Galactic archaeology: from lithium to europium

Valeria Grisoni
Postdoc at the Asterochronometry team
University of Bologna

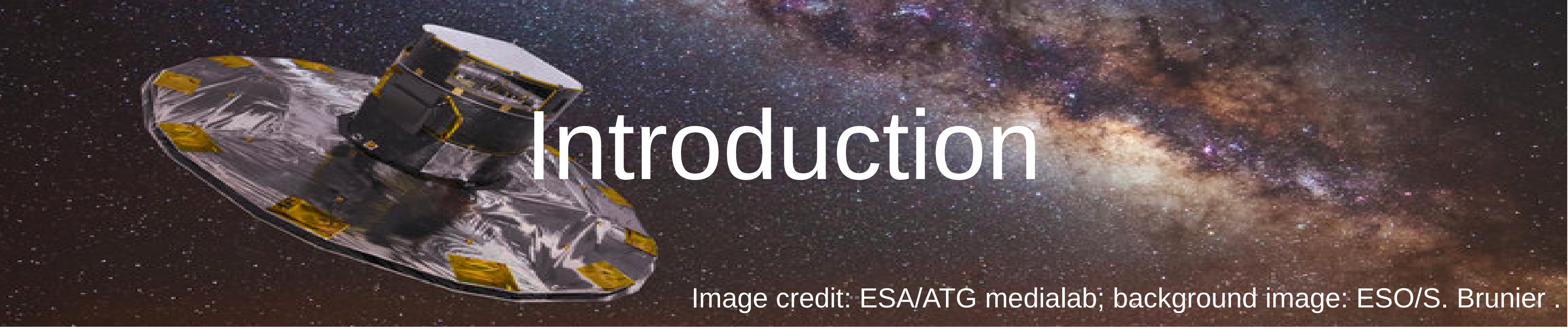
16 November 2021
Astrophysics Talk, Bologna

ASTERO
CHRONOMETRY

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Outline

- Introduction
- The models
- Results for α-elements
- Results for lithium abundance
- Results for neutron-capture elements
- Further results
- Conclusions



Introduction

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

Galactic Archaeology studies the history of formation and evolution of our Galaxy, and we are in a golden era for this field of research. In fact, in recent years many spectroscopic Galactic surveys have been developed: Gaia-ESO (Gilmore et al. 2012), APOGEE (Majewski et al. 2015), AMBRE Project (de Laverny et al. 2013). The value of these surveys has been enhanced by the advent of Gaia mission.

The Milky Way has four main stellar populations: halo, bulge, thick and thin discs.

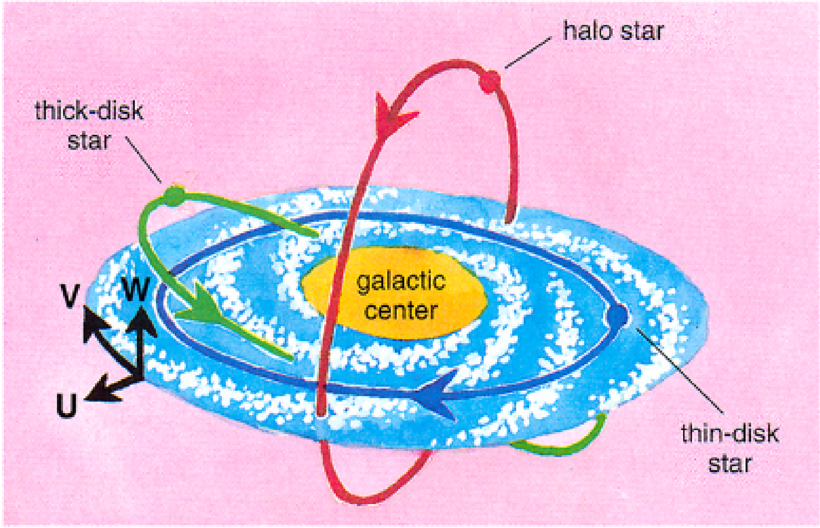
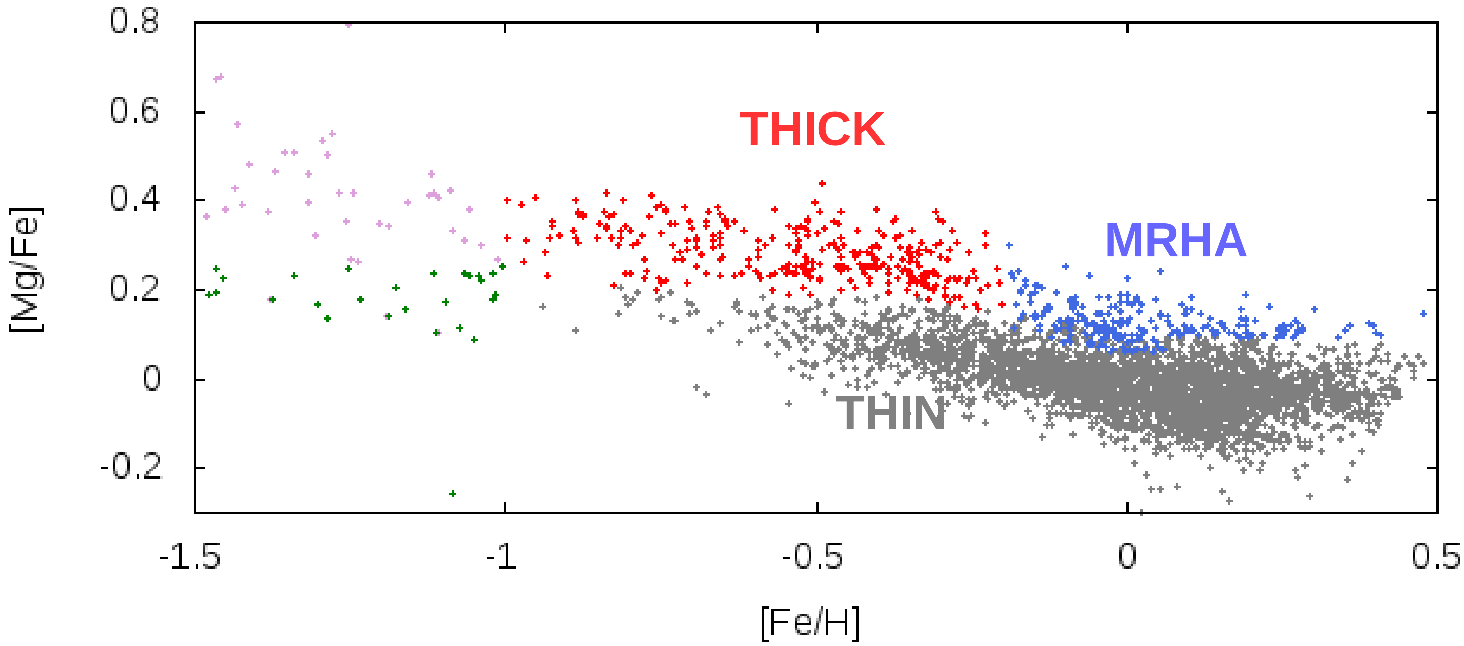


Image credit: Chiappini (2001).

Observational 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.



Observed [Mg/Fe] vs. [Fe/H] from Mikolaitis et al. (2017), where

$$[A/H] = log(N_A/N_H)_\star - log(N_A/N_H)_\odot$$

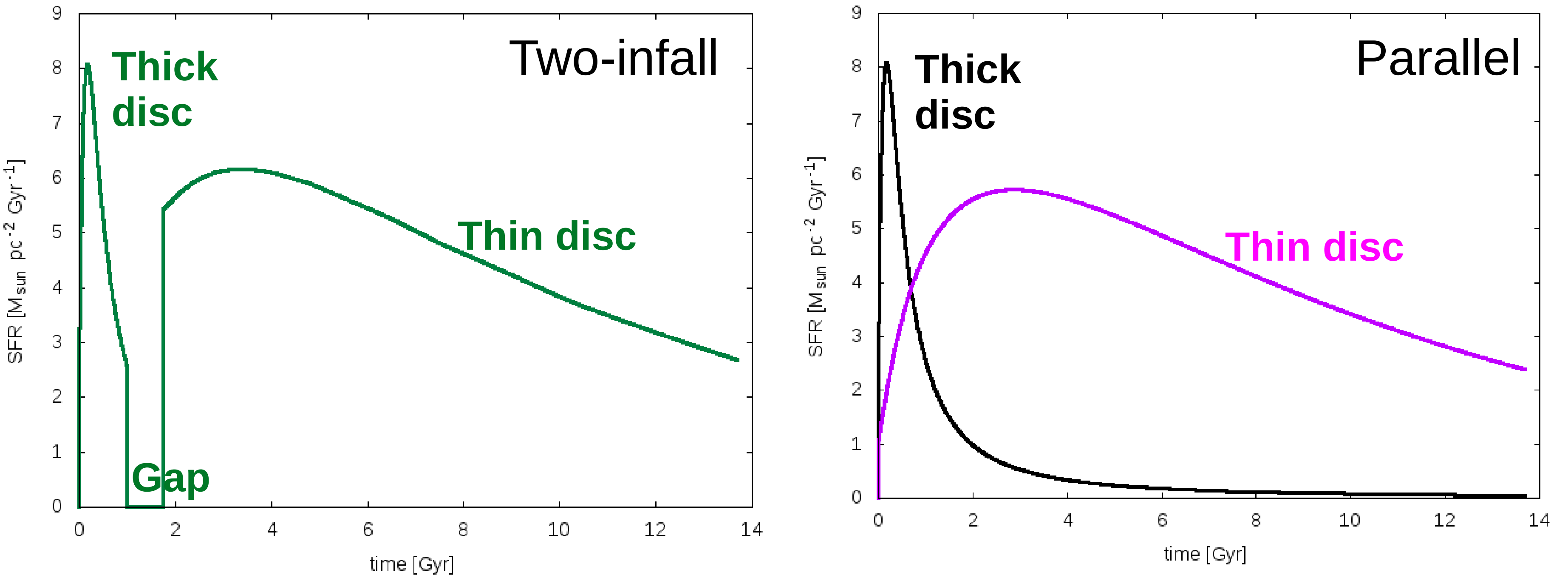
The models for the Galactic disc(s)

