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r-Process Enhanced Halo Stars

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Abundance observations indicate the presence of rapid-neutron capture (*i.e.*, *r*-process) elements in old Galactic halo and globular cluster stars. These observations provide insight into the nature of the earliest generations of stars in the Galaxy – the progenitors of the halo stars – responsible for neutron-capture synthesis of the heavy elements. The large star-to-star scatter observed in the abundances of neutron-capture element/iron ratios at low metallicities – which diminishes with increasing metallicity or [Fe/H] – suggests the formation of these heavy elements (presumably from certain types of supernovae) was rare in the early Galaxy. The stellar abundances also indicate a change from the *r*-process to the slow neutron capture (*i.e.*, *s*-) process at higher metallicities in the Galaxy and provide insight into Galactic chemical evolution. Finally, the detection of thorium and uranium in halo and globular cluster stars offers an independent age-dating technique that can put lower limits on the age of the Galaxy, and hence the Universe.

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1. Introduction

Neutron-capture elements are present in some of the oldest, most metal-poor (*i.e.*, low iron abundance) Galactic halo stars. These elements are synthesized in either the slow (*s*) or rapid (*r*) neutron-capture process in generations of stars preceding the halo stars[1, 2]. The abundances of these *n*-capture elements, particularly where they are enhanced in the Galactic halo stars, are being employed to provide clues and constraints on a number of topics. These topics include the nature of the synthesis and the identities of the stellar generations - those that preceded the halo stars - in the early Galaxy. The stellar abundances are also providing new insight into the astrophysical site (or sites) for *r*-process nucleosynthesis. The *s*-process seems to be identified in asymptotic giant branch (AGB) stars [3]. However, the astrophysical site for the *r*-process has not been determined, although it is likely in a supernova environment[4]. Neutron-capture abundance determinations in a wide variety of stars are also helping in understanding the nature of, and the trends in, Galactic chemical evolution. The detections of the long-lived radioactive elements, such as thorium and uranium, provide direct chronometric age determinations for the oldest stars, which in turn place constraints on age estimates for the Galaxy and the Universe.

2. n-Capture Element Abundances in the Halo Stars

Comprehensive, high resolution abundance studies have been made for a number of *r*-process enhanced halo stars, including CS 22892-052[5], BD +17°3248[6], HD 115444[7], CS 31082-001[8] and HD 221170[9].

2.1 Dependence Upon Atomic Data

The stellar abundance determinations depend critically upon the atomic data. We illustrate this in Figure 1. In the left panel we show the abundances from Ba-Er, based upon previously published atomic data, for the metal-poor halo stars CS 22892-052[5], BD +17°3248[6], HD 115444[7] and the Sun[10]. The abundances are scaled with respect to the *r*-process element Eu. The solid horizontal line is given by $\log\varepsilon(X)_{observed}$- $\log\varepsilon(X)_{S.S.(r-only)} = 0$. The *r*-process-only values are determined by the deconvolution of the solar abundances into individual *s*- and *r*-process contributions[11, 12]. We focus on the abundance determinations for Nd, Sm, Gd and Ho in these four stars. It is clear in the (left panel of the) figure that there is a large amount of scatter for those elements, using the previously published atomic data. The right panel of Figure 1 shows the revised stellar and solar abundances employing new atomic data. There has been a concerted effort in the last decade to place these data on a firm, experimental basis. Newly measured values, particularly transition probabilities, have been obtained for the elements: Nd[13], Ho[14], Pt[15], Sm[16, 17], and Gd[18]. It is clear from the figure that as a result of employing these newly revised atomic data, the abundance scatter for the elements Nd, Ho, Sm and Gd has been dramatically reduced. This indicates that the relative abundances of these elements are the same in all of these metal-poor halo stars. We note further that the abundances of *all* of the *n*-capture elements in the three stars are consistent with the SS *r*-process-only abundances – the stellar abundance values fall close to the solid horizontal line $\log\varepsilon(X)_{observed}$- $\log\varepsilon(X)_{S.S.(r-only)}$ = 0.

