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Abundance analyses of a sample of five faint blue stars in the galactic halo

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Abstract. High resolution optical spectra of five faint high galactic latitude B-type stars, identified from a magnitude limited survey, have been analysed using LTE model atmosphere calculations. All targets have small projected rotational velocities ($\leq$30 km s^{-1}) and hence may be evolved objects. This is supported by their chemical compositions, which indicate that they are old Population II stars; two stars also show enhanced nitrogen abundances probably due to the mixing of nuclear processed material to their surfaces. Their atmospheric parameters are consistent with a post-Asymptotic Giant Branch evolutionary status, although two targets may have evolved directly off the horizontal branch.

Key words: stars: early-type – stars: post-asymptotic giant branch – stars: abundances – Galaxy: halo

1. Introduction

Previously Beers et al. (1985, 1996) have described a magnitude limited objective prism/interference filter survey of some 7500 square degrees in the southern and northern Galactic hemispheres. The primary motivation for this survey was the detection of extremely metal-deficient stars cooler than the main-sequence turnoff of an old stellar population. However, large numbers of hot stars were also noted, including extremely hot sdO-type subdwarfs (see Drilling & Beers 1995) and sdB stars, as well as numerous horizontal-branch stars (Beers et al. 1988), and blue metal poor stars referred to by Preston et al. (1994) as BMP stars. Beers et al. (1992) reported on the initial spectroscopic ($\simeq$1 Å FWHM) followup of some 800 candidate hot stars. Most of these were classified as either field horizontal branch or sdOB-type stars, but four appeared to be normal Population I B-type objects. A fifth star, CS 29520−046, was subsequently identified and details of all five stars are listed in Table 1. Photometry is from Landolt (1992) for CS 22877−023, Beers et al. (1992) for CS 22946−005 and unpublished measurements (Preston, private communication) for CS 29520−046. We have also estimated reddening by interpolating within the maps of Burstein and Heiles (1982). If these five stars are indeed young objects on the hydrogen burning main sequence, they would lie at distances from the galactic plane in excess of 50 kpc. Kinematic arguments would then imply that they must have been formed far out in the galactic halo.

In order to investigate whether they are normal Population I objects, we have observed them at high spectral resolution. An abundance analysis should then differentiate between young B-type stars and, for example, evolved post-Asymptotic Giant Branch (PAGB) objects which can have similar atmospheric parameters (see, for example, Hambly et al. 1996a).

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2. Observations and data reduction

Optical spectra were obtained during two observing runs at the Anglo-Australian Telescope in August/September 1993 and August 1994. In both cases, the RGO spectrograph was used with the 1200B diffraction grating, 82 cm camera and a Tektronix CCD as the detector. Two grating positions with central wavelengths of 4020 Å and 4580 Å (giving a wavelength coverage of 240 Å) were used in the earlier observing run. A similar setup was adopted for the August 1994 observations but with an additional wavelength region covering 4210 - 4450 Å. Hence for CS 29520−046, which was only observed during the August/September 1993 run, the wavelength coverage is less complete.

Image reduction was performed using the IRAF (Image Reduction and Analysis Facility) package (Massey 1989; Shames & Tody 1986). Frames were first debiased and flatfielded and cosmic ray hits were removed automatically. Spectra were extracted and sky-subtracted and then wavelength calibrated using Cu-Ar arc exposures, which bracketed each stellar exposure. The spectra were output to the Starlink package DIPSO

Table 1. Details of stellar targets

Star	RA(1950)	Dec(1950)	V	$B-V$	$U-B$	$E(B-V)$
CS 22877−023	13 23 02	−08 33 43	13.5	−0.14	−0.68	0.05
CS 22946−005	01 14 28	−22 28 02	14.5	−0.21	−0.91	0.02
CS 29493−046	21 47 10	−31 03 11	15.1	-	-	0.00
CS 29501−020	21 00 45	−33 34 58	14.8	-	-	0.08
CS 29520−046	04 32 39	−62 50 08	13.7	−0.04	−0.20	0.00

(Howarth et al. 1993) and after co-addition had a typical continuum signal-to-noise ratio of ≃60.

