How peculiar is the ultra-meta-poor Halo star CS31082-001?

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All elements heavier than Fe are synthesized by neutron-capture and subsequent β-decay, either by the s- or the r-process. The r-process involves extremely neutron-rich nuclei and lacks understanding of nuclear physics input as well of a common consensus on the astrophysical conditions. As huge neutron-fluxes are required, cataclysmic events such as Supernovae of type II or neutron-star mergers are discussed as sites of the r-process.

The recent discovery of the rare class of ultra-metal-poor (UMP) r-process element enriched Halo stars yielded a major step forward in the understanding of the r-process. These ancient stars were formed from the collaps of interstellar gas clouds which had been "contaminated" with heavy elements by only a few explosive events. The precursors had been massive stars with short lifetimes. Therefore, the elemental abundances in these stars originate only from the r-process. Until now, about half a dozen of these stars have been studied with high-resolution spectrometers.

Surprisingly, all of these stars display a common pattern of the abundance distribution for heavy elements ranging from Ba up to the Pt-Ir region, a pattern identical to the r-process residues in the Solar system. For 38≤Z≤47, the UMP stars show underabundances compared to Solar, indicating to a 2^{nd} weak r-process. An example is the star CS22892-052 [1, 2]. As had been shown in [3], also the abundances of the actinide element Th and the endpoint of the natural α-decay chains Pb can consistently be reproduced assuming an age of around 13 Ga (see Fig. 1).

Another UMP star, CS31082-001 [4, 5], shows two major differences. Compared to the rare-earth elements in the other stars, Th and U are overabundant by a factor 2.5. At the same time, the reported Pb abundance is far too low [6]. Some authors take these differences to question in principle the hypothesis that there exists one robust r-process mechanism, at least for elements beyond Ba (see, e.g. [7]).

The calculations in [3] were based on the site-independent "waiting-point" concept [8]. In this model, nuclear structure as well as astrophysical input parameters can be varied easily. The calculations applied a "classical" parameter set used for reproducing the abundances in UMP stars [1]. For CS22892-052, the abundances are obtained as a superposition of components with neutron-densities in the range 10^{23} to $3{\cdot}10^{27}$ cm^{-3}. The enhanced abundances of the heaviest elements in CS31082-001 could be an indication to higher neutron fluxes. We performed calculations with densities in the range $3{*}10^{23}$ to 10^{30} cm^{-3}. As can be seen in Fig. 1, the observed abundances of elements with Z $\geq$ 56 can be reproduced with one exception: Pb.

Therefore, one has to consider alternative explanations for the high Th and U contend. A possibility would be a later transfer of r-process material from a more massive companion star with shorter lifetime. These additional actinoides would not yet have contributed to the Pb abundance. But there are no indications to a binary system.

Although this star rests peculiar, there is no need to question the general mechanism of a robust and unique r-process for elements above the 2^{nd} abundance peak.

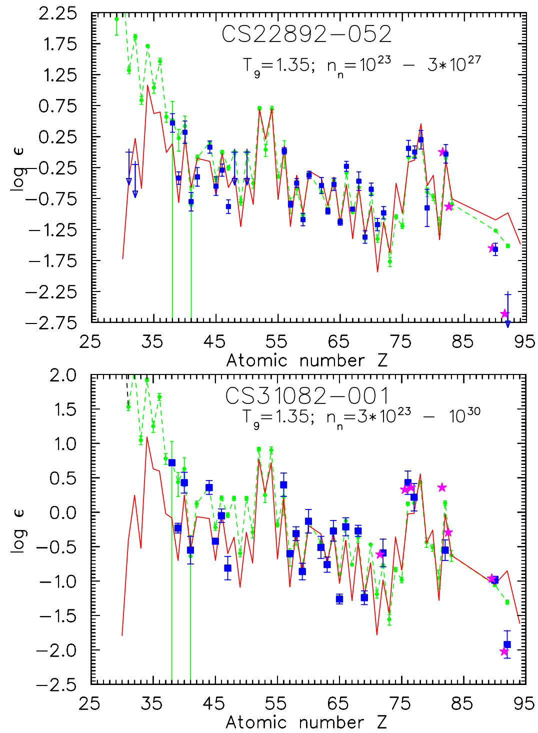

Figure 1: Observed neutron-capture elemental abundances (squares) in the UMP stars CS22892-052 (upper part) and CS31082-001 (lower part) compared to scaled $N_{r,\odot}$ values (dots) and the calculated r-abundance (full line). The calculated abundances for the actinides and the lead isotopes after 13 Ga are indicated by stars (from [3]).

References

[1] J.J. Cowan et al., ApJ 521 (1999) 194.

[2] C. Sneden et al., ApJ 591 (2003) 936.

[3] B. Pfeiffer and K.-L. Kratz, Ann. Rep. Kernchemie, Mainz, (2004) A17.

[4] V. Hill et al., A & A 387 (2002) 560.

[5] H. Schatz et al., ApJ 579 (2002) 626.

[6] B. Plez et al., A & A 428 (2004) L9.

[7] S. Goriely and M. Arnould, A & A 379 (2001) 1113.

[8] K.-L. Kratz et al., Ap. J. 403 (1993) 216.