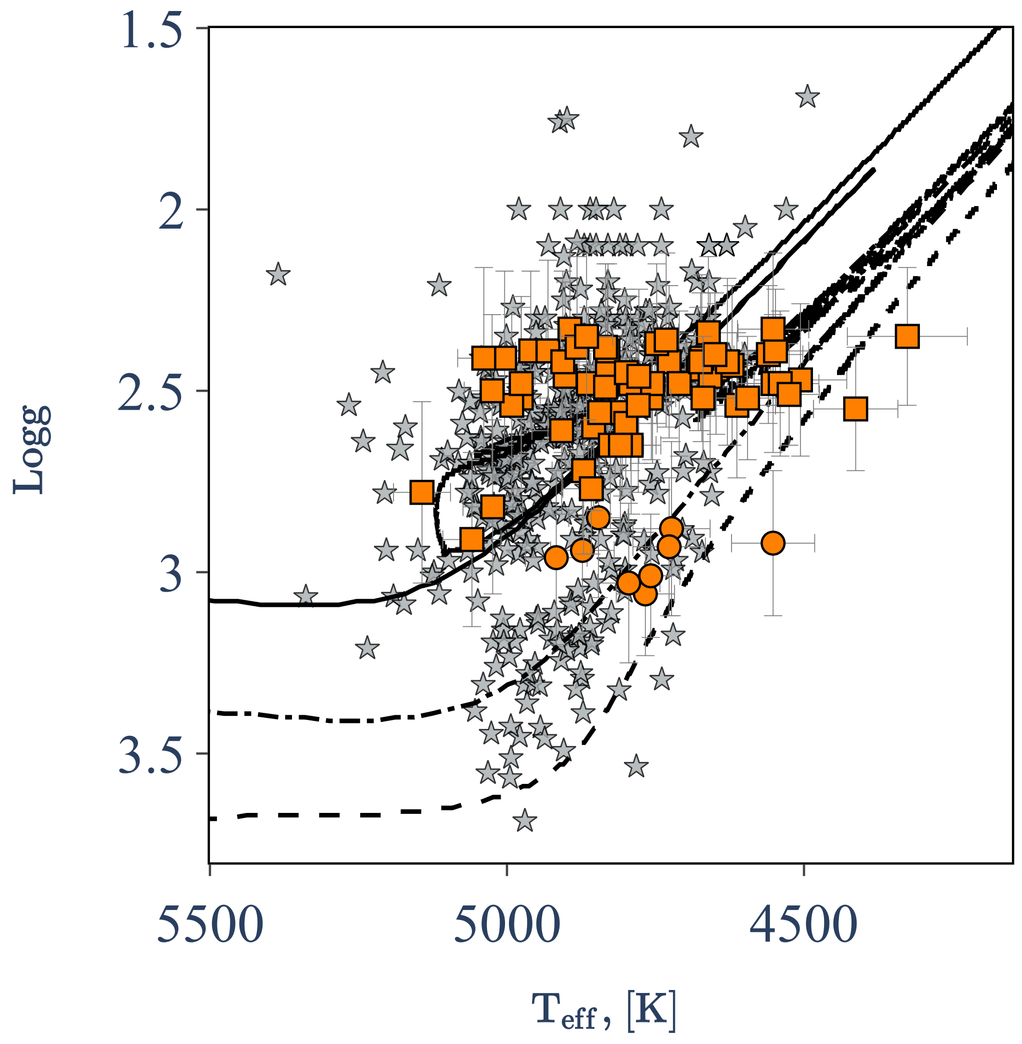
Golden sample

71 giant field stars

Sub-sample of giants with better observational constraints



First ascent RGB

Core He-burning stars

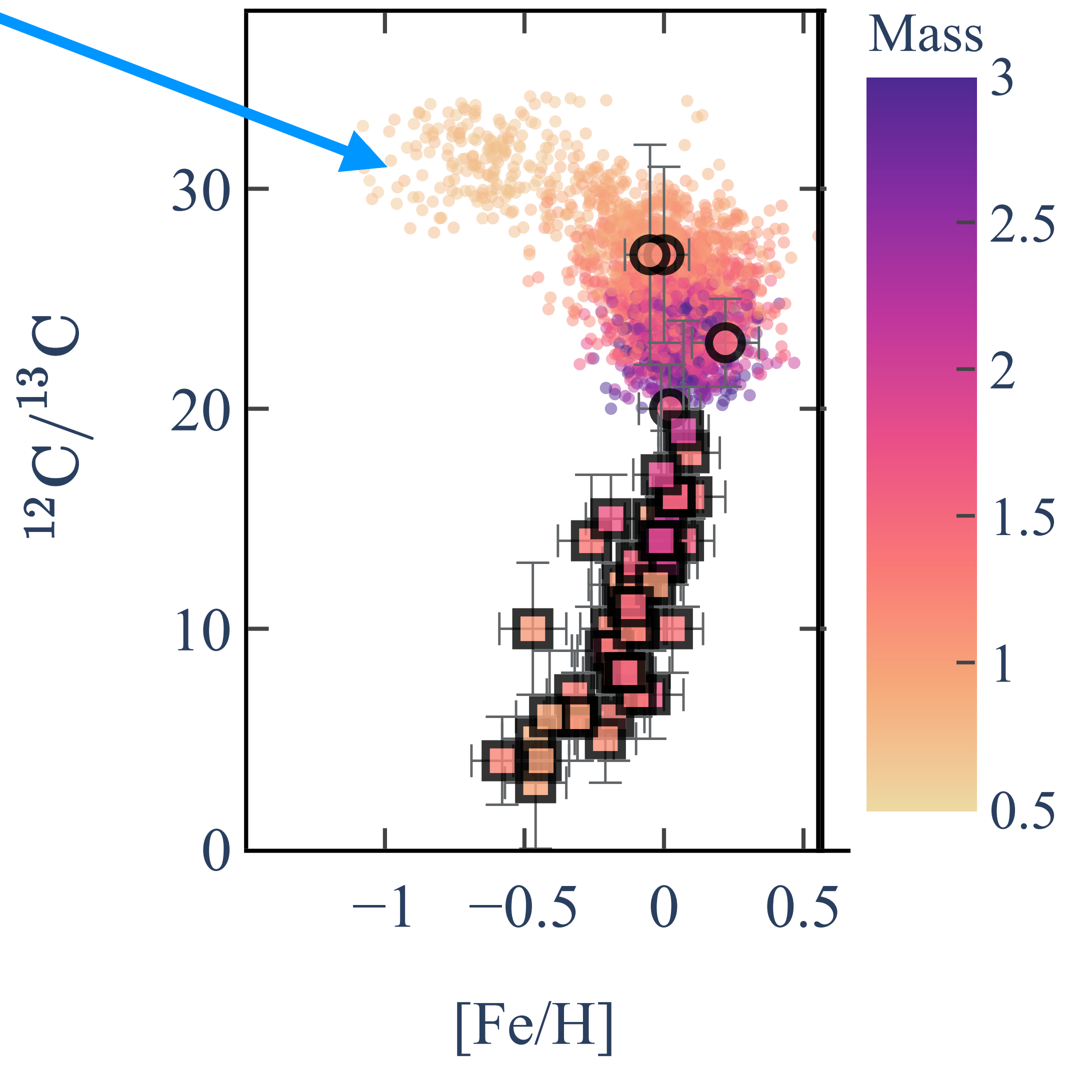
Other spectroscopic studies (*Tautvaisiene et al 2010,2013 ; Gratton 2000 ; Morel et al 2024 ; Takeda et al 2019 ; Aguilera-Gomez et al 2023)*

Lagarde et al. 2024

Stellar population synthesis model
(e.g., Lagarde et al. 2017, 2019)

Stellar evolution models computed with **STAREVOL**

