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# H$\alpha$ Emission from Late Type Be Stars

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**Abstract**. We show here that the H$\alpha$ flux from late type Be stars can be explained as emission from an HII region formed in the gas envelope around the Be star, by the UV flux emitted by a helium star binary companion. We also discuss the observability of the helium star companions.

*Key words.* Be stars—H-alpha line—He stars.

## 1. Introduction

The main characteristic of Be stars is the presence of emission lines in their optical spectra, amongst which the H$\alpha$ line is most prominent. The line emission from Be stars is presumed to originate in an HII region formed in the gas envelope around the Be star, by the Lyman continuum from the Be star. High variability of line emission (sometimes even the vanishing of emission) is a distinct feature of Be stars.

Several models have been proposed for the nature of the gas envelope and its formation around Be stars (see Doazan 1982 for references; also Waters *et al.* 1989 and Apparao 1985). The original suggestion by Struve (1931) envisaged an equatorial disk supported by rotation. Poeckert & Marlborough (1979 and earlier references therein) used a modified version of this model to successfully explain the line profiles of Balmer lines. In this model the temperature of the gas is assumed . The model of Doazan and Thomas (Doazan 1987) starts with high velocity wind from the Be star, which slows down into a thick envelope at a distance. This model suggests that the line emission occurs in the comparatively cool thick portion of the envelope. To our knowledge this model has not been applied to account for the energy in the line emission. Waters, Cote & Lamers (1987) have used a modified disc model to determine the infrared excess in Be stars and compare with observations. They *assume* a temperature throughout the gas and use this to explain the infrared spectra of Be stars and to derive the density distribution in the gas envelope. Kerkwijk, Waters & Marlborough (1995) used both the above disc models to calculate the H$\alpha$ equivalent widthinfrared correlation for several Be stars and compared with observations. They find that the disc model consistently gives lower values for the H$\alpha$ equivalent widths as compared to the observed values, while the wind model gives consistently higher values. We emphasize that in all the above disc models it is tacitly *assumed* that stellar radiation from the Be star is enough to maintain the requisite temperature throughout the gas envelope. It is necessary to show that the assumed temperature is obtained throughout the gas envelope before the results of calculations from these models can be accepted.

Apparao & Tarafdar (1987) have calculated the Hα emission from the gas envelope of Be stars, assuming that the envelope is ionized by the Lyman continuum of the star. They calculated the energy in the emission from the HII region for different spectral types. By comparing with observations they found that this process cannot account for the energy in the H*α* emission for spectral types B3 and later. Apparao & Tarafdar (1987) also considered the absorption of Balmer continuum from the Be star to enhance the ionization in the HΠ region. After considering various uncertainties, they concluded that the energy in the H*α* emission from spectral types later than B5 cannot be explained as due to absorption of Lyman and Balmer continua from the Be star in its gas envelope. They suggested that an additional source of energetic UV photons with energy greater than the hydrogen ionization potential is required. The number of such UV photons was estimated to be about $3\times10^{44}$ $s^{-1}$ and $10^{45}$ $s^{-1}$ for the B8 and B5 spectral types respectively. The purpose of this paper is to suggest a source of these photons and account for the H*α* emission from late type stars.

A model which attempts to account for the observed equivalent widths of Be stars is that of Hoflich (1988). He discussed a cocoon model for Be stars, in which a spherical gas envelope exists in continuation with the photosphere of the star. In this model, a large percentage of the Balmer photons is absorbed to enhance the ionization produced by the Lyman photons. With this model, assuming some parameters like density and size of the envelope, Hoflich has been able to reproduce the observed line profiles and equivalent widths for a few Be stars with spectral types ranging from B1 to B8. But the author himself pointed out that the model is not realistic and models have to be constructed to take account of the asymmetry of the Be star envelopes. It is clear that the nonsphericity of the Be star envelope, for which ample evidence (like polarization of optical radiation) exists, will make the equivalent widths calculated by Hoflich, lower than the observed values. Also, nonsphericity of the envelope will allow escape of photons in directions of lower optical depth and lead to lower temperatures in the envelope and probably consequent lower Hα emission. In any case, it is necessary to work out a realistic model in order to see if it will explain the observed H*α* emission from late type Be stars.

