A&A 368, 160–174 (2001)
DOI: 10.1051/0004-6361:20000409

Astronomy & Astrophysics

BCD spectrophotometry of stars with the B[e] phenomenon⋆,⋆⋆

I. Fundamental parameters

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Received 3 October 2000 / Accepted 29 November 2000

Abstract. Low resolution spectra in the $\lambda\lambda 3500-4600$ Å wavelength range of 23 stars with the B[e] phenomenon are presented. Spectral classification of 15 program stars was performed using the BCD spectrophotometric system, based on the study of the Balmer discontinuity, which is independent of interstellar and circumstellar dust extinctions and of circumstellar gas emissions and/or absorptions. From calibrations of the (λ_1, D) BCD parameters we determined the $(T_{\rm eff}, \log g, M_{\rm bol})$ of the studied stars. For stars where this method could not be applied, we tried to estimate the temperature of the central star by using the Balmer and He I emission lines and/or their visible energy distribution. The colour temperature and the temperatures obtained from the study of Balmer and He I lines are consistent with each other. The new results are compared with those obtained previously by other authors and discussed for each star individually. For some stars, differences between the effective temperatures derived using the BCD classification system and those obtained elsewhere, based on photometric or spectroscopic analysis, imply spectral-type classification disagreements ranging from 2–3 up to 6 B sub-spectral types. The fundamental parameters of AS 119, CD$-24°$5721, Hen2-91, HD 316375 and BD$-11°$4747 were determined for the first time. A simple method was introduced to calculate total (interstellar+circumstellar) dust extinction towards the studied stars. For HD 53179, which is a double stellar system, and for HD 45677 and HD 50138, which are suspected to be binaries, we predicted the characteristics of the components that are consistent with the observed (λ_1, D) parameters. However, the possible binarity of HD 45677 and HD 50138 still needs to be confirmed spectroscopically.

Key words. stars: emission-line, B[e] – stars: fundamental parameters – stars: evolution

1. Introduction

1.1. Aim of the present work

Among B and late O type stars with spectra showing more or less strong hydrogen emission lines, there are some which also have forbidden emission lines in the visual spectral range. In most of these cases, the presence of forbidden transitions is accompanied by a strong infrared flux excess (Allen & Swings 1976). According to the excitation of lines in the optical spectral region, Allen & Swings (1976) divided these objects into three groups: group 1 comprises stars with rather weak Balmer, Fe II and occasionally [O I] emission lines; in group 2 the stars show strong emission lines and forbidden lines from ions with ionization potentials $\chi \lesssim 25$ eV: [O I], [S II], [Fe II], etc.; group 3 comprises stars with ionization states $\chi \gtrsim 25$ eV: He II, O III, etc. By comparing the spectral morphology in the $\lambda\lambda 3800-10\,900$ Å wavelength interval of four B[e] objects with symbiotic and peculiar stars, Ciatti et al. (1974) concluded that the various excitation conditions coexisting in B[e] spectra are compatible with the presence of a hot radiation source and a cool giant or supergiant component. These authors also suggest that stars showing B[e] spectra may be a sequel of stellar evolution that represents a state previous to a planetary nebula. However, Zickgraf (1998, 2000) showed that quite different type of objects and/or at different evolutionary stages present the same B[e]-type characteristics. Detailed reviews of these stars and their spectral properties are given in several contributions in the "B[e] Stars" workshop (Hubert & Jaschek 1998). It thus follows that the physical mechanisms producing the B[e] spectral aspects can be different and that they may be present in stars, either single or binaries, which are in quite different evolutionary stages. Lamers et al. (1998) referred to these objects as presenting the "B[e] phenomenon",

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⋆ Data obtained in CASLEO operated under agreement between the CONICET and the Universities of La Plata, Córdoba and San Juan, Argentina.
⋆⋆ Partially based on observations done at ESO La Silla, Chili.

Table 1. Program stars with the B[e] phenomenon and the comparison B and Be stars

Stars with the B[e] phenomenon						
No.	Star	Ident.	Class	V mag	date UT	exp. h
1	RMC 4	AzV 16	sgB[e]	13.2	09.08.98	1.00
2	CPD−75°116	RMC 50	sgB[e]	11.5	08.08.97	1.00
3	HD 269217	MWC 106	sgB[e]	11.9	10.08.98	1.00
4	BD−10°1351	AS 116	HAeBe	10.4[a]	12.10.97	0.25
5	BD−14°1319	AS 117	HAeBe	10.3[a]	14.10.97	0.42
6	AS 119		unclB[e]	11.0	14.10.97	0.67
7	HD 45677	MWC 142	unclB[e]	8.1	12.10.97	0.25
8	HD 50138	MWC 158	unclB[e]	6.6	10.08.98	0.25
9	HD 53179	Z CMa	HAeBe	9.9	14.10.97	0.50
10	CD−24°5721	AS 160	unclB[e]	10.9	14.10.97	0.83
11	Hen 2-90	ESO 132-1	cPNB[e]	13.0	10.08.98	1.44
12	Hen 2-91		unclB[e]	14.4	09.08.98	1.44
13	CD−42°11721	MWC 865	unclB[e]	11.4	08.08.98	0.58
14	Hen 3-1356	AS 222	unclB[e]	12.5	10.08.98	0.75
15	HD 316248	MWC 270	cPNB[e]	12.1	10.08.98	1.00
16	HD 316375	AS 246	unclB[e]	9.6	11.08.98	0.25
17	HD 163296	MWC 275	HAeBe	6.9	08.08.98	0.05
18	HD 169515	MWC 295	symB[e]	9.1	08.08.98	0.58
19	MWC 297	NZ Ser	HAeBe	12.3	11.08.98	1.17
20	BD−11°4747	AS 321	unclB[e]	11.0[b]	10.08.98	0.25
21	AS 341		symB[e]	11.0	10.08.98	0.75
22	BD+14°3887	MWC 314	sgB[e]	9.9	09.08.98	0.50
23	HD 190073	MWC 325	HAeBe	7.9	08.08.98	0.04

Comparison B and Be stars						
Star	Sp.T. MK(λ_1, D)	V mag	ESO (BCD)	n	CASLEO (B&Ch)	exp. h
HD 15318	B9III	4.28	21-24.11.80	10	09.08.98	0.02
HD 32249	B3V	4.81	01-02.12.80	8	12.10.97	0.01
HD 36512	B0V	4.62	03-12.10.79	10	12.10.97	0.01
HD 120324	B2IV-Ve	3.04	12-14.04.82	8	10.08.98	0.02
HD 144217	B1V	2.62	27-30.05.78	10	08.08.98	0.03
HD 144218	B2V	4.92	27-30.05.78	10	08.08.98	0.07
HD 149438	B0V	2.82	14-15.04.82	4	07.08.98	0.05
HD 184915	B0.5IIIe	4.95	21-25.05.78	16	12.10.97	0.21
HD 214923	B8V	3.40	03-07.10.79	8	09.08.98	0.02
HD 224990	B4III	5.01	22-24.11.80	6	12.10.97	0.21

Note: n = number of spectra used; exp. = exposure time in hours; MK(λ_1, D) = spectral type according to the (λ_1, D) calibrations in MK spectral types; V magnitudes are from CDS; [a] Miroshnichenko et al. (1999); [b] Miroshnichenko (2000, private communication)

rather than considering them as "B[e]-type" stars. They also divide them into five categories, each distinguished by an evolutionary stage. However, in many cases the nature of the central stars in objects with the B[e] phenomenon and their evolutionary stage are little known. Similarly, nothing is known of the specific relation between the physical circumstances leading to the appearance of the B[e] phenomenon and the stellar evolution of these objects. To provide new insight into the nature of the central stars, we observed the spectral region near the Balmer discontinuity (BD) of a sample of southern objects with the B[e] phenomenon. Such observations proved to be of great importance for classical Be stars (highly rotating B stars with circumstellar envelopes, Jaschek et al. 1981). When possible, we aim at determining the fundamental parameters of B[e] stars by taking advantage of the BCD spectrophotometric system.

1.2. The BCD system

The BCD (Barbier-Chalonge-Divan) spectrophotometric system, primarily a stellar classification system, was introduced by Barbier & Chalonge (1941) and Chalonge & Divan (1952). It is based on measurable quantities of the BD, which can be obtained from low resolution spectra in the $\lambda\lambda 3500-4600$ wavelength interval are then suitable. This system is useful for stars ranging from spectral type O4 to F9 where the BD is larger than about 0.005 dex. In the $\lambda\lambda 3500-4600$ region two spectrophotometric parameters can be derived: D in dex and λ_1, this last is commonly presented as the difference λ_1-3700 Å. D is the Balmer jump measured at $\lambda 3700$ Å, which is obtained by extrapolating the Paschen continuum energy distribution in a $\log F_\lambda/B_\lambda$ vs. $1/\lambda$ display (B_λ is a comparison or reference flux distribution). λ_1 gives the mean spectral position of the BD. D is a strong indicator of the effective photospheric temperature and λ_1 easily leads us to the photospheric $\log g$ parameter. Stars with circumstellar envelopes, whose densities are lower than the photospheric layers where Balmer lines of the underlying star form, show two BD components. The first component reflects the photospheric properties of the underlying star. The second BD is due to the circumstellar matter. It can be either in emission or in absorption and it is shifted to the blue from the first, photospheric BD. Both BD components are then clearly distinguished, so that the BCD system is also suitable for spectral classification of stars with circumstellar envelopes. On the other hand, the photospheric BCD parameters are not affected either by interstellar extinction or by circumstellar absorption and/or emission. Moreover, as the (λ_1, D) parameters are obtained from the continuum energy distribution, they are related, on average, to physical properties of deeper photospheric layers than any classification system based on spectral line measurements. The advantages of determining fundamental parameters with the BCD system and the uncertainties of these parameters are discussed in Divan & Zorec (1982a) and Zorec & Briot (1991).

