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Abundances of heavy elements in the kinematic stellar substructures

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Abstract. We study the chemical composition of two kinematically identified groups of stars in the Galactic disc. Based on dynamical properties these stars were suspected to belong to disrupted satellites. Using high resolution spectra obtained with the spectrograph FIES at the Nordic Optical Telescope, La Palma, we determine detailed elemental abundances of elements and look for possible chemical signatures that might give information about the formation history of these possibly accreted kinematic groups of stars. Our results reveal that abundances of chemical elements produced mainly by the *r*-process are overabundant and those mainly produced by the *s*-process are the same as in Galactic thin-disc dwarfs and models. The similar elemental abundance patterns were observed in the Galactic thick-disc stars. Similar chemical composition of project stars and the thick-disc stars might suggest that their formation histories are linked. The homogeneous chemical composition inside each of the groups together with their kinematic properties provide additional evidences of their common origin and possible relation to ancient merging events.

Key words. Stars: abundances – Galaxy: disc – Galaxy: formation – Galaxy: evolution

1. Introduction

The formation of the Milky Way galaxy is complex and not fully understood. It is believed that ancient mergers of dwarf galaxies played an important role. A number of stellar streams, moving and kinematic groups were identified in our Galaxy (Helmi 2008; Klement et al. 2009; Sesar et al. 2012, and references therein). Some of them are suspected to originate from accreted satellites.

Signatures of past accretion in the Milky Way disc may be identified from correlations between stellar orbital parameters, such as apocentre, pericentre, and z-angular momentum, the so-called APL space. Helmi et al. (2006) identified three new coherent groups of stars in the Geneva-Copenhagen survey (Nordström et al. 2004) and suggested that those might correspond to remains of disrupted satellites.

All the Galactic disc stars from Holmberg et al. (2009) are shown in Fig. 1. Stars belonging to two stellar groups investigated in Helmi et al. (2006) are marked with open and filled circles. The disc stars and stars in the investigated groups have radically different distribution in the velocity space. For example, in the kinematic U and V plane, the investigated stars are distributed in a banana-shape,

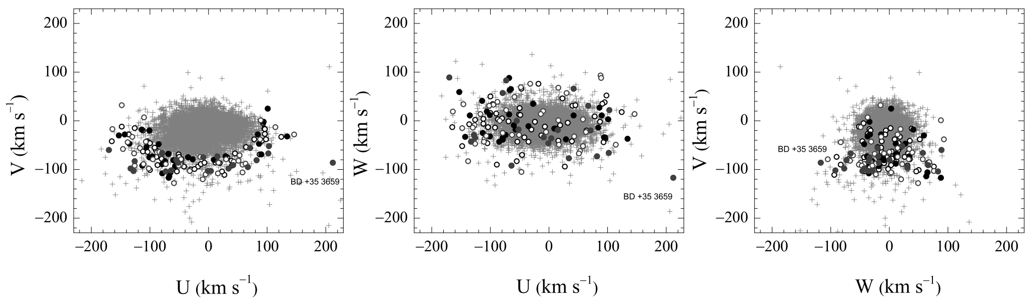

Fig. 1. Velocity distribution for all stars in the Holmberg et al. (2009) sample (plus sings). The Group 2 stars are shown by black open circles & Group 3 stars are shown by dark gray open circles. Those investigated in present work - black and dark gray filled circles, respectively.

whereas the disc stars define a centrally concentrated clump. At the same time, in the *U* and *W* plane the investigated stars populate mostly the outskirts of the distributions, and have a lower mean galactic rotational velocity in comparison to the Milky Way disc stars in the *W* and *V* plane. These properties are characteristic for stars associated with accreted satellite galaxies.

From high-resolution spectra we determine abundances of oxygen, α-elements, iron-peak, *s*- and *r*-process elements in stars belonging to the so-called Group 2 and Group 3 and make a comparison with Galactic disc stars.

