# GHRS Observations of Neutron-Capture Elements in Metal-Poor Halo Stars

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**Abstract.** We examine and compare the abundance levels in metal-poor halo stars of elements produced in the rapid neutron capture process (*i.e.* *r*-process) and the slow neutron capture process (*i.e.* s-process). Using the Goddard High-Resolution Spectrograph (GHRS) of the Hubble Space Telescope (HST), we have detected the very heavy elements osmium and platinum (predominantly synthesized in the *r*-process), and lead (produced by a combination of s- and *r*-processes) in the metal poor giant HD 126238 ([Fe/H] = −1.7) and Os and Pt in HD 115444 ([Fe/H] = −2.7). These are the first such detections of "3$^{\rm rd}$ n-capture-peak" elements in Galactic halo stars. Upper limits on the abundances of these same elements in the metal-poor star HD 122563 ([Fe/H] = −2.7) are also reported. We compare and contrast the spectra and abundances in HD 115444, with elevated n-capture levels, with that of the similarly metal-poor HD 122563 which has a depressed level. GHRS detections of Zr in these same 3 metal-poor halo stars are also reported and compared.

## 1. Introduction

Spectral observations indicate the presence of heavy elements, produced in neutron capture processes (*i.e.* the s(low)-process and the r(apid)-process), in metal-poor, old Galactic halo stars. Since the halo stars were formed early in the history of the Galaxy out of ejecta from a previous generation of stars, these observed heavy element abundances can be used to determine the initial Galactic conditions and nature of the nucleosynthetic processes at the time of the formation of the Galaxy. While observational and theoretical studies (Truran 1981; Sneden and Parthasarathy 1983; Gilroy *et al.* 1988; Sneden *et al.* 1988; Gratton and Sneden 1991) have demonstrated that *r*-process production occurred early in the history of the Galaxy, it has been difficult to accurately assess the nature and extent of such processing and the nature of the earliest generations of Galactic stars. Two of the primary difficulties were, first, the inability to determine accurately the abundances in the halo stars due to extremely weak spectral lines in these old, metal-poor stars. Secondly, only a small number of elements had been

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detected, principally due to the fact that the important heavy elements (with mass numbers A $\sim$ 200), comprising the third (and most massive) solar system $r$-process peak are not (in general) detectable using ground-based observations. Recently, however, the ultra-metal-poor ([Fe/H] = $-3.1$), but neutron-capture-rich star CS 22892-052 has been extensively observed (see Sneden *et al.* 1996a). These high resolution, high signal-to-noise spectra have been used to determine the abundances of 20 heavy elements. Some of the detected elements (such as terbium, holmium, thulium and hafnium) had never previously been detected in such metal-poor halo stars.

The analyses of CS 22892-052 have been based upon ground-based data. In addition, with the exception of the relatively uncertain Os abundance, most of the elements detected in this star (and all the others) have been in the rare-earth region, and not part of the dominant solar $r$-process regions (*i.e.* the $r$-process peaks). Recently we have used the GHRS of the HST to observe the heavy elements in several metal-poor halo stars including HD 126238, HD 122563 and HD 115444 (Cowan *et al.* 1996a, Sneden *et al.* 1996b). While the elements Os, Ir and Pt define one of the three major $r$-process peaks seen in the solar system abundances, they mostly have spectral lines in the ultraviolet, with wavelengths near 3000 Å, and are in general inaccessible from ground-based observations.

## 2. Observations

During HST Cycle 5, we obtained GHRS spectra of HD 126238 of three spectral regions containing low excitation neutral species transitions of Pt, Ir, Os and Pb. These followed acquisition of similar spectra of HD 122563 in HST Cycle 4. We are currently observing HD 115444 during Cycle 6. A detailed discussion of spectrograph parameters, reduction procedures, and analysis techniques will appear in Sneden *et al.* (1996b). Briefly, the GHRS (whose operating characteristics have been discussed extensively by Gilliland (1992) was configured with the low-order grating G270 and the "small science" spectrograph entrance aperture, and for each observation a sub-stepping pattern of four slightly shifted grating positions per detector diode was employed. The spectra each spanned wavelength ranges of approximately 46 Å, and had central wavelengths of $\lambda$2832, 2913, and 3059 Å. The resolving power of each reduced spectrum was R $\simeq$ 32,000 as determined by inspection of calibration lamp spectra, and the signal-to-noise was S/N $\sim$ 70.