2. Data

2.1. Observations

The present set of spectroscopic observations was obtained in October 1997 and August 1998 at the *Complejo Astronómico El Leoncito* (CASLEO, Argentina). We used the Boller & Chivens Cassegrain spectrograph (B&Ch) with a 600 lines mm^{-1} grating and a 512×512 CCD detector attached to the 2.15 m telescope. The observed spectral range is $\lambda\lambda 3500-4600$ Å where the 2 pixel resolution represents 4.53 Å, nearly the same as in the original BCD system at $\lambda 3700$ Å. Reductions were performed with the IRAF software package (version 2.10.2). All but four of the spectra extracted were corrected for atmospheric extinction and they were wavelength and flux calibrated. The remaining four spectra, observed on 14.10.97, were not flux calibrated, since the observation conditions did not allow us to obtain suitable flux-calibrated comparison stars. For these stars we recovered the BCD parameters by using HD 190073 as the comparison star. This star was observed on the same night and has flux-calibrated spectra which were obtained in Aug. 1998. Since the use of this star might lead to less precise flux calibrations of spectra to determine the (λ_1, D) parameters, we studied only some wavelengths at both sides of the BD, as was usually done in the original BCD reduction procedure (Chalonge & Divan 1952).

2.2. Stars observed

We have observed stars with the B[e] phenomenon listed in Jaschek & Egret (1982) of almost all classes introduced by Lamers et al. (1998): B[e] supergiants or "sgB[e]"; pre-main sequence B[e]-type stars or "HAeB[e]"; compact planetary nebulae B[e]-type stars or "cPNB[e]"; symbiotic B[e]-type stars or "symB[e]". A number of objects satisfy the criteria for more than one of the above classes. As their evolutionary phases are unclear, these stars are considered unclassified B[e]-type stars or "unclB[e] stars".

In the original form of the BCD system, parameters are obtained by differential spectrophotometry. In the present case, most of the BCD (λ_1, D) parameters were derived in an absolute way. In order to test the BCD parameters derived using data obtained with the Boller & Chivens spectrograph against those obtained in the original BCD system, we also observed some normal and emission line B stars for which BCD data existed. We also reobserved stars with the B[e] phenomenon already classified in this system and we included several HAeBe stars. The log of observations done is displayed in Table 1. Flux-calibrated spectra normalized to the flux at λ4500 Å of stars whose BD we were able to study are shown in Fig. 1. The flux-uncalibrated spectra of four program stars for which we also determined the BCD parameters are shown in Fig. 2, while those of stars without measurable BD are shown in Fig. 3.

3. Results

3.1. Preliminary comparisons

Once the B&Ch spectra are wavelength and flux calibrated and corrected for earth atmospheric extinction, we normalize them to a suitable Planckian energy distribution, so that when displayed against the wave number $1/\lambda$ they are straight in the $\lambda\lambda$3500−4600 Å wavelength interval. This fact helps to determine the extrapolated edge $\log F_{\lambda 3700^+}$ of the Paschen continuum. In spectra of stars with line and continuum emission we identify $F_{\lambda 3700^-}$ as the flux level where the higher order stellar Balmer lines merge together. As the B&Ch spectra do not have the same resolution as the spectra from which the original BCD λ_1 parameters were obtained, which we used to set the calibrations of (λ_1, D) into $T_{\rm eff}$, log g and $M_{\rm bol}$, it is necessary to compare the new (λ_1, D) determinations with the original ones. Table 2 shows a group of normal and emission line B type stars for which the (λ_1, D) were determined using both types of data. Uncertainties related to the original BCD (λ_1, D) parameters, when determined from at least 5 spectra measured on photographic plates, are on average: $\sigma(\lambda_1) \simeq 2$ Å and $\sigma(_D) \lesssim 0.015$ dex. The uncertainties related to the B&Ch spectra are of the same order, except that to obtain them we need quite a small number of spectra. Though the number of stars compared in Table 2 is not large, no systematic effects seem to be present. Finally, we note that the BCD parameters are determined by drawing a smoothed energy distribution over the observed one (Chalonge & Divan 1952; Chalonge 1955), so that (λ_1, D) do not depend on the S/N ratio of spectra. In addition, this allows us to compare the BCD parameters determined from spectra with quite different exposure times, such as our comparison B and Be stars and the B[e] objects. The spectral resolution determines, however, the scale of λ_1, but it does not affect the value of D.

Obviously, only stars with measurable BD can have fundamental parameters determined using the calibrations of (λ_1, D). A number of hot B[e] stars, mainly of cPNB[e] and symB[e] class, either have a tiny BD or their spectral region near the BD is crowded by strong emission lines, which prevent any direct (λ_1, D) determination. For the stars where these parameters cannot be obtained directly, we used other methods to gain some insight into their fundamental parameters, at least with regard to their effective temperature.

3.2. Fundamental parameters from (λ_1, D)

Among the program stars, only 15 objects have a measurable Balmer discontinuity. The results obtained are presented in Table 3. Those (λ_1, D) parameters which were derived in a differential way are indicated by an asterisk. The $T_{\rm eff}$, log g and the bolometric absolute magnitude, $M_{\rm bol}$, were determined using the (λ_1, D) calibration (Divan & Zorec 1982a; Zorec 1986). In each case we assumed that stars are single and that their photospheric-like spectrum can be represented by the observed (λ_1, D) pair, and thus by $(T_{\rm eff}$, log $g)$. The absolute values of uncertainties of $T_{\rm eff}$, $\log g$ and $M_{\rm bol}$ related to given $(\delta\lambda_1, \delta D)$ observational errors are (λ_1, D)-dependent. For each $X(\lambda_1, D)$ fundamental parameter obtained, Table 3 gives the 1σ dispersion of the corresponding $X(\lambda_1 \pm \delta\lambda_1, D \pm \delta D)$ values. In Table 3 we also give the total extinction A_V (circumstellar+interstellar) obtained as explained in Sect. 3.5.

Some program objects are binaries or supposed binaries. In Sect. 4.3 we discuss the characteristics the components should have in order to produce, within the observational uncertainties, the same (λ_1, D) parameters as those observed.

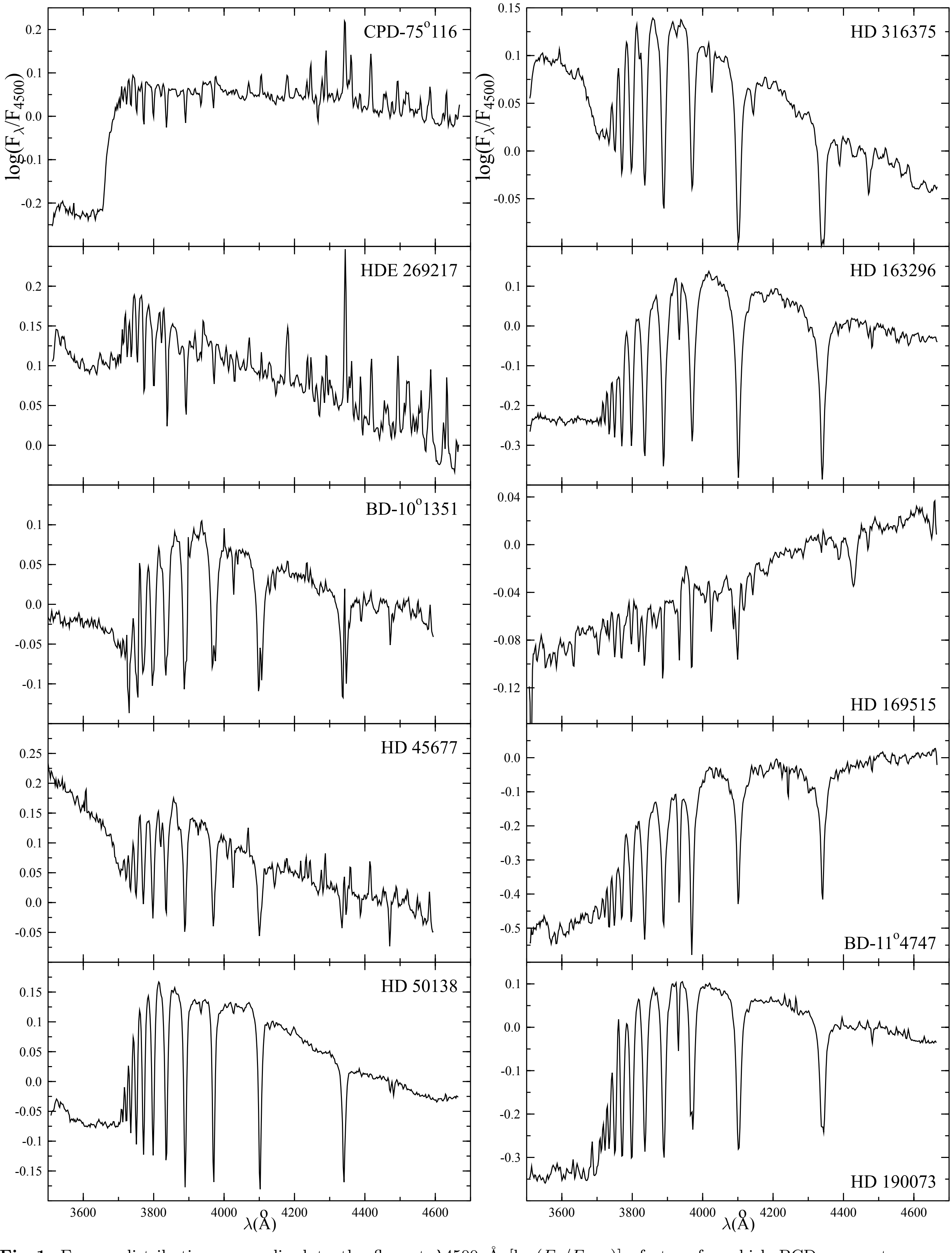

Fig. 1. Energy distributions normalized to the flux at $\lambda 4500$ Å [$\log(F_\lambda/F_{4500})$] of stars for which BCD parameters were determined