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

i) a two-infall approach (Chiappini et al. 1997,2001; Romano et al. 2010) applied to the thick and thin discs (see also Spitoni et al. 2021);

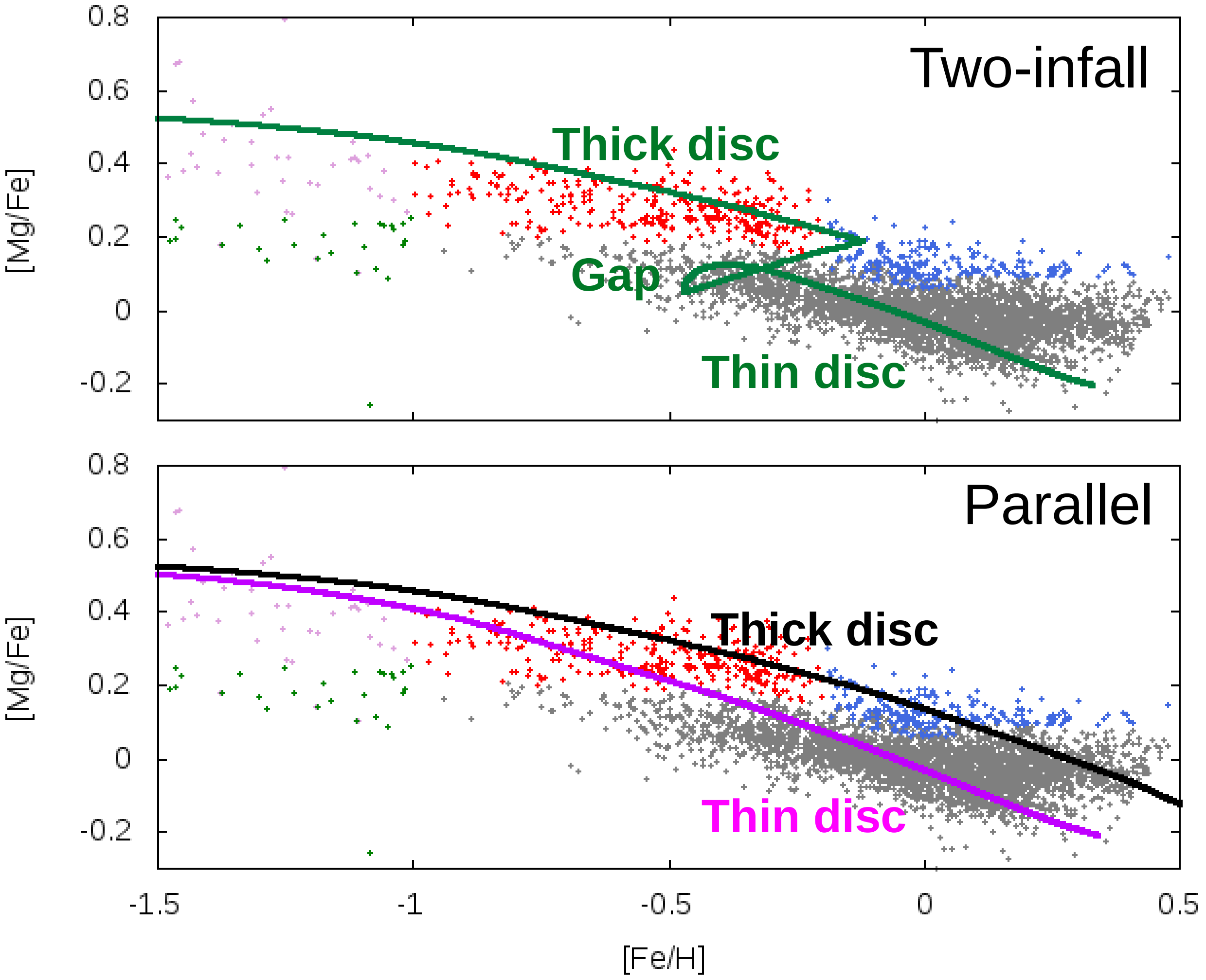
ii) a parallel approach, where thin and thick discs evolve at different rates (see also Chiappini 2009).

Star formation histories



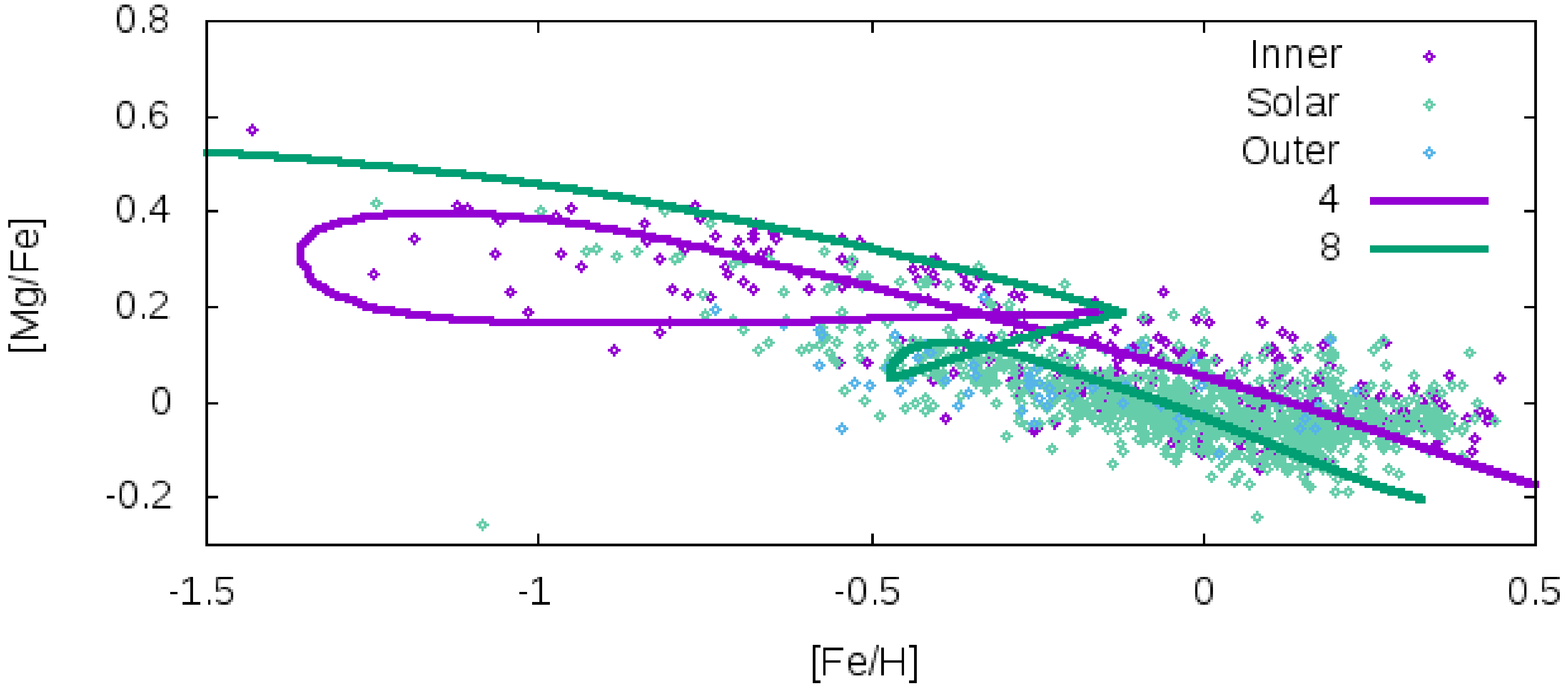
Temporal evolution of the star formation rate for the two-infall model (left) and the parallel model (right) (figure from Grisoni et al. 2017).

