Astron. Astrophys. 337, 216–222 (1998)

ASTRONOMY
AND
ASTROPHYSICS

The chemical composition of HD 196944: a carbon and s-process rich, very metal-poor star[⋆]

Laimons Začs[1], **Poul E. Nissen**[2], **and William J. Schuster**[3]

[1] Ventspils International Radio Astronomy Center, Akadēmijas laukums 1, LV-1050 Riga, Latvia (zacs@latnet.lv)
[2] Institute of Physics and Astronomy, University of Aarhus, DK-8000 Aarhus C, Denmark (pen@obs.aau.dk)
[3] Observatorio Astronomico Nacional, UNAM, Apartado Postal 877, C.P. 22800 Ensenada, B.C., Mexico
(schuster@bufadora.astrosen.unam.mx)

Received 25 February 1998 / Accepted 19 May 1998

Abstract. An LTE abundance analysis of the post-AGB candidate star HD 196944 is presented based on high resolution, high S/N spectra. The radial velocity of HD 196944 is found to be -174 km s^{-1} indicating that it belongs to the halo population. The spectroscopic analysis provides the atmospheric parameters $T_{\rm eff}$ = 5250 K, $\log g$ = 1.7 (cgs), $\xi_{\rm t}$ = 1.9 km s^{-1} corresponding to those for G2-5 (bright) giants. A low iron abundance, [Fe/H] = -2.45, is derived confirming the old, low mass nature of the star. With [C/Fe] = +1.4 and a mean s-process overabundance of [s/Fe] = +1.1 the peculiar atmospheric composition of HD 196944 is confirmed. Possible evolutionary stages of HD 196944, that can explain its atmospheric parameters and composition, are discussed.

Key words: stars: evolution – stars: abundances – stars: chemically peculiar – stars: AGB and post-AGB – stars: individual: HD 196944

1. Introduction

It is now generally accepted that F-G supergiants at large distances from the galactic plane are not Population I objects, but low-mass stars in the late stages of stellar evolution. The high latitude, high space motion, and low metal content are observational indications for the old and low-mass nature of these objects. However, only a few of such stars (HD 36126, HD 187885, HD 158616, IRAS 05341+0852; see Klochkova 1995, Van Winckel et al.1996, Van Winckel 1997, Reddy et al.1997) show clear evidence of chemical evolution as expected after the 3rd dredge-up: a high C/O ratio and enhancement of s-process elements.

By several observational criteria, the high latitude (b = $-27°$), 8.4 magnitude star HD 196944 (HIC 102042) is an unusual object. It was classified by Bidelman (1981) as "extr.wk-lined G/K" with very strong CH. Luck & Bond (1992) have a short notice on HD 196944 suggesting that it is a post-AGB star with [C/Fe] = +1.2, [N/Fe] = +2.0, [O/Fe] = +1.0 and s-process enhancement. In this paper, an analysis of new high-resolution observations of the spectrum of HD 196944 is presented. For comparison a spectrum of HD 211998, a more normal, metal-poor subgiant with colors similar to HD 196944, has also been analyzed.

2. Observations and data reduction

A spectrum of HD 196944 in the wavelength region 5100 to 6100 Å was obtained with the ESO 3.6m telescope and the CASPEC echelle spectrograph as part of a more extensive study of metal abundances in halo stars. The spectrum was observed with a resolution of $R = 30\,000$ and a $S/N = 180$ using a RCA CCD as detector. In addition, $R = 60\,000$ and $S/N = 200$ spectra were obtained in the wavelength ranges 6130 - 6180 Å and 7760 - 7820 Å with the ESO CES instrument and the 1.4m CAT telescope. The reduction of the CCD frames (subtraction of bias, dark and scattered light, flat fielding, extraction of echelle orders and wavelength calibration based on Th-lines) was performed with MIDAS routines. More than 100 weak to medium-strong atomic lines ($2 < EW < 100$ mÅ), free of blends, were identified and their equivalent widths were measured with the IRAF routine SPLOT. An extract from the spectrum of HD 196944 is shown in Fig. 1 along with that of HD 211998, which was also observed with the CASPEC and reduced in the same way. Given that the two stars have about the same $T_{\rm eff}$, it is evident from the Fe I lines, that HD 196944 has a much lower iron abundance than HD 211998. Despite this, HD 196944 has much stronger lines of the s-process elements than HD 211998.

In Table 1 the equivalent widths are given for all lines measured in the spectrum of HD 196944 along with the oscillator strengths and excitation potentials.

3. Analysis and results

3.1. Radial and space velocities

From the CASPEC spectrum (obtained on Oct 16, 1989, UT=01:02) a heliocentric radial velocity of -174 ± 5 km s^{-1} was derived. The relatively large error is due to possible flexures

---

Send offprint requests to: Laimons Začs

[⋆] Based on observations carried out at the European Southern Observatory, La Silla, Chile

Table 1. gf-values, excitation potentials and equivalent widths of lines in the spectrum of HD 196944

