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Abstract.   The outer atmosphere of the first generations of low-mass ($M \leq 0.8\,M_\odot$) stars retain to a great extent the original chemical composition of the interstellar medium (ISM) at the time and place of their birth. The composition of this pristine gas represents the nucleosynthesis of the very first massive stars, that produced and ejected the first heavy elements into the early ISM. Thus a detailed abundance analysis of low-mass, metal-poor stars can help us track these gasses and provide insight into the formation processes that took place in the very early stages of our Galaxy. Preliminary result of a 25-star homogeneously analysed sample of metal-poor candidates from the Hamburg/ESO survey is presented. The main focus is on the most metal-poor stars of the sample; stars with [Fe/H] < -4. The abundance pattern of these ultra metal-poor (UMP) stars is used to extract key information of the earliest ongoing formation processes (ranging from hydrostatic burning to neutron-capture processes).

1. Introduction

Metal-poor stars are the key to unlock the first chapter in the history of the chemical enrichment of our Galaxy. The first stars to form in the universe were presumably massive and short lived ending their lives in a supernova (SN) explosions, and thereby enriching the inter stellar medium (ISM) with heavy elements. The metal-poor stars we observe today are the first generation of stars formed from this freshly enriched ISM. The ESO large program First Stars resulted in the first abundances trends for metal-poor stars. They found a low scatter in the abundances of α and iron-peak elements, and a small over abundance of the α-elements, consistent with a well mixed early inter stellar medium [1]. But they also found a large scatter in the abundances of neutron-capture elements [2]. Large surveys have also shown that a large fraction of the metal-poor stars especially at very low metallicity are carbon-enhanced [3], but the origin of this of carbon in the early universe is still not completely understood. To better constrain the nucleosynthesis processes taking place in the early universe, for both the light and heavy elements, more studies of low metallicity stars are needed. Here abundance analysis of four newly discovered ultra metal-poor (UMP) stars is presented.

2. Observation and Analysis

The stars have been observed with the VLT/UVES, covering a wavelength range from 3100 Å to 5000 Å in the blue and 5800 Å to 9500 Å in the red and have a resolving power of R∼45000. The data was reduced with the UVES reduction pipeline version 2.4.0. In Figure 1 reduced and normalized spectra around the Sr II line at 4077 Å are displayed for three different stars, with decreasing metallicity going from the top to the bottom of the figure. The spectrum in
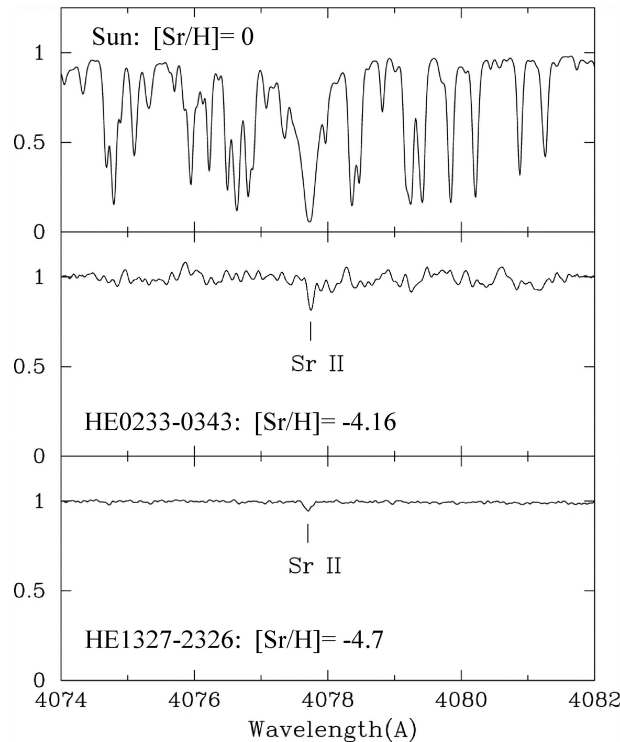
Figure 1. Spectra of the sun (top), HE 0233−0343 (middle) and HE 1327−2326 (bottom) around the Sr II line at 4077 Å.

the top panel is that of the Sun showing multiple lines, the middle panel shows the spectrum of HE 0233−0343, where the Sr line is still visible and at the bottom HE 1327−2326 is shown, here the Sr II line is barely visible. This figure clearly displays the increasing difficulty in abundance determination with decreasing metallicity. Thus highlighting the need for high resolution high signal to noise spectra to facilitate this work.

