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On the ultraviolet fluxes of Be stars

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Abstract. The ultraviolet fluxes of a sample of Be and normal B stars taken from ultraviolet bright-star spectrophotometric catalogue and its supplement have been compared with model atmosphere fluxes. An ultraviolet temperature has been defined from the slopes of the ultraviolet energy distribution curves, and compared with the effective temperatures determined from the visible region both for normal B and Be stars.

Key words : ultraviolet temperature—B stars—Be stars

1. Introduction

The ground based energy distribution studies of Be stars have shown that a large number of Be and shell stars possess unusually large or small Balmer jumps as compared to normal stars (Schild *et al.* 1974; Goraya 1985). Chalonge & Divan (1952) and others have discovered the existence of two Balmer jumps in the spectra of some Be stars. The distribution of the ultraviolet flux in the Balmer continuum (particularly below λ 3000 Å) has been studied by a number of authors. Bless & Code (1972) for example did not find an excess of flux in the far-ultraviolet (λ 1150–3200 Å) spectra of Be stars, though Briot (1978) detected small excess of radiation (λ 1350–2750 Å) for early type Be stars. Beeckmans & Hubert-Delplace (1980) found that early type Be stars (earlier that B5) show an ultraviolet deficiency as compared to the visible. This deficiency is linked to the emission intensity in the visual range and to the strength of the shell.

Zorec, Briot & Divan (1983) on the other hand have shown that the ultraviolet colour indices of Be stars are in general redder than those of B stars of the same subclass. However, there are some stars for which the ultraviolet colour indices are bluer than those of normal B stars of the same subclass.

According to the above authors weak Be stars have nearly the same ultraviolet colours as normal B stars while the strong Be stars have less negative or more negative UV colours than those of normal B stars. Zoree & Briot (1985) have studied the behaviour of the ultraviolet fluxes of Be stars with the emission intensity in their H_α and H_β lines.

In this paper we compare the ultraviolet fluxes of Be stars with visual-region fluxes in a different way. In place of making magnitude differences between the UV flux at one or two specified wavelength points and the V magnitude, we have used the over-all observed range of wavelengths and formed the mean slopes for comparison.

2. Observational material

The observational material for the ultraviolet fluxes has been taken from the ultraviolet bright-star spectrophotometric catalogue by Jamar *et al.* (1976) and its supplement by Macau-Hercot *et al.* (1978). A total of 41 Be stars belonging to different spectral types (O9.5–B8) and 18 normal B stars in almost the same spectral range have been selected. The fluxes of all the stars have been corrected for interstellar reddening. In case of Be stars the colour excesses have been taken from sources which are believed to avoid the circumstellar reddening. Beeckmans & Hubert-Delplace (1980) have used the strength of the λ 2200 Å absorption feature to determine the interstellar-reddening of Be stars. A few of the $E(B-V)$ values given by Goraya (1985) are based on reddening-distance modulus method. We have used these values of the colour excesses.

In a few cases where the colour excess is small the colour excess $E(B-V)$ based on colour-spectral type has been used. The interstellar reddening law given by Nandy *et al.* (1975) has been used to determine A_λ at various wavelengths.

The corrected fluxes have been plotted against inverse wavelength (λ^{-1}) and slopes have been formed from these curves at three wavelength ranges, (1) $6 < \lambda^{-1} < 6.6$, (2) $4.8 < \lambda^{-1} < 6.0$, and (3) $4 < \lambda^{-1} < 4.8$. A few representative curves illustrating the determination of the slopes are shown in figure 1. The sum of these slopes has been defined to give a measure of the overall slope of the energy distribution curves. Similar slopes have been formed from the model atmosphere energy distribution curves taken from Kurucz (1979). The slopes determined from the model atmosphere curves have been plotted against their effective temperatures for two values of log g (3.5, 4.0). From the measured slopes of the B and Be star, their ultraviolet temperatures (T_{uv}) have been derived (table 1). These ultraviolet temperatures have been compared with the effective temperatures determined for these stars based on different methods for the visible range (T_{vis}). The values of T_{vis} for the stars have been taken from different sources listed at the foot of table 1. For 22 stars T_{vis} have been taken from Goraya (1985). These temperatures are based on the model atmosphere fitting of the energy distribution curves of the stars in the wavelenth region λ 4000–5500 Å. This region is the least affected by circumstellar envelope. The $E(B-V)$ values for applying the interstellar reddening corrections to the observed energy distribution curves have been determined by the distance modulus method. The accuracy of these temperatures is about 8%. For nine stars the T_e, $(B-V)$ relation for B stars of Underhill (1980) has been used. The error in these temperatures at $\approx 5\%$ is quite low. For five stars the T_{vis} values are from Peters (1976), where T_{vis} are

