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TOPoS: chemical study of extremely metal-poor stars*

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Abstract. The extremely metal-poor (EMP) stars hold in their atmospheres the fossil record of the chemical composition of the early phases of the Galactic evolution. The chemical analysis of such objects provides important constraints on these early phases. EMP stars are very rare objects; to dig them out, large amounts of data have to be processed. With an automatic procedure, we analysed objects with colours of Turn-Off stars from the Sloan Digital Sky Survey to select a sample of good candidate EMP stars. In the latest years, we observed a sample of these candidates with X-Shooter and UVES, and we have an ongoing ESO large programme to use these spectrographs to observe EMP stars. I will report here the results on metallicity and Strontium abundance.

Key words. Stars: Population II - Stars: abundances - Galaxy: abundances - Galaxy: formation - Galaxy: halo

1. Introduction

We here present new results on the metallicity of extremely melat-poor (EMP) stars, related to our ongoing ESO Large Programme TOPoS and to other previous observations.

* Based on observations obtained at ESO Paranal Observatory, programme 189.D-0165(A)

The first stars formed, Pop. III stars, were massive (tens, hundreds solar masses); they evolved rapidly, synthetised elements hevier than hydrogen in their short life, that they ejected as they exploded as supernovae. EMP stars have a metallicity below about one thousandth the solar metallicity ($Z \leq 10^{-3} Z_{\odot}$). They are formed from primordial gas, enriched by only one/few supernovae explosions, so that they are the direct descendants of the massive Pop. III stars. Their chemical composition put constraints on the metal production of the previous generation(s) of stars, the massive Pop. III stars, so that from the chemical pattern of the EMP stars we can draw some conclusions about the masses of the Pop. III stars.

An other important question we are interested in concerns the formation of low-mass stars in a metal-poor gas cloud. Is there a "critical metallicity" below which low-mass stars cannot form?

To investigate both the above mentioned points, observations are necessary. We have the ESO large programme TOPoS ongoing to observe EMP stars and expect, with previos observations, to have in a short time about a hundred intermediate- high-resolution spectra of EMP stars.

2. Metallicity distribution function

EMP stars are extremely rare objects. To find them, large amounts of data have to be exploited. With our pipeline we analysed the spectra of objects with the colour of turn-off (TO) stars (see Bonifacio et al. 2012)[1] in the SDSS/SEGUE/BOSS surveys (York et al. 2000; Yanny et al. 2009; Dawson et al. 2013). We selected TO stars because among the unevolved stars they are the most luminous. In the SDSS-DR9 we analysed 254 335 spectra of objects with the colour of TO stars. The metallicities we derived for 182 807 of these are presented in the metallicity disctibution function (MDF) in the left panel of Fig. 1. Except for the colour cuts, no other bias, in addition to that present in the SDSS spectroscopic sample, is introduced. The resolving power of the SDSS/SEGUE/BOSS is lower than 2000. The spectra of EMP stars show very few metallic absorption lines at this resolution, so that, overall for spectra with low signal-to-noise ratio (S/N), usually the metallicity we derive from our pipeline is based on very few features, sometimes only the Ca II-K line. Our analysis of SDSS spectra assumes [Ca/Fe]=+0.4, any deviation from this ratio will result in an offset of our metallicity estimate to the star's true metallicity (see Bonifacio et al. 2011). We expect a large error in the metallicity we derive, in particular for the spectra of poor quality. We observed at higher resolution, with UVES (D'Odorico et al. 2006) and X-Shooter (Vernet et al. 2011), a sample of EMP stars, in order to calibrate the analysis on the low-resolution observations. The follow-up stars have beed selected to be EMP, brighter than 19.5 in g magnitude, and to be observable from Paranal. Observations are still ongoing and the complete sample of follow-up stars will be of about a hundred stars. For the high-resolution spectra, the value of [Fe/H] is really derived from Fe I lines, and in the right panel of Fig. 1 the metallicity for the first 39 stars observed in TOPoS is compared to the MDF of the complete sample of SDSS spectra. As can be seen from the right panel of Fig. 1, there seems to be a flattening in the MDF for $[Fe/H] < -4$. Our experience with SDSS-DR7, induces us to believe that this flattening is an artifact due to misidentified spectra at low S/N and white dwarfs. We will use the higher resolution analysis to improve our low-resolution analysis, to derive a more robust MDF. The issue of the biases present in the SDSS spectroscopic sample will also have to be addressed.