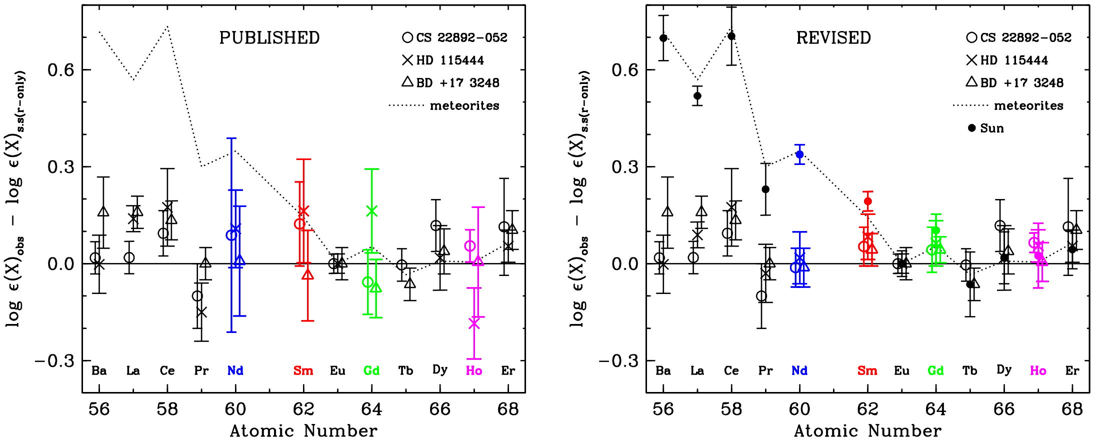

Figure 1: (left) Abundance values (scaled at the element Eu) for selected elements in the stars CS 22892-052 (open circles), HD 115444 (x), BD +17°3248 (triangles) and the Sun (filled circles), based upon previously published atomic data. (right) Newly derived abundance values based upon recent experimental lab data (after [17, 18]).

While the agreement is excellent, there are still some small deviations between the stellar and solar *r*-process abundances. The solar *r*-process values have been obtained as residuals, after first subtracting the *s*-process values from the total Solar System abundances. Since the stellar abundances have become increasingly more reliable, in large part due to the more accurate laboratory atomic data, it may be possible to predict directly the *r*-process abundances, rather than relying on the subtraction of the *s*-process components from the Solar System abundances. This has been attempted recently for the elements Gd, Sm, Nd and Ho[18]. While there are still some uncertainties in the individual values, the technique could be a viable new method of predicting the *r*-process-only contributions to the Solar System abundances.

2.2 Observational Evidence for Two r-Processes in Nature?

Stellar abundances of the enhanced, metal-poor Galactic halo stars have shown a consistently solar *r*-process pattern for the stable elements Ba and above[1, 2]. It has only been in recent years, however, that elemental abundances between Sr-Y-Zr and Ba have been detected in these stars[5]. We illustrate in Figure 2 a summary of the observational data for the five *r*-process enhanced stars CS 22892-052[5] , BD +17°3248[6], HD 115444[7], CS 31082-001[8] and HD 221170[9]. The data have been scaled vertically (except for CS 22892-052) for illustration purposes. A scaled solar system *r*-process only abundance curve (solid line) is superimposed on each set of stellar data. While some of these stars (e.g., HD 115444) have little data between Z=40 and Z=50, most of these lighter *n*-capture element abundances seem to lie somewhat below the solar system curves that fit the heavier *n*-capture data. In particular Ag is below the SS curve in all cases. This seems to suggest a different origin or perhaps a different site for the synthesis of these two groups of *n*-

capture elements, and in particular may support the suggestion (based upon solar system meteoritic data) that there are two *r*-process sites in nature[19]. Whether there are actually two separate supernova sites[20] or just different regions of the same supernova site[21] is still unclear. If there are two sites for this synthesis, it is also unclear at what element the split occurs[22]. Clearly more observational and theoretical studies will be required to better understand the origin of both the lighter and heavier *n*-capture elements.