λ(Å)	loggf	χ(eV)	EW(mÅ)	λ(Å)	loggf	χ(eV)	EW(mÅ)	λ(Å)	loggf	χ(eV)	EW(mÅ)
C I				5127.36	−3.31	0.91	26.2	5473.91	−0.80	4.15	4.6
5380.31	−1.69	7.68	8.9	5133.69	0.23	4.18	31.3	5497.52	−2.85	1.01	55.8
O I				5141.74	−2.12	2.42	9.1	5501.47	−3.05	0.96	42.3
7771.96	0.33	9.15	21.6	5162.29	0.22	4.18	26.6	5506.78	−2.80	0.99	49.5
7774.17	0.19	9.15	21.1	5166.28	−4.20	0.00	34.5	5565.71	−0.29	4.61	5.7
7775.39	−0.03	9.15	13.7	5171.61	−1.79	1.48	74.0	5569.62	−0.52	3.42	32.2
Na I				5192.35	−0.42	3.00	64.8	5572.85	−0.31	3.40	40.0
5688.20	−0.40	2.10	6.7	5194.94	−2.09	1.56	56.3	5576.10	−0.81	3.43	18.4
Mg I				5195.48	−0.15	4.22	11.0	5586.76	−0.14	3.37	50.9
5528.40	−0.56	4.35	69.6	5196.06	−0.67	4.26	3.3	5624.55	−0.79	3.42	21.1
5711.09	−1.69	4.35	10.7	5198.71	−2.14	2.22	19.4	5701.55	−2.14	2.56	7.5
Ca I				5215.18	−1.01	3.27	19.2	5762.97	−0.20	4.21	13.0
5261.71	−0.58	2.52	13.4	5216.28	−2.15	1.61	49.7	5816.38	−0.60	4.55	3.8
5512.98	−0.45	2.93	6.5	5217.39	−1.16	3.21	16.2	5859.61	−0.60	4.55	4.6
5581.97	−0.56	2.52	12.9	5232.96	−0.06	2.94	79.9	5862.36	−0.38	4.55	7.4
5588.76	0.36	2.53	55.5	5242.50	−0.97	3.63	10.4	6024.07	−0.02	4.55	13.0
5590.12	−0.57	2.52	13.9	5250.65	−2.18	2.20	23.5	6065.49	−1.41	2.61	30.4
5601.28	−0.49	2.53	19.5	5253.46	−1.60	3.28	5.2	6136.62	−1.40	2.45	40.9
5857.45	0.24	2.93	29.2	5263.31	−0.91	3.27	21.2	6137.70	−1.35	2.59	36.8
6102.72	−0.79	1.88	32.2	5266.56	−0.39	3.00	55.8	6173.34	−2.88	2.22	4.8
6122.22	−0.32	1.89	62.1	5281.79	−0.83	3.04	34.8	Fe II			
6162.17	−0.09	1.90	82.4	5283.62	−0.52	3.24	42.2	5197.57	−2.23	3.23	40.7
6166.44	−1.14	2.52	5.3	5302.30	−0.75	3.28	28.9	5234.62	−2.15	3.22	44.3
6169.06	−0.80	2.52	12.4	5307.36	−2.99	1.61	12.6	5275.99	−1.97	3.20	56.9
6169.56	−0.48	2.53	18.1	5324.19	−0.14	3.21	61.4	5284.09	−3.31	2.89	18.1
Sc II				5339.93	−0.72	3.27	32.2	5325.55	−3.22	3.22	6.3
5239.82	−0.80	1.46	18.9	5364.88	0.23	4.45	20.4	6149.24	−2.72	3.89	5.3
5526.82	0.02	1.77	34.1	5365.40	−1.28	3.57	8.7	Y II			
Ti I				5367.47	0.44	4.42	27.6	5123.22	−0.83	0.98	28.0
5192.97	−1.01	0.02	24.3	5369.96	0.54	4.37	28.4	5200.42	−0.57	0.98	33.7
5210.39	−0.88	0.05	21.8	5379.58	−1.51	3.69	3.9	5509.90	−1.01	0.98	14.2
Ti II				5383.37	0.65	4.31	36.0	Ba II			
5185.90	−1.46	1.89	33.2	5389.48	−0.22	4.42	8.0	5853.68	−1.01	0.60	86.0
5336.81	−1.59	1.58	46.6	5393.17	−0.75	3.24	35.5	6141.72	−0.08	0.70	146.0
5381.02	−1.94	1.57	28.6	5397.13	−1.99	0.91	94.2	Ce II			
Cr I				5398.28	−0.65	4.45	2.1	5274.22	−0.30	1.04	11.6
5296.69	−1.39	0.89	10.5	5400.51	0.01	4.37	12.5				
5297.38	0.17	2.90	4.5	5405.78	−1.86	0.99	99.4	Nd II			
5345.81	−0.98	1.00	22.2	5410.91	0.40	4.47	25.3	5212.37	−1.49	0.20	6.4
5348.32	−1.29	1.00	9.4	5415.20	0.64	4.39	33.5	5234.21	−0.33	0.54	12.3
5409.79	−0.72	1.03	32.2	5424.08	0.58	4.32	39.7	5249.59	0.20	0.97	14.1
Fe I				5434.53	−2.12	1.01	84.2	5293.16	−0.06	0.81	17.2
5123.73	−3.07	1.01	46.2	5445.04	0.20	4.39	19.5	5319.82	−0.21	0.54	20.3

in the spectrograph (up to 1 pixel on the CCD) that may have occurred between the stellar exposure and the thorium lamp exposure.