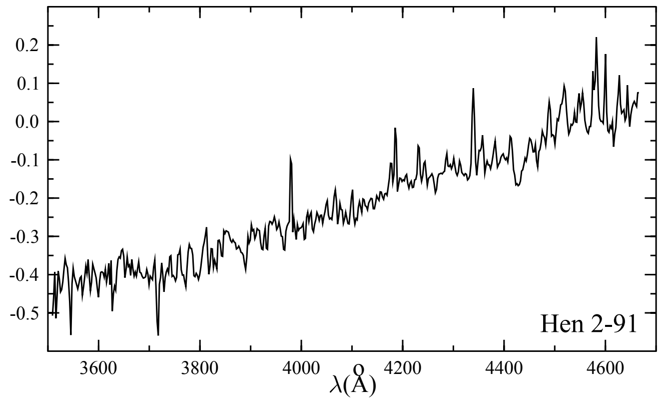

Fig. 1. continued

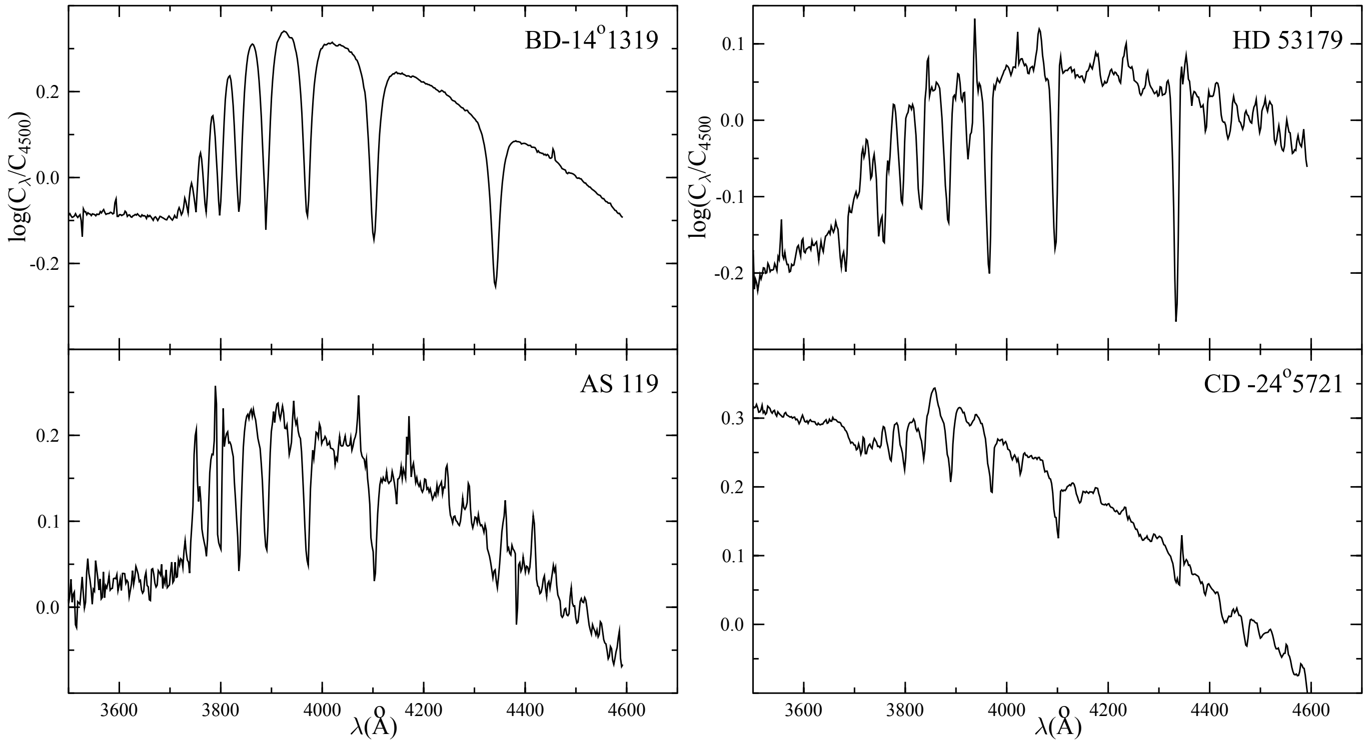

Fig. 2. Flux-uncalibrated spectra of four program stars for which BCD parameters have also been determined [$\log(C_\lambda/C_{4500})$ logarithm of counts normalized at λ4500 Å]

3.3. Effective temperatures obtained from Balmer lines

The spectra of four stars (Nos. 11, 13, 15 and 21) are characterized by strong emission lines in the $\lambda\lambda$ 3500–4600 interval, which entirely obliterate the stellar BD. The Balmer emission lines of these stars, seen up to quantum numbers as high as $n = 12$, 14, can be considered nearly optically thin. This is shown in Fig. 4, where we compare the average of their observed line intensity ratios $\log(I_{\rm n}/I_{\rm H\gamma})$ ($n > 5$) with those predicted by Osterbrock (1989) for emitting nebula in case B. Thus, to obtain some insight into the excitation temperature of the Balmer emission lines provided by the central stars, we assumed they are surrounded by a gaseous circumstellar envelope (CE) or disk. The emitted flux in a line at wavelength λ can then be written as:

$$\psi(\lambda)F_\lambda = \phi(\lambda)F^*_\lambda {\rm e}^{-\tau_\lambda} + \Omega S_\lambda(1 - {\rm e}^{-2\tau_\lambda}) \qquad (1)$$

where ψ represents the emission line profile; ϕ is the underlying photospheric absorption profile; F_λ is the total continuum flux (star+CE); F^*_λ is the underlying stellar continuum flux; τ_λ is the total (line+continuum) optical depth at wavelength λ in the line profile; S_λ is the line source function in the CE; Ω is a geometrical factor which accounts for the CE effective emitting area. Given that the equivalent widths for emission lines are defined as $W^{\rm em} = \int(1-\psi){\rm d}\lambda \leq 0$ and for the stellar absorption

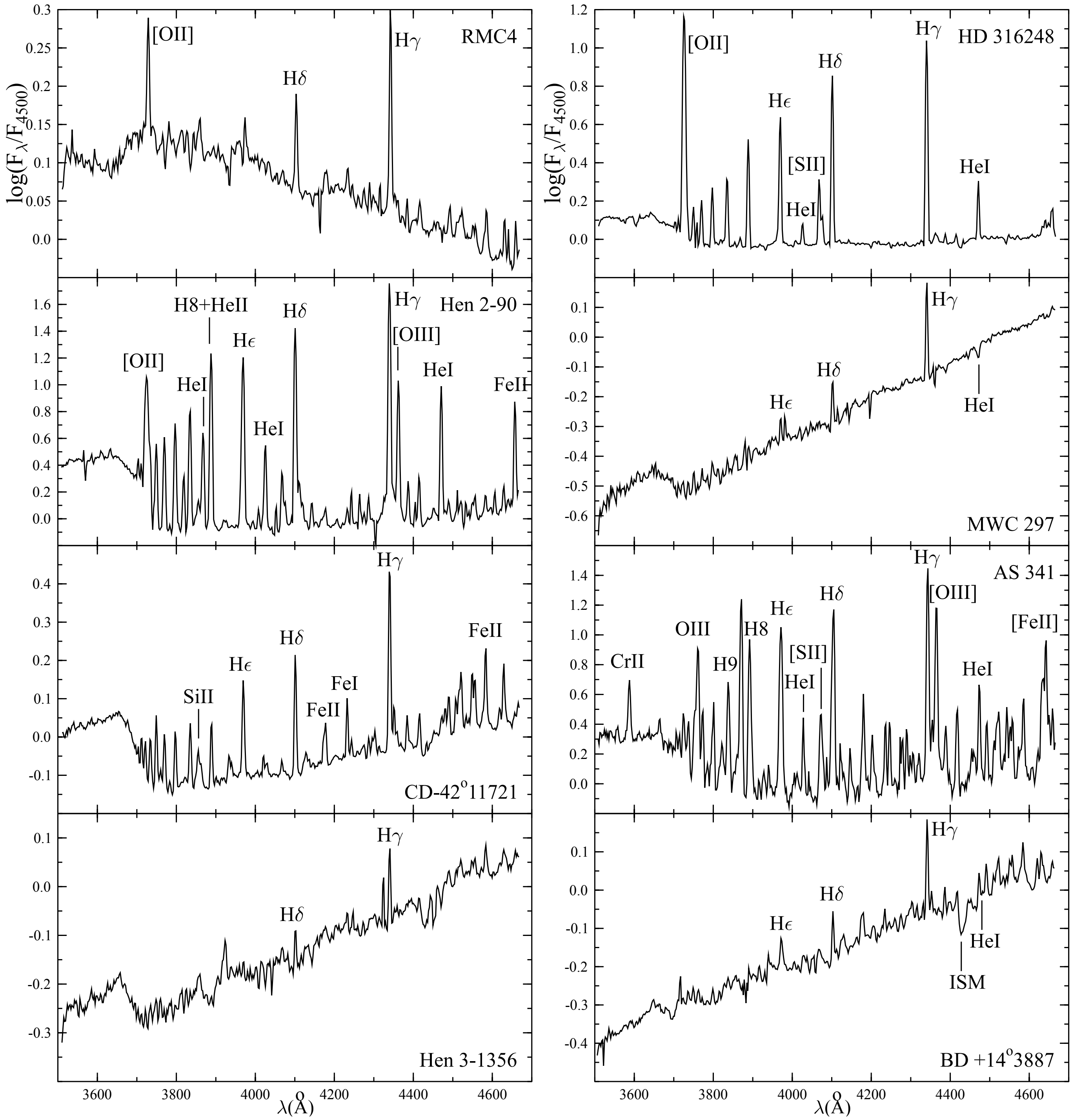

Fig. 3. Energy distributions normalized to the flux at $\lambda4500$ Å $[\log(F_\lambda/F_{4500})]$ of stars for which BCD parameters could not be determined. Some obvious line identifications are shown. ISM = interstellar absorption band

