Study of Hα regions in 120 Be-type stars

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Abstract

DACs and SACs phenomena in Hα line of 120 Be stars

In this study we apply the method proposed by Danezis et al. (2003, 2005) on the stellar spectrographs of 120 Be stars, and we examine the variations of the physical parameters, stated below, as a function of the spectral subtype and the luminosity class.

We found that in the Be-type stellar atmospheres, there are two regions that can produce the Hα Satellite Absorption Components (SACs or DACs). The first one lies in the chromosphere and the second one in the cool extended envelope. With the above method we calculate: a) For the chromospheric absorption components: the optical depth as well as the rotational and radial velocities of the independent regions of matter which produce the main and the satellites components. b) For the emission and absorption components which are created in the cool extended envelope: the FWHM, the optical depth and the radial velocities of the independent regions of matter which produce the main and the satellites components.

1. Introduction

The Hα line profile is the most often and mostly studied profile in the spectra of early type stars. Andrillat & Fehrenbach (1982) and Andrillat (1983) observed that the structure of the emission of Hα line appears to be both very complex and variable and, in most cases, a central absorption is present. In some spectra, the stellar absorption (called "photospheric line") is present and the emission line, having, probably, chromospheric origin, is superposed on it. Hutchings et al. (1971) proposed that the changes in the profiles may be attributed to the rotation of the stars together with inhomogeneities in their envelopes. These phenomena could result from the existence of "knots" of higher-density material in the extended equatorial envelope, which are released at the photosphere (Hutchings 1970a,b, Bohlin 1970). Slettebak & Reynolds (1978) proposed that the changes of the shape and the total energy in the Hα emission line profile of a Be-type star could result from motions within the shell surrounding the star, from a change in the amount of emitting material in the shell, or both. Doazan (1970) studied 26 Be-type stars and observed that the velocities extracted from the width of the emission lines of Hα, are greater than the rotational velocity (Vsini) of the central star. She proposed that the great width of the emission lines of Hα is due to the motion of the envelope, as well as to the motion of matter which is placed in regions far from the central star. She pointed out that the rotation does not provide enough arguments to explain the observed widths of the emission lines. In order to explain the observed large half-width of the Hα emission-line, another source of line broadening is required in addition to envelope rotation, such as electron scattering (Poeckert & Marlborough 1979, Dachs et al. 1981). Andrillat & Fehrenbach (1982) and Andrillat (1983) accepted that this phenomenon is due to electron scattering (Marlborough 1969), or due to the envelope rotation as well as to the motion of the material inside the envelope (Gray & Marlborough 1974, Poeckert & Marlborough 1979).

In this paper, by applying the model proposed by Danezis et al. (2003, 2005), we study whether the hypothesis of Discrete Absorption Components (DACs) and Satellite Absorption Components (SACs) is able to explain the complex structure of the Hα line profile in 120 Be-type stars. With this method we calculate some physical parameters, such as the rotational (V_{rot}) and radial velocities (V_{rad}), as well as the full width at half maximum (FWHM) and the optical depth (ξ), of the independent density layers of matter in the atmospherical regions, where the Hα line is created.

2. The line function

Danezis et al. (2003, 2005) constructed a mathematical model, in order to study the atmospherical regions that create Satellite Absorption Components (SACs).

By solving the equations of radiation transfer through a complex structure, we conclude to a function for the line profile, able to give the best fit for the main spectral line and its SACs at the same time. Such a best fit, through the function of the line 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 SACs.

In the case of spherical symmetry around the star or around the density regions which produce the SACs, the line profile function takes the following form:

$$I_\lambda = \left[I_{\lambda 0} \prod_i e^{-L_i \xi_i} + \sum_j S_{\lambda ej} \left(1 - e^{-L_j \xi_j}\right) \right] e^{-L_g \xi_g} \tag{1}$$

where:

$I_{\lambda 0}$ is the initial radiation intensity, L_i, L_{ej}, L_g are the distribution functions of the respective absorption coefficients, ξ_i, ξ_{ej}, ξ_g are the optical depths in the center of the respective spectral line components and $S_{\lambda ej}$ is the source function which is constant during the observation.

2.1. Rotation distribution function

We consider that the density regions, where the SACs or DACs are created, present spherical symmetry and the main reason of the spectral lines broadening is the rotation of the density regions which create them. In this case the distribution function L has the following form:

$$\mathrm{L}(\lambda) = \begin{cases} \sqrt{1-\cos^2\theta_0}\,, \text{ if } \cos\theta_0 = \dfrac{-\lambda_0 + \sqrt{\lambda_0^2 + 4\Delta\lambda^2}}{2\Delta\lambda z_0} < 1 \\ 0\,, \quad \text{if } \cos\theta_0 = \dfrac{-\lambda_0 + \sqrt{\lambda_0^2 + 4\Delta\lambda^2}}{2\Delta\lambda z_0} \geq 1 \end{cases}$$

where:

λ_0 is the observed wavelength of the center of the spectral line, $\Delta\lambda = \lambda - \lambda_0$ and

$$z_0 = \frac{\Delta\lambda_{rotation}}{\lambda_{lab}} = \frac{V_{rotation}}{c}$$

where λ_{lab} is the laboratory wavelength of the spectral line and ξ is the optical depth in the center of the spectral line.

