The complex structure of the MgII regions of 40 BeV stars

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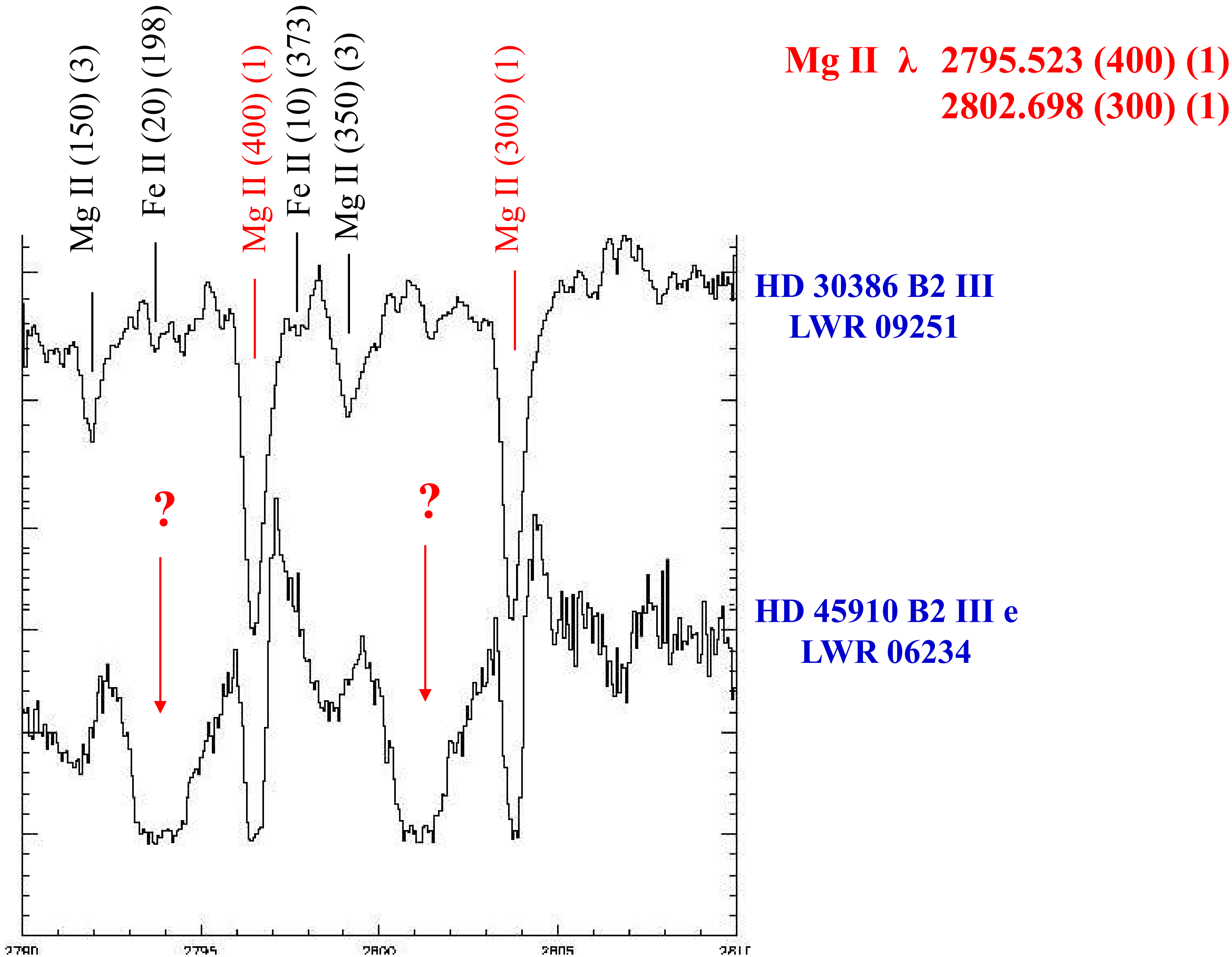
Observation of unknown spectral lines in the spectra of Oe and Be stars



- **Peton (1974)** first pointed out, in the visual spectrum of the binary system AX Mon (HD 45910), the existence of a secondary component of the absorption line FeII λ 4233Å, which, depending on the phase, appeared in the violet or in the red side of the main spectral line. For this reason the secondary component was named "satellite component".
- **Morgan et al. (1977)** studied the MgII resonance lines of γCas and ζTau and detected "significant absorption features" shortward of each resonance absorption which they attributed to "additional absorption within the stars' extended atmosphere".
- **Marlborough et al. (1978)** pointed out that the UV spectra of Be stars are very complex and contain many shell absorption lines which usually have velocity shifts.
- **Lamers et al. (1982)** observed satellite components superimposed on the wide P Cygni profile of the UV resonance lines of the OeIIf star HD 175754 and suggested that they may be the result of ionization gradients in an otherwise spherically symmetric and time-steady wind.

- **Danezis (1984, 1986) and Danezis et al. (1991)** studied the UV spectra of the binary system AX Mon and noted that the absorption lines of many ionization potential ions, are accompanied by two strong absorption components. This means that the regions where these spectral lines are created are not continuous, but they are formed by a number of independent density layers of matter.
- **Sahade et al. (1984) and Sahade & Brandi (1985)** also detected the existence of satellite components in the UV spectrum of AX Mon .
- **Hutsemekers (1985)** observed satellite components in the UV spectrum of another Be star, HD 50138.
- **Bates & Halliwell (1986)**, naming the satellite components "**Discrete Absorption Components" (DACs**), constructed a model of ejection of gas parcels from above the star's photosphere, accelerated by radiation pressure.
- **Laskarides et al. (1992a)** observed one more satellite component in the spectral lines of ions with low ionization potential in the UV spectrum of AX Mon, this in the red side of the main lines. This fact indicates contraction of the outer layers of the gaseous envelope.

Mechanisms responsible for the DACs' creation

- Mechanisms allowing the existence of structures which cover all or a significant part of the stellar disk, such as **shells, blobs or puffs** (Underhill 1975, Henrichs 1984, Underhill & Fahey 1984, Bates & Halliwell 1986, Grady et al. 1987, Lamers et al. 1988, Waldron et al. 1992, Cranmer & Owocki 1996, Rivinious et al. 1997, Kaper et al. 1996, 1997, 1999, Markova 2000).

- 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 DACs result from **independent high density regions** in the stars' environment.

MODEL

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

Fundamental Hypotheses

- The stellar envelope is composed of a number of successive independent absorbing density layers of matter, followed by an emission region and an external general absorption region.

- The angular velocity of rotation is constant.

- Thermal and natural broadening of spectral lines is negligible. This means that the whole width of the line is measured as rotation velocity (Vrot).

- The observer lies on the equatorial plane.

- None of the phenomena are relativistic.

- The only effect of a shell's expansion or contraction is a Doppler shift of the center of the lines.

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 parameters of the independent layers of matter which form the main spectral line and its satellite absorption components, such as the apparent rotation and expansion/contraction velocities and an expression of the optical depth ξ.