lines as $W^* = \int(1-\phi)\mathrm{d}\lambda \geq 0$, from (1) we derive the following expression for the equivalent width of an optically thin emission line:

$$-W^{\mathrm{em}}\left(1+\frac{\Delta F_\lambda}{F^*_\lambda}\right) = W^* - \frac{2\mathcal{V}}{F^*_\lambda}(\epsilon_\mathrm{l}-\epsilon_\mathrm{c}) \qquad (2)$$

where $\Delta F_\lambda = F_\lambda - F^*_\lambda$ represents the continuum flux excess due to the CE; $\mathcal{V}$ is the emitting volume; ϵ_l and ϵ_c are respectively the line and continuum volume emission coefficients in the CE. It can be shown that for Balmer lines $\epsilon_\mathrm{c}/\epsilon_\mathrm{l} \lesssim 1.5\ 10^{-2}$ so that we can neglect ϵ_c in (2). As we may assume that from $\lambda3770$ to $\lambda4304$ $\Delta F_\lambda/F^*_\lambda \simeq$ const., we can consider that in (2) there are three unknowns: $\Delta F_\lambda/F^*_\lambda$, $\mathcal{V}$ and the effective temperature $T_{\rm eff}$ on which F^*_λ depends. Using three different Balmer lines: $\rm Hn_1$, $\rm Hn_2$ and $\rm Hn_3$, we derive from (2) the following useful relation to determine $T_{\rm eff}$:

$$\frac{W_1^{\rm em}}{W_2^{\rm em}}\frac{\left(1-\frac{W_3^{\rm em}}{W_1^{\rm em}}\frac{F_3^*}{F_1^*}\frac{\epsilon_1}{\epsilon_3}\right)}{\left(1-\frac{W_3^{\rm em}}{W_2^{\rm em}}\frac{F_3^*}{F_2^*}\frac{\epsilon_2}{\epsilon_3}\right)}=\frac{W_1^*}{W_2^*}\frac{\left(1-\frac{W_3^*}{W_1^*}\frac{F_3^*}{F_1^*}\frac{\epsilon_1}{\epsilon_3}\right)}{\left(1-\frac{W_3^*}{W_2^*}\frac{F_3^*}{F_2^*}\frac{\epsilon_2}{\epsilon_3}\right)} \quad (3)$$

where $W_i^{\rm em,*}$ are respectively the equivalent widths of the observed $\rm Hn_\mathit{i}$ Balmer emission lines and the stellar absorption components. The ratios $W^*_{{\rm n}_i}/W^*_{{\rm n}_j}$ as well as the flux ratios $F^*_{\lambda({\rm n}_i)}/F^*_{\lambda({\rm n}_j)}$ are nearly log g-independent. Once the $[F^*_{\lambda({\rm n}_i)},T_{\rm eff}]$ and $(W^*_{\rm n},T_{\rm eff})$ relations are given for all the studied Balmer lines (H5 to H12), we can determine the effective temperature which satisfies relation (3). A simplified version of (3) was used by Chkhikvadze (1970) to analyse MWC 84 by considering only two Balmer lines: H6 and H10, with $W_{10}^{\rm em}=0$.

The $[F^*_{\lambda({\rm n}_i)},T_{\rm eff}]$ were established using Kurucz's (1992) models of normal stellar atmospheres. The $(W^*_{\rm n},T_{\rm eff})$ relations were determined using observed values of the $W^*_{\rm n}$ equivalent widths of normal O, B and early A type stars (Boyarchuk 1957; Buscombe 1969; Kopylov 1958; Tereshchenko 1976). The effective temperatures used to obtain the $(W^*_{\rm n},T_{\rm eff})$ relations for normal stars are from the BCD $T_{\rm eff}(\lambda_1,D)$ calibrations. To reveal a luminosity class effect in the $(W^*_{\rm n},T_{\rm eff})$ relations, we grouped stars into three luminosity class groups so that each of them becomes statistically significant: V, IV-V+IV and III-IV+III+II-III. As the $(W^*_{\rm n},T_{\rm eff})$ are not easy to represent analytically, we used $(W^*_{\rm n},S_{70})$ relations, where S_{70} is the value of the BD at $\lambda_1=3700$ Å, which is used in the BCD system as a continuous parameter of spectral classification for early type stars (Zorec et al. 1983; Zorec & Briot 1991, 1997). The $(S_{70},T_{\rm eff})$ relation is also straightforward to represent (Zorec et al. 1983). Figure 5 shows the $(W^*_{\rm n},S_{70})$ relations obtained for Hγ, Hζ and Hι lines of main sequence stars. The S_{70} and $T_{\rm eff}$ of the studied stars with the B[e] phenomenon obtained by the present method are given in Table 4. The dispersions are due to the use of several ($\rm Hn_\mathit{i}$,$\rm Hn_\mathit{j}$,$\rm Hn_\mathit{k}$) combinations. No luminosity class effect on the S_{70} and $T_{\rm eff}$ values is detected.

Figure 4 strongly suggests that the CE of the studied stars are optically thin in Balmer lines, at least from Hγ to H12. However, this condition does not imply that the Balmer line formation regions have low densities. If electron densities are $N_{\rm e}\lesssim 10^7$ cm^{-3}, the ratios of line emission coefficient $\epsilon_{\rm n1}/\epsilon_{\rm n2}$ can be considered density- and temperature-independent (Drake & Ulrich 1980; Osterbrock 1989). At $N_{\rm e}\gtrsim 10^7$ cm^{-3} there are collisional effects for the higher hydrogen energy levels. Nevertheless, we tested that for optically thin media, the low density approximation can still be used up to $N_{\rm e}\sim 10^8$ cm^{-3} to calculate the ratios $\epsilon_{\rm n1}/\epsilon_{\rm n2}$ for $n\lesssim 12$ without introducing larger errors in the estimation of $T_{\rm eff}$ than those quoted in Table 4. For $N_{\rm e}\gtrsim 10^{12}$ cm^{-3}, the ratios of the line emission coefficients are essentially temperature-dependent (Drake & Ulrich 1980). In our calculations we used ratios of line emission coefficients for optically thin media and appropriate for low ($N_{\rm e}\lesssim 10^8$ cm^{-3}) and high ($N_{\rm e}\gtrsim 10^{12}$ cm^{-3}) densities. The electron temperature $T_{\rm e}$ needed to obtain the temperature-dependent $\epsilon_{\rm n1}/\epsilon_{\rm n2}$ ratios was approximated with $T_{\rm e}=0.8\times T_{\rm eff}$. For each star, the effective temperature given in Table 4 is the average of the $T_{\rm eff}$ obtained with ratios of line emission coefficients corresponding to both extreme electron density approximations. Finally, we note that no solution could be obtained from (3) using $\epsilon_{\rm n1}/\epsilon_{\rm n2}$ ratios for optically thick and dense CE.

Table 2. Comparison of (λ_1,D) parameters obtained from B&Ch data with those issued from the original BCD system

Star	B&Ch		BCD	
	λ_1 Å	D dex	λ_1 Å	D dex
HD 15318	60.8 ± 2.2	0.489 ± 0.004	61	0.460
HD 32249	54.0 ± 1.5	0.192 ± 0.003	56	0.185
HD 36512	53.8 ± 2.6	0.059 ± 0.005	57	0.053
HD 120324	54.4 ± 2.1	0.112 ± 0.004	53	0.136
HD 144217	63.0 ± 1.2	0.074 ± 0.003	64	0.083
HD 144218	58.0 ± 2.1	0.156 ± 0.002	60	0.147
HD 149438	51.5 ± 2.4	0.061 ± 0.003	57	0.063
HD 184915	47.4 ± 2.5	0.060 ± 0.002	44	0.070
HD 214923	46.7 ± 0.5	0.435 ± 0.002	49	0.440
HD 224990	45.8 ± 1.3	0.254 ± 0.002	49	0.244

3.4. Temperatures derived from He I lines

Further information on the effective temperature of the star underlying the CE can be obtained from the emitted flux in the He I recombination lines. Hence, we assume that the number of photons emitted by the CE in a specific recombination line is proportional to the number of ionizing photons emitted by the star. It is then shown (Osterbrock 1989) that the ratio between the luminosity of the star in the frequency of the line $L_\nu(T_{\rm eff})$ and the number of ionizing photons $\int_{\nu_{\rm o}}^{\infty}(L^*_\nu(T_{\rm eff})/h\nu){\rm d}\nu$ ($h\nu_{\rm o}=24.6$ eV is the ionizing potential of He I) is given by:

$$\frac{L_\nu(T_{\rm eff})/h\nu}{\int_{\nu_{\rm o}}^{\infty}(L^*_\nu(T_{\rm eff})/h\nu){\rm d}\nu}=\eta\frac{\alpha_\nu^{\rm eff}}{\alpha_{\rm B}}\frac{F_\nu}{F_{\nu_{\rm R}}} \quad (4)$$

where η represents the fraction of He I-ionizing stellar photons absorbed by the nebula; $\alpha_\nu^{\rm eff}$ is the recombination coefficient in the line; $\alpha_{\rm B}$ is the recombination coefficient of He I; F_ν is the flux observed in the studied line and $F_{\nu_{\rm R}}$ is the flux observed in a He I line used as reference. The electron temperature used to calculate the recombination coefficients $\alpha_\nu^{\rm eff}$ and $\alpha_{\rm B}$ is $T_{\rm e}=0.8\times T_{\rm eff}$. However, the ratio $\alpha_\nu^{\rm eff}/\alpha_{\rm B}$ is almost insensitive to the value of the electron temperature assumed. Among those stars for which we could not use the BCD method to determine their

