Study of Hα regions in 120 Be-type stars

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Introduction

As it is already known, the spectra of many Oe and Be stars present Discrete Absorption Components (DACs) which, due to their profiles' width as well as the values of the radial velocities, create a complicated profile of the main spectral lines (Bates & Halliwell, 1986). In this poster paper we detect the presence of this phenomenon (DACs or SACs) in the shape of Hα line in the spectra of 120 Be-type stars.

In our study we apply the method proposed by Danezis et al. (2003, 2005) on the stellar spectrographs of 120 Be stars, 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 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, Danezis et al., 2005). 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 we calculated 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 we calculated the FWHM, the optical depth and the radial velocities of the independent regions of matter which produce the main and the satellites components.

We point out that the new and important aspect of our study is the values' calculation of the above parameters and their variations as a function of spectral subtype and luminosity class, using the DACs or SACs theory. Our results are a successful test of this theory and of Danezis et al. (2003, 2005) proposed method. This study is a part of a Ph. D. Thesis

Observation of DACs and SACs in the spectra of Oe and Be stars

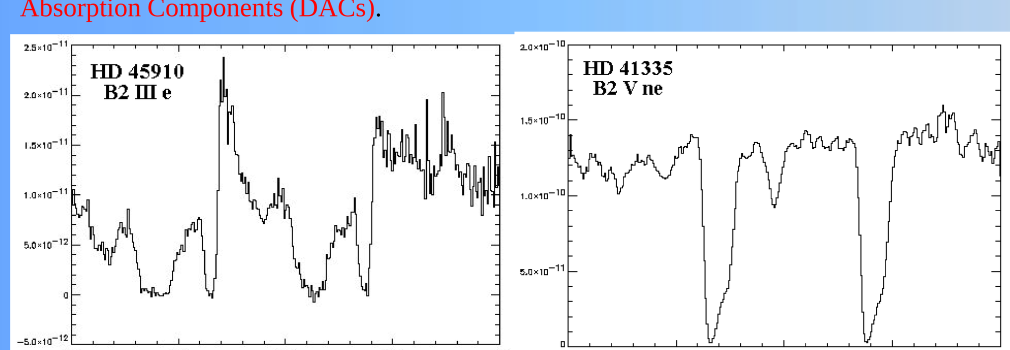
In the spectra of many Oe and Be stars some spectral lines are accompanied by **Discrete Absorption Components (DACs)** (Bates & Halliwell 1986, Prinja 1988, Willis et al. 1989, Bates & Gilheany 1990, Gilheany 1990, Waldron et al. 1994, Henrichs et al. 1994, Telting et al. 1993, Telting & Kaper 1994, 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 et al. 2004).

Definition of DACs – SACs

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).

DACs, now, are not unknown absorption spectral lines, but **spectral lines of the same ion and the same wavelength as a main spectral line, shifted at different Δλ,** as they are created from different density regions which rotate and move radially with different velocities.

If the regions that create such lines rotate quickly and move radially slowly, the produced lines are quite broadened and little shifted. 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 of 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. These regions are formed by the specific ions which create a specific spectral line.

Model

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

Fundamental Hypotheses

- The atmospherical region where a specific line is created is not continuous, but it is composed of a number of successive independent absorbing density regions, a number of emission regions and an external general absorption region.
- The angular velocity of rotation is constant.
- None of the phenomena is relativistic.
- The shift of the center of the line from the laboratory wavelength is only due to the radial motion.

This model is simple, aiming to describe the regions where the spectral lines which present SACs are created. We use this model, as, even if it is simple, it is the only one which is able to reproduce accurately the peculiar and complex line's profiles which present SACs.

We have not included variation with time, as our purpose is to describe the structure of the regions where the SACs are created at the specific moment when a spectrum is taken and not the construction of a time-dependent function of the line's profile. In order to study the time-variation of the calculated physical parameters we should study many spectra of the same star, taken at different moments.

With this model **we study the atmospherical region of a specific ion which creates a specific spectral line**. As our purpose is to study the variations of some parameters of the same regions, we do not need to include the atomic parameters in the used model, as in such a case the atomic parameters remain constant.

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.

