SPECTROPHOTOMETRY OF SOME Be STARS

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Abstract. The continuum energy distributions of six Be stars, namely 25 Cyg, 31 Peg, HR 8758, 14 Lac, 12 Vul, and β Psc, in the wavelength region $\lambda\lambda$3200–7800 Å, are presented. Comparing the observed energy distributions with those of theoretical models given by Kurucz (1979), their effective temperatures are determined.

A near-infrared excess emission at wavelengths above λ6000 Å is seen in most of the stars.

1. Introduction

The most striking manifestation of the Be phenomenon in the visible spectral region is the existence of emission lines in the Balmer series, in a spectrum which would be classified as type B from its absorption lines. Both the continuum spectrum and line spectrum of a Be star are a combination of the spectrum of the central hot, fast rotating star and its circumstellar envelope which exhibits more or less irregular variations with time. A wide range of phenomena take place in Be stars, such as photometric variations, variations in line intensity, mass loss due to radiatively driven stellar wind, and change in Balmer jump. Ultraviolet and infrared excesses, ultraviolet deficiency, variation in emission-line strengths, etc., are common features associated with Be stars.

Energy distribution in the visible region is an important parameter in determining the effective temperatures of early-type stars, since a large portion of the energy radiated by the star is in this region. As with the line spectrum, Be stars also display a wide range of peculiarities in their continuum energy distribution. Barbier and Chalonge (1941) have found that the Balmer jump is smaller for Be stars than for normal B stars, and also the colour temperatures of Be stars are lower than those of B stars. According to Mendoza (1958) and Johnson (1967), the majority of Be stars show excesses in both ultraviolet and infrared regions. Contrary to this, Briot (1978) could not notice any such excesses or deficiencies in the ultraviolet region. However, Delplace and Van der Hucht (1976), Beeckmans (1976), Heap (1976), Schild (1978), and Chkhikvadze (1980) have found deficiency in the ultraviolet region.

In this paper we present our spectrophotometric observations of Be stars and discuss their continuum energy distribution along with its variable nature.

2. Observations and Reductions

The observations of all the programme stars listed in Table I were made with the Hilger and Watts monochromator at the Cassegrain focus of the 104-cm reflector of the Uttar Pradesh State Observatory during November 1983. Their spectral types and luminosity

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TABLE I

A list of Be stars observed in this study

HD	Star	Sp. type	m_{5500}	T_{eff}	Log g	$E(B-V)$
189687	25 Cyg	B3IV	5.00	25000	4.0	$0\overset{m}{.}06 \pm 0.01$
212076	31 Peg	B2V	4.83	22500	4.0	0.06 ± 0.01
217543	HR 8758	B3V	6.28	22500	4.0	0.07 ± 0.01
216200	14 Lac	B3V	5.55	20000	4.0	0.07 ± 0.01
187811	12 Vul	B3V	4.90	18000	4.0	0.06 ± 0.01
217891	β Psc	B6V	4.56	16000	4.0	0.01 ± 0.01

classes are taken from Hoffleit and Jaschek (1982). An exit slot of 0.7 mm, admitting 50 Å of the spectrum on to the photomultiplier, was used for making the observations. Each star was observed four or five times. The reduction techniques were same as used by us earlier (Goraya and Singh, 1984).

The standard stars α Lyr and ξ^2 Cet were observed along with the programme stars. The nightly extinction coefficients were applied for each star using standard star observations. Our transformations of observations to absolute flux values were carried out with the help of the absolute calibration of α Lyr given by Taylor (1984). The absolute monochromatic magnitudes extracted at every 100 Å interval between $\lambda\lambda$3200–7800 Å are corrected for interstellar reddening and normalized to λ5500 Å. These are listed in Table II. The standard deviation of the measurements does not exceed $\pm 0\overset{m}{.}03$ in the entire wavelength region.

3. Corrections for Interstellar Reddening

The determination of interstellar reddening for Be stars is complicated by the presence of the circumstellar envelope. The normal Q method of Johnson and Morgan (1953), valid for Main-Sequence O and B stars, is likely to produce large errors due to ultraviolet and infrared excess emissions in these stars.