2.2. Distribution functions

In case we do not want to consider certain geometry, but only some physical parameters, we may replace the Rotation distribution function with a classical distribution function (Gauss, Lorentz, Voigt).
Gauss: The line broadening is mainly due to the ions' random motion.
Lorentz: The line broadening is mainly due to the collisional effects among the ions.
Voigt: The line broadening is mainly due to the ions' random motion, as well as the collisional effects among the ions, which, in an environment of high pressure and temperature, result to the broadening of the produced spectral lines (synthesis of a Gaussian and a Lorentzian).

3. Application of the model 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) with the telescope of 152 cm in the Observatory of Haute Provence.
We applied the model to the Hα 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 Hα line presents peculiar and complex profiles. Usually the Hα line profile consists of (a) a very broad absorption feature (created in the chromosphere) (b) an emission feature (created in the cool extended envelope) (c) a narrow absorption feature (created in the cool extended envelope).

3.1. Study of the Hα line

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 (the broad absorption line is composed by one to five components) (b) the emission component with Voigt distribution (in 7 of the 120 stars there exist two emission components) (c) the narrow absorption component with Gauss distribution.
The most important point is that the best fit is not a graphical composition of the distributions for each component, but it is the result of the final function of the model where the appropriate distribution function is applied in the place of the exponential.
In Fig. 1 we present the best fit of the Hα line profile in two of the 120 studied stars.

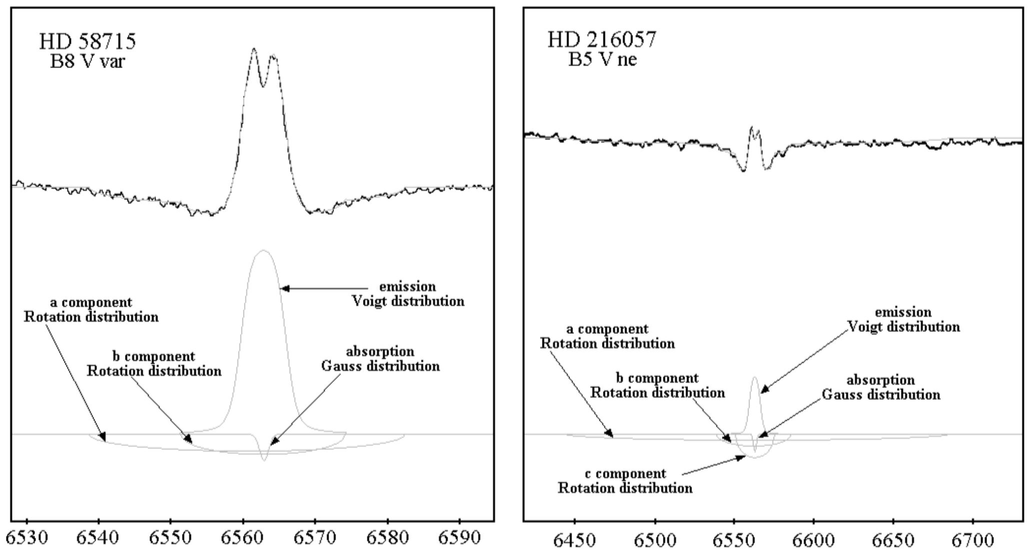

Fig. 1. The best fit of the Hα line profile in two of the 120 studied stars. The thick line presents the observed spectral line profile and the thin one the model fit. The differences between the observed spectrum and its fit are hard to see, as we have accomplished the best fit.

4. Conclusions

In this paper we presented the study of the Hα line in 120 Be stars with the model proposed by Danezis et al. (2003, 2005). Here we give some of our conclusions:

1. The proposed line function (Eq. 1) is able to reproduce accurately the complex Hα profiles of all the 120 studied Be-type stars. This means that the regions where the Hα line is created are not continuous, but they consist of successive independent density regions. In the place of the exponential $e^{-L\xi}$, 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.
2. 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.
3. The density regions which create the SACs of the Hα line, lie in two different atmospherical regions: the chromosphere and the cool extended envelope. Chromospheric absorption regions: one to five successive, independent density regions. Each region creates one Satellite Absorption Component (SAC). Cool extended envelope: density regions which create the emission components and the narrow absorption components.
   (a) The broad absorption components of the Hα line are created in one to five kinematically independent density regions which lie in the chromosphere. The rotational velocity of each density region is 5200±1192 km/s, 990±170 km/s, 536±68 km/s, 352±37 km/s and 152±46 km/s. The five density regions do not appear in all the studied stars. The corresponding radial velocity of each density region is 15±121 km/s, 7±123 km/s, 19±62 km/s, 15±60 km/s and -2±42 km/s.

(b) The emission components of the Hα line are created, mainly, in a density region which lies in the cool extended envelope. Its radial velocity has the value of 20 km/s. In 7 of the 120 studied stars there exist two emission components. The Full Width at Half Maximum (FWHM) of the main emission component fluctuates around the value of 7.1 Å. The FWHM of the second emission component (when it appears) fluctuates around the value of 2.0 Å.

(c) The narrow absorption components of the Hα line are created in a density region which lies in the cool extended envelope. Its radial velocity has the value of 0 km/s. The FWHM of the narrow absorption component fluctuates around the value of 2.0 Å.

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