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Abundance analysis of three metal poor stars: CS 22166-0030, CS 22186-0005, and CS 30344-0033

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Abstract. We present the abundance analysis of three very metal poor stars, CS 22166-0030 ([Fe/H]= −2.96), CS 22186-0005 ([Fe/H]= −2.70), and CS 30344-0033 ([Fe/H]= −2.90). Our study is based on high resolution spectra which were obtained from SARG (on TNG), HARPS (on 3.6m), and UVES (on VLT) spectrographs and one-dimensional ATLAS9 model atmospheres. We derived the abundances for 2, 9, and 16 atomic species in the spectrum of CS 22166-0030, CS 22186-0005, and CS 30344-0033, respectively. The Na and Mg abundances of CS 22166-0030 are highly under-abundant with respect to the solar values. The abundance patterns of CS 22186-0005 and CS 30344-0033 are consistent with the other halo stars within abundance uncertainties.

Keywords. stars: abundances, stars: Population II, Galaxy: abundances, Galaxy: evolution

1. Introduction

Since the atmospheres of stars reflect the chemical composition of the interstellar medium from which they have been formed, metal poor stars provide archeological evidence of the beginning of the universe. This kind of star plays an important role in understanding the nature of the first objects which were formed in the universe and are thought to be the first steps of galactic chemical evolution.

Chemical abundance analysis can be seen as research into the genetic codes of stars. Studying a star's nature (physical and chemical properties, evolution, etc.) generally leads to an understanding of its role in the universe.

CS 22166-0030, one of our target very metal poor stars (VMPSs) was analysed by Ryan *et al.* (1996) and by Yong *et al.* (2013). CS 22186-0005 was identified in the HK objective-prism survey by Beers *et al.* (1992) and classified as a horizontal branch star by Norris *et al.* (1996). For CS 22186-0005, the abundance analysis was performed by Preston *et al.* (2006) and by For & Sneden (2010). Broad-band photometric data of CS 30344-0033 (or HE 2252-3458) was published by Norris *et al.* (1999) and it is a metal weak candidate. This star was also selected as a candidate metal poor star in the Hamburg ESO Survey (HES Christlieb *et al.* 2008). No abundance analysis has been performed for this star up to now.

Our aim in this study is to calculated the chemical abundances of three target VMPSs which contain the yields of the first supernovae in the universe.

2. Observation

The spectra of CS 22166-0030, CS 22186-0005, and CS 30344-0033 were obtained with SARG/TNG, HARPS/3.6m, and UVES/VLT in Service Mode, respectively. Details of the observing sessions and instrumental setups, which include the coordinates and brightness of the stars, observing dates, exposure times, wavelength ranges of the spectra, and resolving powers, are presented in Table 1.

Table 1. The properties and observations log of target stars.

Object	**RA**	**DEC**	**B** [mag]	**Observation date**	**Exposure times**	**Wavelength range**[Å]	**Resolving power**
CS 22166-0030	01 05 27.9	−11 57 31.1	14.03	2000 Jan.		4600 − 6170	46000
CS 22186-0005	04 13 09.1	−35 50 38.7	13.33	2006 March	1800	3778 − 6908	115000
CS 30344-0033	22 55 31.9	−34 42 59	14.61	2006 May	3600	3300 − 5758	40000

We rebinned all spectra by a factor of two to increase their signal-to-noise ratios (S/N). The S/N of each spectrum after rebinning, around 4000 Å and 5000 Å are listed in Table 2.

We measured the radial velocities of the stars, using the Na I D, Mg I b in the red region and the Mg I triplet in the blue region, as well as Fe I lines across the entire wavelength range. The final heliocentric radial velocities for each star are listed in Table 2.

Table 2. Measured S/N and heliocentric radial velocities.

