Chemical evolution models and the [alpha/Fe] bimodality between the thick and thin discs

Valeria Grisoni
INAF Trieste

valeria.grisoni@inaf.it

IAF INAF Astrophysics Fellowship in Italy

INAF ISTITUTO NAZIONALE DI ASTROFISICA OSSERVATORIO ASTRONOMICO DI TRIESTE

October 2023, Trieste
IFPU Focus week “Galactic archaeology: Reconstructing the history of galaxies”

Outline of the talk

- Historical introduction on the [alpha/Fe] vs. [Fe/H] bimodality
- Observational data
- Chemical evolution models for the thick and thin discs
- Results and conclusions

The Milky Way

Image credit: ESA/ATG medialab; background image: ESO/S. Brunier .

Our Galaxy has four main stellar populations: halo, bulge, thick and thin discs.

The thick disc as a distinct structural component of galaxies was identified from the difficulty to account for the light profiles of some edge-on external galaxies with single exponential profile (Tsikoudi 1979, Burstein 1979). In the case of our Galaxy, the thick disc was first discovered by Yoshii (1982) and Gilmore & Reid (1983), as an overdensity of stars at large distances from the Galactic plane. Successively, it has been found that the thick disc differs from the thin disc also on the basis of its chemistry, age distribution and kinematics.

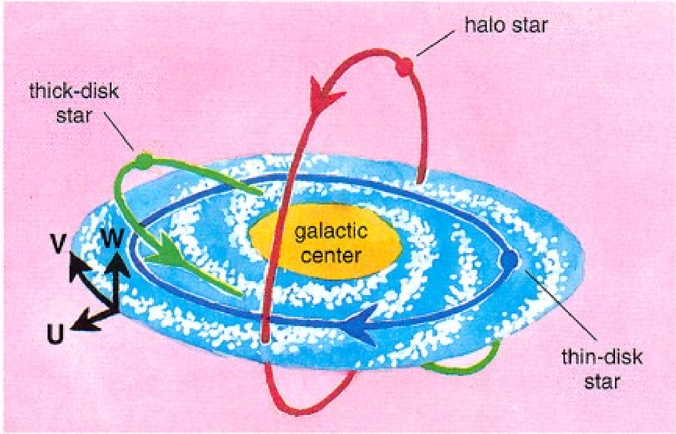
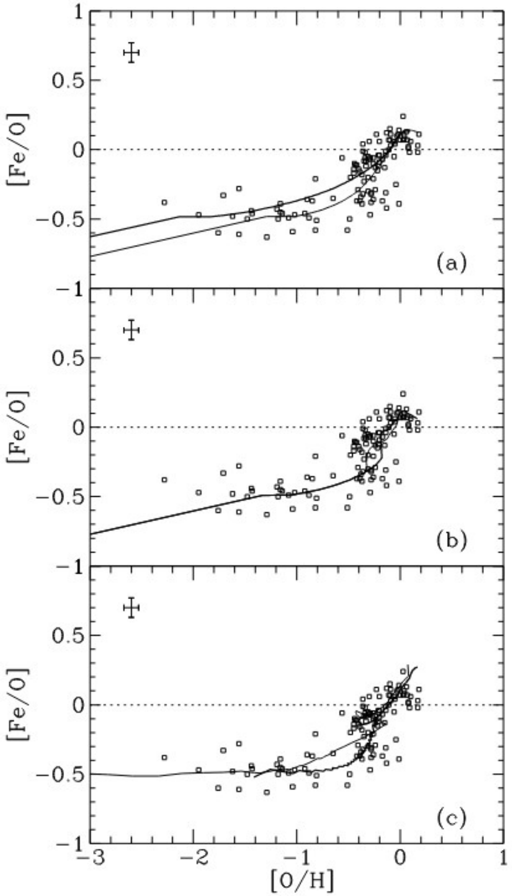


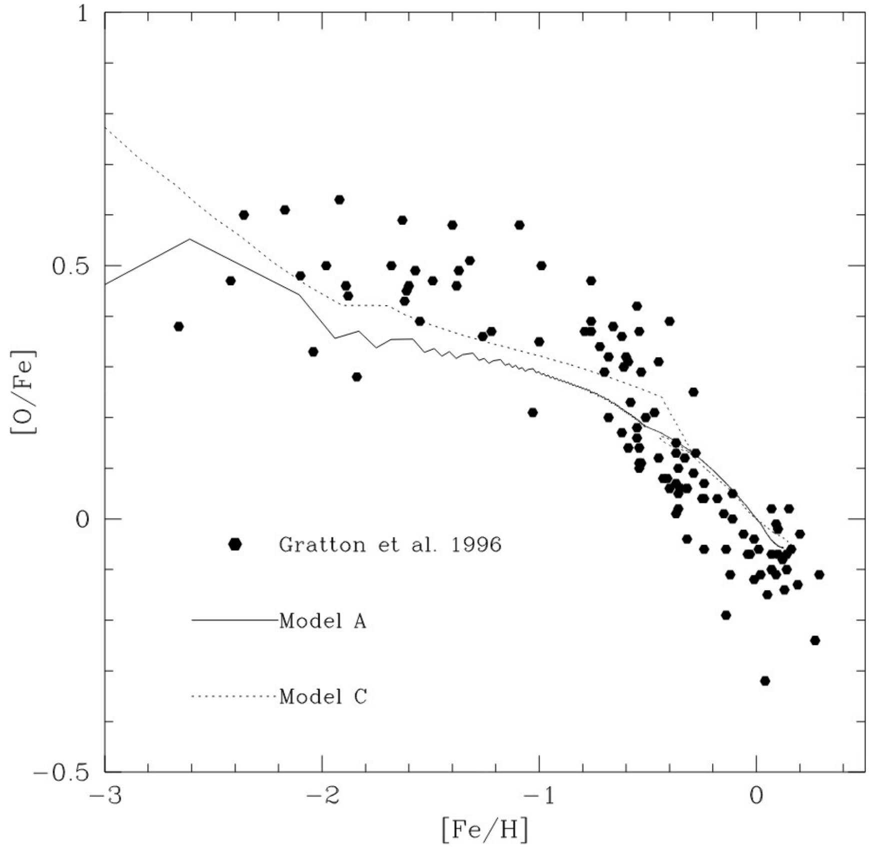
Image credit: Chiappini (2001).

First hints of the disc bimodality

First signatures of a chemical bimodality between the thick and thin discs can be found in Gratton et al. (1996, 2000) (see also Fuhrmann et al. 1988) and predicted by the two-infall model of Chiappini, Matteucci & Gratton (1997).



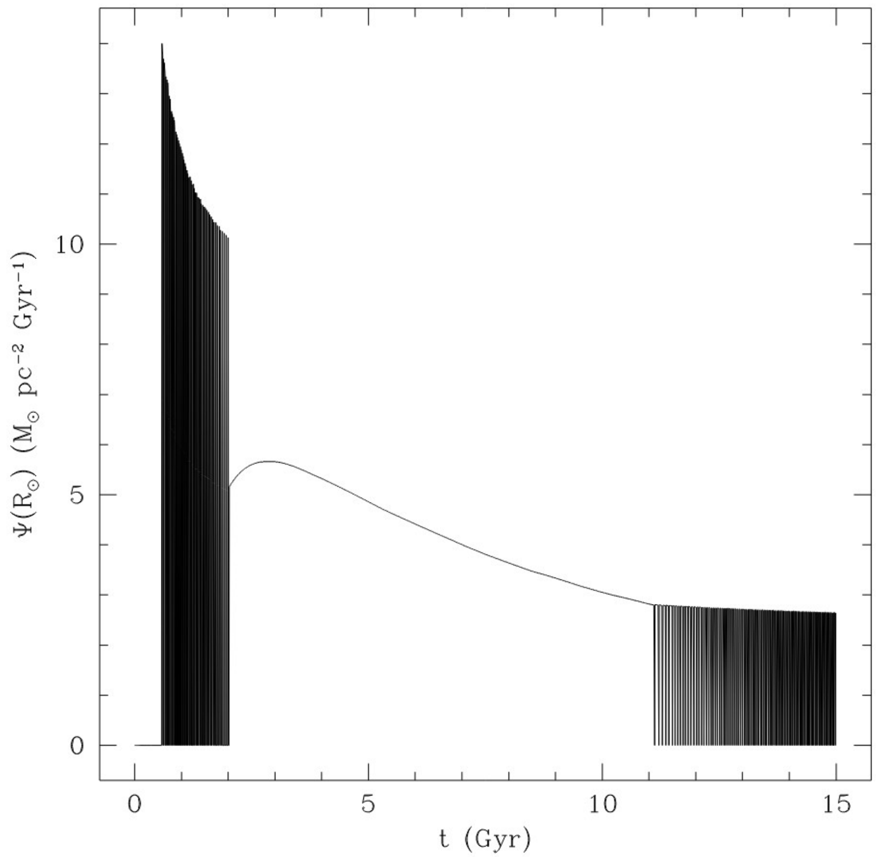
Gratton et al. (1996)
(see also Fuhrmann et al. 1998)



