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Near Infrared Spectroscopic Observations of Early-type Be Stars

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Abstract. The medium resolution (R=1000) near infrared spectra of 30 early type Be stars obtained during the period October 1998-April 1999 are presented. The Paschen β and Brackett γ lines are seen in emission in majority of these stars. The higher order Brackett series lines from m=10 to 19 are detected in emission with significant strength compared to the Brackett γ emission line flux indicating the effect of optical depth. The Fe II line at 1.6873μm is detected in a small number of stars indicating existence of higher density and lower temperature emission zone.

1. Introduction

The Be stars are characterised by the Balmer line emission and IR excess. The recombination process in the ionized circumstellar envelope gives rise to the hydrogen emission lines. The limited observations taken by different groups in 1980s showed that higher quantum level transitions of the Brackett series are present in H band spectra in addition to Brγ emission in K band. The observed line ratios deviated from the Case B values indicating optical depth effect. There is no systematic near infrared spectroscopic study covering the Brackett series emission lines of a large number of Be stars covering the spectral range 1.50 to 2.20μm. A programme of spectroscopy of Be stars has been initiated at Mt.Abu Observatory to investigate the characteristics of Be stars in the near infrared - 1 to 2.5μm - wavelength range. The first results of this programme are presented.

2. Observations

The JHK spectra were obtained with the Mt Abu Observatory 1.2m telescope using the Near Infrared Imager/Spectrometer (PRLNIC) having 256×256 HgCdTe NICMOS3 array. The resolution of the spectrometer is 1000. The spectra in different bands were obtained by rotating the grating. For each position of the grating two spectra were taken with programme star at two different positions on the slit. The slit width is 2 arcsecond and is oriented in North-South direction. The integration times for individual spectra ranged from 2 to 60 seconds. The standard star spectra were obtained either before or immediately following the programme star observations.

Table 1. Spectral Type listing of observed Be stars

S. No.	HR No	HD No	Name	Sp. Type
1	264	5394	27 γ Cas	B0 IVe
2	2855	58978		B0 IVpe
3	3034	63462	o Pup	B0 Vpe
4	1789	35439	25 ψ^1 Ori	B1 Vpe
5	2284	44458	FR CMa	B1 Vpe
6	8539	212571	52 π Aqr	B1 Ve
7	2538	50013	13 κ CMa	B1.5 Vne
8	5440	127972	η Cen	B1.5 Vne
9	1508	30076	56 Eri	B2 Ve
10	1659	32990	103 Tau	B2 V
11	1660	32991	105 Tau	B2 Ve
12	1679	33328	69 λ Eri	B2 IVe
13	1858	36576	120 Tau	B2 IVe
14	2142	41335		B2 Ven
15	2749	56139	28 ω CMa	B2 IVe
16	2921	60855		B2 Ve
17	5193	120324	μ Cen	B2 IVe
18	6118	148184	7 χ Oph	B2 IVpe
19	6712	164284	66 Oph	B2.5 Ve
20	1622	32343	11 Cam	B2.5 Ve
21	1961	37967		B2.5 Ve
22	3135	65875		B2.5 Ve
23	5907	142184		B2.5 ne
24	1934	37490	47 ω Ori	B3 IIIe
25	4625	105521		B3 IVe
26	1910	37202	123 ζ Tau	B4 IIIe
27	3946	86612		B4 Ve
28	193	4180	o Cas	B5 IIIe
29	1087	22192	37 ψ Per	B5 Ve
30	5941	142983	48 Lib	B5 IIIpe

3. Analysis

The spectra were analysed using the IRAF package. The OH airglow lines that register along with the object spectra have been used for spectral calibration. The image pairs were subtracted from each other to remove the dark current of the array. This procedure also removed sky and background emission. The standard star spectra were used to derive spectral sensitivity function using blackbody flux distribution at appropriate effective temperature. The final combined Be star spectra were divided by the standard star spectra.