The spectra were normalised by fitting low order polynomials to regions of the continuum devoid of absorption features. Equivalent widths of metal and non-diffuse helium line features (listed in Tables 2 and 3) were then estimated by non-linear least squares fitting of Gaussian line profiles plus a polynomial to represent the continuum. The errors quoted correspond to the 68% confidence level, and a selection of fits are shown in Fig. 1. The minimum detectable equivalent width was limited by the spectral resolution and statistical noise; from fitting Gaussian profiles to spectral regions that were believed to not contain any absorption lines, this lower limit was conservatively estimated to be approximately 20 mÅ. This relatively small value was principally due to the very sharp lined nature of all our targets. Radial velocities were estimated from the central wavelengths of single isolated lines found during the profile fitting and are listed in Table 4 (after correction to a heliocentric frame). In general, these are in good agreement with those found by Beers et al. (1992) from their low resolution spectroscopy. An attempt was also made to estimate projected rotational velocities using strong metal lines, which were fitted by a convolution of the instrumental profile with a rotational broadening function within a modified version of DIPSO (Dufton 1990). However the relatively broad instrumental profile of 0.7 Å (FWHM, as measured from the arc spectra) allowed only upper limits of typically 30 km s^{-1} to be derived.

3. Analyses

The observed line strengths and profiles were analysed using LTE model atmosphere techniques, with all models being taken from the grid of Kurucz (1991). The results for individual stars are discussed below, with the adopted atmospheric parameters summarized in Table 4 and the chemical compositions in Tables 5 and 6.

3.1. CS 29501−020

This star has the highest effective temperature and together with CS 22946−005 has a relatively rich metal line spectrum. A preliminary effective temperature estimate, T_{eff}=28000 K, was obtained from the He I lines (assuming a normal helium abundance) and then the surface gravity was estimated from the Hϵ, Hδ and Hγ line profiles. The effective temperature estimate was then refined using the Si III/Si IV ionization equilibrium. For both ionic species, non-LTE effects were included by scaling the observed equivalent widths by theoretical LTE/NLTE line strength ratios given by Lennon et al. (1986) before inputting them to the LTE codes. An effective temperature of 27000±2000 K (with a surface gravity log g=3.8±0.2) was obtained, consistent with the temperature estimated from the He I/He II ionization equilibrium when corrected for non-LTE effects (see, for example, Kendall et al. 1995). A microturbulent velocity, V$_t$, of 7 km s^{-1} (with an estimated uncertainty of approximately 5 km s^{-1}) was determined from the O II spectrum using the requirement that there is no systematic variation of oxygen abundance with line strength. The absolute abundance analysis may be significantly affected by non-LTE effects and therefore a differential analysis was also undertaken relative to the bright standard star ξ^1 CMa which has similar atmospheric parameters to CS 29501−020 (T_{eff}=26000 K, log g=3.9, V$_t$=10 km s^{-1}; Hambly et al. 1996a).

3.2. CS 22946−005

CS 22946−005 also has a relatively rich metal line spectrum and a similar analysis to that for CS 29501−020 was performed. However, only lines of Si III are observed and hence ionization balance analyses were performed both for Si II/Si III and Si III/Si IV, using upper limits of 20 mÅ for the equivalent widths of the Si II and Si IV lines. Lower and upper limits for the effective temperature of 17000 K and 23000 K respectively were obtained; a value of T_{eff}=20000±3000 K was adopted, with log g = 2.7±0.3 being estimated from the Balmer lines. This effective temperature estimate is consistent with the value of 18000 K estimated from the UBV photometry and theoretical colours of Kurucz (1991). A microturbulent velocity of 18±5 km s^{-1} was obtained from 28 lines of O II. Once again, absolute abundances were compared with those of normal B-type stars and differentially to the standard star γ Peg using the results of Ryans et al. (1996). This is a main sequence star with a similar effective temperature (T_{eff}=21000 K) to CS 22946−005, but with a higher surface gravity (log g=3.8) and smaller microturbulence (V$_t$=6 km s^{-1}). These differences in atmospheric parameters may affect the reliability of the differential abundances; however an analysis relative to a lower gravity supergiant was not attempted because the chemical compositions of such stars might be affected by the mixing of nucleosynthetic material from the stellar core to the surface (Lennon et al. 1993).