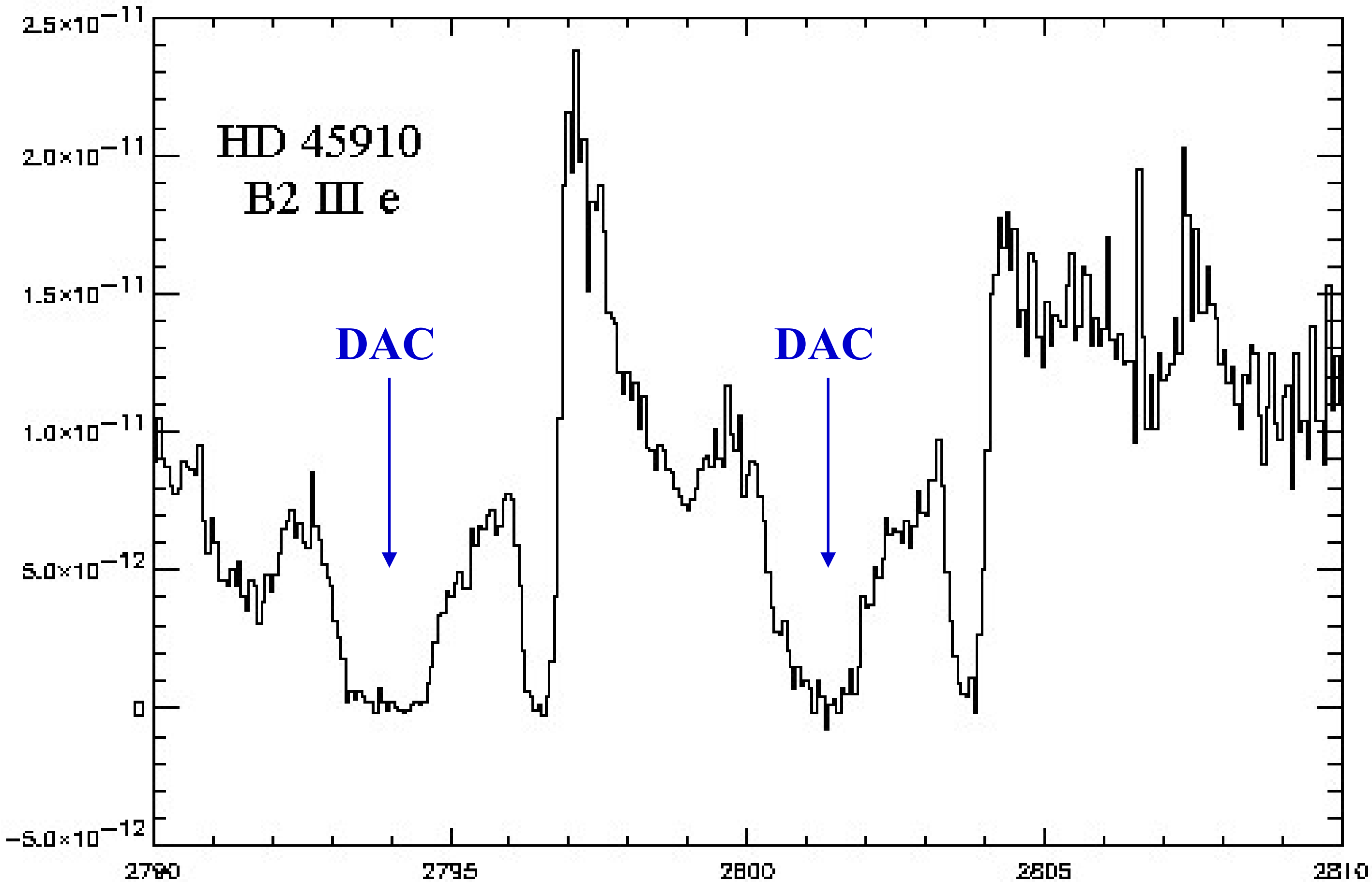
$$\boxed{F_{\lambda final} = \left[F_0(\lambda) \prod_i \exp\{-L_i \xi_i\} + S_{\lambda e}\left(1 - \exp\{-L_e \xi_e\}\right) \right] \exp\{-L_g \xi_g\}}$$

where:

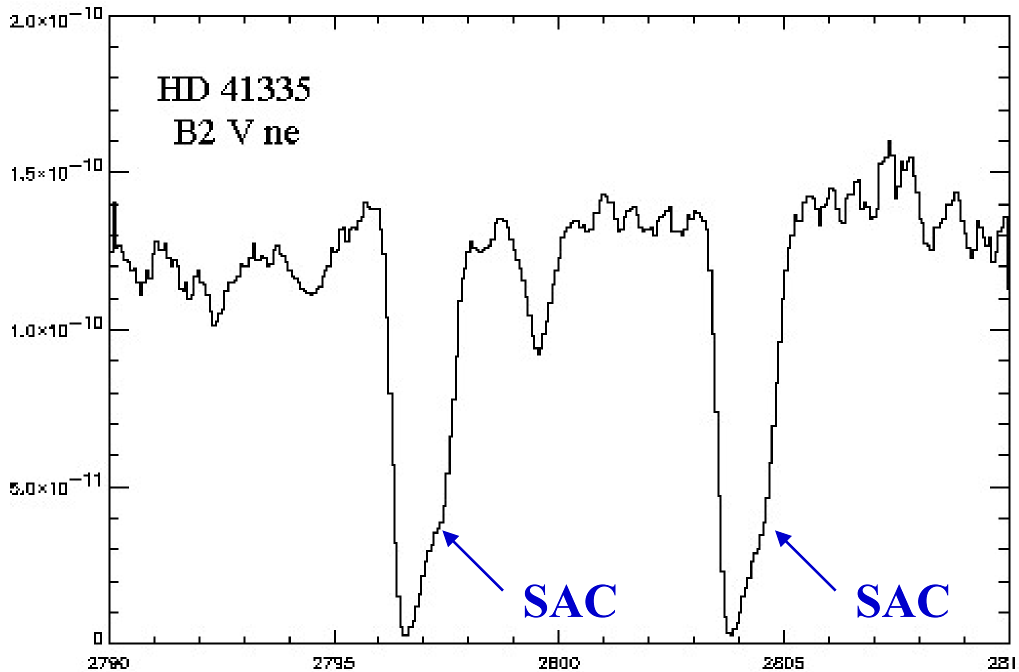
- **$F_{\lambda 0}$**: the initial radiation intensity,
- **L_i**, **L_e**, **L_g**: are the distribution functions of the absorption coefficients $k_{\lambda i}$, $k_{\lambda e}$, $k_{\lambda g}$ respectively. Each L depends on the values of the apparent rotation velocity as well as of the radial expansion/contraction velocity of the density shell, which forms the spectral line (V_{rot}, V_{exp}),
- $\xi = \int_0^s \Omega \rho \, ds$ is an expression of the optical depth τ, where Ω: an expression of k_λ and has the same units as k_λ,
- **$S_{\lambda e}$**: the source function, which, at the moment when the spectrum is taken, is constant

Definition of DACs - SACs

1. DACs 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 at different density regions which rotate and move radially with different velocities. The DACs are discreet lines, easily observed, in the spectra of Be stars of luminosity class III.