The phenomenon of Be stars is very complex indeed and many different explanations may be needed to account for the various observations. In this paper we suggest that a helium star binary companion can supply ionizing photons to produce an HΠ region in the gas envelope around the Be star to give the observed H-alpha emission from late type Be stars. The gas envelope ejected by the Be star expands outwards and reaches the compact companion as is evidenced by the x-ray emission from neutron star binaries [see Waters & van Kerkwijk (1989), who term the expanding envelope as a slow wind; also Apparao (1985) and Doazan (1982)]. The fraction of the ionizing photons from the helium star intercepted by the Be star envelope increases as the envelope approaches the helium star till all the photons are absorbed when the helium star is surrounded by the envelope. The maximum H*α* emission occurs when the helium star is completely surrounded by the Be star envelope and this is calculated in section 2. In section 3 we discuss the implication of the result on the binarity of Be star and also the detectability of the He star companion.

## 2. He star-Be star systems and H$\alpha$ emission

The evolutionary processes leading to Be starcompact star (Be + co) binary systems have been discussed by several authors (see Van den Heuvel & Rappaport 1987 for references; see also Habets 1986 and Pols *et al.* 1991). Starting with a close binary of two stars, one of which is massive, the above authors find that mass transfer takes place from the massive star to the less massive. The mass transfer results in transfer of angular momentum also leading to a fast rotating Be star (see Plavec 1976). After the mass transfer the core of the massive star is left as a helium (He) star. Depending on the mass of the core, after further possible mass transfer, the remnant can become either a white dwarf (WD) or a neutron star (NS). Thus a Be starcompact object system results. Pols *et al.* (1991) have calculated the expected numbers of Be + NS, Be + WD and Be + He systems using the above picture. They find that a fair number of Be stars could have a He star binary companion. They further estimate that within 1 kpc, there should be 13 Be + NS, 129 Be + WD and 784 Be + He systems. Waters *et al.* (1989) estimate that 3 to 7% of all B stars are Be + He systems independent of spectral type.

Cox and Salpeter (1964) have constructed equilibrium models of He stars and have tabulated their properties like radius and surface temperature for several masses of the He star. For the mass range 0.312.0$M_{\odot}$, the temperature $T$ ranges between 35000 and 74000°K and the radius between 0.04 and 0.3$R_{\odot}$. It should be emphasized that the stars with smaller mass have lower temperature and smaller radii. In order to obtain the radiation emission from the He stars, one needs mode atmosphere calculations that give photon fluxes as a function of wavelength. The calculations we are aware of are **i**) for a He star with a temperature $T$ = 18000°K (Hunger & Van Blerkom 1967) and **ii**) for $T$ = 50000°K and 70000°K (Pols *et al.* 1991). **iii**) Dreizler (1993 and references therein) calculated the nature of absorption lines in the ultraviolet and optical regions. The Lyman continuum from the He star ionizes the hydrogen gas in the envelope of the Be star to form an HII region which gives Hα line radiation.We have calculated the energy in the H$\alpha$ emission (Table 1) for the two temperatures of the He star, 50000°K and 70000°K using the values of Lyman continuum given by Pols *et al.* (1991). The Lyman photon flux corresponding to the temperatures are $7.2 \times 10^{44}$ and $2.7 \times 10^{46}$ photons $s^{-1}$. Using this flux and the value of the recombination coefficient $\alpha_B = 2.6 \times 10^{-13}$ $cm^3$ $s^{-1}$, we have calculated the emission measure. Using this emission measure and the value of theemission coefficient given by Osterbrock (1974) for H$\alpha$ emission ($3.56 \times 10^{-25}$ erg $cm^3$ $s^{-1}$), we obtained the energy in the H$\alpha$ emission; these values are given in Table 1. The ionization in the HII region and therefore H$\alpha$ emission can be enhanced by absorption of the Baimer continuum of the He star (Apparao & Tarafdar 1987); we have used their computer code to find the enhanced values which are also given in Table 1. For comparison the corresponding calculated (from the HII region produced by the Lyman continuum of the Be star) and observed values (Apparao & Tarafdar 1987) of H$\alpha$ emission are given for Be stars of the spectral types Bl, B3, B5 and B8. We wish to emphasize here that the calculated values of H$\alpha$ emission due to the He stars are the maximum, when the He star is fully surrounded by the gas envelope of the Be star, as long as the situation is density bound. These values do not depend on the distance of the He star from the Be star.