w/o thermohaline mixing



Lagarde et al. 2024

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Thermohaline instability

Changes the surface abundances of chemical elements such as Li, **^{3}He**, **^{12}C, ^{13}C, ^{14}N but leaves the O values unchanged**

Thermohaline instability is more efficient for **lower-mass and metal-poor giants** (e.g., Lagarde et al 2019)

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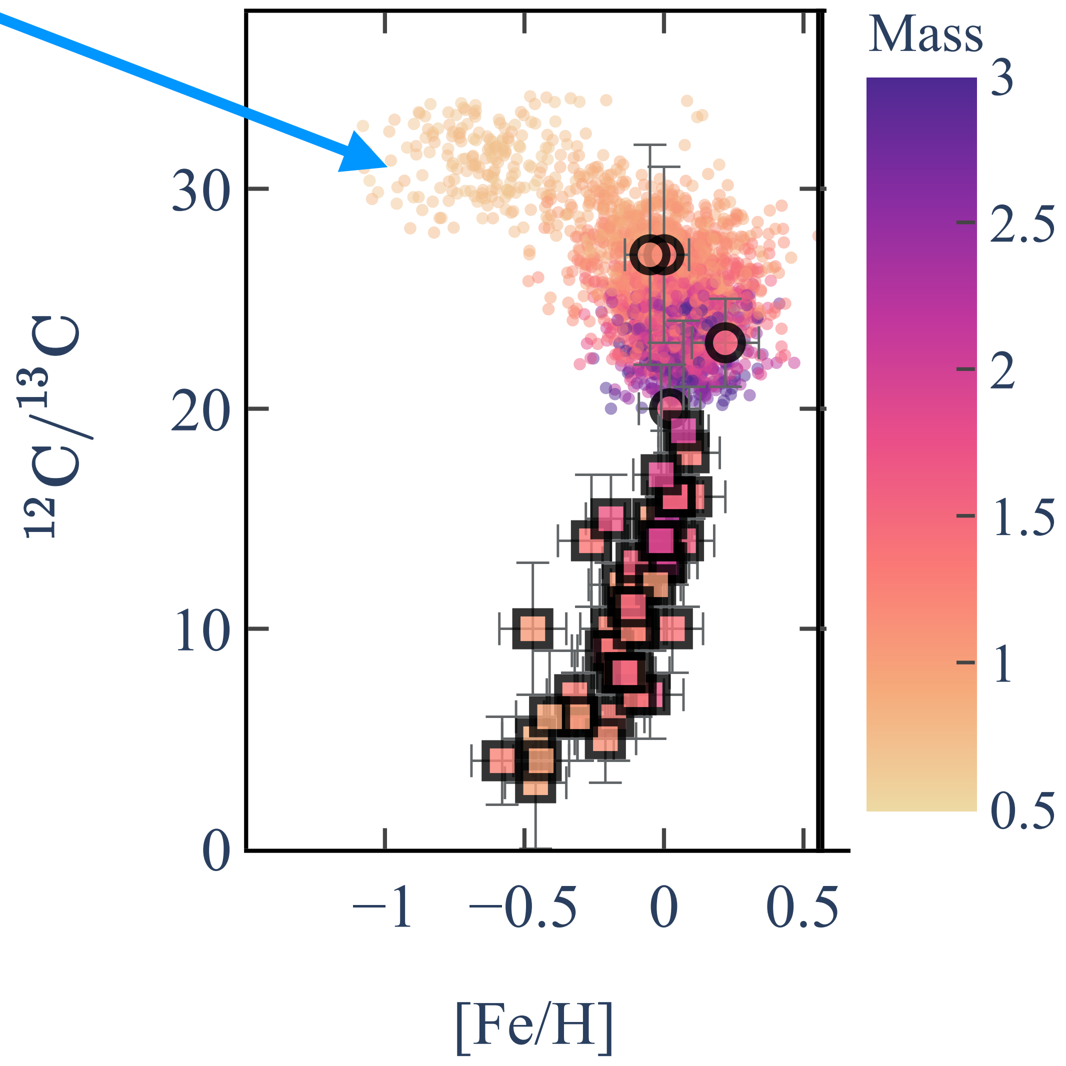

