Neutron-Capture Element Abundances in Halo Stars

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Abstract.   We present new abundance observations of neutron-capture elements in Galactic stars. These include new Hubble Space Telescope (HST) detections of the elements Ge, Zr and Pt in a group of 11 halo stars. Correlations between these elements and Eu (obtained with ground-based observations), and with respect to metallicity, are also presented.

1.   Introduction

Abundance comparisons of neutron-capture elements – those formed in slow (s-process) and rapid (r-process) neutron-capture nucleosynthesis – are providing important new information about the nature of the earliest Galactic nucleosynthesis and the first stellar generations (see recent reviews by Truran et al. 2002, Sneden & Cowan 2003 and Cowan & Thielemann 2004). Most previous studies have been restricted to elements detectable with ground-based observations. We have recently completed a long-term study of the n-capture elements Ge, Zr, Os and Pt – all of these elements with dominant atomic transitions in the UV – in a sample of 11 metal-poor Galactic halo stars using the Hubble Space Telescope, HST (Cowan et al. 2004). These observations were supplemented with Keck I High Resolution Echelle Spectrograph (HIRES) observations of the n-capture element Ir. Our focus has been to examine correlations among these elements in an attempt to help to identify the sites of nucleosynthesis for these elements and also to trace their evolution with Galactic metallicity.

2.   Neutron-Capture Element Abundance Comparisons

In Figure 1 we plot the [Ge/H] values (obtained with HST) with respect to metallicity, [Fe/H], for the 11 Galactic halo stars. The figure makes clear that there is a direct correlation between Ge and Fe but at a depressed level, [Ge/H] = [Fe/H] – 0.79, with respect to the solar value. This element, normally thought of as an n-capture element, appears to have been synthesized in a different manner for low metallicities, early in the history of the Galaxy. Comparison of the Ge and Eu abundances, obtained with ground-based observations (Simmerer et al. 2004), shows no correlation in these stars (see Figure 1 and Cowan et

al. 2004). The abundance data might be explained if Ge were synthesized in charged-particle reactions, for example, during the so-called "α-rich freeze-out" in a supernova environment. Since solar system material shows clear signatures of n-capture for this element (Simmerer et al. 2004), it is expected that at higher metallicities than those studied here, and with the onset of the s-process in the Galaxy, Ge production would no longer correlate with iron abundance.
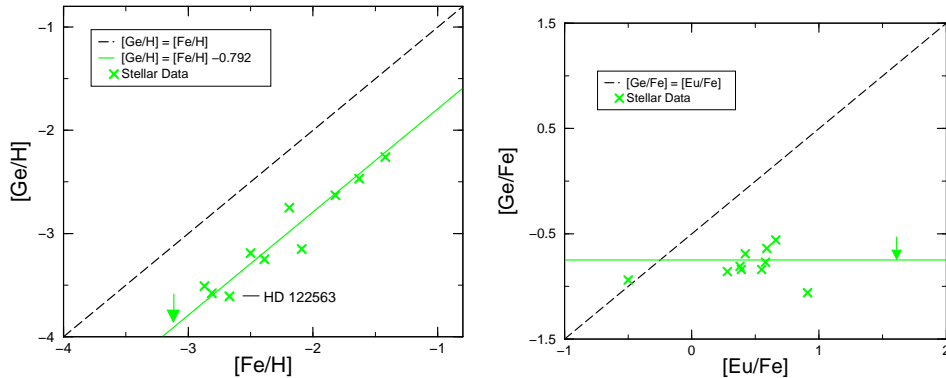

Figure 1.   (left) Relative abundances [Ge/H] displayed as a function of metallicity for our sample of 11 Galactic halo stars. The arrow represents the derived upper limit for CS 22892-052. The dashed line indicates the solar abundance ratio of these elements, [Ge/H] = [Fe/H], while the solid line shows the derived correlation [Ge/H] = [Fe/H] – 0.79. (right) Correlation between the abundance ratios [Ge/Fe] and [Eu/Fe] – obtained with ground-based observations by Simmerer et al. (2004). The dashed line indicates a direct correlation between Ge and Eu abundances. As in the previous figure, the arrow represents the derived upper limit for CS 22892-052. The solid line at [Ge/Fe]r – 0.79 is a fit to the observed data.

Similar abundance comparisons with Zr (see Figure 2) show little correlation with either iron or with Eu. The one exception is CS 22892-052, for which [Zr/Fe] is much higher than in, for example, HD 122563. CS 22892-052 also has one of the largest [Eu/Fe] abundances found in halo stars. Our abundance determinations in these target stars, as well as more extensive abundance analyses by Travaglio et al. (2004), suggest n-capture processes are responsible for some of the production of Zr, but that the nucleosynthetic origin of this element is different than that for heavier n-capture elements such as Ba and Eu. There are even some indications that some type of a (lighter element) primary process is also responsible for some fraction of the synthesis of this element, as well as Sr and Y.

