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Observing metal-poor stars with X-Shooter

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Abstract. The extremely metal-poor stars (EMP) 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 considered. 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. During the French-Italian GTO of the spectrograph X-Shooter, we observed a sample of these candidates. We could confirm the low metallicity of our sample of stars, and we succeeded in finding a record metal-poor star.

Key words. Sun: abundances – Stars: abundances – Hydrodynamics

1. Introduction

The first generation of stars formed from the material of the Universe emerging from the big bang, and synthesised in the primordial nucleosynthesis, hydrogen, helium, and traces of lithium. It is believed that these were massive stars (M > $80 M_\odot$) (Ostriker & Gnedin 1996) that evolved rapidly, synthesised metals that ejected in the inter-stellar medium during their supernovae explosions. The following generations of stars formed from this enriched material, and both massive and low-mass stars (M < $M_\odot$) formed. A M = $0.8 M_\odot$ mass star formed at that time would still be today shining in the main sequence.

There is still a debate on the possibility of forming low-mass stars from primordial gas. To form the star the contracting gas needs to cool. According to the theory of Bromm & Loeb (2003) a minimum amount of oxygen and carbon is necessary in the gas phase, while for example, Omukai et al. (2008) and Schneider et al. (2012) state that the cooling can be driven by dust.

The study of metal-poor stars allows us to better understand the Universe emerging from the big bang. There are some points we are particularly interested in and on which our research is focused on.

- To better draw the behaviour of the metal-weak end ([M/H] < −3.5) of the metallicity distribution function, which is still not clear.
- To determine in the metal-poor stars the relative abundance of the elements, that are the signature of the massive first stars.

- To determine the trend of the lithium abundance in the matter at the beginning of the Galaxy.
- To find the most metal-poor stars.

2. Selection of metal-poor candidates

Metal-poor stars are very rare object, to find them it is fundamental to exploit large data-bases. Usually large surveys have low-resolution spectra, and a high-resolution follow-up is necessary to complete a detailed chemical analysis. We exploited the Sloan Digital Sky Survey (SDSS and SEGUE York et al. 2000; Yanny et al. 2009) in order to select metal-poor candidates to observe with X-Shooter (D'Odorico et al. 2006) or UVES (Dekker et al. 2000). Three carbon-enhanced metal-poor stars described in Behara et al. (2010), fifteen in Bonifacio et al. (2012), one in Sbordone et al. (2012), have been observed with UVES. We could analyse X-Shooter spectra observed during the French-Italian gatantee time of observation. Other on-going X-Shooter observations are part of the ESO large programme TOPoS 189.D-0165.

3. French-Italian X-Shooter GTO

The French and Italian PIs of X-Shooter, F. Hammer, the late R. Pallavicini and, subsequently, S. Randich, decided to invest two and a half nights of GTO on this project.

- Half a night on February 2010; two stars were selected, not extremely metal-poor, but faint, to test the performances of X-Shooter on metal-poor stars. The results are summarised in Bonifacio et al. (2011).
- One night on February 2011. Six extremely metal-poor stars were observed (Caffau et al. 2011b), and within them SDSS J102915+172927, a record metal-poor star (Caffau et al. 2011c, 2012). Also two back-up stars were observed (HE 1044-2509 and HE 1249-3121).
- Half a night on July 2011; no observation could be done due to bad weather.
- Half a night on July 2012; four stars have been observed, the data will be soon analysed.

3.1. SDSS J102915+172927

SDSS J102915+172927, with a *g*-magnitude of about 17, is a relatively bright object for X-Shooter. In 1 h observation time a spectrum of signal-to-noise (S/N) ratio of about 100 at 400 nm can be obtained. The stellar parameters, effective temperature (5811 K) and gravity (4.0), were derived from SDSS photometry (for details see Caffau et al. 2012). No metallic line was clearly detectable on the X-Shooter spectrum of SDSS J102915+172927. Only UVES spectra, obtained in ESO Director Discretionary Time (DDT, programme 286.D-5045), allowed a detailed chemical analysis. This star is extremely metal-poor and does not show enhancement in carbon and nitrogen, for which only an upper limit could be derived. The upper-limits on C and N are stringent enough to ensure the star is not strongly enhanced. The oxygen is not detectable. The most stringent upper-limit we can derive from the S/N of the UVES spectrum in the range of the oxygen triplet at 777 nm is $[O/H] \leq -2$. This upper-limit is so high that gives us no better knowledge in the chemical composition of the star. For the detected elements, the abundances derived are reported in Table 1. The star appear to be a "normal" EMP star. Taking into account the upper-limit on C and N, and assuming an enhancement in oxygen of [O/Fe]=+0.6, its metallicity is $Z \leq 7.40\times10^{-7}$, or $Z = 5\ 10^{-5} Z_{\odot}$, assuming $Z_{\odot} = 1.53 \times 10^{-2}$ (Caffau et al. 2011a).

No lithium is detected in the spectrum of SDSS J102915+172927. An upper limit of A(Li)<1.7 at 3σ, is derived from the S/N ratio and the Cayrel's formula (Cayrel 1988) from the X-Shooter spectrum. The limit is much more stringent from the UVES spectra A(Li)< 0.9 , at 3σ.

