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Spectroscopy of Be stars in young open clusters

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Abstract. A spectroscopic study of 152 Classical Be stars in 42 young open clusters was performed using medium resolution spectra in 3700−9000 Å range, to understand the Be phenomenon. The Balmer decrement is found to have a bimodal distribution which is correlated with the nature of H_β profile. Classical Be stars with higher Balmer decrement (76%) were found to have more number of emission lines, higher H_α equivalent width and $(H-K)_0$ values, suggesting an optically and geometrically thick disk. Massive Be stars of spectral type B0−B4 are found to have enhanced H_α emission at the end of their main sequence lifetime, as inferred from the enhancements observed at 12.5 and 25 Myr. These results support our earlier prediction that early B-type stars (B0−B4) spin up to Be phase while others (B4−A0) are born as Be stars.

Keywords : stars: formation – stars: emission-line, Be – stars: open clusters

1. Introduction

A Classical Be star (CBe) is a rapidly rotating B-type star that produces an equatorial disk which is not related to the natal disk the star had during its accretion phase (Porter & Rivinius (2003)). The spectrum has, or had at some time, one or more Balmer lines in emission (Collins 1987). Mathew et al.(2008) performed a survey to identify emission-line stars in young open clusters using slitless spectroscopy. From the distribution of Be stars with respect to spectral type and age, they found that Be stars in the spectral range B0−B1 have

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evolved into Be phase while others are born as CBe stars. Following the survey, the spectra of the identified emission-line stars were obtained to study their spectral properties. The survey identified a large number of CBe stars covering a wide spectral and age range, thus making the sample ideal for statistical analysis of various spectral characteristics.

2. Observations

The spectroscopic observations of emission-line stars have been obtained using HFOSC available with the 2m Himalayan *Chandra* Telescope (HCT), located at Hanle and operated by the Indian Institute of Astrophysics (IIA). The CCD used for imaging is a 2 K $\times$ 4 K CCD, where the central 500 $\times$ 3500 pixels were used for spectroscopy. The pixel size is 15 μm with an image scale of 0.297 arcsec/pixel. The spectra were taken using Grism 7 (3800 Å – 6800 Å) and 167 μm slit combination in the blue region which gives an effective resolution of 1330. The spectra in the red region is taken using Grism 8 (5800 Å – 8350 Å) /167 μm slit setup, which gives an effective resolution of 2190. The spectra were found to have good signal to noise ratio greater than 100. All the observed spectra were wavelength calibrated and corrected for instrument sensitivity using IRAF tasks. The resulting flux calibrated spectra were normalised and continuum fitted using IRAF tasks. The equivalent width (EW) of the spectral lines were estimated from a Gaussian fit using routines in IRAF.

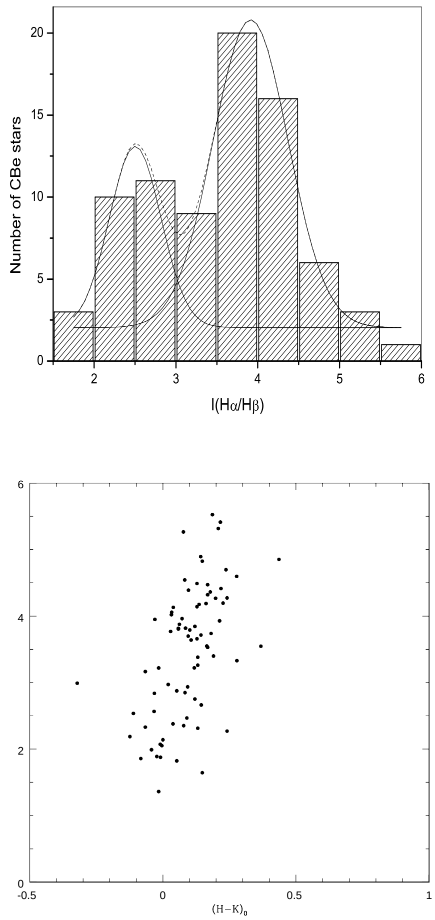
The near Infra-red (near-IR) photometric magnitudes in J, H, K_s bands for all the CBe stars were taken from 2MASS (http://vizier.u-strasbg.fr/cgi-bin/VizieR?-source=II/246) database. The (J$-$H) and (H$-K_s$) colours obtained were transformed to Koornneef (1983) system using the transformation relations by Carpenter (2001). The colours were de-reddened using the relation from Rieke & Lebofsky (1985). For this purpose we used the reddening (E(B$-$V)) of the cluster to which CBe star is associated.

3. Results and discussion

Of the 157 surveyed emission-line stars in 42 open clusters, 5 were found to belong to HAeBe category. They have been removed from our total list of Be stars. To address the Be phenomenon, we used a sample of 152 CBe stars.