We also show in Figure 2 the ratios of [Pt/Fe] as a function of [Eu/Fe] in our sample stars. It is very clear in the figure that there is a direct correlation between the Pt and Eu abundances - indicating a similar origin for both of these n-capture elements. Os and Ir abundance detections also show a similar pattern with metallicity and demonstrate a correlation between Os, Ir, Pt and Eu. Our very-heavy-element abundance comparisons strongly suggest a similar synthesis origin for Eu, Os, Ir, and Pt in the r-process sites that were the progenitors of the observed halo stars.
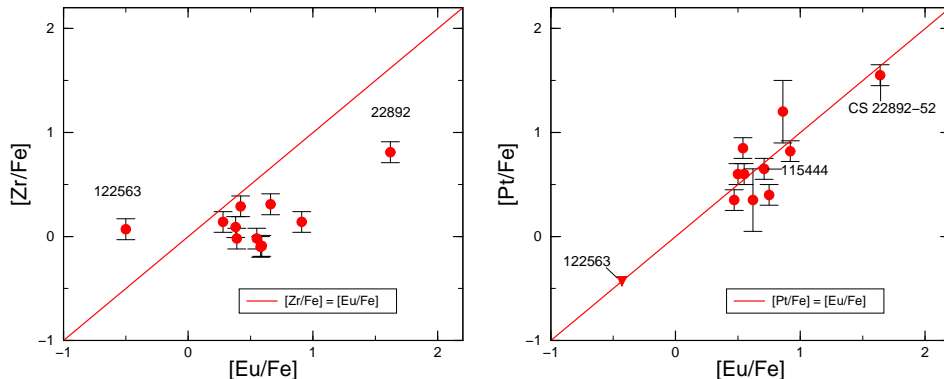
Figure 2.   The ratio of [Zr/Fe] (left) and [Pt/Fe] (right), obtained with HST, is compared to [Eu/Fe] in 11 Galactic halo stars. The abundance data do not show a correlation between Zr and Eu, but clearly do for Pt and Eu.

3.   Galactic Abundance Scatter

Additional abundance comparisons indicate striking differences in the elemental abundance scatter among the elements Ge, Zr, Os, Ir and Pt. We find essentially no scatter in [Ge/H] as a function of [Fe/H] over the metallicity range studied ($-3.1 < $ [Fe/] $ < $ -1.5). The Zr abundances show little scatter with the exception of CS 22892-052. It has been shown previously, however, that [Eu/Fe] shows large scatter, particularly at very low metallicities, early in the history of the Galaxy. Our new 3rd r-process abundance determinations indicate, for the *first* time, that Os-Ir-Pt show a similar abundance scatter, tracking the [Eu/Fe] abundances in these halo stars (Cowan et al. 2004). This is an additional indication that Eu, Os, Ir and Pt have a similar nucleosynthesis origin.

4.   Elemental Abundance Distribution in CS 22892-052

One of the stars in our survey is the well-studied, very metal-poor ([Fe/H] = –3.1) Galactic halo giant CS 22892-052. Our HST and Keck observations have detected the 3rd r-process peak elements Os, Ir and Pt in CS 22892-052. The abundances of these elements fall on the same scaled solar system r-process curve that also matches the abundances of the rare-earth elements (Sneden et al. 2003) such as Eu, as shown in Figure 3. This re-emphasizes the common origin for all four elements. The detailed elemental abundance distribution for this star employs the new atomic experimental data for Pt (Den Hartog et al. 2004) and more reliable determinations for Nd (Den Hartog et al. 2003) and Ho (Lawler, Sneden, & Cowan 2004). The solar system curve (solid line in Figure 3) was determined based upon the classical s-process model and utilizing the most recent r-/s-process deconvolution (Simmerer et al. 2004).

While it is clear from the figure that abundances of the elements from Ba (Z=56) through the 3rd r-process peak are all consistent with the solar r-process abundances, the lighter n-capture elements – including upper limits for Ga and Ge – in general fall below that same solar curve. This might indicate
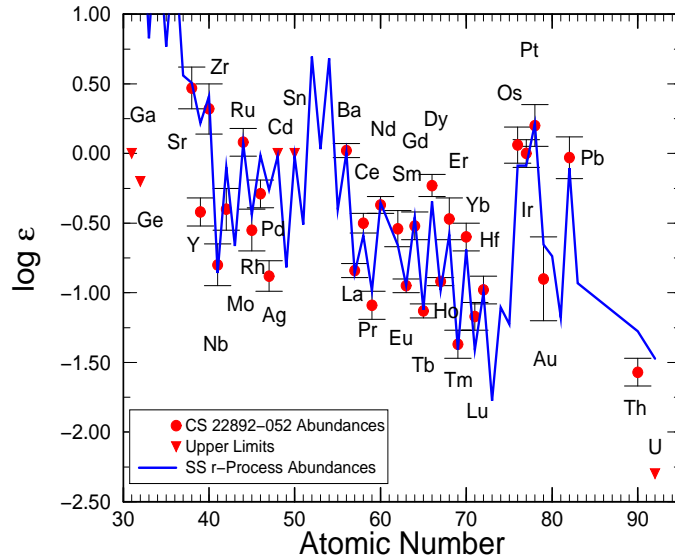
Figure 3.   The neutron-capture elemental abundance pattern in the Galactic halo stars CS 22892–052 compared with the (scaled) solar system *r*-process abundances (solid line).

two different sets of conditions, or perhaps separate sites, for the synthesis of the heavier and lighter *n*-capture elements (see further discussion in Sneden & Cowan 2003). We note that the new HST Zr abundances are consistent with previous ground-based determinations (Sneden et al. 2003) for this element.

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