ENRICHMENT OF THE GALACTIC DISK BY THE NEUTRON CAPTURE ELEMENTS (Ba and Eu)

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ABSTRACT. The abundances of Ba and Eu were determined for 38 red giant stars in the metallicity range -0.6 <[Fe/H] < $+0.25$ using the spectral synthesis technique. The spectra were obtained with spectrograph ELODIE (Haute Provence Observatoire, France), the resolwing power is 42000, S/N is more than 100. For the Ba and Eu lines the effects of hyperfine structure and isotope shifts are included, assuming the isotope ratios of the r-process component of the solar system material. Abundances of the n-capture element (Ba and Eu) for 38 red giants with metallicities [Fe/H] from -0.6 to +0.25 and correlation of the [Ba/Eu] ratios with stellar metallicities are present. The [Ba/Eu] ratio reflects substantial production of Ba in the s-process for the stars with metallicity -0.6 <[Fe/H] < $+0.25$.

Key words: nucleosythesis: neutron captures; stars: abundances; stars: giants.

1. Introduction

Chemical elements heavier than the Fe peak (Z> 30) are formed in two processes of neutron capture: r-process and s-process (Burbidge et al. 1957). At the relatively low neutron densities (N_n=108 cm^-3 ; Pagel 1997), the time between their captures is more, than time of the β-decays. Such captures are refered to s-processes (slow). If the density of neutrons is rather high there are many neutron-captures between the β-decays, and such captures are refered to r-processes (rapid). According to the theory of evolution (Travaglio et al.1999), s-process nuclei are mainly synthesized during the thermally pulsing asymptotic giant branch phase of the low-mass stars (2-4 $M_{\odot}$). There is a necessary flux of neutrons for maintenance of a chain of s-process.

Theory proposes an existence of several quite different astrophysical sites for the operation of the two neutron-capture nucleosyntheses mechanisms. For the case of s-process, the two possible astrophysical environments are: a) the helium burning cores of massive stars (M> 10$M_{\odot}$). Then reaction $^{22}Ne(\alpha,n)^{25}Mg$ is responsible for the elements with atomic mass A< 90 (the "weak" component) (Peters (1968), Lamb et al. (1977), Sneden, Cowan (2003) and Truran et al. (2002)): b) The thermally pulsing helium shells of asymptotic giant branch stars. The reaction $^{13}C(\alpha,n)^{16}O$ produces neutrons that leads to the elements formation A> 90 (the "main" component) (Schwarzschild (1967), Busso et. al (1999)). However, the specific site of the r-process is an unsolved problem, but it is strongly suspected that Type II Supernovae play an important role. Truran et al. (2002) point out four possible sites, three of which occur in SNeII explosions.

Contributions from various processes are different at the different stages of the Galaxy evolution, the course of various elements with metallicity differs also. It allows one to trace the sources of the contribution to an enrichment of the ISM. If we can identify stellar environments in which either the s-process or r-process contributions dominate, we can use this information to constrain the detailed characteristics of the corresponding nucleosynthesis mechanism. If we can distinguish s-process and r-process elemental contributions, we can use stellar abundance data to trace the chemical evolution of such processes over the Galactic history.

In this paper, we present n-capture element abundances (Ba and Eu) for 38 red giants with metallicities [Fe/H] from -0.6 to +0.25. Use of the high-resolution spectra (R=42000), the reliable stellar parameters and detailed structure of the Ba and Eu lines. Ba and Eu abundnces are determined and detect the trends in the behaviour of elemental ratios [Ba/Fe], [Eu/Fe] and [Ba/Eu]. A decrease of [Eu/Fe] and [Ba/Fe] with the metallicity increase have been obtained.

