Mem. S.A.It. Vol. 95, 41

Memorie della

Galactic archaeology with light and heavy elements

Valeria Grisoni[1]

INAF, Osservatorio Astronomico di Trieste, via G.B. Tiepolo 11, I-34131, Trieste, Italy
e-mail: `valeria.grisoni@inaf.it`

Received: 30 November 2023; Accepted: 24 January 2024

Abstract. We discuss detailed chemical evolution models of the Galactic thick and thin discs in the light of recent data from large surveys and missions. We are in a golden era for Galactic archaeology thanks to the advent of large spectroscopic Galactic surveys, which are enhanced by the advent of *Gaia* mission. In this way, detailed stellar abundances of stars Milky Way can be obtained. Then, by means of detailed Galactic chemical evolution models, it is possible to predict the chemical abundances expected in the stars of each Galactic component: halo, bulge, thick and thin discs. In particular, we will focus on the chemical bimodality between the Galactic thick and thin discs. We will start by discussing the dichotomy in the [α/Fe] vs. [Fe/H] diagram where we can clearly see two distinct sequences corresponding to the thick and thin discs, and then we will discuss applications to other abundance patterns, from lithium up to europium.

Key words. Galaxy: formation, Galaxy evolution, Galaxy: abundances

1. Introduction

The goal of Galactic archaeology is to reconstruct the history of formation and evolution of our Galaxy from chemical abundances (for a comprehensive review, see Matteucci 2021).

We are now in a period of great advances for this field of research thanks to the large spectroscopic surveys, such as APOGEE (Majewski et al. 2017), *Gaia*-ESO (Gilmore et al. 2012), GALAH (De Silva et al. 2015). Moreover, these surveys are enhanced by *Gaia* mission, which has recently provided a comprehensive chemical cartography of our Galaxy (Gaia Collaboration et al. 2023). In this way, detailed stellar abundances of stars in the Milky Way can be obtained.

In particular, a clear dichotomy in the [α/Fe] vs. [Fe/H] plot between the Galactic thick and thin discs has been revealed (Recio-Blanco et al. 2014; Hayden et al. 2015), with the thick disc being α-enhanced suggesting a shorter timescale of formation for this Galactic component. To explain this chemical bimodality, in recent years detailed Galactic chemical evolution models have been developed (see e.g. Grisoni et al. 2017, 2018; Spitoni et al. 2019, 2021, among the others).

This paper is structured in the following way. In Section 2, we describe state-of-the-art Galactic chemical evolution models. In Section 3, we present results for different chemical elements, from the light ones to the heavy ones.