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

where:

- $\boldsymbol{I_{\lambda 0}}$: the initial radiation intensity,
- $\boldsymbol{S_{\lambda ej}}$: the source function, which, at the moment when the spectrum is taken, is constant
- $e^{-\tau}$: the appropriate distribution function (Gauss, Lorentz, Voigt, Rotation)

Rotation distribution function

We considered that:
- the density regions, where the SACs or DACs are created, present spherical symmetry
- the main reason of the spectral lines' broadening is the rotation of the density regions which create them

and we calculated the rotation distribution function $e^{-L\xi}$, where:

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

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

$z_0 = \dfrac{\Delta\lambda_{rotation}}{\lambda_{lab}} = \dfrac{V_{rotation}}{c}$ where λ_{lab} is the laboratory wavelength of the spectral line and

ξ is the optical depth in the center of the spectral line.

Distribution functions

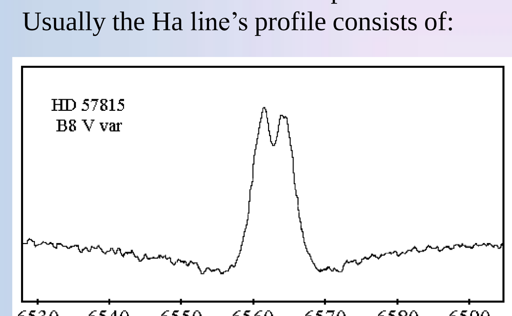
In case we do not want to consider certain geometry, but only some physical parameters, we may replace the Rotation distribution function with a classical distribution function (Gauss, Lorentz, Voigt).
Gauss: The lines' broadening is mainly due to the ions' random motion.
Lorentz: The lines' broadening is mainly due to the collisional effects among the ions.
Voigt: The lines' 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 distribution).

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 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 (created in the chromosphere)
an emission feature (created in the cool extended envelope)
a narrow absorption feature (created in the cool extended envelope).

Study of the Hα line

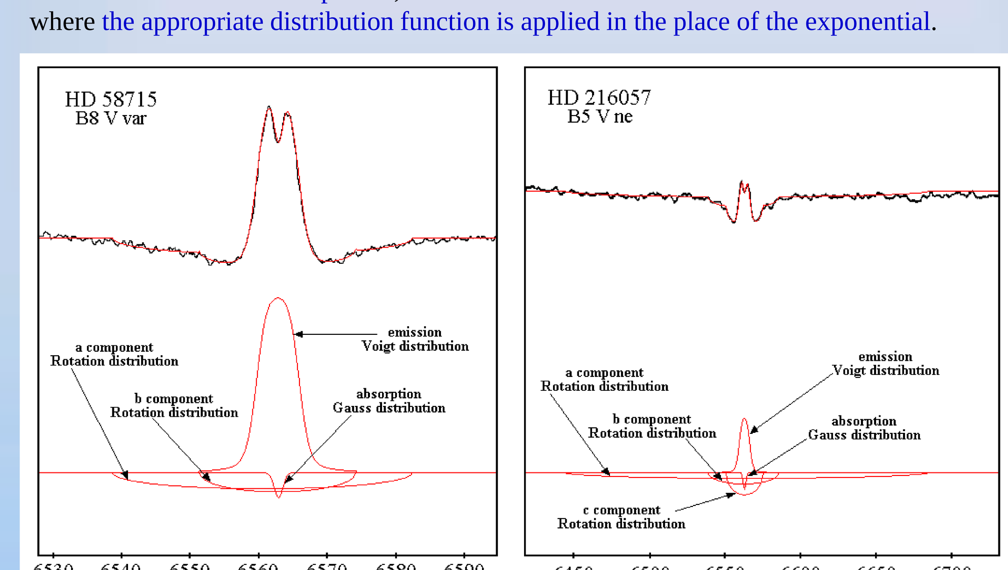
We applied the proposed model in order to reproduce these complex profiles. We tried to fit the observed profiles by applying all the classical distribution functions (Gauss, Lorentz, Voigt, Rotation).

