The General Assembly of Galaxy Halos: Structure, Origin and Evolution
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Chemical evolution of r-process elements in the Draco dwarf spheroidal galaxy

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Abstract. A dominant astrophysical site for r-process, which is responsible for producing heavy neutron-capture elements, is unknown. Dwarf spheroidal galaxies around the Milky Way halo provide ideal laboratories to investigate the origin and evolution of r-process elements. We carried out high-resolution spectroscopic observations of three giant stars in the Draco dwarf spheroidal galaxy to estimate their europium abundances. We found that the upper-limits of [Eu/H] are very low in the range [Fe/H]< -2, while this ratio is nearly constant at higher metallicities. This trend is not well reproduced with models which assume that Eu is produced together with Fe by SNe, and may suggest the contribution from other objects such as neutron-star mergers.

Keywords. stars:abundances, galaxies:dwarf, galaxies:individual (Draco)

1. Motivation

Heavy neutron-capture elements are mainly originated from r-process. These elements are ubiquitous among very metal-poor stars in the Milky Way halo, which suggests that the r-process has been operating since the early Universe (e.g. Sneden *et al.* 2008, Roederer *et al.* 2014). Although the physical conditions required for the r-process are well understood, the corresponding astrophysical sites are still unknown. Theoretical studies suggest that core-collapse supernovae (SNe) and/or mergers neutron-stars (or neutron star-black hole systems) could be possible sites for the r-process (e.g. Wanajo & Ishimaru 2006). These events are expected to have different enrichment timescales and thus can be tested by observed chemical evolution of r-process elements in old stellar populations.

We carried out high-resolution spectroscopic observations to measure europium (Eu) abundances in three giant stars in the Draco dwarf spheroidal galaxy (dSph), which is known to host an old, metal-poor and relatively simple stellar population and thus is a particularly ideal laboratory to study individual r-process events in the early universe. Europium is almost purely produced in the r-process, with little contamination from s-process (c.f. Ba), and thus provides a clean test for the r-process enrichment in this galaxy.

2. Results and discussion

The observations of the three Draco stars were carried out with the High-Dispersion Spectrograph (HDS; Noguchi *et al.* 2002) mounted on the Subaru telescope during Aug

Table 1. Summary of the atmospheric parameters and abundances.

	$T_{\rm eff}$	$\log g$	ξ	[Fe/H]	[Eu/H]
Irwin 19826	4028	0.6	1.7	-1.45 ± 0.12	-1.33 ± 0.21
Irwin 20751	4278	0.6	1.7	-2.12 ± 0.13	< -2.0
Irwin 21275	4406	0.7	2.3	-2.51 ± 0.09	< -2.1

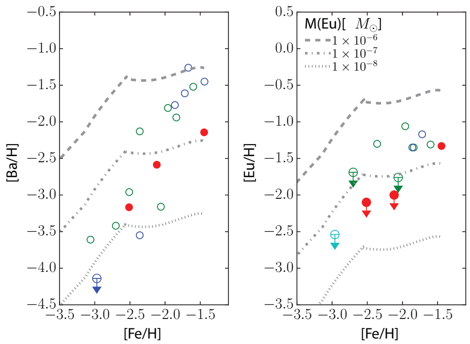

Figure 1 Observed [Ba/H] and [Eu/H] abundances in this study (filled circles) and those from literature. The gray lines are predictions of chemical evolution models assuming that Eu is produced in every SNe (10-40$M_\odot$) by an amount 10^{-6}, 10^{-7}, $10^{-8}\,M_\odot$. They are calculated based on the model of Kirby *et al.* (2011), whose model parameters have been obtained to reproduce observed α-elements and [Fe/H] distributions in Draco. Mass of Ba, assumed to be produced in SNe, is adopted according to the Eu yields with the r-process ratio [Ba/Eu]r-process= -0.7. Note that contribution from s-process is not taken into account.

16-18, 2014. An optical wavelength range was covered with a spectral resolution $R \sim 30000$.

Results of the Eu measurements are summarized in Table 1. An absorption line of Eu II (6645 Å) was weakly detected in the most metal-rich star in our sample, Irwin 19826, while only upper limits were obtained for the two more metal-poor stars. Figure 1 shows [Ba/H] and [Eu/H] abundances plotted against [Fe/H] for the sample stars and for stars from literature (Shetrone *et al.* 2001, Fulbright *et al.* 2004, Cohen & Huang 2009). The [Eu/H] abundances in the Draco stars are characterized by the very low values at [Fe/H]< -2, and an apparent plateau ([Eu/H]~ -1.3 dex) at higher metallicities. This trend is not well reproduced by canonical chemical evolution models under the simple assumption that Eu is exclusively produced in SNe together with Fe (gray lines). These models generally predict a steep increase of [Eu/H] with [Fe/H] at [Fe/H]< -2, which becomes shallower at higher metallicities, due to the onset of Type Ia SNe, and thus are unable to simultaneously explain the observed features over the whole [Fe/H] range.

This result may indicate that r-process elements were produced, at least in part, in neutron-star mergers (Tsujimoto & Shigeyama 2014; Tsujimoto *et al.* 2015). Further observations are needed to test whether similar [Eu/H]-[Fe/H] trends are observed in other faint dSphs around the Milky Way.

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