2. Observations and parameters

All the spectra used in this paper are extracted from the most recent version of the library of stellar spectra collected with the ELODIE echelle spectrograph at the Observatory de Haute-Provence by Soubiran et al. (1998) and Prugniel & Soubiran (2001). The performances of the instrument mounted on the 193cm telescope, are described in Baranne et al (1996). A resolving power of 42 000 in the wavelength range $\lambda\lambda$ 3850–6800 ÅÅ. Spectrum extraction, wavelength calibration and radial velocity measurement have been performed at the telescope with the on-line data reduction software while straightening of the orders, removing of cosmic ray hits, bad pixels and telluric lines were performed as described in Katz et al (1998). The continuum level drawing and equivalent width measurements were carried out by us using DECH20 code (Galazutdinov 1992).

Highly precise temperatures ($\sigma = 10 - 15$ K) have been determined from line depth ratios (Kovtyukh et al. 2006). The spectral lines of high and low excitation potentials respond differently to the change in effective temperature ($T_{\rm eff}$). This method is independent of interstellar reddening and takes into account the individual characteristics of the star's atmosphere.

The surface gravity log g was determined using two different methods, the method based on the ionisation balance for iron and a second method by fitting the wings of a Ca I line profole.

Microturbulent velocities $V_{\rm t}$ were determined by forcing the abundances determined from individual FeI lines to be independent of equivalent width.

3. Elemental abundances

Ba and Eu abundances are determined from the line profile fitting of the stellar spectra using the STARSP code developed by Tsymbal (1996). We have used the grid of stellar atmospheres from Kurucz (1993). The line list is extracted from Kurucz (1994) compilation, and it includes all the relevant atomic and molecular lines. Elemental abundances are derived from the BaII resonance line λ 4554Å and from the EuII subordinate line λ 6645Å. The atomic data for these lines were taken from Mashonkina & Gehren (2000). BaII and EuII ions considered here have the lines that show appreciable hyperfine structure. We adopt the hfs patterns of Mashonkina & Gehren (2000) for Ba II. Mashonkina & Gehren (1999). have shown, that for line Ba λ 4554Å an account for the hyperfine structure is important. They have presented 3-component HFS model of this line. Oscillator strengths of these components are identical to those in the solar spectrum. Recent NLTE calculation for BaII and EuII have been carried out by Mashonkina & Gehren [1999], [2000]. They have shown that for the line II λ 4554Å which we used in our calculations, NLTE effects are small for FeH> -1.9. For Eu λ 6645Å the correction NLTE ranges from 0.04 dex to 0.06 dex. Therefore we did not take into account the NLTE effects in our calculations. The behavior of elements in our study with metallicity is shown in Fig. 1 and Fig. 2.

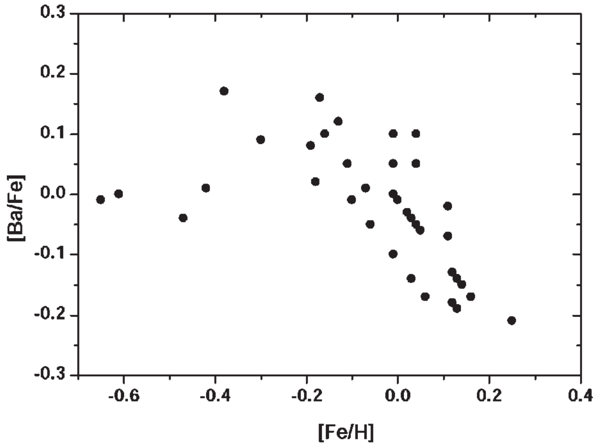

Figure 1: The run of [Ba/Fe] with [Fe/H]

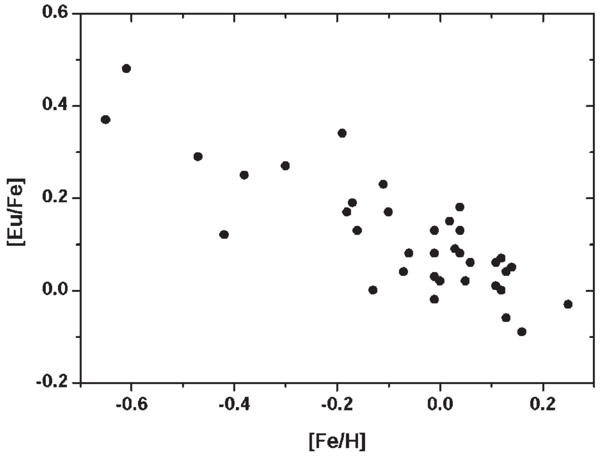

Figure 2: The run of [Eu/Fe] with [Fe/H]

