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Simultaneous Infrared and H-alpha Measurements of Be Stars

Krishna M. V. Apparao, S. P. Tarafdar & R. P. Verma *Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400 005*
K. V. K. Iyengar *Indian Institute of Astrophysics, Bangalore 560 034*
K. K. Ghosh *Vainu Bappu Observatory, Kavalur, Alangayam 75301, Tamilnadu*

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Abstract. The observed infrared excess in Be stars is usually interpreted as free-free and free-bound emission from a hot gas envelope around the Be star. This hot gas should also emit H-alpha line radiation. Earlier observations had suggested that the infrared excess and Hα radiation were not consistent with models in which they arise from the same ionized region; however the observations were made at different times. We have made simultaneous observation of infrared and H-alpha line radiation. Our observations imply that either both these radiations cannot arise from the same hot gas or additional processes have to be invoked to account for the observed excess infrared radiation.

Key words: Be-stars—H-alpha—infrared.

1. Introduction

Occasional episodes of line emission, in addition to periods of display of normal stellar absorption lines, is a characteristic of Be stars (Doazan 1982). The line emission is attributed to a gas envelope around the Be star, presumably ionized by the radiation from the star (Doazan 1982; Apparao and Tarafdar 1987). The gas envelope expands slowly and is sometimes termed a 'wind' with a low velocity (Waters 1986). Infrared emission both in the near region (1–10μ) and the far region (greater than 20μ) was observed. It was found that when a Be star is in the emission line stage, the infrared emission is more than that due to the star in its non-emission-line state (Doazan 1982). It is generally believed that the excess infrared radiation is free-free and free-bound radiation from ionized gas. On the basis of this hypothesis Waters *et al.* (1987) used the infrared observations from the IRAS satellite to infer emission measures (see Lamers 1987) for different spectral types of Be stars (Table 1). This ionized gas also emits H-alpha radiation. In column 3 of table 1, we have given the expected H-alpha energy E(Hα) using the emission measures given by Lamers (1987). This can be compared with the range of observed values of E(Hα) (Ashok *et al.* 1984). It is seen clearly that the H-alpha emission implied by the infrared observations is larger than that observed. However, the infrared and H-alpha observations (see Ashok *et al.* 1984) were not performed at the same time. Due to the known variability of H-alpha and infrared radiation from Be stars the above discrepancy, though unlikely,

Table 1. Infrared and H-alpha luminosities of Be stars.

Spectral type	Log (EM)[1] (cm^{-3})	Log E(Hα) (calc.) ($ergs\ s^{-1}$)	Log E(Hα) (obs.) ($ergs\ s^{-1}$)	L_{IR}/L_L^2	L_{IR}/L_* ($\times 10^{-2}$)
B0–B1.5	60.6–61.1	36–36.5	33.6–34.4	0.04–0.54	0.57–6.67
B2–B3	59.4–60.4	34.8–35.8	33.1–34.0	0.09–1.13	0.57–5.27
B4–B5	59.2–59.9	34.6–35.3	32.2–33.7	2.02–5.57	2.68–3.75
B6–B7	58.2–59.5	33.6–34.9	32.1–33	9.26–11.67	3.53–4.14
B8–B9	57.7–58.2	33.1–33.6	32.4–32.8	15.42–22.56	1.67–2.44

[1] From Lamers (1987).
[2] See Ashok *et al.* (1984).

can be attributed to non-simultaneity of the two observations. In order to check the possibility of the discrepancy being due to variability or otherwise we have made simultaneous measurements of infrared and H-alpha radiation from several Be stars, and report them in this paper. Section 2 gives the details of observations and section 3 gives the results and discusses the implications.

2. Observations

Simultaneous infrared JHK photometry and optical spectroscopy of Be stars were made with the 75 cm and the 102 cm reflectors of Vainu Bappu Observatory, Kavalur, India. The observations were made on two occasions: the nights of February 24/25, 1992 and March 13/14, 1993. The infrared observations were carried out in the JHK bands using a liquid nitrogen cooled InSb photometer at the f/13 cassegrain focus of the 75 cm telescope. The beam was chopped using a vibrating mirror close to the focal plane at a frequency of 20 Hz. A field view of 40 arc seconds was used and the chopper-throw was set at 55 arc seconds.