Object	S/N [@4000Å]	S/N [@5000Å]	v_{helio}[km s^{-1}]
CS 22166-0030	-	15	46.8 ± 1.2
CS 22186-0005	-	30	193.3 ± 1.2
CS 30344-0033	40	120	101.1 ± 0.6

3. Abundance Analysis

3.1. *Stellar parameters*

We computed atmospheric models for CS 22166-0030 and CS 22186-0005, using initial stellar parameters given by Casagrande *et al.* (2010) and by For & Sneden (2010), respectively. To determine the final atmospheric parameters we followed a traditional method: for the effective temperature (T_{eff}) we assume that the abundances of individual Fe I lines show no trend with excitation potential, for the microturbulence (ξ) that there shall be no trend of the abundances with equivalent width (EW) of the Fe I lines, and for the surface gravity ($log\ g$) that ionization equilibrium be achieved between the abundances derived from the Fe I (adopting a non-LTE correction for Fe I of 0.1 dex from Lind *et al.* 2012) and Fe II lines. To determine the effective temperature of CS 30344-0033 from the available colors given by Christlieb *et al.* (2008), we employed the Casagrande *et al.* (2010) temperature calibrations. The surface gravity of CS 30344-0033 was derived from photometry by means of Yale-Yonsei isochrones. For this we used 10 and 12 Gyr isochrones with an iron abundance of [Fe/H]$= -2.5$ dex, $\alpha-$enhancement of $[\alpha/\text{Fe}] = 0.3$ dex and the photometrically derived T_{eff} of the star. These values were used as initial stellar parameters and final stellar parameters were determined by using the aforementioned traditional method. The stellar parameters of three target VMPSs obtained by this procedure are listed in Table 3.

Table 3. Stellar parameters of target stars.

Object	T_{eff} [K]	*log g* [cgs]	ξ [km s^{-1}]	**[Fe/H]**[dex]
CS 22166-0030	6250	4.56	2.10	−2.96
CS 22186-0005	6160	2.60	3.55	−2.70
CS 30344-0033	6100	2.70	3.20	−2.90

We employed a linux version of the ATLAS9 code (Kurucz 1993a, Kurucz 2005, Sbordone *et al.* 2004) for computing individual model atmospheres for each star. In the computation, local thermodynamic equilibrium (LTE), plane-parallel geometry, hydrostatic equilibrium, and no convective overshooting are assumed.

Starting from grids of ATLAS9 model atmospheres that were computed by Castelli & Kurucz (2003) for a metallicity of [M/H]= −3.0 dex with $\alpha-$enhanced (by a factor 0.4 dex) new opacity distribution functions (ODFs), we computed tailored models for the target stars.

3.2. *Line list, equivalent width measurement and spectrum synthesis*

We compiled the line lists from Sbordone *et al.* (2010), Roederer *et al.* (2010), Aoki *et al.* (2007) and Hayek *et al.* (2009) for the measurements of atomic absorption lines in the spectra of the stars. For Fe II lines, we used the *log gf* values determined by Melendez & Barbuy (2009).

EW measurements were done by fitting a Gaussian profile to the lines simultaneously with a straight-line continuum, where the continuum and line regions were chosen interactively.

From EW measurements, abundances were derived using the WIDTH9 code (Kurucz 2005, Sbordone *et al.* 2004), which uses ATLAS9 model atmospheres to compute line formation in LTE. For the abundance analysis, we did not use lines with EWs larger than 165 mÅ.

Line lists that include hyperfine structure (HFS) splitting for Sc, Mn, and Co were downloaded from Robert Kurucz's web page. Since the EW method is not appropriate for lines where HFS splitting has to be taken into account, we applied the spectrum synthesis method for Sc, Mn, and Co lines: we produced synthetic spectra with the SYNTHE code (Kurucz 1993b, Kurucz 2005) and then those spectra were convolved with a Gaussian profile that includes the broadening effects due to the instrumental profile, and the macroturbulence velocity. The abundances of the species were adjusted until the observed and synthetic spectrum were in good agreement.