Table 2. Metal and non-diffuse helium line equivalent widths (in mÅ) for CS 29501−020, CS 22946−005, CS 22877−023 and CS 29493−046. A number in parenthesis after the ion indicates that the line is a close blend. A dash in the equivalent width column indicates that the line was not observed and hence will have normally have an equivalent width of less than 20 mÅ.

Line	λ (Å)	Equivalent widths (mÅ)			
		CS 29501−020	CS 22946−005	CS 22877−023	CS 29493−046
O ii	3912.09	21±8	-	-	-
O ii	3945.05	26±17	19±14	-	-
O ii	3954.37	30±17	30±16	-	-
He i	3964.73	105±10	136±17	163±27	135±21
O ii	3982.76	23±7	-	-	-
N ii	3995.00	37±12	109±8	26±5	34±8
N ii	4041.29	21±6	41±12	-	-
N ii	4043.53	25±6	-	-	-
O ii(2)	4060.78	-	35±12	-	-
O ii(2)	4069.77	88±14	91±11	-	37±10
O ii	4072.16	64±15	83±11	-	42±10
O ii	4075.87	69±15	75±12	-	31±10
O ii	4078.86	29±15	-	-	-
O ii	4083.91	19±15	-	-	-
O ii(2)	4084.89	22±15	23±13	-	-
Si iv	4088.85	75±14	-	-	-
O ii	4089.29	*	43±12	-	-
O ii	4112.03	-	22±5	-	-
Si iv	4116.10	30±27	-	-	-
O ii	4119.22	46±24	40±11	-	31±19
He i(2)	4120.90	164±45	201±10	128±43	153±29
O ii	4132.81	23±20	29±25	-	-
He i	4143.76	340±70	332±62	275±40	359±14
N ii(2)	4236.94	-	18±7	-	-
N ii	4241.39	-	38±7	-	-
O ii	4253.74	-	40±7	-	-
O ii(2)	4281.61	-	23±7	-	-
O ii	4303.82	30±11	-	-	-
O ii	4317.14	44±11	57±17	-	-
O ii	4319.63	58±10	66±16	-	-
O ii	4345.56	40±7	47±8	-	-
O ii	4349.43	68±14	110±15	-	-
O ii	4351.21	-	47±21	-	-
O ii	4366.90	22±7	57±10	-	-
O ii	4414.91	72±13	84±25	-	-
O ii	4416.98	46±14	76±26	-	-
He i	4437.55	84±12	108±12	88±9	82±16
N ii	4447.03	-	32±12	-	-
Mg ii(2)	4481.23	33±6	23±6	41±9	-
Si iii	4552.62	75±15	187±31	33±6	49±10
Si iii	4567.82	48±9	149±36	23±8	40±10
Si iii	4574.76	15±9	80±39	23±7	-
O ii	4590.97	31±9	52±9	-	-
O ii	4596.17	59±16	58±9	-	-
N ii	4601.48	-	38±9	-	-
O ii	4602.13	25±10	-	-	-
N ii	4607.16	-	37±9	-	-
O ii	4609.42	29±9	-	-	-
N ii	4613.87	-	25±9	-	-
N ii	4630.54	33±20	59±16	-	-
O ii	4638.85	52±12	63±16	-	-
O ii	4641.81	91±21	125±16	-	-
C iii	4647.40	34±12	-	-	-
O ii	4649.14	102±21	151±14	-	48±10
C iii	4650.16	36±11	-	-	-
O ii	4650.84	46±17	72±31	-	-
O ii	4661.64	55±12	73±18	-	27±10
O ii	4676.23	35±12	58±18	-	-
He ii	4685.68	44±12	-	-	-
O ii	4699.21	51±12	-	-	-
O ii	4705.36	43±12	-	-	-

