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Letter to the Editor

Analysis of two CH/CN-strong very metal-poor stars*

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Abstract. Two very metal-deficient stars, BPS CS 22948-27 and BPS CS 29497-34, recently identified in the HK objective-prism/interference-filter survey of Beers and collaborators, which exhibit, at low resolution, strong CH and CN bands and metallicities [Fe/H] ≈ -3, have been observed at high spectral resolution and high S/N at the NTT at ESO with the EMMI echelle spectrograph. A preliminary analysis of these spectra shows that these objects are very unusual. The high-resolution work confirms the very low metallicity of these stars and indicates: (i) effective temperatures $T_{\rm eff} \approx 4000$ K and surface gravities log g $\approx$ 0.0 to 1.5; (ii) a very large overabundance of carbon and nitrogen, by $\sim$2 dex with respect to iron; (iii) a similar overabundance of a few neutron-capture elements, in particular Ba, La and Nd, also by $\sim$2 dex; (iv) a low isotopic ratio $^{12}C/^{13}C$; (v) a variable radial velocity for one of the stars (CS 22948-27). These findings suggest that the two stars are extreme cases of CH stars. The spectra are considerably richer in molecular bands than the spectrum of the remarkable star CS-22892-52, identified in the same survey and studied by Sneden et al. The determination of the ratio of s-process to r-process elements in these two stars must await observations in the blue spectral region.

Key words: Stars: abundances - Stars: Population II

1. Introduction

The large HK objective-prism/interference-filter survey of Beers and collaborators (Beers, Preston & Schectman 1992, hereafter BPS, and further unpublished work) has led to the discovery of numerous new metal-poor stars. Currently, over 100 stars are known to have metallicities in the range $-4.0 <$ [Fe/H] < -3.0, compared to the handful of such stars known only a decade ago.

Already BPS pointed out the presence of very metal-poor stars with strong CH and CN bands in their survey. Sneden et al. (1994, 1996) analysed one of these peculiar stars (CS 22892-52) and found large overabundances of C, N, and neutron-capture elements.

Two very-low-metallicity, CH/CN-strong stars were selected from a programme at moderate spectral resolution, carried out by the authors at the ESO 1.5m spectrographic telescope as a follow-up to the HK survey. The metallicities from the low-resolution spectra (Beers et al. 1990), are given in Table 3 in the column $[Fe/H]_c$. In this Letter we present the first results obtained at high spectral resolution for these two peculiar stars. For comparison, the ultra-metal-poor star CD $-$ 38°245 is also re-analyzed with spectra obtained during the same observing runs.

2. Observations and data reduction

The observations were carried out with the ESO Multi-Mode Instrument (EMMI) in the dichroic mode, at the 3.5-m New Technology Telescope (NTT) at ESO, La Silla, Chile. The red channel used the echelle grating and the Tektronix 2048 $\times$ 2048 CCD at a resolution of $R \approx 30000$. In the blue channel, the holographic grating and a Tektronix 1024 $\times$ 1024 CCD were used to observe the NH molecular band at 336 nm and the CN and CH bandheads at 426 and 430 nm at $R \approx 9000$. The summed spectra have S/N $\geq$ 80. The observing log is given in Table 1.

* Based on observations collected at ESO, La Silla, Chile.

Table 1. Logbook of the observations. The first column lists visual magnitudes and coordinates (B1950) below the name of each new star. Radial velocities are given in the last column.

Star	date	exp. min	λ nm	λ nm	V_{hel} kms^{-1}
CS22948-27	14-09-95	120	500-820		-48.7
$12^{m}\!.66$	16-09-95	105	500-820		-49.6
21 34 39.3	02-11-95	60	500-820	330-340	-55.9
−39 40 51	03-11-95	60	500-820	420-430	-56.6
	04-11-95	55	500-820	420-430	-56.9
CS29497-34	13-09-95	120	500-820		-30.2
$13^{m}\!.5$	13-09-95	95	500-820		-30.4
00 39 12.0	02-11-95	90	500-820	330-340	-31.4
−26 35 22	03-11-95	75	500-820	420-430	-30.7
CD–38°245	14-09-95	70	500-820		
$12^{m}\!.0$	01-11-95	60	500-820	330-340	