Abundance patterns



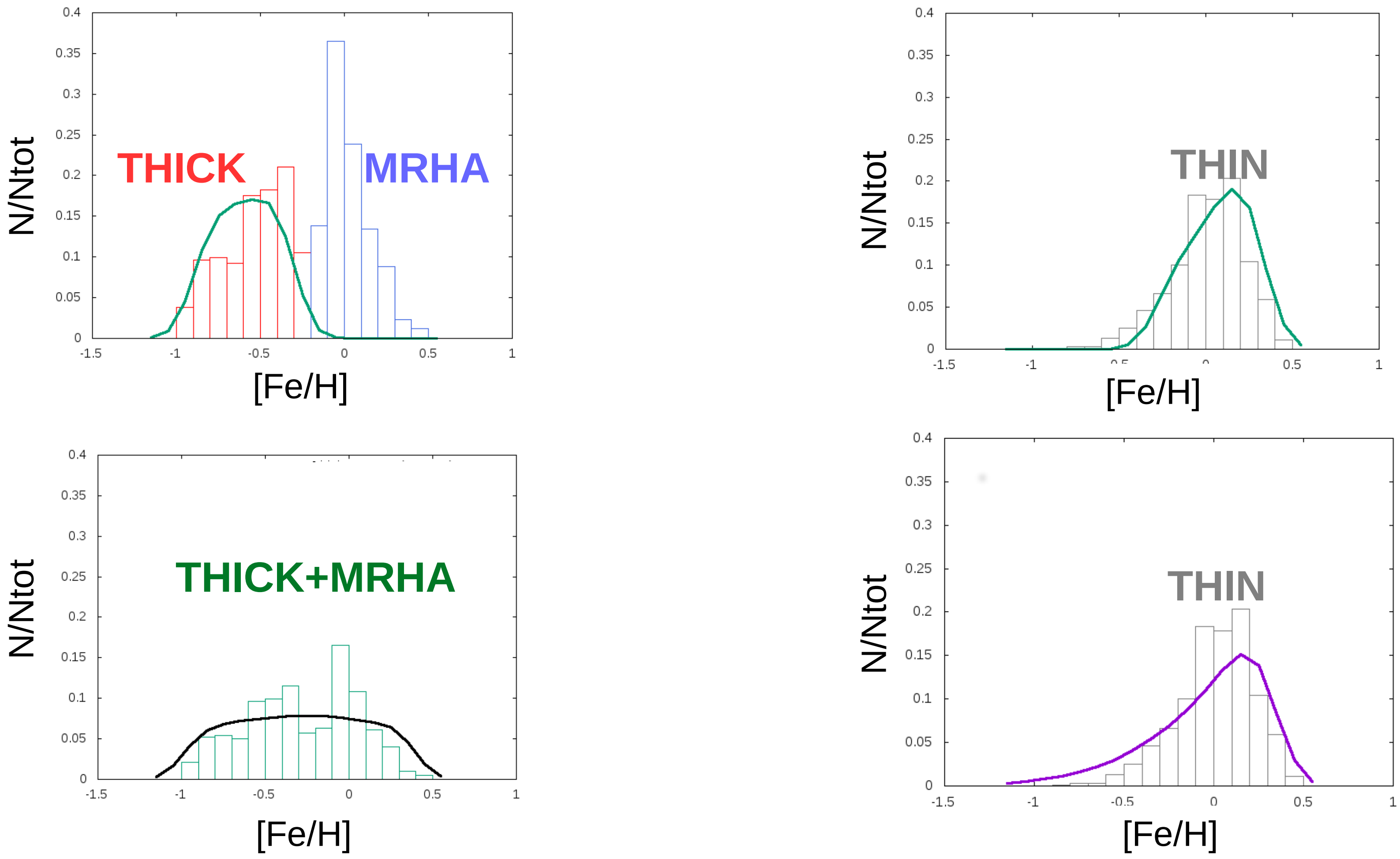
Observed and predicted [Mg/Fe] vs. [Fe/H] for the two-infall model (upper panel) and the parallel model (lower panel).

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

How do abundance gradients form?

- Inside-out scenario (Matteucci and Francois 1989; Chiappini et al. 2001);
- Variable SFE (Prantzos & Boissier 2000, Colavitti et al. 2009);
- Radial gas flows (Portinari & Chiosi 2000, Spitoni & Matteucci 2011).

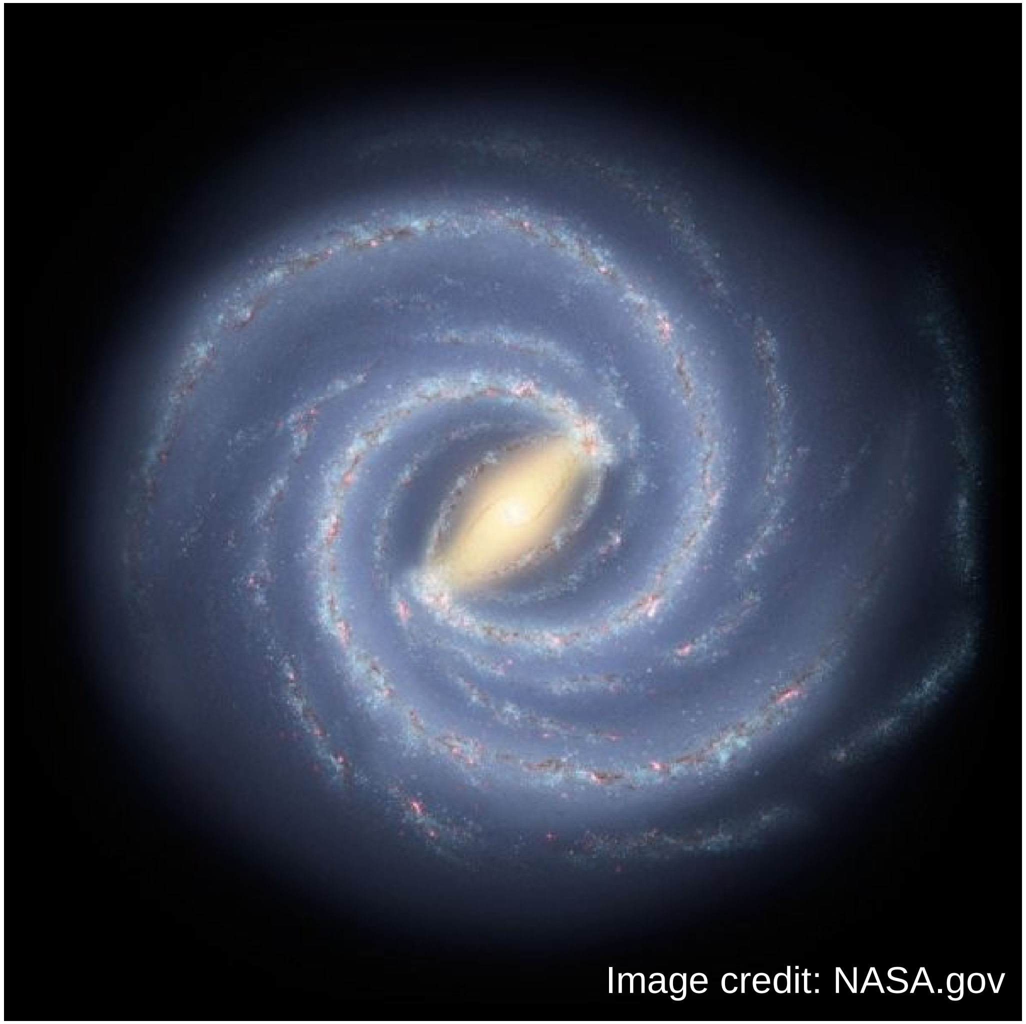
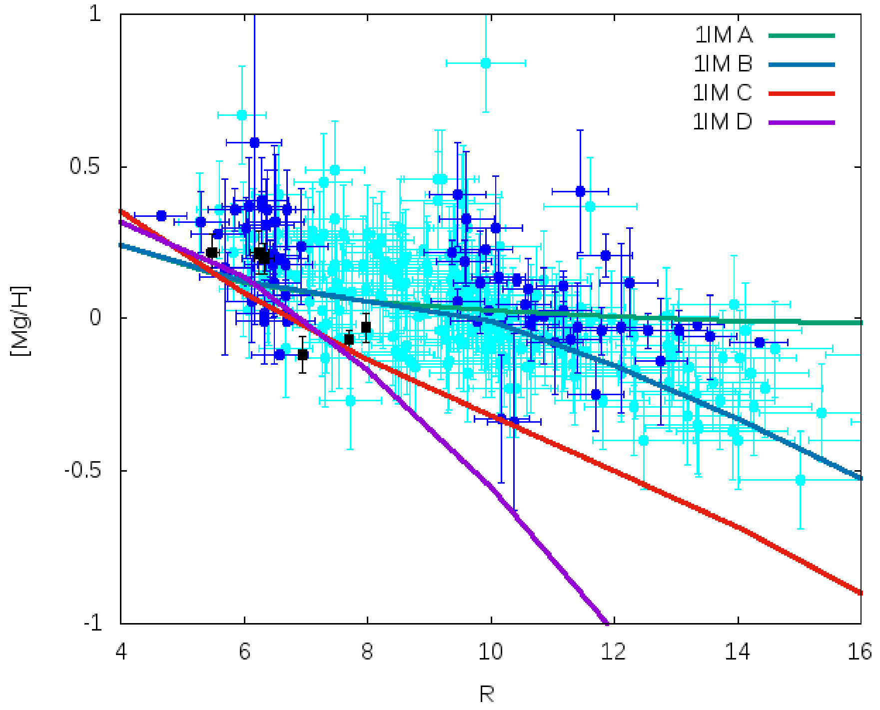


Image credit: NASA.gov

Results of Grisoni et al. (2018)



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. We compare observations with our model predictions for the one-infall model: **1IMA (only inside-out)**, **1IMB (variable star formation efficiency SFE)**, **1IMC (radial gas flows)**, **1IMD (variable SFE+radial gas flows)**.