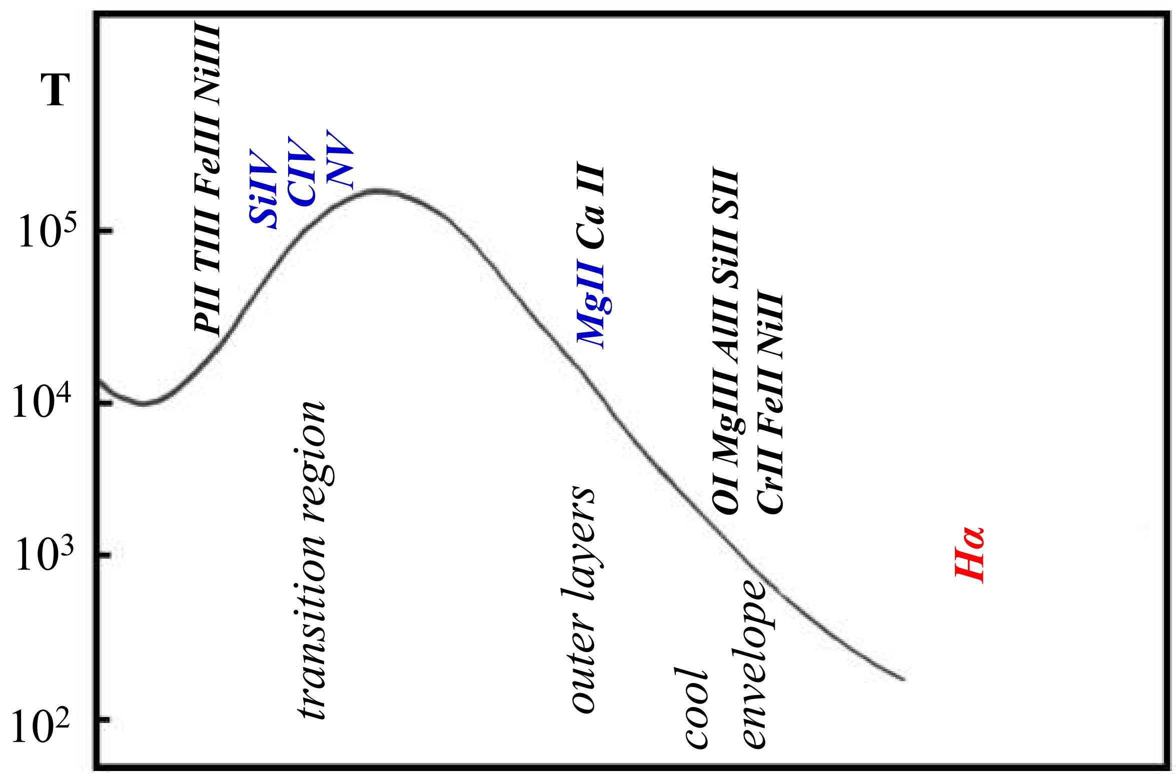
2. If the layers that give rise to such lines rotate with quite large velocities and move radially with small velocities, then the produced lines are quite broadened and little shifted. As a result they may not be discrete absorption spectral lines, but lines that are blended among themselves as well as with the main spectral line. In such a case they are not observable, but we can detect them through the analysis of our model. As Peton (1974) first pointed out, these components appear as "satellites" in the violet or in the red side of the main spectral line as a function of the time or the phase in the case of a binary system. For these reasons we prefer to name them **Satellite Absorption Components (SACs)** and not Discrete Absorption Components (DACs).



Main Purposes

1. Do Satellite Absorption Components (SACs) exist in the spectra of Be stars where Discreet Absorption Components (DACs) are not observed, but the lines present peculiar profiles?

2. Till which distance from the star is the rotation model appropriate? Meaning till which atmospheric layer does the model give satisfactory results?