The results on Group 3 were published by Stonkutė et al. (2012, 2013), a paper on Group 2 is in preparation by Ženovienė et al. In this contribution we overview our results on abundance determinations of neutron-capture elements in these two kinematic groups.

2. Observations and analysis

Spectra of high-resolving power ($R \approx 68\,000$) in the wavelength range of 3680–7270 Å were obtained at the 2.56 m Nordic Optical Telescope with the FIES spectrograph. All spectra were exposed to reach a signal to noise ratio higher than 100. Reductions of CCD images were performed with the FIES pipeline *FIEStool*.

The spectra were analysed using a differential model atmosphere technique. The *BSYN* program package, developed at the Uppsala Astronomical Observatory, was used to carry out the calculation of abundances from synthetic spectra. A set of plane parallel, line-blanketed, flux constant LTE model atmospheres (Gustafsson et al. 2008) were taken from the MARCS stellar model atmosphere and flux library (`http://marcs.astro.uu.se/`).

Effective temperature, gravity, [Fe/H], and microturbulent velocity values of the programme and comparison stars were determined using spectroscopic methods. Stellar rotation was taken into account using values of *v*sin*i* from Holmberg et al. (2007).

We measured abundances of neutron-capture elements such as Y II, Zr I, Zr II, Ba II, La II, Ce II, Pr II, Nd II, Sm II and Eu II. Atomic parameters of lines were compiled from the Vienna Atomic Line Data Base (VALD, Piskunov et al. 1995). Hyperfine structure and isotop shifts were taken into account.

3. Results and conclusions

We measured abundances of *s*- and *r*-process elements from high-resolution spectra in stars belonging to two kinematic groups of stars identified by Helmi et al. (2006), which were suspected to be remnants of disrupted satellite galaxies. Our main goal was to investigate the chemical composition of the stars within each group and to compare them with Galactic disc stars and chemical evolution models.

The elemental-to-iron abundance ratios derived for 32 Group 2 stars, 21 Group 3 stars and 14 comparison stars are shown in Fig. 2.