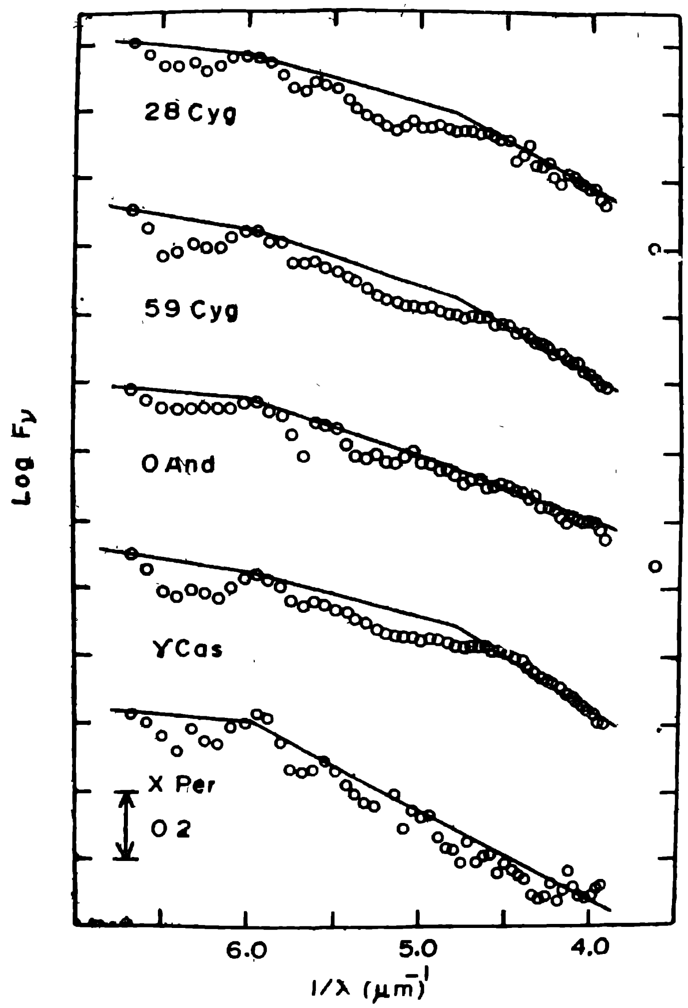

Figure 1. A few representative curves showing the manner in which slopes between various wavelength points have been formed.

assigned on the basis of spectral types, intrinsic UBV colours, and photospheric line strengths. The maximum error in the temperatures is quoted as $\pm$ 2000 K at 28000 K. For the remaining five stars T_{vis} have been taken from Snow (1982), Code *et al.* (1976), Kontizas & Theodossiou (1980) and Persi, Ferrari-Toniolo & Grasdalen (1982). T_{vis} for β CMi and 25 Cyg taken from Knotizas & Theodossiou (1980) are based upon model atmosphere fitted to the entire UV and visible region of the energy distribution curve. From the above, it is assumed that the maximum error in T_{vis} determinations is ~ 10%.

In order to see the discrepancies in the T_{uv} determined by us on account of the interstellar reddening correction, the choice of g, and the fitting of the slopes, we have also determined T_{uv} of 18 normal B stars, and compared them with the T_{vis} determined by other authors. In case of normal stars it is expected that the temperatures determined from different regions should agree with one another, if proper corrections have been applied. The difference ΔT between the T_{uv} and T_{vis} for these normal stars comes out to be $\pm$ 20% except in case of one star

Table 1. The derived ultraviolet temperatures and other parameters of program stars