3.3. *Abundance results*

For CS 22166-0030 we determined the abundances for only two atomic species Na I and Mg I. Na and Mg abundances were derived from 5889-5895 Å and 5172-5183 Å lines, respectively. Our data do not permit us to measure the elemental abundances other than these species. The Na is under-abundant by −0.16 dex and the Mg is highly under-abundant by −0.34 dex with respect to the solar values. We show abundance patterns of CS 22166-0030 in Fig. 1.

We determined the abundances for nine atomic species on the spectrum of CS 22186-0005. The Na, Mg, Al, and Si abundances were derived from 5889-5895 Å lines of Na,

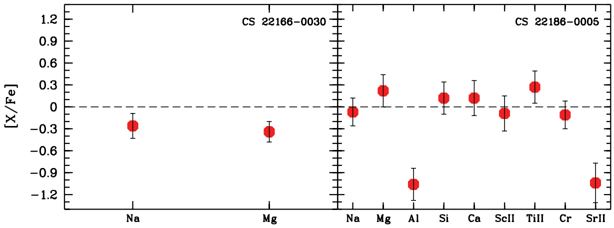

Figure 1. Abundance patterns of CS 22166-0030 and CS 22186-0005. The error bars indicate the standard deviations of the abundance ratios over the square root of the number of lines.

5172-5183 Å lines of Mg, 3961 Å of Al, and 3905 Å of Si. We also determined the abundance of Sr, a neutron capture element, using the 4077 and 4215 Å lines. Na, Al, Sc, Cr, and Sr are under-abundant by −0.07, −1.06, −0.09, −0.11, and −1.04 dex, respectively, while Mg, Si, Ca, and Ti are over-abundant by 0.22, 0.12, 0.12, and 0.27 dex, respectively, with respect to the solar values, as shown in Fig. 1.

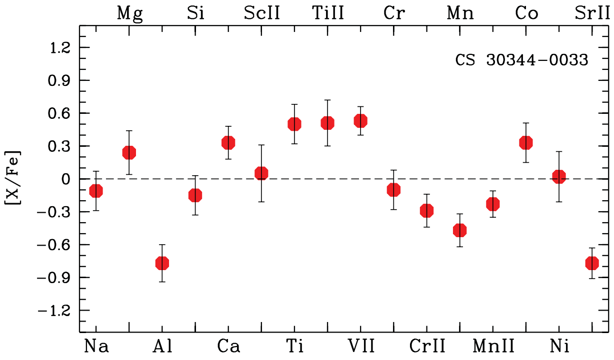

Figure 2. Abundance patterns of CS 30344-0033. The error bars are the same as in Fig. 1.

In Fig. 2, we show the abundance pattern of CS 30344-0033. We derived the abundances for the iron peak elements Sc, V, Cr, Mn, Co, and Ni, the $\alpha-$elements Mg, Si, Ca, and Ti, the light odd element Na and Al, and the neutron-capture element Sr. The abundance results, the number of lines, and abundance uncertainties are listed in Table 4.

3.4. *Comparisons with the previous studies*

We compared the abundance ratios of CS 22166-0030 and CS 22186-0005 with previous studies, as shown in Fig 3. The Na abundance for CS 22166-0030 is slightly lower than the value given by Yong *et al.* (2013), while the Mg abundance is lower by ~ -0.3 dex than their study. Yong *et al.* (2013) applied a non-LTE correction for Na I of −0.1 dex, when we applied that correction for Na, the differences in between the Na and Mg abundance ratios are almost same; in other words both of our results are lower than those found Yong *et al.* (2013). The differences are probably due to [Fe/H], because they determined a metallicity of −3.28 and ours is −2.96 dex.

We also compared the abundance ratios of CS 22186-0005, with those from For & Sneden (2010). Our results for CS 22186-0005 are about the same as those of For & Sneden (2010) within the abundance uncertainties. In comparing the abundance ratios with previous studies we did not make any effort to use the same solar abundances.

Table 4. Abundances of target stars.