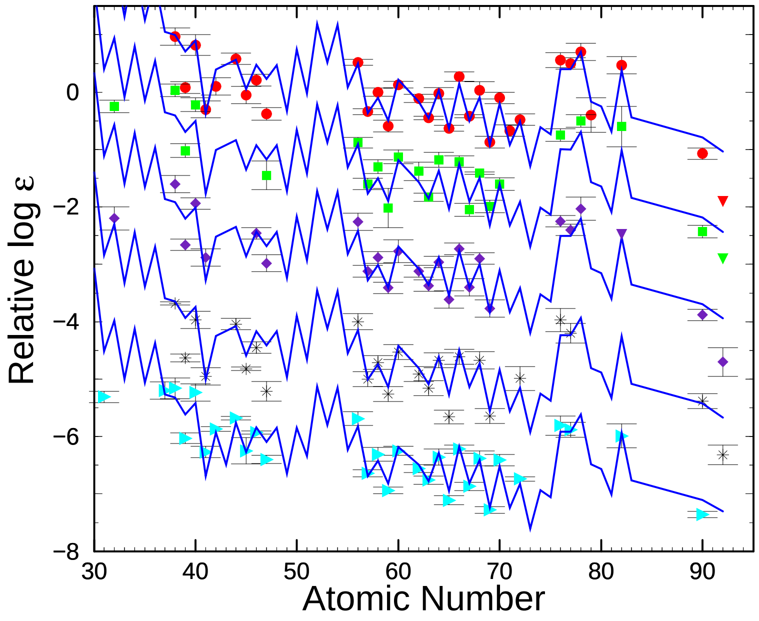

Figure 2: An observational summary of the observed n-capture elements in five r-process rich halo stars: CS 22892-052 (filled circles, [5]), HD 115444 (filled squares,[7]), BD +17°3248 (filled diamonds,[6]), CS 31082-001 (stars,[8]), and HD 221170 (filled triangles,[9]). The vertical scale for the CS 22892-052 abundance set is true, and abundances of all of the other stars have been vertically scaled downward for display purposes. Each of these stellar abundance sets is overlaid with the scaled solar system *r*-process abundance distribution that best fits the observed abundances (solid lines).

3. Chemical Evolution of the Elements

In the last few years observations using the STIS of the HST have opened up the element range available for study in these halo stars. In particular elements such as Ge have their strongest transitions in the UV part of the spectral region, and thus are not available to ground-based observations. A recent survey of this element (along with Zr, Os, Ir and Pt) in a group of 11 metal-poor, *n*-capture enhanced Galactic halo stars was undertaken[23]. The results are shown for Ge in Figure 3. Surprisingly, it appears that the Ge abundances in these stars correlate with the iron abundance, with a ratio of [Ge/H] $\simeq$ [Fe/H] - 0.8. Since Ge is normally thought of as an *n*-capture element, this behavior seemed initially surprising. It may be, however, that for these most metal-poor stars, some type of charged-particle reactions could be responsible for the earliest Galactic synthesis of Ge[24], before the eventual *s*-process contribution sets in.

Certain chemical evolution trends can be understood with comparisons of *r*- and *s*-process elements as a function of metallicity - very roughly a time relationship. While the (*s*-process) el-