Using this radial velocity, plus the proper-motion and parallax data from Hipparcos (ESA 1997), and the matrix equations of Johnson & Soderblom (1987), the Galactic space velocities of HD 196944 have been calculated with respect to the Local Standard of Rest, as well as the standard deviations of these velocities. The results are, (U,V,W) = (144,-123,-13) ± (20,23,57) km s^{-1}. So, $V_{\rm rot}$ = V + 220 km s^{-1} = +97 ± 23 km s^{-1} is the rest-frame rotation velocity of HD 196944 about the Galactic center. This value for $V_{\rm rot}$, plus [Fe/H] = -2.45 from the analysis below, indicates quite definitively that HD 196944 is a halo star, according to the $V_{\rm rot}$,[Fe/H] diagram of Schuster et al. (1993, Fig. 5) and the discussions therein.

3.2. Atmospheric parameters

Atmospheric parameters and the metal abundance for HD 196944 and HD 211998 were initially estimated from Strömgren $uvby-\beta$ photometry by Olsen (1983) (see Table 2). It is seen that the two stars have practically the same

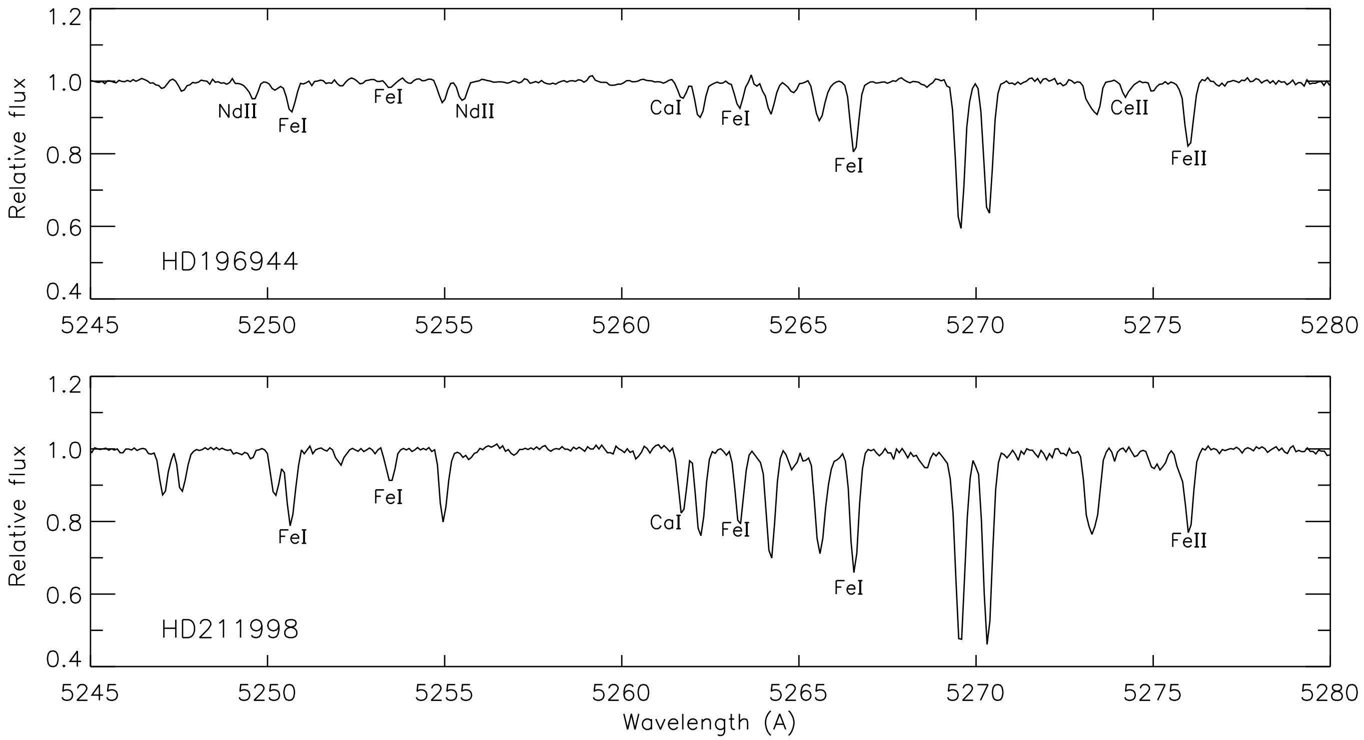

Fig. 1. Sample spectra for HD 196944 and the comparison star HD 211998. Lines used in the abundance analysis are identified by their chemical symbol

Table 2. Strömgren photometry of HD 196944 and HD 211998 (Olsen 1983)

Star	V	$b-y$	m_1	c_1	β
HD 196944	8.40	0.450	0.112	0.348	2.543
HD 211998	5.28	0.453	0.110	0.233	2.545

values of the temperature sensitive indices, $b-y$ and β, and of the metallicity index m_1. Using the metallicity calibration of Schuster & Nissen (1989a), [Me/H] = -1.5 is derived for both stars. According to the $T_{\rm eff}-(b-y)$ and $T_{\rm eff}-\beta$ calibrations of Alonso et al. (1996), which are based on effective temperatures determined with the infrared flux method, $T_{\rm eff}(b-y)=5315$ K, and $T_{\rm eff}(\beta)=5265$ K are derived for HD 196944, and $T_{\rm eff}(b-y)=5240$ K, $T_{\rm eff}(\beta)=5290$ K for HD 211998. Since the H_β index is not affected by interstellar reddening, the good agreement between the effective temperatures derived from $(b-y)$ and β suggests that neither of the stars is affected by interstellar or circumstellar reddening in the 4500 - 6000 Å spectral region.