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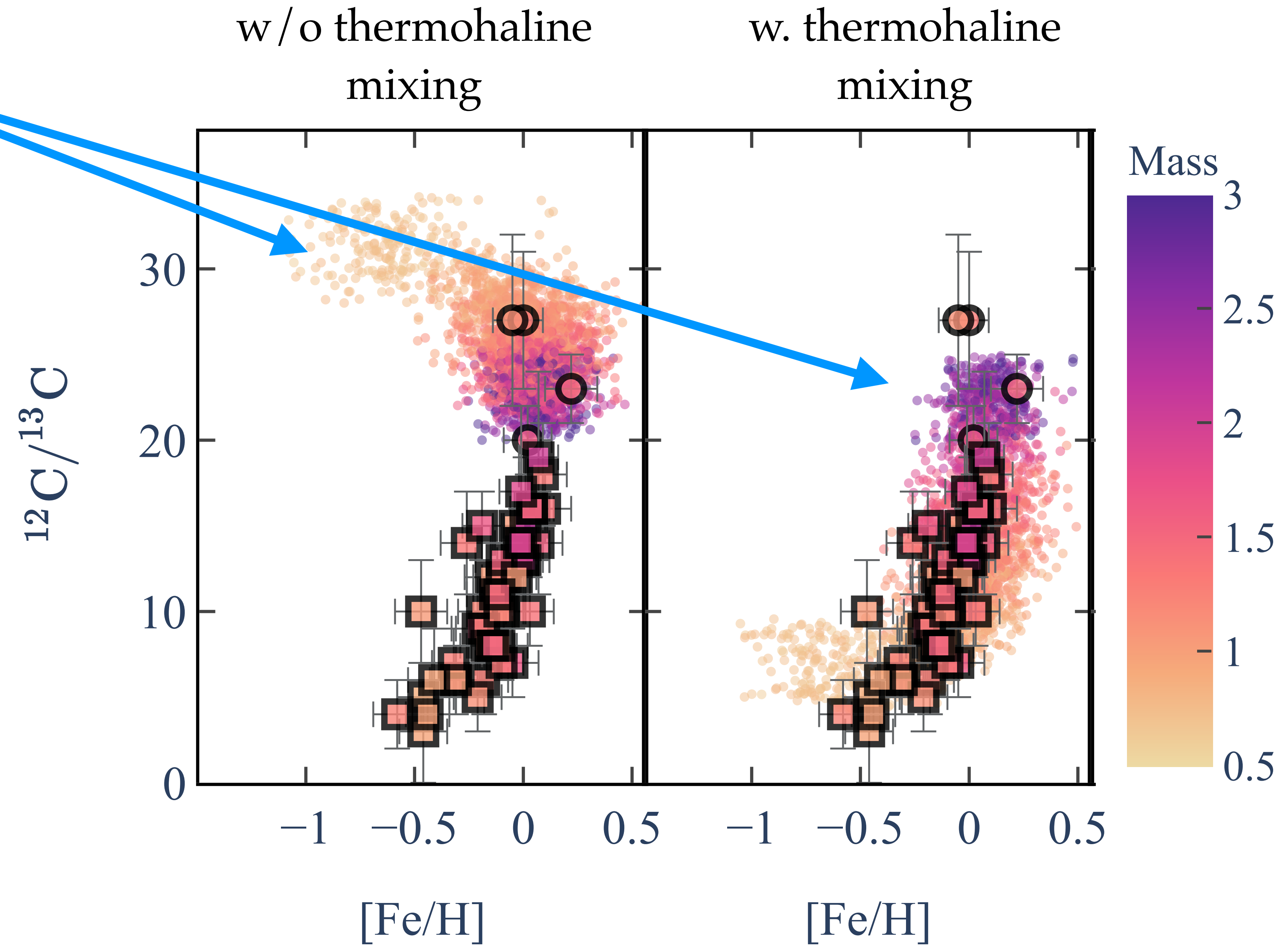

