Astron. Astrophys. 138, 19–24 (1984)

ASTRONOMY AND ASTROPHYSICS

Continuum energy distributions of some bright Be stars

P. S. Goraya

Uttar Pradesh State Observatory, Manora Peak, Naini Tal-263129, India

Received December 28, 1983; accepted March 28, 1984

Summary. The absolute flux distributions of seven bright Be stars, in the wavelength range $\lambda\lambda$350–750 nm is presented. The observed energy distribution curves are compared with Kurucz (1979) model atmospheres to estimate their effective temperatures. Some peculiarities in the energy distributions and the evolutionary stages of the Be stars are discussed.

Key words: Be stars – energy distributions – variability – effective temperatures – evolution

1. Introduction

Both the continuum and the line spectrum of a Be star are a combination of the spectrum of the central hot, fast-rotating star and its circumstellar envelope which exhibit more or less irregular variations with time. Feinstein (1975) has reported variations in *V* and (*B–V*) magnitudes of some Be stars. Nordh and Olofsson (1974) have studied the *UBV* and H_α variation of a few Be stars.

Some peculiarities have already been recognized in the continuum energy distribution of Be stars. A study by Schild (1976) has shown that the filling-in of the Balmer continuum near the discontinuity is a common feature. However, Chkhikvadze (1980) has pointed out that a majority of Be stars with shells have anomalously large Balmer jumps. The Paschen continuum of a Be star is also affected by the existence of the broad near-infrared excess emission feature which appears to become prominent in the λ550 nm region any is seen at the 2–10 μm region.

Although a few studies have already been made of the continuum of Be stars, systematic investigation of the variations of light and continuum energy distributions are important. Also, it is difficult to infer, from broad-band photometry, simultaneously the nature of Balmer discontinuity and Paschen continuum. Thus the study of the continuum energy distribution can potentially improve our understanding of the exact nature of Be stars.

2. Observations and reduction

The basic data of the observed Be stars in this programme are given in Table 1. The stars were observed during 1977–1980 with the 52-cm reflector, using a Hilger and Watts spectrum scanner. The instrumentation used for taking observations has been described earlier (Goraya, 1980). An exit slot of 0.7 mm, admitting 50 Å of the spectrum to fall on the photomultiplier, was used for taking the observations. Each star was observed many times during every night and the continuum was drawn through each scan. Then each scan was reduced to instrumental magnitudes separately and all observations of individual stars during each night were averaged. The instrumental magnitudes were measured every 10 nm of the entire continuum. The observations of each star were repeated on another night. Along with the programme stars; standard stars γ Gem, α Leo, and ξ^2 Cet were also observed many times during a night; at twenty discrete wavelengths (Oke, 1965) between $\lambda\lambda$339–755 nm, for applying extinction correction and to reduce instrumental magnitudes of programme stars into absolute magnitudes. The absolute magnitudes of programme stars correspond to

Table 1. Basic data for Be stars

Star	HD	Sp.T.[a]	m_{5500}	$T_{\rm eff}$	log *g*	$m/m_\odot$	*E(B–V)*	Distance[a] (pc)	B.C.[b]	*v* sin *i*[d] (km s^{-1})
χ Oph	148184	B2Ve	2^m60–2^m78	22,500 K / 18,000 K	4.0	10	$0^m30\pm0^m02$	150	-2^m36	134
ω Ori	37490	B3IIIe	4^m24	18,000 K	3.5	8	$0^m06\pm0^m02$	310	-1^m94	194
ϕ Per	10516	B1IVe	3^m40	25,000 K	4.0	15	$0^m11\pm0^m02$	350	-2^m59	450
25 Ori	35439	B1Ve	4^m28–4^m68	25,000 K	4.0	14	$0^m05\pm0^m02$	490	-2^m59	316
ψ Per	22192	B5Ve	4^m28	17,000 K	4.0	6	$0^m11\pm0^m02$	160[c]	-1^m44	369
o Aqr	209409	B7Ve	4^m70	14,000 K	4.0	4	$0^m03\pm0^m02$	95	-0^m94	227
ε PsA	214748	B8Ve	4^m30–4^m01	12,000 K	4.0	3	0^m00	75	-0^m61	290

References: The data are taken from the references indicated in the column head: [a] Hirshfeld and Sinnott (1982); [b] Hayes (1978); [c] Underhill and Doazan (1982); [d] Uesugi and Fukuda (1982)

Table 2. Reddening corrected monochromatic magnitudes of Be stars normalized to wavelength λ550 nm