* blended with the Si IV line at 4088.85 Å

3.3. CS 22877−023 and CS 29493−046

Both stars exhibit relatively sparse metal line spectra despite their small projected rotational velocities. Assuming a normal helium abundance, the He I spectra imply effective temperatures of approximately 15000 K but this is inconsistent with the absence of Si II lines. Therefore we have adopted for both stars T_{eff}=20000±3000 K, following similar arguments as for CS 22946−005, with the hydrogen line profiles implying surface gravities, log g=3.0±0.3 for both stars. The adopted effective temperatures then lead to small (0.2 to 0.3 dex) helium deficiencies. For both stars, there are insufficient metal lines to deduce a microturbulent velocity, and values of 5 km s^{-1} has been adopted. This may be an underestimate for such low sur-

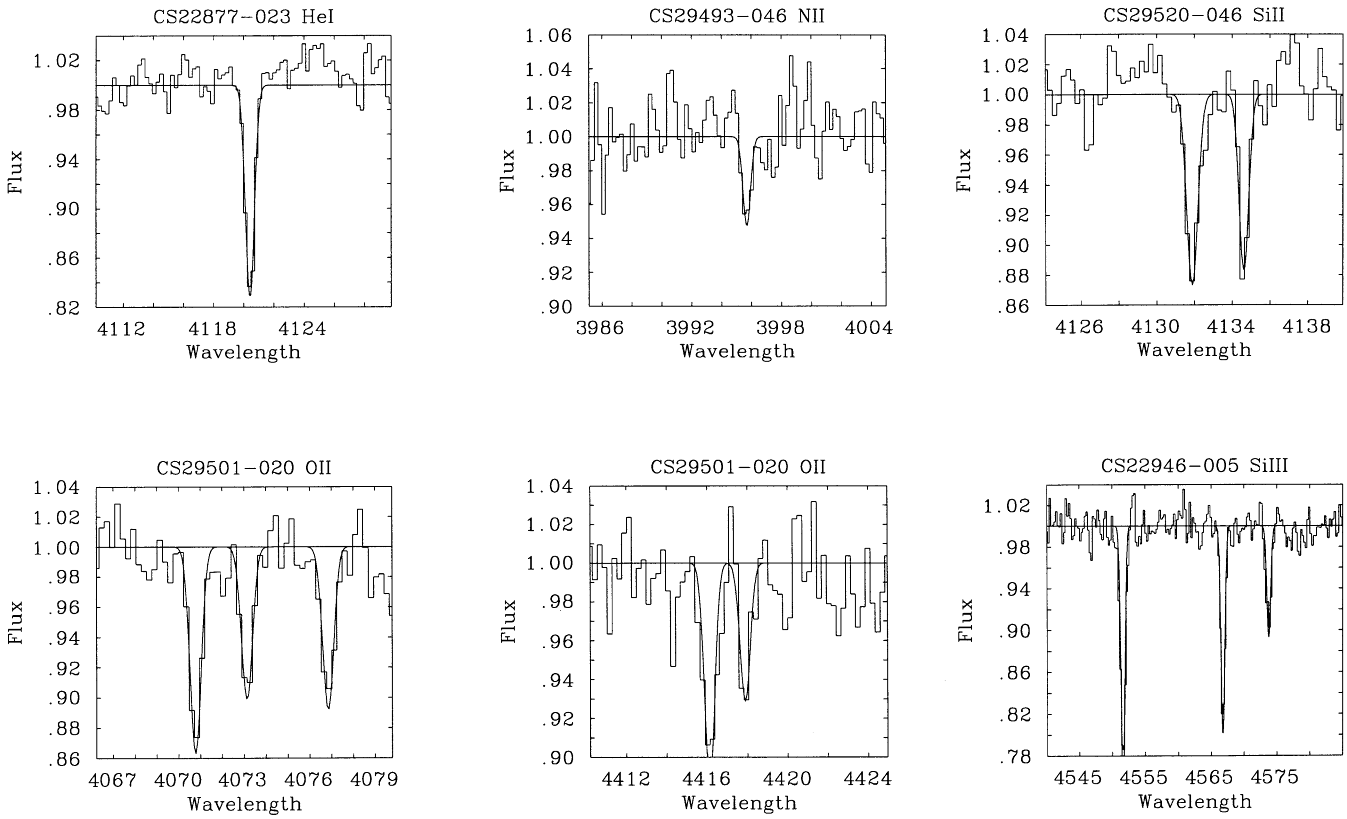

Fig. 1. Selected fits to the observed absorption line spectra of the halo stars listed in Table 1

face gravity stars, and the effects of adopting a higher value will be discussed in Sect. 4.