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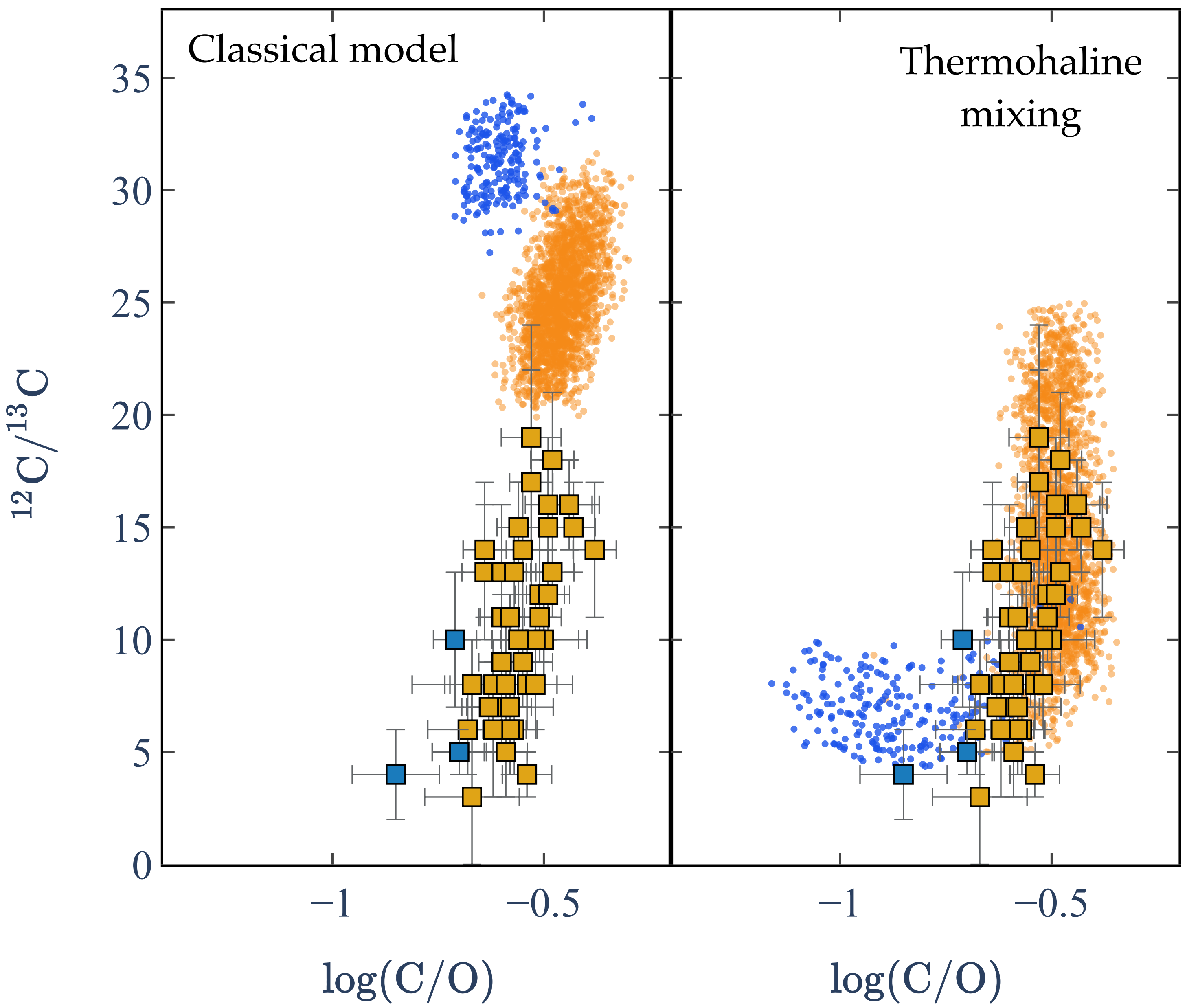
Lagarde et al. 2024

What about considering the different stellar populations?