Wave-length λ (nm)	$1/\lambda$ (μm^{-1})	χ Oph		ω Ori		ϕ Per
		1979 March 10	1979 April 18	1979 Feb. 28	1979 March 10	1977 Nov. 16
350	2.86	$-0^m.465$	$-0^m.223$	$-0^m.096$	$-0^m.118$	$-0^m.110$
360	2.78	$-0^m.357$	$-0^m.132$	$-0^m.006$	$-0^m.081$	$-0^m.085$
370	2.70	$-0^m.431$	$-0^m.064$	$-0^m.017$	$-0^m.100$	$-0^m.054$
380	2.63	$-0^m.484$	$-0^m.189$	$-0^m.186$	$-0^m.257$	$-0^m.208$
390	2.56	$-0^m.514$	$-0^m.307$	$-0^m.342$	$-0^m.399$	$-0^m.448$
400	2.50	$-0^m.530$	$-0^m.466$	$-0^m.469$	$-0^m.480$	$-0^m.585$
410	2.44	$-0^m.485$	$-0^m.440$	$-0^m.448$	$-0^m.440$	$-0^m.548$
420	2.38	$-0^m.465$	$-0^m.395$	$-0^m.434$	$-0^m.450$	$-0^m.516$
430	2.33	$-0^m.450$	$-0^m.374$	$-0^m.401$	$-0^m.410$	$-0^m.459$
440	2.27	$-0^m.395$	$-0^m.342$	$-0^m.355$	$-0^m.367$	$-0^m.426$
450	2.22	$-0^m.365$	$-0^m.284$	$-0^m.304$	$-0^m.318$	$-0^m.380$
460	2.17	$-0^m.346$	$-0^m.272$	$-0^m.270$	$-0^m.301$	$-0^m.335$
470	2.13	$-0^m.286$	$-0^m.220$	$-0^m.230$	$-0^m.243$	$-0^m.293$
480	2.08	$-0^m.269$	$-0^m.195$	$-0^m.189$	$-0^m.210$	$-0^m.251$
490	2.04	$-0^m.212$	$-0^m.180$	$-0^m.163$	$-0^m.200$	$-0^m.208$
500	2.00	$-0^m.194$	$-0^m.150$	$-0^m.142$	$-0^m.175$	$-0^m.172$
510	1.96	$-0^m.144$	$-0^m.108$	$-0^m.128$	$-0^m.150$	$-0^m.148$
520	1.92	$-0^m.118$	$-0^m.078$	$-0^m.078$	$-0^m.123$	$-0^m.125$
530	1.89	$-0^m.102$	$-0^m.051$	$-0^m.059$	$-0^m.085$	$-0^m.101$
540	1.85	$-0^m.055$	$-0^m.017$	$-0^m.030$	$-0^m.039$	$-0^m.045$
550	1.82	$0^m.000$	$0^m.000$	$0^m.000$	$0^m.000$	$0^m.000$
560	1.79	$+0^m.008$	$+0^m.017$	$+0^m.025$	$+0^m.011$	$+0^m.031$
570	1.75	$+0^m.018$	$+0^m.051$	$+0^m.051$	$+0^m.023$	$+0^m.059$
580	1.72	$+0^m.036$	$+0^m.084$	$+0^m.075$	$+0^m.055$	$+0^m.080$
590	1.69	$+0^m.082$	$+0^m.125$	$+0^m.102$	$+0^m.085$	$+0^m.112$
600	1.67	$+0^m.120$	$+0^m.150$	$+0^m.132$	$+0^m.147$	$+0^m.165$
610	1.64	$+0^m.166$	$+0^m.180$	$+0^m.170$	$+0^m.159$	$+0^m.180$
620	1.61	$+0^m.214$	$+0^m.215$	$+0^m.174$	$+0^m.200$	$+0^m.224$
630	1.59	$+0^m.230$	$+0^m.228$	$+0^m.178$	$+0^m.228$	$+0^m.242$
640	1.56	$+0^m.240$	$+0^m.255$	$+0^m.220$	$+0^m.224$	$+0^m.265$
650	1.53	$+0^m.290$	$+0^m.280$	$+0^m.262$	$+0^m.245$	$+0^m.275$
660	1.51	$+0^m.290$	$+0^m.300$	$+0^m.270$	$+0^m.290$	$+0^m.312$
670	1.49	$+0^m.335$	$+0^m.325$	$+0^m.300$	$+0^m.285$	$+0^m.330$
680	1.47	$+0^m.345$	$+0^m.345$	$+0^m.303$	$+0^m.271$	$+0^m.331$
690	1.45	$+0^m.323$	$+0^m.382$	$+0^m.334$	$+0^m.334$	$+0^m.359$
700	1.43	$+0^m.314$	$+0^m.375$	$+0^m.320$	$+0^m.329$	$+0^m.398$
710	1.41	$+0^m.297$	$+0^m.392$	$+0^m.286$	$+0^m.323$	$+0^m.462$
720	1.39	$+0^m.354$	$+0^m.405$	$+0^m.295$	$+0^m.415$	$+0^m.510$
730	1.37	$+0^m.323$	$+0^m.410$	$+0^m.332$	$+0^m.369$	$+0^m.519$
740	1.35	$+0^m.370$	$+0^m.419$	$+0^m.379$	$+0^m.398$	$+0^m.493$
750	1.33	$+0^m.376$	$+0^m.415$	$+0^m.394$	$+0^m.417$	$+0^m.525$