(see more recently Palla et al. 2020, Spitoni et al. 2021).

Lithium

Another lively topic in Galactic Archaeology regards the Galactic lithium evolution, and the understanding of the A(Li) vs [Fe/H] plot (where A(Li)=log(Li/H)+12).

Important features:
-”Spite plateau” (Spite 1991) at low metallicities
-steep rise at higher metallicities

Li is produced during the Big Bang, but also by stars (AGB, novae…) as well as cosmic rays.

Our study concerns the upper envelope of the data.

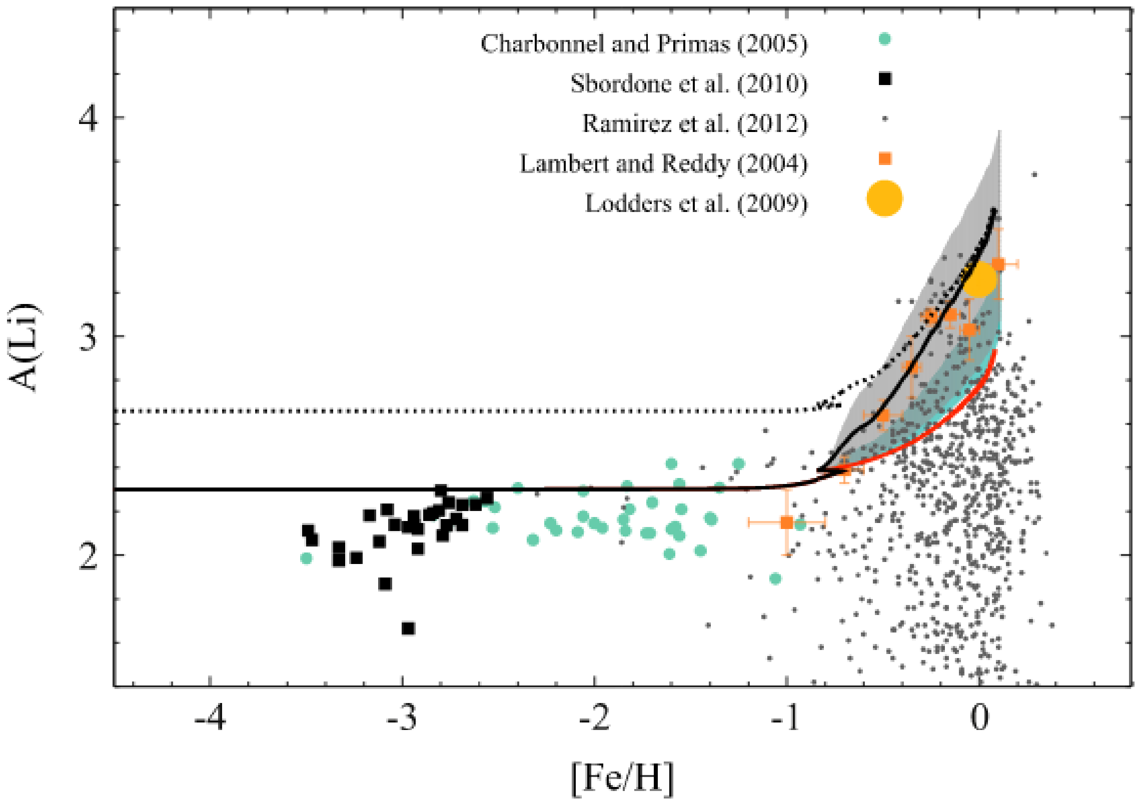


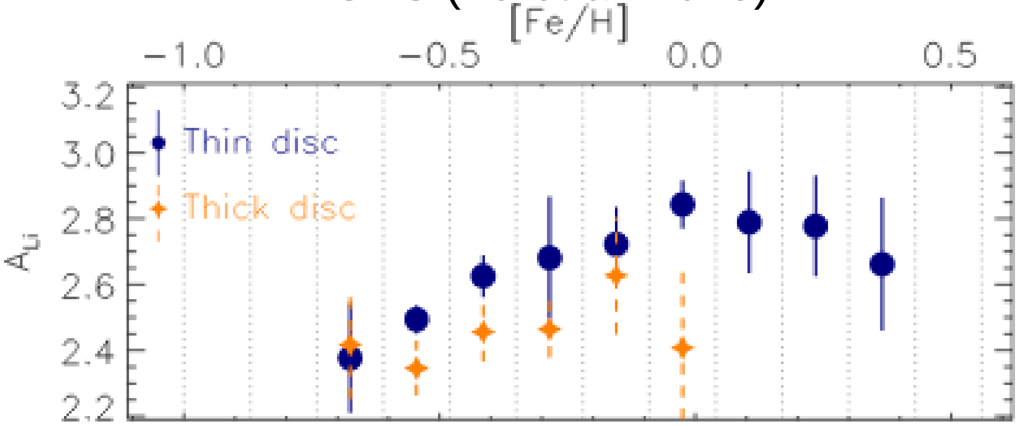
Image credit: Izzo et al. (2015). The predictions are from the chemical evolution model of Romano et al. (1999,2001).

Lithium in the disc(s)

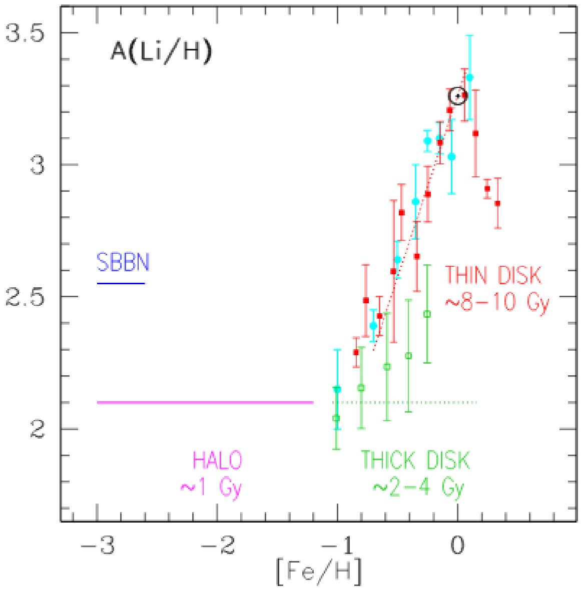
Recently, many spectroscopic surveys such as AMBRE (Guiglion et al. 2016) and Gaia-ESO Survey GES (Fu et al 2018) show a clear dichotomy between the thick and thin discs and an evident ISM lithium decline at high metallicities, that however is still matter of debate (see Charbonnel et al. 2021).

This feature still needs to be well-understood in terms of Galactic chemical evolution models. Possible explanations that have been proposed in the literature are:
i) lower yields of Li from single stars at high metallicities (Prantzos et al. 2017)
ii) radial migration (Guiglion et al. 2019).