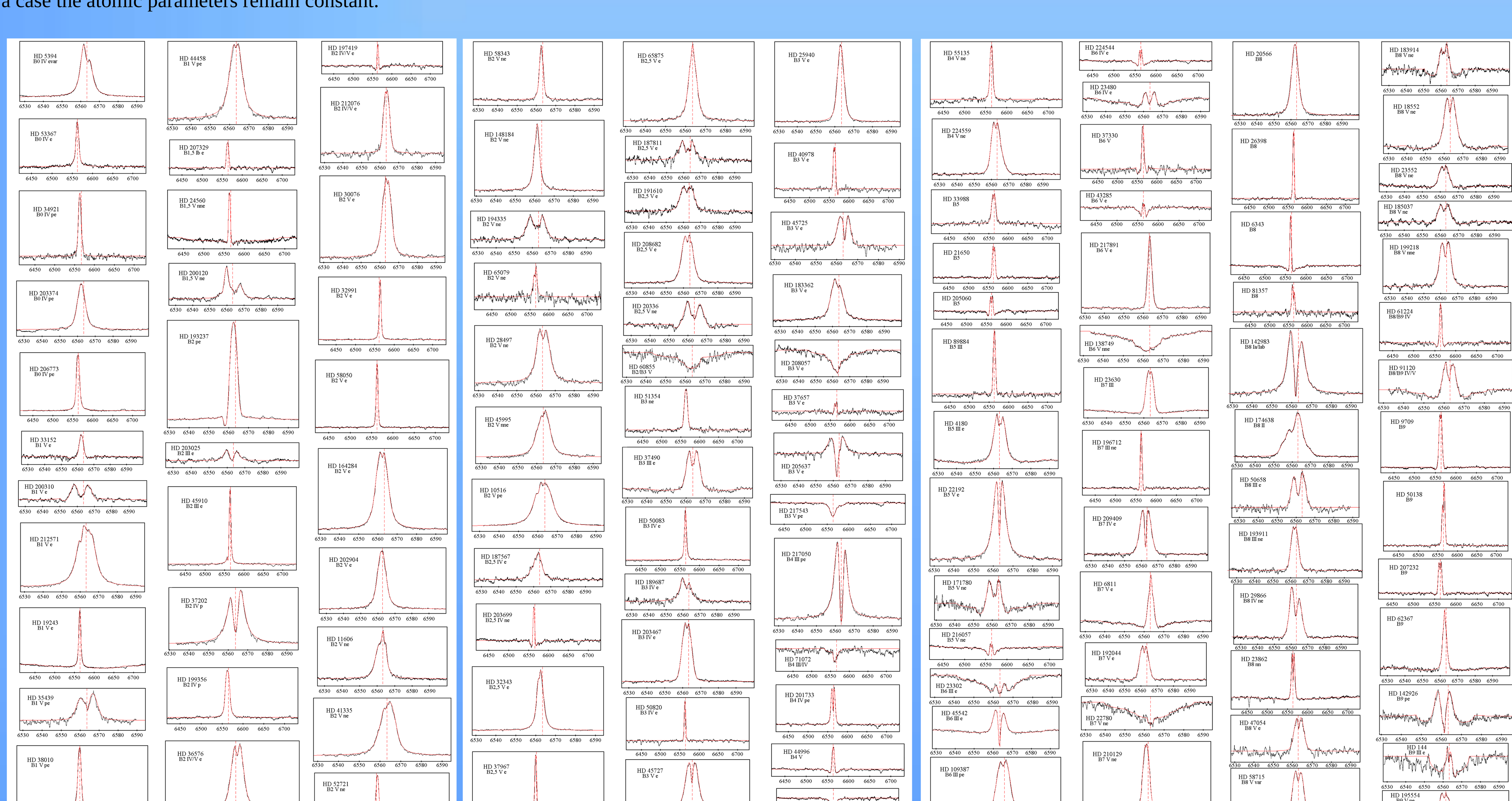
We concluded that the best fit is accomplished when we fit:
- the very broad absorption component with Rotation distribution

(the broad absorption line is composed by one to five components)
- the emission component with Voigt distribution