3.4. CS 29520−046

This star is the coolest in our sample, with absorption lines of Fe II, Ti II and Cr II, characteristic of AB-type stars (Jaschek & Jaschek 1990). The UBV photometry implies an effective temperature estimate of approximately 11000 K, while the absence of Si III lines provides an upper limit of 15000 K. In addition, the diffuse He I lines at 4009, 4026 and 4471Å imply T_{eff} ≃9500 K for a normal helium abundance. In view of the uncertainties (especially the assumption of a normal helium abundance) in placing these limits, the UBV temperature of T_{eff}=11000±2000 K has been adopted, with a gravity, log g=2.25±0.2, being determined for the Balmer lines. A microturbulence of 5 km s^{-1} has been assumed, although this may again be an underestimate given the low surface gravity.

4. Discussion

In this section, the results of the abundance analyses of the five halo stars are presented and discussed in terms of their possible PAGB evolutionary status. Standard differential methods were employed for the abundance analyses with further details being given in, for example, Ryans et al (1996). The derived stellar parameters and chemical compositions are shown in Tables 4, 5 and 6. Also listed in Table 4 are the distance moduli (DM) estimated from the atmospheric parameters and apparent magnitudes. These estimates incorporate masses deduced from the evolutionary tracks of Schönberner (1983; 1987) and hence implicitly assume that our targets are at a PAGB evolutionary stage; the associated error estimates principally reflect uncertainties in the atmospheric parameters.

4.1. CS 29501−020

The chemical composition of CS 29501−020 is compatible with it being an evolved object. The helium abundance is effectively normal, while there is a general metal depletion of around −0.8 dex with respect to normal B-type stellar abundances. The carbon deficiency derived from an upper limit of 20 mÅ on the strength of the C II 4267 Å line is larger, in line with previous studies of hot PAGB stars which have made use of this line (McCausland et al. 1992); however the spectra for the comparison star ξ^1 CMa did not cover this spectral region, so it is not possible to verify this depletion via a differential analysis. Upper limits on the strength of the C II 3918 and 3920 Å lines give a depletion, relative to the Population I abundance, of ≤ -0.8 dex, consistent with the general depletion observed for all metals, while a differential analysis yields a limit of only ≤ -0.5 dex. The weak C III lines observed at 4647 and 4650 Å imply a differential carbon depletion of −1.0 dex, though once again these lines may not be well modelled in LTE (Lennon, private com-

Table 3. Metal and non-diffuse helium line equivalent widths (in mÅ) for the cooler halo star CS 29520−046

Line	λ (Å)	W_λ (mÅ)
Ca II(K)	3933.66	182±38
He I	3964.73	75±7
Si II	4128.07	94±13
Si II	4130.89	75±24
Ti II	4443.80	49±13
Mg II(2)	4481.23	283±36
Fe II(2)	4508.27	52±16
Fe II	4515.33	60±16
Fe II	4520.23	57±17
Fe II	4522.63	67±16
Fe II	4534.17	64±16
Ti II	4549.82	151±17
Fe II	4555.89	73±19
Cr II(2)	4558.74	82±21
Fe II	4583.84	109±25
Cr II	4588.30	51±17
Fe II	4629.33	44±12
Cr II	4634.11	26±13
Fe II	4635.33	63±13

munication). We note that the absence of the 4267 Å line is unlikely to be due to circumstellar emission, as no such emission is observed in the two dimensional CCD frames at either this wavelength or those of the Balmer lines.

The lower limits on the underabundances of sulphur and aluminium also rely on the absence of expected features (the S III line at 4285 Å and the Al III doublet at 4529 Å), in the observed spectrum. The absence of Fe III in the spectra of CS 29501−020 does not allow any meaningful constraint to placed on the iron abundance.

