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A carbon rich star BD +75° 348: a binary?

L. Začs[1], **M.R. Schmidt**[2], **and W.J. Schuster**[3]

[1] Ventspils International Radio Astronomy Center, Akadēmijas laukums 1, 1050 Riga, Latvia
[2] N. Copernicus Astronomical Center, ul. Rabiańska 8, 87-100 Toruń, Poland
[3] Observatorio Astronomico Nacional, UNAM, Apartado Postal 877, C.P. 22800 Ensenada, B.C., Mexico

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Abstract. An LTE abundance analysis of the "CH-like" star BD $+75^{\circ}$ 348, with an unknown evolutionary status, is presented based on high resolution, high signal-to-noise spectra. With [C/Fe] = $+0.5$ dex and a mean s-process overabundance of [s/Fe] $\simeq +1.6$ dex the peculiar atmospheric composition of BD $+75^{\circ}$ 348 is confirmed. The modest iron deficiency, [Fe/H] = -0.8, and the kinematic data support the idea that BD $+75^{\circ}$ 348 is an old disk population object. Possible evolutionary stages, that can explain its atmospheric parameters and peculiar chemical composition, are discussed.

Key words: stars: evolution – stars: abundances – stars: chemically peculiar – stars: individual: BD $+75^{\circ}$ 348

1. Introduction

The "CH-like stars" were first recognized as a distinct class among the ordinary carbon stars of early spectral types (the C0-C3 classifications of Keenan & Morgan (1941); the Harvard R0-R3 classifications) by Yamashita (1972). This "CH-like" nomenclature resulted because these stars' spectra closely resemble those of classical CH stars. However, the CH stars have large radial velocities (RV), typically $\sim$200 km s^{-1}, indicating that they are halo objects, while the ordinary C0-C3 and CH-like stars are concentrated in the range of $RV < 60$ km s^{-1} (Yamashita 1975). It is probable from these velocity distributions that the CH stars and the CH-like stars are from different stellar populations, and that the CH-like stars form a single natural group. However, their real nature is rather uncertain at this time (for reviews, see Pilachowski 1988 and Wallerstein & Knapp 1998). Here for the first time the results of an abundance analysis are presented for one star of this group, BD $+75^{\circ}$ 348. The equivalent widths and individual abundances will be published in a companion paper, in the Supplement Series.

This high latitude (b = $+34^{\circ}$), 9.5 magnitude star (= SAO 6630 = HIC 43042) has been classified before as R0 (Vandervort 1958), C3,0 ch (Yamashita 1975), and K0 III BaII (Alania et al. 1989). Yamashita (1972, 1975) noted a low $RV_{\odot}$ of $+63$ km s^{-1} and low proper motion for this object in spite of the enhanced Ba II line at 4554 Å. The photometry obtained until now does not indicate any significant variability; the visual magnitude (V) measured by different authors ranges from 9.54 to 9.56 (Vandervort 1958; Yamashita 1975; Kižla, private communication; Alania et al. 1989; ESA 1997).

Send offprint requests to: L. Začs (zacs@latnet.lv)

2. Observations and reduction

Spectroscopic data were obtained using the 6m BTA telescope with the echelle spectrometer LYNX equipped with a 530 $\times$ 580 pixel CCD detector (Panchuk et al. 1993) with a resolving power of $\sim$30 000. Two 3600 s exposures of BD $+75^{\circ}$ 348 were taken on 1994 May 27. The spectra covered the spectral region 5000 - 7200 Å in 29 wavelength bands and had a S/N ratio of more than 100. Each region spanned from 50 to 80 Å. The resulting rectified spectrum for one region along with a synthesized one is presented in Fig. 1; also shown is the spectrum for the standard star ϵ Vir.

