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Follow-up of stars enriched in neutron-capture elements identified in the GALAH survey

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Abstract. Old, metal-poor stars provide valuable information for understanding the formation and evolution of our Galaxy. Interestingly, a fraction of these old stars have been found to be enriched in r-process elements. The r-process is a neutron capture nucleosynthetic mechanism that produces the heaviest elements in the periodic table, alongside the s-process. However, the complete details of the astrophysical sources of the r-process elements are still a mystery. Neutron star mergers (NSM) have recently been confirmed to be one such source, but the long timescale for their coalescence suggests that NSM cannot be the only r-process site. In this work, we report preliminary results of an observational campaign to follow up chemically peculiar metal-poor stars identified from the catalogue of large surveys. We present preliminary values of atmospheric parameters and abundances of Mg, Ba, and Eu. We also discuss the dynamic properties of these stars, which are used to understand if they were formed in situ in the Galactic halo or were accreted from external galaxies.

Resumo. Estrelas velhas e pobres em metais oferecem informações valiosas para a compreensão da formação e da evolução da nossa Galáxia. Curiosamente, descobriu-se que uma fração destas estrelas antigas é enriquecida em elementos formados pelo processo r. O processo r é um mecanismo nucleossintético de captura de nêutrons que produz os elementos mais pesados da tabela periódica, juntamente com o processo s. No entanto, as fontes astrofísicas dos elementos do processo r ainda são um mistério. As fusões de estrelas de nêutrons (NSM) foram recentemente confirmadas como uma dessas fontes, mas a longa escala de tempo para sua coalescência sugere que NSM não pode ser o local exclusivo no qual ocorre o processo r. Neste trabalho, relatamos resultados preliminares de uma campanha observacional para acompanhar estrelas pobres em metais quimicamente peculiares identificadas em catálogos grandes levantamentos espectroscópicos. Apresentamos valores preliminares para os parâmetros atmosfêricos e as abundâncias dos elementos Mg, Ba, e Eu. Também analisamos as propriedades dinâmicas destas estrelas para entender se elas foram formadas dentro no halo galáctico ou se foram acretadas de galáxias satélites canibalizadas pela nossa Galáxia

Keywords. Stars: abundances – Stars: fundamental parameters – Stars: Population II

1. Introduction

The current era of large stellar surveys, such as *Gaia* (Gaia collaboration 2016), APOGEE (Apache Point Observatory Galactic Evolution Experiment, Majewski et al. 2017), and GALAH (GALactic Archaeology with HERMES, de Silva et al. 2015), provides the means for the identification and study of large samples of metal-poor stars. With this comes the unique opportunity to obtain a holistic view of all the possible sources of the rapid neutron-capture process (r-process). In this work, we report preliminary results of an observational campaign to follow up chemically peculiar metal-poor stars identified from the catalogue of large surveys. For target selection, we cross-matched GALAH DR3 sources (Buder et al. 2021) with the *Gaia* EDR3 catalogue (Gaia collaboration 2021). We selected stars with [Fe/H] ≤ -2 and relative [Ba/Fe] and [Eu/Fe] abundances that deviate by more than three standard deviations from the mean of the sample. Our aim was to select a list of stars that may have peculiar combinations of both r- and s-process elements. Particularly interesting are those that have extreme abundance patterns in which only one process dominates. Such stars might be key to disentangle the early contribution of both processes to the Galactic chemical enrichment. Our selection resulted in 34 candidates for follow-up.

2. Methods

As a pilot study, we obtained data for two stars (TYC 9219−2422−1 and BPS CS 29529−0089) with the UV-visual echelle spectrograph (UVES, Dekker et al. 2000) at the Very Large Telescope (VLT) of the European Southern Observatory (ESO), at Cerro Paranal, Chile, in period 108. Two exposures were obtained for TYC 9219−2422−1 and three for BPS CS 29529−0089. Each spectrum has R~41,000 and S/N~50 at 372.4 nm. We used UVES with a dichroic configuration to obtain spectra in two arms: blue, centred at 390 nm, and red, centred at 580 nm.

We derived the effective temperature ($T_{\rm e}$ff) of the stars using the Infrared Flux Method calibrations from González Hernández & Bonifacio (2009) and 2MASS photometry (Skrutskie et al. 2006). Surface gravity (log g) was derived using *Gaia* parallaxes (Gaia collaboration 2021) and bolometric corrections from Masana et al. (2006) assuming a stellar mass of 0.8 $M_{\odot}$. We used the code iSpec (Blanco-Cuaresma et al. 2014) to measure radial velocities, metallicities (using equivalent widths of Fe II lines from the same list of lines adopted in Smiljanic et al. 2021) and chemical abundances (the latter using spectral synthesis).

