Study The Neutron-Capture Processes Based On The Odd Isotopic Fractions Of Barium

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Introduction

Stars with enhanced n-capture elements are very important for our understanding on the characteristics of n-capture processes under environments with different metallicities. The element abundances are usually used as the constraints on the nucleosynthesis model. While the problem appears, which is that, for example, the abundance fitting for the r/s star HE 0338-3945 cannot successfully identify the suggested formation mechanisms, such as the mixed contributions from the r- and s-process (Cui et al., 2010, ApJ; Bisterzo et al., 2012, MNRAS), or from the i-process alone (Hampel et al., 2016, ApJ). The odd isotopic fractions of barium can provide more strict constraint, which could directly show the relative contributions from the s- and r-processes, even maybe from the i-process.

Data and Reduction

The high resolution spectra of metal-poor stars obtained from ESO archive, which observed by the VLT spectrograph UVES.

We derived the stellar parameters of the sample stars via the spectroscopic approach, namely, the effective temperature T_{eff} was determined by requiring the equilibrium between the excitation and iron abundance from Fe I lines, and the surface gravity log*g* was derived from the ionization equilibrium of Fe I and Fe II. During the abundance measurement, the NLTE corrections for Fe are considered.

Results

NLTE Ba Abundances and Ba odd-isotope Fractions for the Sample Stars, Respectively

Name	[Ba/Fe][a]	[Ba/Fe]	σ(total)	$f_{odd,Ba}$	Δ
CS 29491-069	0.24	0.26	0.13	0.46	0.08
HE 1219-0312	0.65	0.72	0.10	0.51	0.09
HE 2327-5642	0.31	0.34	0.05	0.50	0.13
HE 2252-4225	0.29	0.16	0.08	0.48	0.12

Table 3. NLTE Ba abundances and Ba odd-isotope fractions for HE 0338-3945 and CS 31082-001, respectively.

Name	[Ba/Fe]	σ(total)	$f_{odd,Ba}$	Δ
HE 0338-3945	2.47	0.11	0.23	0.12
CS 31082-001	1.14	0.05	0.43	0.09

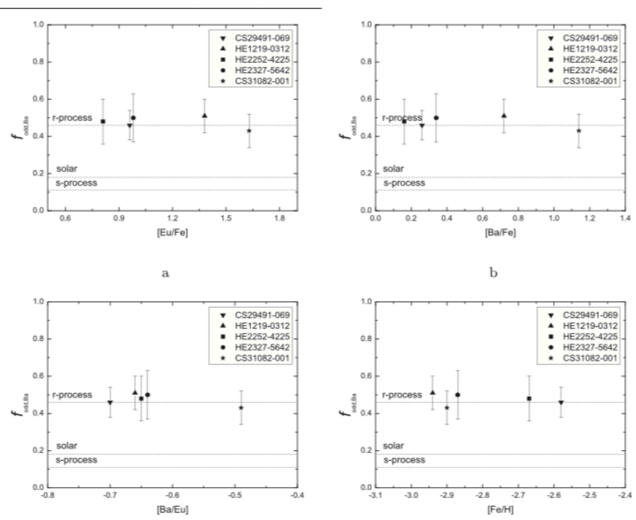

Figure 2. Fraction of the odd Ba isotopes, $f_{odd,Ba}$, vs. a: [Eu/Fe] (LTE), b: [Ba/Fe] (NLTE), c: [Ba/Eu], and d: [Fe/H] (NLTE except CS 31082-001). Filled upsidedown triangle represents CS 29491-069, filled triangle for HE 1219-0312, filled square for HE 2252-4225, and filled circle for HE 2327-5642, respectively. The $f_{odd,Ba}$ value of CS 31082-001 (asterisk) derived by Meng et al. (2016) was also presented for comparison. Uncertainties are shown by short vertical lines. Dotted horizontal lines indicate the $f_{odd,Ba}$ values, 0.18 for the solar system, 0.46 for the pure r-process, and 0.11 for the pure s-process in the solar barium abundance predicted by Arlandini et al. (1999). The Eu abundance of CS 29491-069 and HE 1219-0312 adopted from Hayek et al. (2009), from Mashonkina et al. (2010) for HE 2327-5642, and from Mashonkina et al. (2014) for HE 2252-4225.