Chiappini et al. (1997)

First hints of the disc bimodality

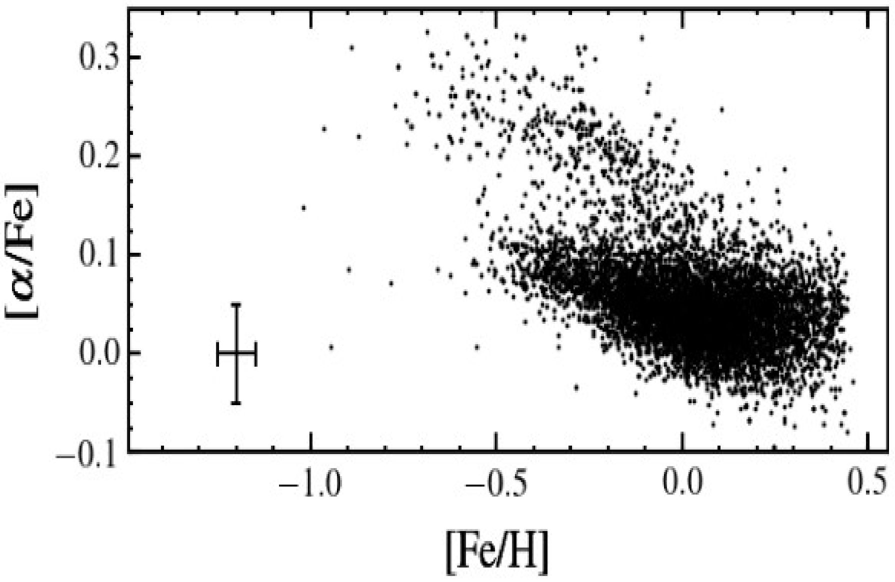
First signatures of a chemical bimodality between the thick and thin discs can be found in Gratton et al. (1996, 2000) (see also Fuhrmann et al. 1988) and predicted by the two-infall model of Chiappini, Matteucci & Gratton (1997).



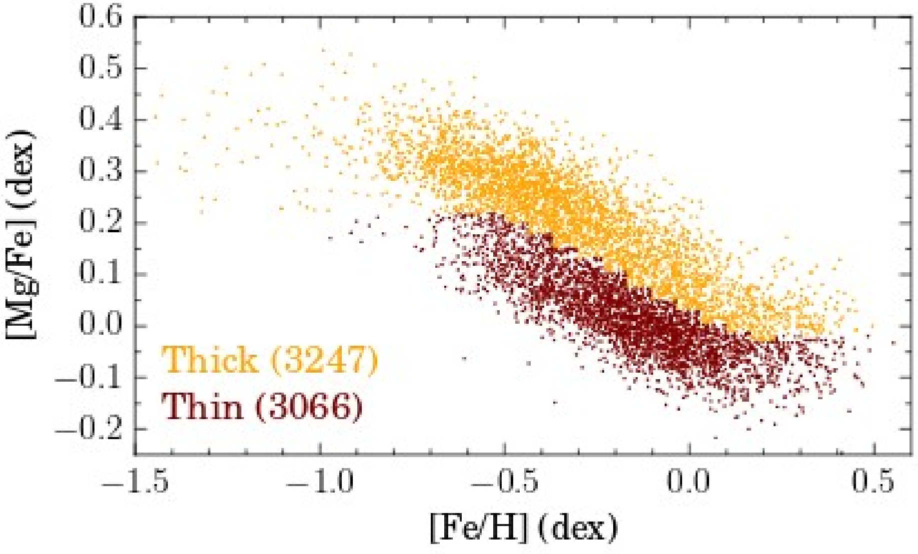
Chiappini et al. (1997)

APOGEE and Gaia-ESO data

New data from large spectroscopic surveys then clearly showed a chemical bimodality in the [alpha/Fe] vs. [Fe/H] diagram. In particular, APOGEE and Gaia-ESO data first showed a clear bimodality between the high- and low-alpha sequences, i.e. the thick and thin discs pointing out a clear bimodality among the two components.



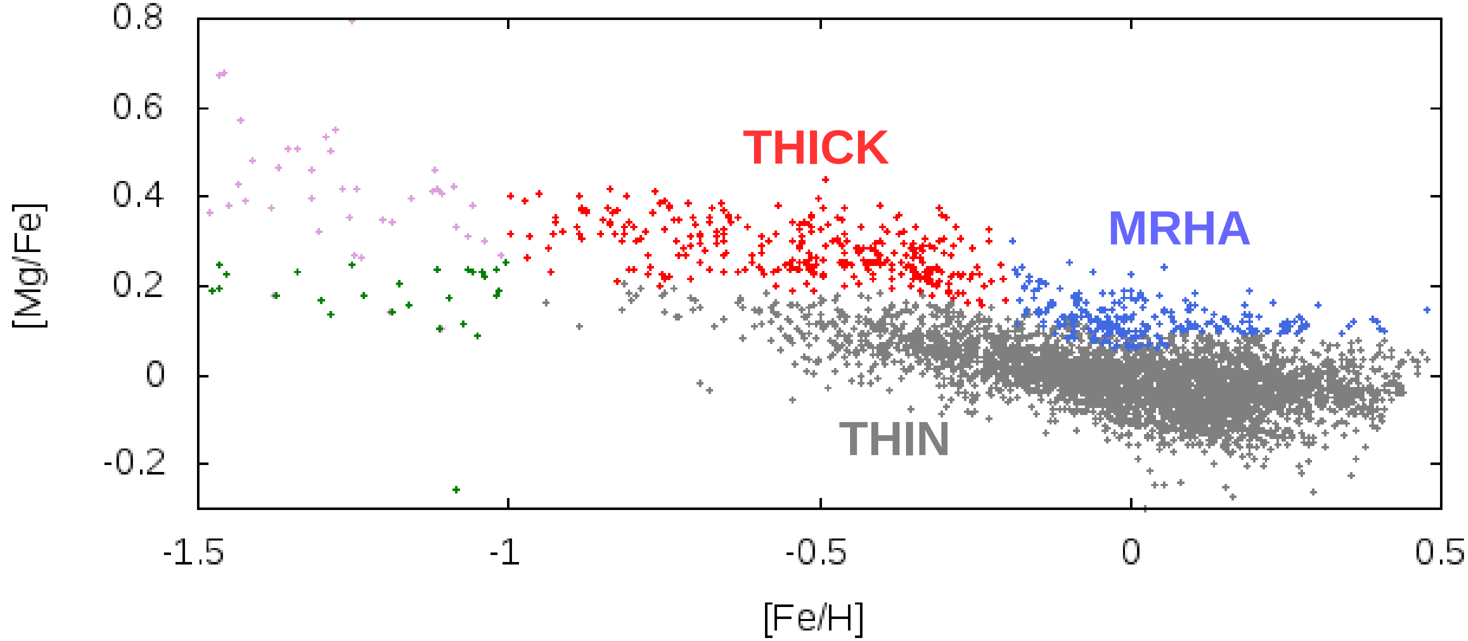
Hayden et al. (2015)



Rojas-Arriagada et al. (2017)

The AMBRE data

AMBRE data (Mikolaitis et al. 2017) show that in the abundance patterns of the α-elements there are two distinct sequences corresponding to **thick** and **thin** disc stars, and also a further metal-rich high-α **MRHA** population.



Mikolaitis et al. (2017)