The abundance analysis was performed using the LTE (local thermal equilibrium) stellar line analysis program MOOG [4]. The model atmospheres are α-enhanced ($[\alpha/\mathrm{Fe}]^1 = +0.4$) models from the NEWODF grid of ATLAS9 models by Castelli & Kurucz 2003[5]. Temperatures where deduced from the infrared flux method, by fitting model atmospheres to spectrophotometric observations, for this α-enhanced ($[\alpha/\mathrm{Fe}] = 0.5$) MARCS models [6] where used. Gravities are from Y^2 isochrones [7] assuming age=10 Gyr and $[\alpha/\mathrm{Fe}] = +0.3$ and the metallicity was deduced from Fe I lines. The stars with their parameters and derived abundances of carbon, barium and strontium are listed in Table 1.

3. Results
3.1. α and iron-peak elements
In Figure 2 the derived abundances for the α-elements magnesium, calcium and titanium (left) and the iron-peak elements manganese and nickel (right) are plotted as a function of metallicity. For comparison abundances for the most metal-poor stars from the Yong et al 2013 [8] and Frebel 2010 [9] samples plus abundances for SDSS J102915+172927 [10] are added to the plot. The four newly discovered UMP stars clearly follow the trend of the other samples with a small

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[1] $[\mathrm{X/Y}] = \log\left(\frac{N_X}{N_Y}\right)_* - \log\left(\frac{N_X}{N_Y}\right)_\odot$

Table 1. UMP stars in this sample

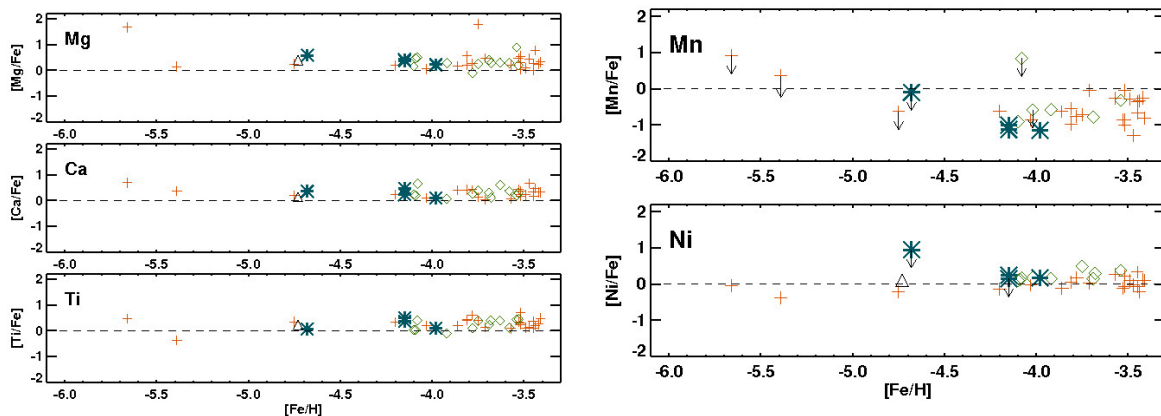| Stellar ID	T_{eff}	Logg	[Fe/H]	[C/Fe]	[Ba/Fe]	[Sr/Fe]
HE 0134−1519	5525	3.22	−4.0	+1.1	< −0.8	−0.3
HE 0233−0343	6075	3.49	−4.7	+3.5	< +0.9	+0.5
HE 1310−0536	4975	1.88	−4.2	+2.5	−0.5	−1.1
HE 2239−5019	6125	3.57	−4.2	< +1.8	<0.0	< −0.6

Figure 2. Derived abundances for the α-elements Mg, Ca and Ti (left) and the iron-peak elements Mn and Ni (right). Blue asterisks: Hansen et al. in prep., Green diamonds: Yong et al. 2013 [8], red crosses: Frebel 2010 [9] grey triangle: Caffau et al. 2011[10]. Dashed line is solar value.

over abundance in the α elements. Consistent with the existing picture of α abundances in metal-poor stars reflecting the enrichment from core-collapse SNe in the early universe. The abundances for the iron-peak elements also follow the trends seen in the abundances for the larger samples, displaying a very low scatter in the abundances of these elements. Hence these four new UMP stars behave normally compared to other metal-poor stars.