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Table 2. Equivalent widths and Line ratios of Brackett Series lines

Feature	Equivalent Width (Å)		CaseB	Observed Line Ratio	
	HR 1858	HR 1961	Line Ratio	HR 1858	HR 1961
Br 10	10.9	4.7	1.00	1.00	1.00
Br 11	13.3	6.0	0.77	1.22	1.28
Br 12	9.2	7.0	0.60	0.84	1.49
Br 13	12.1	8.0	0.47	1.11	1.70
Br 14	11.6	8.5	0.38	1.06	1.81
Br 15	11.8	7.5	0.31	1.08	1.60
Br 16	14.3	9.2	0.25	1.31	1.96
Br 17	10.1	7.2	0.21	0.93	1.53
Br 18	6.8	5.6	0.17	0.62	1.19
Br 19	8.0	3.6	0.15	0.73	0.77

4. Results

We present new observations of both the emission lines and the continuum in the near infrared region - 1 to 2.4μm. The list of observed Be stars according to their spectral types is given in Table 1. The JHK spectra are recorded with good signal to noise ratio and allow equivalent width measurements of high m Brackett emission lines upto Br 19 starting from Brγ and also Paschen β at 1.2818μm. The results for two stars are given in Table 2.

4.1. H I emission

H I emission is seen in majority of the spectra indicating that these stars are in active Be phase. We have compared the Brackett line ratios with the predicted ratios given by Hummer & Storey (1987) for typical values of T_e=10000 K and N_e=10^{10} cm^{-3} expected in the Be star envelopes. The observed line ratios for two stars HR 1858 and HR 1961 and the predicted case B line ratios are given in Table 2. The deviation of the observed line ratios from the predicted case B values is clearly seen indicating that Brackett series lines are optically thick.

During the period of our observations four stars - HR 1659, HR 1679, HR 5907, HR 8539 - did not exhibit HI lines in emission indicating that they were in quiescent phase and three additional stars - HR 1934, HR 2855, HR 8539 - exhibited very weak Brγ emission lines.

4.2. Line emission from other elements

The optical spectra of Be stars have shown the presence of Fe II emission(Jaschek 1991) and Ca II triplet emission(Polidan & Peters,1980). Our H band spectra clearly show emission line near 1.690μm in four stars : HR 1087, HR 1961, HR 2142 and HR 3135. We tentatively identify this line with Fe II line at 1.6873μm. The difference of 0.0015μm between the observed and theoretical wavelength needs to be looked into. The emission from Fe II is attributed to the presence of cooler and dense environment ($T_e \approx$ 5000K and $N_e > 10^{-9}$ cm^{-3}, Porter, Drew & Lumsden 1998). An additional weaker emission line is seen near 1.576μm in a

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few stars spectra, e.g., HR 1961 and HR 2142. The wavelength match suggests this line to most likely arise from Mg I transition at 1.5766μm. We present sample JHK-band spectra in Figure 1.

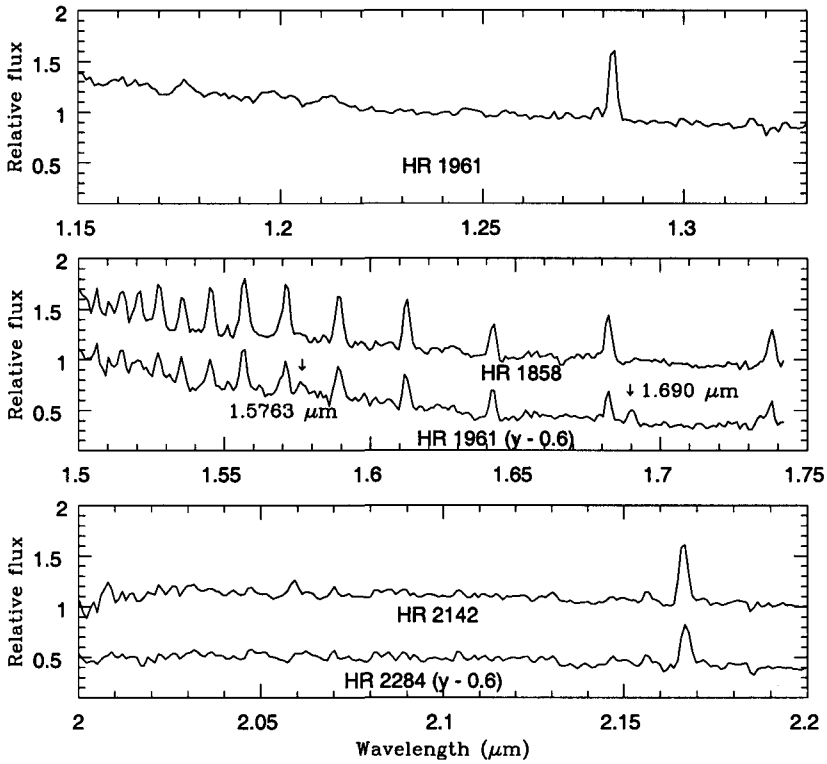

Figure 1. JHK spectra of selected programme stars

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