Thin disc stars

Thick disc stars

Lagarde et al. 2024

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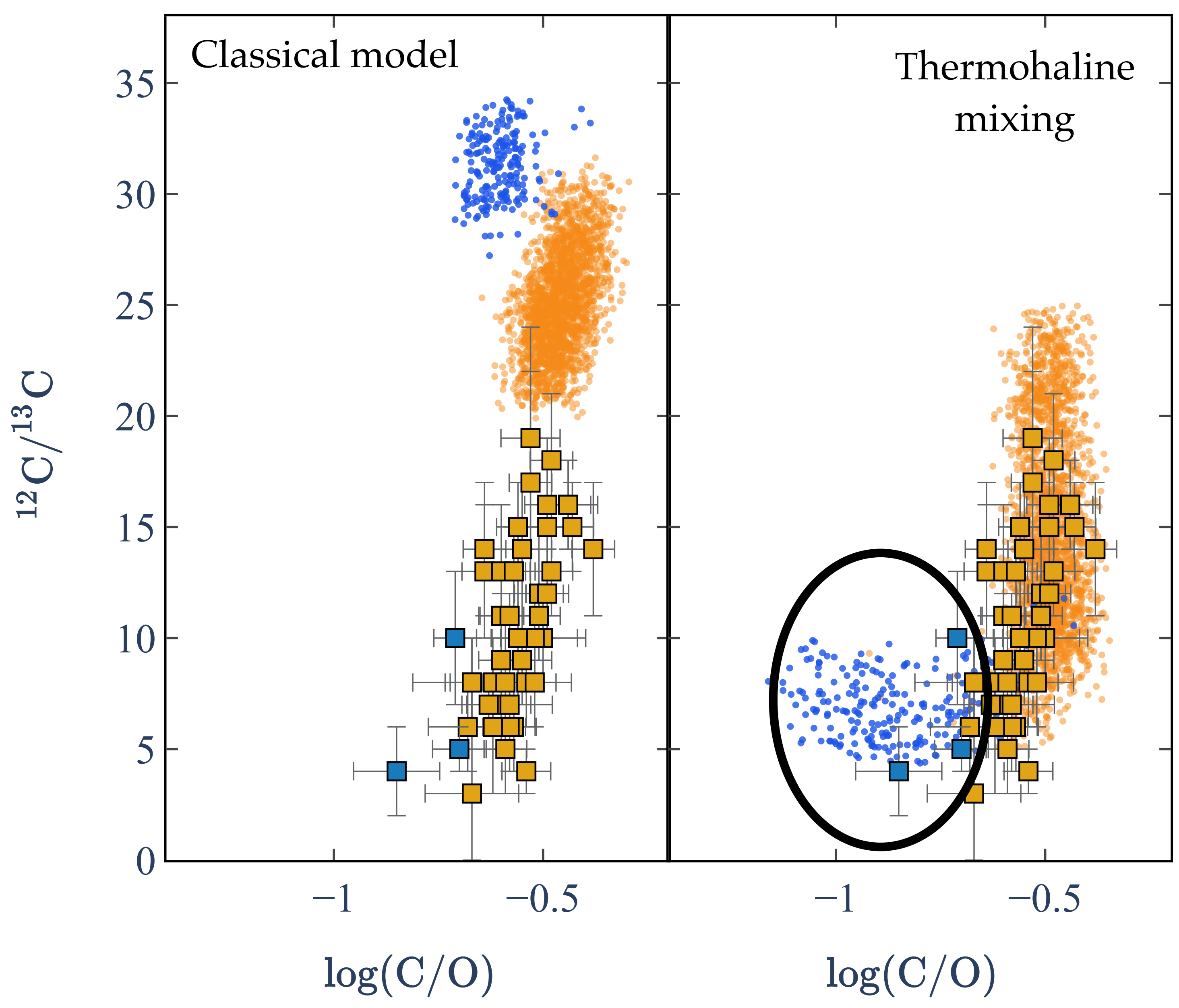
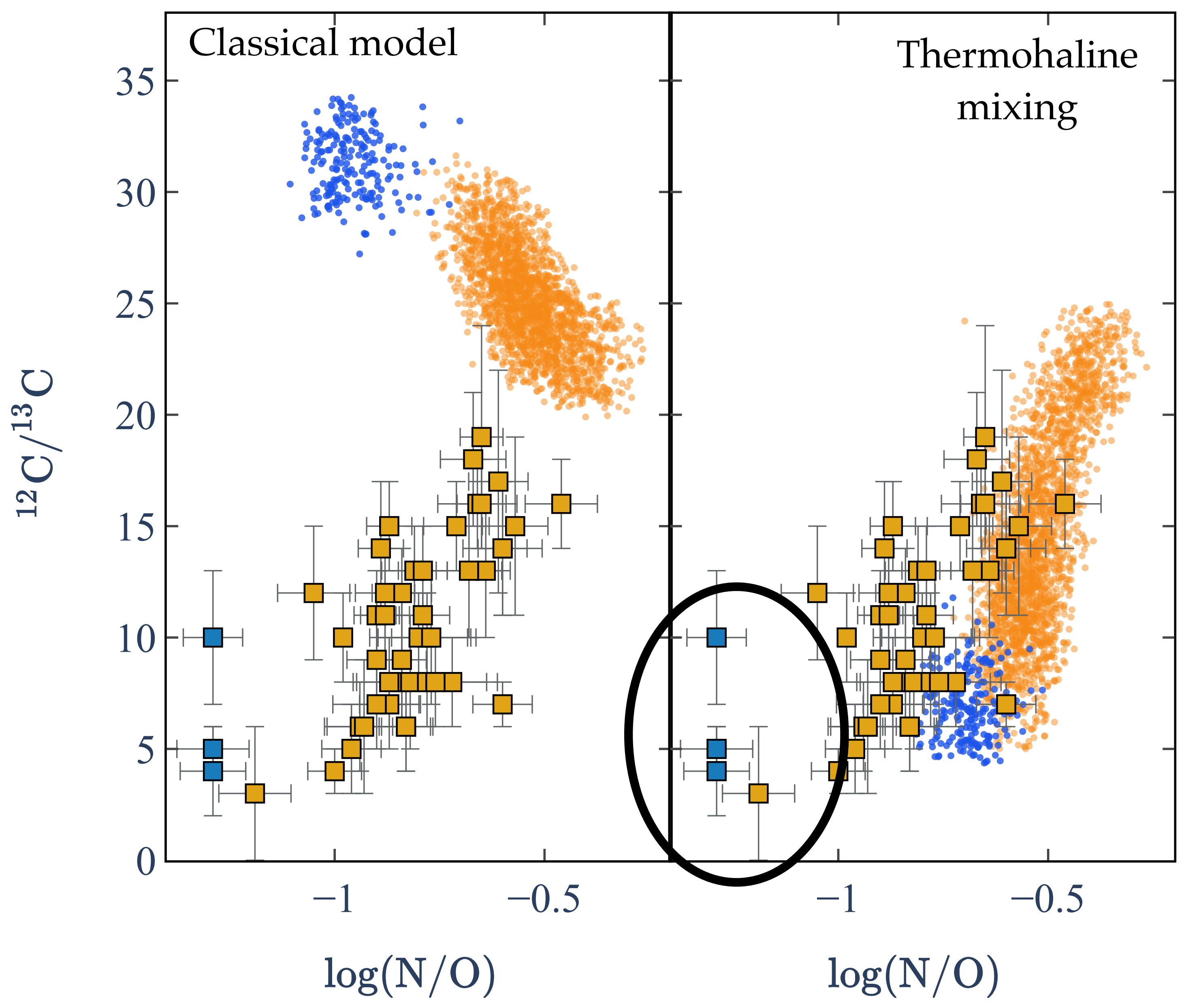