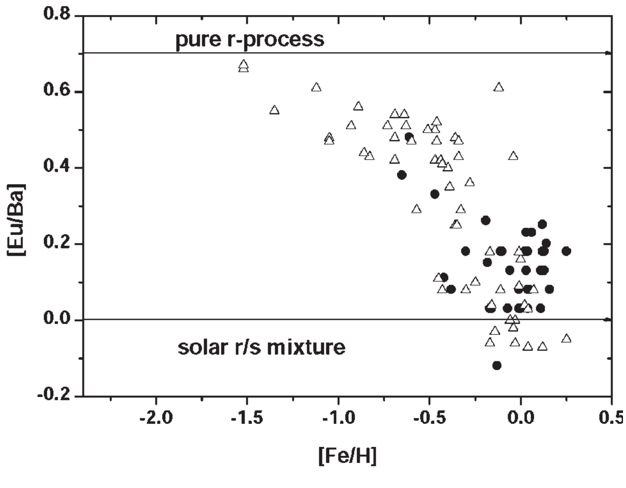

Figure 3: The run of [Ba/Eu] with [Fe/H]. Filled circles are from this paper open triangles are from Mashonkina (2001)

We observe in our sample of giants the trend of Ba/Fe and [Eu/Fe] versus [Fe/H] (Fig. 1, 2) similar to the that for disk stars collected in the work Burris et al. (2000) (see Fig. 5, Burris et al. (2000)).

Solar barium and europium abundances, $\log \varepsilon_{\mathrm{Ba},\odot} = 2.21$ and $\log \varepsilon_{\mathrm{Eu},\odot} = 0.53$, and van der Waals damping constants C_6 for the BaII and EuII lines were determined in the paper Mashonkina & Gehren (2000) from the solar line profile fitting.

The resulting mean Ba and Eu abundances are [Ba/Fe]=-0.02±0.11 and [Eu/Fe]=0.09±0.12. Europium is overabundant relative to barium with a mean value [Eu/Ba] = 0.11±0.08

4. Abundance ratios [Eu/Ba]

A comparison of Ba wit h Eu abundances shows the relative contributions of the r- s-process, since Ba may be product of the both processes. [Eu/Ba] abundance ratios are shown in Fig. 3. The contributions from the s- and r-process to the solar Ba abundance consist of 87% and 13%, respectively, according to Kappeler et al. (1989), 81% and 19% according to the data of Arlandini et al. (1999), 85% and 15% according to Burris et al. (2000). On the other hand the solar Eu is primarily a r-process product: 91% according to Cameron (1982) and Wisshak et al. (1996), and 97% according to Burris et al. (2000). The elemental abundances and the ratio of these two elements are presented in the Table1. The Ba and Eu abundances in Table1 can also be used to estimate the fraction of Ba produced by the r- and s-process in each star, using the assumptions that Eu is produced only by the r-process but Ba may be product in both processes.

[Eu/Ba] abundance ratios are shown in Fig. 3. The solar abundance ratio of Eu to Ba contributed by the r-process (Arlandini et al. 1999) relative to the total abundances, $[\mathrm{Eu/Ba}]_r = 0.70$, is indicated in Fig. 3 by solid line. Fig. 3 shows the [Eu/Ba] abundances ratios from our studies and the stars studied by Mashonkina & Gehren (2000, 2001). Using the deviation of the observed values of [Eu/Ba] from $[\mathrm{Eu/Ba}]_r = 0.70$, we can estimate the s-process contribution to Eu abundanse. For the our disk stars, the [Eu/Ba] values are all between 0.00 and 0.20. In the stars with metallicity about $[\mathrm{Fe/H}] > -0.50$ the s-process contribution to Eu is significant.