According to the position of the stars in the $(b-y)-c_1$ diagram (Schuster & Nissen 1989b) both stars are subgiants with $\log g$ values in the range 3.0 - 3.5. These calibrations refer, however, to stars of normal composition, but HD 196944 appears to have a peculiar composition. Therefore, both m_1 and c_1 may be affected by the abundance peculiarities. For example, according to Bond (1974) the c_1 index of the CH subgiants is systematically smaller than that of normal stars with the same $(b-y)$ index. This is due to the ”violet deficiency”, also called the ”Bond-Neff depression” (Bond & Neff 1969), which decreases the flux in the Strömgren v band. The actual surface gravity of HD 196944 might therefore be lower than the value derived from the Strömgren photometry. Furthermore, the m_1 index is affected in such a way that a too high metallicity of HD 196944 is derived.

To obtain a colour-independent estimate of the temperature for HD 196944, an excitation analysis of the Fe I lines has been employed. $T_{\rm eff}$ was chosen so that the derived iron abundance vs. excitation potential has zero slope (see Fig. 2). In this way, $T_{\rm eff}=5250\pm100$ K for both HD 196944 and HD 211998.

Surface gravities for the stars were determined by requiring that Fe I and Fe II lines should provide the same iron abundance. From this ionization balance, $\log g=1.7\pm0.3$ (cgs) for HD 196944. The Ti I/Ti II ionization balance confirms this value. For HD 211998 the spectroscopic analysis gives $\log g=3.5\pm0.3$ (cgs).

An independent determination of the surface gravity can be made using the well known relations $g\propto M/R^2$ and $R^2\propto L/T_{\rm eff}^4$, if the parallax of the star is known (Nissen et al. 1997). Unfortunately, the parallax for HD 196944 is rather uncertain. Hipparcos data (ESA 1997) give 2.06 ± 1.17 mas. Using this value, m_V = 8.40 mag, $BC=-0.15$, $T_{\rm eff}=5250$ K and adopting a mass of $M=0.6M_\odot$ the relation of Nissen et al. (1997) leads to $\log g$ in the range 1.4 to 2.5 (cgs). For HD 211998 the new Hipparcos value of 34.60 ± 0.60 mas implies $\log g=3.44\pm0.10$ (cgs) in excellent agreement with the spectroscopic analysis. Thus, the comparison of spectroscopic results obtained

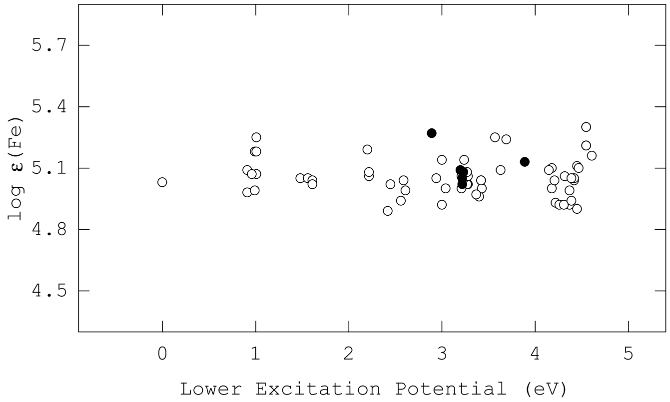

Fig. 2. The abundances of iron derived from the Fe I (○) and Fe II (●) lines vs. the excitation potential of the lower energy level of the line, illustrating the estimation of the spectroscopic temperature for HD 196944

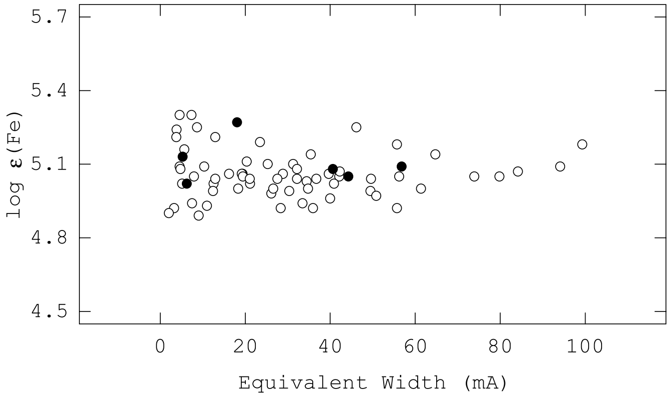

Fig. 3. The abundances derived from the Fe I (○) and Fe II (●) lines plotted vs. the equivalent width of the line, illustrating the estimation of the microturbulent velocity for HD 196944

for HD 196944 and the normal metal-poor subgiant HD 211998 indicates that HD 196944 is a much more luminous object than HD 211998. The parallaxes are consistent with this conclusion.

The procedure for estimating the microturbulent velocity is illustrated in Fig. 3 for the atmospheric model (5250, 1.7, -2.0). As we can see, a good agreement between the iron abundances derived from individual lines was found using $\xi_{\rm t} = 1.9$ km s^{-1} for HD 196944.

The systematic errors in abundances produced by uncertainties in $T_{\rm eff}$ (± 100 K) and $\log g$ (± 0.3 dex) would lead to errors, less than 0.1 dex for most elements. Only for O I the total error may approach 0.12 dex. The final errors in the abundances resulting from the choice of [Me/H] and microturbulence (± 0.3 km s^{-1}) for the model were found to be negligible (< 0.03 dex), excluding BaII, for which the microturbulence uncertainties may lead to errors in the abundances of 0.25 dex.