Table 2. Observed Fe lines

λ Å	χ_{ex}	log gf	W(mÅ) -38 245	W(mÅ) 22948-27	W(mÅ) 29497-34
Fe I					
5168.91	0.05	-4.000	–	67.	46.
5171.61	1.48	-1.793	29.	97.	71.
5227.19	1.56	-1.352	40.	109.	85.
5269.54	0.86	-1.321	88.	143.	115.
5328.04	0.91	-1.466	74.	133.	112.
5341.02	1.61	-2.06	12.	71.	49.
5371.49	0.96	-1.645	65.	129.	111.
5397.13	0.91	-1.993	50.	109.	92.
5405.77	0.99	-1.844	53.	102.	96.
5429.70	0.96	-1.879	54.	102.	85.
5434.52	1.01	-2.122	34.	111.	91.
5446.92	0.99	-3.109	48.	112.	88.
Fe II					
5169.05	2.89	-1.1		103.	77.
5234.63	3.22	-2.15		44.	22.
5316.62	3.15	-1.95		57.	32.
5316.78	3.22	-2.5		22.	15.

3. Analysis

3.1. Determination of model atmosphere parameters

The grid of Bell-Gustafsson models for metal-deficient giants (Gustafsson et al. 1975; MARCS models), with later improvements and extensions towards lower gravities, was adopted to model the atmospheres of our stars. For CS 22948-27 the $(B-V)$ colour was measured by BPS (Table 3). As the spectra of CS 22948-27 and CS 29497-34 are very similar, we adopted the same $(B-V)$ for the two stars as a first approximation. In any case, few if any good calibrations between $(B-V)$ and temperature exist for such peculiar stars.

In a first approach, we determined the temperature of our stars by comparison with CS 22892-52, which also shows over-abundances of C and N ([C/Fe]=+1.0, [N/Fe]=+0.8; Sneden et al. 1994, 1996). With a difference in $(B-V)$ of 0.33 we adopt a temperature difference of 550K, and thus a temperature of 4200K for CS 22948-27 and CS 29497-34.

As an alternative, the $(B-V)$ colour calibration for CH stars by Aoki and Tsuji (1996), was used to yield T_{eff} =4700K. As colours are difficult to use for effective temperature determination in stars with strong molecular bands, we have also used the relative intensities of the (1,1) and (0,0) bandheads of C_2 to get an independent measurement of the temperature. As explained in section 4, we find $T_{eff} \approx 4200$ K from this method. The subsequent analysis has been made for two assumed temperatures (4700 and 4200 K), although there is strong evidence in favour of the lower value.

Our two programme stars show very few measurable atomic lines, due to the combination of very low abundance (weak lines) and a forest of C_2 and CN lines covering most of the spectrum. However, in the range $\lambda 515-545$ nm some iron lines are measurable and were used to determine the model atmosphere parameters and metallicities of the stars. The same lines were also measured in the spectrum of CD-38^{o}245, where no molecular lines are seen. The gf values were adjusted by fitting the observed solar spectrum of Kurucz et al. (1984) with a synthetic spectrum based on the Holweger-Müller (1974) solar model. The results are very close to the gf values given by Fuhr et al. (1988) and O'Brien et al. (1991).

For the assumed temperatures, the microturbulence velocity was found by requiring that the abundance be independent of the equivalent width of the FeI lines, and the gravity by forcing the Fe I and FeII lines to give the same abundance. The list of lines and adopted atomic constants used for the metallicity determination is given in Table 2, and a sample curve of growth in Fig. 1.

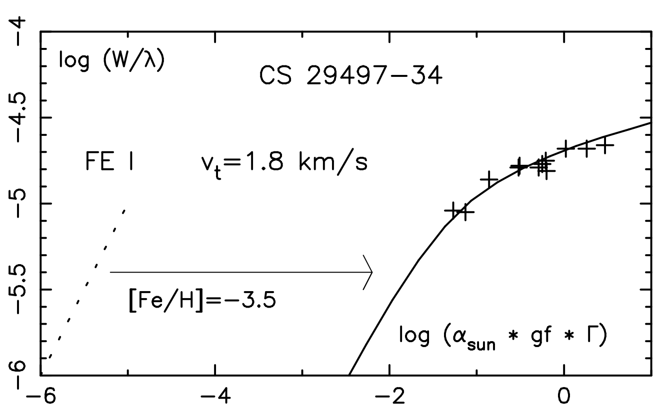

Fig. 1. Curve of growth of FeI for CS 29497-34 (T_{eff} =4200K)