On these spectra we detected two Os I lines ($\lambda\lambda$2838.61, 3058.65 Å), two Pt I lines ($\lambda\lambda$2929.79, 3064.71 Å), and one Pb I line ($\lambda$2833.05 Å) in HD 126238. None of these transitions was visible on our HD 122563 spectra. In HD 115444, we also detected osmium and platinum. The Zr line at $\lambda$ 3060 was detected in all three stars. We illustrate this in Figure 1, comparing an Os I and a Zr II line in the three stars.

## 3. Results and Discussion

Our HST observations of the giant star HD 126238 ([Fe/H] = $-1.7$) indicate the presence of platinum, osmium and lead. With only one spectral region obtained

Figure 1. Comparison of GHRS spectra of HD 122563 ([Fe/H] = −2.7), HD 115444 ([Fe/H] = −2.7) and HD 126238 ([Fe/H] = −1.7) in the spectral region near Os I $\lambda$3059 and Zr II $\lambda$3060 .

thus far, we have also detected Os and Pt in HD 115444 ([Fe/H] = −2.7). These are the first such detections of "3$^{\rm rd}$ n-capture-peak" elements in Galactic halo stars. Figure 1 illustrates the differences in the spectra and abundances in HD 115444, with elevated n-capture levels, with that of the similarly metal-poor HD 122563 which has a depressed level. We note the Os line present in the former star while no line is visible in the latter. We also note the strong Os line seen in the more metal-rich star HD 126238. The elemental abundances of Os and Pt in HD 126238 are consistent with solar *r*-process abundances, when scaled for the lower metallicity of this star (Cowan *et al.* 1996a). Upper limits on the abundances of these same elements in the metal-poor star HD 122563 ([Fe/H] = −2.7) and the initial abundance detections of Os and Pt in HD 115444 are also consistent with solar *r*-process abundances (Sneden *et al.* 1996b, Cowan *et al.* 1997).

These three metal-poor halo stars, along with the ultra-metal-poor star CS 22892-052 were formed early in the history of the Galaxy, and all are thus quite old. The space-based (and ground-based) observations and analyses of the neutron-capture elements (for Z > 55) in these stars (and others) strongly suggest that the basic mechanism of *r*-process nucleosynthesis has not changed significantly over the history of the Galaxy, and thus, that the solar system *r*-process abundances could not be the average of *r*-process products from a number of different environments (see Cowan *et al.* 1995, 1996a; Sneden *et al.* 1996a). Additionally, the solar system *r*-process only signature observed in the very old star CS 22892-052 confirms that contributions from the *r*-process dominated at the earliest stages of Galactic history. Since the site for the *r*-process is most likely associated with supernovae (see *e.g.* Cowan *et al.* 1991), these results suggest the presence of a generation (or generations) of massive stars, the progenitors of Type II supernovae, early in the history of the Galaxy (see also Cowan *et al.* 1995).

Most of the stellar observations have concentrated on elements with $Z > 56$. Very recently using the GHRS we have detected Zr in the same three metal-poor stars, as illustrated in Figure 1. We note that, consistent with the results of Gilroy *et al.* (1988) based upon ground-based observations, the abundance of Zr is essentially the same in HD 115444 and HD 122563. We also find that the abundance of Zr is much higher in the more metal-rich HD 126238. Future examination of the abundance trends of Zr and elements of similar mass number will help in studying the recent suggestion that lighter n-capture elements may be produced in a different process, or second *r*-process (Wasserburg *et al.* 1996). Future observations will also help in examining the conditions that occurred early in the history of the Galaxy.

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