		CS 22166-0030				**CS 22186-0005**				**CS 30344-0033**			
Species	*log* $\epsilon_{\odot}{}^{a}$	N^b	**A(X)**	**[X/Fe]**	σ^c	N^b	**A(X)**	**[X/Fe]**	σ^c	N^b	**A(X)**	**[X/Fe]**	σ^c
[FeI/H]	7.50	12	4.58	-2.92	0.13	27	4.80	-2.70	0.19	83	4.60	-2.90	0.14
[FeII/H]	7.50	3	4.58	-2.92	0.09	7	4.86	-2.64	0.12	6	4.69	-2.81	0.11
Na I	6.33	2	3.25	-0.16	0.12	2	3.56	-0.07	0.13	2	3.32	-0.11	0.13
Mg I	7.58	2	4.32	-0.34	0.10	2	5.10	0.22	0.16	6	4.92	0.24	0.08
Al I	6.47					1	2.71	-1.06	0.22	2	2.80	-0.77	0.12
Si I	7.55					1	4.97	0.12	0.22	1	4.50	-0.15	0.18
Ca I	6.36					5	3.78	0.12	0.11	4	3.79	0.33	0.08
Sc II^{hfs}	3.17					2	0.45	-0.09	0.17	8	0.41	0.05	0.09
Ti I	5.02									1	2.62	0.50	0.18
Ti II	5.02					9	2.65	0.27	0.07	28	2.72	0.51	0.04
V II	4.00									2	1.72	0.53	0.09
Cr I	5.67					2	2.86	-0.11	0.13	6	2.67	-0.10	0.07
Cr II	5.67									1	2.57	-0.29	0.15
Mn I^{hfs}	5.39									3	2.02	-0.47	0.09
Mn II	5.39									2	2.35	-0.23	0.08
Co I^{hfs}	4.92									4	2.35	0.33	0.09
Ni I	6.25									12	3.37	0.02	0.07
Sr II	2.97					2	-0.71	-1.04	0.19	2	-0.61	-0.77	0.10

Notes:
[a] Solar abundance ratios are taken from Grevesse & Sauval (1998)
[b] The number of lines
[c] The standard deviations of the abundance ratios over the square root of the number of lines

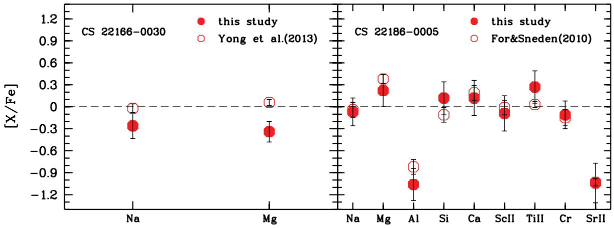

Figure 3. Comparison of the abundances of the previous with the present study. The error bars are the same as in Fig. 1.

4. Conclusion

Using the high resolution spectra, we derived the elemental abundances of three VMPSs, their metallicities are lower than −2.5 dex.

The abundance analysis of CS 22166-0030 and CS 22186-0005 are available in the literature. The abundances in CS 22166-0030 are lower than those of Yong *et al.* (2013). Our abundance results for CS 22186-0005 agree with the study of For & Sneden (2010). This study is first abundance analysis of CS 30344-0033. We derived the abundances for the iron peak elements Sc, V, Cr, Mn, Co, and Ni, the $\alpha-$elements Mg, Si, Ca, and Ti, the light odd element Na and Al, and the neutron-capture element Sr.

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Discussion

HANS-GÜNTHER LUDWIG: When you showed the results of your analysis the slopes which determining T_{eff} and ξ were not exactly zero. Does this indicate that it was in fact impossible to obtain a slope of zero simultaneously?

ŞEYMA CALISKAN: Yes.

BIRGITTA NORDSTRÖM: Did you measure any of the elements heavier than Sr?

ŞEYMA CALISKAN: We did not measure any element heavier than Sr.