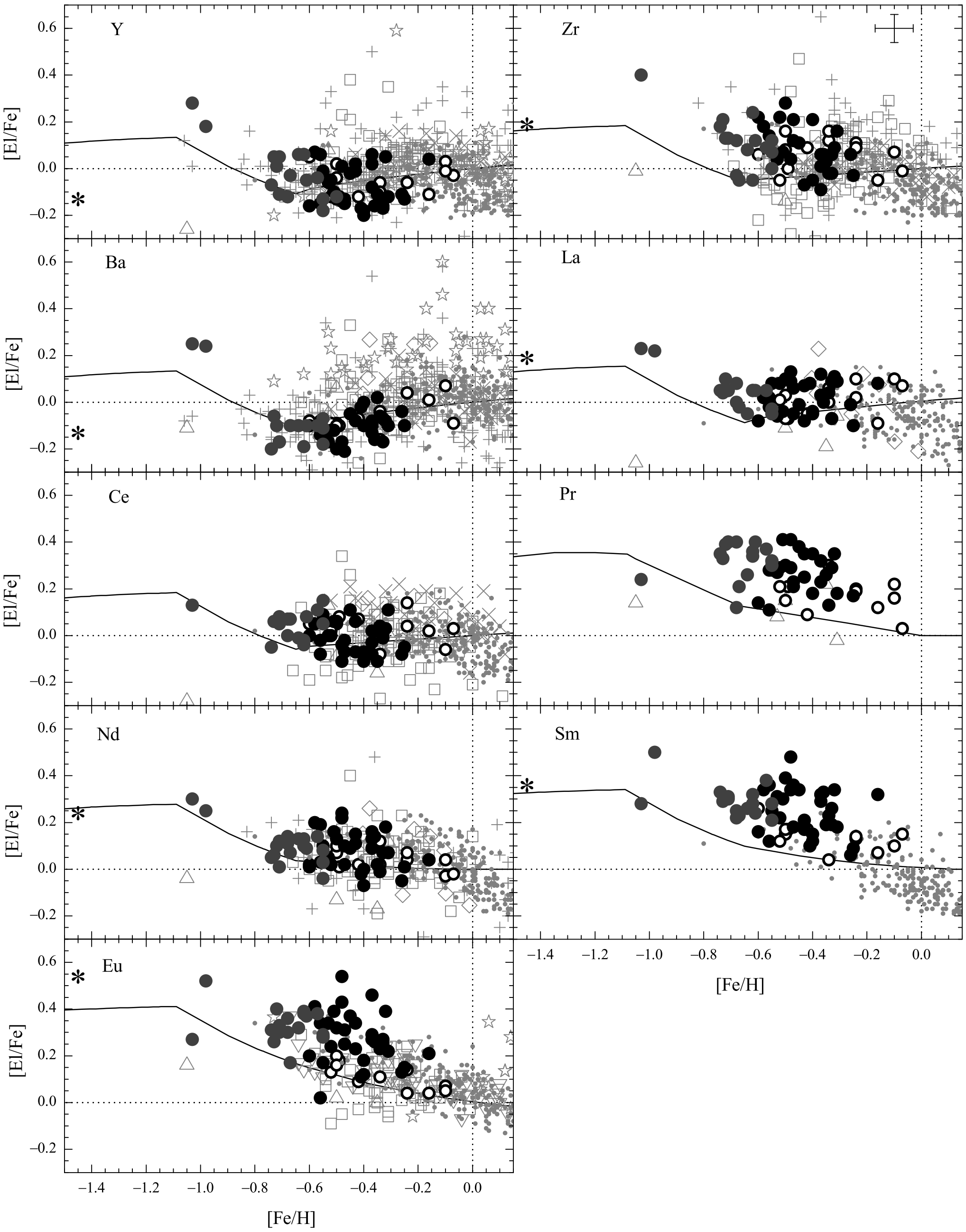

Fig. 2. Elemental abundance ratios of stars in Group 2 (black filled circles) and Group 3 (dark gray filled circles) and comparison stars (open circles). For this comparison the data for Milky Way thin-disc dwarfs are plotted: Edvardsson et al. (1993, plus signs), Gratton & Sneden (1994, triangles), Koch & Edvardsson (2002, upside down triangles), Bensby et al. (2005, stars), Reddy et al. (2006, 2003, squares), Brewer & Carney (2006, diamonds), Mashonkina et al. (2007, crosses), Mishenina et al. (2013, dots). Solid lines show the Galactic thin-disc chemical evolution models by Pagel & Tautvaišienė (1997). Average uncertainties are shown in the box for zirconium.

The comparison thin-disc dwarfs were observed and analysed using the same method. The mean metallicity for the Group 2 stars is: [Fe/H] = −0.42 ± 0.10. For Group 3 stars it is: [Fe/H] = −0.69 ± 0.14. Our study of Group 3 stars shows that BD +73 566 is an *s*-process-enhanced star.

From the detailed chemical composition of the stars investigated we conclude that:

1. The chemical composition of the stars within each group is homogeneous.
2. The abundances of chemical elements produced predominantly by the *r*-process are overabundant in comparison with Galactic thin-disc dwarfs of the same metallicity. The most prominent overabundances are seen for europium, samarium, and praseodymium.
3. The abundances of chemical elements produced mainly by the *s*-process are similar to those in the Galactic thin-disc dwarfs of the same metallicity.
4. Group 2 and Group 3 might originate from the same satellite galaxy.
5. The chemical composition of stars in both kinematic groups is similar to thick-disc stars, which might suggest that their formation histories are linked.
6. The chemical composition together with the kinematic properties and ages of stars in the investigated Group 2 and Group 3 of the Geneva-Copenhagen survey support a gas-rich satellite merger scenario as the most suitable origin for those two stellar groups.

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