3. Results and Discussion

We integrated the orbits for the stars adopting *Gaia* EDR3 parallaxes and proper motions and the heliocentric radial velocities measured in this work. Orbits were computed using the Python code galpy (Bovy 2015). For these calculations, we adopted the Milky Way potential of McMillan (2017) and performed a Monte Carlo simulation to determine the uncertainties. We then analysed the position of these stars in diagrams of dynamic quantities (the Lindblad diagram and the action map, both shown in

Table 1. GALAH parameters

Star	ϖ (mas)	$T_{\rm eff}$ (K)	log g	[Fe/H]	[Mg/Fe]	[Ba/Fe]	[Eu/Fe]
TYC 9216-2422-1	1.5552 (113)	5220	2.98	-2.25	0.72	-0.12	2.34
BPS CS 29529-0089	0.2766(124)	5120	2.85	-1.79	0.37	0.96	0.85

Table 2. Parameters determined in this work

Star	$T_{\rm eff}$ (K)	log g	[Fe/H]	[Mg/Fe]	[Ba/Fe]	[Eu/Fe]
TYC 9216-2422-1	5181(101)	3.08(3)	-2.29(28)	0.24(3)	1.87(4)	0.26(2)
BPS CS 29529-0089	5006(42)	2.24(8)	-2.24(23)	0.20(4)	1.37(5)	2.56(10)

Fig. 1), to identify the Milky Way population to which these stars belong.

3.1. TYC 9219-2422-1

According to the GALAH DR3 data (Tab. 1), TYC 9219-2422-1 could be classified as a very metal-poor ([Fe/H] < −2) r-II star (Beers & Christlieb 2005). Our results (Tab. 2), on the other hand, show a strong s-process enrichment ([Ba/Fe] = +1.87 ± 0.04) along with a mild enrichment of the r-process ([Eu/Fe] = +0.26 ± 0.02). Dynamically, TYC 9219-2422-1 is a halo star (Fig. 1). Further analysis is required to confirm the possibility that it is a member of the Gaia-Enceladus merger (Helmi et al. 2018).

3.2. BPS CS 29529-0089

BPS CS 29529-0089 in GALAH DR3 data (Tab. 1) is a peculiar star enhanced in both r- and s-process elements ([Ba/Fe] = +0.96 and [Eu/Fe] = +0.85). Our analysis confirmed the chemical enrichment in elements of both processes, but we found higher values for the abundances of Ba and Eu: [Ba/Fe] = +1.37 ± 0.05 and [Eu/Fe] = +2.56 ± 0.10 (Tab. 2). BPS CS 29529-0089 is probably a thick disc star (Fig. 1).

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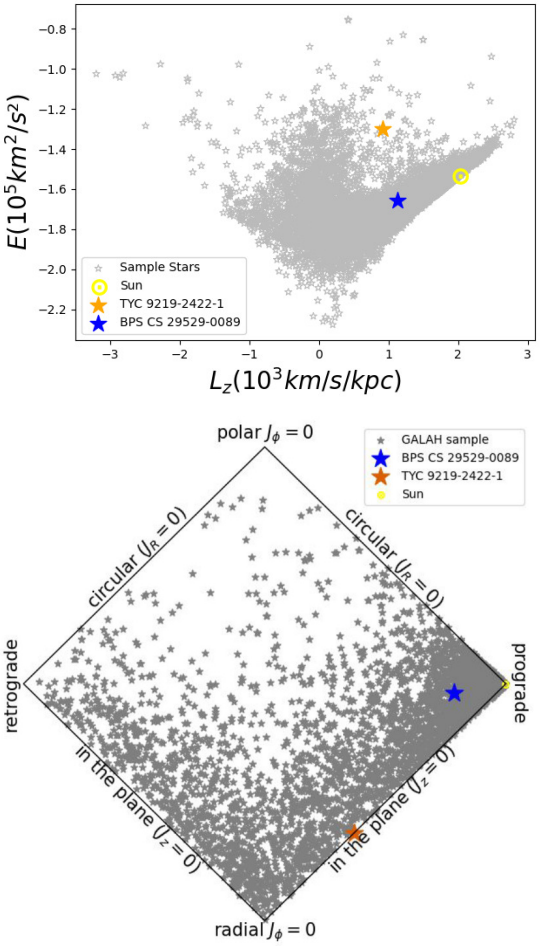

Figure 1. *Top* - Lindblad Diagram (Total orbital potential energy by angular momentum in the direction of galactic north pole). GALAH stars with [Fe/H] < -0.8 are presented in gray, the Sun in yellow symbol, and our two stars, TYC 9219-2422-1 and BPS CS 29529-0089, in orange and blue, respectively. *Bottom* - The Action Map - the same symbols and colors are used. From these two diagrams we can observe that BPS CS 29529-0089 is probably a thick disk star, while TYC 9219-2422-1 is a halo star.

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