For CD-38^{o}245 we adopt the stellar parameters given by Peterson et al. (1990): (T_{eff}, log g, v_t) = (4750 K, 1.88 dex, 2.5

km s^{-1}), which are very close to those obtained by McWilliam et al. (1995b) of (T_{eff}, log g, v_t) = (4730 K, 1.80 dex, 1.97 km s^{-1}). We then derive a metallicity of [Fe/H] = –4.1 from the Fe I lines, in excellent agreement with both Peterson et al. (1990; [Fe/H] = –4.04) and McWilliam et al. (1995b; [Fe/H] = –4.01).

In Table 3, we give the gravities and metallicities for CS 22948-27 and CS 29497-34, assuming both T_{eff} =4200K and T_{eff} =4700K. At fixed temperature, we estimate the error of [Fe/H] to be ±0.2, mainly due to uncertainties in the microturbulence velocity. The metallicities found assuming T_{eff} =4200K are very close to those estimated from the low resolution spectra ($[Fe/H]_c$ in Table 3). For comparison, Table 3 also gives our results for CD-38°245 and those of Sneden et al. (1994, 1996) for CS 22892-52.

Table 3. Main stellar parameters and metallicities. $[Fe/H]_c$ is the estimate from the low-resolution spectra, v_t is the microturbulence velocity (km s^{-1}). [Fe/H] in the last column is derived from our new spectra and model atmospheres.

star	B-V	$[Fe/H]_c$	T_{eff}	log g	v_t	[Fe/H]
CD-38°245	0.76	-4.3	4750	1.9	2.5	-4.1
CS 22948–27	1.13	-3.2	4200	0.2	2.0	-3.2
			4700	1.2	2.0	-2.8
CS 29497–34	-	-3.6	4200	0.2	1.8	-3.5
			4700	1.2	1.8	-3.1
CS 22892–52	0.80	-3.1	4760	1.3	2.3	-3.1

4. Carbon and nitrogen abundances

Rotational lines of the C_2 $A^3\Pi$ - $X^3\Pi$ Swan system and CN $A^2\Pi$ - $X^2\Sigma$ red system lines were used. The adopted molecular constants are described in Barbuy et al. (1991).

The carbon, nitrogen and oxygen abundance determinations depend on each other: We start by deriving the C abundance from the C_2 band strengths, then N from CN lines. For both stars [O/Fe] = 0.5 was assumed compatible with the absence of measurable OI 630.03 nm line in the spectrum. The C and N abundances were then refined by successive iteration, taking into account the actual abundances of the other elements. In addition, we used the C_2 lines to check our choice of effective temperature by verifying which model atmosphere best reproduces the relative intensities of the (v',v") = (0,0) and (1,1) vibrational bandheads, since the (1,1)/(0,0) bandhead ratio increases with temperature. With this method, we find a temperature of Teff=4000 K to be suitable for CS 22948-27, 4200 K for CS 29497-34. Thus, the molecular lines favour relatively low temperatures for the two stars.

From a fit to the C_2 Swan bands, in particular the (0,0) bandhead at λ 516.524 nm, we derive the carbon overabundances reported in Table 4. Fig. 2 illustrates the fit to the observed spectrum and the change in C_2 (0,0) bandhead strength for different carbon overabundances.

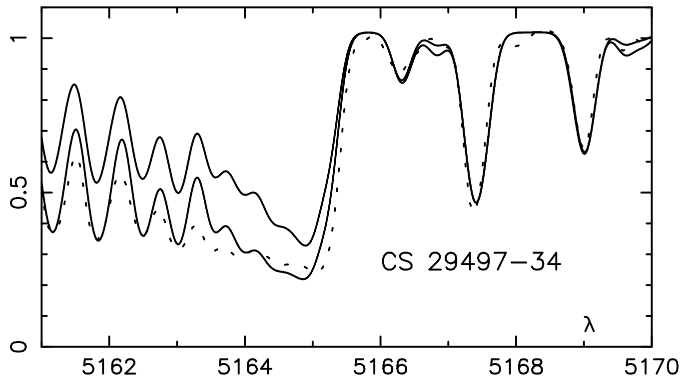

Fig. 2. Observed (dots) and synthetic spectrum (solid lines) of the C_2 (0,0) bandhead in CS 29497-34, computed for [C/Fe] = +2.2 and +2.5

We next determine the nitrogen abundance from the red CN bands, the lines of which are strong and distributed throughout the red spectrum. A fit to these lines yields to the N abundances given in Table 4. CO association is less important in these stars than in stars of more normal abundances, given the large excess of C relative to O.