3. Analysis

An inspection of the spectrum for BD $+75^{\circ}$ 348 shows that the lines of the iron-peak elements are weaker (see, for example, Fig. 1), while features due to C_2, CN, and neutron-capture elements are enhanced relative to the normal giant ϵ Vir (G8 IIIab). Note that the typical R0-R3 stars show relatively weak molecular bands, and their atomic-line spectra are equivalent to the G9-K2 normal giants; however, the s-process elements usually are not enhanced (Dominy 1984). The most prominent molecular feature for BD $+75^{\circ}$ 348 in the observed region is the C_2 Swan system band (0,0) at 5165 Å (see Fig. 2) with a total equivalent width of the head of $\simeq$1 Å. Since all stars shown in Fig. 2 lie in a similar temperature/luminosity domain (K0-2 giants), the strength of the C_2 band reflects in general the level of carbon overabundance. Such a pattern supports the schematic representation of early-type barium and carbon stars in the three-dimensional space proposed by Yamashita & Norimoto (1981; Fig. 10). Clearly visible in BD $+75^{\circ}$ 348 also are the lines of the C_2 band (0,1). Besides, the bands (5,1) and (7,3) of the CN red system are evident. Although continuum definition becomes an increasingly serious problem at the later spectral types, the spectral synthesis of the atomic spectrum for BD $+75^{\circ}$ 348 over

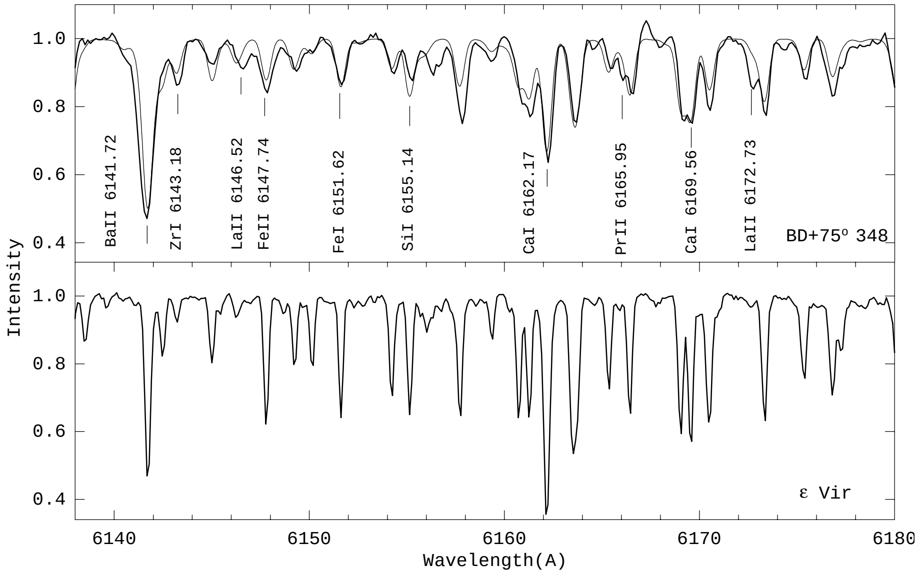

Fig. 1. Observed (thick line) and synthetic spectra of BD $+75^\circ$ 348 longward of the Ba II line at 6141 Å. The synthetic photospheric spectrum has been generated using the atmospheric model with $T_{\rm eff} = 4750$ K, $\log g = 2.0$ (cgs), $\xi_t = 2.0$ km s^{-1}, [Me/H] = -1, and enhanced abundances for the neutron-capture elements of [n/Fe] = $+1.8$ dex, on the average. Also shown is the spectrum for the standard star ϵ Vir.

the entire observed spectral region gives evidence that the continuum redward of 5300 is clearly defined; however, the atomic lines in several regions are significantly blended with molecular lines. These regions include the region shortward of 5165 Å (due to C_2 (0,0)), the region from 5635 to 5510 Å (due to C_2 (0,1)), the region from 6380 to 6530 Å (due to CN (5,1)), and the region from 6650 to 6780 Å (due to CN (7,3)).

3.1. Radial and space velocities

The radial velocity was measured using more than 100 symmetric absorption lines. The observed velocity has been corrected onto a heliocentric system by subtracting -11.5 km s^{-1}. The mean $RV_\odot$ measured for BD $+75^\circ$ 348 was found to be $+43.3 \pm 0.5$ km s^{-1}. Using this radial velocity, plus the proper-motion and parallax data from Hipparcos (ESA 1997; $\pi = 1.02 \pm 1.32$ mas, $\mu_\alpha = -12.86 \pm 0.94$ mas, and $\mu_\delta = +0.34 \pm 1.01$ mas) and the matrix equations of Johnson & Soderblom (1987), the Galactic space velocities have been calculated with respect to the Local Standard of Rest, as well as the standard deviations of these velocities: $(U_{\rm LSR}, V_{\rm LSR}, W_{\rm LSR})$ = (+53,+45,−16) ± (47,9,61) km s^{-1}. In spite of the significant standard deviation due to the uncertainty in the parallax value, these indicate that the star is most probably a disk object, especially the $V_{\rm LSR}$ value, which shows evidence that this star leads the LSR. For example, with [Fe/H] = -0.8 and $V_{\rm rot}$ = $V_{\rm LSR}$+220 = +265 km s^{-1}, BD $+75^\circ$ 348 has X = -25.9, which is the stellar-population discriminator of Schuster et al. (1993). According to the Gaussian fit of their X-histogram (their Fig. 8), BD $+75^\circ$ 348 has a 59% probability of being an old thin-disk star, 38% of being thick disk, and only 3% of being halo.