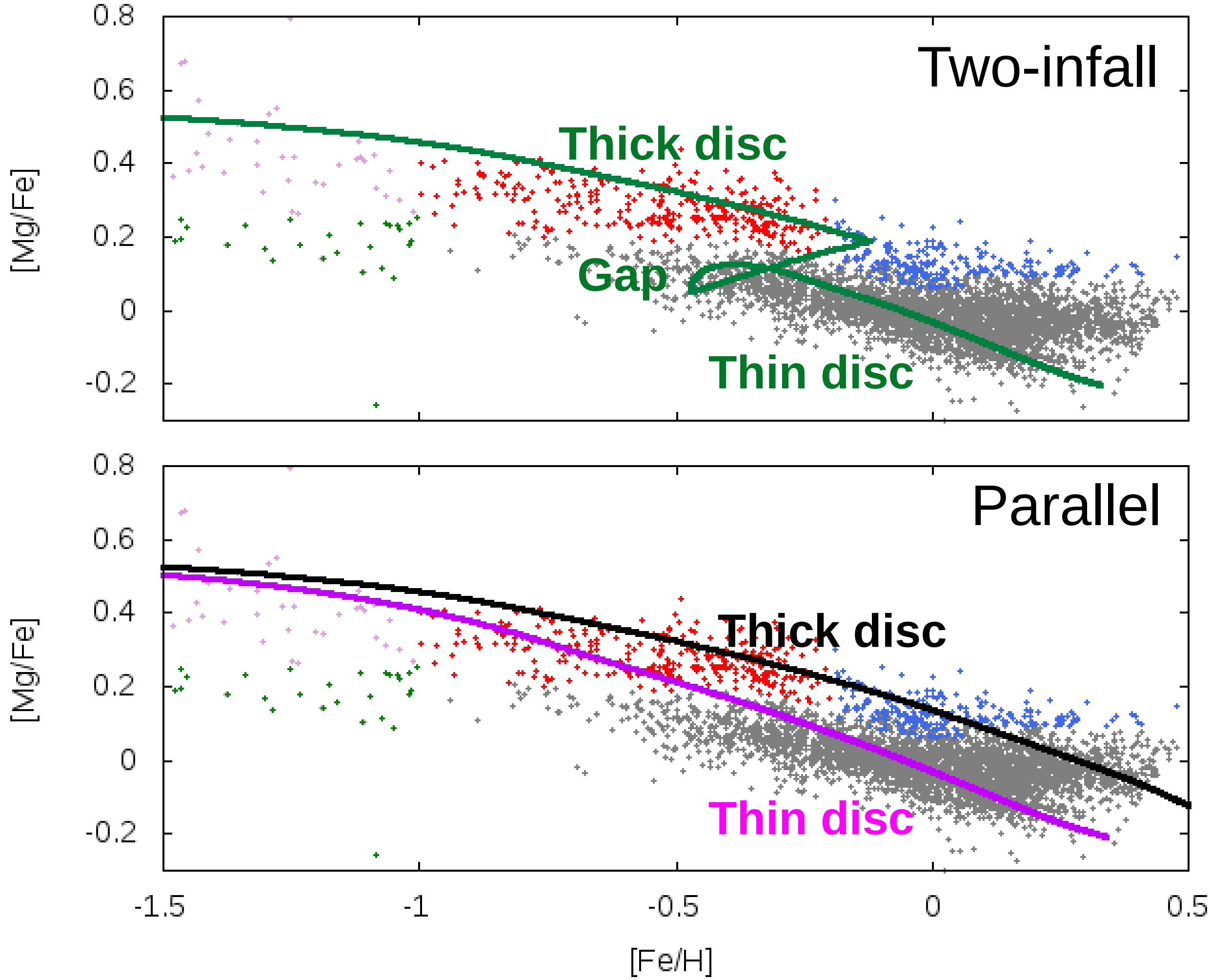
The models for the Galactic disc(s)

In Grisoni et al. (2017), we model the thick and thin disc evolution by adopting two different chemical evolution approaches:

i) a revisited two-infall approach (Chiappini et al. 1997; Romano et al. 2010) but applied only to the disc (thick and thin discs);

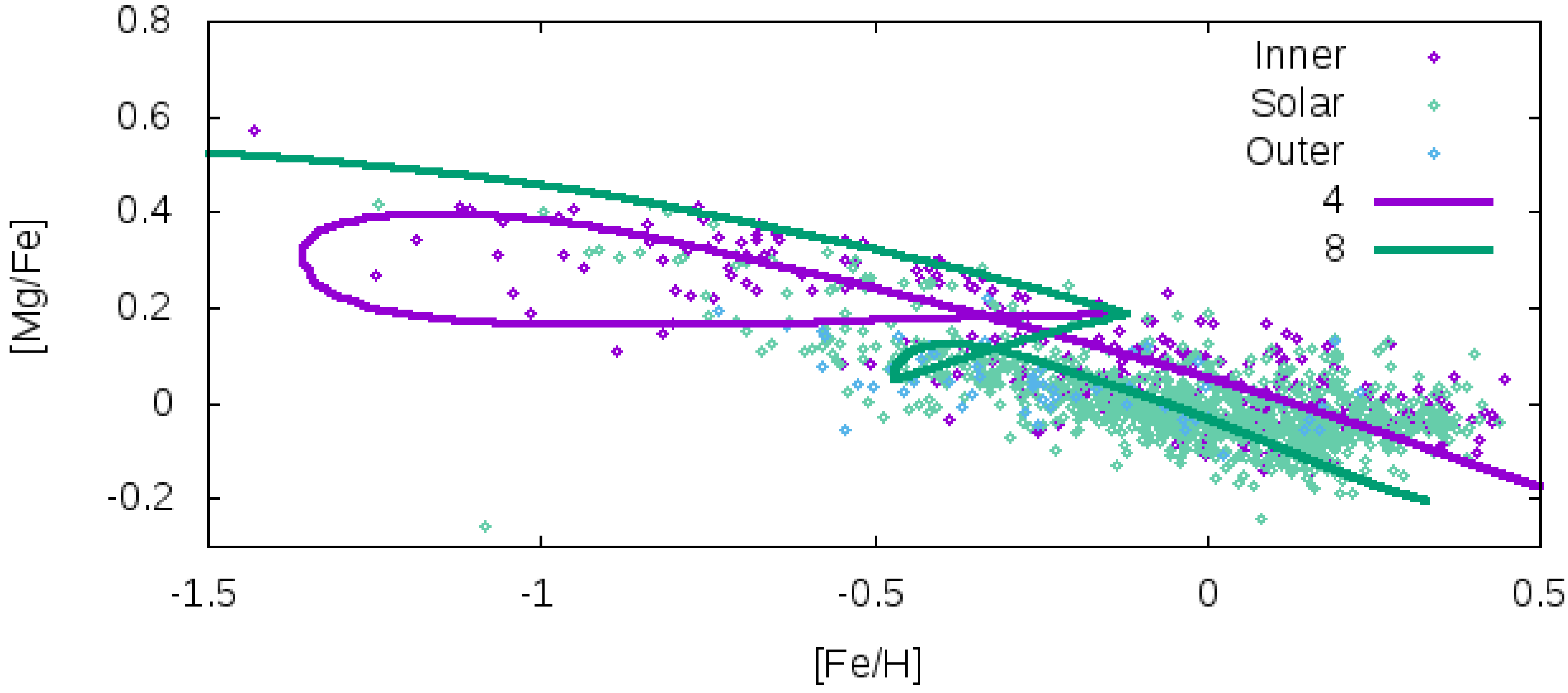
ii) a new parallel approach, where the evolution of the thin and thick discs can be followed separately.

Abundance patterns



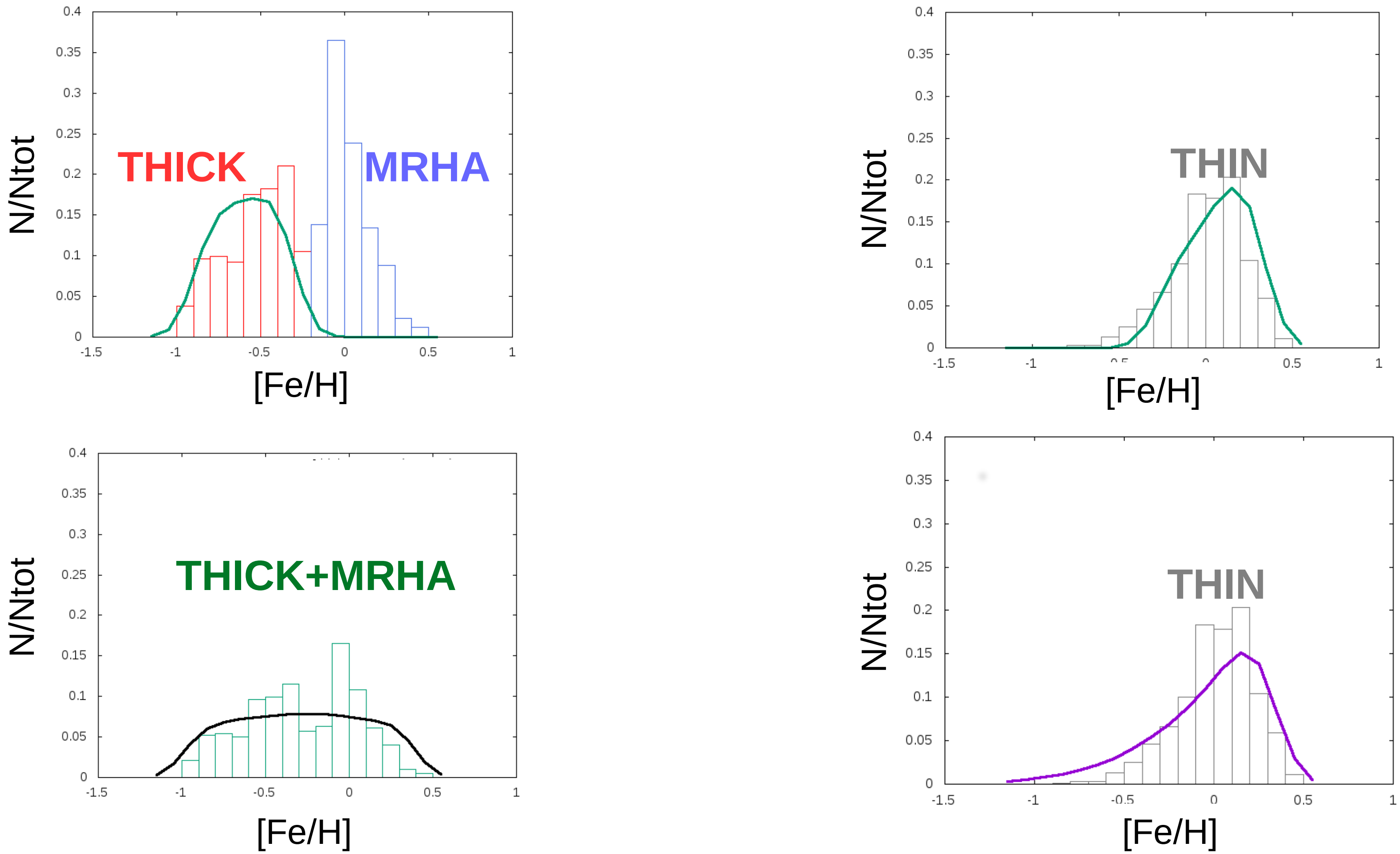
Observed and predicted [Mg/Fe] vs. [Fe/H] for the two-infall model (upper panel) and the parallel model (lower panel).