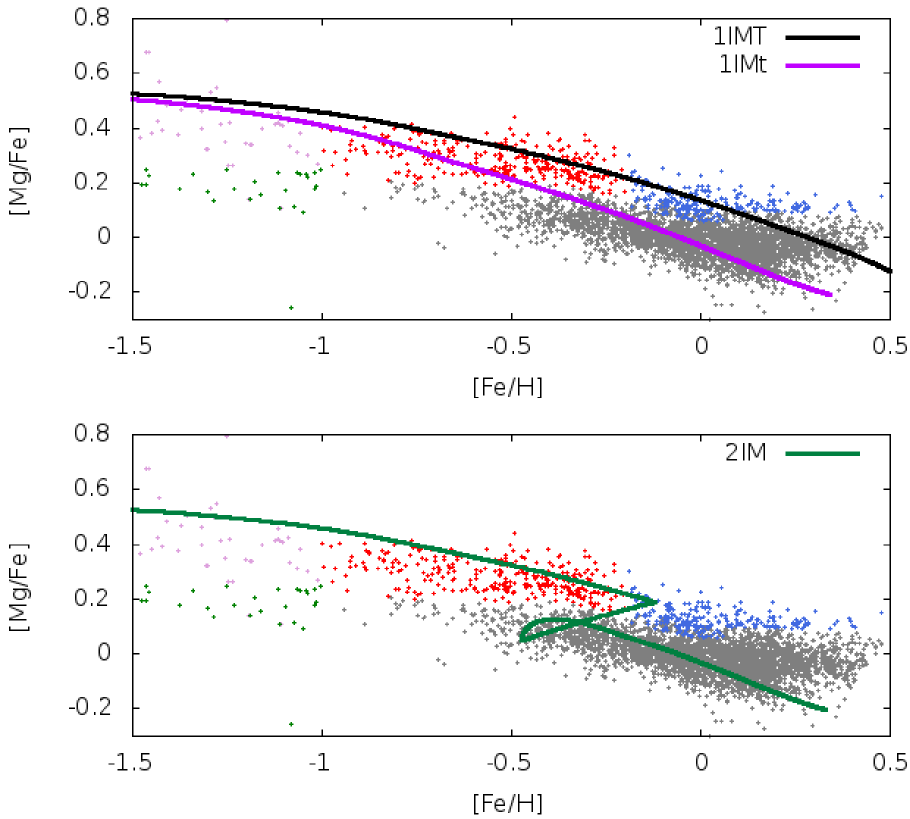

Fig. 1. Upper panel: [α/Fe] vs. [Fe/H] predicted by the parallel model for the thick disc (black line) and thin disc (purple line). Data are from the AMBRE Project (Mikolaitis et al. 2017) for thick disc stars (in red), thin disc (in gray) and metal-rich α-enhanced (in blue). Lower panel: same as the upper panel, but predicted by the two-infall model (green line). See text for discussion. Figure from Grisoni et al. (2017).

Finally, in Section 4, we summarize our conclusions.

2. Chemical evolution models

To model the chemical evolution of the Galactic thick and thin discs, different approaches have been proposed in the literature (Grisoni 2020, and references therein).

In the parallel model (Grisoni et al. 2017, see also Nykytyuk & Mishenina 2006; Chiappini 2009; Goswami et al. 2021), we assume that the Galactic thick and thin discs start forming at the same time, but evolve at different rates. In particular, the thick disc evolves on a shorter timescale of formation (t_1=0.1 Gyr) and with higher star formation efficiency (ν_1=2 Gyr^{-1}) with respect to the thin disc (t_2=7 Gyr, ν_1=1 Gyr^{-1}). These parameters have been constrained in order to reproduce the metallicity distribution function and other observational constraints for thick and thin disc stars. An alternative scenario is the two-infall model (first developed by Chiappini et al. 1997, and then applied to the thick and thin discs by Grisoni et al. 2017 and more recently by Spitoni et al. 2019, 2021). In this scenario, there are two main infall episodes giving rise to the Galactic disc: the first one forming the thick disc, and the second one, delayed with respect to the first one, giving rise to the thin disc on a longer timescale. For further details on these mod-

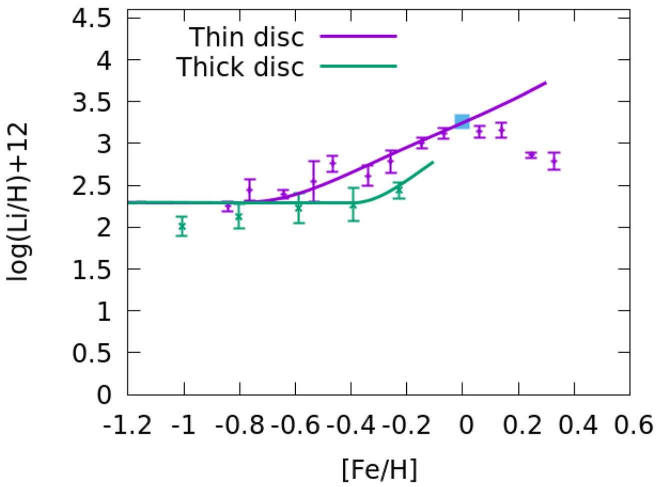

Fig. 2. Log(Li/H)+12 vs. [Fe/H] predicted by the parallel model for the thin disc (purple line) and thick disc (green line). Data are from the AMBRE Project (Guiglion et al. 2016) for the thin disc (in purple) and the thick disc (in green). Figure from Grisoni et al. (2019).

els, we address the interested reader to Grisoni et al. (2017).

3. Results

Here, we present results based on the comparison between model predictions and observations. We start by defining our best models on the basis of the [α/Fe] vs. [Fe/H] diagram, where there is a clear dichotomy between the Galactic thick and thin discs. Then, we apply them to study several chemical elements, from the light ones up to the heaviest ones.