Thin disc stars

Thick disc stars



N abundances for thick disc stars not very explain
=> Need a larger sample of thick disc stars with strong chemical constraints

Conclusions

Lagarde et al. 2017

BGM to highlight selection biases in the observed sample
and also mechanisms reveal by observations and not included in the model

Contact me !

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Lagarde et al. 2017

to highlight selection biases in the observed sample
and also mechanisms reveal by observations and not included in the model

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Lagarde et al. 2021

(1) **Probably, a small sign of SFR increase between 2 and 5.5 Gyr in both samples** remains to be confirmed with larger seismic sample**.**

(2) a **flat age–metallicity relation for the thin disc**

(3) **Different behaviours of σ_Z with age in the BGM simulations and in the observations, inducing a more complex chemo-dynamical scheme** to explain the data (e.g., mergers and radial migration effects).

Lagarde et al. 2017

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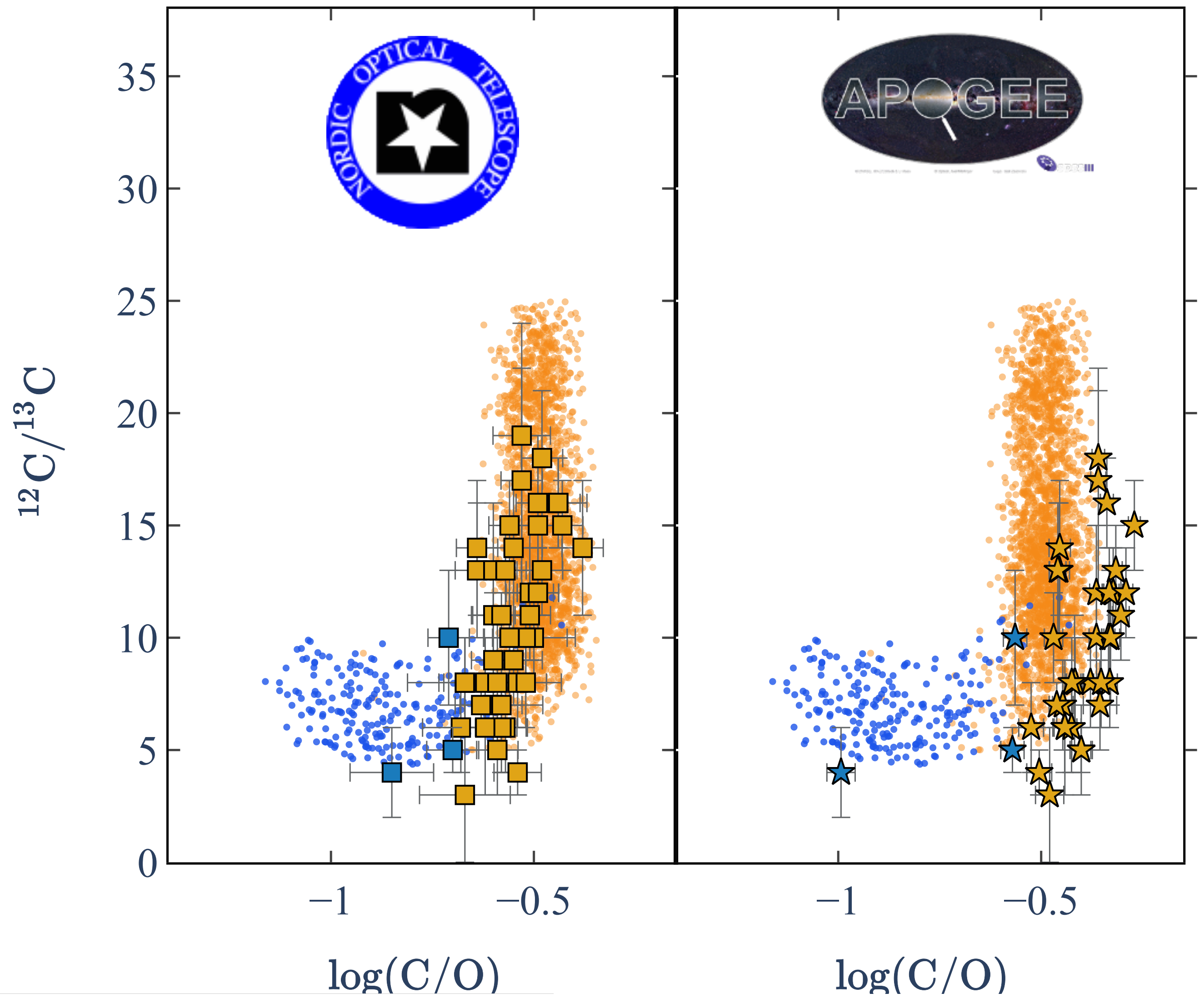
Lagarde et al. 2024