Hα spectroscopic observations of the Be stars were made using the Universal Astronomical Grating Spectrograph at the cassegrain focus of 102 cm reflector of VBO. All the spectra were obtained with a 254 mm camera using Photometrics CCD detector (Ram Sagar & Pati 1989) with a reciprocal dispersion of 20 Å mm^{-1}. The typical S/N around continuum level at Hα, attained in the 30 min exposures made, was in the range 200–300. The data reductions were made using the revised version of the RESPECT (Prabhu, Anupama & Giridhar 1987) software package following the procedure described in a previous paper (Ghosh *et al.* 1991). The observations of the four Be stars of η Tau (HR 1165), ζ Tau (HR 1910), κ CMa (HR 2538) and β CMi (HR 2845) were made on the night of 24/25 February 1992. On the night of March 13/14, 1993, the stars η Tau, ζ Tau, β CMi, HR 3858, HR 4123 and δ Cen (HR 4621) were observed. Several calibration stars were also observed throughout the nights.

The J, H, K infrared magnitudes are obtained using the calibration stars and making the appropriate mean extinction corrections for the site. These are given in Table 2. The H-alpha equivalent widths are obtained in the usual fashion by integrating the flux under the profile and are given in Table 2. The equivalent widths are converted to H-alpha luminosity using the stellar atmospheric tables of Kurucz (1987) and these

Table 2. Infrared and H-alpha Observation of Be stars.

Star	Spectral type	Magnitudes J	H	K	H-alpha eq. width Å	L_{IR} ergs s^{-1}	$L_{H\alpha}$ ergs s^{-1}	$(L_{IR}/L_{H\alpha})$ R
η Tau	B7 III	3.01	2.84	2.98	−6.9 (±0.05)	$< 10^{34}$*	5.4×10^{32}	< 18.5
HR 1165	B7 III	3.07	3.05	2.98	−6.9 (±0.07)	$< 10^{34}$*	5.4×10^{32}	< 18.5
ζ Tau	B2 III	3.33	3.1	3.06	−21.5 (±0.18)	2.5×10^{35} (±0.6)	1.1×10^{34}	22
HR 1910	B2 III	3.2	3.2	2.98	−17.35 (±0.20)	4×10^{35} (±1.0)	9×10^{33}	44
κ CMa / HR 2538	B2 V	3.96	3.35	3.51	−22.18 (±0.20)	7.8×10^{35} (±0.8)	2×10^{33}	390
β CMi	B8 V	3.01	2.96	3.0	−6.34 (±0.08)	1.6×10^{34} (+1.0)	4.3×10^{31}	372
HR 2845	B8 V	3.09	3.11	3.05	−5.96 (±0.06)	4.5×10^{33}	4×10^{31}	112
δ Cen / HR 621	B2 V	2.67	2.65	2.55	−28.7 (±0.34)	8.3×10^{35} (±0.8)	2.6×10^{33}	319
HR 3858	B6 V	5.14	5.16	5.03	−10.28 (±0.12)	1.7×10^{34} (±0.9)	5.6×10^{32}	30.3
HR 4123	B9 V	5.71	5.65	5.50	−6.35 (±0.11)	$< 2.7 \times 10^{33}$*	7×10^{31}	< 38.6

*No excess detected within error of measurement.

are also given in Table 2. The calculation of the near infrared luminosity L_{IR} from the J, H, K magnitudes has been outlined by Ashok *et al.* (1984) and using these we obtained the values given in Table 2. The ratios (R) of the infrared luminosity to the H-alpha luminosity are also given in Table 2.

3. Discussion

The assumption that both the infrared and H-alpha emission arise due to free-free and free-bound emission from the same ionized gas would predict a luminosity ratio R of about 3 (Ashok *et al.* 1984). The ratios obtained for five of the seven observed stars are larger than 3 suggesting that the discrepancy referred to in the Introduction remains; namely that the observed infrared and Hα emissions are not compatible with the hypothesis that they arise from the same region of hot gas. Recently Roche *et al.* (1993) have compiled Hα, V magnitude and infrared H, J, K observations of X-Persei. They find a strong correlation between them. In fact during a shell episode during the years 1990–92 all the above quantities were at a minimum, suggesting that they are related and arise, presumably in the gas disk around the star. Of course, this does not prove that they arise from the same region in the gas disk.

In Table 1, the ratio of the infrared luminosity L_{IR} to the luminosity of the Lyman continuum L_L is given. It is seen that for later types of Be stars $L_{IR} > L_L$. This again suggests that the bulk of the infrared emission may not arise from regions ionized by the Lyman continuum. On the other hand the ratio of L_{IR} to the luminosity of the star L_* is of the order of one percent. In the later types most of the energy is in the Balmer continuum. It seems necessary therefore to convert part of this Balmer continuum to infrared luminosity. It is also possible that other mechanisms may operate, for example C-shocks in the gas envelope around the Be star, which can heat the gas without ionizing, thus leading to infrared luminosity without H-alpha emission. Some of these possibilities are under investigation. One other possibility is that in the case of the early type Be stars, the H-alpha emission is highly self absorbed in the HII region. This possibility is being examined.

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