The nitrogen abundance has been estimated from both observed N II lines at 3995, 4041, 4043 and 4630 Å and the absence of an additional six lines for which an upper limit of 20 mÅ was again set. These latter lines yielded limits on the nitrogen depletions compatible with those from the observed lines. From the differential analysis, nitrogen appears to be somewhat less depleted than other metals. This may indicate the presence of some CNO cycle processed material at the stellar surface.

The chemical composition for CS 29501−020 is consistent with a low metallicity precursor star that has evolved either up the AGB branch (see, for example Hambly et al. 1996a) or off the horizontal branch (see, for example Hambly et al. 1996b, 1996c). In the former case, the carbon depletion can be explained if the star had not passed through the third dredge-up on the AGB (Trams et al. 1991), or perhaps as the result of hot bottom burning (Becker & Iben 1980; Renzini & Voli 1981). CS 29501−020 lies near to a 0.546 $M_\odot$ PAGB track (see figure 2), implying that it would be a relatively low mass PAGB object. Alternatively, its atmospheric parameters and chemical composition are similar to those of PG 0832+676 discussed by Hambly et al. (1996b), who were unable to distinguish between a post AGB or horizontal branch (HB) evolutionary status. Additionally Hambly et al. (1996c) have found similar evidence for CNO processed material in two high galactic latitude stars with effective temperature of approximately 20000 K. These objects are probably at a post-HB evolutionary stage and CS 29501−020 may be a hotter analogue. In summary we cannot unambiguously distinguish between a post-HB or post-AGB evolutionary status for CS 29501−020, although evolutionary timescale arguments (see, for example, Hambly et al 1996b) imply that the stars is more likely to be post-HB. However we can probably preclude it being a young hydrogen burning object.

4.2. CS 22946−005

This star is significantly cooler than CS 29501−020 but shows a similar abundance pattern, a normal helium abundance, and a general metal depletion of around −0.7 dex and hence is also probably an old evolved star. The lower limits on the depletions of carbon, sulphur, iron and aluminium have been obtained by the same methods as above. The differential carbon depletion (with respect to γ Peg) of ≤ -1.2 dex obtained from the 4267 Å line may be uncertain but is greater than that found for the other elements. No differential comparison of the C II 3918 and 3920 Å lines is possible, but a depletion (relative to normal B-type stellar abundances) of ≤ -1.3 dex is found.

A meaningful constraint on the iron abundance is possible (which should reflect the original metallicity) and implies that CS 22946−005 originally had a Population II chemical composition. In addition, its lower effective temperature, compared with that of CS 29501−020, has enhanced the N II spectrum and from the differential analysis, nitrogen again appears to be less depleted than the other elements. Its atmospheric parameters places CS 22946−005 between the 0.565 and 0.644 $M_\odot$ PAGB evolutionary tracks (see Fig. 2) and we tentatively identify it as a PAGB object.

4.3. CS 22877−023

A small helium deficiency of $\simeq -0.2$ dex is found for this star but may not be significant given the uncertainties in its atmospheric parameters. The general metal depletion of $\simeq -1.2$ dex is greater than in the previous two cases, implying that this star is a Population II object. The lower limit on the carbon depletion of ≤ -1.9 dex taken from the absence of the 4267 Å line may again be unreliable, and the value of ≤ -1.4 dex obtained from the 3918 and 3920 Å lines is more consistent with the generally observed metal depletion. The adopted microturbulent velocity of 5 km s^{-1} may be unreliable for a star of this surface gravity; however using a higher value of 15 km s^{-1} would result in lower abundances (by typically less than 0.2 dex) and hence larger depletions. Owing to the paucity of metal line features, no differential analysis was performed. The similarity of its atmospheric parameters and chemical composition to those found for the globular cluster PAGB star, Barnard 29 (Conlon et al. 1994) indicates that CS 22877−023 may be a field analogue.

Table 4. Stellar parameters for the halo stars. Column 4 lists the radial velocities (corrected to a heliocentric frame) and column 5 the microturbulent velocities. For the latter, values shown in brackets, the metal line spectra was too weak for them to be independently determined. Also listed are the estimated distance moduli (DM).