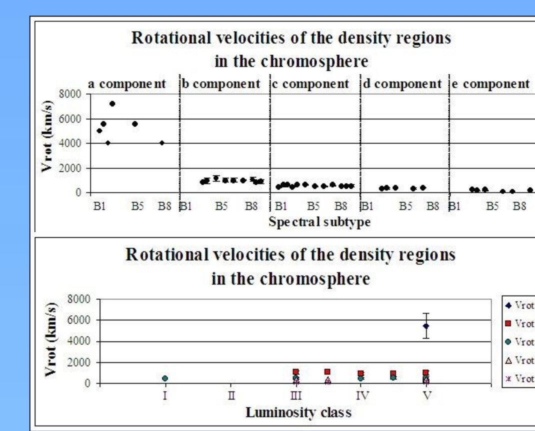
(in 7 of the 120 stars there exist two emission components)
- the narrow absorption component with Gauss distribution.

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.

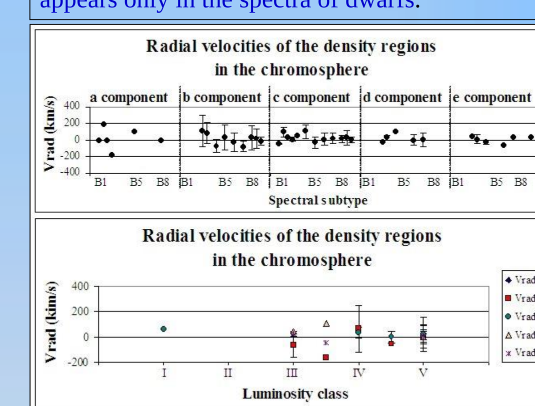




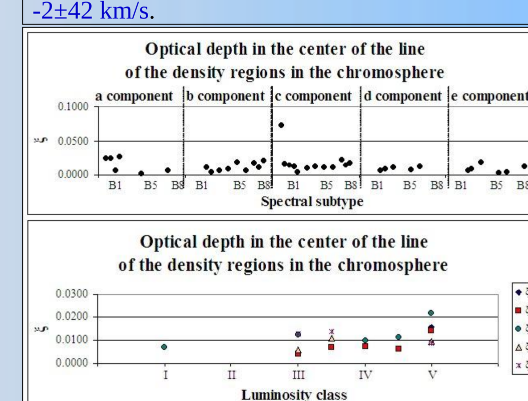
Chromosphere



Mean values of the rotational velocities, as a function of the spectral subtype and the luminosity class, of the five density regions 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 dispersion around the mean value dicreases from the first to the fifth desity region and is probably due to the different rotational axis inclination, of the regions which create the SACs. The very broad absorption components appears only in the spectra of dwarfs.

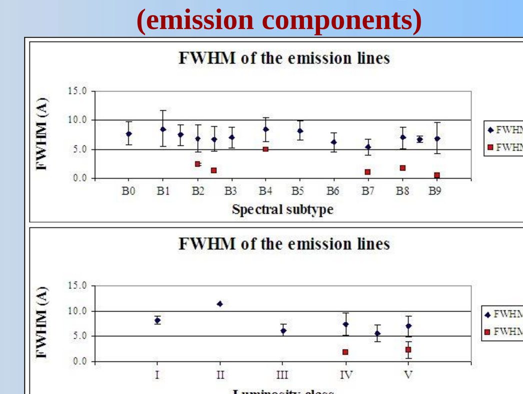


Mean values of the radial velocities, as a function of the spectral subtype and the luminosity class, of the five density regions. The radial velocity of each density region is 15±121 km/s, 7±123 km/s, 19±62 km/s, 15±60 km/s and -2±42 km/s.

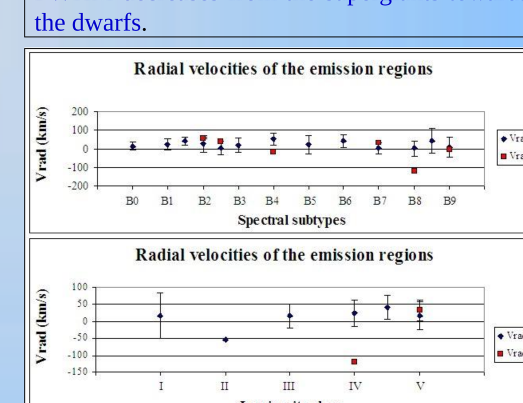


Mean values of the optical depth (ξ) for the five density regions, as a function of the spectral subtype and the luminosity class. The optical depth increases from the supergiants towards the dwarfs. The optical depth in the center of the spectral line (ξ), for the five density regions, is between the values:
a) 0.0020 and 0.0255 d) 0.0024 and 0.0196 and
b) 0.0033 and 0.0964 e) 0.0025 and 0.0230.
c) 0.0029 and 0.1296