Table 3. Program B[e] stars with BCD classification and fundamental parameters obtained from (λ_1, D) calibrations

Star		λ_1 Å	D dex	Spectral type[a]	$T_{\rm eff}$ K	$\log g$	$M_{\rm bol}$ mag	A_V mag	Previous spectral classifications
CPD−75°116		11.1 ± 4.7	0.064 ± 0.004	B5Ia	$13\,500 \pm 100$	–	–	1.0	B2-3 (10)
HD 269217		10.5 ± 1.7	0.078 ± 0.011	B5-6Ia	$13\,200 \pm 260$	–	–	0.4	B3Ib: (8), B2-3 (10)
BD−10°1351		67.6 ± 3.7	0.181 ± 0.012	B3V	$19\,900 \pm 700$	4.3	-3.60 ± 0.25	1.1	B7 (6), B3 (6)
BD−14°1319	*	78.0 ± 1.6	0.454 ± 0.010	A1V:	9600 ± 200	4.3	$+0.74 \pm 0.16$	1.2	A0 (6)
AS 119	*	49.3 ± 4.0	0.197 ± 0.015	B3IV	$18\,000 \pm 720$	3.7	-3.84 ± 0.30	2.7	
HD 45677		54.8 ± 1.6	0.144 ± 0.004	B2IV-V	$21\,850 \pm 300$	3.9	-4.89 ± 0.12	1.4	B2III-IV/B2V (11)
HD 50138		41.7 ± 0.6	0.295 ± 0.004	B6III-IV	$13\,270 \pm 100$	3.4	-2.38 ± 0.06	0.4	B6III-IV (11)
HD 53179	*	47.0 ± 9.0	0.142 ± 0.023	F8III-IV	–	–	–	2.3	B5 (1), B5/8 (9)
CD−24°5721	*	75.0 ± 5.0	0.116 ± 0.012	B1.5V:	$25\,800 \pm 1200$	4.4	-5.28 ± 0.32	1.7	O9.5 (4)
Hen 2-91		–	0.081 ± 0.030	B0	$32\,500 \pm 2600$	–	–	5.8	
HD 316375		63.0 ± 1.3	0.164 ± 0.010	B2V	$21\,000 \pm 740$	4.2	-4.13 ± 0.20	0.7	B8 (2)
HD 163296		73.4 ± 2.0	0.434 ± 0.006	A0V:	9200 ± 270	4.3	$+0.48 \pm 0.10$	0.2	A1V (5), A0/2V (9)
HD 169515		> 80	0.062 ± 0.035	O9.5V:	$32\,000 \pm 3000$	–	-6.97 ± 1.20	2.9	O9.5Ib+O5.5V (3)
BD−11°4747		66.8 ± 4.2	0.375 ± 0.012	B9V	$11\,540 \pm 200$	4.2	-0.48 ± 0.14	2.8	
HD 190073		50.4 ± 0.3	0.433 ± 0.002	B9IV	$11\,120 \pm 70$	3.7	-0.72 ± 0.03	0.5	A0III (7), A0IV(9)

Notes: "*" stars with flux-uncalibrated spectra; "[a]" MK spectral types derived from the (λ_1, D) calibration (Chalonge & Divan 1973; the average uncertainty of $\log g$ is $\overline{\delta}_{\log g} = \pm 0.1$ dex; the average error of A_V is $\overline{\delta}_{A_V} = \pm 0.1$ mag.

Refs.: (1) Buscombe (1977), (2) Cannon & Walton Mayall (1949), (3) Chlebowski & Harnden (1989), (4) Drilling (1991), (5) Hauck & Jaschek (2000), (6) Miroshnichenko et al. (1999), (7) Ringuelet et al. (1987), (8) Smith & Bruhweiler (1999), (9) Thé et al. (1994), (10) Zickgraf et al. (1996), (11) Zorec et al. (1998).

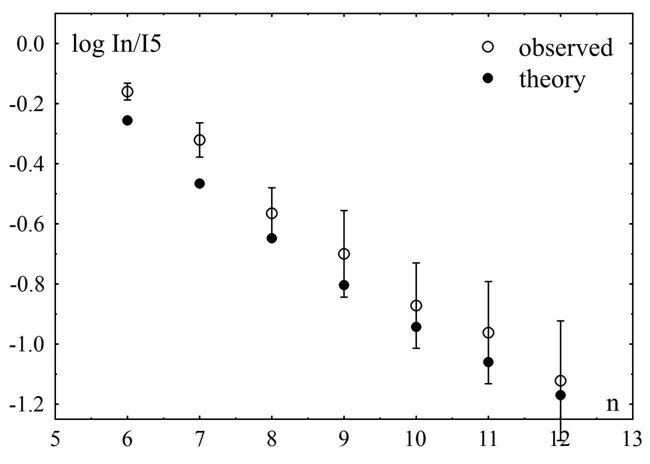

Fig. 4. Mean observed ratios $\log(I_{\rm n}/I_{\rm H\gamma})$ compared to theoretical predictions for optically thin Balmer lines (Case B)

fundamental parameters, only five have measurable He I emission lines. In these cases we used the following He I lines: λ4471, λ4120 and λ4026 Å. The typical relative error in the equivalent width measuremets of these lines is 8%. Different permutations for the reference line in (4) lead to somewhat different values of the stellar effective temperature $T_{\rm eff}$. The average of these determinations and the respective dispersion (1σ) for each studied star are given in Table 4. In Table 4 we see that the effective temperatures derived from (4) are slightly higher than those obtained by other methods. This effect is reminiscent of the temperature excess known as the "Zanstra discrepancy", according to which electron temperatures obtained from H lines are more or less systematically lower than those obtained using He lines (Osterbrock 1989).

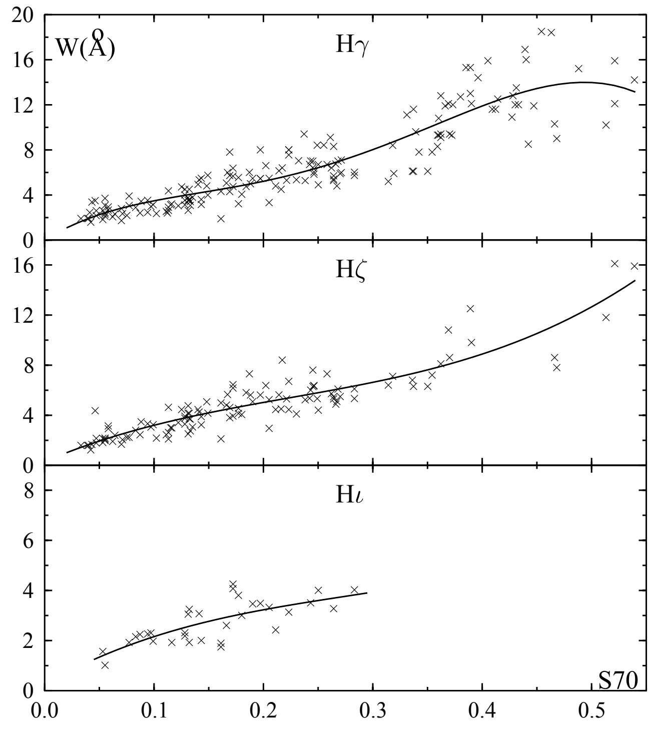

Fig. 5. $(W^*_{\rm n}, S_{70})$ relations for Hγ, Hζ and Hι lines of main sequence stars

3.5. Colour temperatures

In normal early type stars the colour temperature $T_{\rm c}$ of the Paschen continuum energy distribution closely corresponds to the effective stellar temperature (Thomas 1983). In hot stars, where the dominant opacity source in the CE is electron scattering, the observed Paschen energy

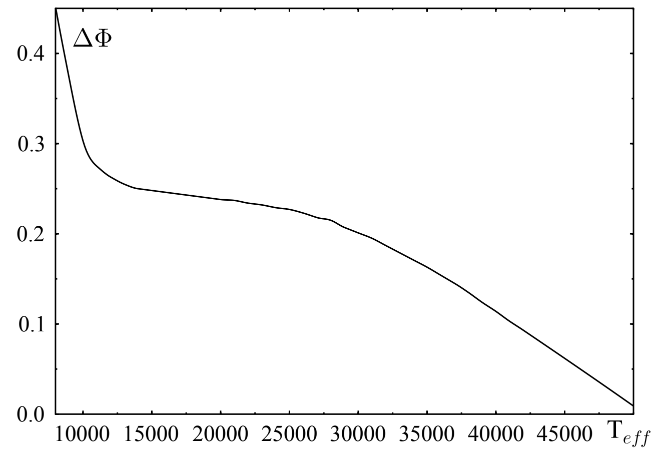

Fig. 6. Gradient index $\Delta\Phi$ against effective temperature

distribution due to the star+CE system should also closely reflect the underlying stellar Paschen energy distribution. We may then try to infer the colour temperature of the continuum energy distribution of those stars with the B[e] phenomenon for which the methods used in the preceding subsections cannot be applied.

