Rediscovering our Galaxy
Proceedings IAU Symposium No. 334, 2017
C. Chiappini, I. Minchev, E. Starkenburg
& M. Valentini, eds.

doi:10.1017/S1743921317008183

The oldest stars of the bulge: new information on the ancient Galaxy

Gabriele Cescutti[1], **Cristina Chiappini**[2] **and Raphael Hirschi**[3,4]

[1]I.N.A.F. Osservatorio Astronomico di Trieste, Italy;
email: `cescutti@oats.inaf.it`

[2]Leibniz-Institut fuür Astrophysik Potsdam (AIP)

[3]Astrophysics Group, Faculty of Natural Sciences, Keele University

[4]Kavli IPMU (WPI), University of Tokyo

Abstract. Recently the search for the oldest stars have started to focus on the Bulge region. The Galactic bulge hosts extremely old stars, with ages compatible with the ages of the oldest halo stars. The data coming from these recent observations present new chemical signatures and therefore provide complementary constraints to those already found in the halo. So, the study of the oldest bulge stars can improve dramatically the constraints on the nature of first stars and how they polluted the pristine ISM of our Galaxy. We present our first results regarding the light elements (CNO) and the neutron capture elements. Our findings in the oldest bulge stars support the scenario where the first stellar generations have been fast rotators.

Keywords. Galaxy: bulge, Galaxy: evolution, nuclear reactions, nucleosynthesis, abundances

1. Introduction

In our recent work, we have provided an interpretation of the presence in halo stars of specific chemical signatures by means of stochastic chemical evolution models (Chiappini 2013). Our results supported the scenario in which the first stars that exploded and polluted the pristine interstellar medium (ISM) were rotating faster than the present day massive stars. Stellar evolution codes coupled with nuclear reaction chains have shown that this rotation produces mixing in the interior of the stars. This mixing impacts the nucleosynthesis of light elements such as carbon, nitrogen, and oxygen, and it also predicts the production of s-process elements (Frischknecht *et al.* 2016). In this scenario in which the stars were fast rotating, chemical evolution models were able to explain several chemical anomalies observed in the early Universe: the almost solar ratio of [N/O] and the increase and spread in the [C/O] ratio (Chiappini *et al.* 2006); the low ^{12}C/ ^{13}C ratios (Chiappini *et al.* 2008); the spread present in the [C/O] and [N/O] ratios (Cescutti & Chiappini 2010) and between light and heavy neutron capture elements (Cescutti *et al.* 2013; Cescutti & Chiappini 2014; Cescutti *et al.* 2015, 2016).

The same nucleosynthesis acting in other environments produces different results due to the different star formation (SF) histories. Therefore it is important to test our predictions in other environments that have hosted the explosions of the first stars. In our neighbourhood, we expect to find signatures of the enrichment by the first stars also in the stars belonging to the dwarf spheroidal galaxies and the oldest stars of the Galactic bulge. In this proceedings, we focus on the *old bulge*, that is seen as a sort of an extreme case of the halo population, with an increased density and faster chemical enrichment. The Galactic bulge is a very complex component of our Galaxy and it is likely that different populations share this locus, with different histories of SF and chemical enrichment.

Recent investigations have highlighted the presence of a very old component and the evidence shows that the efficiency of chemical enrichment has been higher in this system compared to the Galactic halo. A higher efficiency can be quite naturally connected to a higher density on the ISM. This has been also supported by recent evidence of the existence of mature bulges at redshifts of z$\sim$2.2 (Tacchella *et al.* 2015), and is also predicted by models of strong early turbulent gas accretion (see Bournard 2016, and references therein).

2. Stochastic chemical evolution model for the Bulge

Our chemical evolution model for the *old bulge* is an extreme case of the halo model. Compared to the halo model, it has an increased density ($\sim$ 10x) and SF efficiency ($\sim$20x) with no outflows. The increased efficiency is consistent with the SF efficiencies adopted in other chemical evolution models for the bulge (Cescutti & Matteucci 2011). The nucleosynthesis prescriptions are those adopted in Cescutti & Chiappini (2014). The bulge model is constrained by reproducing the metallicity distribution of the oldest bulge stars, as well as by the [α/Fe], see Fig. 1. On this classical chemical evolution scheme, we implement a stochastic formation of stars similar to the chemical evolution model for the halo (Cescutti 2008). Compared to the halo model the length scale for the mixing zone has been decreased from 90pc (for the halo) to 30pc (for the bulge). The modification of this typical length scale is due to the dependency of the dimension of the SNe bubble to the ISM density. More details are available in Cescutti *et al.* (2018a).