The only way to interpret the MRHA stars in terms of the two-infall model is by assuming radial migration, i.e. stars moving from other Galactocentric radii.



Observed and predicted [Mg/Fe] vs. [Fe/H] for the two-infall model at various Galactocentric radii (inside-out scenario). The data are color-coded according to their guiding radii (Hayden et al. 2017).

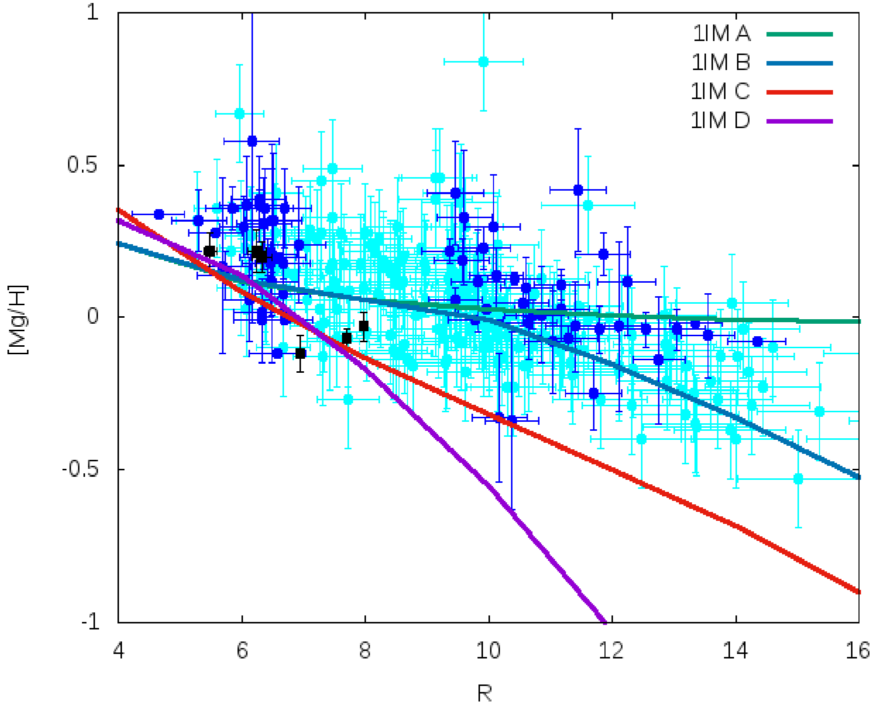
Metallicity distribution function



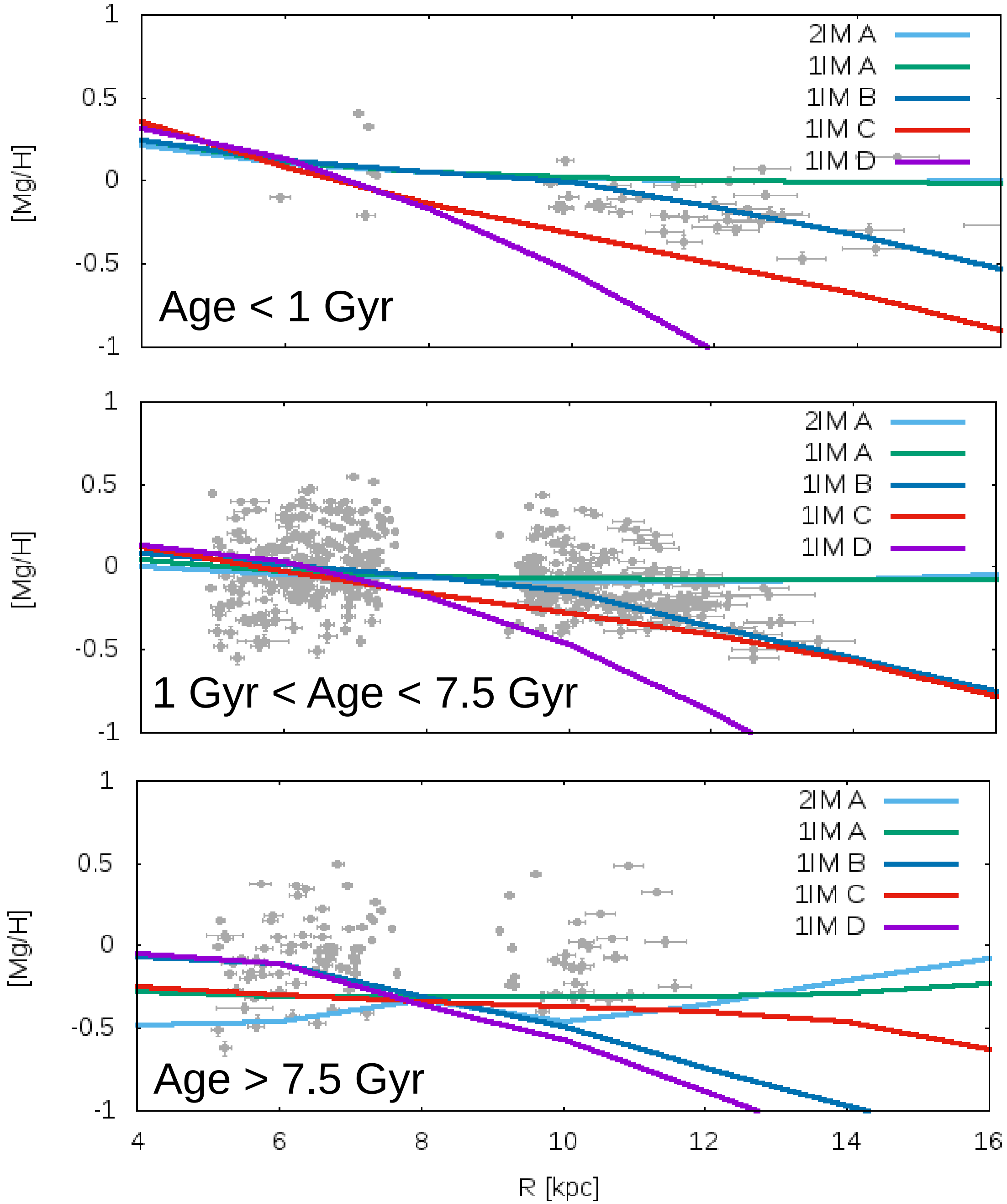
MDFs observed and predicted by the two-infall model (upper panels) and by the parallel model (lower panels).

Abundance gradients

In Grisoni et al. (2018), we then compare observations with our model predictions for the Galactic thin disc: **1IMA (only inside-out)**, **1IMB (variable star formation efficiency SFE)**, **1IMC (radial gas flows)**, **1IMD (variable SFE+radial gas flows)**.