3.2. Atmospheric parameters

The atmospheric parameters were initially estimated from photometry. Using (B-V) = 1.17 (Yamashita 1975), (V-R) = 0.78 (Kižla, unpublished) and neglecting the interstellar reddening, $E(B-V) \le 0.02$ (see Bergeat et al. 1999), the effective temperature was found to be, $T_{\rm eff} \simeq 4700$ K, according to the Johnson (1966) calibration. Such an estimate is approximately in agreement with the temperature subtype (see Johnson 1966) of the spectral classification for BD $+75^\circ$ 348 (∼K0 III). The color (b-y) = 0.645 of Strömgren photometry observed by Alania et al.(1989) gives $T_{\rm eff} \sim$ 4450 K, using the calibration of Olsen (1984, Eq. (9)), again neglecting interstellar reddening, and assuming a main-sequence surface gravity; if in fact BD $+75^\circ$ 348 is as evolved as a bright giant, the synthetic colors of Kurucz (1991) would give $T_{\rm eff} \sim$ 4850 K. In such a way the photometry indicates that the effective temperature of BD $+75^\circ$ 348 apparently lies in the range from $\simeq 4500$ to 4800 K.

However, standard temperature calibrations refer to stars of normal chemical composition, and therefore may be affected by abundance peculiarities. To obtain a color-independent estimate for the temperature of BD $+75^\circ$ 348, an excitation analysis of the Fe I lines has been employed. (See Začs et al. 1998). Also, the surface gravity ($\log g$) was determined using the Fe I/Fe II ionization balance, and the microturbulent velocity by forcing the abundances of individual Fe I lines to be independent of equivalent width. The resulting atmospheric parameters for BD $+75^\circ$ 348 are as follows: $T_{\rm eff} = 4700$ K, $\log g = 1.8$ (cgs), and ξ_t = 2.0 km s^{-1}, approximately equal to those for normal K bright giants (Gustafsson & Bell 1979).

3.3. The abundance analysis

The standard LTE line analysis program WIDTH9 developed by R. L. Kurucz has been employed, and the model atmospheres were extracted from Kurucz (1993). Spectral lines stronger than 200 mÅ were not used for abundance calculations. The clean lines (Table 1) were selected by successive iteration using the synthetic spectrum over the entire spectral region. The synthetic spectra were generated using the spectral synthesis code devel-

Table 1. Averaged absolute and relative abundances for BD $+75^\circ$ 348. The standard deviations and the numbers of lines used in the analysis are also given

Element(X)	$\log\epsilon$(X)	σ	n	[X/Fe]
C I	8.16			+0.5
Na I	6.06		1	+0.6
Mg I	7.21		1	+0.5
Si I	7.15	0.24	2	+0.5
Ca I	5.77	0.03	3	+0.3
Ti I	4.77	0.29	3	+0.6
V I	3.30	0.17	8	+0.2
Cr I	5.11	0.08	2	+0.3
Fe I	6.64	0.26	32	
Fe II	6.62	0.06	3	
Ni I	5.75	0.08	4	+0.4
Y I	2.52	0.14	2	+1.1
Y II	2.89	0.28	2	+1.5
Zr I	3.43	0.27	3	+1.7
Zr II	3.24		1	+1.5
Ba II	2.94		1	+1.7
La II	2.31	0.20	5	+2.0
Ce II	2.62	0.13	4	+1.9
Pr II	1.32	0.17	7	+1.5
Nd II	2.05	0.25	12	+1.4
Sm II	2.33	0.13	4	+2.2
Eu II	1.27		1	+1.6