3. Results adopting two different r-process events

We display the bulge results adopting the same nucleosynthesis prescriptions adopted in the halo model results shown in Cescutti & Chiappini (2014), where the details of the different nucleosynthesis can be found. We display only the results for [Ba/Fe] as a typical case of neutron capture element. In the left panel of Fig.2, the same nucleosynthesis of the *EC+s2* model of Cescutti & Chiappini (2014) is adopted for the the bulge model. We briefly recall that in this model an r-process contribution is assumed from all the stars between 8-10 $M_{\odot}$, assumed to explode as electron capture supernovae (EC SNe).

In this model, due the intense SF after 20-30 Myr (the lifetime of a 8-10 $M_{\odot}$ star) all the individual volumes have already exploded massive stars despite of the stochasticity; this was not the case for the halo model. So, all the r-process events turn out to happen in an environment which is already enriched in Fe and not so inhomogeneous; for this reason the r-process in this model does not produce an important spread but simply a rise on the [Ba/Fe] vs [Fe/H] space moving from low metallicity to solar metallicity. The spread at lower metallicity is driven by the differential enrichment by the spinstars as a function of their masses. The stellar distribution obtained does not appear to be consistent to the data. In the bulge the delay between the enrichment by r-process and the spinstars can be appreciated and it produces the late rise of the [Ba/Fe] ratio at around [Fe/H]~ -1.5, whereas the Ba enrichment up to this metallicity is manly due to s-process by spinstars. The combination of the two different productions is the cause of the "V" shape visible in this plot. Focusing on the most metal poor stars in the sample, the observational data present a higher [Ba/Fe] ratio compared to the model results. This is a signature that within the timescale of the chemical evolution of the bulge the EC scenario is not well supported as r-process event.

In the right panel of Fig.2, we show the results assuming the nucleosynthesis model named *MRD +s B2* in Cescutti & Chiappini (2014). We recall that in this model r-process

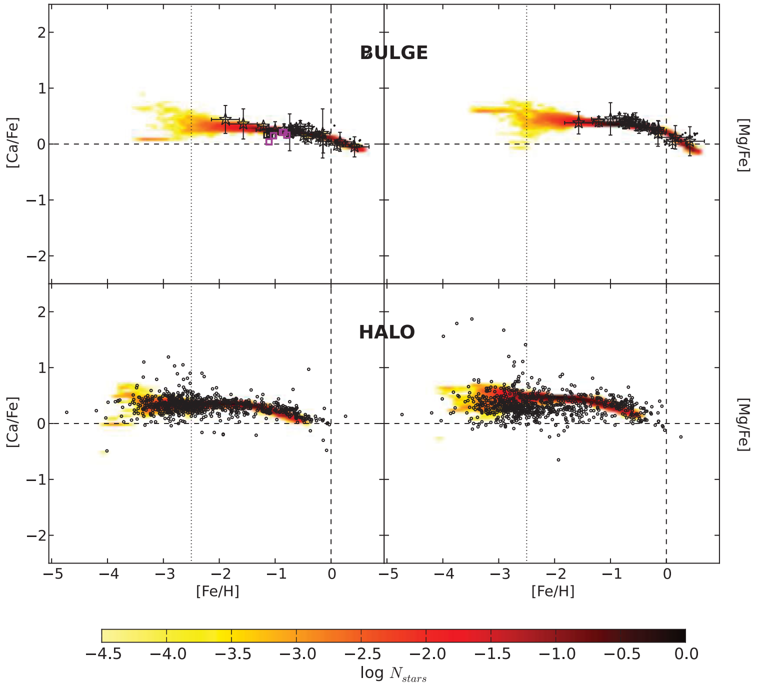

Figure 1. [Ca/Fe] and [Mg/Fe] vs [Fe/H], from left to right. We present the results of the bulge model in the upper panels and of the halo model in the lower panels (Cescutti *et al.* 2013). The density plots are the distribution of simulated long-living stars for our models; the density is on a logarithmic scale and the bar under the figure describes the assumed color scale. The abundance ratios for bulge stars (upper panels) and halo stars (lower panels) are shown (for the data used see Cescutti *et al.* 2013, 2018a).

events are assumed from 10% of all the massive stars that explode as magneto rotationally driven supernovae (MRD SNe, see Winteler *et al.* 2012). With these nucleosynthesis prescriptions the bulge model produces results completely different to the EC+s model; in particular the *MRD +s B2* model is able to explain much better the data in the bulge stars for [Ba/Fe], whereas for the halo the results were very similar (see Cescutti & Chiappini 2014). The different model predictions for the halo and bulge are due to the vigorous and fast chemical evolution in the bulge model coupled to the differences between this two possible r-process events, and the difference chiefly resides in the timescales for the two sites of production, which varies from 30 Myr to less than 5 Myr (for more details see Cescutti *et al.* 2018b).