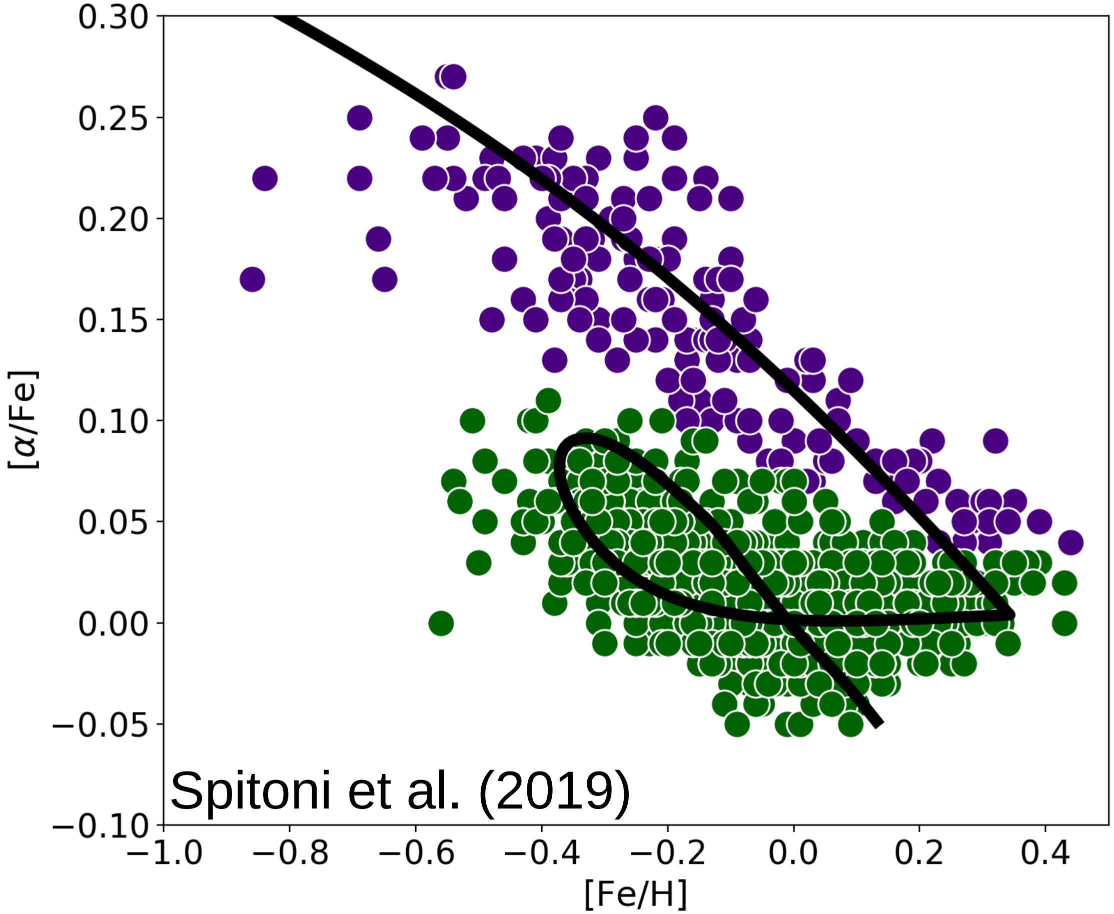
Observed and predicted abundance gradient for magnesium. The data are from Genovali et al. 2015 (blue dots), Luck and Lambert 2011 (light-blue dots) for Cepheids, and from Magrini et al. 2017 (black squares) for young OCs.



Time evolution of the radial abundance gradient for Mg observed by Anders et al. (2017) with COROGEE and predicted by Grisoni et al. (2018). **1IMA (only inside-out)**, **1IMB (variable star formation efficiency SFE)**, **1IMC (radial gas flows)**, **1IMD (variable SFE+radial gas flows)** (see Emma's talk with K2 data)

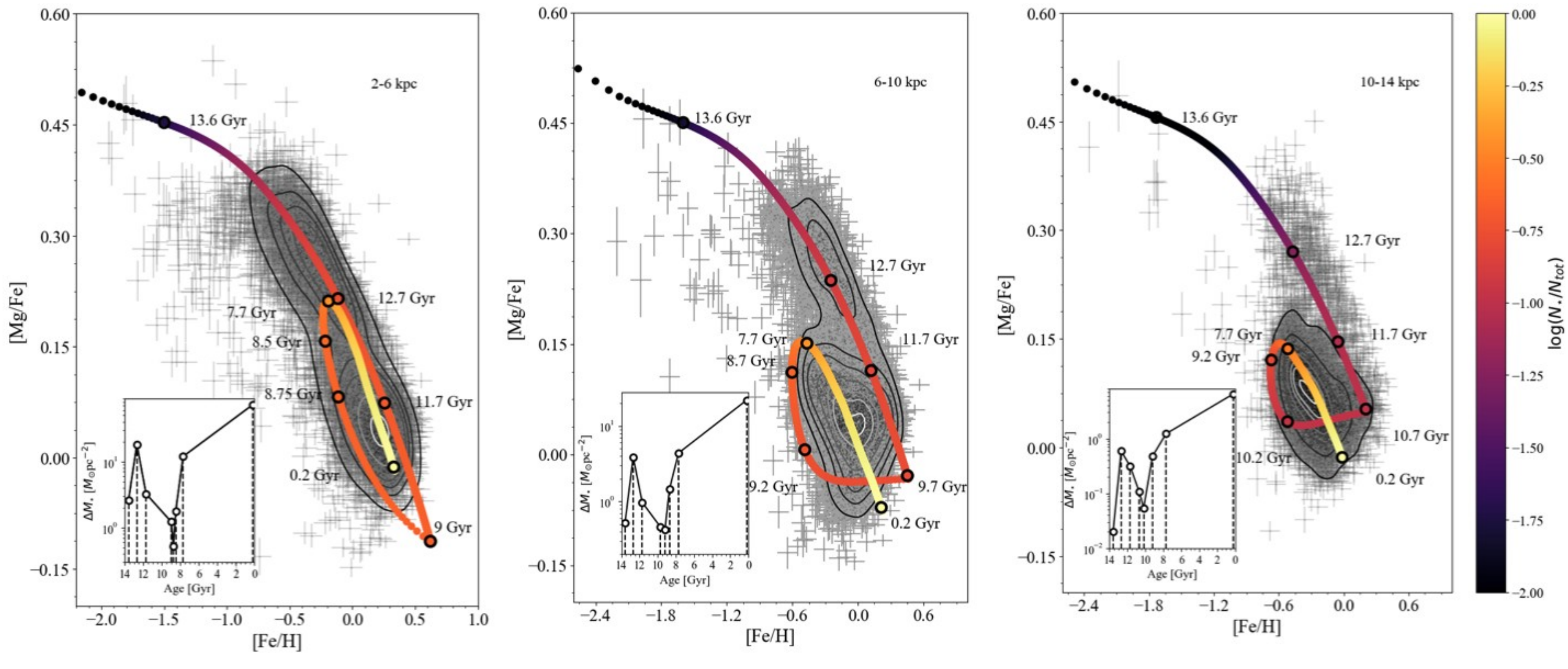
The “ribbon” model

In Spitoni+VG et al. (2019), we tested these models in the light of new data from APOKASC. We pointed out the importance of a delayed second infall episode with a delay of about 4.3 Gyr.



The whole Galactic disc

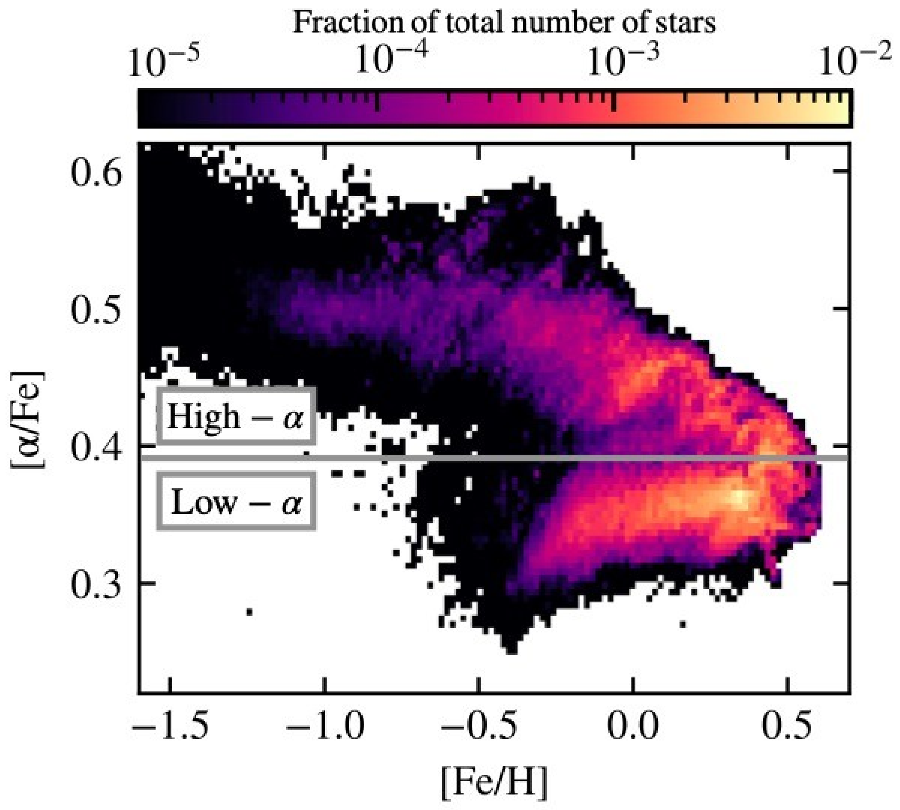
In Spitoni+VG et al. (2021), we extended the revised two-infall model to the whole Galactic disc, from the inner to the outer regions.