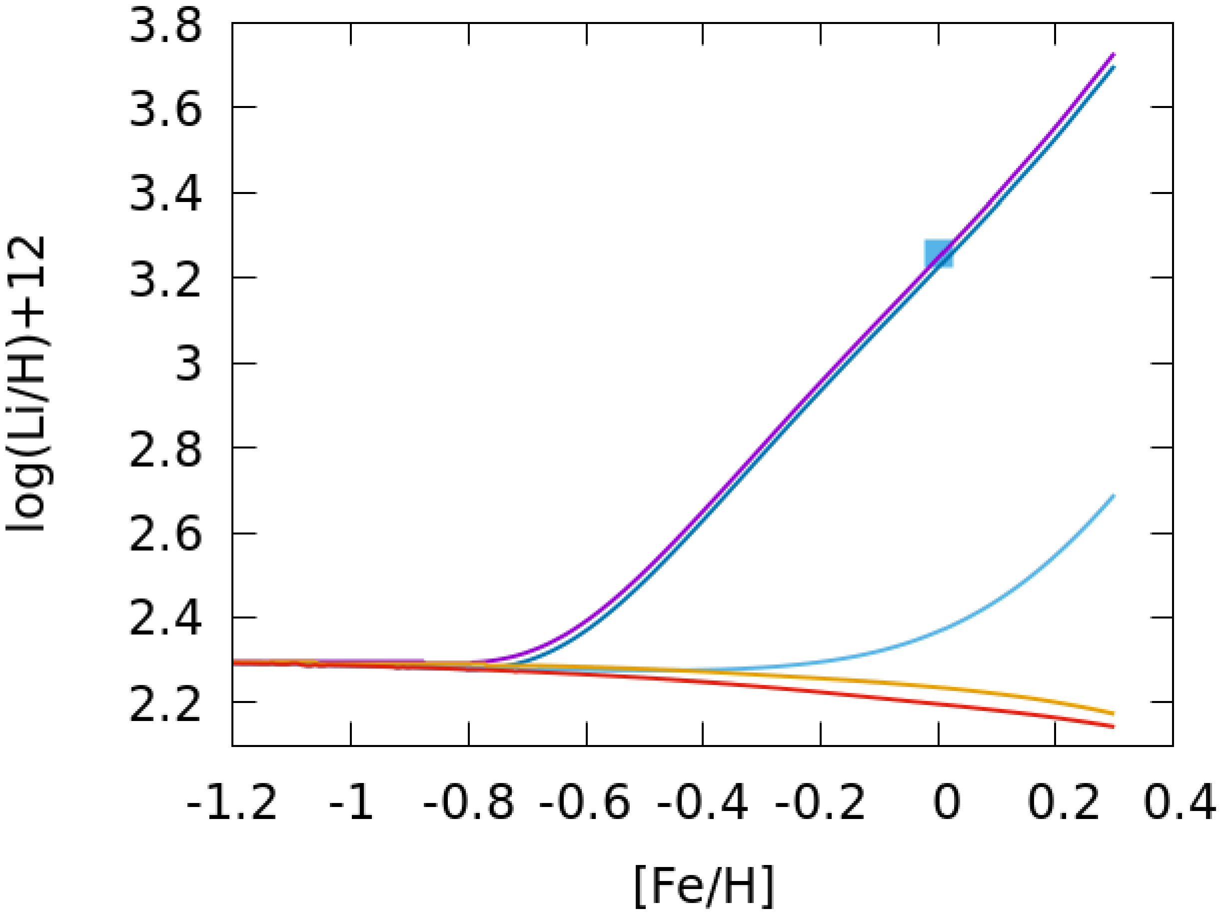
GES (Fu et al. 2018)



AMBRE (Guiglion et al. 2016)

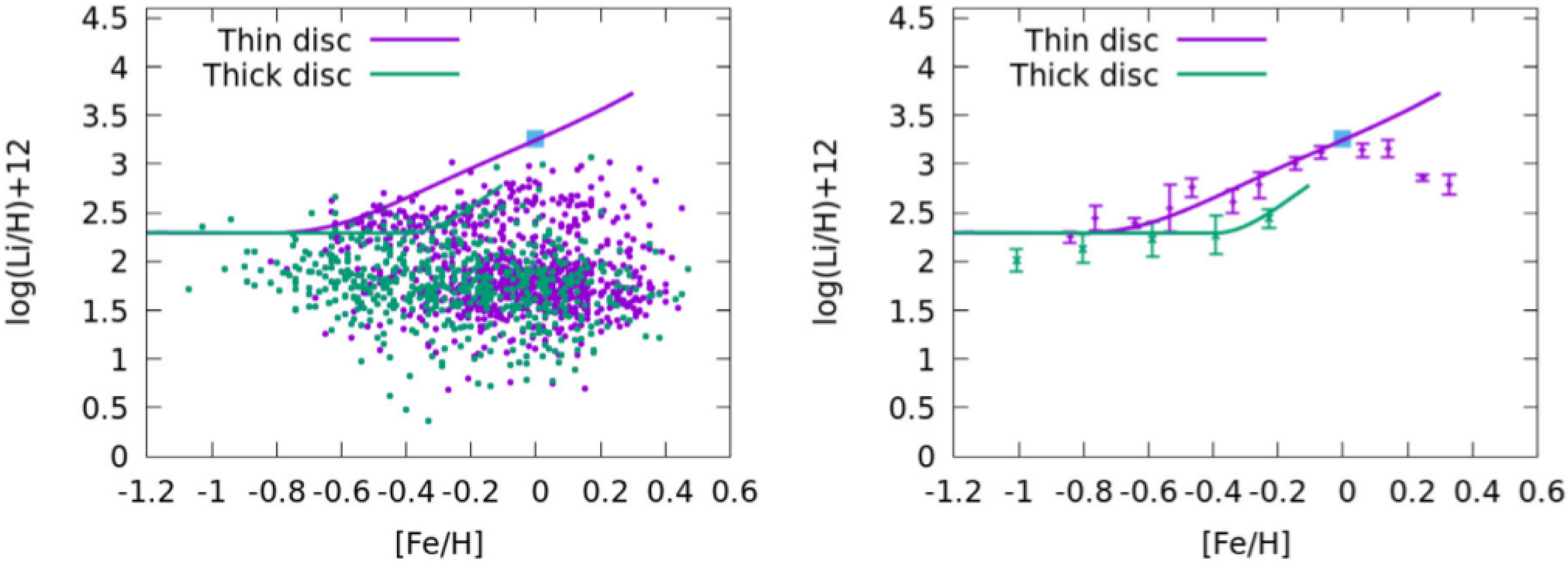


Results of Grisoni et al. (2019)



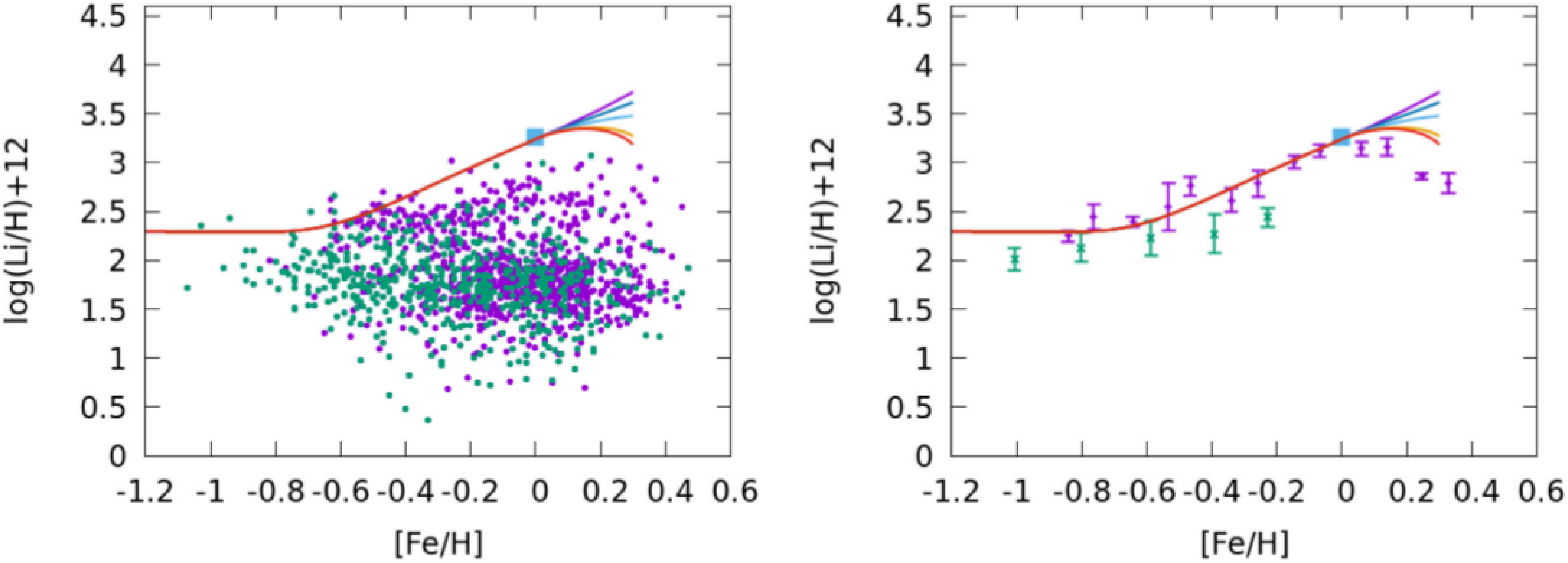
Log(Li/H)+12 vs. [Fe/H] predicted by the parallel model for the thin disc of Grisoni et al. (2017) with the various lithium sources: **all the sources**, **astration, only AGB, only GCR, only novae** (see also Cescutti & Molaro 2019).