Tug et al. (1977) calibration of α Lyr. The standard deviation of the measurements on an individual night does not exceed ± 0.03 mag in the entire wavelength range. Finally, the magnitudes were corrected for interstellar reddening and were normalized to a wavelength of λ550 nm. The reddening corrected mangitudes thus obtained, are listed in Table 2. A plot of these is shown in Fig. 1.

3. Correction for interstellar reddening

The determination of the interstellar reddening for Be stars is complicated due to the presence of the circumstellar envelope. The normal Q method of Johnson and Morgan (1953), valid for the main sequence O and B stars, is likely to produce large errors because of the ultraviolet and near-infrared excess emissions in these stars. The near-infrared excess emission affects the continuum flux at wavelength as short as V of the UBV system, so that the Be stars have an intrinsic (B–V) colour excess relative to normal stars of the same spectral type. An excess of continuum emission below the Balmer discontinuity affects the U colour producing an intrinsic (U–B) colour excess.

To estimate the interstellar reddening for the stars discussed in the present paper, first we have plotted the $E(B–V)$ values of

Table 2 (continued)

Wave-length λ (nm)	1/λ (μm^{-1})	25 Ori		ψ Per		*o* Aqr		ε PsA	
		1980 Oct. 1	1980 Oct. 15	1980 Sept. 27	1980 Sept. 30	1980 Sept. 30	1980 Oct. 1	1980 Oct. 2	1980 Oct. 15
350	2.86	$-0^{m}.083$	$-0^{m}.072$	$+0^{m}.185$	$+0^{m}.176$	$+0^{m}.225$	$+0^{m}.215$	$+0^{m}.508$	$+0^{m}.618$
360	2.78	$-0^{m}.060$	$-0^{m}.025$	$+0^{m}.215$	$+0^{m}.190$	$+0^{m}.324$	$+0^{m}.314$	$+0^{m}.553$	$+0^{m}.607$
370	2.70	$-0^{m}.042$	$-0^{m}.001$	$+0^{m}.255$	$+0^{m}.230$	$+0^{m}.325$	$+0^{m}.353$	$+0^{m}.555$	$+0^{m}.575$
380	2.63	$-0^{m}.208$	$-0^{m}.150$	$-0^{m}.005$	$+0^{m}.030$	$+0^{m}.161$	$+0^{m}.200$	$+0^{m}.452$	$+0^{m}.276$
390	2.56	$-0^{m}.360$	$-0^{m}.348$	$-0^{m}.151$	$-0^{m}.210$	$-0^{m}.108$	$-0^{m}.111$	$+0^{m}.109$	$+0^{m}.022$