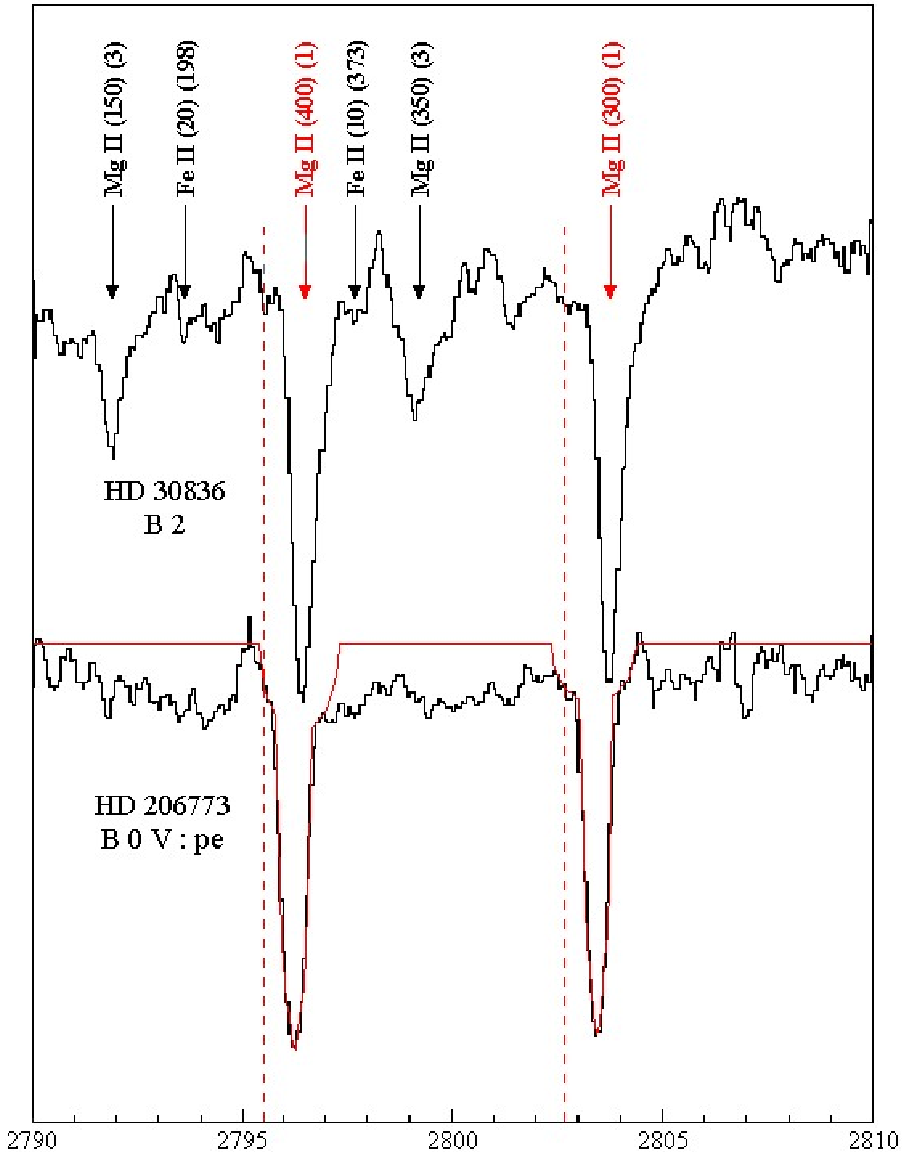


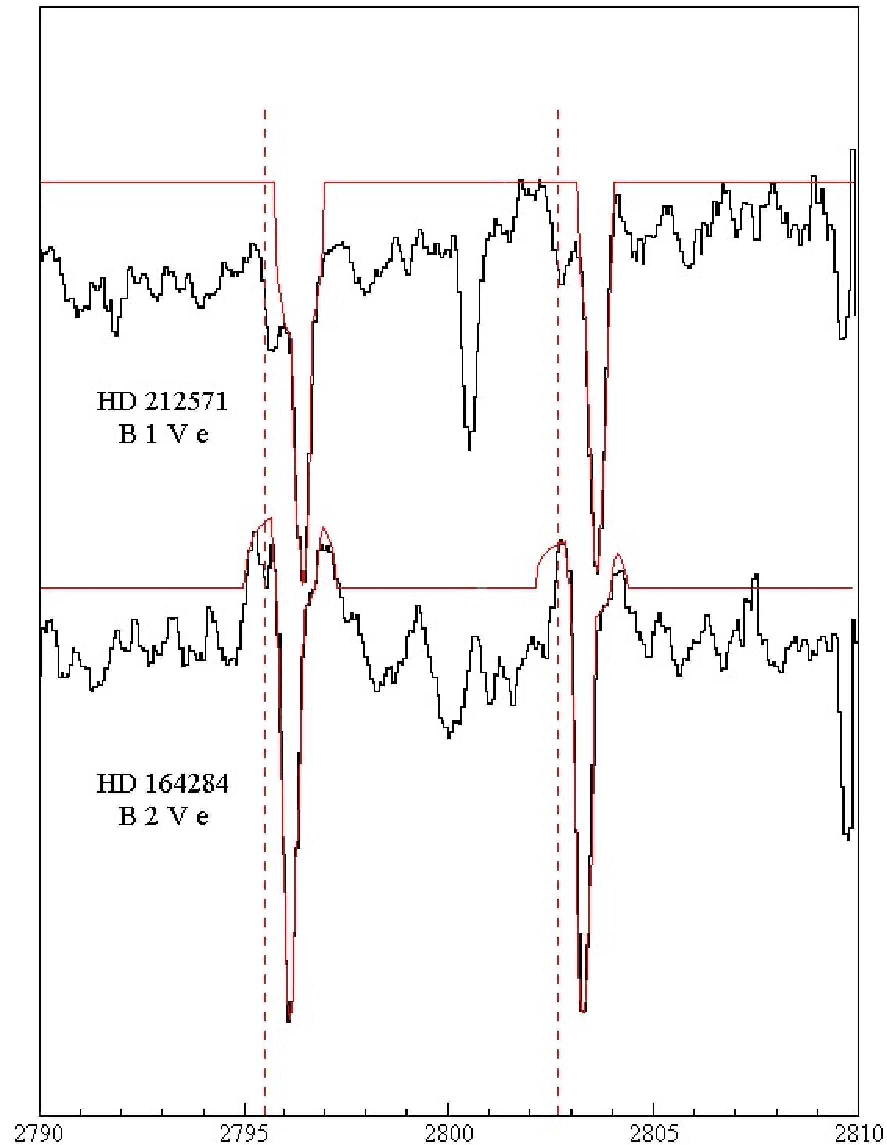
Data

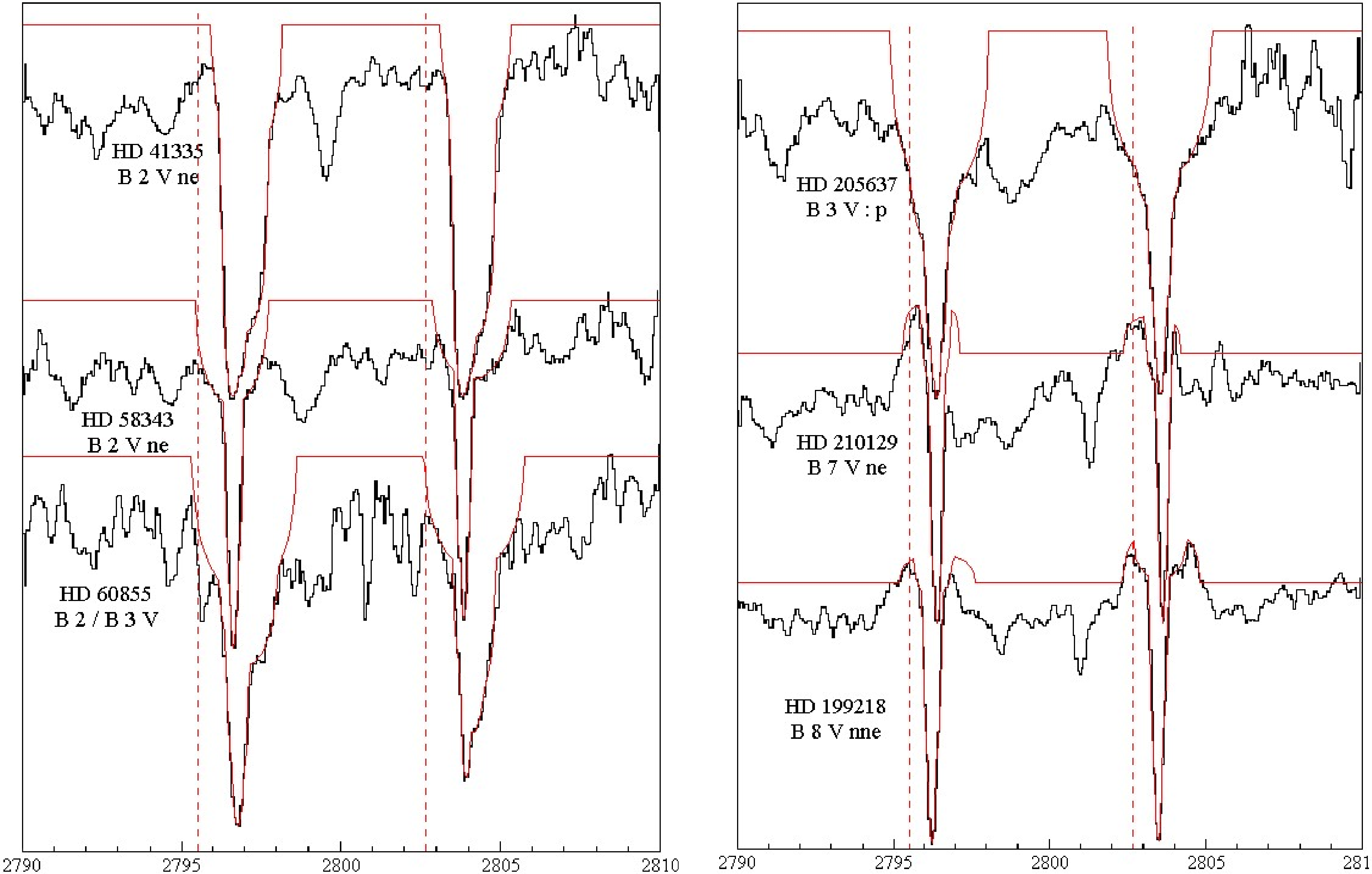
The data we used are the MgII resonance lines of 40 Be V stars. The stars' spectrographs are available by the Villafranca Space Agency (Vilspa) and have been taken with the International Ultraviolet Explorer (IUE). The stars' spectral types have been taken by the SIMBAD database (Centre de Données Astronomiques de Strasbourg (CDS), Strasbourg, France).