Results of Grisoni et al. (2019)



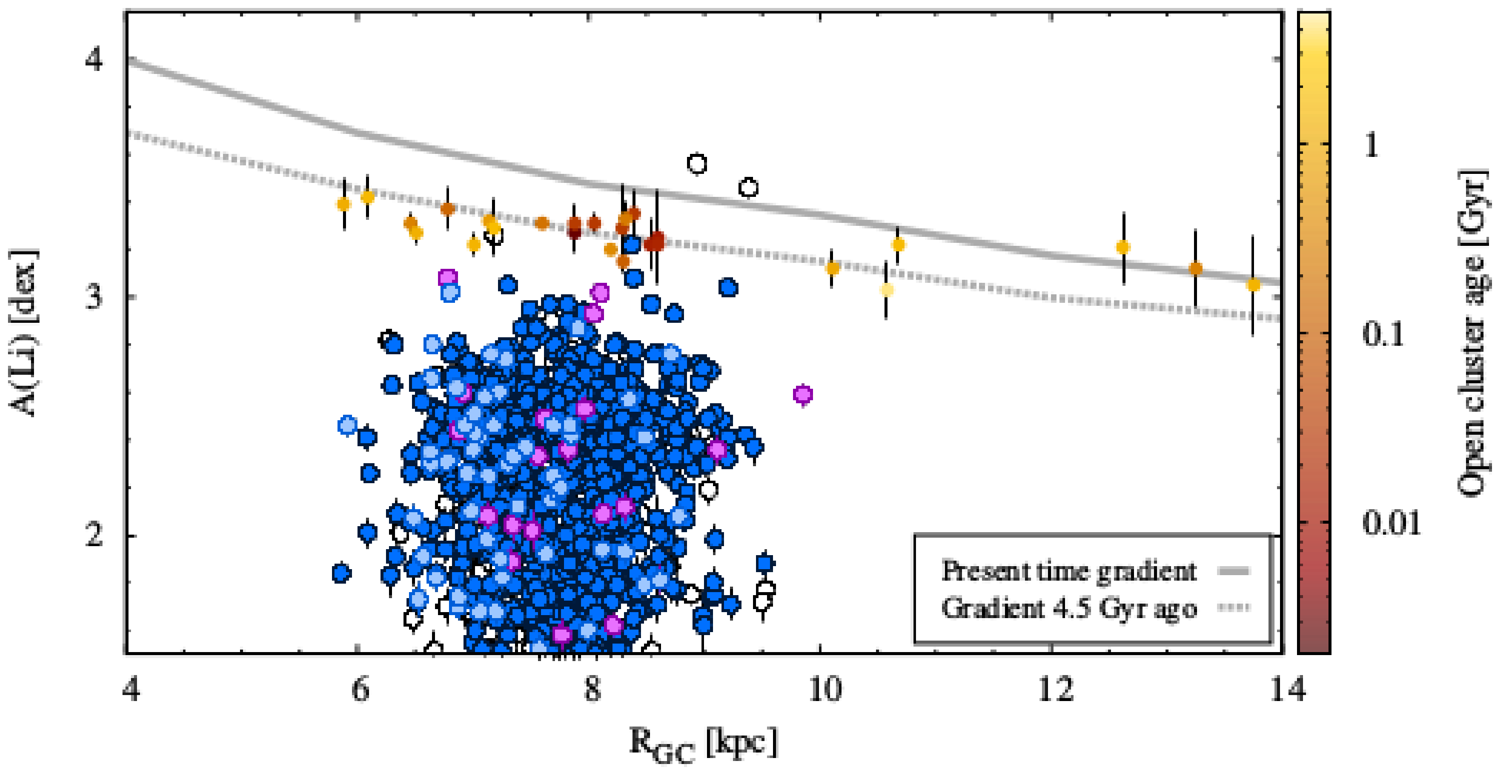
Log(Li/H)+12 vs. [Fe/H] observed by Gaia-ESO (left) and AMBRE (right) and predicted by the parallel model for thick and thin discs.

Results of Grisoni et al. (2019)



Log(Li/H)+12 vs. [Fe/H] observed by Gaia-ESO (left) and AMBRE (right) and predicted by the parallel model. We consider also the case of variable fraction of binary systems giving rise to novae, which provides the bending at high metallicities (linear coefficient β=0.1, 0.2, 0.3 and 0.33 from the violet line to the red line, respectively).

Results of Romano et al. (2021)



Radial profiles of lithium abundance. The theoretical predictions refer to the gradient at Sun's birth (t = 9.2 Gyr, dotted curve) and at the current time (t = 13.7 Gyr, solid line). Data for our sample of GES DR6 field stars, separated in different sub-populations, are shown. Average maximum Li abundances for 26 OCs selected from GES DR6 are also displayed (small colour-coded circles).

Neutron-capture elements

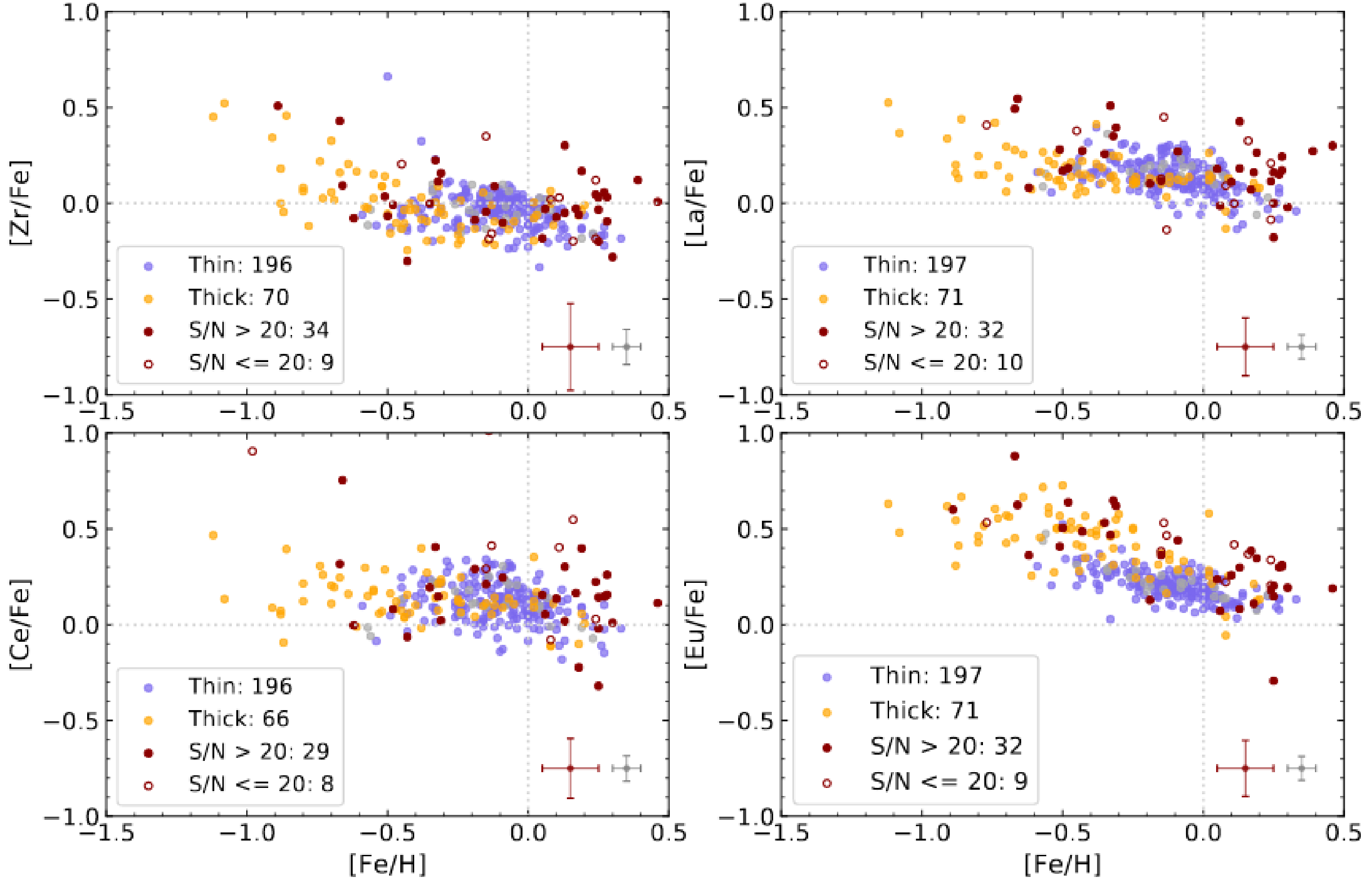
The elements beyond the iron peak (A>60) are mainly formed through neutron capture on heavy seed nuclei. Two possible cases:

- **s-process** (“slow”, $t_c >> t_\beta$): the main production sites are suggested to be low-mass AGB stars with 1.5-3.0 Msun (Cristallo et al. 2009, 2011; Karakas 2010). Massive stars can also produce neutron capture elements via s-process, but in this case the neutron flux is weaker.