Of the 39 stars presented here, 19 have been observed in the TOPoS LP, and the other are from previous programmes (Bonifacio et al. 2012; Caffau et al. 2011, 2012, 2013). Of the sample, three stars have $[Fe/H] < -4$, twelve $[Fe/H] < -3.5$, and 37 $[Fe/H] < -3$.

3. Strontoum abundance

It has long been noted that the abundance of Sr in old stars is not uniform even when normalised by a comparable element such as Ba

[1] $0.18 \leq (g-z)_0 \leq 0.70$ and $(u-g)_0 > 0.70$

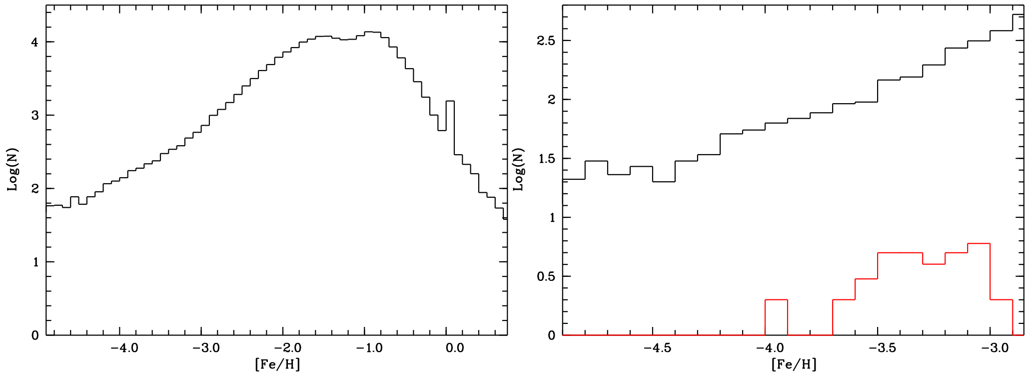

Fig. 1. Left panel: MDF of the SDSS-DR9 from our pipeline; the analysis is based on 182 807 objects with colous of TO stars. Right panel: MDF as on the other panel but for objects selected to be observable from Paranal and with magnitude g< 19.5 (113 222 objects, solid black) compared with the MDF derived from the analysis of UVES or X-Shooter spectra of a sample of 39 TO stars (solid red).

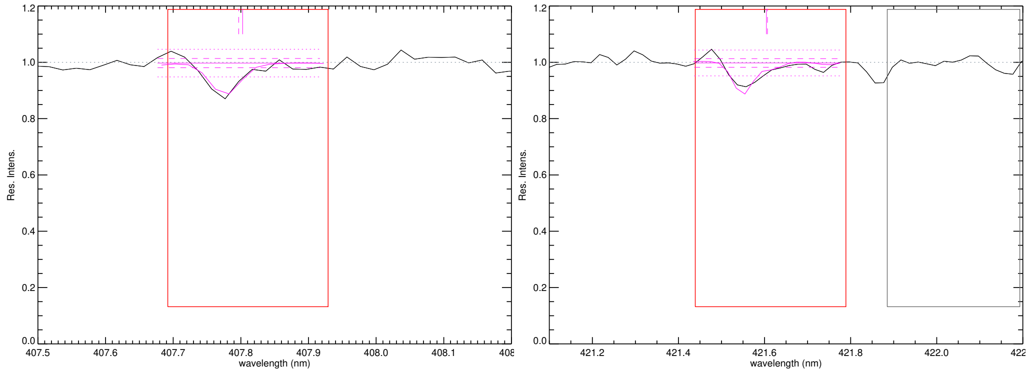

Fig. 2. The observed spectrum of SDSS J014036+234458 (solid black) in the range of the two Sr II lines at 407 and 421 nm, respectively, and superimposed the best fir (solid magenta). A(Sr) is –3.2 and –2.9, respectively, the S/N ratio per pixel is slightly above 60.