Cool extended envelope (emission components)

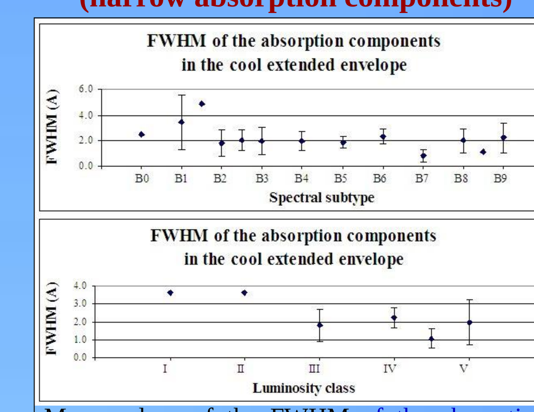


Mean values of the FWHM of the emission components, as a function of the spectral subtype and the luminosity class. The FWHM of the main emission component fluctuates around the value of 7.1 Å. The FWHM of the second emission component (when it appears) fluctuates around the value of 2.0 Å. The FWHM decreases from the supergiants towards the dwarfs.

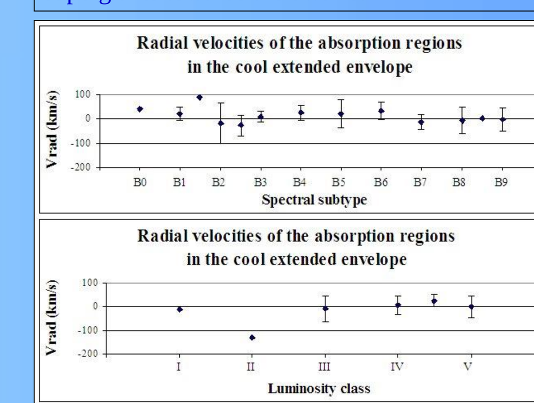


Mean values of the radial velocities of the emission components, as a function of the spectral subtype and the luminosity class. The radial velocity of the two emission regions fluctuates around the value of 20 km/s.

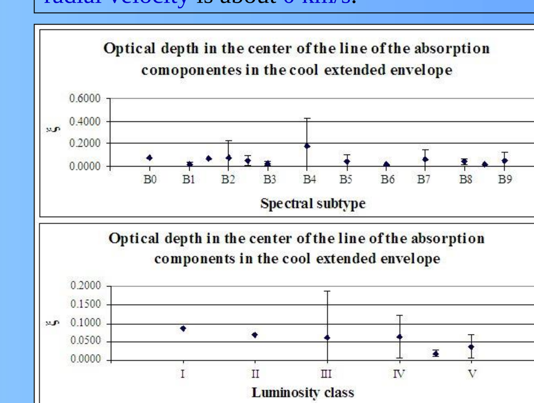
Cool extended envelope (narrow absorption components)



Mean values of the FWHM of the absorption components, as a function of the spectral subtype and the luminosity class. The FWHM is about 2.0 Å. The FWHM decreases from the supergiants towards the dwarfs.



Mean values of the radial velocity of the absorption component, as a function of the spectral subtype and the luminosity class. The radial velocity is about 0 km/s.



Mean values of the optical depth (ξ) in the center of the line, of the absorption component, as a function of the spectral subtype and the luminosity class. The optical depth decreases from the supergiants towards the dwarfs and is between the values 0.0039 and 0.6250.

Conclusions

1. 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.

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

3. The absorption regions of the Hα line, lie in two different atmospherical regions: one in the chromosphere and one in 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.

4. 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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XXVIth IAU General Assembly, Prague, Czech Republic, August 14-25, 2006