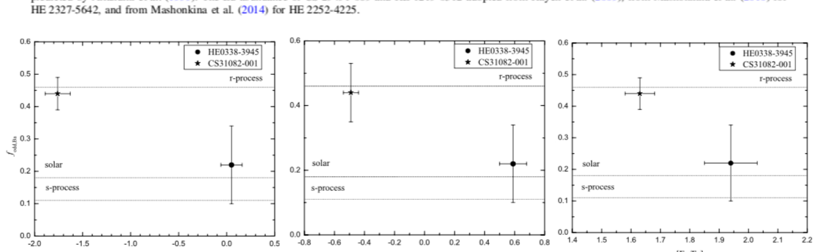

Fig. 3. The fraction of the odd Ba isotopes, $f_{odd,Ba}$, versus [Ba/H] (*top panel*), [Ba/Eu] (*middle panel*), and [Eu/Fe] (*bottom panel*). Filled cir- cle and Asterisk represent HE0338-3945 and CS31082-001, respec- tively. Uncertainties are shown by short horizontal and vertical lines. Dotted horizontal lines indicate the $f_{odd,Ba}$ values, 0.18 for the solar system, 0.46 for the pure *r*-process, and 0.11 for the pure *s*-process in production of the solar barium abundance predicted by Arlandini et al. (1999).

Reference

Cui et al 2010, ApJ, 708, 51
Hampel et al 2016, ApJ, 831, 171
Bisterzo et al 2012, MNRAS, 422, 849
Dardelet et al 2015, arXiv:1505.05500

Based on Meng et al. 2016, A&A, 593,A62; Cui et al. 2018, ApJ ,854,131

Method

The fraction of the odd barium isotopes is defined as:

$$f_{odd,Ba} = \frac{N(^{135}Ba) + N(^{137}Ba)}{N(^{134}Ba) + N(^{135}Ba) + N(^{136}Ba) + N(^{137}Ba) + N(^{138}Ba)}$$

Measurement

The fraction of the odd barium isotopes can be obtained by fitting the asymmetric profile of the Ba II resonance line at 4554 angstrom, which is resulted by the significant hyperfine splitting for its odd isotopes. To find the best fit from a set of synthetic spectra to the observed ones, the reduced chi-square are calculated.

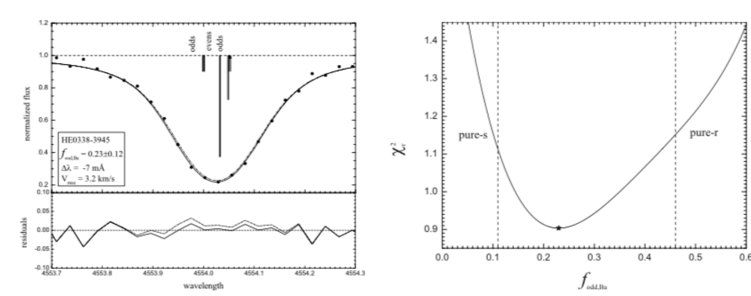

Fig. 1. *Left panel*: best statistical fit synthetic profile obtained with $f_{odd,Ba}$ = 0.23 and NLTE line shapes for the observed (filled circles) Ba II resonance line at 4554 Å in HE0338-3945 with the residual plots below. For comparison, a line with $f_{odd,Ba}$ = 0.11 (i.e. 0.23 − σ) and residual have been plotted (dash-dot line). The value for V_{mac} has been optimized to one that minimizes χ_r^2, and the value for [Ba/Fe] remains the same. *Right panel*: χ_r^2 fit for the 4554 Å line, the star shows where the minimum of the fit lies.

Conclusion

We firstly measured the fractions of the odd barium isotopes of four r-II stars and one r/s stars.

We found that the different enhancement level of Eu and Ba, including other relative heavy elements in the r-II stars should be mainly due to the dilution effects by the clouds before they formed, as their $f_{odd, Ba}$ shows an intrinsic nature and has no trends with [Eu/Fe] and [Ba/Fe] ratios. In addition, we also found that the $f_{odd, Ba}$ in r-II stars has no trends with the metallicity. Thus, we inferred that the $f_{odd, Ba}$ value for the main r-process is stable and universal throughout the whole Galaxy history, which is about 0.46.

We found that $f_{odd, Ba}$ in r-II stars show good agreement with the solar pure r-process value 0.46. In addition, the mean $f_{odd, Ba}$ in r-II stars supports that the r-process contributed 100% of their heavy elements beyond Ba and up to Pb, which is slightly different from the fact that only a small contribution from the s-process for the s-nuclei was deduced from their mean [Ba/Eu] (Mashonkina et al. 2010).

For r/s stars, the $f_{odd, Ba}$ shows that the r- or s-process could not produce the enhanced abundance pattern of their heavy elements alone. And more measurements for r/s stars are needed to identify that if the i-process is important.