Astrophysical calculations for explosive nucleosynthesis

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In general, only **elemental** abundances can be measured in ultra-metal-poor, neutron-capture-rich halo stars by optical spectroscopy to be compared with the values in the solar system. In case of strong hyperfine splitting in absorption lines, from high-resolution, high signal-to-noise spectra also **isotopic** abundances can be determined. Very recently, Sneden et al. [1] have measured the isotopic abundances of the rare-earth element Eu in three metal-poor giant stars. Lambert et al. have redetermined the isotopic abundances of Ba in the halo star HD140283, as contradictory results were reported in the past (see [2, 3] and references therein). In the case of Ba, the odd isotopes ^{135,137}Ba (which have a pronounced hyperfine splitting) are produced mainly in r-process nucleosynthesis, whereas the s-process mainly contributes to the even isotopes. The s/r-isotope mixture is therefore reflected in the absorption line widths.

As described in detail in [3, 4], we have calculated the r-process yields of the 3 nuclides ^{135,137,138}Ba, which lie just beyond the 2^{nd} r-peak. Fig. 1 shows our model predictions of the abundance ratio f^r_{odd} as a function of partial sums of 16 n_n-components between n_n=10^{20} [cm^{-3}] and 10^{30} [cm^{-3}]. Similar to Eu [4], the solar-system r-process ratio can only be reproduced for $n_n \geq 10^{22}$ cm^{-3}. However, given the large uncertainty of the observation, which overlaps with both r- and s-process values, the quantity f_{odd} alone cannot give an unambiguous answer about the s/r-mixture in HD140283.

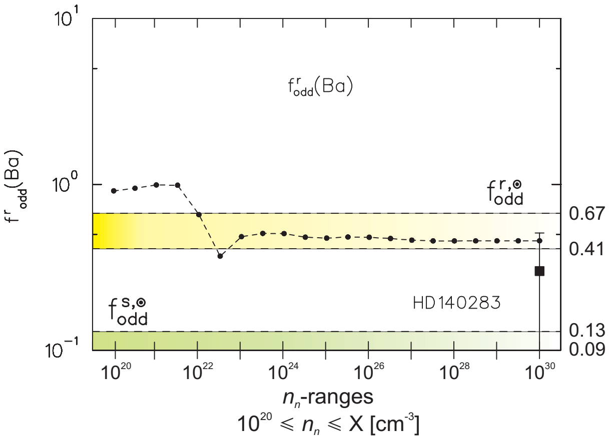

Figure 1: Comparison of calculated r-process ratios f$_{odd}$ = (^{135}Ba+^{137}Ba)/(^{135}Ba+^{137}Ba+^{138}Ba) with solar s- and r-values and the observation in HD140283 (Ref.[2]).

Therefore, a second observational quantity, in this case the elemental abundance ratio of Ba to Eu normalized to the respective solar values, i.e. [Ba/Eu], has to be considered. And indeed, the value observed in HD140283 [2] clearly excludes an $s,\odot$-ratio and indicates that an r-process has been the main contributor to this old star. This is shown in Fig. 2, where the observed [Ba/Eu] value is compared to the solar-system ratio for pure s- and r-process and to our r-process calculations [Ba/Eu]$_{r,calc}$ as a function of n_n-ranges. In these calculations, the solar r-process value can only be obtained for $n_n \geq 10^{24}$ [cm^{-3}]. These are the conditions under which the "main" r-process is just forming the full A$\simeq$130 peak and the matter flow starts to overcome this bottle-neck. For $n_n < 10^{22}$ [cm^{-3}] the predicted r-process [Ba/Eu] ratio may "mimic" different s/r-mixtures, even up to the pure solar-system s-process value.

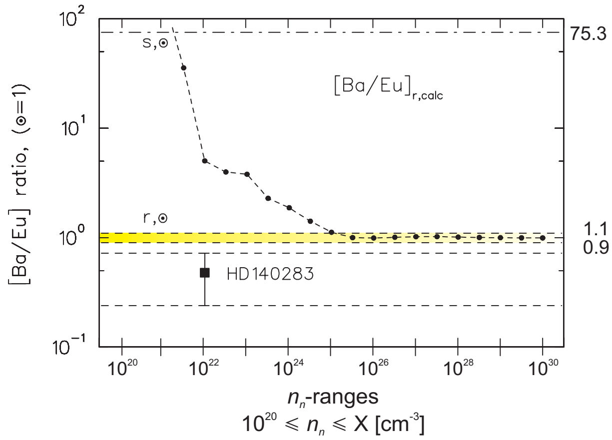

Figure 2: Calculated r-process abundance ratios [Ba/Eu]=(Ba$_{obs}$/Ba$_{\odot}$)/(Eu$_{obs}$/Eu$_{\odot}$), compared to the solar s- and r-values, as well as to the observed ratio in HD140283 (Ref.[2]).

Therefore, it is extremely important to perform more high-resolution optical spectroscopy of these elements in halo stars. A systematic study of the metallicity dependence of element or isotope abundance ratios as shown above can either determine the onset of a secondary "weak" r-process of so far unknown astrophysical site, and/or of s-process nucleosynthesis in medium-mass AGB stars which evolve slower than the high-mass progenitors of supernovae, the most probable site of the "main" r-process.

References

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