

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 $^{135,137}\text{Ba}$ (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 $^{135,137,138}\text{Ba}$, which lie just beyond the 2nd r-peak. Fig. 1 shows our model predictions of the abundance ratio f_{odd}^r as a function of partial sums of 16 n_n -components between $n_n=10^{20} [\text{cm}^{-3}]$ and $10^{30} [\text{cm}^{-3}]$. Similar to Eu [4], the solar-system r-process ratio can only be reproduced for $n_n \geq 10^{22} \text{ cm}^{-3}$. 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.

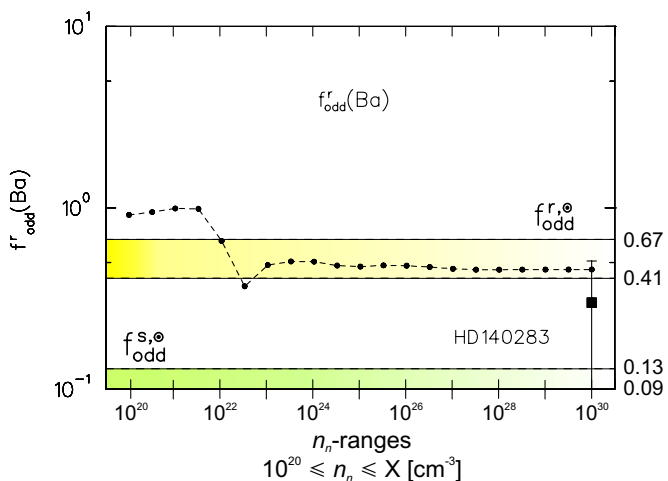


Figure 1: Comparison of calculated r-process ratios $f_{\text{odd}} = (^{135}\text{Ba} + ^{137}\text{Ba}) / (^{135}\text{Ba} + ^{137}\text{Ba} + ^{138}\text{Ba})$ with solar s- and r-values and the observation in HD140283 (Ref.[2]).

Therefore, a second observational quantity, in this case the elemental abundance ratio of Ba to Eu normalized to the respective solar values, i.e. $[\text{Ba}/\text{Eu}]$, 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 $[\text{Ba}/\text{Eu}]$ value is compared to the solar-system ratio for pure s- and r-process and to our r-process calculations $[\text{Ba}/\text{Eu}]_{r,\text{calc}}$ as a function of n_n -ranges. In these calculations, the solar r-process value can only be obtained for $n_n \geq 10^{24} [\text{cm}^{-3}]$. These are the conditions under which the “main” r-process is just forming the full $A \approx 130$ peak and the matter flow starts to overcome this bottle-neck. For $n_n < 10^{22} [\text{cm}^{-3}]$ the predicted r-process $[\text{Ba}/\text{Eu}]$ ratio may “mimic” different s/r-mixtures, even up to the pure solar-system s-process value.

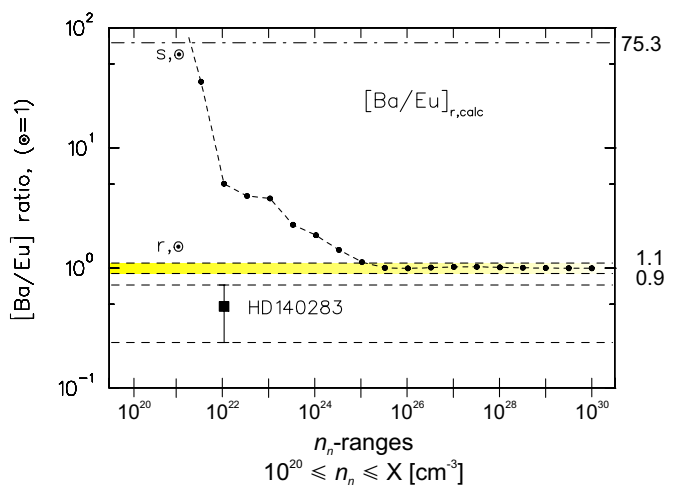


Figure 2: Calculated r-process abundance ratios $[\text{Ba}/\text{Eu}] = (\text{Ba}_{\text{obs}}/\text{Ba}_{\odot}) / (\text{Eu}_{\text{obs}}/\text{Eu}_{\odot})$, compared to the solar s- and r-values, as well as to the observed ratio in HD140283 (Ref.[2]).

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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