3.2. neutron-capture elements
The abundances derived for the neutron-capture elements show a very different picture from that of the α and iron-peak elements. In Figure 3 the strontium (left) and barium (right) abundances are plotted as a function of metallicity. A large star-to-stars scatter is seen for both elements. Recent work by Hansen et al. 2013 [11] show that this scatter at least for Sr persists even with correction for NLTE and with using 3D model atmospheres, i.e. the scatter is real and not just an artifact of a simplified analysis procedure. This large scatter points to more than one formation process for these elements. There are several candidates for the formation sites of neutron-capture elements in the early universe such as the r-process in the neutrino driven wind following supernova explosions [12] or in low mass faint electron capture supernovae [13] or the s-process in massive fast rotating stars [14]. To put further constraints on the production of the neutron-capture elements key information can be derived from the correlation or anti-correlation of one element with another. In Figure 4 the Sr abundances are plotted as a function of the Ba abundances. A clear correlation between the two elements is seen (dashed line is a 1:1
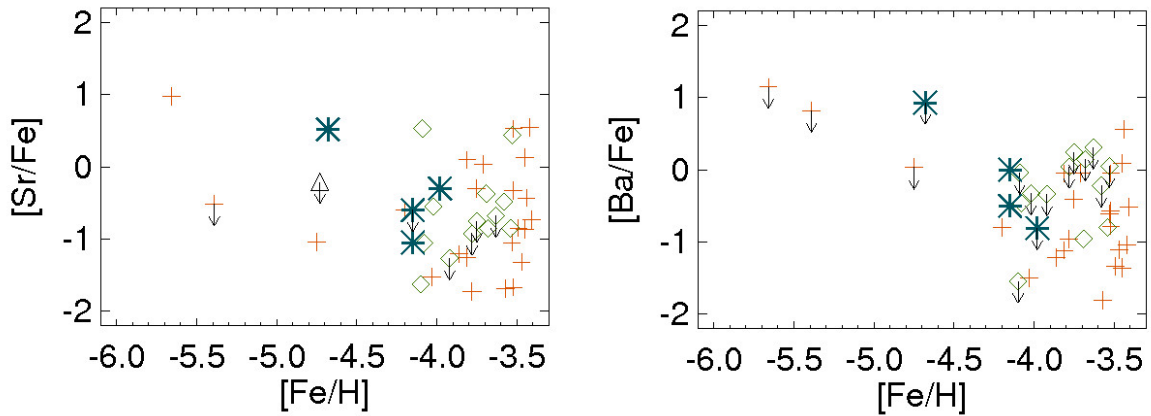
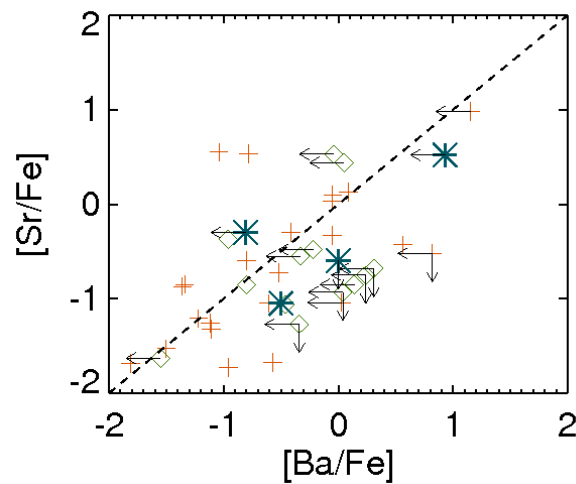**Figure 3.** Abundances of Sr (left) and Ba (right) as function of metallicity. Symbols as in Figure 2

Figure 4. Sr abundances as function of Ba abundances. Symbols as in Figure 2, the dashed line corresponds to a 1:1 correlation.

correlation). The same result have been seen in Andrievsky et al. 2011 [15] for a smaller but NLTE corrected sample and in Roederer 2013 [16] for a much larger sample. The correlation of the two elements show that their abundances grow simultaneously over time. So regardless of the production processes or sites, roughly equal amount of Sr and Ba have been produced at a given time in the history of the Galaxy.

3.3. Carbon enhanced stars
Three of the four stars in our sample are carbon-enhanced metal-poor stars (CEMP), but none of these three show any enhancement in neutron-capture elements (see Table 1), hence they belong to the CEMP-no class [3]. The origin of the large carbon enhancements but low neutron-capture element abundances of these stars are unknown. One possible explanation is that they are part of a binary system, so the star we observe have received mass from a former AGB companion, the companion having now evolved into a white dwarf. To test this hypothesis a radial velocity

monitoring program have been under way at the Nordic Optical Telescope for the last of 6 years. Preliminary results from this program show that nine out of the eleven CEMP-s program stars are definite long period binaries where as only two of the eight CEMP-no program stars are binaries.

4. Summery

Four new ultra metal-poor stars have been presented. The derived abundances show very low star-to-star scatter in α and iron-peak elements abundances and hence follow the picture seen for abundances of these elements in larger samples of metal-poor stars. A large star-to-star scatter is observed for the neutron-capture element abundances, pointing to different formation processes for these elements. But with Ba and Sr correlating, making the formation of these two co-dependent. Among the four stars, three are carbon-enhanced, but with no enhancement in neutron-capture elements, i.e. CEMP-no stars. The nature of these stars is unknown but preliminary results from radial velocity monitoring show that they are not binaries and hence points to an alternative explanation than mass transfer from an AGB companion.

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