Star	T_{eff}/K	log g	V_r/km s^{-1}	V$_t$/km s^{-1}	DM
CS 29501−020	27000±2000	3.8±0.2	65±7	7±5	14.9±0.6
CS 22946−005	20000±3000	2.7±0.3	−54±11	18±5	16.9±1.0
CS 22877−023	20000±3000	3.0±0.3	−56±6	(5)	16.1±1.0
CS 29493−046	20000±3000	3.0±0.3	45±10	(5)	16.8±1.0
CS 29520−046	11000±2000	2.25±0.2	275±11	(5)	16.0±1.0

Table 5. Abundances for the halo stars. Normal B-type star abundances are also given for comparison. These have been obtained using non-LTE and LTE methods and have been taken from the following sources: He,C,N,O,Al,Si,S,Fe: Gies and Lambert 1992; Mg: Lamers et al. 1973; Ca: Mihalas 1973; and Cr: Warner 1968, Wolnik et al. 1970. All abundances are logarithmic by number, relative to [H]=12. The number of lines used in the abundance determination is given in brackets. The quoted errors are derived from the uncertainties in the atmospheric parameters, except in cases where the standard deviation of the estimates from different lines is larger.

Elem.	CS 29501−020	CS 22946−005	CS 22877−023	CS 29493−005	CS 29520−046	B-star
He	11.0(2)	10.9(2)	10.7(2)	10.8(2)	10.3±0.7(3)	11.0
C[a]	<6.7(1)	<6.4(1)	<6.3(1)	<6.3(1)	-	8.2
C[b]	<7.4(2)	<6.9(2)	<6.8(2)	<6.8(2)	<8.0(2)	8.2
C[c]	7.3(2)	-	-	-	-	8.2
N	7.3±0.2(10)	7.4±0.2(11)	6.8(1)	7.0(1)	-	7.8
O	7.9±0.2(33)	8.2±0.3(28)	<7.9	8.0±0.7(6)	-	8.7
Mg	6.6(1)	6.0(1)	6.2(1)	-	6.7(1)	7.4
Al	<5.8	<5.5	-	-	-	6.5
Si	6.2±0.3(4)	6.9±0.3(3)	6.0(2)	6.3(2)	6.4(2)	7.6
S	<6.3(1)	<6.5(1)	-	-	-	7.2
Ca	-	-	-	-	3.7(1)	6.3
Cr	-	-	-	-	4.8(3)	5.6
Fe	<7.0	<6.1	-	-	6.8±0.6(7)	7.7

[a] Values from upper limit on 4267Å line
[b] Values from upper limits on 3918 and 3920Å lines
[c] Value from observed C III 4647 and 4650Å lines

4.4. CS 29493−046

This star is similar to CS 22877−023, with the same effective temperature having been adopted. Again a small helium underabundance of $\simeq -0.2$ dex may exist, while the general metal deficiency is of the order −1.0 dex. The carbon depletion derived from the C II 4267 Å line may again be unreliable, and the more modest deficiency derived from the 3918 and 3920 Å lines is consistent with the generally observed depletion. The only significant difference to CS 22877−023 is that the strongest lines of O II are visible, giving a more reliable constraint on the oxygen depletion. The adoption of a larger microturbulence would again decrease the absolute abundances (and hence increase the depletions) by normally less than 0.3 dex. Neither this star nor CS 22877−023 show any evidence for nitrogen having an anomalous depletion and the only conclusion that can be drawn is that CS 29493−046 is an evolved object and may again be an analogue of Barnard 29.

4.5. CS 29520−046

This star is significantly cooler than the other four, the adopted atmospheric parameters being T_{eff}=11000 K and log g=2.25, while helium may be significantly depleted (although this estimate is very sensitive to the adopted effective temperature). The region including the C II 4267 Å line was not observed, but the absence of the 3918 and 3920 Å lines only constrains the carbon depletion to ≤ -0.2 dex. Many lines of Fe II are visible in the spectrum, with an iron depletion of −0.7 dex being found, although again these lines are temperature sensitive. Similar arguments apply to the abundance of chromium, while that of titanium is not usefully constrained. The adopted microturbulent velocity of 5 km s^{-1} may again be too low and the effect of increasing it to 15 km s^{-1} was considered. For most lines the effect is small (<0.2 dex), the exceptions being Si II 4128 Å (0.3 dex), Ca II 3933 Å (0.7 dex), Mg II 4481 Å (0.6 dex) and Cr II 4588 Å (0.4 dex). Calcium and magnesium especially may therefore be significantly more depleted than indi-