3.1 The distribution of Balmer decrement (D_{34})

The Balmer decrement (I(H_α)/I(H_β), D_{34}) of Be stars have been studied extensively by several authors (Slettebak et al. 1992; Burbidge & Burbidge 1953;



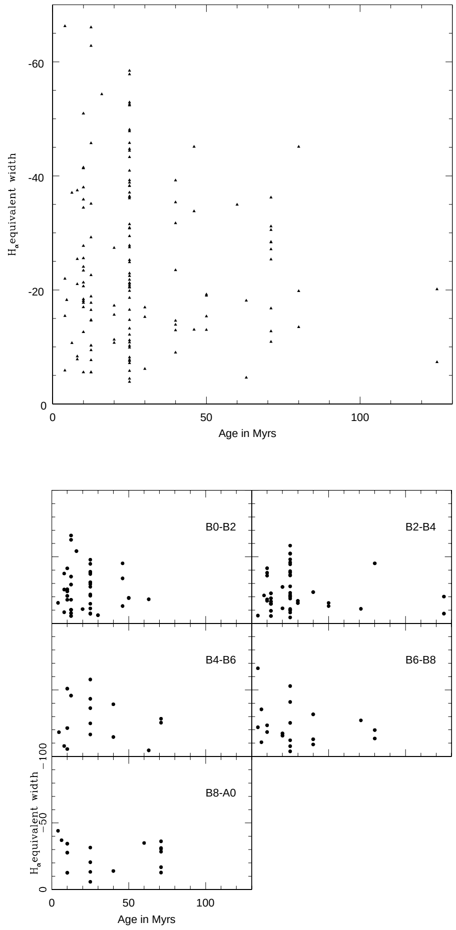
(a)

(b)

Figure 1. (a) The Balmer decrement distribution of surveyed CBe stars. (b) The variation of Balmer decrement with respect to the near-IR colour $(H-K_s)_0$.

Dachs et al. 1990) and they all agree with the theoretical value of nebular region, even though the Be star envelopes have different density and temperature structure than nebulae. For nebular region, the peak emission strength ratio of H_α to H_β is given as 2.7 for a typical electron density of $10^6/\mathrm{cm}^3$ and a temperature of 20,000 K (Brocklehurst 1971; Hummer & Storey 1987).

The Balmer decrement was calculated for 88 CBe stars, which show emission in both H_α and H_β line profiles. The Balmer decrement values of 67 CBe stars (76%) were found to be more than the standard nebular value of 2.7. We have plotted the histogram of Balmer decrement (with bin size of 0.5) in Fig. 1. CBe stars were found to have values ranging from 1.5 to 6.5 with a mean around



(a)

(b)

Figure 2. (a) The H_α EW of CBe stars are plotted with respect to the age of the cluster to which they are associated. (b) The H_α EW of CBe stars are shown with respect to age for various spectral bins.

3.5 as shown in Fig. 1(a). We fitted a Gaussian curve for the 2 peaks seen in the distribution and they are found to peak at 2.5 and 3.9 respectively. The population in the first peak are found to have an emission in absorption (or filled-in) profile for H_β line, while H_α profile showed emission above the continuum. The population in the second peak are found to have emission above the continuum in H_α and H_β with no filled-in features. Moreover, the peak emission strength of H_α is found to be lower for CBe stars having filled-in H_β profiles so that the lower value of Balmer decrement is related to the reduction in intensities of both profiles. Since we address the ratio of relative intensities, the deblending of stellar absorption component is unlikely to change the distribution of

Balmer decrement. Hence the bimodal distribution of Balmer decrement and its deviation from the nebular value needs to be addressed in detail. Another interesting finding is that CBe stars belonging to the first group (with a peak of 2.5) have less number of emission lines (especially FeII lines) compared to those in the second group. To check the correlation between the extent of disk and opacity, we plotted Balmer decrement with $(H-K_s)_0$, as shown in Fig. 1(b). The de-reddened $(H-K_s)$ colour $(H-K_s)_0$ has been used to estimate near-IR excess, which is due to free electrons and dust in circumstellar disk. It can be seen that Balmer decrement is directly proportional/linearly correlated with $(H-K_s)_0$. The Balmer decrement (correlated to line optical thickness) is high for a geometrically thick and extended circumstellar disk (higher value of $(H-K_s)_0$).

3.2 The variation of H_α EW as a function of age

The H_α EW of CBe stars are plotted as a function of their age in Fig. 2(a). The age of CBe stars are taken from the references listed in Mathew et al. (2008). The clusters younger than 30 Myr are found to have CBe stars with a range of H_α EWs. For older clusters there is a total absence of stars with EWs greater than -40 Å. The plot also suggests that the H_α EW peaks at about 10 Myr. We looked for the evolution of H_α EW with age for each spectral type, as shown in Fig. 2(b). For the spectral bin B0$-$B2, the H_α EW is found to peak at 12.5 Myr. A similar rising and decaying trend in EW is found in B2$-$B4 spectral bin with a peak at 25 Myr. The CBe stars in the spectral bins B4$-$B6, B6$-$B8 and B8$-$A0 do not show peaking in the age range 40$-$100 Myr, which correspond to the final phase of their main-sequence (MS) lifetime. Hence they may be born as CBe stars. To summarise, most of the stars of spectral type B0$-$B4 form circumstellar disk at the end of their MS lifetime, as inferred from the enhancements in H_α emission observed at 12.5 and 25 Myr.

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