3.1. α-elements

First, we start with the α-elements, where the dichotomy between the thick and thin discs is more evident (Recio-Blanco et al. 2014; Hayden et al. 2015; Mikolaitis et al. 2017).
In Fig. 1, we show the predictions of both the two-infall model and the parallel one for the [Mg/Fe] vs. [Fe/H] plot, where we consider Mg as reference for α-elements. We consider the data from the AMBRE Project (Mikolaitis et al. 2017, see also Hayden et al. 2017). In the parallel model, we can explain the bimodality between the thick and thin disc stars (see also Nykytyuk & Mishenina 2006, their Fig. 3) and also the presence of metal-rich α-enhanced stars, that in the two-infall scenario can only be explained by radial migration from the inner regions. These models have been constrained in order to reproduce observations in the solar vicinity (Grisoni et al. 2017) as well as abundance gradients along the Galactic disc Grisoni et al. (2018).

3.2. Lithium

Once the reference chemical evolution models have been defined on the basis of α-elements, we apply them to study other chemical elements, such as lithium. In Fig. 2, we see a bimodality also in the lithium plot, with the thin disc being lithium enhanced in this case (Grisoni et al. 2019). Recently, the models have been extended to reproduce also the lithium gradient along the disc (Romano et al. 2021).

3.3. Neutron-capture elements

Then, we focus on neutron-capture elements. In Fig. 3, we show the observed and predicted

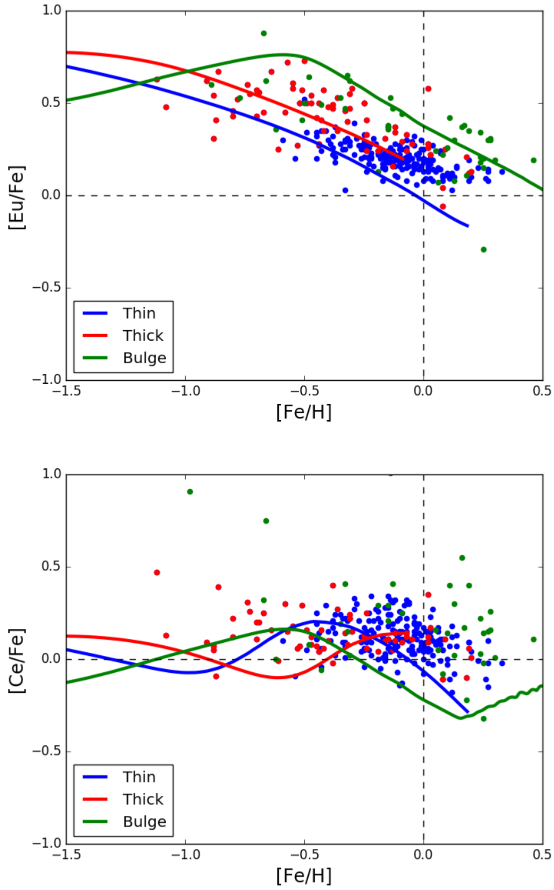

Fig. 3. [X/Fe] vs. [Fe/H] predicted by the parallel model for the thick and thin discs, and the bulge model. Data are from (Forsberg et al. 2019). Figure from Grisoni et al. (2020a).

[Eu/Fe] vs. [Fe/H] and [Ce/Fe] vs. [Fe/H]. We consider the parallel model to follow the evolution of the thick and thin discs, and also the bulge model of Matteucci et al. (2019), which assumes an even shorter timescale of formation and higher star formation efficiency with respect to the discs (see also Matteucci et al. 2020). For Eu, we can clearly see both from observations and model predictions that there are three distinct sequences corresponding to the thick disc, thin disc and bulge, similarly to what happens to the α-elements. On the other hand, for s-process elements such as Ce, the three populations are mixed and it is more difficult to disentangle between them (see also Contursi et al. 2023; Casali et al. 2023). Still, we can interpret different behaviors among the various populations by assuming different star formation histories in the different components.

The parallel model has been applied then to follow the evolution of several other chemical elements, such as fluorine (Grisoni et al. 2020b), carbon (Romano et al. 2020) and nitrogen (Grisoni et al. 2021).

4. Conclusions

We have discussed recent advances in the field of Galactic archaeology, which is now facing a golden era thanks to the advent of large spectroscopic surveys providing a great amount of data that need to be interpreted by theoretical models. In the following, we summarize the main conclusions, based on the comparison between observations and models predictions.