4. Conclusions

We apply the nucleosynthesis for two different r-process events in our stochastic modelling for the old bulge. The nucleosynthesis resulting from either of these r-process were able to reproduce the chemical enrichment in [Ba/Fe] observed in halo stars. The comparison of the results obtained for the bulge model to the [Ba/Fe] abundances measured in the bulge supports a r-process event with a timescale very close to the lifetime of massive stars, as the MRD scenario and it seems to exclude r-process events with longer timescale, as the EC scenario. This outcome is also compatible with neutron star mergers as r-process events, providing short merging timescales (Cescutti *et al.* 2015).

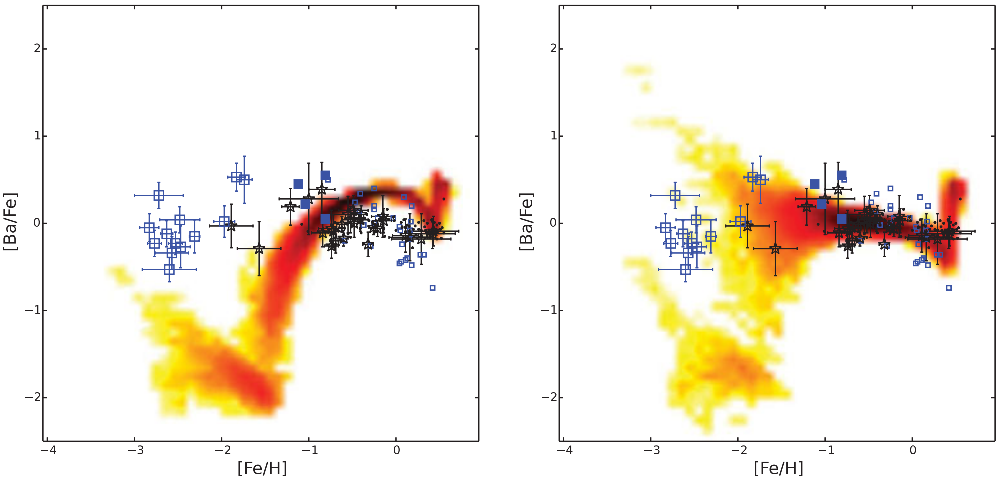

Figure 2. [Ba/Fe] vs [Fe/H]. In the figures above we present the results of the bulge model; on the left with the nucleosynthesis *EC+s2*, on the right with the one *MRD +s B2*. In both figures we show abundance ratios for bulge stars (for details of the different authors see Cescutti *et al.* 2018b)

Acknowledgements

G.C. acknowledges financial support from the European Union Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 664931. RH acknowledges support from the World Premier International Research Center Initiative, MEXT, Japan. C. C. acknowledges support from DFG Grant CH1188/2-1. This work has been partially supported by the the EU COST Action CA16117 (ChETEC) and by the European Research Council (EU-FP7-ERC-2012-St Grant 306901).

References

Bournard, F. 2016, *Galactic Bulges*, Springer International Publishing, 418, 355
Cescutti, G. 2008, *A&A* , 481, 691
Cescutti, G. & Chiappini, C. 2010, *A&A* , 515, A102
Cescutti, G. & Chiappini, C. 2014, *A&A* , 565, A51
Cescutti, G., Chiappini, C., & Hirschi, R., 2018a, in prep.
Cescutti, G., Chiappini, C., & Hirschi, R., 2018b, in prep.
Cescutti, G., Chiappini, C., Hirschi, R., Meynet, G., & Frischknecht, U. 2013, *A&A* , 553, A51
Cescutti, G. & Matteucci, F. 2011, *A&A* , 525, A126
Cescutti, G., Romano, D., Matteucci, F., Chiappini, C., & Hirschi, R. 2015, *A&A* , 577, A139
Cescutti, G., Valentini, M., François, P., *et al.* 2016, *A&A* , 595, A91
Chiappini, C. 2013 *AN* 334, 595
Chiappini, C., Ekström, S., Meynet, G., *et al.* 2008, *A&A* , 479, L9
Chiappini, C., Frischknecht, U., Meynet, G., *et al.* 2011, *Nature* , 472, 454
Chiappini, C., Hirschi, R., Meynet, G., *et al.* 2006, *A&A* , 449, L27
Frischknecht, U., Hirschi, R., Pignatari, M., *et al.* 2016, *MNRAS*, 456, 1803
Tacchella, S. Carollo, C. M., Renzini, A., *et al.* 2015, *Science*, 348, 314
Winteler, C., Käppeli, R., Perego, A., *et al.* 2012, *ApJ* , 750, L22