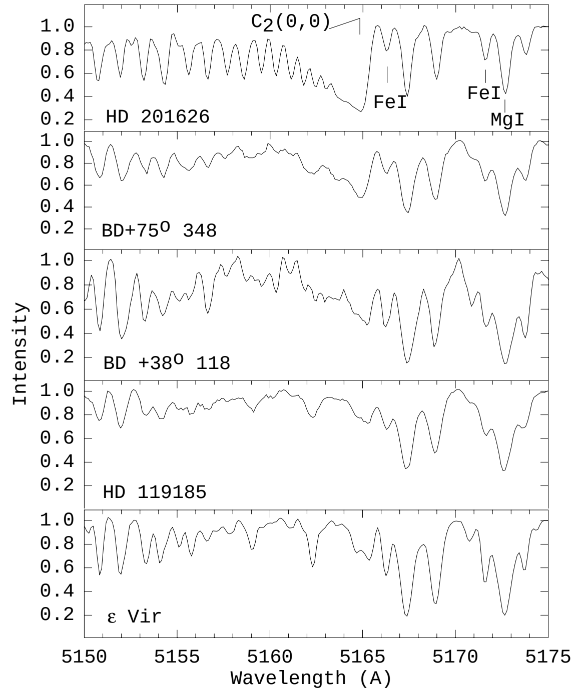

Fig. 2. The observed spectrum of the CH-like star BD $+75^\circ$ 348 around the C_2 Swan system bandhead (0,0) along with those for the CH-star HD 201626, the strong barium star BD $+38^\circ$ 118 (K2 III Ba5), the mild barium star HD 119185 (K0 III Ba1), and the standard G8 IIIab star ϵ Vir.

oped by one of us (M.S.). The C_2 Swan system (0,0) bandhead at 5165 Å was used to determine the carbon abundance for BD $+75^\circ$ 348 (Fig. 3). Since the C_2 band is not fixed by the carbon abundance alone (the CO molecule determines the partial pressures of free carbon and oxygen so that the C_2 band depends on both the C and O abundances), an independent estimate of the oxygen abundance is needed. Unfortunately, neutral oxygen does not show any useful lines for abundance analysis due to the high line density. Therefore, its abundance has been fixed at the enhanced value of [O/Fe] = $+0.2$, according to the trend of oxygen abundance with metallicity (see McWilliam 1997; and references therein).

Atomic and molecular partition functions and the continuous opacity package have been adopted from ATLAS9 (Kurucz 1992). The VALD database for atomic lines (Piskunov et al. 1995) has been used. For the calculation of ionization and dissociation equilibria Tsuji's (1973) molecular constants have been used. The dissociation energy of C_2 equal to 6.25 eV was measured by Cooper (1981). The wavelengths of the molecular lines of the C_2 Swan-system band, $(v', v") : (0, 0)$, were taken from Amiot (1983). The oscillator strengths have been calculated using the Swan-band f value: f(0,0) = 0.0239 (Lambert 1978) and the rotational line strengths tabulated in Kovács (1969) (assuming Hund's case b).

The systematic errors in abundances produced by uncertainties in $T_{\rm eff}$ (±200 K), $\log g$ (±0.3 dex), and ξ_t (±0.5 km s^{-1}) would lead to errors less than 0.3 dex, a little worse that those for barium stars with similar effective temperatures (see Začs et al. 1997). Note, for the carbon abundance determination only the bandhead has been used because shortward of 5165 Å the molecular contribution increases dramatically and the continuum is poorly defined. To check this methodology our result for the CH star HD 201626 has been compared with that derived by Vanture (1992a), and reasonable agreement ($\log\epsilon$(C) = 8.55 and 8.4, respectively) has been found.

Large enhancements of the s-process elements relative to solar values are found; [s/Fe] $\simeq +1.6$ dex on the average. The fit between the observed and synthesized spectra confirms in general a moderate iron deficiency along with the overabundance of neutron-capture elements (see, for example, Fig. 1). The heavy s-process elements are relatively more enhanced than the light s-process peak elements, $[hs/ls] \simeq +0.4$ dex. Spectral synthesis of the molecular band provides enhanced carbon abundances for BD $+75^\circ$ 348, [C/Fe] = +0.5 dex. This suggests that material rich in carbon and neutron-capture elements has been added to the envelope of this star. In order to obtain reliable estimates of the carbon isotope ratio, a useful criterion in understanding the evolutionary status of the star, an analysis of the CN red system (5,1) band near 6415 Å was made. The spectrum synthesis of this region indicates that ^{13}C isotopic lines for BD $+75^\circ$ 348 absent, therefore the ^{12}C/^{13}C abundance ratio can be no lower than 10.