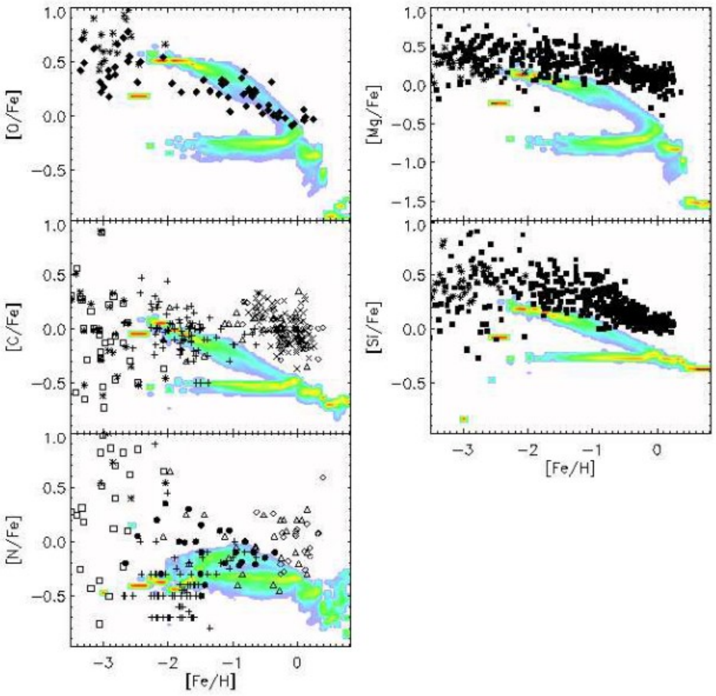
Spitoni et al. (2019)

Other works in the literature

Cosmological simulations and semi-analytic models can naturally predict a dilution, consistently with the chemical evolution models.



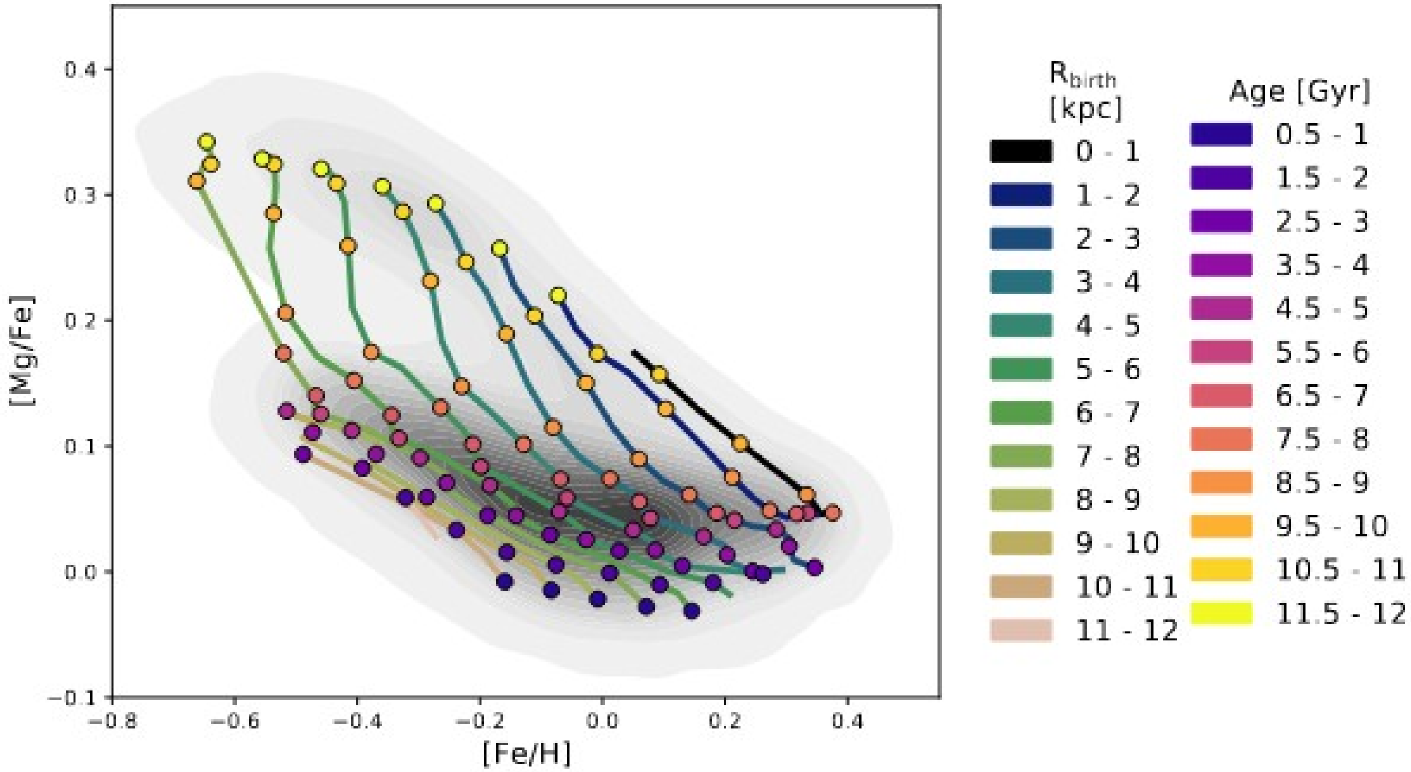
Agertz et al. (2021)



Calura & Menci (2009)

Radial migration

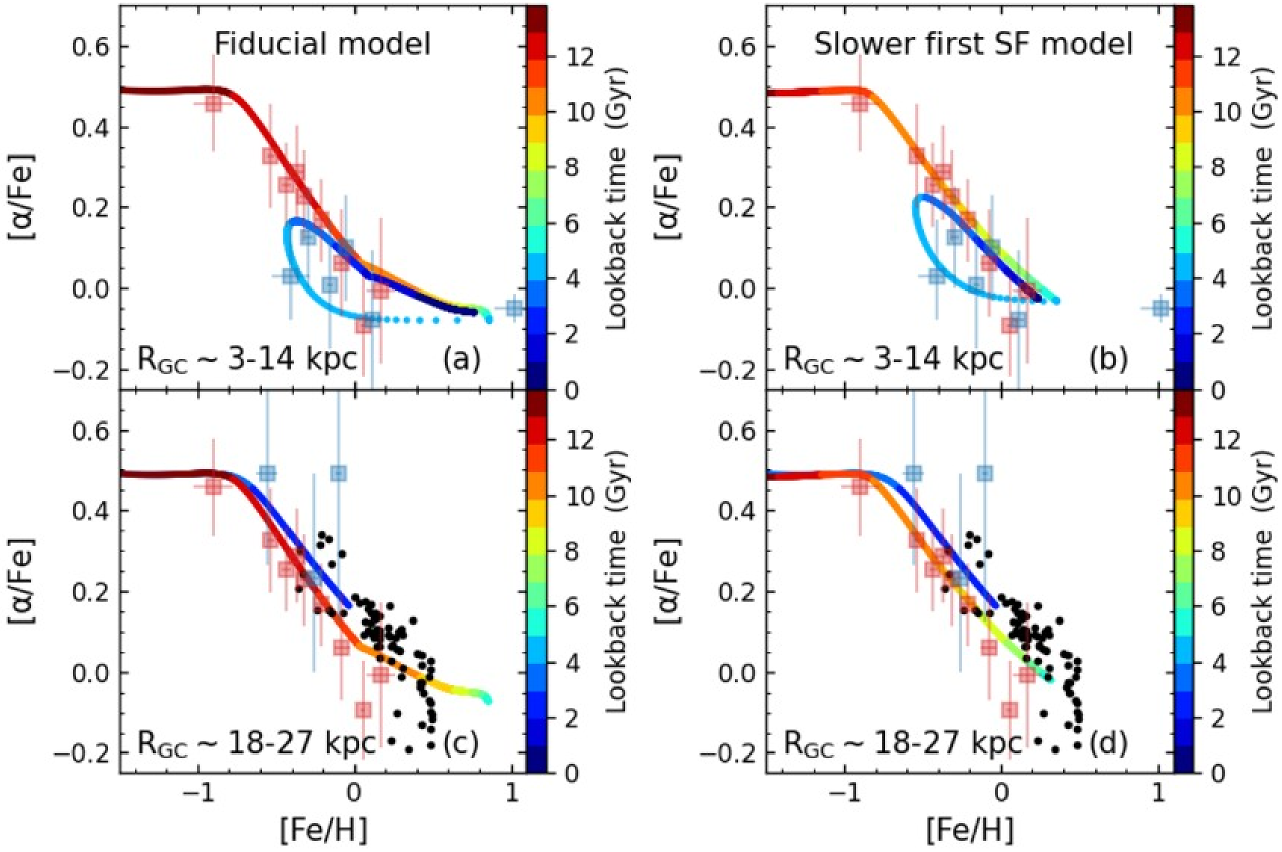
The [alpha/Fe] vs. [Fe/H] bimodality as been also explained in terms of radial migration of stars (Schönrich & Binney 2009; Minchev et al. 2013; Kubryk et al. 2015a,b; Grand et al. 2015 among others).



Ratcliffe et al. (2023) (see Ivan’s talk)

Is the bimodality universal?