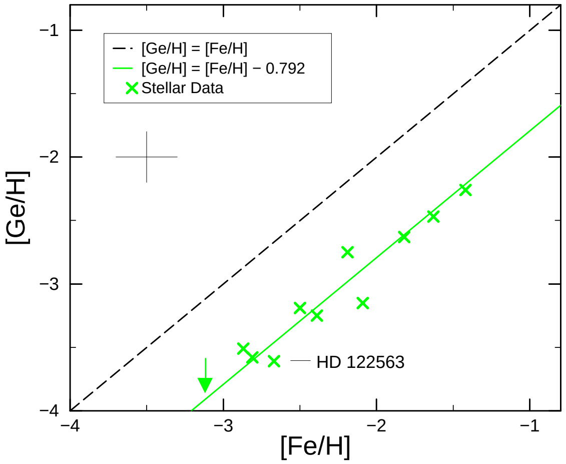

Figure 3: Relative abundances of the elemental ratio [Ge/H] as a function of metallicity (*i.e.*, Fe) for a sample of 11 Galactic halo stars (after [23]). The arrow represents the derived upper limit for CS 22892-052. The dashed line indicates the solar abundance ratio of these elements, [Ge/H] = [Fe/H], while the solid green line shows the derived correlation [Ge/H] = [Fe/H] – 0.79. A typical error is indicated by the cross.

ement Ba has been used in ratio to the (*r*-process) element Eu[25], recent studies have employed La/Eu[11]. We illustrate in Figure 4 the abundances [La/Eu] in a group of Galactic halo[11] (blue circles) and disk[30] (red diamonds) stars as a function of metallicity. Superimposed on the abundance data are predictions for the *r*-process only ratios: dotted line[25], dashed line[27] and long-dashed line[26]. (An additional value would fall between the dashed line and the long-dashed line, based upon a very recent experimental determination of the neutron capture cross section of ^{139}La, S. Marrone, private communication.) The magenta squares in Figure 4 are the *r*-process rich stars CS 22892-052, HD 115444, CS 31082-001 and BD +17°3248. There are several important points worth noting in this figure. The general upward trend in the abundance ratio with increasing [Fe/H] reflects the increased contribution from the *s*-process to La production – lower-mass stars have time to evolve and enrich the interstellar gas with *s*-process-rich ejecta. It is also seen that at very low metallicities some of the ratios of La/Eu appear to lie above the *r*-process only value. This suggests some *s*-process contributions even at very low metallicities and, presumably, early Galactic time. However, the onset of the bulk Galactic *s*-process nucleosynthesis occurs at somewhat higher metallicity, but still below [Fe/H] = –2[25, 11]. Exactly where this main *s*-process production begins – with implications for the identities of the (mass ranges of) sites and nature of *s*-process synthesis – depends upon the value of the *r*-process only ratio of La/Eu. This illustrates the critical nature and importance of the nuclear experimental data with regard to the neutron cross-section measurement of ^{139}La, which in turn determines the *s*- and *r*-process components for this element.

Additional information regarding the synthesis in the earliest generations of stars can be obtained by comparing elemental production as a function of metallicity. We illustrate this behavior for Eu and Mg in a group of Galactic halo and disk stars in Figure 5[2]. The large scatter in the Eu/Fe abundance at very low metallicities suggests that the Galaxy was chemically inhomogeneous (*i.e.*, unmixed) in *n*-capture elements at early times. At later times, and higher metallicities, this scatter diminishes. In contrast the (α-element) Mg abundance data[28, 29] does not show this scatter. These abundance comparisons suggest that *r*-process synthesis (whatever the site) was a

