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Stars with a low Sr/Ba ratio

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Abstract. The abundance of neutron-capture elements published in the literature for some extremely metal-poor stars have shown possible anomalies. The detailed analysis of high resolution, high S/N ratios spectra of four such stars, shows that in one of the star the anomaly is not confirmed. The 3 other ones are reclassified and found conform to the other stars of their new family, but a full determination of the exact status of the stars would need a radial velocity monitoring.

Key words. Stars: abundances – Stars: atmospheres – Stars: Population II – Galaxy: abundances

1. Introduction

The heavy elements (heavier than strontium), are formed by neutron capture onto nuclei (see e.g. Sneden et al. 2008). This neutron capture process produces quite different effects, whether the addition is "slow" (s-process) or rapid (r-process) compared to the β decay time of the nuclei.

It has been shown that the "s-process" mainly occurs towards the end of the evolution of low mass AGB stars. These stars have a long lifetime and thus could not enrich the matter of the first phases of the Galaxy.

In single stars with metallicities below [Fe/H]=–2.5 the heavy elements, from strontium onward, are mainly due to the r-process and should show the signature (element ratios) of this r-process.

Let us note that in binaries a primary AGB can produce a late contamination of the atmospheres of the very metal-poor secondary star (today observed), providing there a significant amount of both C and s-process elements : such contaminations are indeed observed in binaries (see below).

It is well known that the abundance of the heavy elements in (single) extremely metal poor stars (EMP stars : [Fe/H] < -3) is very scattered (see e.g. François et al. 2007; Spite & Spite 2014) and even the RATIO of two heavy elements like Sr and Ba is very scattered. The ratio Sr/Ba in EMP stars is found equal to, or higher than, the value of the solar r-process: $[\mathrm{Sr/Ba}]_{\odot,\mathrm{r}} = -0.5$: e. g. Mashonkina & Gehren (2001).

2. Possible anomalies

In a recent paper, Aoki et al. (2013) point out a few EMP stars with interesting features :

1- they have a very low Sr/Ba ratio, lower than the r-only solar value.
2- they are classical EMP stars, they are not C-enriched enough to reach the criterion of classification as CEMP of Beers & Christlieb (2005).

A Sr/Ba ratio lower than the solar r-value is encountered in stars where the atmosphere has been contaminated by carbon and s-process elements provided by an AGB: the addition of Ba-rich s-elements lowers the ratio Sr/Ba and strongly increases Ba/Fe: [Ba/Fe] > 1.0. But the stars indicated by Aoki et al. (2013) are not significantly enriched in C and [Ba/Fe] $\simeq$ 0.5.

These stars deserve some investigation.

One of them, CS 30322-023 has been studied in detail by Masseron et al. (2006) and we analyze three other stars: CS 22950-173, CS 29493-090, and HE0305-4520.

3. Observation and analysis

The analysis was made from high resolution spectra obtained at the VLT telescope with the UVES spectrograph. The resolving power of the spectra is about 40,000 with 5 pixels per resolution element and a S/N ratio of about 100 per pixel at 420nm.

We carried out a classical LTE analysis of these stars with OSMARCS model atmospheres (Gustafsson et al. 1975, 2003) and the `turbospectrum` spectral synthesis code (Alvarez & Plez 1998; Plez 2012)

4. Abundances

4.1. The turnoff star CS 22950-173

CS 22950-173 is the only dwarf (turnoff star) of the sample. In this star we measured [Fe/H]=–2.6, [Sr/Fe]=–0.64, [Ba/Fe]=–0.53 and thus [Sr/Ba]=–0.11. This new value of [Sr/Ba] is higher than the solar r-process value : this new high resolution high S/N analysis shows that CS 22950-173 is not a star with an anomalously low Sr/Ba ratio.

4.2. The giant stars

The main parameters of CS 29493-090 and HE0305-4520, are compared in Table 1 to CS 30322-023, following Masseron et al. (2006). These three stars have very similar characteristics.

Their temperatures are low ($T_{\rm eff} \leq$ 4800K), their ratios ^{12}C/^{13}C are close to the equilibrium value, showing that part of the original carbon has been transformed into ^{13}C and N.

Table 1. LTE Abundances in low [Sr/Ba] ratio giant stars.

	BPS CS 30322-023	BPS CS 29493-090	HE 0305-4520
$T_{\rm eff}$	4100	4700	4800
log g	-0.3	1.3	1.3
[Fe/H]	-3.40	-3.10	-2.95
[C/Fe]	0.80	0.73	0.42
[N/Fe]	2.91	1.51	1.58
^{12}C/^{13}C	4	5.5	4
[Sr/Fe]	-0.50	-1.02	-0.76
[Ba/Fe]	0.52	0.50	0.32
[Sr/Ba]	-1.0	-1.5	-1.1
[Eu/Fe]	-0.63	-0.21	-0.31
[Pb/Fe]	1.49	1.15	1.58

When [(C+N)/Fe] is plotted vs. [Fe/H], the low Sr/Ba stars are situated in the region occupied by the carbon-rich stars i.e. [(C+N)/Fe] $\geq$ 1.0. As a consequence we consider that these stars are CEMP stars, where the original atmosphere has been mixed with CNO processed material. The low Sr/Ba ratios could be also explained by (intrusive or extrusive) mixing.

