Halo Star Abundances and Heavy Element Nucleosynthesis

J. J. Cowan[1], *C. Sneden*[2]

[1] *Department of Physics & Astronomy, University of Oklahoma, Norman, OK 73019*
[2] *Department of Astronomy and McDonald Observatory, University of Texas, Austin, TX 78712*

1.1 Introduction

Abundance observations of neutron-capture elements in halo stars are providing a wealth of new information on the nature of heavy element nucleosynthesis in evolved stars. In particular these observations provide clues and constraints to the synthesis mechanisms for the n-capture elements, suggestions for the site (or sites) for the r-process and Galactic chemical evolution. We have been obtaining such stellar abundance data both with ground-based telescopes and recently with the Hubble Space Telescope (HST). We present a small sample of the results of our new observations, along with some preliminary analysis, in this short proceedings paper. A more complete listing of the new HST abundance data and more detailed analyses will be forthcoming in Cowan *et al.* [1].

1.2 n-Capture Observations and the r-Process

We show in Figure 1 the latest observations of the well-known r-process-rich Galactic halo star CS 22892−052 [2], along with a scaled solar system r-process abundance distribution (solid line). A total of 57 elements (52 detections and five upper limits) have been observed in CS 22892−052 – more than in any other star except the Sun. As has been noted previously, the agreement between the heavier n-capture elements (Ba and above) and the solar r-process abundances is quite striking [3, 4]. This agreement has been expanded and strengthened with our new HST observations of the 3$^{\rm rd}$ r-process peak elements Os and Pt in CS 22892−052. More accurate and reliable abundance determinations have also been obtained for the elements Nd [5] and Ho [6] as a result of new atomic physics data. Ga and Ge are not observable from the ground and necessitated the HST. While attempts to detect these elements in CS 22892−052 were unsuccessful, meaningful upper limits were established (see Figure 1). Those abundance limits fall far below the solar system r-process curve and suggest that the synthesis of Ga and Ge may be different than that (for example) of the rare-earth elements, and may be tied to the (very low) stellar iron abundance.

The agreement between the solar system r-process curve and the heavy ($Z \geq 56$) elemental abundances in CS 22892−052 has now been seen in several other halo stars [7], and suggests a robust r-process operating over many billions of years. It also implies a well-defined range of astrophysical conditions (*e.g.*, neutron number densities) and/or that not all supernovae are responsible for the r-process – instead perhaps only a narrow mass range. We note, however, that the well-studied stars showing this pattern are all r-process-rich and much less is know about r-process-poor stars, such as HD 122563.

What has not been as well explored in the halo stars is the elemental abundance regime of $Z = 40$-50. The new data for CS 22892−052, along with some very sparse data in several other