(McWilliam 1998) and has been confirmed by homogeneous data in LTE, and re-analysed in NLTE by Andrievsky et al. (2011).

For other similar elements (neutron capture elements) the scatter is large, but significantly less. Strontium is therefore a particularly sensitive test of the production process of these heavy elements, and a detailed analysis of the peculiarities of the abundance distribution of Sr should open the way to understand the nature and peculiarities of the events producing Sr and the neutron capture elements.

Two lines of strontium fall in the UBV arm of X-Shooter: the Sr II lines at 407.7709 nm and at 421.5519 nm, both lines are from the ground level. For log gf we choose +0.167 and –0.145, respectively (Warner 1968). For the reference solar abundance we take $A(Sr)_{\odot} = 2.92$ from Lodders et al. (2009). For only one star, SDSS J014036+234458, both lines are visible (see in Fig. 2), while for SDSS J002558-101509 and SDSS J124121-021228 only the line at 421.5 nm was detected. For the stars for which we had no clear detection of Sr we computed upper limits based on Cayrel's formula (Cayrel 1988) with a $3\,\sigma$ detection. The results are shown in Fig.3.

For SDSS J014036+234458 the Ba II line at 455.4 nm line is not visible, and a $3\,\sigma$ detection with Cayrel's formula gives A(Ba)< −3.2.

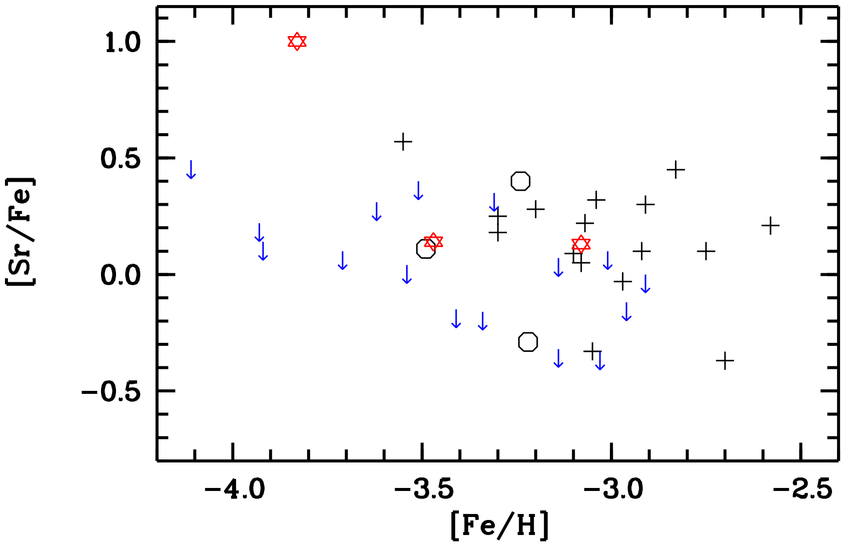

Fig. 3. [Sr/Fe] vs. [Fe/H] for the stars in the TOPoS sample, (red stars for which Sr abundance has been derived, blue downward arrows for the upper limits) compared to the sample of Andrievsky et al. (2011) (black crosses) and to three stars from Caffau et al. (2011) (black circles).

This star seems a Ba-poor EMP star, probably similar to HD 122563.

4. Discussion

Our selection of EMP stars from SDSS spectra is very successful and allowed us to collect a sample of interesting TO stars with which we will calibrate the low-resolution analysis. Strontium could be detected only in a subsample of (six) stars. In particular one star shows a high A(Sr) even if we have no detection of Ba.

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