5. Heavy elements patterns

In Fig.1 we compare the [Sr/Ba] ratio in the three stars of Table 1 to:

– the classical EMP stars studied in the frame of the ESO Large Programme “First Stars”(Hill et al. 2002; François et al. 2007; Bonifacio et al. 2009),
– a sample of CEMP stars (Depagne et al. 2002; Sneden et al. 2003; Barbuy et al. 2005; Yong et al. 2013).

In this figure we see that the classical EMP stars (black dots) are practically all in a region delimited by [Sr/Ba] = [Sr/Ba]$_{\odot,r}$ = −0.5, dotted line), and [Sr/Ba] = −[Ba/Fe] + 0.5 (dashed line).

Several CEMP stars (open circles) are located in the same region of the diagram. But other CEMP stars associate a high value of [Ba/Fe] ([Ba/Fe] > 1.0) with a very low value

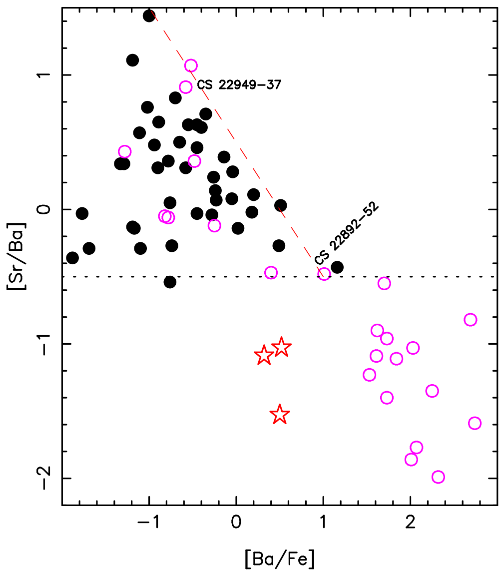

Fig. 1. [Sr/Ba] vs. [Ba/Fe] for a sample of EMP stars (filled symbols) and CEMP stars (open circles). Following Aoki et al. (2001), Aoki et al. (2002) Barbuy et al. (2005) and Yong et al. (2013). The star symbols represent the three Sr/Ba poor stars: CS 29493-090, CS 30322-023, HE0305-4520. The dotted line represent the r-only solar value of [Sr/Ba], and the dashed line the line with [Sr/Ba] = −[Ba/Fe] + 0.5.

of [Sr/Ba] ([Sr/Ba] < −0.5). In these stars the Pb abundance (when it has been measured) is very high, and is interpreted as the signature of an important s-process enrichment. These stars are CEMP-s or CEMP-rs stars (Masseron et al. 2010; Barbuy et al. 2005). They are generally found binaries, and their abundances are thus understood as the result of a transfer of (Ba-rich) material from a defunct AGB companion.

The three stars here studied (Table 1, star symbols in Fig. 1), have characteristics similar to the CEMP-s or CEMP-rs stars, ([Ba/Eu] > 0.5, high abundance of Pb) although [Ba/Fe] < 1.0. It is obviously interesting to check the binarity of these stars.

Following Masseron et al. (2006), a comparison of radial velocities measured on spectra obtained between 2001 and 2006 does not bring clear support in favor of a binary nature of CS 30322-023.

For CS29493-090 (spectra obtained in 2005) we measured the same radial velocity (inside the measurement errors) as the one measured by Barklem on spectra obtained in 2003 (Barklem et al. 2005).

For HE0305-4520 (spectra obtained in 2006) we also measured the same radial velocity as the one measured by Barklem on spectra obtained in 2002 (Barklem et al. 2005).

None of these star shows evidence of binarity: a monitoring of their radial velocity is obviously important.

6. Conclusion

To date the low Sr/Ba stars are found only among giants stars.

The turnoff star CS22950-173 pointed out by Aoki was found to have a normal Sr/Ba ratio for an EMP star ([Sr/Ba] > −0.5).

If it is confirmed that the three giant stars studied here, are single stars, their abundances of C, N and s-elements would suggest that they are AGB stars as proposed by Masseron et al. (2006). In the case of CS 30322-023, this hypothesis is reinforced by the fact that the profile of the Hα line shows a strong emission, suggesting the existence of a stellar wind (however no emission is suggested by the Hα profile of CS29493-090 and HE0305-4520).

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