(1) ^{12}**C/**^{13}**C** at the surface of **core He-burning stars increases with [Fe/H] (and M)** while it decreases with stellar age**.** Simulations done with the BGM and including the effects of thermohaline mixing explain these trends in an exceptional way

(2) Spectroscopic analysis shows that **low ^{12}C/^{13}C values are correlated with low C/O and N/O**
Pb : N abundances for stars belonging to the thick disc
=> Need more thick disc stars with all observational constraints…

Lagarde et al. 2024



Thin disc stars

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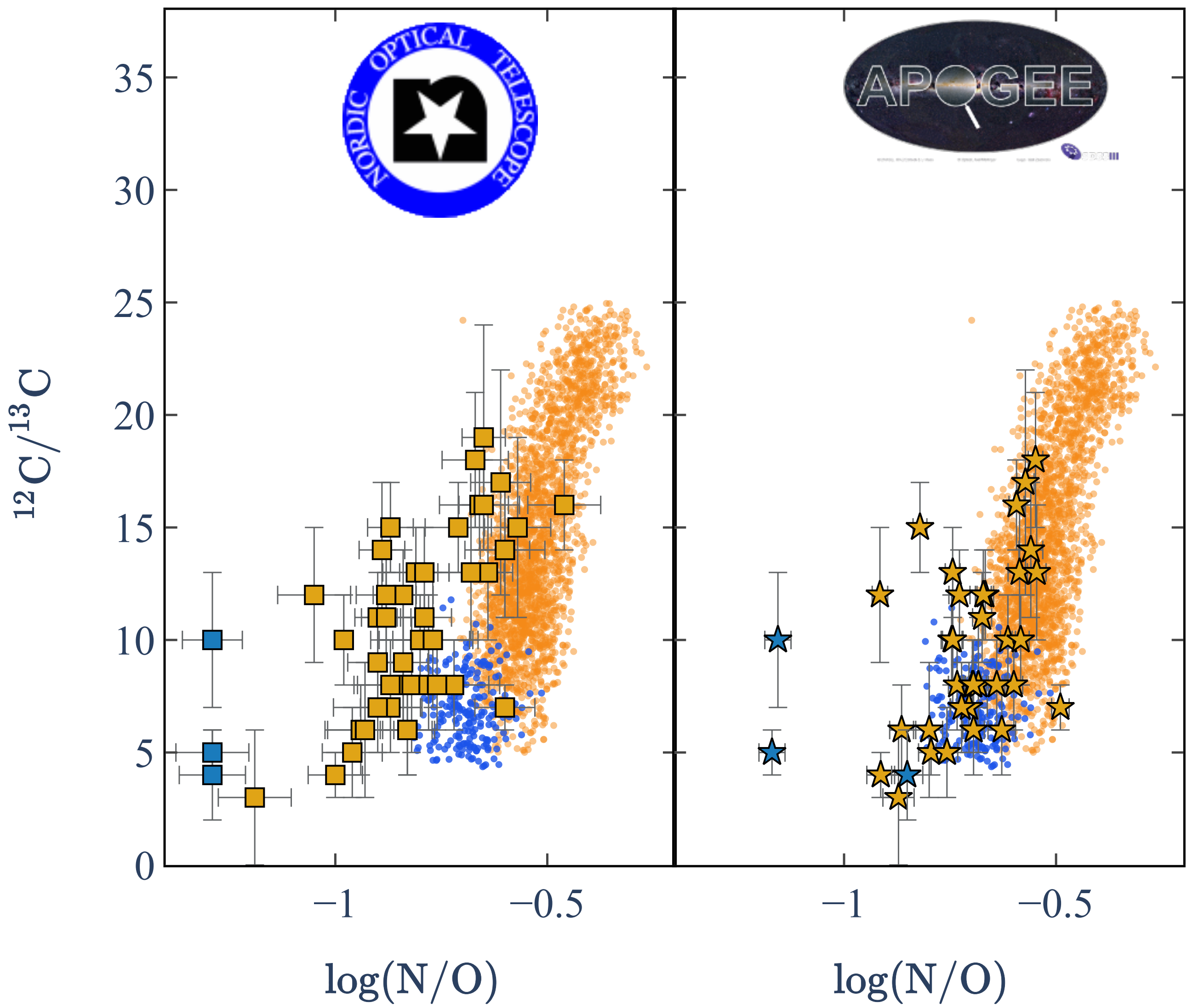