The observed spectral range we have at our disposal to determine $T_{\rm c}$ is extremely reduced and so it is possible that the inferred values of $T_{\rm c}$ may be highly uncertain. Although they probably do not represent the only possible solution, we shall consider them as indicative of temperatures that reproduce energy distributions which are compatible with those observed in the studied wavelength interval. The wavelength interval analysed is $\lambda\lambda4000-4600$ Å, where the theoretical energy distributions agree quite well with observations of normal early type stars. As the studied stars are probably heavily obscured and reddened by the interstellar and circumstellar dust, photometric or spectrophotometric colour indices need to be defined so that they are insensitive to these extinctions. The energy distributions to be studied are so crowded with emission and/or absorption lines that colour indices defined from monochromatic fluxes may well result in excessive uncertainties. We then preferred to use gradients defined as:

$$\Phi = 5\lambda - \frac{{\rm d}\ln F_\lambda}{{\rm d}1/\lambda} \quad (5)$$

which are considered constant over a given wavelength interval. The gradients Φ can then be determined by least squares using a series of F_λ observed points which are assumed to be as close as possible to the continuum energy distribution. From (5) we can readily obtain a gradient index independent of the interstellar+circumstellar dust extinction, such as:

$$\Delta\Phi = \Phi_1 - R_\Phi \Phi_2 \quad (6)$$

where Φ_1 is defined in the wavelength interval $\lambda\lambda4000-4200$ Å and Φ_2 in $\lambda\lambda4200-4600$ Å. R_Φ is the ratio of gradient excesses $(\Phi_1 - \Phi_1^{\rm o})/(\Phi_2 - \Phi_2^{\rm o})$, where the $\Phi^{\rm o}$ are the extincion-free gradients. Making use of Cardelli et al. (1989) and O'Donnell's (1994) monoparametric representation of dust extinction laws:

$$\frac{A_\lambda}{A_V} = a_\lambda + \frac{b_\lambda}{R_V} \quad (7)$$

where a_λ and b_λ are universal functions of λ and $R_V = A_V/E(B-V)$, it can readily be shown that $R_\Phi = 0.810 \pm 0.004$ for R_V ranging from 2.0 to 6.0. This shows that $\Delta\Phi$ defined in (6) is not only independent of $E(B-V)$ but also of the value of R_V. The resulting calibration of $\Delta\Phi$ against $T_{\rm eff}$ obtained using Kurucz's (1992) models is shown in Fig. 6. In spite of the many advantages quoted for $\Delta\Phi$, Fig. 6 shows that this gradient index is quite insentitive to the effective temperatures in the range from $T_{\rm eff} \simeq 14\,000$ K to $T_{\rm eff} \simeq 24\,000$ K. However, (6) may give reliable results for effective temperatures outside this interval. The colour temperatures $T_{\rm c}$ determined using this method are also given in Table 4. We see that within the quoted uncertainties we may consider $T_{\rm c} \sim T_{\rm eff}$, where $T_{\rm eff}$ is determined from Balmer and He I lines.

As a byproduct, an estimate of the total dust extinction (ISM+circumstellar) affecting the stellar energy distribution can be determined using the Φ_1 and Φ_2 gradients. Assuming that the luminosity class dependence of the Φ_i gradients can be neglected, we derived the total extinction in the V magnitude from: $A_V = 1.91 \times [\Phi_1 - \Phi_1^*(T_{\rm eff})]$ and $A_V = 1.54 \times [\Phi_2 - \Phi_2^*(T_{\rm eff})]$. The errors in determining Φ_i by least squares are $\delta(\Phi_i) \simeq 0.02$. As the model uncertainties regarding Φ_i are of the same order, the error concerning the extinction is $\delta(A_V) \lesssim 0.1$ mag. The ratios $A_V/[\Phi_i - \Phi_i^*(T_{\rm eff})]$ depend slightly on the value of R_V. In the above definitions we used $R_V = 3.1$. The extinction A_V obtained is commented briefly in Sect. 4.2.

4. Discussion

The main purpose of this work is to infer fundamental parameters of stars with the B[e] phenomenon using the spectrophotometric BCD system. This system deals with parameters, which are related to deeper atmospheric layers than those where, on average, the spectral lines are formed. Since the BCD parameters are not affected by either ISM or circumstellar extinctions, we hope they may help us to obtain more precise information on the central stars of the studied objects. However, with the aim of using the BCD system for different classes of stars with B[e] phenomenon and for as many sets of objects as possible, attainable from CASLEO during the allocated observing runs, we recorded a number of spectra that finally had no measurable BD. Nevertheless, we then tried to make the most of these spectra by using several methods to determine temperatures, which may be related to or are indicative of the central star effective temperature. As these temperatures are subject to more uncertainties than those obtained from the BCD calibrations and because they do not represent direct determinations of $T_{\rm eff}$, we comment the results obtained for both sets of objects

Table 4. Effective temperatures derived from methods other than BCD

1 - *Effective temperatures derived from Balmer lines*

Star	$S_{70} \pm \sigma$ dex	$T_{\rm eff}{}^{+\sigma_1}_{-\sigma_2}$ K
Hen 2-90	0.061 ± 0.030	$32\,470^{+7300}_{-5100}$
CD$-42°$11721	0.102 ± 0.031	$27\,700^{+2700}_{-5500}$
HD 316248	0.080 ± 0.043	$28\,900^{+9100}_{-5700}$
AS 341	0.073 ± 0.044	$30\,100^{+10100}_{-6200}$

2 - *Effective temperatures obtained from He I lines*

Star	$T_{\rm eff} \pm \sigma$ K	Star	$T_{\rm eff} \pm \sigma$ K
Hen 2-90	$32\,300 \pm 500$	AS 341	$35\,400 \pm 1500$
CD$-42°$11 721	$35\,700 \pm 2100$	BD+14°3887	$32\,000 \pm 3700$
HD 316248	35300 ± 4000		

3 - *Colour temperatures*

Star	Φ_1 μm	Φ_2 μm	$T_{\rm c}{}^{+\sigma_1}_{-\sigma_2}$ K
RMC 4	1.31	1.35	$26\ 500^{+3600}_{-7400}$
Hen 2-90	2.62	3.00	$31\ 800^{+2200}_{-3300}$
CD$-42°$11721	2.79	3.21	$31\ 400^{+2600}_{-2900}$
Hen 3-1356	3.17	3.62	$24\ 000^{+4500}_{-9000}$
HD 316248	2.24	2.60	$37\ 000^{+2000}_{-2000}$
MWC 297	4.22	4.98	$32\ 800^{+2200}_{-2800}$
AS 341	2.76	3.15	$29\ 000^{+3000}_{-4000}$
BD+14°3887	3.46	3.99	$23\ 000^{+9000}_{-11000}$

separately. Finally, as Z CMa is a double star system and two other program stars are suspected binaries, in this section we also discuss the characteristics the binary components must have to lead to the observed (λ_1, D) values and whether the conclusions drawn in this paper by assuming they are single stars are misleading.

4.1. Stars with measurable BCD parameters

The new (λ_1, D) determinations for HD 45677 and HD 50138 are in good agreement with previous ones obtained from the original, photographic BCD data (Zorec et al. 1998; Lamers et al. 1998).

Comparing the new spectral classifications with the previous ones, found in the literature, we can see that differences appear only for three stars. The $T_{\rm eff}$ obtained from the BCD calibrations for CPD$-75°$116 (RMC 50; S65) and HD 269217 (R82) are lower than the value inferred for them by Zickgraf et al. (1986), who mainly used a spectroscopic approach. CPD$-75°$116 has a deep second BD in absorption, as in classical Be stars with a strong spectroscopic shell phenomenon (Divan & Zorec 1982b; Moujtahid et al. 1998), that could erroneously be interpreted as representing a B9 supergiant. This absorption, if any, is very small in HD 269217. Measuring the BD carefully from the merging of Balmer lines, the earliest spectral types we could assign to these stars are given in Table 3. On the other hand, the B3 supergiant-type suggested for this star in the literature requires $\lambda_1 = 20$–24 Å, which is not consistent with the observed value of λ_1. HD 316375 has two well-separated BD components, one of which is in emission, while the other is photospheric-like. The latter unambiguously suggests a B2V spectral type, which is not consistent with the B8-type assigned to the star in the HD catalogue and apparently have not been superseded since then (see Table 3). Differences in the spectral classification and effective temperature determination for CPD$-75°$116 and HD 269217, respectively members of SMC and LMC, could perhaps be due to a chemical abundance effect which deserves further deeper discussion. In this respect we note that the calibrations of BCD parameters into MK spectral types and fundamental parameters we used in the present work were made only with stars of our Galaxy.

The spectral type determined by Miroshnichenko et al. (1999) for BD$-14°$1319, as well as the spectral type of CD$-24°$5721 which we inferred from Drilling's (1991) data, are photometric spectral types. As BD$-14°$1319 has neither emission lines near the BD nor any strong indication for possible anomalous BD, its photometric classification should not be disregarded. However CD$-24°$5721 seems to have a small second BD in emission and the photometric classification can lead to a slightly earlier spectral type as compared with the spectrophotometric one. The spectral type of BD$-10°$1351 has also been discussed by Miroshnichenko et al. (1999). Using photometric data these authors classify the star as B3-type, while spectroscopic arguments, mainly the fit of wings of Balmer lines, suggest a B7 spectral type. We note that in our spectra the Balmer lines H12 and H13 seem to be too deep if they are compared to Hn, with $n < 12$. Such deep absorptions in H12 and H13 lines may imply that: a) all Balmer lines Hn with $n < 12$ have emission components in their core, which cannot be seen in all of them in our low resolution spectra; b) the spectral type of the central star is cooler than B3; c) the circumstellar component of the BD rises at $\lambda \gtrsim 3700$ Å, which implies that the circumstellar regions responsible for the Balmer continuum emission have electron densities $N_{\rm e} \gtrsim 10^{13}$ cm^{-3} (see Moujtahid et al. 1999 for discussion of $N_{\rm e}$ inferred from the second component of the BD). For such densities the wings of the higher members of the Balmer series can be optically thick. In this case the use of model atmospheres for normal stars can lead to misleading spectral type determinations. Simultaneous observations of the BD and of Balmer line profiles towards the end of the Balmer series at phases of different emission intensity, could help to determine more reliably the spectral type of the central star.