Star	Spectral Type	Camera	Star	Spectral Type	Camera	Star	Spectral Type	Camera
HD 206773	B0 V : pe	Lwr 14808	HD 65079	B2 V ne…	Lwp 30119	HD 217543	B3 V pe	Lwp 13326
HD 200310	B1 V e	Lwr 09544	HD 28497	B2 V : ne	Lwr 07337	HD 22192	B5 V e	Lwr 09071
HD 212571	B1 V e	Lwr 05948	HD 45995	B2 V nne	Lwr 08648	HD 217891	B6 V e	Lwr 09069
HD 44458	B1 V pe	Lwp 30173	HD 10516	B2 V pe	Lwr 07335	HD 138749	B6 V nne	Lwr 07858
HD 200120	B1.5 V nne	Lwr 11035	HD 32343	B2.5 V e	Lwr 05890	HD 6811	B7 V e	Lwr 09070
HD 36576	B 2 IV-V e	Lwp 14029	HD 65875	B2.5 V e	Lwr 05616	HD 192044	B7 V e	Lwp 08135
HD 32991	B2 V e	Lwr 11426	HD 191610	B2.5 V e	Lwr 07342	HD 210129	B7 V ne	Lwp 23173
HD 58050	B2 V e	Lwr 14810	HD 60855	B2/B3 V	Lwp 15477	HD 47054	B8 V e	Lwp 13074
HD 164284	B2 V e	Lwr 11038	HD 25940	B3 V e	Lwr 05950	HD 58715	B8 V e	Lwp 10104
HD 41335	B2 V ne	Lwr 07384	HD 45725	B3 V e	Lwp 10041	HD 183914	B8 V e	Lwr 04609
HD 52721	B2 V ne	Lwp 05462	HD 183362	B3 V e	Lwp 11044	HD 23552	B8 V ne	Lwr 08744
HD 58343	B2 V ne	Lwr 07363	HD 208057	B3 V e	Lwp 29221	HD 185037	B8 V ne	Lwp 08136
HD 148184	B2 V ne	Lwr 06744	HD 205637	B3 V : p	Lwr 05947	HD 199218	B8 V nne	Lwp 09903
HD 202904	B2 V ne	Lwr 07343						

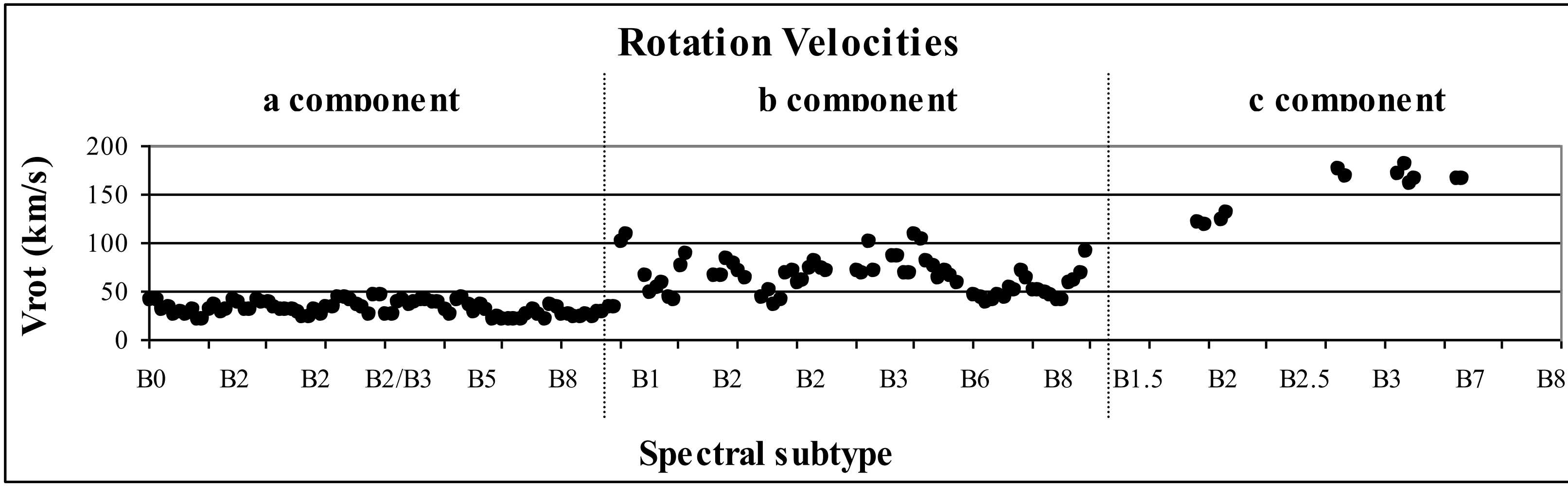
By the study of the interstellar lines we calculated a systematical error which leads to a displacement of about +98±18 km/s. Our results have undergone the appropriate corrections.





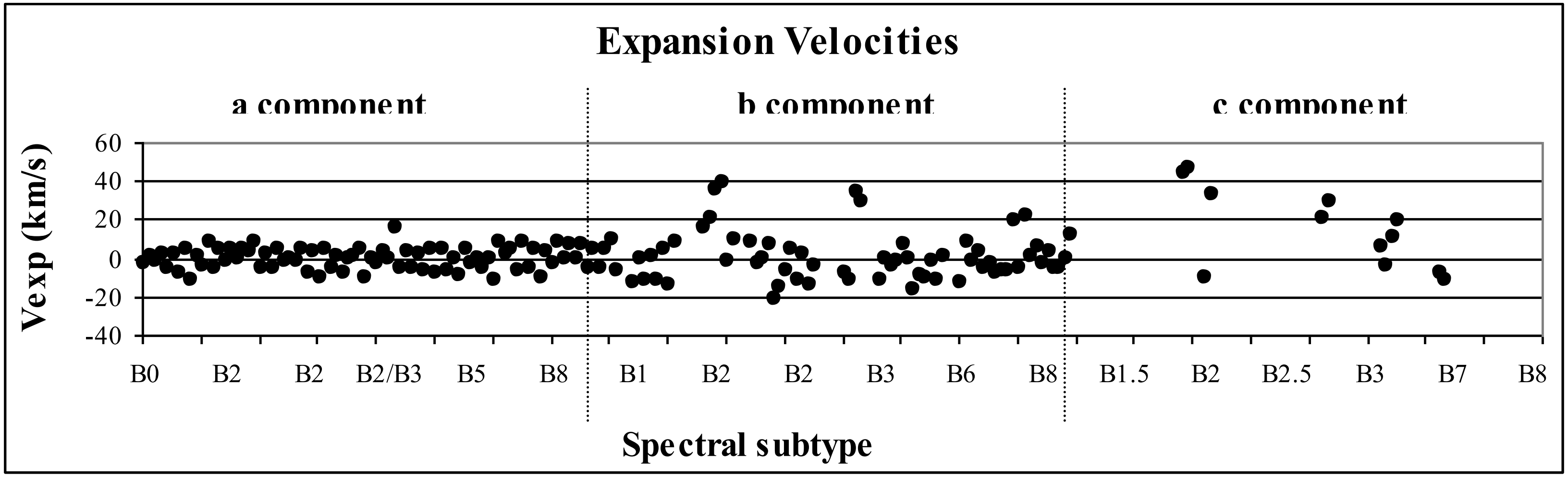


HD 41335
B 2 V ne
HD 58343
B 2 V ne
HD 60855
B 2 / B 3 V
HD 205637
B 3 V : p
HD 210129
B 7 V ne
HD 199218
B 8 V nne
2790
2795
2800
2805
2810



Apparent rotation velocities of all the SACs as a function of the spectral subtype. The rotation velocity presents a uniform fluctuation, which we could not accept as accidental.

