A New Approach For The Structure Of Ha Regions In 120 Be-type Stars

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Abstract. In this paper we present a statistical study of the Hα line profiles of 120 Be-type stars using the model proposed by Danezis et al. (2003) and Lyratzi & Danezis (2004). This model proposes that the density layers which produce the Hα line lie in different regions in the stellar atmosphere. In the Be-type stellar atmospheres, there are two regions that can produce the Hα satellite components. The first one lies in the chromosphere and the second one in the cool extended envelope. By fitting the Hα line profiles with the line function of the proposed model we are able to calculate: a) For the chromospheric absorption components we calculated the rotational and radial velocities as well as the optical depth. b) For the emission and absorption components which are created in the cool extended envelope we calculated the radial velocities, the FWHM and the optical depth. Finally, we present the relation between these parameters with the spectral subtype and the luminosity class.

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INTRODUCTION

In the spectra of many Oe and Be stars some spectral lines are accompanied by Discrete Absorption Components (DACs) (Bates & Halliwell 1986, Prinja 1988, Willis et al. 1989, Bates & Gilheany 1990, Gilheany et al. 1990, Waldron et al. 1994, Henrichs et al. 1994, Telting et al. 1993, Telting & Kaper 1994, Cranmer & Owocki 1996, Prinja et al. 1997, Fullerton et al. 1997, Kaper et al. 1996, 1997, 1999, Cranmer et al. 2000) or Satellite Absorption Components (SACs) (Peton 1974, Lamers et al. 1982, Sahade et al. 1984, Sahade & Brandi 1985, Hutsemékers 1985, Danezis 1987, Danezis et al. 1991, 2003, Laskarides et al. 1992a,b, Lyratzi and Danezis 2004).

The DACs were considered to be unknown spectral lines, which accompanied some spectral lines (Si IV, C IV, N IV, N V, Mg II) in the spectra of Oe and Be stars (Bates & Halliwell 1986, Prinja 1988, Willis et al. 1989, Bates & Gilheany 1990, Gilheany 1990, Kaper et al. 1990, Waldron et al. 1994, Henrichs et al. 1994, Telting et al. 1993, Telting & Kaper 1994, Cranmer & Owocki 1996, Prinja et al. 1997, Fullerton et al. 1997, Kaper et al. 1996, 1997, 1999, Cranmer et al. 2000).

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DACs, now, are not unknown absorption spectral lines, but spectral lines of the same ion and the same wavelength as the main spectral line, shifted at different $\Delta\lambda$, as they are created in different density regions which rotate and move radially with different velocities.

If the regions, where such lines are created, rotate quickly and move radially slowly, the produced lines are quite broadened and with small shifts. So, they may not be discrete absorption spectral lines, but blended among themselves. In such a case, they are not observable, but we can detect them through the analysis of the profile. As Peton (1974) first pointed out, these components appear as "satellites" in the violet or in the red side of a main spectral line, as a function of the time or the phase, in the case of a binary system. For these two reasons and in order to include all these components, either they are discreet or not, to a unique name, we prefer to name them Satellite Absorption Components (SACs) and not Discrete Absorption Components (DACs).

MECHANISMS RESPONSIBLE FOR THE SACs' CREATION

The creation of SACs is due to mechanisms which allow the existence of structures which cover all or a significant part of the stellar disk, such as shells, blobs or puffs (Underhill 1975, Underhill & Fahey 1984, Bates & Halliwell 1986, Grady et al. 1987, Lamers et al. 1988, Cranmer & Owocki 1996, Kaper et al. 1996, 1997, 1999, Markova 2000) or interaction of fast and slow wind components, Corrotation Interaction Regions (CIRs), structures due to magnetic fields or spiral streams as a result of the star's rotation (Underhill & Fahey 1984, Mullan 1984a,b, 1986, Prinja & Howarth 1988, Cranmer & Owocki 1996, Fullerton et al. 1997, Kaper et al. 1996, 1997, 1999, Cranmer et al. 2000).

Though we do not know yet the mechanism responsible for the formation of such structures, it is positive that the SACs result from independent high density regions in the stars' environment (Fig. 1). These regions are formed by the specific ions which create a specific spectral line.

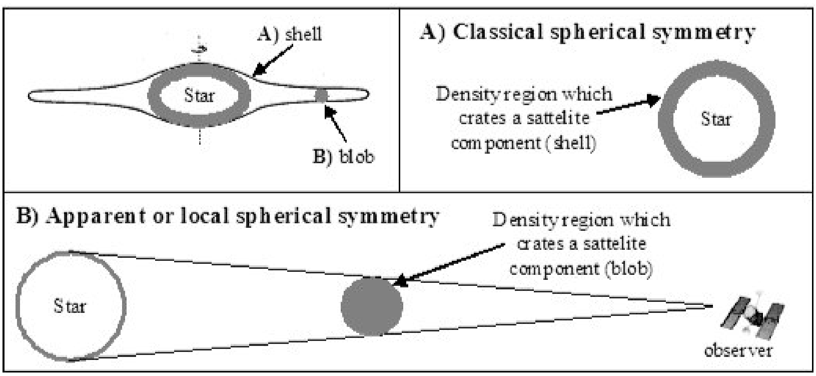

FIGURE 1. Density regions which create the Satellite Absorption Components.