Due to the characteristics of the (λ_1, D) calibration into MK spectral types (double display of the (λ_1, D) parameters, Chalonge & Divan 1973), the BCD parameters obtained for Z CMa could correspond either to a B2III or to a F8III-IV type star. The absorptions at λ3933 Ca II and λ3968-70 H+Ca II lines suggest, however, that the spectrum is probably F-type. In "normal" stars, the intrinsic gradient Φ_b defined in the $\lambda\lambda 4000-4600$ Å wavelength interval can help to distinguish a B2 from a F8-type star (Chalonge & Divan 1973). The rather high interstellar+circumstellar dust extinction towards Z CMa prevents the use of the observed gradient, $\Phi_b^{obs} = 3.77 \pm 0.18$ μm, to make such a choice. However, the total A_V extinction deduced from Φ_b^{obs} seems to be consistent with an F8 spectral type, where $\Phi_b^* = 2.4$ μm. Hence, we deduce $A_V = 1.65 \times (\Phi_b^{obs} - \Phi_b^*) = 2.3$ mag, which is intermediate between the value $A_V = 1.8$ mag suggested by Hartmann et al. (1989) and $A_V = 2.8$ mag derived by Berilli et al. (1992).

Another outstanding advantage of the BCD system is its simplicity. From the results obtained and the discussion above, we can see that the method leads to well-defined and model-independent fundamental stellar parameters. On the other hand, it has been shown (Zorec 1998) that reliable determinations of spectral type and luminosity class of stars with the B[e] phenomenon are helpful in determining their distance and in quantitatively separating the dust extinction due to the CE from the interstellar one. These quantities are relevant not only to discussion of the bolometric luminosity of the central object when studying the evolutionary stage of stars, but also to determination of the amount of dust in their circumstellar environment. Further details of this method will be presented in a separate paper (Zorec & Cidale 2000, in preparation).

4.2. Stars without measurable BCD parameters

In this subsection we merely wish to compare the temperature we obtained with some latest effective temperatures reported in the literature for these stars.

RMC 4: This object, a spectroscopic binary with an LBV-type component, has been thoroughly discussed by Zickgraf et al. (1986, 1996) and classified as a sgB[e] star. In order to fit the observed spectral line intensities and the energy distribution, these authors iterated the effective temperature of both components using models of stellar atmospheres. They obtained $T_{\rm eff}$(B-comp.) = 27 000 K and $T_{\rm eff}$(A-comp.) = 9500 K. Our estimate of the colour temperature agrees with the effective temperature obtained by Zickgraf et al. for the B component.

Hen 2-90: This object is considered as a PN with a very dense and compact nebula (Costa et al. 1993). In their analysis of the chemical composition of the nebula, these authors used $T_{\rm eff} = 5.0\ 10^4$ K for the underlying star, which was determined using the Zanstra method. It is nearly the same as the temperature obtained by Preite-Martinez et al. (1991) with the energy-balance method. Our excitation temperatures, derived from Balmer and He I lines and from the observed energy distribution, are nearly the same, but lower than the previous ones. We note that $T_{\rm eff} \simeq \overline{T} = 3.22\ 10^4$ is probably justified, since in the spectrum of this star we only see He I 4471 but no He II emission line.

CD−42°11721: This object is considered as a HAeBe star (Henning et al. 1998). Lorenzetti et al. (1999) guessed that the spectral type of the central star might be hotter than B0. Depending on the authors, it was classified: B0[e]p (de Winter & Thé 1990; Brooke et al. 1993; de Winter & Pérez 1998), B4-5 (Benedettini et al. 1998), B7 (Hillenbrand et al. 1992) and Aep (Natta et al. 1993). Lamers et al. (1998) considered it among the unclB[e] stars. From Balmer and He I lines and from the energy distribution we obtained a mean $\overline{T} = 31\,600$ K, which corresponds to a B0-1 spectral type if $\overline{T}$ is understood as $T_{\rm eff}$. Using $T_{\rm eff} = \overline{T}$ and the measured gradients Φ_1, Φ_2 we derived a total dust extinction $A_V = 4.2$ mag. This extinction was also estimated by other authors: $A_V = 7.1$ mag (de Winter & Thé 1990), $A_V \sim 5$ mag (Brooke et al. 1993), $A_V = 6.1$ mag [= 1.6(ISM)+4.5(circumstellar)] (Natta et al. 1993) and $A_V = 4.3$ mag (Hillenbrand et al. 1992). Our total A_V is close to that obtained by Hillenbrand et al. (1992) and to the A_V(circumstellar) derived by Natta et al. (1993), as the interstellar component of A_V was negligible. However, a low value of A_V(ISM) should not be excluded, because the interstellar extinction towards this star is roughly 1mag/kpc (Neckel & Klare 1980) and many authors estimated the distance of CD−42°11721 being less than 500 pc: $d = 160$ pc (Hillenbrand et al. 1992); $d = 220$ pc (Pezzuto et al. 1997); $d = 400$ pc (de Winter & Thé (1990). On the other hand, distances of this object in the range $d = 2000-2600$ pc were suggested by Natta et al. (1993) and Shore et al. (1990).

Hen 3-1356: This rarely studied star was considered by Allen & Swings (1976) to belong to "group 1", which except for the [O I] line is nearly a classical Be star. Emission in the Balmer lines is seen up to Hϵ and there is a strong second BD in emission. The CE can then be optically thick in the visual spectral range, so that the colour temperature should be considered only as a lower limit for its effective temperature. The visual energy distribution is strongly affected by the ISM and the circumstellar dust extinction. From our data we obtained $A_V = 4.9$ mag.

HD 316248: This PN, commonly known as M 1-26, was classified by Górny et al. (1997) as an "e" type, which implies that the object is seen as a compact disk without any structure. Using the Zanstra method, these authors estimated $T_{\rm eff} = 30\,000$ K. Using a non-LTE spectroscopic approach, Méndez et al. (1992) estimated $T_{\rm eff} = 33\,000$ K. Our average temperature determination, based on the Balmer and He I lines and the energy distribution, is of the same order. The presence of He I and He II emission lines in the spectrum confirms such a high $T_{\rm eff}$.

MWC 297: In the current literature this star is considered as a HAeBe object. It was classified as B0 by Henning et al. (1994), considered between a late O and early B by Andrillat & Jaschek (1998) and B1.5Ve by Drew et al. (1997). As discussed in Sect. 3.5, errors in determining the gradients Φ_1 and Φ_2 can easily explain the difference between the colour temperature $T_c = 32\,800$ K we obtained for this star and $T_{\rm eff} = 25\,000$ K, which suits a B1.5V spectral type. However, we note that the spectrum of MWC 297 shows a second BD component in quite strong emission, which implies that the observed Paschen continuum may also be affected by some flux excess, as in classical Be stars (Moujtahid et al. 1998, 1999). Due to this excess the equivalent widths of photospheric-like lines are smaller by a factor $e^{-\tau_c}/[1+(\Delta F_c/F_c^*)]$ (Zorec et al. 2000) as compared to that of the same star without flux excess (τ_λ is the continuum optical depth of the CE at the line wavelength, ΔF_c is the flux excess and F_c^* is the stellar continuum flux). In the $\lambda\lambda$4630−4660 spectral region used by Drew et al. (1997) to compare the observed spectrum of MWC 297 with that of stars without emission, there are lines which shallow up from spectral types B0 to B3. If the spectral lines of MWC 297 are affected by the veiling effect mentioned above, the spectral type of the star will be considered cooler and the effective temperature underestimated. So, we can guess that the effective temperature of MWC 297 could be in the interval $25\,000 \lesssim T_{\rm eff} \lesssim 32\,800$ K, though probably $T_{\rm eff} \lesssim 30\,000$ K, as we see He I 4471 in absorption but no He II lines. The energy distribution of this star reveals strong dust extinction. Assuming $T_{\rm eff} = 29\,000$ K, we derived $A_V = 6.9$ mag, which is somewhat lower than $A_V \sim 8$ mag estimated by Drew et al. (1997).

AS 341: Allen & Glass (1975) argued that this object might be of VV Cephei type, where a hot B star has an M supergiant companion. From the [O III] lines they derived a lower limit to the temperature of the hottest component, which dominates the visible spectrum: $T_{\rm eff} \gtrsim 22\,000$ K. From the Balmer and He I lines and from the continuum energy distribution we obtained a mean value $\overline{T} = 31\,500$ K. The star is certainly rather hot since we see He I and He II lines.

BD+14°3887: In the latest and extensive study of high-resolution spectroscopy of this LBV candidate, Miroshnichenko et al. (1998) concluded that an effective temperature $T_{\rm eff} = 25\,000$ K is the most likely to represent its visible line spectrum and the energy distribution. Using the He I lines we obtained $T_{\rm eff} = 32\,000$ K. The stellar $T_{\rm eff}$ must be rather high as there is no visible Mg II line in the spectrum. The determination of the continuum energy distribution is more uncertain in this star and the errors affecting Φ_1 and Φ_2 are twice as large than for other program stars, which produce $\Delta\Phi = 0.23 \pm 0.04$, the middle of the flat part of $\Delta\Phi$ against $T_{\rm eff}$ in Fig. 6. Using the measured gradients Φ_1, Φ_2 and the mean value $T_{\rm eff} = 26\,700$ K we obtain $A_V = 5.3$ mag, which is close to the ISM extinction $A_V = 5.7$ mag determined by Miroshnichenko (1996).