**Table 1.** H$\alpha$ emission from HII region formed by He stars and Be stars.

| Star | Temperature °K | H$\alpha$ Emission Ergs $s^{-1}$ Lyman | Lyman + Balmer | Observed* (maximum) H$\alpha$ emission Ergs $s^{-1}$ |
|---|---|---|---|---|
| He | 50000 | $9.9 \times 10^{32}$ | $2.5 \times 10^{33}$ | — |
| He | 70000 | $3.7 \times 10^{34}$ | $8 \times 10^{34}$ | — |
| B1 | 25000 | $8.2 \times 10^{33}$ | $2.7 \times 10^{34}$ | $2.5 \times 10^{34}$ |
| B3 | 20000 | $2.4 \times 10^{32}$ | $5.8 \times 10^{32}$ | $4 \times 10^{33}$ |
| B5 | 16000 | $3.6 \times 10^{30}$ | $8.3 \times 10^{30}$ | $8 \times 10^{32}$ |
| B8 | 13000 | $7.0 \times 10^{28}$ | $1.7 \times 10^{29}$ | $5 \times 10^{32}$ |

The last four lines are from Apparao & Tarafdar (1987).

* In the calculation of H$\alpha$ emission for different spectral types using the observed equivalent widths, a spectral type determined from observations is used. There could be an error of up to one unit in the determination of the spectral type number; this can lead to an error of up to about a factor of two in the value of the H$\alpha$ emission given. The observational errors are much smaller.

## 3. Discussion

It is seen from Table 1 that the. H$\alpha$ emission from a HII region formed by the Lyman continuum from a He star companion in the envelope of the Be star is adequate to explain the H$\alpha$ emission observed from Be stars. In the early type Be stars the emission due to their own Lyman continuum is adequate. The present explanation for the H$\alpha$ emission from late type Be stars would suggest that those late type stars which show H$\alpha$ emission can be binaries with a He star companion. We will discuss the consequences of this below.

The Be stars with He star companions envisaged here will not show occulations even in the most favourable conditions, because of the small size of the He stars compared to the size of the Be stars. However for low orbital periods of the helium stars, the radial velocity of the Be star may be detectable.In the present case where we require He stars with the surface temperature of about 50000°K, the mass of the He star is about $0.75M_{\odot}$ (Cox & Salpeter 1964). For an orbital period of say 20 days for the He star orbiting around a $4.5M_{\odot}$ B8 star, the orbital velocity of the Be star will be about 75 km $s^{-1}$ which may be detectable. A systematic study of radial velocities of late type Be stars can reveal the presence of He stars with low period systems.