400	2.50	$-0^{m}.485$	$-0^{m}.535$	$-0^{m}.444$	$-0^{m}.473$	$-0^{m}.342$	$-0^{m}.355$	$-0^{m}.257$	$-0^{m}.274$
410	2.44	$-0^{m}.480$	$-0^{m}.510$	$-0^{m}.430$	$-0^{m}.439$	$-0^{m}.367$	$-0^{m}.360$	$-0^{m}.350$	$-0^{m}.285$
420	2.38	$-0^{m}.455$	$-0^{m}.478$	$-0^{m}.408$	$-0^{m}.392$	$-0^{m}.335$	$-0^{m}.325$	$-0^{m}.319$	$-0^{m}.290$
430	2.33	$-0^{m}.430$	$-0^{m}.440$	$-0^{m}.372$	$-0^{m}.374$	$-0^{m}.314$	$-0^{m}.325$	$-0^{m}.311$	$-0^{m}.295$
440	2.27	$-0^{m}.408$	$-0^{m}.398$	$-0^{m}.335$	$-0^{m}.339$	$-0^{m}.300$	$-0^{m}.285$	$-0^{m}.297$	$-0^{m}.269$
450	2.22	$-0^{m}.350$	$-0^{m}.364$	$-0^{m}.311$	$-0^{m}.305$	$-0^{m}.277$	$-0^{m}.269$	$-0^{m}.241$	$-0^{m}.238$
460	2.17	$-0^{m}.312$	$-0^{m}.325$	$-0^{m}.275$	$-0^{m}.291$	$-0^{m}.235$	$-0^{m}.224$	$-0^{m}.211$	$-0^{m}.225$
470	2.13	$-0^{m}.268$	$-0^{m}.290$	$-0^{m}.243$	$-0^{m}.260$	$-0^{m}.201$	$-0^{m}.219$	$-0^{m}.190$	$-0^{m}.204$
480	2.08	$-0^{m}.255$	$-0^{m}.248$	$-0^{m}.231$	$-0^{m}.220$	$-0^{m}.182$	$-0^{m}.192$	$-0^{m}.150$	$-0^{m}.174$
490	2.04	$-0^{m}.205$	$-0^{m}.218$	$-0^{m}.195$	$-0^{m}.187$	$-0^{m}.151$	$-0^{m}.162$	$-0^{m}.146$	$-0^{m}.157$
500	2.00	$-0^{m}.169$	$-0^{m}.180$	$-0^{m}.153$	$-0^{m}.152$	$-0^{m}.122$	$-0^{m}.143$	$-0^{m}.112$	$-0^{m}.135$
510	1.96	$-0^{m}.140$	$-0^{m}.150$	$-0^{m}.124$	$-0^{m}.109$	$-0^{m}.100$	$-0^{m}.117$	$-0^{m}.099$	$-0^{m}.115$
520	1.92	$-0^{m}.087$	$-0^{m}.110$	$-0^{m}.095$	$-0^{m}.082$	$-0^{m}.082$	$-0^{m}.085$	$-0^{m}.065$	$-0^{m}.092$
530	1.89	$-0^{m}.070$	$-0^{m}.080$	$-0^{m}.065$	$-0^{m}.060$	$-0^{m}.052$	$-0^{m}.055$	$-0^{m}.040$	$-0^{m}.065$
540	1.85	$-0^{m}.039$	$-0^{m}.032$	$-0^{m}.035$	$-0^{m}.019$	$-0^{m}.027$	$-0^{m}.036$	$-0^{m}.020$	$-0^{m}.050$
550	1.82	$0^{m}.000$	$0^{m}.000$	$0^{m}.000$	$0^{m}.000$	$0^{m}.000$	$0^{m}.000$	$0^{m}.000$	$0^{m}.000$
560	1.79	$+0^{m}.032$	$+0^{m}.023$	$+0^{m}.015$	$+0^{m}.037$	$+0^{m}.043$	$+0^{m}.019$	$+0^{m}.034$	$+0^{m}.007$
570	1.75	$+0^{m}.059$	$+0^{m}.050$	$+0^{m}.059$	$+0^{m}.070$	$+0^{m}.073$	$+0^{m}.047$	$+0^{m}.065$	$+0^{m}.052$