4.3. BCD parameters vs. binaries

HD 53179 (Z CMa) is a double star (Koresko et al. 1991; Lamzin et al. 1999) and HD 45677 and HD 50138 were suspected by Sheikina et al. (2000) to be binaries. For HD 45677 there are period determinations of its photometric variations (Halbedel 1989; Miroshnichenko 1998). The spectral type obtained for Z CMa and the fundamental parameters of HD 45677 and HD 50138 have been derived in this paper assuming that these objects were single stars. The question may then arise whether a stellar companion may modify interpretation of the observed BCD data. As we have no spectroscopic data available to challenge the stellar classifications obtained only from spectrophotometric observations, we simply sought for binary components that within the standard uncertainties of the BCD parameters [$\delta D \simeq \pm 0.015$ dex; $\delta\lambda_1 \simeq \pm 2.5$ Å (Divan & Zorec 1982a; Zorec & Briot 1991)] can produce the observed (λ_1, D) parameters.

Parallaxes measured by the HIPPARCOS satellite show that HD 45677 ($d \simeq 355$ pc) and HD 50138 ($d \simeq 290$ pc) (Zorec 1998) are not inside the southern filament of the Orion and Monoceros system of molecular clouds ($d \sim 500$ pc), in front of which they project in the sky (Maddalena et al. 1986). Hence, they are isolated objects, but placed in the Gould belt plane between the Orion and Vela complexes. Using the standard model of rotation of our Galaxy (Wielen 1982), the observed radial velocities and proper motions of these objects, we deduced that they could escape from the Ori A-B molecular clouds and cover the distance separating them ($\Delta d \lesssim 200$ pc) in about 1–7 10^7 yr. Knowing that the oldest members of the Ori OB1 association have ages roughly of 2 10^7 yr, we adopted this time as the age of our stars. Thus, if each of our stars is supposed to be a binary, their components have to be in the same evolutionary isochrone. From Schaller's et al. (1992) grids of stellar models with metallicity $Z = 0.02$, we interpolated the masses, effective temperatures and radii of stars lying on the $t = 2\ 10^7$ yr isochrone. Then, to interpret the data, we assumed three configurations: a) the secondary star is completely eclipsed by the primary and the bolometric luminosity of the system is the observed one $M_{\rm bol}(\lambda_1, D)$; 2) both components are seen and they are well separated, so that $M_{\rm bol} - |\delta M_{\rm bol}|$ is assumed to represent the bolometric luminosity of the system; 3) the secondary eclipses the primary and the luminosity of the configuration is $M_{\rm bol} + |\delta M_{\rm bol}|$. We note that $|\delta M_{\rm bol}|$ is mainly due to the uncertainty on the λ_1 parameter ($\delta\lambda_1$). In each of these cases we sought for components lying on the 2 10^7 yr isochrone that reproduce the corresponding $M_{\rm bol} \pm |\delta M_{\rm bol}|$ luminosity. Finally, from the effective temperatures of components we derived the discontinuities D(primary), D(secondary) and, according to each binary configuration, $D_{\rm bin} = D$(primary+secondary). Table 5 gives the averages and the 1σ dispersions of the inferred parameters.

After trying to produce discontinuities of binary systems so that $D_{\rm bin} = D_{\rm obs}$, we might expect dispersions of $D_{\rm bin}$ and differences $\Delta D = |D(\text{primary}) - D_{\rm obs}|$ higher than 0.015 dex, the standard uncertainty of D, to be signs of the presence of binary components. In Table 5 we see that for HD 45677 these deviations do not fulfil this requirement, whereas in HD 50138 $\sigma_{D_{\rm bin}} \gtrsim 0.015$ dex and $\Delta D \simeq 3 \times 0.015$ dex do not contradict the binarity hypothesis. The bolometric magnitude variations

Table 5. Predicted characteristics of binary components in two program stars

Star	$D \pm \sigma_D$ dex	$M \pm \sigma_M$ $M_\odot$	$T_{\rm eff} \pm \sigma_T$ K	$R \pm \sigma_R$ $R_\odot$
HD 45677	$^a0.141 \pm 0.009$			
Primary	0.150 ± 0.004	9.3 ± 0.5	$21\,600 \pm 350$	6.6 ± 0.5
Secondary	0.219 ± 0.029	4.8 ± 0.9	$16\,380 \pm 1670$	2.9 ± 0.6
HD 50138	$^a0.290 \pm 0.022$			
Primary	0.241 ± 0.049	4.2 ± 1.3	$15\,160 \pm 2670$	2.6 ± 0.7
Secondary	0.300::	1.5 ± 0.9	7280 ± 2200	1.1 ± 0.5

^{a}: $D = D_{\rm bin}$

$|\delta M_{\rm bol}| \lesssim 0.16$ mag assumed here are smaller than the more or less regular visual photometric variations of these stars (Miroshnichenko 1998). In HD 45677 these variations imply periodicities, which according to the authors range from about 297$^{\rm d}$ (Halbedel 1989) to 1600$^{\rm d}$ (Miroshnichenko 1998). Spectroscopic observations could perhaps confirm either periodic variation of radial velocities, or at least the presence of double systems of spectral lines consistent with masses similar to those predicted in Table 5. We finally conclude that within the assumed $|\delta M_{\rm bol}|$ variations, the possibility of some binarity does not notably change our previous spectral classification and/or fundamental parameter determination for HD 45677. In HD 50138, however, depending on the predicted effective temperatures, there are many possible spectral types for the primary, which range from B4 to B7.

Z CMa belongs to the FU Ori type objects (FUORs). It is a pre-main-sequence double star system (0$''$.1 separation), where the secondary (Z CMa SE) dominates the optical continuum and the primary (Z CMa NW) shows an emission line spectrum. The secondary not only dominates the IR, but also the total luminosity of the system ($L \sim 10^4$ $L_\odot$, Koresko et al. 1991; Berilli et al. 1992; Garcia et al. 1999). Lamzin et al. (1999) have also concluded that the secondary is probably the main source of the observed optical variations. Z CMa shows wavelength-dependent spectral types, as is usual for FUORs (Hessman et al. 1991). Though Z CMa is normally classified as an Ae/Be star, with spectral types B5 or B5/8 (Buscombe 1977; Thé et al. 1994), it has features of a late B star and of an F-type spectrum (Strom et al. 1972). It may be, however, that the B-type classification depends upon the strength of the Balmer absorption lines, which can be produced in an outflowing wind (Covino et al. 1984). Hartmann et al. (1989) also suggested that Z CMa may be a pre-main-sequence rotating accretion disk surrounding a central object of mass $M \sim 1{-}3$ $M_\odot$, which is consistent with our F-type spectral classification. The strong accretion, $\dot{M} \sim 10^{-3}$ $M_\odot$ yr^{-1}, may presently be building up a large fraction of the stars.

The measured total luminosity of the Z CMa system, as well as the inferred mass and radius, are highly uncertain (Hartmann et al. 1989; Berilli et al. 1992) and can hardly be used as observational constraints to infer new characteristics of the components. On the other hand, the (λ_1, D) parameters are not calibrated for F-type stars into $(T_{\rm eff}, M_{\rm bol})$. We only know that there is a difference $\Delta V \sim 2$ mag between both components (Finkenzeller & Mundt 1984). Using this V magnitude-restriction and assuming, only as a conjectural hypothesis, that the components of Z CMa are "ordinary" stars, the obtained BCD parameters are consistent with global "normal" MK spectral types which range from F8IV to F8II-III. Within this same framework, the first of these classifications could also correspond to an F8+K0 system and the second to an F6/7+G2/5 system.

5. Conclusions

In this paper we present low resolution spectra of 23 stars with the B[e] phenomenonin in the $\lambda\lambda3500{-}4600$ Å wavelength range. Spectral classification and fundamental stellar parameters of 15 program stars were studied using the BCD spectrophotometric system. The BCD system is suitable for spectral classification of objects that display a measurable Balmer discontinuity and among them also for those with CE. For stars with CE we can determine the properties of the underlying star without concern for the extra emissions and/or absorptions in the lines and in the continua, produced in the visual spectral range by the circumstellar matter. The parameters obtained ($T_{\rm eff}$, log g, $M_{\rm bol}$) are model-independent and constitute a valuable tool to study the evolutionary stage of stars with the B[e] phenomenon. The average absolute relative error of the effective temperatures thus obtained is $|\delta T_{\rm eff}/T_{\rm eff}| \simeq 0.04$. The fundamental parameters derived also help to determine, on the one hand, reliable distances of these objects and on the other hand, the ISM and the circumstellar dust extinction separately. The determination of distances of stars with the B[e] phenomenon is now in progress and it will be presented in another contribution. In the present work we also give an estimation of the effective temperature of another 8 stars with the B[e] phenomenon which have no measurable BCD parameters. These effective temperatures were determined by studying the emission intensity of Balmer and He I lines and/or the energy distribution in the Paschen continuum. The average error of the effective temperatures obtained from lines is $|\delta T_{\rm eff}/T_{\rm eff}| \lesssim 0.20$. The colour temperature and the temperatures obtained from the study of Balmer and He I lines are consistent with each other within the estimated errors in each determination. The new results were compared with those obtained previously by other authors and discussed for each star individually. For some stars, differences between the effective temperatures derived using the BCD classification system and those obtained by other authors, based on photometric or spectroscopic analysis, imply spectral-type classification disagreements ranging from 2–3 up to 6 B sub-spectral types. The fundamental parameters for AS 119, CD$-24°5721$, Hen 2-91, HD 316375 and BD$-11°4747$ were obtained for the first time. A simple method was introduced to calculate total (interstellar+circumstellar) dust extinction of the studied stars. For HD 53179, which is a double stellar system, and for HD 45677 and HD 50138, which are suspected binaries, we predicted the characteristics of the components that are consistent with the observed (λ_1, D) parameters. However, the possible binarity of HD 45677 and HD 50138 still needs to be confirmed spectroscopically.

Acknowledgements. L. C. is grateful to the "Société de Secours des Amis des Sciences", Paris, for a grant which helped to complete the present work. We are deeply indebted to Dr. A. S. Miroshnichenko (referee) for his detailed reading of the manuscript and for his valuable suggestions that contributed to improve the presentation of this paper. We acknowledge the help of A. Garcia (IAP) in making the plots.

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