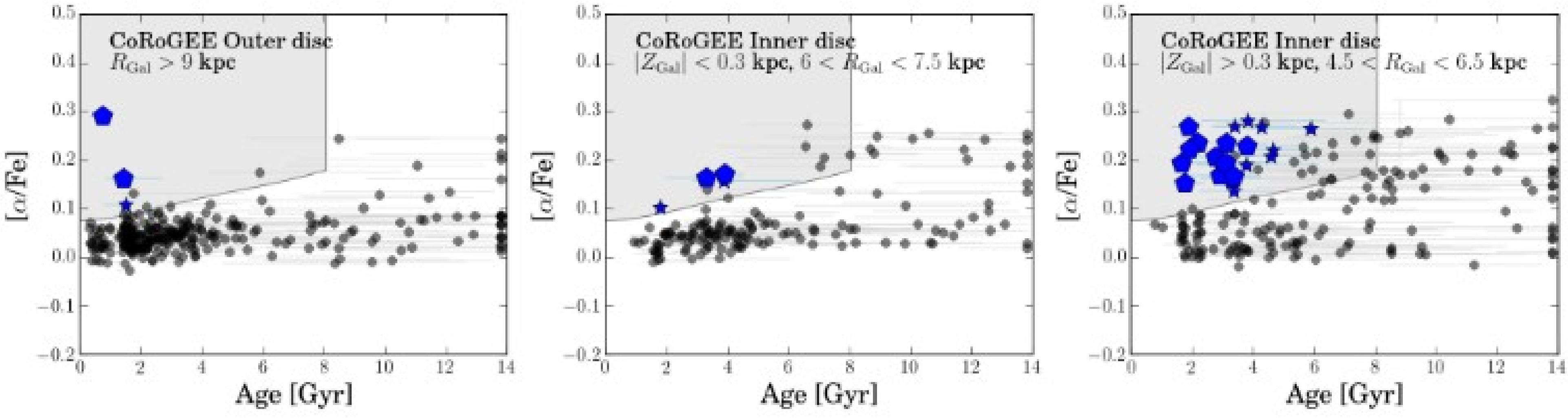
An open question is whether the alpha/Fe bimodality exists in other disk galaxies. Kobayashi et al. (2023) present a bimodality in M31 using galactic chemical evolution models that can explain observations in the M31 disks (abundances of PNe and of RGB stars observed with JWST).



Kobayashi et al. (2023)

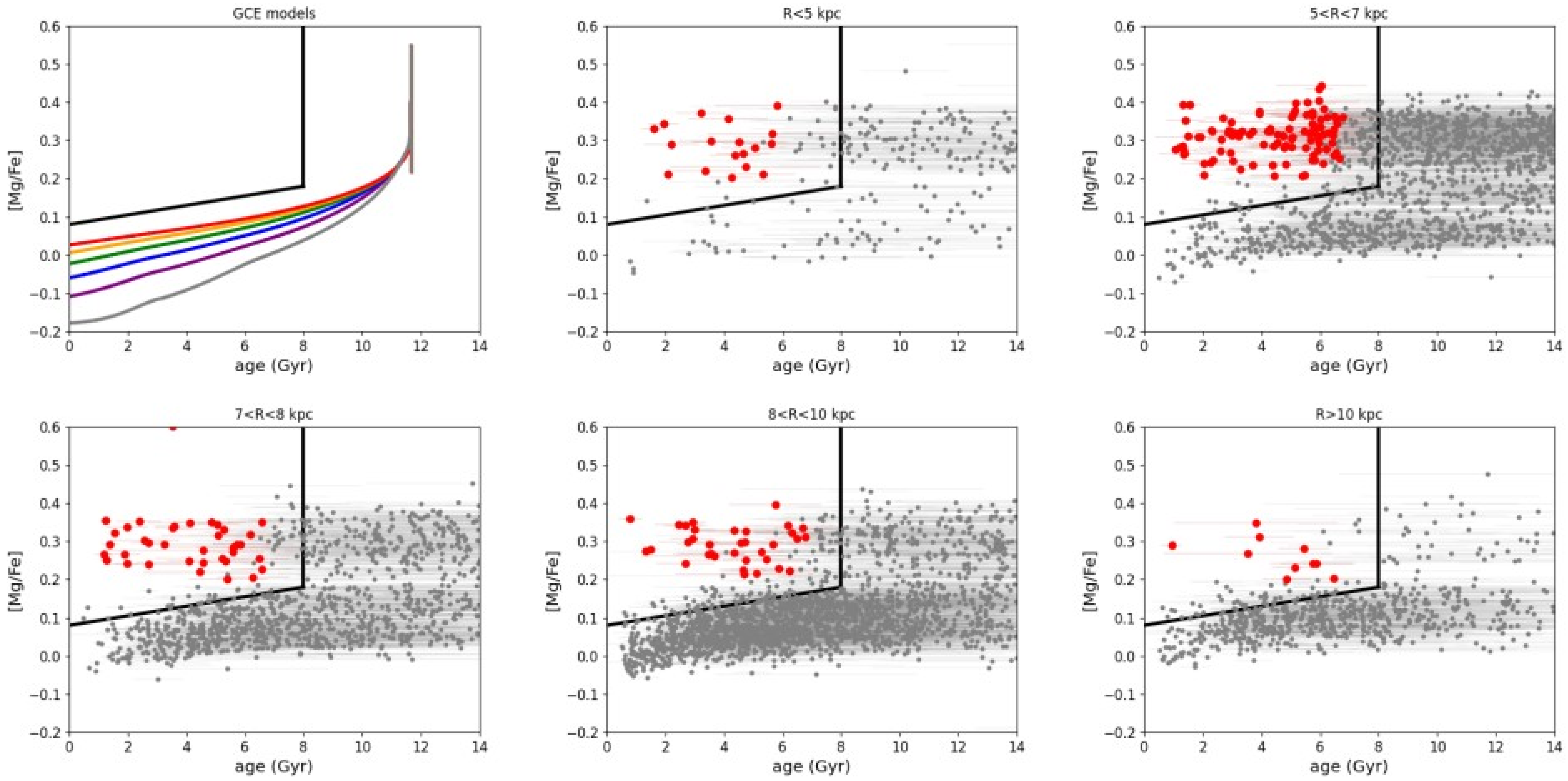
Young alpha-rich stars

Chiappini et al. (2015) discovered a class of young alpha-rich stars that cannot be explained by chemical evolution models. Two possible explanations proposed: i) related to binary evolution/mass transfer or ii) related to a peculiar star formation in e.g. the corotation region.

