

# Enrichment of Thorium (Th) and Lead (Pb) in the early Galaxy

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**Abstract.** We have been determining abundances of Th, Pb and other neutron-capture elements in metal-deficient cool giant stars to constrain the enrichment of heavy elements by the r- and s-processes. Our current sample covers the metallicity range between  $[\text{Fe}/\text{H}] = -2.5$  and  $-1.0$ . (1) The abundance ratios of Pb/Fe and Pb/Eu of most of our stars are approximately constant, and no increase of these ratios with increasing metallicity is found. This result suggests that the Pb abundances of our sample are determined by the r-process with no or little contribution of the s-process. (2) The Th/Eu abundance ratios of our sample show no significant scatter, and the average is lower by 0.2 dex in the logarithmic scale than the solar-system value. This result indicates that the actinides production by the r-process does not show large dispersion, even though r-process models suggest high sensitivity of the actinides production to the nucleosynthesis environment.

**Keywords.** Galaxy:halo, stars:abundances, stars:Population II

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## 1. Introduction

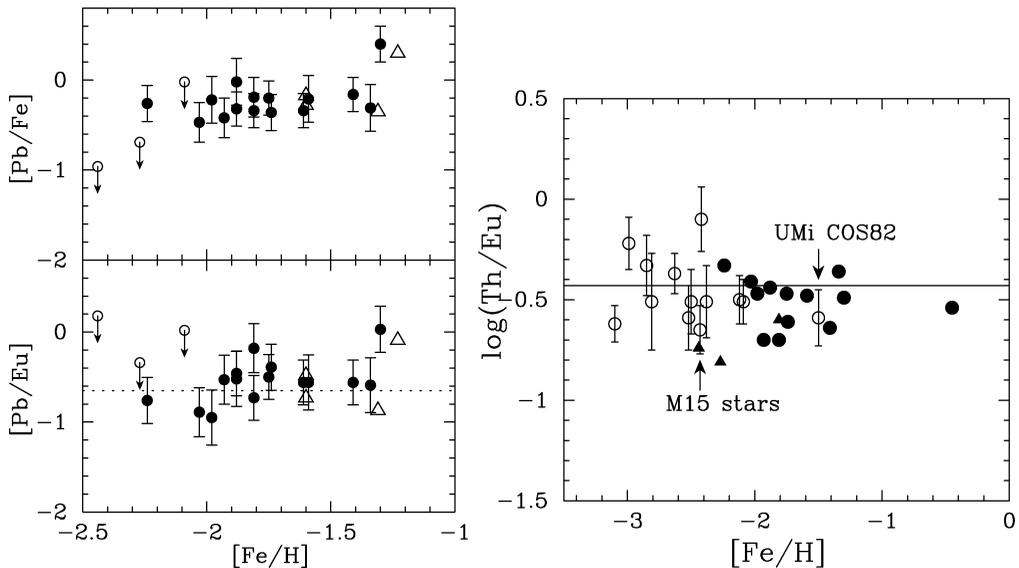
Th and Pb are key elements to understand the production of heavy elements by neutron-capture reactions. The difficulty in observational studies for these elements are the weakness of spectral lines in optical range, and also contaminations of spectral features of other elements and molecules. For this reason, measurements of these elements have been limited to very metal-poor stars with relatively large enhancements in neutron-capture elements (see Roederer *et al.* (2009) and references therein).

In order to investigate the enrichment of Th and Pb, we have been extending the measurements for higher metallicity range than that previously studied. The spectral lines of these elements are relatively strong in cool giants (the effective temperature lower than 4500 K), and the Th line at 5989 Å is little blended with other features. This paper reports the preliminary results of our measurements of Pb and Th abundances obtained by high resolution spectroscopy with the Subaru Telescope High Dispersion Spectrograph (HDS) for bright metal-poor giants.

## 2. Measurements

Pb abundances are determined from the Pb I 4057 Å line, which is the almost unique line found in optical spectra of metal-poor stars. Although CH molecular lines exist in this spectral range, the contamination is not severe because of low carbon abundances in evolved red giants in our sample.

Th abundances have been measured from the Th II 4019 Å line for most of metal-poor stars in previous studies. This line is, however, severely blended with other absorption



**Figure 1.** left:  $[\text{Pb}/\text{Fe}]$  and  $[\text{Pb}/\text{Eu}]$  as a function of  $[\text{Fe}/\text{H}]$  for halo stars (circles) and globular clusters (triangles). This sample includes that of Aoki & Honda (2008). The dotted line in the lower panel indicates the r-process component of the solar-system material estimated by Arlandini *et al.* (1999). right: Th/Eu ratio as a function of  $[\text{Fe}/\text{H}]$ . Filled circles are the preliminary results obtained by the present work. The solid line indicates the solar Th/Eu value.

lines in mildly metal-poor stars. In such stars (in particular cool red giants), the Th II 5989 Å line is sufficiently strong to measure the Th line. This line is almost free from contaminations of other species (Aoki *et al.* 2007).

### 3. Results and Discussion

Figure 1 (left) shows that the Pb/Fe is almost constant in  $-2 < [\text{Fe}/\text{H}] < -1$  while it decreases with decreasing metallicity in  $[\text{Fe}/\text{H}] < -2$  with an exception (the r-process-enhanced star CS 31082-001). The Pb/Eu ratio is also constant and agrees with the estimate for the r-process component in solar-system material (Arlandini *et al.* 1999). While a few stars show enhancement of Pb/Eu, suggesting a large contribution of s-process to these stars, others are interpreted as the results of the r-process

We have been extending the Th measurements to  $[\text{Fe}/\text{H}] > -2$ . Our results (Fig. 1, left; filled circles) indicates that most objects in our sample have Th/Eu slightly lower than the solar value (solid line). This suggests that the Th/Eu ratio produced by the r-process statistically agrees with the value estimated for the initial solar composition, but Th has significantly decayed in these metal-poor stars. While some star-to-star scatter of Th/Eu is found in  $[\text{Fe}/\text{H}] < -2$ , no significant scatter is detected in our sample, probably because the mixing of inter-stellar material before formation of these stars were efficient.

### References

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