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Early chemical enrichment of the Milky Way dwarf satellites from high-resolution and NLTE analysis of VMP stars

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Abstract. We present the NLTE abundances of 10 chemical species in 65 very metal-poor stars in eight dSphs and the Milky Way halo. The classical dSphs Sculptor, Ursa Minor, Sextans, and Fornax reveal a similar plateau at [α/Fe] = 0.3 for each of Mg, Ca, and Ti, similarly to the MW halo. We provide the evidence for a decline in α/Fe in the Boötes I UFD, that is probably due to the ejecta of SNeIa. The dichotomy in the [Sr/Ba] versus [Ba/H] diagram is observed in the classical dSphs, similarly to the MW halo, calling for two different nucleosynthesis channels for Sr. The Boötes I and UMa II UFDs reveal very similar ratios of [Sr/Mg] = −1.3 and [Ba/Mg] = −1. The stars in the Coma Berenices and Leo IV UFDs are even poorer in Sr and Ba. The subsolar Sr/Ba ratios of Boötes I and UMa II indicate a common r-process origin of their n-capture elements.

Keywords. stars: abundances, galaxies: abundances, galaxies: dwarf, galaxies: evolution

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Current knowledge of the first stages of star formation in galaxies is still poor. The stellar abundance trends and dispersions of very metal-poor (VMP, [Fe/H] < -2) stars reveal the nature of the first generations of stars, their masses, numbers, and spatial distribution, the energetics of the explosion of supernovae, and the level of homogeneity of the interstellar medium. The proximity of the Local Group dwarf spheroidal galaxies (dSphs) allows the derivation of chemical abundances with comparable quality as in the Milky Way (MW). The comparison of these galaxies with very different masses, star formation histories, and level of chemical enrichment can provide crucial information regarding the universality of the physical processes at play.

We initiate a big project aiming at providing a homogeneous set of atmospheric parameters and elemental abundances for the VMP stars in a set of dSphs as well as for a MW halo comparison sample by employing high-resolution spectral observations and treating the non-local thermodynamic equilibrium (NLTE) line formation. This makes possible to push the accuracy of the abundance analysis to the point where the trends of the stellar abundance ratios with metallicity can be robustly discussed.

Stellar sample and observations. In the literature, we selected the dSphs with the largest samples of the VMP stars, which were observed in a broad spectral range with R > 20 000. These are the classical dSphs Sculptor (11 stars) and Ursa Minor (10 stars) and the Boötes I (11 stars) ultra-faint dwarf (UFD). We also include the UMa II and Coma Berenices UFDs with three stars in each galaxy. Our MW comparison sample includes 23 halo giants in the $-4 <$ [Fe/H] < -1.7 metallicity range. Preselection was made in order to exclude C-enhanced stars. For references, see Mashonkina *et al.* (2017a). Our results are based on high-resolution spectroscopic datasets taken from different sources: (i) spectral archives of VLT2, Subaru, and Keck I; (ii) the Magellan/MIKE spectra provided by R. Ezzeddine, Anna Frebel, and Joshua D. Simon; and published equivalent widths.

Stellar atmosphere parameters. For the dSph stars, their effective temperatures ($T_{\rm eff}$) and surface gravities (log g) are based on non-spectroscopic methods. We calculate $T_{\rm eff}$ from the Johnson system photometric colours, using calibrations of Ramírez, Meléndez (2005). For three stars in the Coma Berenices UFD, BVR$_c$I$_c$JHK photometry was performed with the 2.5m telescope at the Caucasus Mountain Observatory of MSU (Russia). The determination of log g benefits from known distance. With the obtained $T_{\rm eff}$ / log g, the mean NLTE abundance difference Fe I – Fe II = 0.026±0.075. Microturbulent velocities and the Fe abundances were derived from the NLTE analysis of lines of Fe I and Fe II. The method used is described in detail by Mashonkina *et al.* (2017a).

The same photometric method was applied to determine $T_{\rm eff}$ of the MW stars. Their surface gravities were derived from the NLTE analysis of lines of Fe I and Fe II. The spectroscopic gravities are found to be consistent with the ones based on the Gaia DR2 parallaxes (Gaia Collaboration *et al.* 2018).

NLTE abundance ratios. The NLTE calculations were performed for Na I, Mg I, Al I, Si I, Ca I, Ti I-Ti II, Fe I-Fe II, Sr II, and Ba II. We obtain that VMP stars in the classical dSphs in Sculptor, Ursa Minor, Sextans, and Fornax are α-enhanced, at [α/Fe] $\simeq$ 0.3, and our homogeneous NLTE analysis removes discrepancies between different α-elements and between the classical dSphs and the MW halo (Mashonkina *et al.* 2017b). Previous high-resolution LTE abundance analyses (for example, Jablonka *et al.* 2015) deduced a common conclusion on enhancement of Mg in the classical dSphs, however, different results were reported in different papers on Ca/Fe and Ti/Fe. We put on a firm ground the evidence for a decline in α/Fe with increasing [Fe/H] in the Boötes I UFD, that is probably due to the ejecta of SNeIa. Once the NLTE effects are taken into account, the MW halo and all dSphs reveal indistinguishable trends with metallicity for Na/Fe, Na/Mg, and Al/Mg, suggesting that the processes of Na and Al synthesis are identical in all systems, independent of their mass. The dichotomy in the [Sr/Ba] versus [Ba/H] diagram is observed in the classical dSphs, similarly to the MW halo, calling for two different nucleosynthesis channels for Sr. The subsolar Sr/Ba ratios of Boötes I and UMa II indicate a common r-process origin of their n-capture elements.

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