No.	HD	Name	Spectral type	$v \sin i$	Assumed $\log g$	T_{uv}	T_{vis}	ΔT %	$E(B-V)$
1.	5394	γ Cas	B0.5Ve	300	4.0	26900	32000[G]	+15.9	0.07[1]
2.	24534	X Per	09.5ep	150	4.0	26300	30200[PS]	+12.9	0.29[1]
3.	25940	48 Per	B3Ve	217	4.0	22100	16000[P]	−38.1	0.17[3]
4.	32343	11 Cam	B2.5Ve	131	4.0	18800	22500[G]	+16.4	0.08[1]
5.	35439	25 Ori	B1Vn	316	4.0	24000	25000[G]	+ 4.0	0.04[3]
6.	36576	120 Tau	B2IV-V	270	4.0	18900	21000[G]	+10.0	0.24[1]
7.	37490	ω Ori	B2IIIe	195	3.5	10700	18000[G]	+40.6	0.09[1]
8.	43285	—	B6V	290	4.0	12800	15000[G]	+14.7	0.04[3]
9.	45542	νGem	B6III	215	3.5	13600	17500[G]	+22.3	0.02[3]
10.	45995	—	B2.5Ve	320	4.0	12200	13600*	+10.3	0.06[1]
11.	50013	κ CMa	B2.5IVne	—	4.0	22100	25700*	+14.0	0.02[3]
12.	54309	—	B3Vne	290	4.0	20600	17400*	−18.4	0.09[3]
13.	56014	27 CMa	B3IIIp	173	3.5	24800	16800[G]	−47.6	0.0
14.	56139	ω CMa	B2IV-Ve	137	4.0	17400	15000[G]	−16.0	0.06[3]
15.	58343	—	B2.5IVe	33	4.0	20500	18000[S]	−13.9	0.17[3]
16.	58715	βCMi	B7V	270	4.0	10400	12000[K]	13.3	0.04[3]
17.	60606	—	B3Vne	297	4.0	12000	18500*	+35.1	0.14[3]
18.	63462	ο Pup	B1IVnne	374	4.0	26200	30000[G]	+12.7	0.15[2]
19.	68980	—	B1.5IIIe	167	3.5	29900	27000*	−10.7	0.15[1]
20.	83953	I Hya	B6Ve	358	4.0	12500	15000[G]	+16.7	0.02[3]
21.	86612	—	B4Ve	—	4.0	17000	16400*	− 3.7	0.08[3]
22.	109387	κ Dra	B6IIIp	250	3.5	11000	15400*	+28.6	0.04[1]
23.	120324	μ Cen	B2IV-Ve	190	4.0	27500	20000[P]	−37.5	0.08[3]
24.	138749	θ CrB	B6Vnn	400	4.0	12000	13000*	+ 7.6	0.03[3]
25.	142983	48 Lib	B5IIIep	400	4.0	31000	15780[Sn]	−96.5	0.83[2]
26.	143184	χ Oph	B1.5Ve	123	4.0	33800	24000[P]	−45.5	0.30[1]
							22500[G]		
27.	149757	ζ Oph	09.5Ve	396	4.0	21100	31900[C]	+33.9	0.21[1]
28.	164284	66 Oph	B2Ve	240	4.0	24800	23000[P]	− 7.9	0.16[1]
29.	178175	—	B2Ve	226	4.0	15500	22000[P]	+29.5	0.17[1]
30.	183362	—	B2Vne	258	4.0	12000	22000[G]	+45.5	0.05[1]
31.	187811	12 Vul	B2.5V	280	4.0	23600	19000[G]	−24.2	0.06[2]
32.	189687	25 Cyg	B3IV	230	4.0	13600	22500[G]	+33.1	0.03[3]
							18500[K]		
33.	191610	28 Cyg	B2.5V	310	4.0	14600	20000[G]	+27.0	0.06[1]
34.	193911	25 Vul	B8IIIn	250	3.5	10900	13000[P]	+16.2	0.04[3]
35.	194335	—	B2Ven	—	4.0	25600	21000[G]	−21.9	0.02[2]
36.	200120	59 Cyg	B1.5enn	450	4.0	24000	25000[G]	+ 4.0	0.07[1]
37.	203467	6 Cep	B3IVe	148	4.0	23400	20000[G]	−17.0	0.17[3]
38.	208682	—	B2.5Ve	350	4.0	24000	31600*	+30.9	0.25[3]
39.	217050	EW Lac	B4IIIep	350	3.5	26600	22500[G]	−18.2	9.14[3]
40.	217675	ο And	B7IVe	330	4.0	10200	14000[G]	+27.1	0.05[3]
41.	217891	β Psc	B6Ve	147	4.0	15500	15000[G]	− 3.3	0.04[3]

(i) Spectral types and rotational velocities are from the ultraviolet bright star catalogue and its supplement, except a few which have been taken from Zorec, Briot & Divan (1983).

(ii) T_{vis} are from, G—Goraya (1985); S—Schild (1976); Sn—Snow (1982); *θ_e, $B-V$ relation for B stars (Underhill 1982); P—Peters (1976); K—Kontizas & Theodossiou (1980); Ps—Persi *et al.* (1982); C—Code *et al.* (1976).

(iii) $E(B-V)$ are, 1—Δm_{2200} absorption band (Beeckman & Hubert-Delplace (1980); 2—Goraya (1985); 3—ultraviolet bright star catalogue and supplement.

namely 35 Eri, where the error is about 25%. Thus the error level including both the error in T_{vis} determinations and T_{uv} determination has been taken to be $\pm$ 20%.

3. Discussion and results

Figure 2 shows that all the normal B stars except 35 Eri fall within a band of $\pm$ 20% in the ΔT, spectral type plot. A total of 23 out of the 41 Be stars studied also fall on this band.