580	1.72	$+0^{m}.095$	$+0^{m}.082$	$+0^{m}.078$	$+0^{m}.071$	$+0^{m}.086$	$+0^{m}.065$	$+0^{m}.077$	$+0^{m}.057$
590	1.69	$+0^{m}.132$	$+0^{m}.118$	$+0^{m}.120$	$+0^{m}.144$	$+0^{m}.099$	$+0^{m}.112$	$+0^{m}.115$	$+0^{m}.066$
600	1.67	$+0^{m}.160$	$+0^{m}.150$	$+0^{m}.130$	$+0^{m}.150$	$+0^{m}.148$	$+0^{m}.130$	$+0^{m}.136$	$+0^{m}.067$
610	1.64	$+0^{m}.170$	$+0^{m}.187$	$+0^{m}.170$	$+0^{m}.154$	$+0^{m}.168$	$+0^{m}.144$	$+0^{m}.154$	$+0^{m}.081$
620	1.61	$+0^{m}.200$	$+0^{m}.215$	$+0^{m}.188$	$+0^{m}.175$	$+0^{m}.177$	$+0^{m}.163$	$+0^{m}.164$	$+0^{m}.099$
630	1.59	$+0^{m}.249$	$+0^{m}.231$	$+0^{m}.217$	$+0^{m}.194$	$+0^{m}.196$	$+0^{m}.182$	$+0^{m}.181$	$+0^{m}.110$
640	1.56	$+0^{m}.291$	$+0^{m}.270$	$+0^{m}.230$	$+0^{m}.229$	$+0^{m}.204$	$+0^{m}.196$	$+0^{m}.196$	$+0^{m}.111$
650	1.53	$+0^{m}.312$	$+0^{m}.293$	$+0^{m}.265$	$+0^{m}.283$	$+0^{m}.252$	$+0^{m}.237$	$+0^{m}.221$	$+0^{m}.146$
660	1.51	$+0^{m}.330$	$+0^{m}.320$	$+0^{m}.285$	$+0^{m}.300$	$+0^{m}.280$	$+0^{m}.272$	$+0^{m}.247$	$+0^{m}.188$
670	1.49	$+0^{m}.362$	$+0^{m}.345$	$+0^{m}.315$	$+0^{m}.301$	$+0^{m}.293$	$+0^{m}.303$	$+0^{m}.263$	$+0^{m}.189$
680	1.47	$+0^{m}.398$	$+0^{m}.350$	$+0^{m}.325$	$+0^{m}.341$	$+0^{m}.336$	$+p^{m}.342$	$+0^{m}.287$	$+0^{m}.200$
690	1.45	$+0^{m}.400$	$+0^{m}.330$	$+0^{m}.350$	$+0^{m}.338$	$+0^{m}.379$	$+0^{m}.339$	$+0^{m}.327$	$+0^{m}.182$
700	1.43	$+0^{m}.410$	$+0^{m}.337$	$+0^{m}.375$	$+0^{m}.359$	$+0^{m}.373$	$+0^{m}.328$	$+0^{m}.312$	$+0^{m}.199$
710	1.41	$+0^{m}.435$	$+0^{m}.345$	$+0^{m}.395$	$+0^{m}.384$	$+0^{m}.415$	$+0^{m}.398$	$+0^{m}.310$	$+0^{m}.211$
720	1.39	$+0^{m}.465$	$+0^{m}.350$	$+0^{m}.412$	$+0^{m}.430$	$+0^{m}.418$	$+0^{m}.416$	$+0^{m}.343$	$+0^{m}.212$
730	1.37	$+0^{m}.482$	$+0^{m}.357$	$+0^{m}.440$	$+0^{m}.428$	$+0^{m}.438$	$+0^{m}.392$	$+0^{m}.342$	$+0^{m}.223$
740	1.35	$+0^{m}.485$	$+0^{m}.360$	$+0^{m}.451$	$+0^{m}.432$	$+0^{m}.448$	$+0^{m}.405$	$+0^{m}.382$	$+0^{m}.242$
750	1.33	$+0^{m}.495$	$+0^{m}.363$	$+0^{m}.455$	$+0^{m}.436$	$+0^{m}.451$	$+0^{m}.438$	$+0^{m}.382$	$+0^{m}.242$