Three rotation velocity groups are presented. The rotation velocity of the first SAC presents a small dispersion around the value of 31±7 km/s whereas in the case of the second SAC the dispersion increases around the greater value 64±18 km/s. The third SAC's rotation velocity increases more and presents a greater dispersion around the value 153±24 km/s. **These velocity groups do not appear in all the 40 Be V stars of this study.**

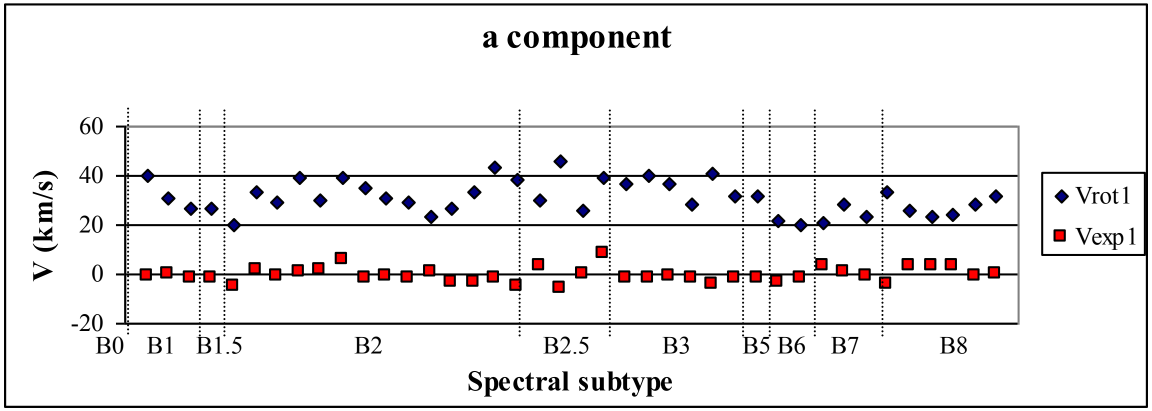


Apparent expansion /contraction velocities of all the SACs as a function of the spectral subtype.

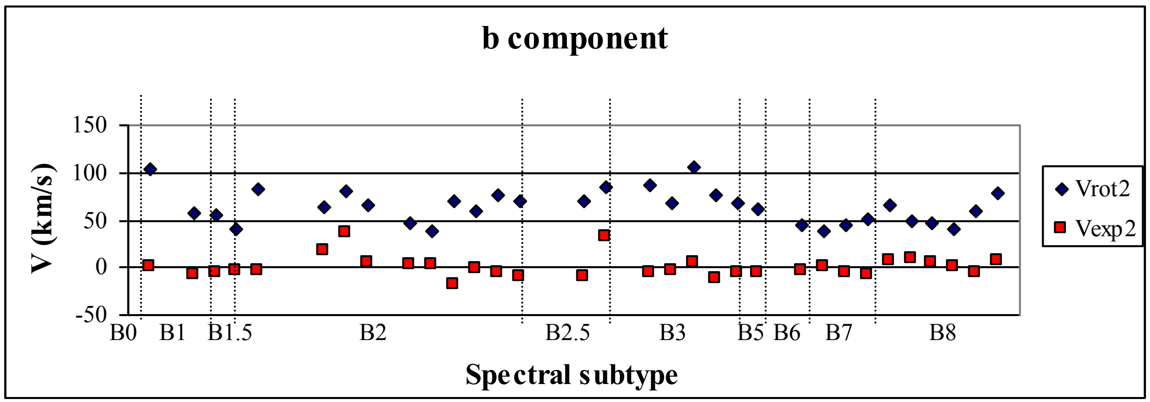
The values of the expansion/contraction velocity of all the SACs lie in a narrow range between -18 km/s and +18 km/s and present two maxima of +42 km/s and +29 km/s, which correspond to stars with spectral subtypes B2 and B2/B3, respectively.

As in the case of the rotation velocity, the expansion/contraction velocities of the first, second and third SAC present increasing dispersion around the values of -1 km/s, 0 km/s and +15 km/s, respectively.

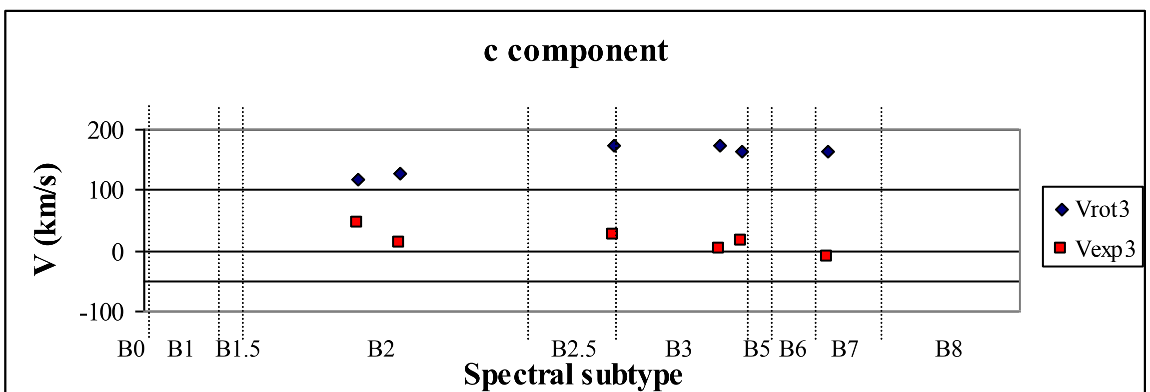
Apparent rotation (Vrot) and expansion/contraction velocities (Vexp) of the three SACs as a function of the spectral subtype, independently.



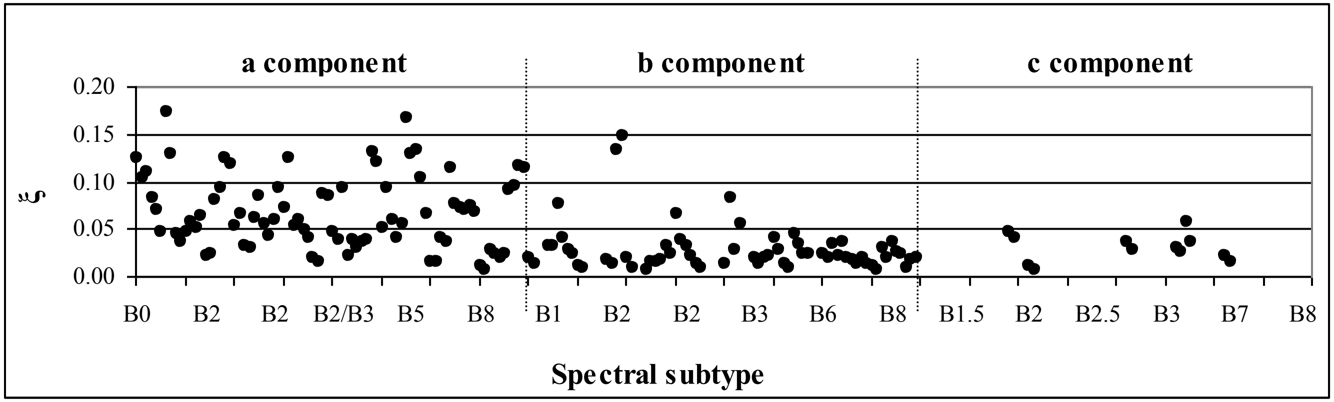
The first SAC's rotation and expansion/contraction velocities present a uniform fluctuation, in a narrow range, around the values of 31 km/s and -1 km/s respectively.