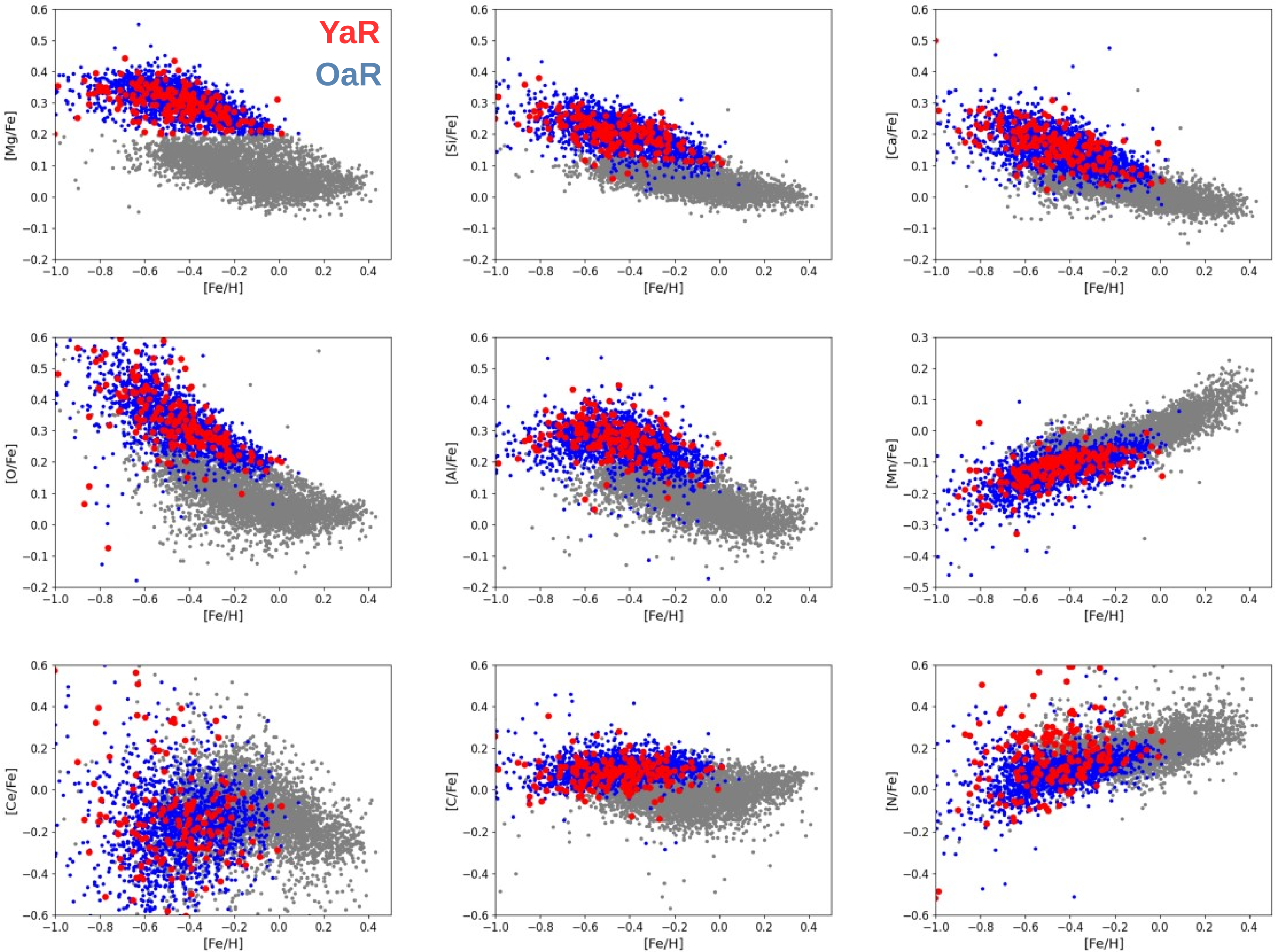


Chiappini et al. (2015)

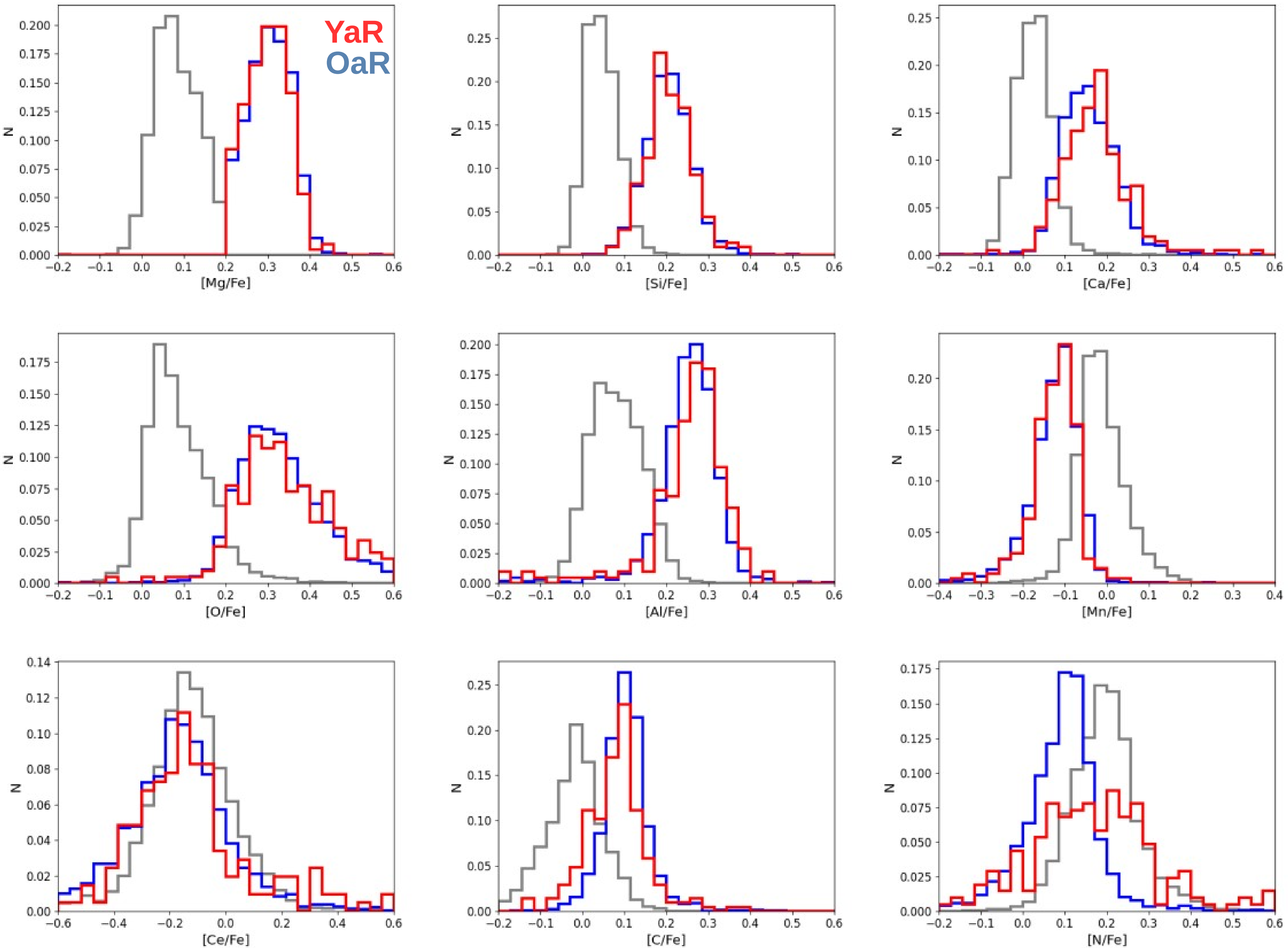
New results with K2



Grisoni et al. (submitted): the forbidden region is defined by the multi-zone chemical evolution models of Grisoni et al. (2017) and the data are from K2-APOGEE (see also Emma's talk).



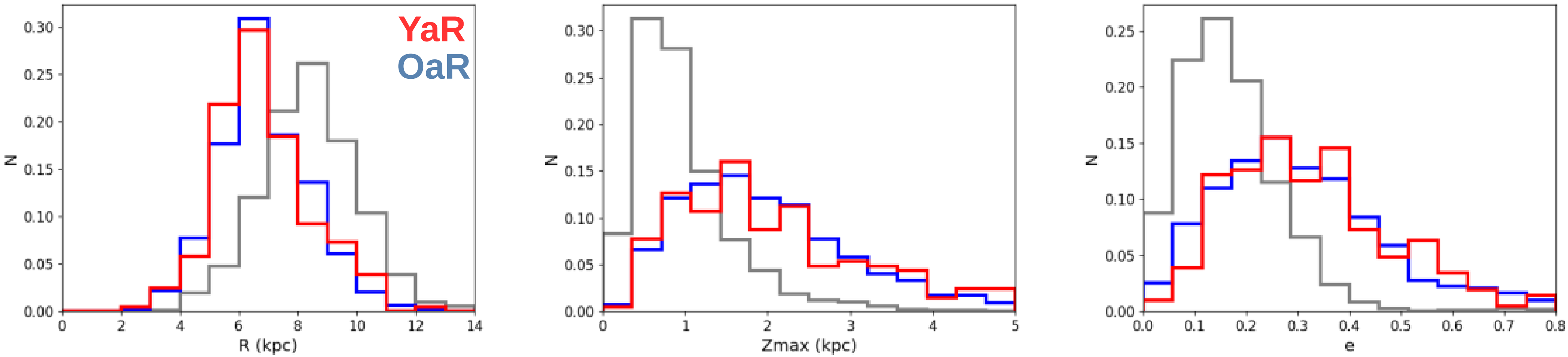
Grisoni et al. (submitted)



Grisoni et al. (submitted)

Kinamatic properties

Besides the chemical properties, also from the kinematic point of view, young-alpha rich stars are overlapping with the old alpha-rich population. This fact suggests that these young alpha-rich stars should be considered as stragglers of the thick disc, in agreement with other recent complementary studies (e.g. Cerqui et al. 2023, Jofre et al. 2023), at variance with other scenarios proposed in the literature so far.



Grisoni et al. (submitted)

Summary

- We developed detailed chemical evolution models that can follow the evolution of the different Galactic components, such as the thick and thin discs (high-alpha and low-alpha populations). We adopted two different approaches to model the thick and thin disc evolution *(Grisoni et al. 2017,2018)*:

  i) a revised two-infall approach: can explain the metal-rich α-enhanced stars, only as they are the result of stellar migration;

  ii) a new parallel approach: it can fit the metal-rich α-enhanced stars, as metal rich thick disc stars.

  In both approaches, the thick disc has formed on a timescale of 0.1 Gyr, whereas the thin disc formed in 7 Gyr in the solar region. In the two-infall model, there is a gap in star formation between the thick and thin discs as due to the threshold assumed for the star formation.

- The models have been applied then to study the bimodality in several other abundance patterns, from light to heavy elements *(Grisoni et al. 2019, 2020a,b, Grisoni et al. 2021).*
- Young alpha-rich stars have similar occurrence rate in different parts of the Galaxy and they share similar properties as the normal high-alpha population. This suggests that these stars are not genuinely young, but products of binary evolution/mass accretion *(Grisoni et al. submitted).*