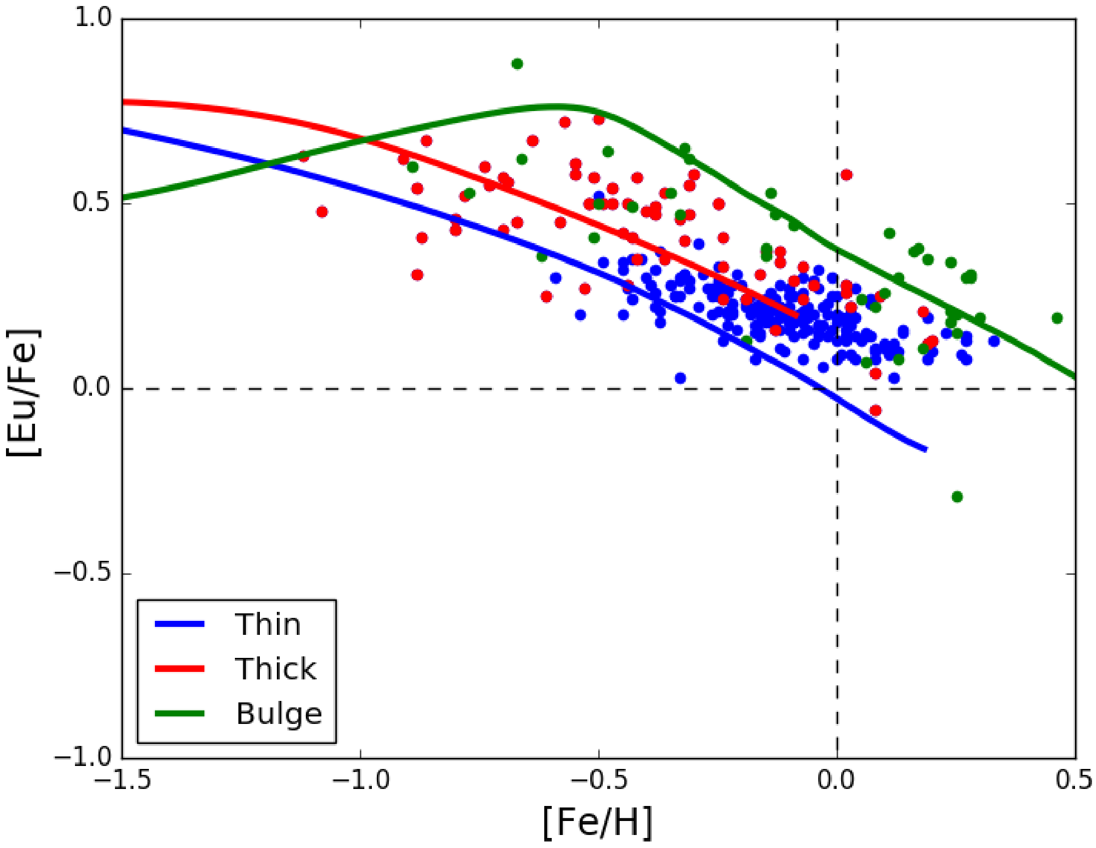
- **r-process** (“rapid”, $t_c << t_\beta$): an extremely neutron-rich environment is required and in literature several production sites have been proposed: core-collapse SNe, electron capture SNe, magneto-rotationally driven (MRD) SNe and neutron star mergers (NSM).

Observational data

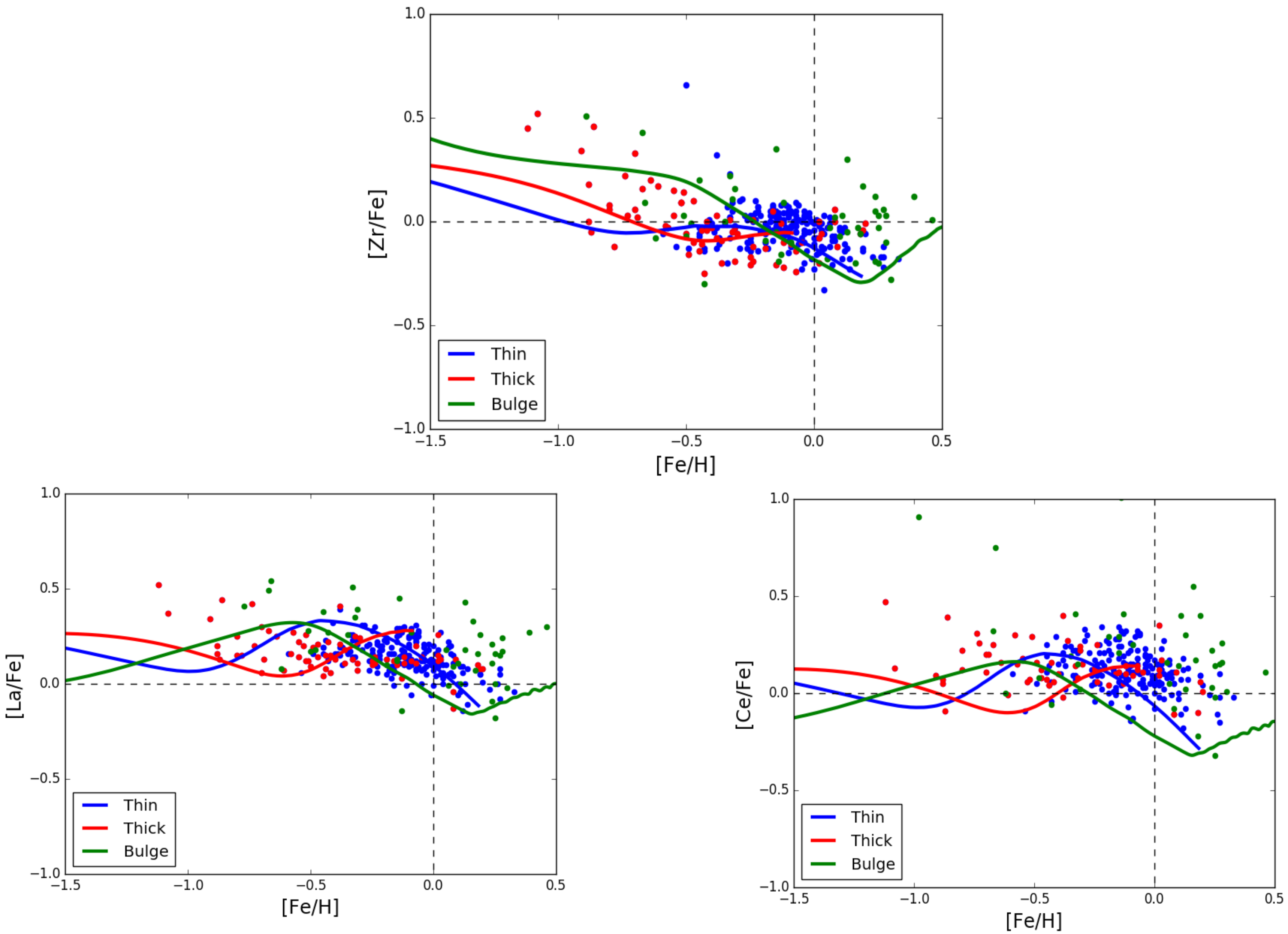
We consider the recent observational data by Forsberg et al. (2019).



Results of Grisoni et al. (2020a)

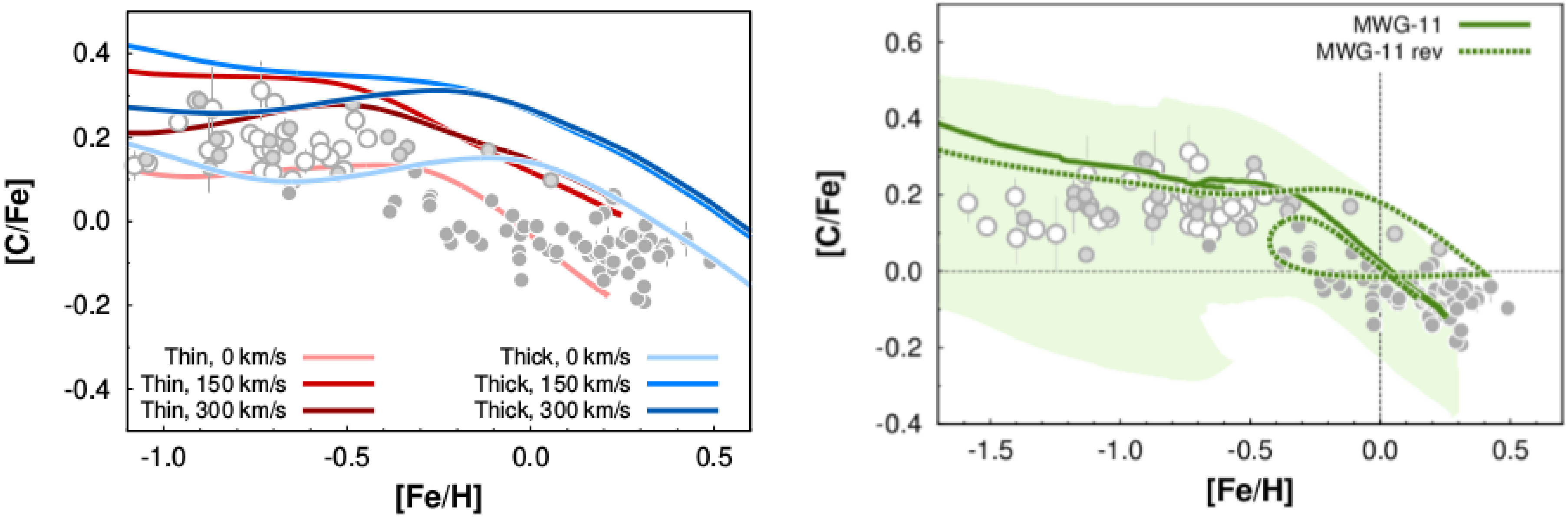


[Eu/Fe] vs. [Fe/H] observed by Forsberg et al. (2019) and predicted by the parallel model of Grisoni et al. (2017) for the thick and thin discs and the bulge model of Matteucci et al. (2019).