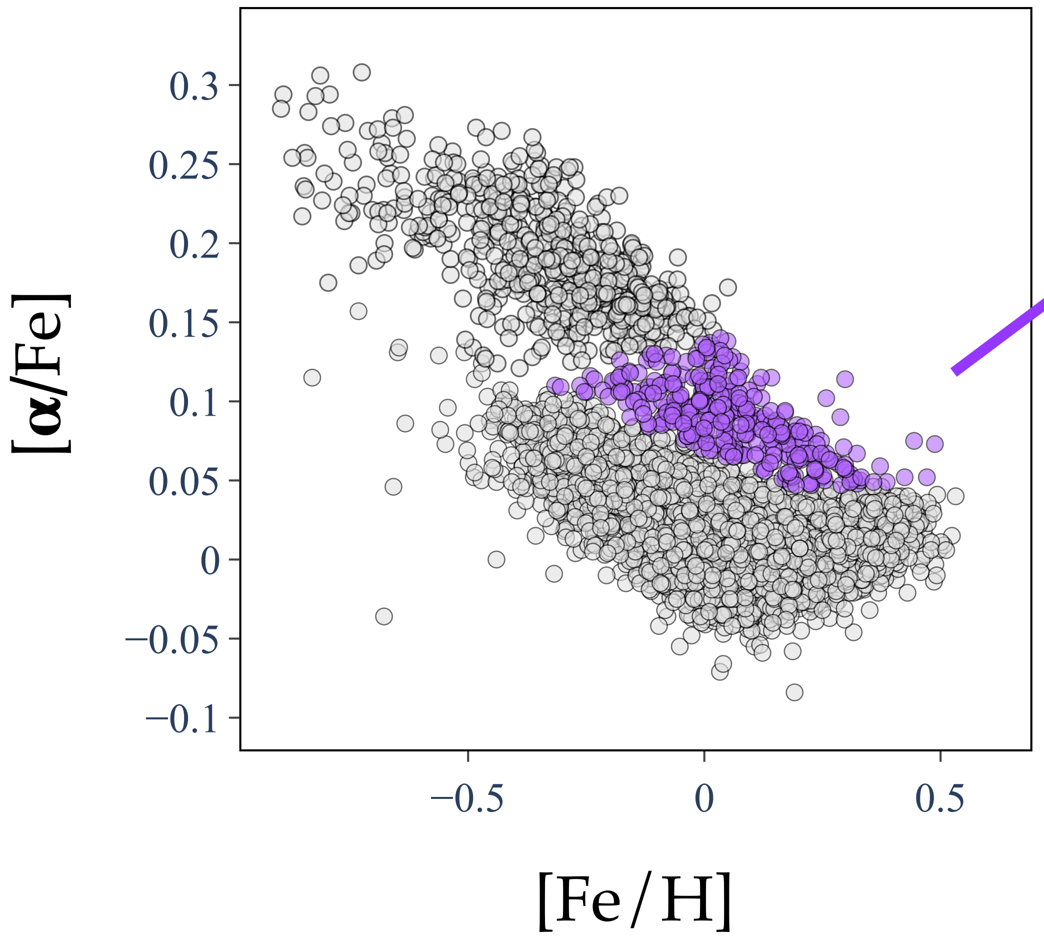

- **[α/Fe]** is between the two other populations
- [Fe/H] is very similar to that of the thin disc
- Age distribution : mimics that of the hαmp thick-disc population, with a similar mean age.
- The kinematics seems to follow that of the thin-disc population more closely than that of the high-α metal-poor thick disc
- The σ_Z with age is clearly lower than for the thick metal-poor disc and is almost identical with the thin disc.

It represents a link between the thin and the high-α metal-poor thick disc

These behaviours are not simulated by the BGM, suggesting a different formation scenario for these stars that is not included in the model.

These properties might suggest a different origin and history for these stars:

- by migration from the inner disc as proposed by *Anders et al. (2018)*
- or as a transition region between the old thick disc and the young thin disc as proposed by *Ciuca et al. (2021)*.

Lagarde et al. (2021)