4. Discussion and conclusions

Three principal hypotheses can be advanced to account for the abundance anomalies. First, mass transfer might occur from

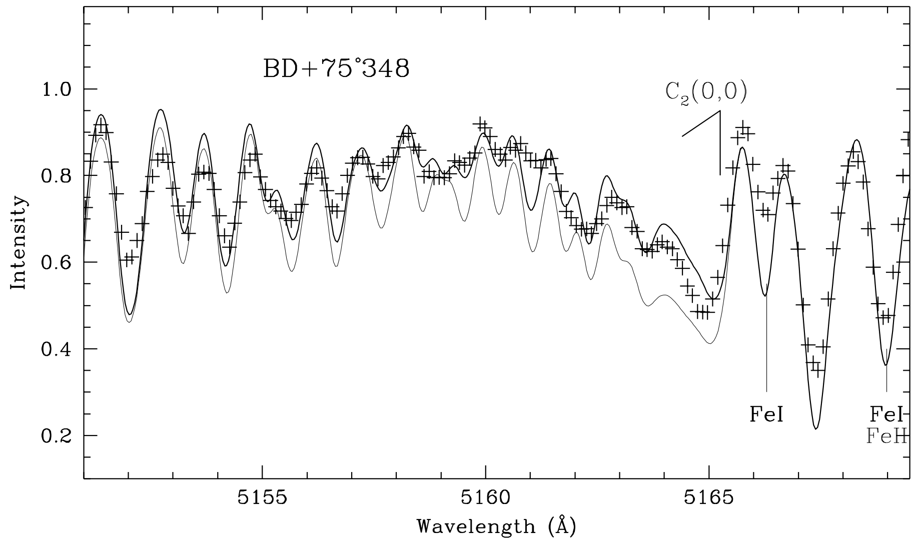

Fig. 3. Observed (crosses) and synthetic spectra for BD $+75^\circ$ 348 in the region of the C_2 Swan system bandhead (0,0) at 5165 Å. Solid lines represent the synthetic spectra with carbon abundances of $\log \epsilon(C)$ = 8.06 (thick) and 8.26 (thin), respectively.

an AGB star to a less evolved companion which is converted to a peculiar star. Unfortunately, only one measurement of the radial velocity, carried out by Yamashita (1975) on the basis of a medium resolution spectrum, was found in the literature for BD $+75^\circ$ 348. Any unpublished high precision determinations seem to be absent (R.D. McClure and R. Griffin, private communications). Bearing in mind the relatively large standard deviation of 13 km s^{-1} (Yamashita 1974) for the value derived by Yamashita (1975), it is difficult to draw any definite conclusion about the variability of the radial velocity (binarity) of BD $+75^\circ$ 348. Therefore, accurate RV monitoring is needed to confirm (or rule out) its binary status.

Anyway, BD $+75^\circ$ 348 is a very intriguing object, because the [hs/ls] ratio in its atmosphere is clearly higher than has been found for the typical disk binaries, the barium stars. In addition, only a few known barium stars display detectable carbon bands (a high carbon abundance). On the other hand, the typical halo binaries, the CH stars, are high velocity objects with large [hs/ls] ratios of $\sim +0.9$ dex on the average (Vanture 1992b). In fact, BD $+75^\circ$ 348 could be the analog of the classical CH and barium stars in the old disk population, in agreement with the hypothesis by Yamashita (1975).

Second, BD $+75^\circ$ 348 might be a carbon and neutron-capture-element rich single star. It is unlikely that the analyzed object is a post-AGB star due to its low luminosity and low temperature (Blöcker 1995b). The Hipparcos parallax (ESA 1997) yields an absolute magnitude, $M_V \simeq -0.4$, and the spectroscopic parameters using a mass of $M = 0.6 M_\odot$ lead to $M_V \simeq -0.5$. It could be an AGB star for which the peculiar atmospheric composition is due to nuclear reactions and mixing inside the star; however, theoretical calculations do not support such a scenario for bright giants (see, for instance, Blöcker 1995a).

Third, it is worthwhile to note that some of the carbon and s-process rich stars may have occurred because of enrichments from the abundances of the Galactic interstellar gas. Therefore, the nature of this peculiar object still remains a matter of considerable uncertainty.

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