Stellar Populations - Planning for the Next Decade
Proceedings IAU Symposium No. 262, 2009
Gustavo Bruzual & Stéphane Charlot, eds.

doi:10.1017/S1743921310003479

Abundance Patterns Among Very Metal-Poor Stars in the Halo of the Galaxy: A Statistical Approach

Vinicius M. Placco[1], **Silvia Rossi**[1], **Timothy C. Beers**[2] **and Sara Lucatello**[3]

[1]Departamento de Astronomia - Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, São Paulo, SP 05508-900, Brazil

[2]Department of Physics & Astronomy and JINA: Joint Institute for Nuclear Astrophysics, Michigan State University, East Lansing, MI 48824, USA

[3]Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, 35122 Padua, Italy

Abstract. The main goal of this work is to explore the abundance patterns of the very metal-poor stars ([Fe/H]<−2.0) observed by the HERES (Hamburg ESO R-process Enhanced Star - Christlieb *et al.* 2004) survey. This type of study allows the analysis of the correlations among chemical elements, and place some constraints on the operation of the neutron-capture (r and s) processes in the early Galaxy. This approach makes use of statistical tools, such as agglomerative nesting, which can identify the formation of natural groups based on relations among elemental abundances (e.g. [C/Fe], [Sr/Fe], [Ba/Fe], and [Eu/Fe]), and can also be used in a series of "large-sample like" studies.

This study provides a comprehensive analysis of a sample of 326 metal-poor stars, and introduces two new subclasses (r-0 and s-I) for metal-poor stars with determined abundances of neutron-capture elements, aiming to standardize the nomenclature for those objects and, by reproducing previous results, confirms the validity of the statistical method used.

Keywords. Galaxy: halo, Galaxy: stellar content, stars: abundances, methods: statistical

1. Introduction

Elements with atomic masses above A∼60 are formed by neutron-capture processes (r-process and s-process). Their presence in the spectra of low-mass stars (which have long life times) and low metal content suggests episodes of enrichment by high-mass stars that took place at early times. Thus, the study of those metal-poor stars (Beers & Christlieb 2005) enriched by neutron-capture elements may help reproduce the physical conditions of the environment from where they were formed.

2. Natural Groups Identification

The variables for this particular statistical analysis were chosen based on the correlations with one another, the relative importance of each neutron-capture process, and the number of determinations in the database. Besides Ba and Eu (second-peak s- and r-process elements), two more variables were selected: Sr, representing the first peak for the s process and C, due to its common relationship with heavy s-process elements (Lucatello *et al.* 2006) and [Fe/H].

The number of objects for the clustering approach was 77 out of 326, mainly due to the few Eu and Sr determinations. This analysis does not support any missing data and

Table 1. Subclasses proposed by this work for metal-poor stars with neutron-capture elements enhancement. Adapted from Beers & Christlieb (2005).

Class	**Criteria**		
r-0	$[\mathrm{Eu/Fe}] < +0.3$	and	$[\mathrm{Ba/Eu}] < 0.0$
r-I	$0.3 \leqslant [\mathrm{Eu/Fe}] \leqslant +1.0$	and	$[\mathrm{Ba/Eu}] < 0.0$
r-II	$[\mathrm{Eu/Fe}] > +1.0$	and	$[\mathrm{Ba/Eu}] < 0.0$
s-I	$[\mathrm{Ba/Fe}] > +1.0$ $[\mathrm{Eu/Fe}] < +1.0$	and	$[\mathrm{Ba/Eu}] > +0.5$
s-II	$[\mathrm{Ba/Fe}] \geqslant +1.0$ $[\mathrm{Eu/Fe}] \geqslant +1.0$	and	$[\mathrm{Ba/Eu}] > +0.5$
r/s	$0.0 \leqslant [\mathrm{Ba/Eu}] \leqslant +0.5$		

also cannot use upper limits, since it performs distance calculations in a n-parameter space. In order to keep all the values in the same scale, one can only use variables in the form [X/Fe], so the metallicity and any other combination (such as [Ba/Eu]) are excluded from the analysis. Table 1 shows the subclasses proposed, based on the already existing classifications of Beers & Christlieb (2005). This work introduces a subclass for low Eu content (r-0), and makes the distinction between two regimes for *s*-process enhancements.

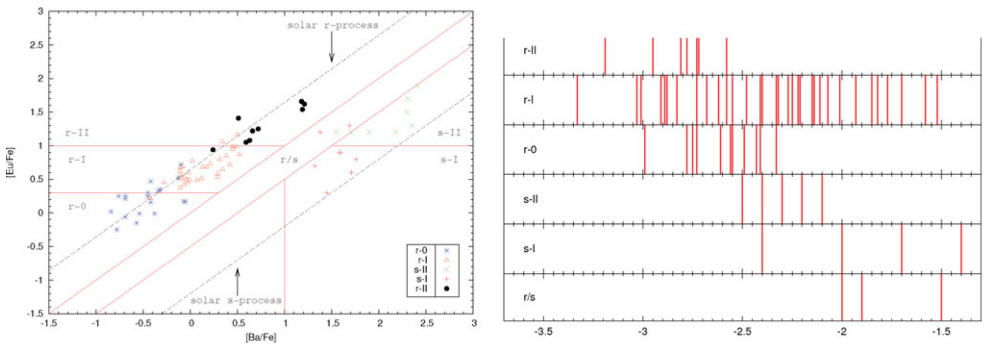

Figure 1. Left: Groups formed in the cluster analisys. Some overlaps are expected and the r/s subclass could not be separated due to the lack of abundance determinations. Right: The distribution of [Fe/H] for neutron-capture enhanced stars identified in HERES.

The left panel of Figure 1 shows the result of the agglomerative nesting employed on the 77 star sample, using [C/Fe], [Sr/Fe], [Ba/Fe] and [Eu/Fe]. Although the r/s subclass could not be found in the analysis, the nomenclature was kept, since a number of studies (Barbuy *et al.* 2005, Jonsell *et al.* 2006) point to the existence of such objects.

The metallicity distribution for the 6 subclasses is shown on the right panel of Figure 1. One can see that the r-II and s-II stars tend to form less dispersed groups, and the lower limit for the s-II panel can also give hints on the onset of the Galactic *s*-process.

Acknowledgements

V. M. P. and S. R. acknowledge CAPES (PROEX), CNPq, JINA and FAPESP funding (2005/01023-8). T. C. B. acknowledges JINA.

References

Barbuy, B., Spite, M., Spite, F. *et al.* 2005, A&A, 429, 1031
Barklem, P. S., Christlieb, N., Beers, T. C. *et al.* 2005, A&A, 439, 129
Beers, T. C. & Christlieb, N. 2005, ARA&A, 43, 53
Christlieb, N., Beers, T. C., Barklem, P. S. *et al.* 2004, A&A, 416, 1117
Jonsell, K., Barklem, P. S., Gustafsson, B. *et al.* 2006, A&A, 451, 651
Lucatello, S., Beers, T. C., Christlieb, N. *et al.* 2006, ApJ, 652, L37

https://doi.org/10.1017/S1743921310003479 Published online by Cambridge University Press