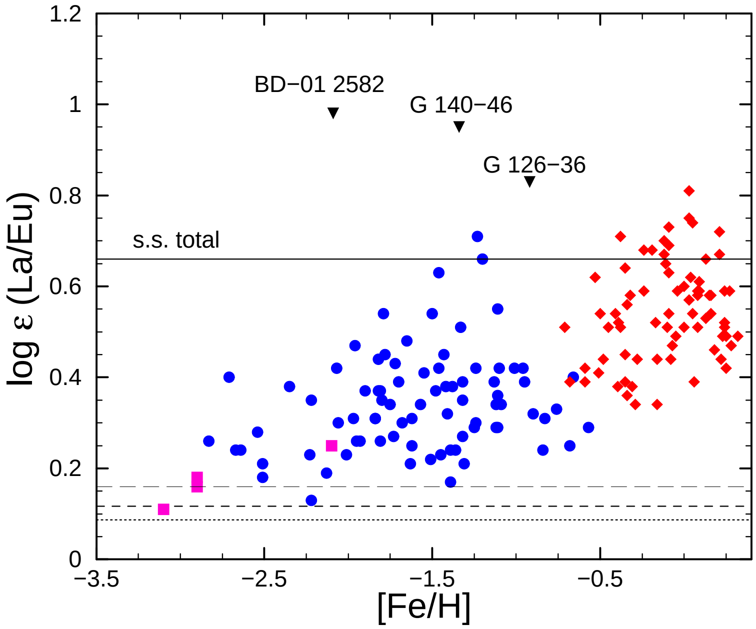

Figure 4: Abundance trends with respect to metallicity for the elemental ratio La/Eu in a large number of halo (blue circles) and disk stars (red diamonds) in our Galaxy (after [11]). The long-dashed[26], dashed[27] and dotted[25] lines are predictions for *r*-process only ratios by different investigators, and the solid line is the total Solar System abundances. The labeled stars are all *s*-process rich. The magenta squares are well-studied *r*-process enhanced stars.

relatively rare event, while Mg production must have been more common at early Galactic times. These comparisons further suggest possibly different sites for the major Eu and Mg synthesis. Since Mg is commonly thought to be produced in massive stars, Eu might instead be synthesized in less massive stars that become supernovae[4].

4. Chronometers

The detection of Th, with its very long half-life, allows for chronometric estimates for the ages of the halo stars. The preferred chronometer pair for these age determinations is U/Th, since both elements are made entirely in the *r*-process and they are nearby in mass number (see discussions in [1, 4, 2]). U/Th has been employed to determine the ages of CS 31082-001 (12.5 ± 3 Gyr,[32]; 14 ± 2.4 Gyr[8], ; 15.5 ± 3.2 Gyr[31], 14.1 ± 2.5 Gyr[34],) and BD +17°3248 (13.8 ± 4 Gyr[6]). However, uranium (with its low abundance and frequent spectral blending with molecules) is difficult to detect in most stars.

Despite being widely separated in mass number from Th, Eu is easily detected with ground-based observations and made almost entirely in the *r*-process[11]. For these reasons chronometric age estimates based upon the Th/Eu ratio have been made for a number of halo stars, typically with age ranges of 11–15 Gyr [33, 36, 37, 38, 7, 35, 6, 5, 9] and with average age uncertainties $\simeq$ 3-4 Gyr. This approach has also yielded a similar age for one globular cluster[39]. These stellar values are also consistent with age determinations for the Galaxy based upon main-sequence turn-

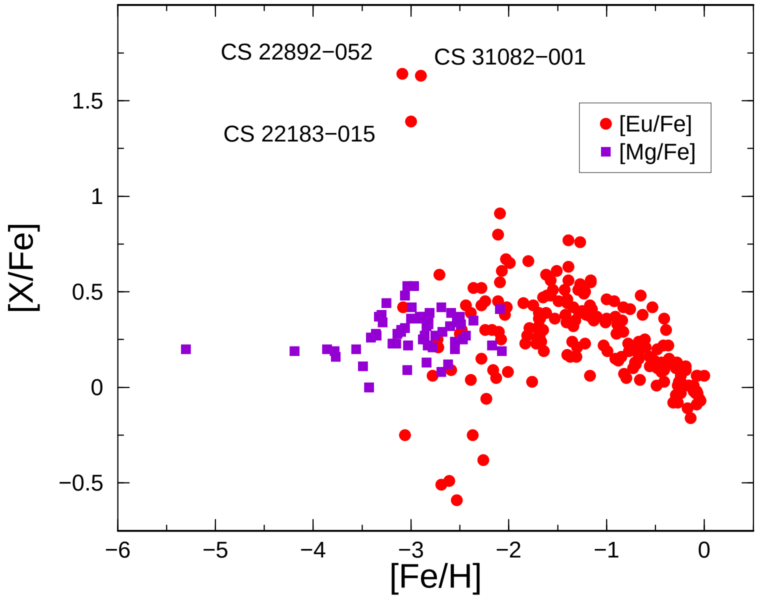

Figure 5: Abundance scatter of elemental ratios [Eu/Fe] ([11, 30]) and [Mg/Fe] ([28, 29]) versus metallicity for samples of halo and disk stars in our Galaxy (after [2])

off ages for globular clusters[40] and recent cosmological age estimates from WMAP[41] and Type Ia SNe[42, 43].