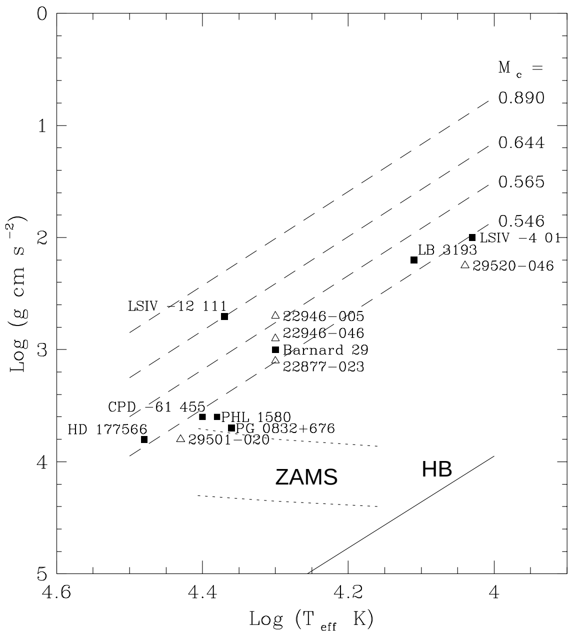

Fig. 2. Positions of the five target stars (denoted by open triangles) on the log g - logT_{eff} plane, together with the PAGB evolutionary tracks of Schönberner (1983; 1987) and Wood & Faulkner (1986) and the zero age horizontal branch of Gingold (1976). Also labelled are the positions of other previously studied hot PAGB stars (filled squares) for which the references are in the text. CS 22946−005 and 22877−203 have been shifted by ±0.1 dex in gravity to reduce confusion.

cated in Table 5. However, if the adopted effective temperature is correct the iron depletion provides excellent evidence for a Population II composition, while the star lies close to a 0.546 $M_{\odot}$ PAGB evolutionary track.

Another possibility is that CS 29520−046 has evolved from the horizontal branch. Such stars are found by their positions in the colour magnitude diagrams of globular clusters and often exhibit sharp, deep Balmer lines and weak lines of other elements, including helium (Greenstein & Sargent 1974; Jaschek & Jaschek 1990). CS 29520−046, with its very large calcium depletion, together with a more modest depletion of magnesium, and in particular its helium deficiency, conforms to this description.

5. Conclusion

From their general metal deficiencies, we conclude that all five targets are evolved objects, and their narrow-lined spectra and the coincidence of their atmospheric parameters on the log T_{eff}-log g plane with the evolutionary tracks of Schönberner (1983; 1987) and Wood & Faulkner (1986) makes a PAGB evolutionary status possible for all the targets. However two stars (CS 29501−020 and 29520−046) may alternative have evolved directly off the horizontal branch. Ultraviolet spectra would be very useful, not only for providing additional lines of elements such as carbon and silicon, but also to derive reliable iron abundances and hence provide good estimates of the initial metallicities of these objects.

Table 6. Differential abundances for the two halo stars CS 29501−020 and CS 22956−005. The comparison stars are ξ^1 CMa and γ Peg respectively

Elem.	CS 29501−020	CS 22946−005
He	+0.09(1)	−0.02(2)
C[a]	-	$< -1.2(1)$
C[b]	$< -0.5(2)$	-
C[c]	−1.0(2)	-
N	−0.4±0.2(9)	−0.2±0.1(7)
O	−0.6±0.2(20)	−0.5±0.3(18)
Mg	−0.7±0.2(1)	−1.1±0.4(1)
Al	-	< -0.65
Si	−1.1±0.2(3)	−0.5±0.2(2)
S	< -0.5	< -0.5
Fe	-[d]	< -0.5

[a] Value from upper limit on 4267Å line
[b] Value from upper limits on 3918 and 3920Å lines
[c] Value from observed C III 4647 and 4650Å lines
[d] Value is not usefully constrained

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