– In the [α/Fe] vs. [Fe/H] diagram, there is a clear dichotomy between the Galactic thick and thin discs, that we can explain by means of i) a two-infall approach, or ii) a parallel model, that can follow separately the evolution in the two components.
– The dichotomy between the two populations is present also in the A(Li) vs. [Fe/H] diagram, with the thin disc being lithium enhanced.
– In the [Eu/Fe] vs. [Fe/H] diagram, we predict three distinct sequences corresponding to the thick disc, thin disc and bulge, similarly to what happens for the α-elements.
– For s-process elements, the three populations are mixed, but still we can interpret different behaviors by assuming different star formation histories in the three components.

Acknowledgements. We thank the referee for useful comments and suggestions. VG acknowledges financial support from INAF under the program "Giovani Astrofisiche ed Astrofisici di Eccellenza - IAF: Astrophysics Fellowships in Italy" (Project: GalacticA, "Galactic Archaeology: reconstructing the history of the Galaxy").

References

Casali, G., Grisoni, V., Miglio, A., et al. 2023, A&A, 677, A60
Chiappini, C. 2009, in The Galaxy Disk in Cosmological Context, ed. J. Andersen, Nordströara, B. m, & J. Bland-Hawthorn, Vol. 254, 191–196
Chiappini, C., Matteucci, F., & Gratton, R. 1997, ApJ, 477, 765
Contursi, G., de Laverny, P., Recio-Blanco, A., et al. 2023, A&A, 670, A106
De Silva, G. M., Freeman, K. C., Bland-Hawthorn, J., et al. 2015, MNRAS, 449, 2604
Forsberg, R., Jönsson, H., Ryde, N., & Matteucci, F. 2019, A&A, 631, A113
Gaia Collaboration, Recio-Blanco, A., Kordopatis, G., et al. 2023, A&A, 674, A38
Gilmore, G., Randich, S., Asplund, M., et al. 2012, The Messenger, 147, 25
Goswami, S., Slemer, A., Marigo, P., et al. 2021, A&A, 650, A203
Grisoni, V. 2020, PhD thesis, University of Trieste, Italy
Grisoni, V., Cescutti, G., Matteucci, F., et al. 2020a, MNRAS, 492, 2828
Grisoni, V., Matteucci, F., & Romano, D. 2021, MNRAS, 508, 719
Grisoni, V., Matteucci, F., Romano, D., & Fu, X. 2019, MNRAS, 489, 3539
Grisoni, V., Romano, D., Spitoni, E., et al. 2020b, MNRAS, 498, 1252
Grisoni, V., Spitoni, E., & Matteucci, F. 2018, MNRAS, 481, 2570
Grisoni, V., Spitoni, E., Matteucci, F., et al. 2017, MNRAS, 472, 3637
Guiglion, G., de Laverny, P., Recio-Blanco, A., et al. 2016, A&A, 595, A18
Hayden, M. R., Bovy, J., Holtzman, J. A., et al. 2015, ApJ, 808, 132
Hayden, M. R., Recio-Blanco, A., de Laverny, P., Mikolaitis, S., & Worley, C. C. 2017, A&A, 608, L1
Majewski, S. R., Schiavon, R. P., Frinchaboy, P. M., et al. 2017, AJ, 154, 94
Matteucci, F. 2021, A&A Rev., 29, 5
Matteucci, F., Grisoni, V., Spitoni, E., et al. 2019, MNRAS, 487, 5363
Matteucci, F., Vasini, A., Grisoni, V., & Schultheis, M. 2020, MNRAS, 494, 5534
Mikolaitis, Š., de Laverny, P., Recio-Blanco, A., et al. 2017, A&A, 600, A22
Nykytyuk, T. V. & Mishenina, T. V. 2006, A&A, 456, 969
Recio-Blanco, A., de Laverny, P., Kordopatis, G., et al. 2014, A&A, 567, A5
Romano, D., Franchini, M., Grisoni, V., et al. 2020, A&A, 639, A37
Romano, D., Magrini, L., Randich, S., et al. 2021, A&A, 653, A72
Spitoni, E., Silva Aguirre, V., Matteucci, F., Calura, F., & Grisoni, V. 2019, A&A, 623, A60
Spitoni, E., Verma, K., Silva Aguirre, V., et al. 2021, A&A, 647, A73