normal B stars, lying in the direction of the programme stars, against their apparent distance moduli. The $E(B–V)$ values for normal B stars were computed through the Q method. Their apparent distance moduli were taken from the spectral and luminosity class versus M_v calibration for early type stars (Borgman and Blaauw, 1963). Second, from the distance moduli versus $E(B–V)$ plot for normal B stars, the $E(B–V)$ values of programme Be stars corresponding to their distance moduli were estimated and are listed in Table 1, along with expected errors. The reddening corrections were then determined by adopting the mean value of total to selective extinction $(R)=3.25$ (Moffat and Schmidt-Kaler, 1976) and using the mean interstellar reddening curve by Hayes et al. (1973).

For the star ψ Per the value of $E(B–V)$ has been taken from Ultraviolet Bright-Star Spectrophotometric Catalogue (Jamar et al., 1976), because sufficient number of normal B stars in the direction of ψ Per star were not available for estimating $E(B–V)$ by the above mentioned method.

4. Continua and effective temperatures

Although the continuum of a Be star is modified due to envelope contribution, we have made an attempt to derive the effective temperature of Be stars by comparison with models. The models given by Kurucz (1979) have been superimposed on the observed

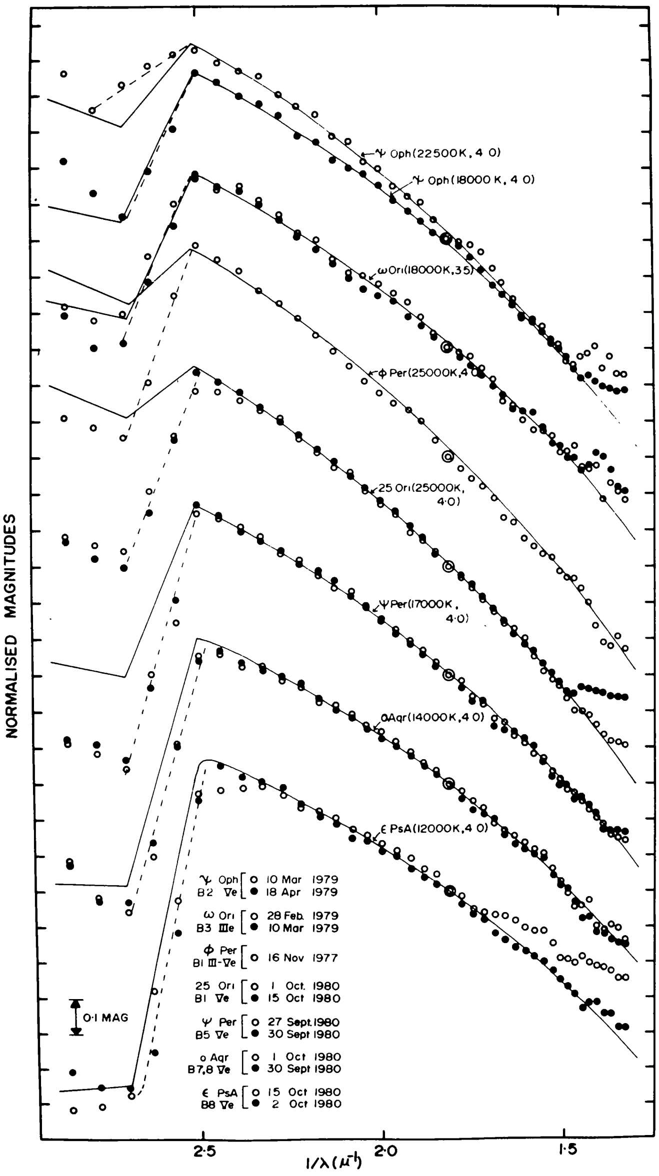

Fig. 1. Normalized energy distribution curves of Be stars (filled and open circles) matched to the best fitting models (continuous curves). The matching has been done by eye. The normalization has been done at λ 550 nm, which is denoted by double circles

continuum in the $\lambda\lambda$ 400–550 nm region (which is least affected by the envelope emissions) to determine the effective temperature, assuming $\log g = 4$ for luminosity class V and IV and $\log g = 3.5$ for luminosity class III. The fitting of models (solid lines) with observations (open and filled circles) are shown in Fig. 1. The numbers in the bracket denote the values of $T_{\rm eff}$ and $\log g$ of the fitted models. The temperatures estimated for our Be stars are listed in Table 1, wherein the MK spectral types are those adopted from Sky Catalogue by Hirshfeld and Sinnott (1982). The effect of gravity on the energy distribution of these stars is relatively small, for example a change in gravity from $\log g = 4$ to $\log g = 2$ would be equivalent to a change in temperature of less than 500 K at 10,000 K (Kontizas and Theodossiu, 1980). Therefore, in using fluxes to determine the temperatures of Be stars, the gravity will not need to be known with great accuracy (Nandy and Schmidt, 1975).

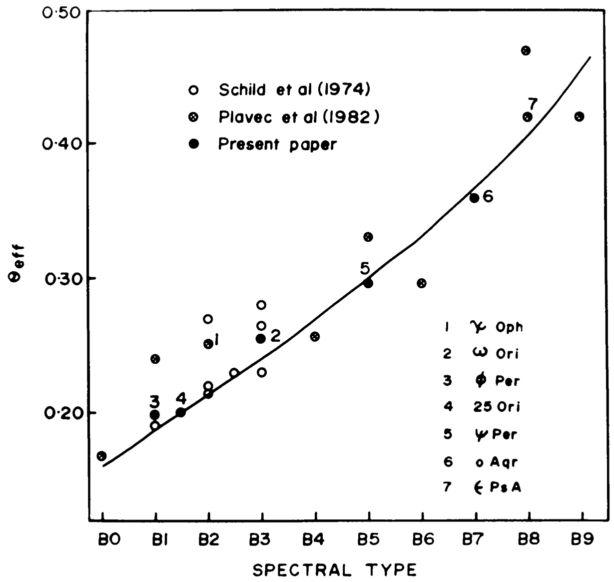

Fig. 2. The $\theta_{\rm eff}$-spectral type relation for Be stars. The solid curve is the mean relation for normal B stars obtained from the data given by Kontizas and Theodossiu (1980)