We note, however, that the chronometric age estimates depend sensitively upon the initial predicted values of Th/Eu, which in turn depend on the nuclear mass formulae and *r*-process models employed in making those determinations (see discussion in [31, 44]). We also note that in at least one case, the chronometer ratio Th/Eu does not appear to be usable. While the abundances of the stable elements (through the 3^{rd}*r*-process peak) in CS 31082-01 are consistent with the scaled solar system *r*-process distribution, Th and U are enhanced with respect to the other *n*-capture elements[8, 31]. Thus, in this star the Th/Eu chronometer leads to unreasonably low age determinations, while the U/Th ratio predicts an age consistent with other ultra metal-poor halo stars. However the lead abundance[45], which predominantly results from α decay of Th and U isotopes, in CS 31082-01 seems to be too low with respect to such high abundance values of these radioactive elements[46]. Clearly, additional observational and theoretical studies of this star, and others with enhanced Th and U abundances, will be needed to better understand and further refine the chronometric age determinations.

5. Conclusions

Abundance studies of the old, metal-poor Galactic halo stars are providing a wealth of data and information regarding the nature of early nucleosynthesis and the identities of the earliest stellar generations. New clues to the site of the *r*-process are also coming from such studies. Comparisons of the abundance levels in these stars, with respect to younger and more metal-rich Galactic stars, provides insight into the history of chemical evolution in the Galaxy. In particular the influence, and period of onset, of *s*-process nucleosynthesis in the Galaxy are seen in these comparisons. The detection of the radioactive elements (such as Th and U) provides a technique to determine the ages of the oldest stars, which will help to determine the age of the Galaxy and the Universe.

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References

[1] Sneden, C. & Cowan, J. J. The genesis of the heaviest Elements in the Milky Way galaxy. *Science* **299**, 70-75 (2003).

[2] Cowan, J. J. & Sneden, C. Heavy element synthesis in the oldest stars and the early universe. *Nature* **440**, 1151 (2006).

[3] Busso, M., Gallino, R. & Wasserburg, G. J. Nucleosynthesis in asymptotic giant branch stars: Relevance for galactic enrichment and solar system formation. *Ann. Rev. Astron. Astrophys.* **37**, 239-309 (1999).

[4] Cowan, J. J. & Thielemann, F.-K. R-process nucleosynthesis in supernovae. *Phys. Today.* **57**, 47-53 (2004).

[5] Sneden, C., *et al.* The extremely metal-poor neutron capture-rich star CS 22892-052: A comprehensive abundance analysis. *Astrophys. J.* **591**, 936-953 (2003).

[6] Cowan, J. J., *et al.* The chemical composition and age of the metal-poor halo star BD +17°3248. *Astrophys. J.* **572**, 861-879 (2002).

[7] Westin, J., Sneden, C., Gustafsson, B., & Cowan, J.J. The r-process enriched low-metallicity giant HD 115444. *Astrophys. J.* 530, 783-799 (2000).

[8] Hill, V., *et al.* First stars. I. The extreme r-element rich, iron-poor halo giant CS 31082-001. Implications for the r-process site(s) and radioactive cosmochronology. *Astron. Astrophys.* **387**, 560-579 (2002).

[9] Ivans, I., Simmerer, J., Sneden, C., Lawler, J. E., Cowan, J. J., Gallino, R. & Bisterzo, S. Near-UV observations of HD 221170: New insights into the nature of *r*-process-rich stars. *Astrophys. J.* **645**, 613-633 (2006).

[10] Lodders, K. Solar System Abundances and Condensation Temperatures of the Elements. *Astrophys. J.* **591**, 1220-1247 (2003).