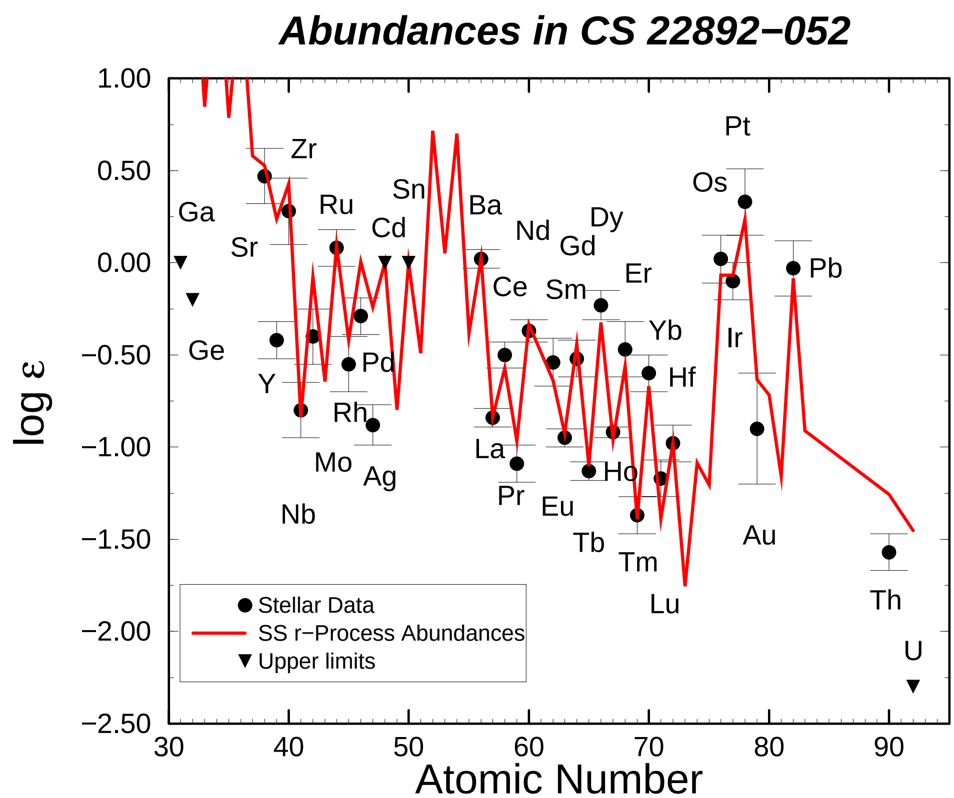

Figure 1: n-capture elemental abundances in CS 22892−052 compared to a (scaled for metallicity) solar system r-process abundance curve (solid line).

stars, apparently indicate a different abundance pattern between the elements in this regime and those for Ba and above. Thus we see in Figure 1 that the elements from Z = 40-50, in general, fall below the same curve that fits the heavier (upper) end of the n-capture element distribution. This seems to suggest different synthesis sources or origins for the two different ranges of n-capture elements. These results strengthen earlier suggestions of two r-process sites for the lighter and heavier n-capture elements [8]. Those two sites could be different mass ranges or frequencies of supernovae [9] or perhaps a combination of supernovae and neutron-star binary mergers. Alternatively, all of the n-capture elements might be synthesized under different sets of conditions in the same core-collapse supernova (see Cowan and Sneden [6] and references therein for further discussion).

We note in Figure 1 that the elements Sr and Zr appear to lie on the solar r-process curve for CS 22892−052, while Y does not. Extensive observations of these elements versus metallicity in other stars indicates that the nucleosynthetic origin of Sr-Y-Zr is different than heavier elements such as Ba [10]. Furthermore, there is a possibility that a primary process – tentatively identified as a lighter element primary process (LEPP) [10] – might be responsible for some fraction of the synthesis of each of these three elements.

1.3 Abundance Trends in Halo Stars

Our new HST abundance observations of a sample of 11 halo stars have provided new information not previously attainable concerning both the very light n-capture elements (such as Ge) and the 3rd r-process peak elements including Pt and Os. While Ge was not detected in CS 22892−052 it was found in many of the other target stars. Zr was also detected in these stars using HST. The results of those observations will be forthcoming [1]. We show here the elemental abundance trends of [Pt/Fe] and [Os/Fe] with respect to [Eu/Fe] in Figure 2. The consistency between the solar system curve and the halo star abundances (for the elements from Ba and above) has, in the past, mostly been predicated on the rare-earth elements detected from the ground. Now with the HST detections of elements such as Os and Pt – with dominant spectral transitions in the near UV – that agreement seems to extend through the 3rd r-process peak. We see a direct comparison of these two latter elements with the r-process element Eu – the abundances of this element were obtained with ground-based observations [11]. It is clear in Figure 2 that the abundances of both Pt and Os seem to be correlated – there is a 45% angle straight-line relationship – with Eu in these metal-poor halo stars. This strongly suggests a similar synthesis origin for all three of those n-capture elements in the halo star progenitors.