To estimate the interstellar reddening for the stars discussed in this paper the colour excess $E(B-V)$ was determined by the method of distance moduli method. The details of the determination of $E(B-V)$ by this method have already been described in a previous paper (Singh, 1985). The $E(B-V)$ determined by this method is given in Table I. The reddening corrections were calculated by adopting a mean value of total-to-selective extinction; $R = 3.25$ (Moffat and Schmidt-Kaler, 1976) and using the interstellar reddening curve given by Lucke (1980).

4. Continua and Effective Temperatures

As a general rule, all the Be stars are variable in their line spectrum as well as their continuum spectrum. Such variability has been observed in a wide range of spectral regions, from the ultraviolet to the visible and the infrared. The high rotation and geometrical position of the star also affect the effective temperatures.

TABLE II

Reddening corrected monochromatic magnitudes of the programme Be stars normalized to λ5500 Å

λ (Å)	1/λ (μ^{-1})	25 Cyg	31 Peg	HR 8758	14 Lac	12 Vul	β Psc
3200	3.13	− 0.450	− 0.480	− 0.552	− 0.305	− 0.403	− 0.025
3300	3.03	− 0.425	− 0.443	− 0.502	− 0.354	− 0.291	− 0.053
3400	2.94	− 0.404	− 0.403	− 0.401	− 0.275	− 0.354	− 0.140
3500	2.86	− 0.350	− 0.413	− 0.415	− 0.285	− 0.190	− 0.105
3600	2.78	− 0.300	− 0.352	− 0.375	− 0.250	− 0.200	− 0.095
3700	2.70	− 0.375	− 0.347	− 0.325	− 0.204	− 0.125	− 0.110
3800	2.63	− 0.440	− 0.412	− 0.427	− 0.403	− 0.187	− 0.061
3900	2.56	− 0.560	− 0.575	− 0.575	− 0.562	− 0.296	− 0.462
4000	2.50	− 0.520	− 0.600	− 0.556	− 0.550	− 0.603	− 0.450
4100	2.44	− 0.775	− 0.627	− 0.575	− 0.590	− 0.728	− 0.524
4200	2.38	− 0.591	− 0.479	− 0.548	− 0.525	− 0.578	− 0.540
4300	2.33	− 0.495	− 0.418	− 0.488	− 0.450	− 0.525	− 0.403
4400	2.27	− 0.437	− 0.388	− 0.420	− 0.414	− 0.494	− 0.356
4500	2.22	− 0.497	− 0.381	− 0.375	− 0.313	− 0.472	− 0.276