3.3. Abundance analysis

The chemical abundances were computed using the standard LTE line analysis program WIDTH6, written by R. L. Kurucz and adapted by V. Tsymbal for use on a personal computer, which employs an input model atmosphere to compute the strength of a given atomic line formed in such an atmosphere. The model atmospheres were interpolated from the grid of Gustafsson et al. (1975) or extracted from Kurucz (1993).

Table 3. Averaged absolute and relative (to the Sun) abundances for HD 196944. The standard deviation and the number of lines used in the analysis are also given

Element(X)	logε(X)	σ	n	[X/Fe]
C I	7.55		(1)	+1.42
O I	7.61	0.05	(3)	+1.11
Na I	3.94		(1)	+0.04
Mg I	5.55	0.07	(2)	+0.40
Ca I	4.29	0.09	(13)	+0.36
Sc II	0.86	0.08	(2)	+0.19
Ti I	2.82	0.08	(2)	+0.26
Ti II	2.80	0.01	(3)	+0.24
Cr I	3.09	0.08	(5)	-0.15
Fe I	5.06	0.10	(64)	
Fe II	5.11	0.08	(6)	
Y II	0.39	0.09	(3)	+0.58
Ba II	1.26	0.30	(2)	+1.56
Ce II	0.61		(1)	+1.49
Nd II	0.01	0.17	(5)	+0.94

Oscillator strengths for the lines have been taken from a variety of sources and are given in Table 1. A majority of the values are from high precision laboratory measurements. References for the Mg I, Ca I, Ti I, Cr I, Fe I and Fe II lines can be found in Nissen et al. (1994). Additional references are: C I and O I (Lambert 1878), Na I (Lambert & Warner 1968), Sc II (Lawler & Dakin 1989), Y II (Hannaford et al. 1982), Ba II (Gallagher 1967), Ce II (Grevesse & Blanquet 1969) and Nd II (Ward et al. 1985).

The mean absolute and relative abundances in the scale of $\log \varepsilon$(H) = 12.0 derived from a model atmosphere (Gustafsson et al. 1975) with $T_{\rm eff}$ = 5250 K, log g = 1.7, $\xi_{\rm t}$ = 1.9 km s^{-1} and [Me/H] = -2.0 for HD 196944 are given in Table 3, together with the standard deviation of abundances estimated from individual lines, and the number of lines used in the analysis. The abundances relative to the Sun were calculated using solar photospheric data by Anders & Grevesse (1989), except in the case of iron, for which we used the meteoritic solar abundance of 7.51 recently confirmed from analysis of Fe II lines (Holweger et al. 1990, Biémont et al. 1991).

As a test the abundances were derived also using a Kurucz (1993) model with the same physical parameters. The difference between both results is not significant (< 0.1 dex). Inspection of the derived composition given in Table 3 shows that the atmosphere of HD 196944 is very metal poor ([Fe/H] = -2.45 dex) and carbon rich ([C/Fe] = +1.4 dex). Furthermore, a significant enhancement of the s-process elements is found (the mean for 4 elements [s/Fe] = + 1.1 dex).

For metal poor stars the hot UV radiation field might lead to overionization. Such non-LTE effects have been reported in

K giants (Brown et al. 1983; Ruland et al. 1980) and in F supergiants (Venn 1993; and references therein). The abundances were found to be systematically smaller when derived from low-excitation lines than from high-excitation lines of iron-peak elements. These effects increase with increasing effective temperature and decreasing metallicity. Due to overionization, the FeI state is less populated than determined under the assumption of LTE, therefore, the neutral lines give underabundances of iron. Thus the non-LTE effects can have an effect on the atmospheric parameters determined spectroscopically. However, since overionization occurs mostly in the upper layers of the atmosphere, using weak lines with high excitation potentials (i.e. lines that form deeper in the atmosphere) may minimize the effect. For the (bright) giant HD 196944 the temperature and gravity are not so extreme, therefore, by limiting the abundance analysis to weak lines, the non-LTE effects are thought to be not very large. Indeed, the excitation temperatures for both HD 196944 and HD 211998 are in good agreement with the effective temperatures obtained from photometry.

Concern exists about hyperfine structure effects on the Ba lines, which are fairly strong. Sneden et al. (1996) have studied this in detail for another very metal-poor, neutron-capture-rich giant star, CS 22892-052, which has Ba lines of similar strength as HD 196944. For the two Ba lines used by us, the hfs effects were found to be negligible (< 0.02 dex). Therefore, we did not take broadening by hyperfine splitting into account.

4. Discussion and conclusions

The standard LTE analysis of a high resolution and high S/N spectrum gives for HD 196944 the spectroscopic atmospheric parameters T_eff = 5250 K, $\log g = 1.7$ (cgs), and $\xi_\mathrm{t} = 1.9$ km s^{-1} approximately equal to those for normal G2-5 (bright) giants. The metal deficiency is a strong indicator that HD 196944 is an old star. Its radial velocity of -174 km s^{-1} is characteristic for halo objects. HD 196944 is located at a galactic latitude of b = -27°, which puts it at a distance $z \simeq 220$ pc above the galactic plane for a parallax value of 2 mas.

The abundance pattern of HD 196944 shows clear evidence of chemical evolution. Are these peculiarities the result of internal processes (nuclear reactions inside the star and mixing to the surface) or an external process (mass transfer or exchange across a binary system)?