We now compare the radiation from the He star with the binary Be star companion, in the optical and UV bands, in order to assess the detectability of the He star [Dr. J. Heise has kindly provided us with the fluxes from atmospheric calculations with the parameters given in Pols *et al.* (1991), which are also given above]. Table 2 gives the relative fluxes from a $T$ 13000°K B8 star and that from a $T$ = 50000°K He star, in the wavelength range 1150-3000 angstroms. To facilitate comparison the He star flux is multiplied by $(R_{He}/R_{B8})^2$ and is given in Table 2. We used $R_{He} = 0.2R_{\odot}$ and $R_{B8} = 2.81R_{\odot}$. In Table 2, we have given the fluxes in the UV range, above the detectable limit of the IUE satellite. In the optical range and the near UV wavelengths, the Be star dominates the radiation. However below 2000A, the flux from the He star is comparable to that from the B8 star. In the Lyman-$\alpha$ trough the He star may dominate; the flux of the He star here may however depend on the H/He ratio ( the value assumed in the atmosphere calculations used here is 0.1). A careful

**Table 2.** Relative fluxes of a B8 star and a He star.

| Wavelength (angstroms) | Relative flux (ergs $cm^{-2}$ $s^{-1}$ $A^{-1}$) He star[@] ($T$ = 50000°K) | B8 star* ($T$ = 13000°K) |
|---|---|---|
| 3000 | $1.29 + 7^{+}$ | $7.71 + 7$ |
| 2000 | $5.01 + 7$ | $1.49 + 8$ |
| 1500 | $1.24 + 8$ | $2.36 + 8$ |
| 1300 | $1.79 + 8$ | $2.80 + 8$ |
| 1238 | $2.10 + 8$ | $1.51 + 8$ |
| 1219 | $2.01 + 8$ | $5.37 + 7$ |
| 1216 | $7.68 + 7$ | $2.39 + 7$ |
| 1150 | $2.62 + 7$ | $2.08 + 8$ |

[+] $a + n$ means $\alpha \times 10^n$.

[@] Relative fluxes of a B8 star and a He Star Relative flux obtained by using the ratio of radii of the He star and the B8 star; the values of radii used are given in the text..

* Values taken from Kuracz (1979).

comparison of the continuum of late type Be stars below 2000A, with that of B stars of the same spectral type may reveal the presence of the He star. We plan to undertake such a study.

The He star radiation is dominant in the short wavelength radiation (below the Lyman edge wavelength) when compared to that from the Be star(see Pols *et al.* 1991), and can be detected. He stars radiate copiously in the 200–1000 Å wavelength region, and these photons can be detected (e.g., by the EUVE satellite) if the stars are close enough so that interstellar absorption is minimal. In the case of higher temperature He stars, radiation can be detected by the Wide Field Camera (WFC) of the ROSAT satellite. WFC detected nine B stars of which two are binaries with G stars and one is Algol. Of the nine, two stars HD59635 (B5Vp) and HD 79464 (B9.5Vp) are late spectral type stars (Pounds *et al.* 1993). These two stars were also detected by the EUVE satellite (Malina *et al.* 1993). Further observations have to be performed to determine the flux and temperature in order to establish that the EUV radiation belongs to the He star companion.

The presence of the He star will lead to V/R variation in the H$\alpha$ emission (see Doazan 1982). If the usual dimension (~ $10^{12}$ cm) and density ($10^{11}$–$10^{12}$ H atoms $cm^{-2}$) are used the He star will ionize a portion of the gas envelope of the Be star. As the He star revolves around the Be star in its binary motion, different regions of the disk get 'illuminated' by the radiation of the He star. As the gas in the Be star disk itself is revolving, the H$\alpha$ emission will appear to move from violet to red sides of the rest wavelength of the H$\alpha$ line, thus leading to a V/R variation. In the case of early types, a hot He star (see Table 1) will contribute H$\alpha$ emission comparable to that of the Be star, while for later types the He star contribution dominates. The V/R variation due to the He star will be periodic. In this context it is interesting to note that the observed V/R variation in the case of the Be stars 88 Her (spectral type B6) and 4 Her (spectral type B8) display periodicities similar to their RV (radial velocity) periodicities which are identified with binary periodicities (Doazan *et al.* 1982; Harmanec *et al.* 1978). It is also interesting to note that the V/R periodicities are in phase with the RV periodicities which agrees with our suggestion.

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