4600	2.17	− 0.356	− 0.351	− 0.350	− 0.284	− 0.434	− 0.271
4700	2.13	− 0.323	− 0.326	− 0.332	− 0.263	− 0.411	− 0.250
4800	2.08	− 0.255	− 0.272	− 0.265	− 0.211	− 0.341	− 0.216
4900	2.04	− 0.219	− 0.225	− 0.253	− 0.202	− 0.289	− 0.191
5000	2.00	− 0.171	− 0.204	− 0.203	− 0.176	− 0.249	− 0.154
5100	1.96	− 0.129	− 0.172	− 0.201	− 0.156	− 0.221	− 0.121
5200	1.92	− 0.055	− 0.130	− 0.098	− 0.110	− 0.225	− 0.076
5300	1.89	− 0.057	− 0.072	− 0.089	− 0.084	− 0.175	− 0.037
5400	1.85	− 0.017	− 0.026	− 0.042	− 0.033	− 0.125	− 0.015
5500	1.82	0.000	0.000	0.000	0.000	0.000	0.000
5600	1.79	+ 0.091	+ 0.038	+ 0.049	+ 0.037	− 0.022	+ 0.024
5700	1.75	+ 0.120	+ 0.021	+ 0.097	+ 0.032	+ 0.040	+ 0.031
5800	1.72	+ 0.151	+ 0.067	+ 0.129	0.000	− 0.014	+ 0.044
5900	1.69	+ 0.142	+ 0.061	+ 0.132	+ 0.014	− 0.022	+ 0.063
6000	1.67	+ 0.174	+ 0.051	+ 0.253	+ 0.006	− 0.016	+ 0.052
6100	1.64	+ 0.237	+ 0.043	+ 0.309	− 0.058	− 0.010	+ 0.004
6200	1.61	+ 0.290	+ 0.006	+ 0.272	− 0.042	− 0.005	+ 0.028
6300	1.59	+ 0.255	+ 0.002	+ 0.352	− 0.031	+ 0.003	+ 0.025
6400	1.56	+ 0.298	+ 0.022	+ 0.420	− 0.051	+ 0.045	+ 0.060
6500	1.53	+ 0.322	+ 0.026	+ 0.449	− 0.016	+ 0.062	+ 0.095
6600	1.51	+ 0.333	+ 0.018	+ 0.447	− 0.042	+ 0.081	+ 0.103
6700	1.49	+ 0.336	+ 0.067	+ 0.453	− 0.019	− 0.021	+ 0.086
6800	1.47	+ 0.359	+ 0.075	+ 0.473	− 0.045	+ 0.092	+ 0.081
6900	1.45	+ 0.329	+ 0.085	+ 0.556	− 0.049	+ 0.098	+ 0.045
7000	1.43	+ 0.403	+ 0.118	+ 0.583	− 0.049	− 0.026	+ 0.045
7100	1.41	+ 0.410	+ 0.179	+ 0.513	− 0.022	+ 0.185	+ 0.033
7200	1.39	+ 0.446	+ 0.232	+ 0.523	+ 0.060	+ 0.154	+ 0.039
7300	1.37	+ 0.432	+ 0.207	+ 0.561	+ 0.017	+ 0.147	+ 0.019
7400	1.35	+ 0.388	+ 0.203	+ 0.650	+ 0.008	+ 0.131	+ 0.098
7500	1.33	+ 0.454	+ 0.226	+ 0.630	+ 0.066	+ 0.136	+ 0.055
7600	1.31	+ 0.426	+ 0.216	+ 0.606	+ 0.058	+ 0.143	+ 0.080
7700	1.29	+ 0.471	+ 0.282	+ 0.676	+ 0.146	+ 0.126	+ 0.014
7800	1.27	+ 0.410	+ 0.276	+ 0.672	+ 0.084	+ 0.130	+ 0.012