[11] Simmerer, J., Sneden, C., . Cowan, J. J., Collier, J., Woolf, V. & Lawler, J. E. The rise of the s-process in the Galaxy. *Astrophys. J.* **617**, 1091-1114 (2004).

[12] Cowan, J. J., Lawler, J. E., Sneden, C., Den Hartog, E. A. & Collier, J. Nucleosynthesis: Stellar and Solar Abundances and Atomic Data. To appear in the *Proceedings of the NASA Laboratory Astrophysics Workshop* ed. V. Kwong (2006)

[13] Den Hartog, E. A., Lawler, J. E., Sneden, C., & Cowan, J. J. Improved laboratory transition probabilities for Nd II and application to the neodymium abundances of the Sun and three metal-poor stars. *Astrophys. J. Supp.*, **148**, 543-566 (2003).

[14] Lawler, J. E., Sneden, C., & Cowan, J. J. Improved atomic data for Ho II and new holmium abundances for the Sun and three metal-poor halo stars. *Astrophys. J.* **604**, 850-860 (2004).

[15] Den Hartog, E. A., Herd, T. M., Lawler, J. E., Sneden, C., Cowan, J. J., & Beers, T. C. Improved laboratory transition probabilities for Pt I and application to the Platinum abundances of BD +17 3248 and the Sun. *Astrophys. J.*, **619**, 639-655 (2005).

[16] Biémont, E., Grevesse, N., Hannaford, P., & Lowe, R. M. Lifetimes in SM II and the solar abundance of samarium *Astron. & Astrophys.* **222**, 307-310 (1989).

[17] Lawler, J. E., Den Hartog, E. A., Sneden, C., & Cowan, J. J. Sm transition probabilities and abundances. *Astrophys. J. Supp.*, **162**, 227-260 (2006).

[18] Den Hartog, E. A., Lawler, J. E., Sneden, C., & Cowan, J. J. Gd transition probabilities and abundances. *Astrophys. J. Supp.*, in press (2006)

[19] Wasserburg, G. J., Busso, M. & Gallino, R. Abundances of actinides and short-lived nonactinides in the interstellar medium: diverse supernova sources for the r-processes *Astrophys. J.* **466**, L109-L113 (1996).

[20] Wasserburg, G. J. & Qian, Y.-Z. Prompt iron enrichment, two r-process components, and abundances in Very Metal-Poor Stars. *Astrophys. J.* **529**, L21-L24 (2000).

[21] Cameron, A.G.W. Some properties of r-process accretion disks and jets *Astrophys. J.* **562**, 456-469 (2001).

[22] Kratz, K.-L., Pfeiffer, B., Sneden, C., Truran, J. W., & Cowan, J. J. Explorations of the *r*-process: comparisons between calculations and observations of low metallicity stars. *Astrophys. J.*, submitted (2006).

[23] Cowan, J. J., *et al.* Hubble Space Telescope observations of heavy elements in metal-poor galactic halo stars. *Astrophys. J.* **627**, 238-250 (2005).

[24] Frölich, C., *et al.* Neutrino-induced nucleosynthesis of A>64 nuclei The νp-process. astro-ph/0511376, *Phys. Rev. Lett.* **96**, 142502-1–142502-4 (2005)

[25] Burris, D. L., Pilachowski, C. A., Armandroff, T. A., Sneden, C., Cowan, J. J., & Roe, H. Neutron-capture elements in the early Galaxy: Insights from a large sample of metal-poor giants. *Astrophys. J.* **544**, 302-319 (2000).

[26] Winckler, N., Dababneh, S., Heil, M., Käppeler, F., Gallino, R., & Pignatari, M. *Astrophys. J.* **647**, 685 (2006).

[27] O'Brien, S., *et al.* Neutron capture cross section of 139La. *Phys. Rev. C* **68** 035801-035807 (2003).