Out of the 18 Be stars, 11 lie above the + 20% level and 7 lie below the − 20% level. Assuming that the $\pm$ 20% level is the likely error level in the ΔT determination from the two temperatures, the existence of stars beyond the $\pm$ 20% level leads us to infer that Be stars have both higher and lower ultraviolet temperatures than their T_{vis}. If we identify the high negative ΔT as due to increased slope of the energy distribution curve in the ultraviolet, it implies that (i) the optical thickness of the shell is significant in the Balmer continuum radiation; and that

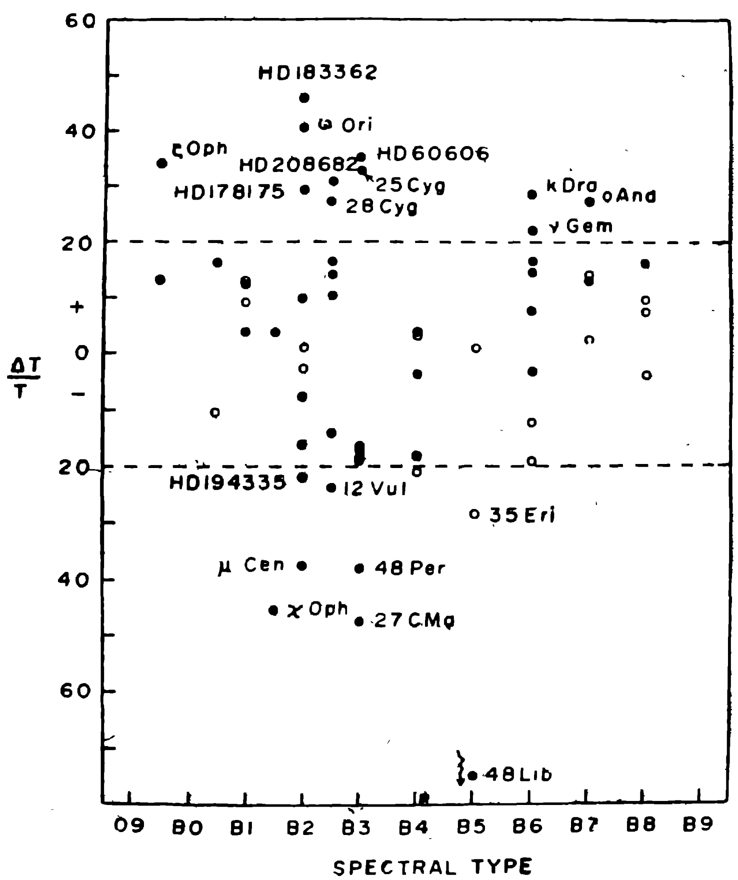

Figure 2. A plot between the spectral subtypes and the parameter $\frac{\Delta T}{T}$ expressed as percentage. $\left(\frac{\Delta T}{T} = \left(\frac{T_{vis} - T_{uv}}{T_{vis}}\right) \times 100\right)$. Open circles—normal B stars. Filled circles—Be stars.

(ii) there is less of line blanketing. On the other hand, if the shell is thin, the stellar Balmer continuum may get augmented by the shell emission, mimicking a lower colour temperature in the ultraviolet.

By far the largest negative ΔT was obtained in case of 48 Lib The UV temperature determined by Rovira *et al.* (1985) from IUE high dispersion spectra is 16000 K, $\log g = 4.5$. Earlier Ringuelet, Fontenla & Rovira (1981) have determined the temperature and gravity of the star as $T = 18000$ K, $\log g = 4.0$. The UV temperature from S2/68 data determined in this paper comes out to be $T_{uv} = 31000$ K assuming $\log g = 4.0$. 48 Lib is known to be a strong variable shell star. Large variation in the shell strength could be a reason for the large difference in the UV and visible range temperatures, the two being of different epochs.

Zorec, Briot & Divan (1983) have defined two colours in the ultraviolet spectra of several Be stars, and formed a colour index G which is numerically given by $(m_{1460} - m_{2740}) - K(m_{1460} - m_{2350})$ where m_{1460}, m_{2350} and m_{2740} are the observed magnitudes of the star at wavelengths 1460, 2350, and 2740 Å and K is the ratio of the colour excesses:

$$\frac{E(m_{1460} - m_{2740})}{E(m_{1460} - m_{2350})}.$$

The index G is more negative for early type stars and becomes less negative for later types.

We have compared our ΔT values with the G index given by Zorec *et al.* (1983) for the stars common in the two studies. Six of the seven stars for which ΔT has large negative values also have large negative G values. The average G value for these stars comes out to be -16.33. On the other hand the average of the G values for the nine stars which have high positive ΔT value is -12.61.

Conclusion

It is concluded that Be stars in general can have ultraviolet excess or deficiency as compared to normal B stars. Stars having strong shell lines generally show high UV temperature. The excess or deficiency does not seem to be correlated with $v \sin i$.

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