The photometric error of the observed fluxes introduce an uncertainty in the estimated $T_{\rm eff}$ which is $\pm 5\%$ around 20,000 K and $\pm 2\%$ around 10,000 K. The fit of the computed to the observed flux introduces an additional error that varies from ± 500 K for cool stars to ± 800 K for the hot ones.

The estimated values of the effective temperature of Be stars are plotted on the $\theta_{\rm eff}$-spectral type relation for normal B stars as shown in Fig. 2. The solid curve for normal B stars was obtained from the $T_{\rm eff}$ and spectral type data of stars given by Kontizas and Theodossiu (1980). In Fig. 2 we have also plotted other Be stars taken from Schild et al. (1974) and Plavec et al. (1982), whose effective temperatures have also been determined by fitting models with the observed continua of those stars. It is obvious from Fig. 2 that the $\theta_{\rm eff}$-spectral type relation for normal B stars fits with the late Be stars. A careful examination of Fig. 2 reveals that early Be stars tend to show lower effective temperatures than that of the normal B stars of the same spectral class.

From Fig. 1, it is clear that the observed energy distribution curves of stars fit with models in the Paschen continuum. The stars χ Oph, ω Ori, 25 Ori, and ε PsA, show slight excess emission at near-infrared region. The excess emission was found only during one night for 25 Ori and ε PsA stars. The stars ϕ Per, ψ Per, and o Aqr do not show such excess emission. Near-infrared excess emission at visual and near-infrared wavelengths have been interpreted by Schild et al. (1974) in terms of H^- free-bound emission, first predicted by Milkey and Dyck (1973). The stars χ Oph, ω Ori, o Aqr, and ε PsA match well with models in the Paschen, as well as in the Balmer continuum. The stars ϕ Per, ω Ori, and ψ Per deviate strongly in Balmer continuum from models and show Balmer jump strongly in absorption. Several Be stars with anomalously high Balmer jump have also been studied by Chkhikvadze (1980), who points out that such stars with anomalously large Balmer jump may be classified as shell stars. Such a phenomenon may be due to an appreciable opacity of the envelope of Be stars in the Balmer continuum. The density of the envelope may change with time, resulting in the change of opacity of the envelope, which may produce variable Balmer continuum, as has been observed in a few of these stars.

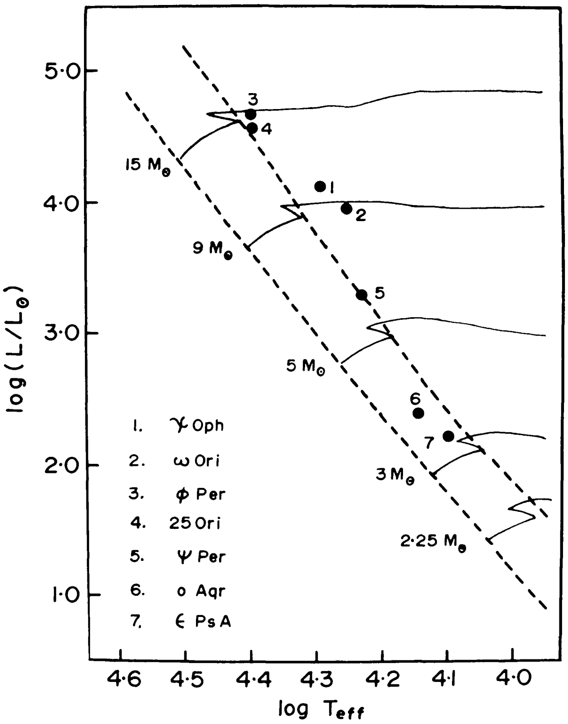

Fig. 3. The evolutionary tracks in the H–R diagram. The mass of each star is given at the left of the track. The dotted lines indicate the boundaries of the main sequence. (Taken from Novotny, 1973)

5. Evolutionary stage of Be stars

The evolutionary status of Be stars is still not well understood. Schmidt-Kaler (1964b) and Crampin and Hoyle (1960) suggested that all Be stars are in the secondary contraction phase, followed by hydrogen exhaustion in the core. Thus, the shrinking of the stellar core decreases the moment of inertia, thereby causing it to spin faster in order to conserve total angular momentum. The rotation might be brought to critical speeds in this way and to produce extended envelopes.