Luck & Bond (1992) suggested that HD 196944 is a post-AGB star, which often have z-heights larger than the Galactic scale-height for massive stars ($\simeq$ 120 pc). Therefore, HD 196944 would be a good candidate. Comparison of the photospheric abundance for HD 196944 with published results for two post-AGB stars (HD 187885, HD 158616) shows in general similarities of the abundance patterns (Fig. 4): the enhancement of carbon, the overabundance of α-elements (here Mg, Ca and Ti) relative to Fe and a very significant enhancement of s-process elements. HD 196944 displays, however, a more extreme iron deficiency, [Fe/H] = -2.45, and a high abundance ratio of the heavy s-process peak elements to the light s-process peak elements (Luck & Bond 1991), [hs/ls] = [hs/Fe] - [ls/Fe] $\simeq +0.8$ dex.

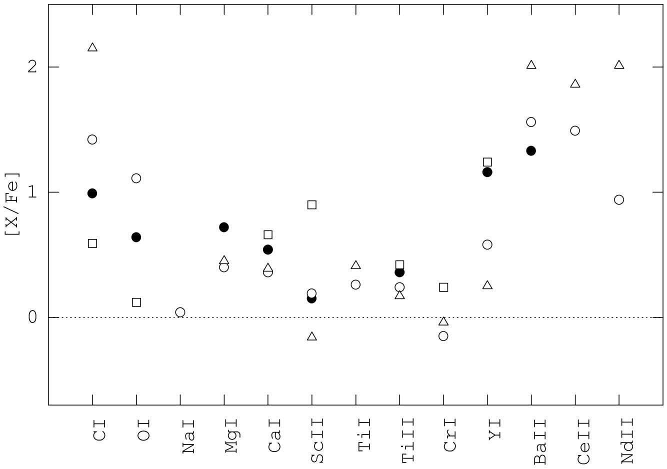

Fig. 4. The abundance comparison for HD 196944 (○), two post-AGB stars (● - HD 187885, □ - HD 158616), and the extremely metal-poor object LP 625-44 (△)

The typical temperature of the post-AGB phase is assumed to range from 5000 to $30\,000$ K. HD 196944 with $T_\mathrm{eff} = 5250$ K would be a relatively young and thus cool post-AGB star, because at about 5000 K the star moves off the AGB. Concern exists, however, about its luminosity if it is a post-AGB star. The Hipparcos parallax yields for HD 196944 an absolute magnitude M_V in the range 1.0 to -2.0., and the spectroscopic parameters using a mass of $M = 0.6 M_\odot$ lead to $M_V \simeq -1.5$. It seems to be too faint for such a cool (young) post-AGB star (Blöcker 1995).

Strong evidence against the post-AGB nature of HD 196944 is the absence of an IR excess due to circumstellar material. A few hundred years after the star has left the AGB, the dust shell has cooled and should contribute strongly to the IRAS 12 μm flux (Oudmaijer 1996). We examined the position of the HD 196944 in comparison with IRAS PSC and FSC sources and none of those are identified with HD 196944. A significant IR excess at 12 and 25 μm is absent and therefore its post-AGB status is doubtful.

Bright giants with the enhancement of s-process elements have been found in globular clusters (Kraft 1994, and references therein). For example, some ω Cen stars are known to present an enrichment of carbon, nitrogen and s-process elements. These abundance anomalies suggest that some form of mixing occured in these stars. Possibly, they are in the asymptotic giant branch phase (François et al. 1988). The effective temperature of 5250 K for HD 196944 and the luminosity ($\log(L/L_\odot)$ from 2 to 2.5) places it in the region of the H-R diagram occupied by shell helium burning Pop. II stars (Iben 1991). Possibly, HD 196944 is a hotter analog of halo carbon stars.

Finally, the abundance peculiarities of HD 196944 are similar to those for CH stars (Keenan 1942) in which the molecular bands of CH are very strong and heavy elements are enhanced. In addition to being metal poor, the CH stars have large radial velocities, typically 200 km s^{-1}, indicating that they are halo objects. The derived characteristics for HD 196944 correspond to those of CH stars, except for the very low metallicity (for classical (early type) CH stars [Fe/H] lies in the range from -0.5 to -1.7; see, for example, Vanture (1992a)). Moreover, the average ratio of the heavy-to-light s-process elements, [hs/ls], in the CH stars is +0.9 dex (Vanture 1992c), in agreement with that obtained for HD 196944.

The oxygen abundance for HD 196944 was found to be [O/Fe] = 1.1 using the O I triplet, in good agreement with that derived by Luck & Bond (1992) from the [OI] forbidden line at 6300 Å. Since studies of the IR triplet in giants of spectral type G and K (see for instance Eriksson & Toft 1979) indicate that the O I triplet is subject to non-LTE effects, the conclusion has been made that in HD 196944 non-LTE effects are not significant. On the other hand, analyses of the O I triplet in halo giants indicate [O/Fe] $\simeq$ 0.8 to 1.1 in a wide range of metallicities from [Fe/H] = -1.5 to -3.0 (Cavallo et al. 1997). Following Cavallo et al. (1997) one would expect for HD 196944 ([Fe/H] $\simeq -2.5$) [O/Fe] $\simeq 1$. This means apparently that in the atmosphere of HD 196944 oxygen must be considered as primordial and equal to the value which is expected for a relatively unevolved halo object with a given [Fe/H]. Thus the abundance analysis of HD 196944 indicates that material enhanced in CN and s-process nuclei but not in O has been added to the atmosphere of HD 196944, in agreement with that obtained for classical CH stars (Vanture 1992b). Note that the oxygen abundances in CH giants follow the normal pattern found in field and cluster giants.