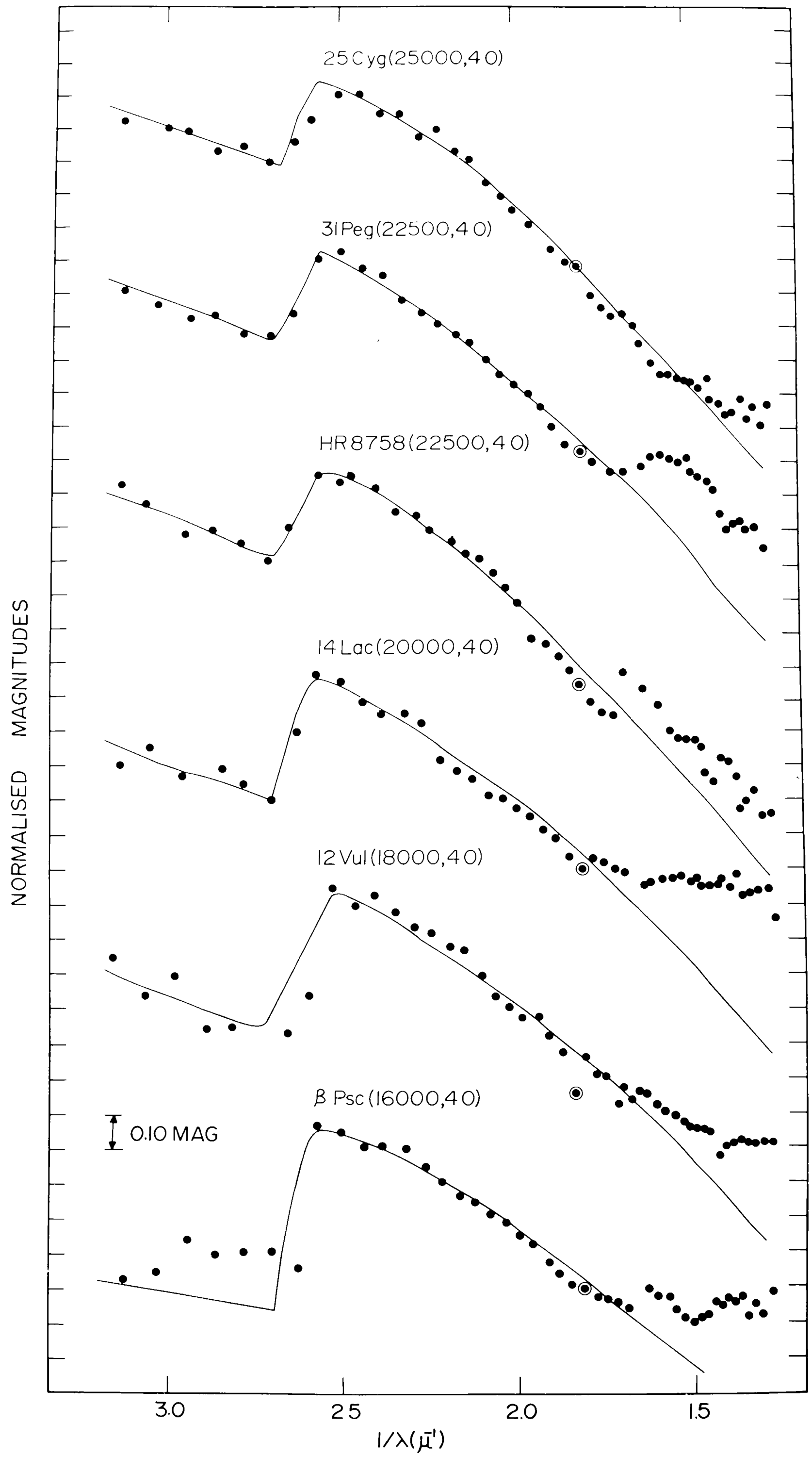

Fig. 1. Normalized de-reddened energy distribution curves of Be stars (filled circles) superimposed on best fitting models (solid continuous curves). The normalization has been done at λ5500 Å, denoted by a filled circle surrounded by an open circle. The matching has been done by eye.

In this paper we have used synthetic spectra constructed by Kurucz (1979) with normal chemical composition for deriving the effective temperatures of the programme stars.

Kurucz model atmospheres with solar abundances and microturbulence velocity of 2 km s^{-1} were superimposed on the observed spectra in order to derive effective temperatures assuming $\log g = 4.0$ for luminosity class IV and V. The model fitted (solid curve) and observations (filled circles) are shown in Figure 1. Since the effect of gravity on the effective temperature is small, it is not necessary to know the correct value of gravity (Nandy and Schmidt, 1975). A change from $\log g = 4$ to $\log g = 2$ would be equivalent to a change in temperature of less than 500 K at 10000 K (Kontizas and Theodossiu, 1980).

The uncertainty in the temperatures due to errors of the observed fluxes is estimated to be $\pm 5\%$ around 25000 K and $\pm 2\%$ around 10000 K. The fitting of the computed to the observed fluxes introduces an additional error that varies from $\pm$ 500 K from cool stars to $\pm$ 800 K for hot stars.

5. Discussion and Conclusions

The observed energy distribution curves of all the programme stars are shown in Figure 1 along with the computed Kurucz (1979) model fluxes. The derived effective temperatures and gravities are given in brackets. From Figure 1, it is clear that the observed energy distribution curves fit the models well. A near-infrared excess emission is observed in most of the stars. Out of the six Be stars observed by us, four stars had been included in the infrared (JHKL) observation programme by Ashok *et al.* (1984) and they noted that there exists an infrared excess for 25 Cyg, 12 Vul, and β Psc. They also concluded that the infrared excess is correlated with the luminosity of the Hα emission line. The existence of a correlation between L_{IR} and $L_{H\alpha}$ suggests that the Be stars should exhibit infrared variability since the Hα line strength of Be stars exhibits temporal variations. Recently, Bhatt *et al.* (1984) have inferred that the presence of the Hα line in the emission at the time of observation is a strong indication of the presence of infrared excess.

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