Merrill (1933) and Merrill and Burwell (1933) suggested that the Be stars might be intrinsically about one magnitude brighter than normal B stars. However, Wilson (1941) and Smith (1947) showed no significant difference in their luminosities.

Many investigators like Bidelman (1947), Mendoza (1958), Schmidt-Kaler (1964a, b), Schild (1965), Meisel (1968), and Slettebak (1968) suggest that on the average, Be stars are located 0.5–1.0 mag above the main sequence. On the other hand Bond (1973), Schild and Romanishin (1976), Abt and Levato (1977), have shown that Be stars in clusters do not lie above the main sequence but are also found near the zero age main sequence.

In order to study the evolutionary status of our programme Be stars, we have plotted the position of these stars (filled circles) in the H-R diagram shown in Fig. 3. This Figure is taken from Novotny (1973). The boundaries of the main sequence are shown by dashed lines. The evolutionary tracks (thick continuous lines) for different solar masses have also been shown in the same figure.

To show the position of our programme stars in the $\log T_{\text{eff}}$ versus $\log L/L_{\odot}$ plot, we have used the T_{eff} values determined by us from model computations. The values of luminosities have been determined from the measured apparent magnitude (m_{5500}) of these stars after correcting for interstellar absorption. These magnitudes were converted into absolute visual magnitudes (M_v), with the help of their distances. The values of the distances have been taken from Sky Catalogue by Hirshfeld and Sinnott (1982). The absolute visual magnitudes (M_v) were converted into bolometric magnitudes (M_{bol}) by using bolometric corrections (BC) given by Hayes (1978).

The magnitudes of the Be stars may be affected by their high rotational velocities. The effect of rotation on luminosities of Be stars has been studied by Hardorp and Strittmatter (1968a). They have pointed out that the effect of rotation is to increase the luminosity of a star by as much as about 1.0 mag. They suggested that the higher luminosity observed in some Be stars may be due to their high rotational velocities.

This paper points out a possible effect of rotation, along with the effect of stellar evolution. Concerning the former effect, we have given the values of $v \sin i$ of Be stars in Table 1. It is interesting to see in Fig. 3 that the stars χ Oph and ω Ori which are both slower rotators than others, exhibit the highest deviation above the main sequence. These stars are seen to be located about 0.8 mag above the main sequence. This infers that the effect of rotation may be minor as compared with the effect of stellar evolution.

From Fig. 3, it is clear that most of the stars lie on the main sequence near the turning points of evolutionary tracks, suggesting that these stars may be in the stage of core contraction after exhaustion of hydrogen at the centre, and have undergone hydrogen burning in the thick shell i.e. in secondary contraction phase as has been suggested by Crampin and Hoyle (1960) and Schmidt-Kaler (1964b). From the position of stars on the H–R diagram, one can have an idea about their masses. The estimated values of mass have been tabulated in Table 1.

6. Variability

Detection of variability in *UBV* system becomes a useful diagnostic in the study of Be stars as their energy distribution are becoming better understood. Variability in (*B–V*) colour could indicate that the near-infrared excess had changed in strength. Variability in (*U–B*) colour could indicate that the filling-in of the Balmer jump had changed in ammount. And variability in *V* magnitude with no colour change might signal eclipses in a binary system.

In our present observing programme, three stars namely ε PsA, 25 Ori, and χ Oph had shown significant variations of $0^{\text{m}}30$, $0^{\text{m}}40$, and $0^{\text{m}}18$, respectively, at visual magnitude (m_{5500}) in their respective continuum. The variation at m_{5500} in Be stars ε PsA and χ Oph is also accompanied by the change in the slope of the continuum, resulting in the change of effective temperature (T_{eff}) by as much as 1000 K for ε PsA and 4000 K for χ Oph as can be seen in Fig. 1. No change at m_{5500} as well as in the slope of the continuum has been noticed for ϕ Per, ψ Per, ω Ori, and *o* Aqr stars.

Acknowledgements. The author is grateful to Dr. R.E. Schild, Smithsonian Institution, USA, Dr. T. Kogure, University of Kyoto, Japan, and Dr. P. Harmanec, Astronomical Institute, Czechoslovakia for critically going through the manuscript and for valuable comments and helpful suggestions.

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