Recently a few extremely metal-poor, carbon-rich, and s-process enhanced stars have been analysed using high-resolution spectra (Kipper & Jørgensen 1994; Barbuy et al. 1997; Norris et al. 1997). The abundance pattern of one of these stars LP 625-44 (Norris et al. 1997) is compared with that obtained for HD 196944 in Fig. 4. Although these carbon-rich halo objects have different temperatures (from 3000 to 6000 K) and luminosities (from dwarfs to supergiants), their abundance patterns display a lot of similarities: very low metallicity, high average level of the s-process enhancement, high C/O and [hs/ls] ratio, and low ^{12}C/^{13}C ratio. Besides some of these stars show clear evidence for velocity variations (CS 22948-27, LP 625-44), while for the rest duplicity needs to be confirmed (CS 29497-34, LP 706-7, HD 187216, and HD 196944).

Fig. 5 presents a comparison of some recent abundance results for known carbon-rich Galactic halo stars: early type CH stars (Vanture 1992a,b,c), late type CH stars (Kipper et al. 1996), and extremely metal-poor carbon-rich objects (Kipper & Jørgensen 1994; Barbuy et al. 1997; Norris et al. 1997; present work). For comparison purposes subgiant CH stars of the disk population (Luck & Bond 1991) are also shown. Inspection of the figure suggests that a correlation of [C/Fe] with [Fe/H] exists, [C/Fe] is found to increase with decreasing metallicity. Note that there is not a large gap of almost 1 dex in [C/Fe] as hypothesized by Norris et al. (1997). Unfortunately, a relatively large dispersion in the [s/Fe] values exists probably because [s/Fe] has been calculated as the arithmetic mean of [ls/Fe] and [hs/Fe] using a different number of s-process elements for different stars. It seems, that there is only a weak dependence of the average s-process overabundance, [s/Fe], with [Fe/H].

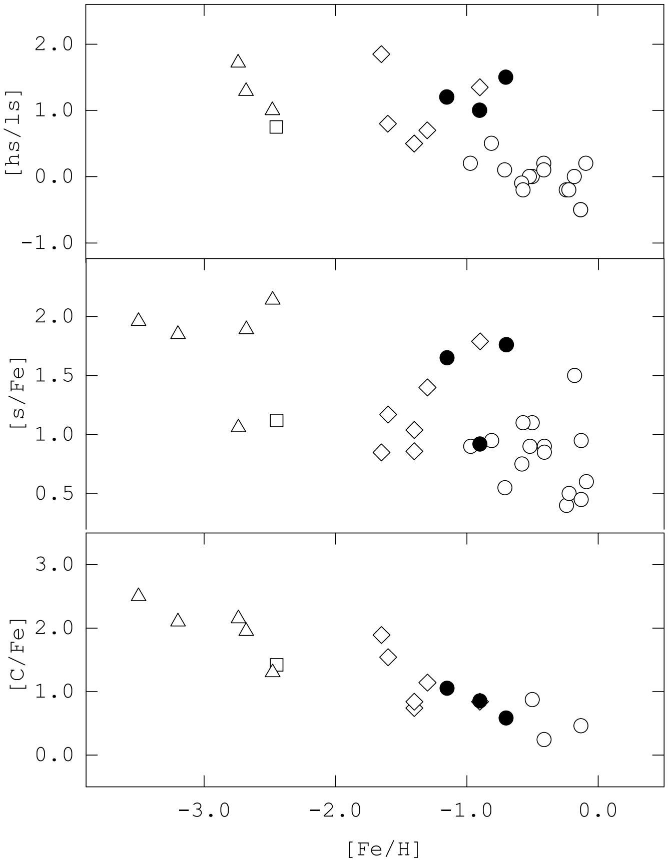

Fig. 5. [hs/ls], [s/Fe], and [C/Fe] as functions of [Fe/H] for early type CH stars (◇), late type CH stars (●), extremely metal-poor carbon-rich objects (△), and HD 196944 (□) in comparison with disk subgiant CH stars (○)

On the other hand, halo carbon-rich objects display an approximately constant [hs/ls] ratio $\simeq 1.1 \pm 0.4$. According to Luck & Bond (1991) the ratio of [hs/ls] is a good indicator of the neutron exposure in the processed material; high values of [hs/ls] corresponding to higher exposures. This means that the synthesis of heavy metals in the atmospheres of the carbon-rich halo stars has occurred under similar conditions, characterized by a high neutron exposure and apparently a single exposure event (Vanture 1992c). The simplest explanation of Fig. 5 is that the analyzed carbon and s-process rich objects are the result of carbon and s-process enriched mass transfer in double star systems. The apparent absence of radial velocity variations in four out of six very metal-poor peculiar halo stars cannot be used as a strong argument against this hypothesis. Some binaries could have either very long orbital periods or highly inclined orbital planes. Note that the efficiency of accretion in the wind mass transfer scenario is great enough to be to explain systems with periods as long as 100 yr (Boffin & Jorissen 1988). On the other hand, if the abundance anomalies in the halo carbon-rich stars are the result of mass transfer from a companion which has undergone AGB evolution, some examples of single halo AGB and post-AGB stars with high [hs/ls] ratios resulting from internal processes should be seen. The known s-process rich post-AGB stars (Klochkova 1995; Začs et al. 1995; Van Winckel et al. 1996; Van Winckel 1997; Reddy et al. 1997) display low heavy-to-light s-process ratio.