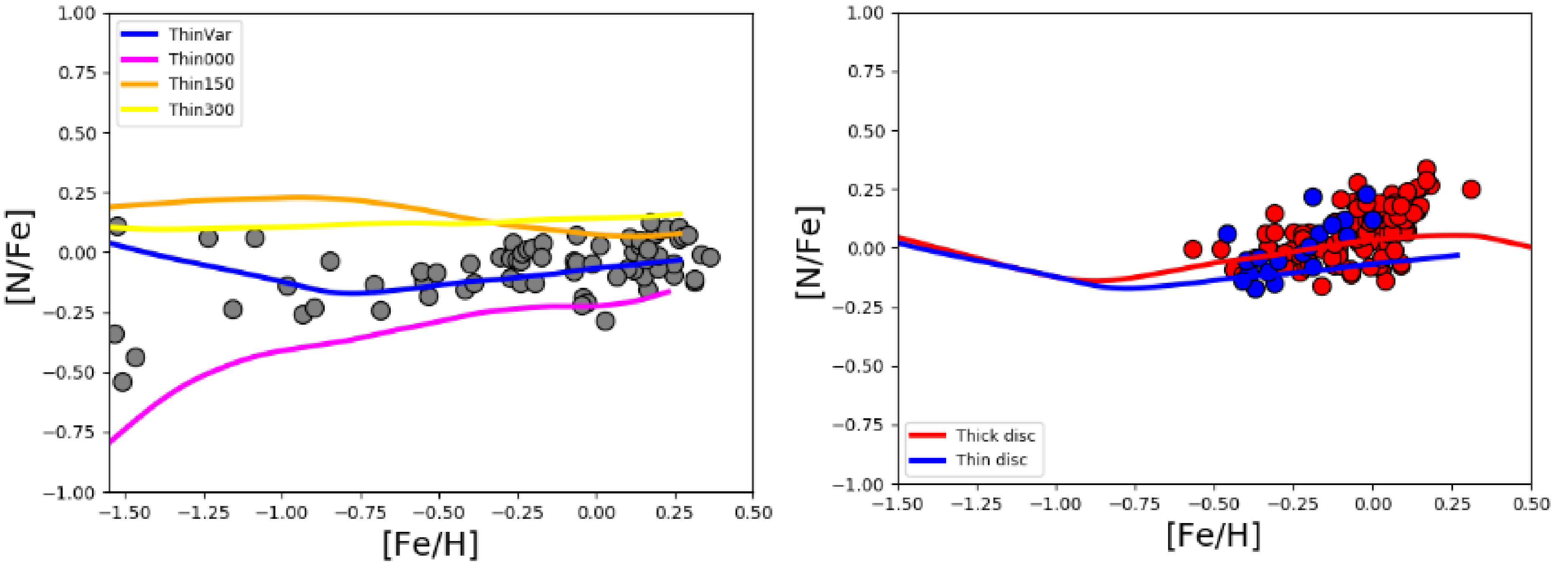
[s/Fe] vs. [Fe/H] observed by Forsberg et al. (2019) and predicted by the parallel model of Grisoni et al. (2017) for the thick and thin discs and the bulge model of Matteucci et al. (2019).

Results of Romano et al. (2020): carbon



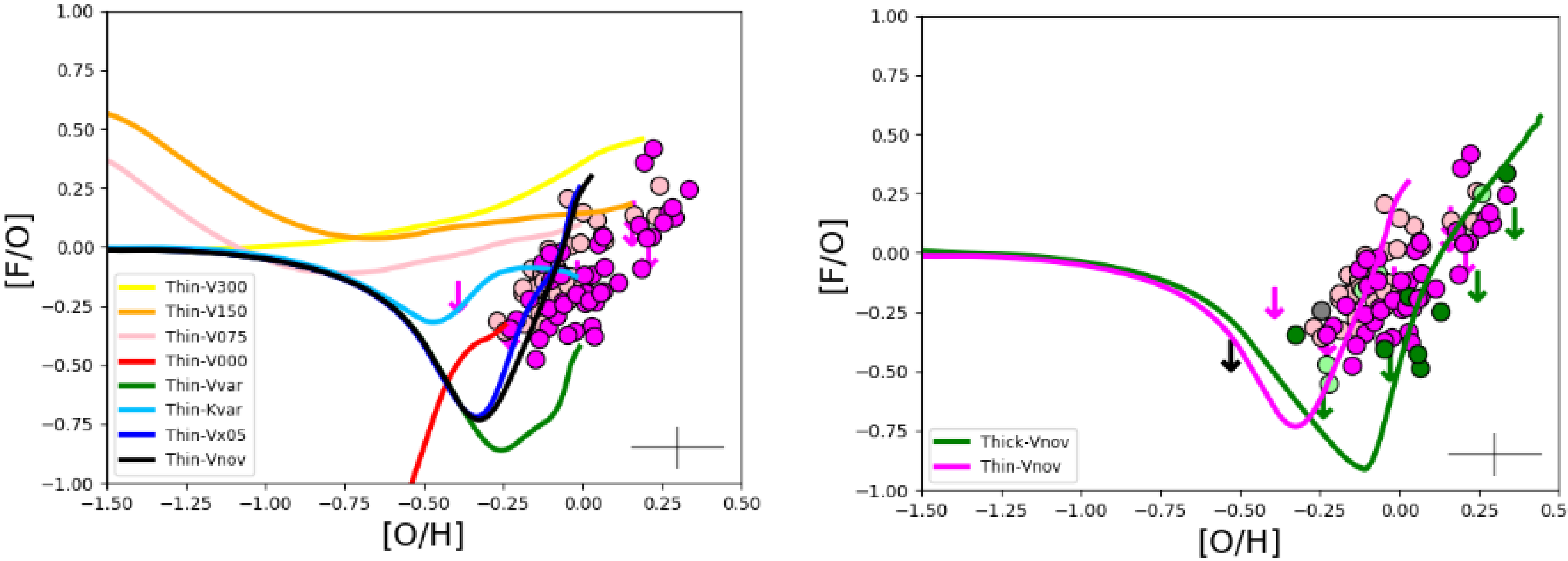
[C/Fe] vs. [Fe/H] predicted by the parallel model for thick- and thin-disc (on the left) and by the two-infall model (right).

Results of Grisoni et al. (2021): nitrogen



[N/Fe] vs. [Fe/H] predicted by the parallel model for thick- and thin-disc formation by Grisoni et al. (2017) compared to the data of Israelian et al. (2004) (left) and Magrini et al. (2018) for thick and thin disc (right).

Results of Grisoni et al. (2020b): fluorine



[F/O] vs. [O/H] predicted by the parallel model for thick- and thin-disc formation by Grisoni et al. (2017) compared to the data of Ryde et al. (2020) for thick and thin disc stars.

Summary

Alpha-elements (Grisoni et al. 2017, 2018):

We adopted two different approaches to study the evolution of the Galactic thick and thin discs:

i) a two-infall approach (Chiappini et al. 1997) applied to thick and thin discs;

ii) a parallel approach (see also Chiappini 2009), that allows to follow separately the evolution in the two Galactic components.

- **Lithium (Grisoni et al. 2019):**

  The dichotomy between thick and thin discs stars is present also in the A(Li) vs. [Fe/H] diagram, with the thin disc being lithium enhanced due to novae.

  We also propose a novel explanation for the ISM lithium decline at high [Fe/H], due to a lower number of binary systems giving rise to novae which are the main lithium producers in the Galaxy.

  New results have appeared concerning the abundance gradient of lithium along the disc (Romano et al. 2021).

- **Neutron-capture elements (Grisoni et al. 2020a):**

  In the [Eu/Fe] vs [Fe/H] diagram, we observe and predict three distinct sequences corresponding to the thick disc, thin disc and bulge, similarly to what happens for the α-elements. We can nicely reproduce the three sequences by assuming different timescales of formation and star formation efficiencies for the three different components, with the thin disc forming on a longer timescale of formation with respect to the thick disc and bulge. On the other hand, in the [X/Fe] vs [Fe/H] diagrams for Zr, La and Ce, the three populations are mixed and also from the model point of view there is an overlapping between the predictions for the different Galactic components, but the observed behaviour can be also reproduced by assuming different star formation histories in the three components,

- **Further results (Grisoni et al. 2020b, 2021):**

  The previous findings are supported also by the conclusions obtained when looking at the abundance patterns of other chemical elements such as nitrogen and fluorine, with the thick disc forming on a shorter timescale of formation with respect to the thin disc.