From Lithium to Uranium: Elemental Tracers of Early Cosmic Evolution
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r-process elements in globular clusters

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Abstract. We have observed seven giants in the metal-poor globular cluster M15 using Subaru/HDS. We confirmed that there are significant star-to-star variations in the neutron-capture elemental abundances. This abundance variation means there were primordial chemical inhomogeneities in the proto-globular cluster cloud of M15. This result implies that there was insufficient time for complete mixing after r-process nucleosynthesis. It suggests that the main r-process occurs probably in supernovae which explode in later stages of globular cluster formation.

Keywords. Stars: abundances

There is still no widely accepted theoretical model of globular cluster formation. Since stars of a given globular cluster generally show the same [Fe/H] within 10%, they are believed to be formed at the same time and from the same material. However, Sneden *et al.* (1997, 2000a) have reported a significant spread in [Ba/Fe] of M15 giants. If the Ba in M15 was only produced by r-process, this scatter probably gives a clue to study the origin of the main r-process and globular cluster formation. Unfortunately, those data did not have enough quality for conclusive discussion except for the three giants in Sneden *et al.* (2000b).

High-resolution spectra of seven giants in the metal-poor globular cluster M15 (NGC 7078, [Fe/H]/$\sim$$-2.4$) were obtained via the Subaru telescope using HDS in 2004 July. Three high-Ba stars and four low-Ba stars from Sneden *et al.* (1997, 2000a) were selected as the targets since confirmation of the abundance variation in r-process elements was part of this study. Part of spectra are shown in Fig. 2. We confirmed there is significant scatter. The ratios of La and Eu in target stars show there are no (or insignificant) contributions from s-processes (Fig. 3).

Since chemical composition of stars in globular clusters are believed not to be affected by explosive events after their formation, there exists clear inhomogeneities in abundance of neutron-capture elements in the gases from which cluster stars formed, while the lighter elements like Fe are essentially uniform (Fig. 1). If we assume the main r-processes occur after enough Fe enrichment, uniform [Fe/H] and the spread of neutron-capture elements can be reproduced (Otsuki *et al.* 2004). Recently, Galactic chemical evolution studies by several authors reported that main r-processes probably occurred in lighter supernovae to reproduce observed Pop II stellar abundances (e.g., Travaglio *et al.* 2001). Since lighter supernovae explode later, the main r-process in lighter supernovae is consistent with our observational results. Detailed analysis of the timescale of supernovae shell dynamics and star formations could answer whether globular clusters were self-enriched or not.

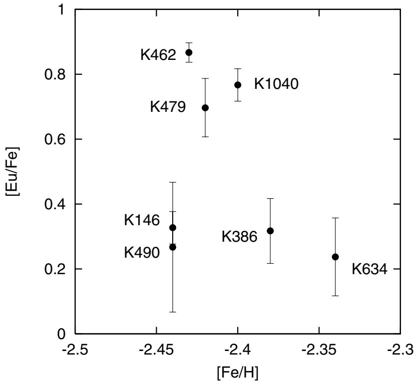

Figure 1. [Eu/Fe] vs. [Fe/H].

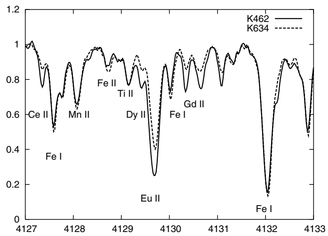

Figure 2. Spectra of two M15 giants, K462 and K634.

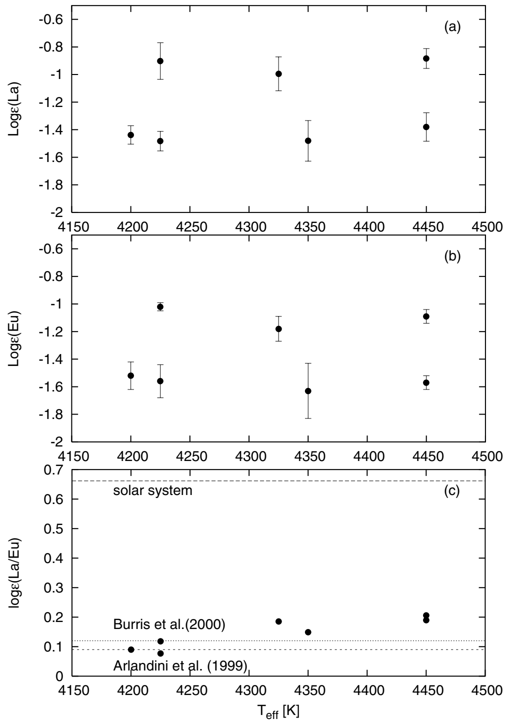

Figure 3. La,Eu abundances and La/Eu ratios as a function of T_{eff}. La/Eu ratios in solar system and in pure r-process derived by two different theoretical calculations are shown in lowest pannel.

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