(Note that if we adopted T_{eff} = 4700K, the C overabundances would be +3.0 and +3.3 dex, respectively, for CS 22948-27 and CS 29497-34.)

The $^{12}C/^{13}C$ isotope ratio was measured for both stars from the CN lines at 800.3-800.4 nm. The low value of this ratio (Table 4) suggests that extensive mixing occurred in these stars.

Table 4. C, N, and neutron-capture element abundances relative to iron, and $^{12}C/^{13}C$ ratios, all computed for T_{eff} =4200K

	CS22948-27	CS29497-34	CS22892-52
C	+2.1	+2.5	+1.0
N	+1.55	+2.1	+0.8
Na	+0.8	+1.6	+0.1
Mg	+0.6	+0.8	+0.4
Y	$\leq$ +1.7	$\leq$ +1.7	+0.45
Ba	+1.9	+2.25	+0.91
La	+1.9	+2.0	+1.09
Nd	+2.25	+2.4	+1.27
Eu	$\leq$ +2.2	$\leq$ +2.1	+1.7
$^{12}C/^{13}C$	14±4	12±4	

5. Abundances of α- and neutron-capture elements

The abundances of Mg and the neutron-capture heavy elements Y, Ba, La, Nd, Eu were determined by spectrum synthesis. For the Mg lines, solar oscillator strengths were used, while laboratory atomic oscillator strengths were adopted for the heavy elements (references for the heavy elements are as in McWilliam & Rich 1994). The abundances are given in Table 4.

6. Discussion and conclusions

The two program CH/CN-strong giants have some similarities with CS 22892-52, the star studied by Sneden et al. (1994, 1996), McWilliam et al. (1995), and Cowan et al. (1995), but they are much more extreme in their overabundances of C and N with respect to iron. All these stars have [Fe/H] $\approx$ –3.0, the α-elements are enhanced by factors typical for halo stars, and the neutron-capture elements are also strongly enhanced. However, the two cool stars studied here have higher [C/Fe] ratio than CS 22892-52: $[C/Fe] \approx$ +2 instead of $[C/Fe] \approx$ +1. They also have a higher [N/Fe] ratio, and we note that Anthony-Twarog & Twarog (1992, 1994) suggest that the N abundance increases in CH giants with [Fe/H] $<$ –3.2 dex. The present data are too limited to decide whether the abundances of our program stars are the products a nearby supernova which ejected the elements, as suggested by Sneden et al. (1994) for the case of CS 22892-52, or whether they are CH stars of the classical mass-transfer type (Luck & Bond 1991).

Finally, radial velocities referred to telluric absorption lines were measured from the high-resolution spectra (Table 1). The radial velocity of CS 22948-27 clearly changed with time (Table 5), indicating that it is a binary, which supports a CH-star nature. No significant velocity change is seen for CS 29497-34, but our medium-resolution spectra suggest a variability, which needs to be confirmed.

Table 5. Radial velocity variations of CS 22948-27 and CS 29497-34

Star	Date	RV_{hel} km s^{-1}	error km s^{-1}
CS 22948-27	Sep 1995	-49.2	$\pm$1
	Nov 1995	-56.5	$\pm$1
CS 29497-34	Sep 1995	-30.3	$\pm$1
	Nov 1995	-31.1	$\pm$1

The most interesting feature of these stars is the link between the overabundances in neutron-capture elements and those of C and N. Most heavy elements can be produced either by s- or r-processes, the best discriminant being the Eu/Ba ratio. However, in our spectra the Eu II lines are severely blended, so the abundances (Table 4) are only an upper limits. Our current spectra being taken mostly in the red region, we could not yet measure as many heavy elements as McWilliam et al. (1995a,b). We therefore plan to determine additional heavy-element abundances from blue spectra.

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