[28] Cayrel, R., *et al.* First stars V - Abundance patterns from C to Zn and supernova yields in the early Galaxy. *Astron. & Astrophys.*, **416**, 1117-1138 (2004)

[29] Arnone, E., Ryan, S. G., Argast, D., Norris, J. E., & Beers, T. C. Mg abundances in metal-poor halo stars as a tracer of early Galactic mixing. *Astron. & Astrophys.*, **430**, 507-522 (2005)

[30] Woolf, V. M., Tomkin, J. & Lambert, D. L. The r-Process element Europium in Galactic disk F and G dwarf stars. *Astrophys. J.* **453**, 660-672 (1995).

[31] Schatz, H., Toenjes, R., Kratz, K-L., Pfeiffer, B., Beers, T. C., Cowan, J. J., & Hill, V. Thorium and uranium chronometers applied to CS 31082-001. *Astrophys. J.* **579**, 626-638 (2002).

[32] Cayrel, R., *et al.* Measurement of stellar age from uranium decay. *Nature* **409**, 691-692 (2001).

[33] Sneden, C., McWilliam, A., Preston, G. W., Cowan, J. J., Burris, D. L., & Armosky, B. J. The ultra-metal-poor, neutron-capture-rich giant star CS 22892-052. *Astrophys. J.* **467**, 819-840 (1996).

[34] Wanajo, S., Itoh, N., Ishimaru, Y., Nozawa, S., & Beers, T. C. The r-process in the neutrino winds of core-collapse supernovae and U-Th cosmochronology. *Astrophys. J.* **577**, 853-865 (2002).

[35] Johnson, J. A., & Bolte, M. Th ages for metal-poor stars. *Astrophys. J.* **554**, 888-902 (2001).

[36] Pfeiffer, B., Kratz, K.-L., & Thielemann, F.-K. Analysis of the solar-system r-process abundance pattern with the new ETFSI-Q mass formula. *Zeit. fur. Physik. A* **357**, 235 (1997).

[37] Cowan, J. J., Pfeiffer, B., Kratz, K.-L., Thielemann, F.-K., Sneden, C., Burles, S., Tytler, D., & Beers, T. C. r-process abundances and chronometers in metal-poor stars. *Astrophys. J.* **521**, 194-205 (1999).

[38] Sneden, C., Cowan, J. J., Ivans, I. I., Fuller, G. M., Burles, S., Beers, T. C., & Lawler, J. E. Evidence of multiple r-process sites in the early Galaxy: New observations of CS 22892-052. *Astrophys. J.* **533**, L139-L142 (2000).

[39] Sneden, C., Johnson, J., Kraft, R. P., Smith, G. H., Cowan, J. J., & Bolte, M. S. Neutron-capture element abundances in the globular cluster M15. *Astrophys. J.* **536**, L85-L88 (2000).

[40] Krauss, L. M. & Chaboyer, B. Age estimates of globular clusters in the Milky Way: Constraints on cosmology. *Science* **299**, 65-69 (2003).

[41] Tegmark, M., *et al.* Cosmological parameters from SDSS and WMAP. *Phys. Rev. D* **69**, 103501 (2004).

[42] Riess, A. G., *et al.* Observational evidence from supernovae for an accelerating universe and a cosmological constant. *A.J.*, **116**, 1009-1038 (1998).

[43] Perlmutter, S., *et al.* Measurements of Omega and Lambda from 42 high-redshift supernovae. *Astrophys. J.* **517**, 565-586 (1999).

[44] Cowan, J. J. & Sneden, C. Advances in r-process nucleosynthesis. in *Carnegie Observatories Astrophysics Series, Vol. 4: Origin and Evolution of the Elements*, ed. A. McWilliam & M. Rauch (Cambridge: Cambridge Univ. Press), 27–42 (2004).

[45] Plez, B., *et al.* Lead abundance in the uranium star CS 31082-001. *Astron. & Astrophys.* **428**, L9-L12 (2004).

[46] Kratz, K.-L., Pfeiffer, B., Cowan, J. J. & Sneden, C. r-process chronometers. *New Astron. Rev.* **48**, 105-108 (2004).