We conclude that it is unlikely that HD 196944 is a post-AGB star. It could be an AGB star for which the peculiar atmospheric composition is due to nuclear reactions and mixing inside the star. Alternatively, it is a CH star, for which the abundance peculiarities are due to mass transfer from a companion that has undergone AGB evolution. The latter hypothesis is an attractive explanation of the six very metal-poor stars recently studied on the basis of high resolution spectra. Despite the very different evolutionary stages of these stars, ranging from turnoff stars and subgiants to late M giants, they have similar abundance patterns. It is, however, premature to label HD 196944 as a binary CH star. Accurate radial velocity monitoring of HD 196944 and the other very metal-poor stars are needed to confirm their binary status.

Acknowledgements. This research has been supported (for LZ) in part from the Latvian Scientific Council (grant 96.0173). LZ acknowledges Imants Platais, Miroslaw Schmidt, and Ryszard Szczerba for assistance. WJS has received support in Mexico from CONACyT, projects D111-90386 and 1219-E9203, and from the University, DGAPA project No. IN101495. We thank the anonymous referee for useful comments.

References

Alonso A., Arribas S., Martinez-Roger C., 1996, A&A 313, 873
Anders E., Grevesse N., 1989, Geochim. Cosmochim. Acta, 53, 197
Barbuy B., Cayrel R., Spite M., et al., 1997, A&A 317, L63
Bidelman W.P., 1981, AJ 86, 553
Biémont E., Baudoux M., Kurucz R.L., Ansbacher W., Pinnington E.H. 1991, A&A 249, 539
Blöcker T., 1995, A&A 299, 755
Boffin H.M.J., Jorissen A., 1988, A&A 205, 155
Bond H.E., 1974, ApJ 194, 95
Bond H.E., Neff J.S., 1969, ApJ 158, 1235
Brown J.A., Tomkin J., Lambert D.L., 1983, ApJ 265, L93
Cavallo R.M., Pilachowski C.A., Rebolo R.,1997, PASP 109, 226
Eriksson K., Toft S.C., 1979, A&A 71, 178
ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200
François P., Spite M., Spite F., 1988, A&A 191, 267
Gallagher A. 1967, Phys. Rev. 157, 24
Grevesse N., Blanquet G. 1969, Solar Physics 8, 5
Gustafsson B., Bell R.A., Eriksson K., Nordlund A., 1975, A&A 42, 407
Iben I.Jr., 1991, ApJS 76, 55
Hannaford P., Lowe R.M., Grevesse N., Biémont E., Whaling W. 1982, ApJ 261, 736
Holweger H., Heise C., Kock M. 1990, A&A 232, 510
Johnson D.R.H., Soderblom D.R. 1987, AJ 93, 864
Keenan P.C., 1942, ApJ 96, 101
Kipper T., Jørgensen U.G., 1994, A&A 290, 148
Kipper T., Jørgensen U.G., Klochkova V.G., Panchuk V.E., 1996, A&A 306, 489
Klochkova V.G., 1995, MNRAS 272, 710
Kraft R.P., 1994 PASP 106, 553
Kurucz R.L., 1993, CD-ROM 13, Smithsonian Astrophys.Obs.
Lambert D.L. 1978, MNRAS 182, 249
Lambert D.L., Warner B. 1968, MNRAS 138, 181
Lawler J.E., Dakin J.T. 1989, J. Opt. Soc. Am. B6, 1457
Luck R.E., Bond H.E., 1991, ApJS 77, 515
Luck R.E., Bond H.E., 1992, Bull.American Astron. Soc. 24, 786
Nissen P.E., Gustafsson B., Edvardsson B., Gilmore G., 1994, A&A 285, 440
Nissen P.E., Høg E., Schuster W.J. 1997, ESA SP-402, Hipparcos Venice '97, Ed. B. Battrick, p. 225.
Norris J.E., Ryan S.G., Beers T.C., 1997 ApJ 488, 350
Olsen, E.H., 1983, A&AS 54, 55
Oudmaijer R.D., 1996, A&A 306, 823
Reddy B.E., Parthasarathy M., Gonzalez G., Bakker E.J., 1997, A&A 328, 331
Ruland F., Biehl D., Holweger H., Griffin R., Griffin R., 1980, A&A 92, 70
Schuster W.J., Nissen P.E., 1989a, A&A 221, 65
Schuster W.J., Nissen P.E., 1989b, A&A 222, 69
Schuster W.J., Parrao L., Contreras Martínez M.E., 1993, A&AS 97, 951
Sneden C., McWilliam A., Preston G.W., et al., 1996, ApJ 467, 819
Vanture A.D., 1992a, AJ 103, 2035
Vanture A.D., 1992b, AJ 104, 1986
Vanture A.D., 1992c, AJ 104, 1997
Van Winckel H., 1997, A&A 319, 561
Van Winckel H., Waelkens C., Waters L.B.F.M., 1996, A&A 306, L37
Venn K.A., 1993, ApJ 414, 316
Ward L., Nogel O., Arnesen A., Hallin R., Wännström A. 1985, Physica Scripta 31, 161
Začs L., Klochkova V.G., Panchuk V.E., 1995, MNRAS 275, 764