3.2. HE 1044-2509/

This star was observed as back-up because, due to the strong wind, the telescope could not point north, and the SDSS targets are all to the north from Paranal. HE 1044-2509 was analysed by Barklem et al. (2005) that derived from a UVES spectrum (programme

Table 1. The chemical abundances of SDSS J102915+172927 derived from line profile fitting.

Element	$[X/H]_{1D}$	$[X/H]+NLTE+3D$	N lines	$A(X)_{\odot}$
C	≤ −3.8	≤ −4.5	G-band	8.50
N	≤ −4.1	≤ −5.0	NH-band	7.86
Mg I	−4.71 ± 0.11	−4.49 ± 0.12	5	7.54
Si I	−4.27	−3.96	1	7.52
Ca I	−4.72	−4.54	1	6.33
Ca II	−4.60 ± 0.11	−4.95 ± 0.09	3	6.33
Ti II	−4.75 ± 0.18	−4.84 ± 0.16	6	4.90
Fe I	−4.73 ± 0.13	−4.89 ± 0.10	43	7.52
Ni I	−4.55 ± 0.14	−4.90 ± 0.11	10	6.23
Sr II	≤ −5.10	≤ −5.09	1	2.92

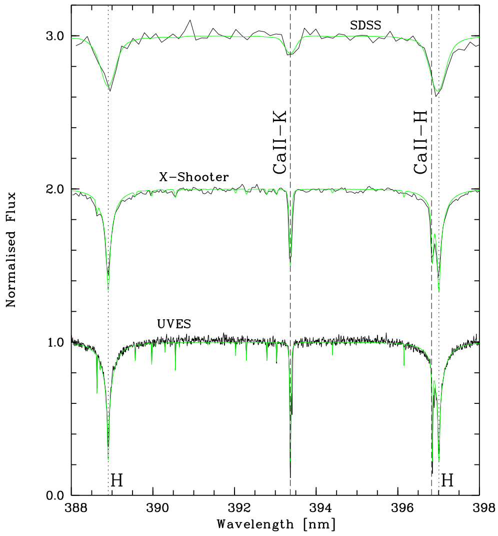

Fig. 1. The range of the Ca II H and K lines of SDSS, X-Shooter, and UVES spectra (solid black), with over-imposed a synthetic spectrum with metallicity -4.5, α-enhanced by 0.4 dex (solid green).

68.B-0320) the parameters 5227 K/2.78/–2.89, and a radial velocity of 386 km s^{-1} . From our X-Shooter spectrum we derived a radial velocity of 339 km s^{-1} . A third UVES spectrum observed again as a back-up in programme 081.D.0373 gives a radial velocity of 357 km s^{-1} . We can conclude that the star is in a binary system, but it is a single lined system (SB1) since no sign of the secondary is visible in the spectrum.

The two (UBV and VIS) X-Shooter spectra show a difference in radial velocity of 7km/s.

A feature at the wavelength of the Li doublet is visible. Its equivalent width is about 1.65 pm in agreement in UVES and X-Shooter spectra. By using the fitting function of Sbordone et al. (2010) we derive $A(Li)_{3DNLTE}$ = 1.24; this value is extrapolated.

4. Turn Off PrimOrdial Stars

The ESO large programme TOPoS (189.D-0165 PI E. Caffau), to observe turn-off metal-poor stars, started in ESO semester 89. We have 150 h assigned at VLT divided in 120 h X-Shooter and 30 h UVES, over four semesters. We plan to observe with X-Shooter a sample of about 80-100 turn-off stars selected from SDSS, and to select the stars (about five) that, according to the X-Shooter spectrum, are the most interesting, to have a higher resolution spectrum with UVES. The scientific goals of TOPoS are the following:

- to determine the metal-weak tail of the Halo metallicity distribution function, below [M/H]=–3.5, where the low resolution SDSS spectra are inadequate;
- to determine in EMP stars the relative abundances of the elements, that are the signature of the massive first stars;
- to determine the trend of the lithium abundance in the matter at the beginning of the Galaxy;
- to improve in understanding the star formation from primordial gas.

5. Conclusions

The analysis on high resolution spectra of EMP candidates selected from SDSS confirms their low metallicity. A sample of twenty stars observed with UVES and eight with X-Shooter supports this claim. In a relatively small sample of twenty-five stars, we also discovered a record metal-poor star.

The resolution of X-Shooter (7400 in the UBV arm when using the IFU) is somehow a limiting factor for the chemical analysis of metal-poor stars. An X-Shooter spectrum of an extremely low-metallicity star, as SDSS J102915+172927, shows no clear metallic line, except the Ca II-K line. But the very high efficiency of X-Shooter allows to observe a useful sample of faint EMP stars in a single night. We think that the resolution of X-Shooter is sufficient for the chemical analysis of stars with $[M/H] \gtrapprox -4.0$. The stars with metallicity lower than –4.0 are so few, that one can re-observe them with UVES.

SDSS J102915+172927 is a primordial star which shows no strong enhancement in carbon and nitrogen. Its composition does not allow the cooling of the gas forming this star according to the theory described in Bromm & Loeb (2003), while this theory can perfectly explain the formation of the other EMP stars we observed. But the cooling by dust, as stated by Schneider et al. (2012), can perfectly explain the formation of a star with this composition. The discovery of SDSS J102915+192927 gave new impulse to the study of star formation from low-metallicity clouds.

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