THE USED MODEL

Danezis et al. (2003) constructed a mathematical model, in order to study the atmospheric regions that give rise to SACs.

By solving the equations of radiation transfer through a complex structure as the one described, we conclude to a function for the line's profile, able to give the best fit for the main spectral line and its Satellite Absorption Components in the same time. Such a best fit, through the function of the line's profile, enables us to calculate some parameters (rotational and radial velocities, FWHM, optical depth) of the independent layers of matter, which form the main spectral line and its satellite absorption components. (See Danezis et al. 2005a, b, Lyratzi et al. 2005).

$$I_\lambda = \left[I_{\lambda 0} \prod_i e^{-\tau_i} + \sum_j S_{\lambda ej} \left(1 - e^{-\tau_j} \right) \right] e^{-\tau_g} \tag{1}$$

where: $I_{\lambda 0}$: is the initial radiation intensity, $S_{\lambda ej}$ is the source function, which, at the moment when the spectrum is taken, is constant and $e^{-\tau_i}$, $e^{-\tau_j}$, $e^{-\tau_g}$ are the appropriate distribution functions (Gauss, Lorentz, Voigt, Rotation) of the absorption, emission and general absorption lines respectively. This function I_λ does not depend on the geometry of the regions which create the observed feature.

APPLICATION TO THE Hα LINE OF 120 Be STARS

In our study we use the stellar spectrographs which were taken by Andrillat & Fehrenbach (1982) and Andrillat (1983) (resolution 5,5 and 27 Å). We applied the model on the Ha line 6562.817 Å in the spectra of 120 Be stars of all the spectral subtypes and luminosity classes. In most of the Be stellar spectra the Ha line presents peculiar and complex profiles. Usually the Ha line's profile consists of: a very broad absorption feature, an emission feature and a narrow absorption feature (Fig. 2).

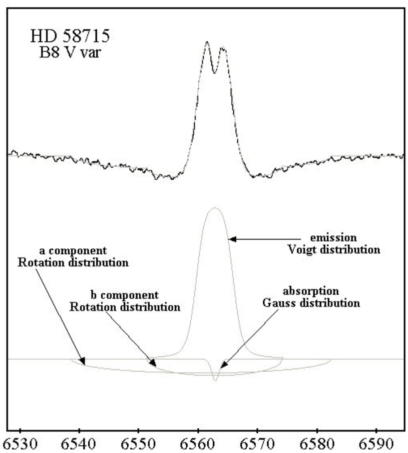

FIGURE 2. Analysis of the Ha line profile of the Be star HD 58715.

We applied the proposed model in order to reproduce these complex profiles. We tried to fit the observed profiles by applying all the classical distribution functions (Gauss, Lorentz, Voigt, Rotation). We concluded that the best fit is accomplished when we fit: a) the very broad absorption component with Rotation distribution, b) the emission component with Voigt distribution and c) the narrow absorption component with Gauss distribution.

CONCLUSIONS

The proposed line function $I_\lambda = \left[I_{\lambda 0} \prod_i e^{-\tau_i} + \sum_j S_{\lambda ej} \left(1 - e^{-\tau_j} \right) \right] e^{-\tau_g}$ is able to reproduce accurately the complex Hα profiles of all the 120 studied Be-type stars. This means that the regions where the Ha line is created are not continuous, but they consist of successive independent density regions. In the place of the exponential $e^{-\tau}$, which gives the profile of each component, we apply the appropriate distribution function. The choice of the appropriate distribution function depends on the physical conditions of the regions which create the SACs. The most important point is that, in any case, the proposed line function remains the same. The important advantage of this method is that we are able to accomplish the best fit of the observed spectral lines, by applying a line function, to which we conclude after the solution of the radiation transfer equations, through a complex atmospherical structure, and not by a graphical composition of mathematical distribution functions with no physical meaning.

The existence of SACs is a general phenomenon in the spectra of Be-type stars.

The absorption regions of the Hα line, lie in two different atmospherical regions: in the chromosphere and in the cool extended envelope. In the chromosphere we detected one to five successive, independent density regions, which rotate with 5200±1192 km/s, 990±170 km/s, 536±68 km/s, 352±37 km/s and 152±46 km/s and move radially with 15±121 km/s, 7±123 km/s, 19±62 km/s, 15±60 km/s and -2±42 km/s. Each region creates one Satellite Absorption Component (SAC). In the Cool Extended Envelope there are the density regions which create the emission components and the narrow absorption components. The emission regions move radially with 20 km/s and create SACs with Full Width at Half Maximum (FWHM) about 7.1 Å. In 7 of the 120 stars where we detected one more emission region, with the same radial velocity and FWHM about 2.0 Å. The narrow absorption components have FWHM about 2.0 Å and the regions which create them have radial velocity of 0 km/s.

The profiles of the studied Hα lines appear to be peculiar and complex, as they do not present only one spectral line, but a number of SACs, which are created in independent density regions. All the studied stars do not present the same number of independent density regions.

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