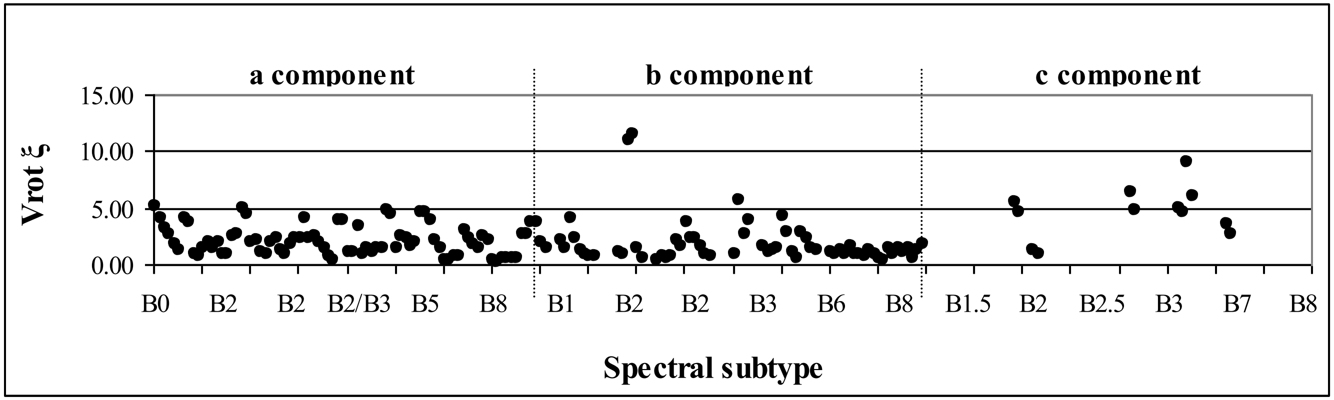
A less intense uniform fluctuation is also presented in the second SAC's rotation and expansion/contraction velocities around the values of 64 km/s and 0 km/s respectively and present greater dispersion than the values of the first SAC.



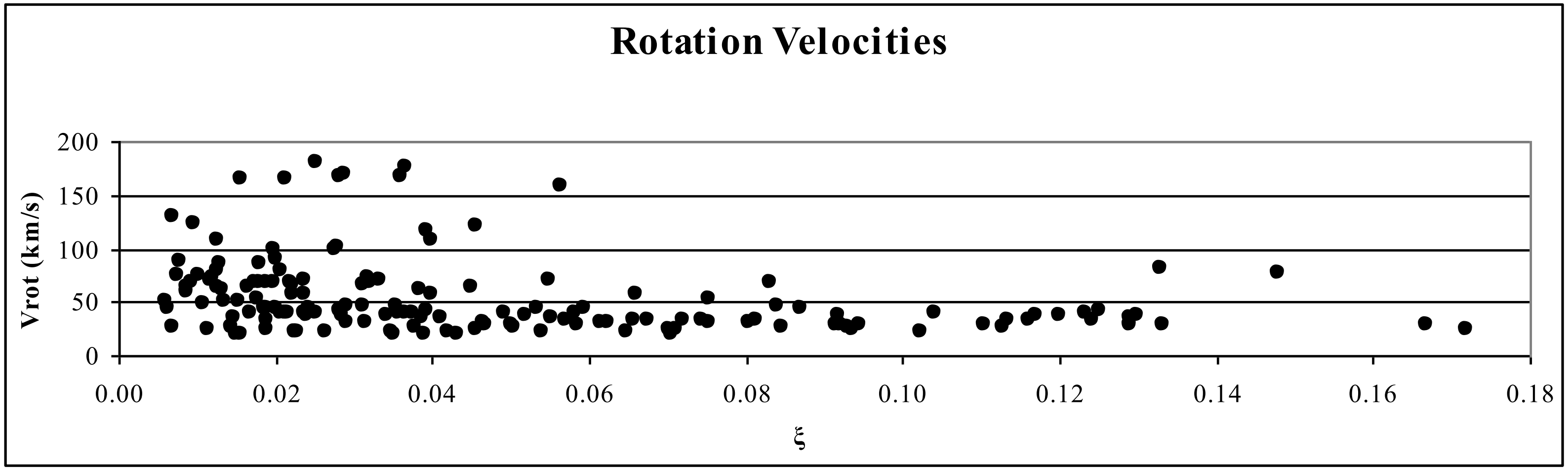
A slight increase is observed in the rotation velocity of the third SAC around the value of 153 km/s, whereas the respective expansion velocity presents a slight decrease around the value of +15 km/s.



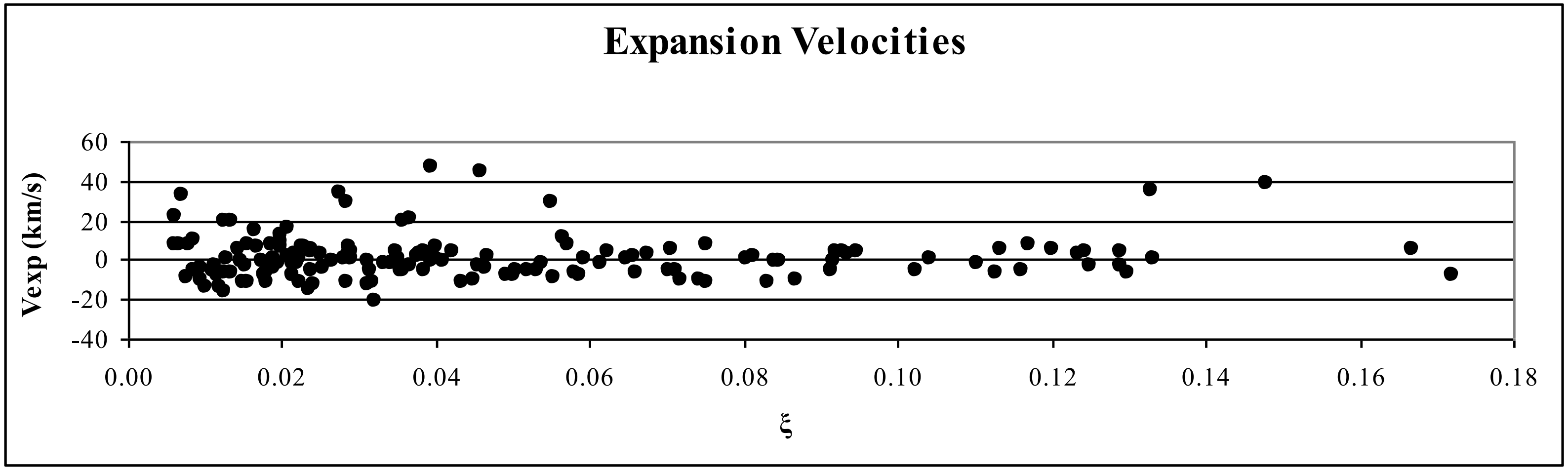
The ξ values of each SAC as a function of the spectral subtype. For the first SAC the values of ξ lie between 0.011 and 0.172, while for the second SAC the values of ξ lie in a smaller range, mainly, between 0.006 and 0.083 and for the third SAC in an even smaller range, between 0.007 and 0.057.