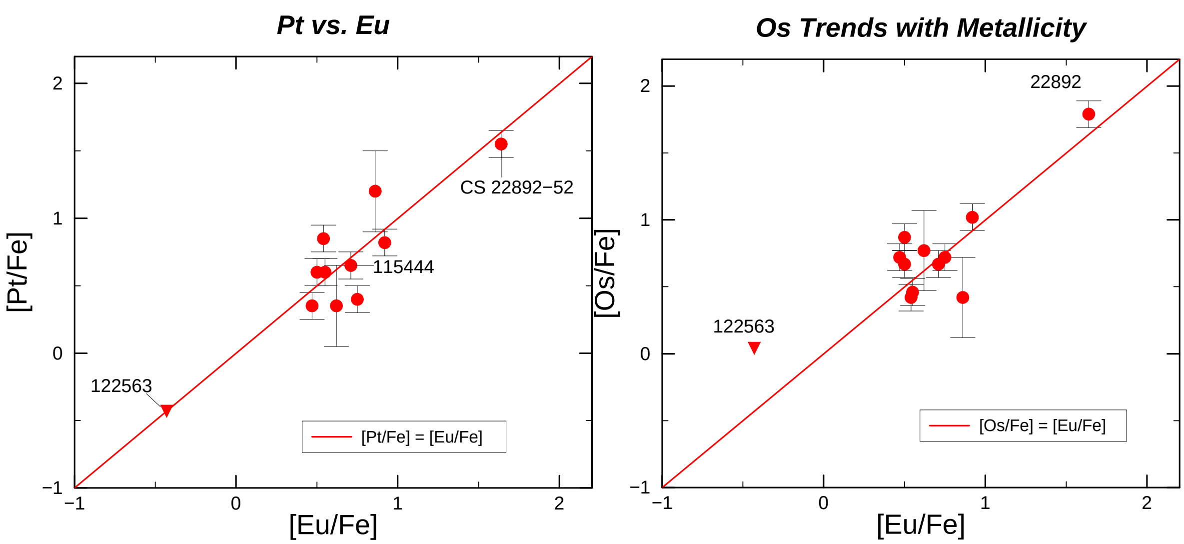

Figure 2: Abundance correlation between [Pt/Fe] (left panel) and [Os/Fe] (right panel) and [Eu/Fe].

Acknowledgments

We thank our collaborators for their contributions to this work. This research has been supported in part by NSF grants AST-9986974 and AST-0307279 (JJC), AST-9987162 and AST-0307495 (CS), and by STScI grants GO-8111 and GO-08342.

References

[1] J.J. Cowan et al., *Ap. J.* (2004) in preparation.

[2] C. Sneden et al., *Ap. J.* **591** (2003) 936.

[3] J.W. Truran, J.J. Cowan, C.A. Pilachowski and C. Sneden, *PASP* **114** (2002) 1293.

[4] C. Sneden and J.J. Cowan, *Science* **299** (2003) 70.

[5] E.A. Den Hartog, J.E. Lawler, C. Sneden and J.J. Cowan, *Ap. J. Supp.* **148** (2003) 543.

[6] J.J. Cowan and C. Sneden, astro-ph/0309802, To appear in *Carnegie Observatories Astrophysics Series, Vol. 4: Origin and Evolution of the Elements*, ed. A. McWilliam & M. Rauch (Cambridge: Cambridge Univ. Press) (2004).

[7] J.E. Lawler, C. Sneden and J.J. Cowan, *Ap. J.* **608** (2004) 850.

[8] G.J. Wasserburg, M. Busso and R. Gallino, *ApJ* **466** (1996) L109.

[9] G.J. Wasserburg and Y.-Z. Qian, *Ap. J.* **529** (2000) L21.

[10] C. Travaglio et al., *Ap. J.* **601** (2004) 864.

[11] J. Simmerer et al., *Ap. J.* (2004) submitted.