The Search for New "r-Process Enhanced" Metal-Poor Stars

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I describe the motivations for, and present progress, in a new effort to discover additional examples of very metal-poor stars that exhibit large excesses of r-process elements, relative to solar values, in the halo of the Galaxy.

The extremely metal-poor ([Fe/H] = -3.1) halo giant CS 22892-052 has been shown, by a host of studies, to exhibit large enhancements of the ratios of its neutron-capture elements, e.g., Eu/Fe, that exceed the solar values by factors of 30 or more. In a paper in preparation, Sneden et al. (2002) report measurements or strong upper limits for as many as 57 of the 92 naturally occurring elements in the Periodic Table, the largest number of elements observed in any star other than the Sun. The relative abundances of species in the range $56 < Z < 82$ (i.e., Ba through Pb) in CS 22892-052 is in excellent agreement with a scaled solar pattern, prompting the suggestion that the r-process may leave a unique signature over the long history of Galactic chemical evolution, and hence might be associated with a unique astrophysical process. The measurement of the radioactive species Thorium has allowed the application of cosmo-chronometry techniques that provide strong lower limits on the age of the Galaxy, via the chronometry pair Th/Eu.

The second star shown to exhibit such large enhancements of its r-process elements is the very metal-poor ([Fe/H] = -2.9) giant CS 31082-001, in which Cayrel et al. (2001) measured the abundance of the radioactive species Uranium (as well as Thorium), and established the utility of a new cosmo-chronometry pair, U/Th. However, CS 31082-001 has also been shown (Hill et al. 2002) to exhibit a clear "boost" of the elemental abundances for the actinides, roughly a factor of four above the ratios observed in CS 22892-052, so that application of the Th/Eu chronometry pair appears invalid for this star.

A handful of other, more moderately r-process enhanced very metal-poor stars (e.g., HD 115444 and BD+17:3248, see Cowan et al. 2002), exhibit Th/Eu ratios that are more similar to CS 22892-052 than to CS 31082-001. However, a number of other unpublished studies have claimed the existence of stars with actinides that are more consistent with the "high values" seen in CS 31082-001. Clearly, the Universe has more to tell nuclear astrophysics about the r-process enhancement phenomenon than is known at present.

For convenience, we refer to metal-poor stars that exhibit r-process ratios that fall in the range 3/1-10/1, relative to the solar ratios, as "r-I" stars. Those stars with much larger r-process ratios, in the range 10/1 or more, are referred to as "r-II" stars.

We have initiated a high-resolution "quick survey" of giants with [Fe/H] < -2.5, searching for stars that exhibit clear enhancements of the element Eu, known to originate almost completely in the r-process. This survey is being carried out with the UVES spectrograph on the VLT/Kueyen telescope of the European Southern Observatory (Christlieb et al. Large Programme). The survey technique is to obtain moderate S/N spectra of as many of the targeted objects as possible, using short exposures of typically 15-30 minutes, for metal-poor giants selected from the Hamburg/ESO objective prism survey. On the basis of statistics compiled from previous high-resolution work, we estimate that ~ 3% of giants with [Fe/H] < -2.5 might be r-II stars. Hence, if we manage to observe the total number of targets envisioned, on the order of 300-500, we might expect to identify another 10-15 r-process enhanced giants such as CS 22892-052 and CS 31082-001. The less r-process-enhanced r-I stars appear to be more common by at least a factor of two, so we might expect to identify another 20-30 examples during the course of this survey.

During execution of a pilot project for this survey, completed in the fall of 2001, observations of some 40 [Fe/H] < -2.5 giants from the HES and the HK survey yielded discovery of one additional r-II star, as well as two new r-I stars, so at least for now, our rough estimates of the frequency of the phenomenon appear reasonable. The questions of vital interest for understanding the nature of the astrophysical r-process which we seek to quantify are the following:

- What is the frequency of the r-I and r-II phenomenon amongst very metal-poor stars ?

- Is there a relationship between the frequency of the phenomenon and overall metallicity ? We note that, to date, all r-II stars have [Fe/H] ~ -3.0, while some r-I stars exhibit iron abundances as high as [Fe/H] ~ -2.0.

- Is there a continuous variation in the observed enhancement of r-process elements (in which case the division into r-I and r-II stars is artificial), or do they cluster around specific values ?

With a suitable sized sample of r-I and r-II stars, one might then be able to quantify:

- The dispersion in the pattern of r-process elements, which appears to mimic the solar pattern so well (but is there NO star-to-star variation ?).

- The dispersion in the level of the actinides for r-process-enhanced stars. How unique is the case of CS 31082-001?