Table 1: Abundance results for Ba and Eu

HD	T_{eff}	log g	[Fe/H]	[Ba/Fe]	[Eu/Fe]	[Ba/Eu]
2910	4756	2.7	0.12	-0.18	0.07	-0.25
4188	4809	2.7	0.04	-0.05	0.13	-0.18
6319	4650	2.3	0.06	-0.17	0.06	-0.23
6482	4738	2.4	-0.11	0.05	0.23	-0.18
10975	4881	2.4	-0.19	0.08	0.34	-0.26
11749	4679	2.4	-0.10	-0.01	0.17	-0.18
11949	4708	2.3	-0.16	0.10	0.13	-0.03
15453	4696	2.4	-0.07	0.01	0.04	-0.03
15755	4611	2.3	-0.01	-0.10	-0.0	-0.08
15779	4821	2.7	0.02	-0.03	0.15	-0.18
16400	4840	2.5	-0.01	0.05	0.08	-0.03
17361	4646	2.5	0.12	-0.18	0.00	-0.18
18885	4722	2.5	0.16	-0.17	-0.09	-0.08
19787	4832	2.75	0.14	-0.15	0.05	-0.20
25602	4693	2.4	-0.42	0.01	0.12	-0.11
25604	4764	2.7	0.13	-0.14	0.04	-0.18
26546	4743	2.25	-0.01	0.00	0.03	-0.03
26755	4630	2.2	-0.06	-0.05	0.08	-0.13
27371	4955	2.7	0.11	-0.07	0.06	-0.13
28292	4453	2.1	-0.18	0.02	0.17	-0.15
28305	4925	2.55	0.11	-0.02	0.01	-0.03
28307	4961	2.7	0.12	-0.13	0.00	-0.13
31444	5080	2.75	-0.17	0.16	0.19	-0.03
33419	4708	2.3	0.00	-0.01	0.02	-0.03
33618	4590	2.3	0.05	-0.06	0.02	-0.08
34200	5055	2.8	0.04	0.05	0.08	-0.03
34559	5010	2.9	0.04	0.10	0.18	-0.08
37638	5093	2.8	-0.01	0.10	0.13	-0.03
40020	4670	2.3	0.13	-0.19	-0.06	-0.13
42341	4655	2.6	0.25	-0.21	-0.03	-0.18
43023	4994	2.6	-0.13	0.12	0.00	0.12
45415	4762	2.53	0.03	-0.04	0.09	-0.13
46374	4661	2.3	0.03	-0.14	0.09	-0.23
46758	5003	2.9	-0.30	0.09	0.27	-0.18
53329	5012	2.8	-0.38	0.17	0.25	-0.08
54810	4669	2.4	-0.47	-0.04	0.29	-0.33
64967	4864	2.55	-0.65	-0.01	0.37	-0.38
67539	4781	2.45	-0.61	0.00	0.48	-0.48

Conclusion

Using the spectra of the high quality, we have carried a detailed analysis of the abundances of Ba and Eu in the stars of the Galactic disk.

We observe in our sample of giants the trend of Ba/Fe and Eu/Fe versus Fe/H (Fig. 1, 2) similar to the those for disk stars studied in the work of Burris et al. (2000) (see Fig. 5, Burris et al. (2000)).

The [Ba/Eu] ratio reflects substantial production of Ba in the s-process in the stars with metallicity $-0.6 <$[Fe/H] $< +0.25$. One can make a conclusion that the s-process prevailed in the synthesis of heavy elements at the time of disk stars formation.

Withing the metallicity domain of about -0.5 there is a jump of the [Eu/Ba] ratio, and this can indicate the decreasing contribution from the s-process and respective increasing of the r-process contribution in the Eu and Ba abundances of the metallicities [Fe/H] < -0.50.

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