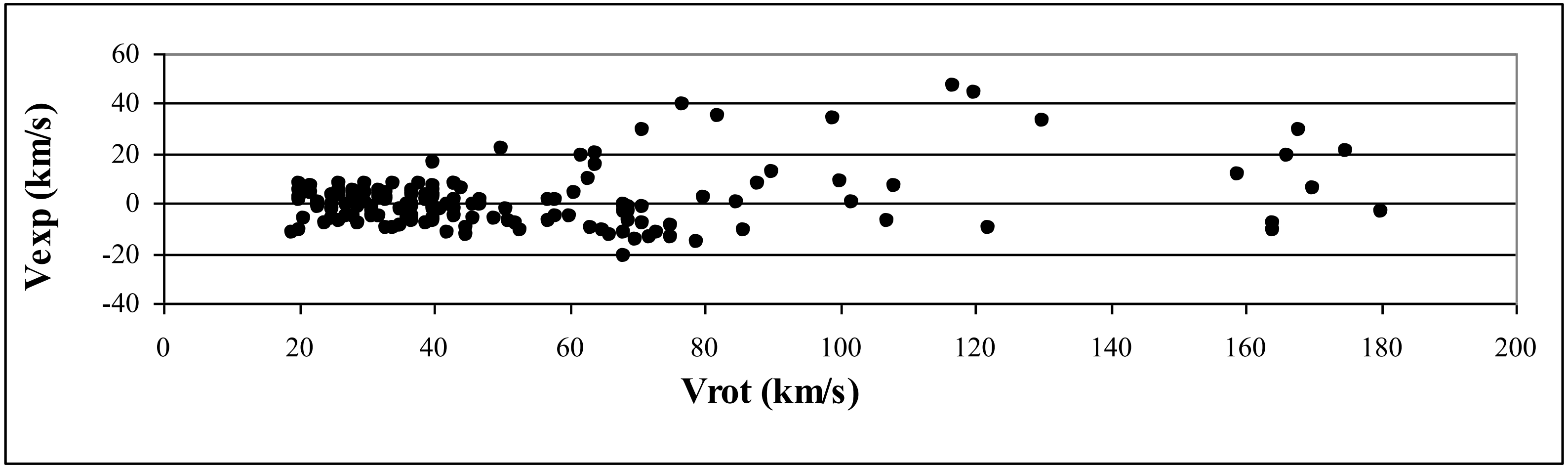
Values of the product of ξ and the apparent rotation velocities (Vrotξ) as a function of the spectral subtype, presented separately for each SAC. The product Vrotξ is an expression of the absorbed energy. It appears that Vrotξ is more of less stable with the spectral subtype, presenting a fluctuation.



Apparent rotation velocities (Vrot) of all the SACs as a function of the respective value of ξ. For small values of ξ the Vrot lies in the range of 16 to 100 km/s. As the value of ξ increases the Vrot's values lie in a smaller range between 20 and 82 km/s. The points referring to greater values of rotation velocities (between 102 and 180 km/s) correspond to the third SAC which presents small values of ξ (between 0.007 and 0.057).



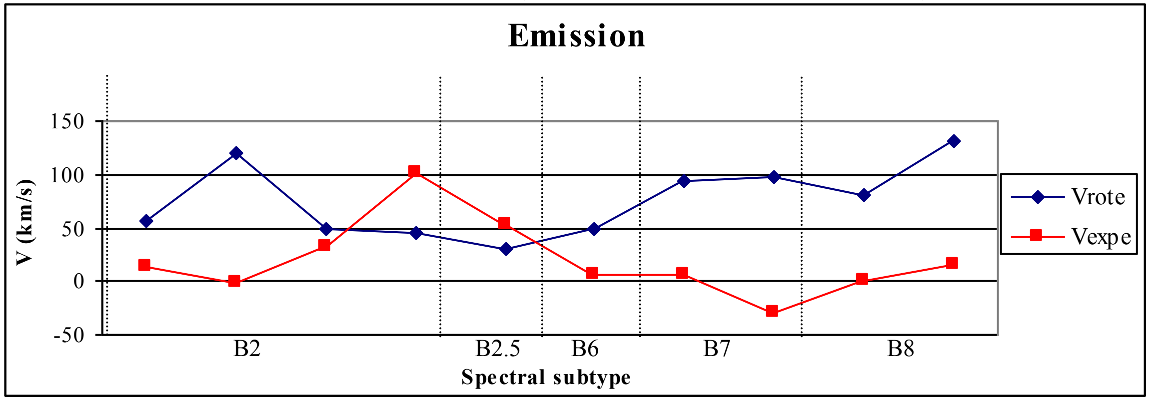
Expansion/contraction velocities of all the SACs as a function of the respective value of ξ. For small values of ξ the expansion/contraction velocity lies in the range of -21 to +47 km/s. As the value of ξ increases the expansion/contraction velocity's values lie in a smaller range between -12 and +8 km/s. The points referring to greater values of expansion/contraction velocities (between +20 and +47 km/s) correspond to the second and third SAC.



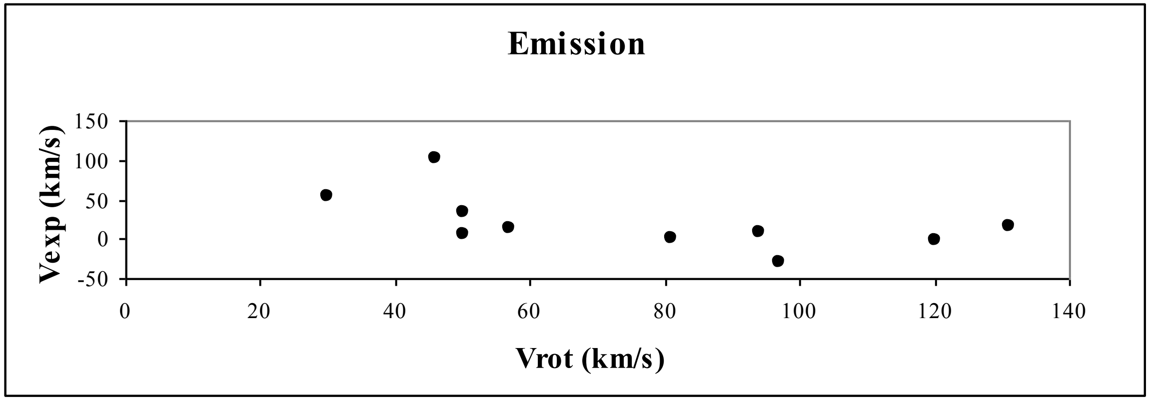
Expansion/contraction velocities of all the SACs as a function of the respective apparent rotation velocities. For small values of the rotation velocity, between 16 and 66 km/s, the values of the expansion/contraction velocity lie in a small range between -11 and +22 km/s. As the rotation velocity increases, the expansion/contraction velocity increases too and presents greater dispersion and its values, which lie between -21 and +47 km/s, seem to gather to two branches around 0 and +35 km/s.

Emission

The stars that present emission are of spectral subtypes **B2, B6, B7 and B8**. Thus, the emission appears in the spectra of the earliest and the latest spectral subtypes of the Be V stars (Kondo et al. 1975).



Apparent rotation and expansion/contraction velocities of the emission component as a function of the spectral subtype.



Expansion/contraction velocities of the emission component as a function of the respective apparent rotation velocities. As the values of the rotation velocity increase, the values of the expansion/contraction velocity decrease in contrast with the relation of the two velocities of the absorption components..

Conclusions

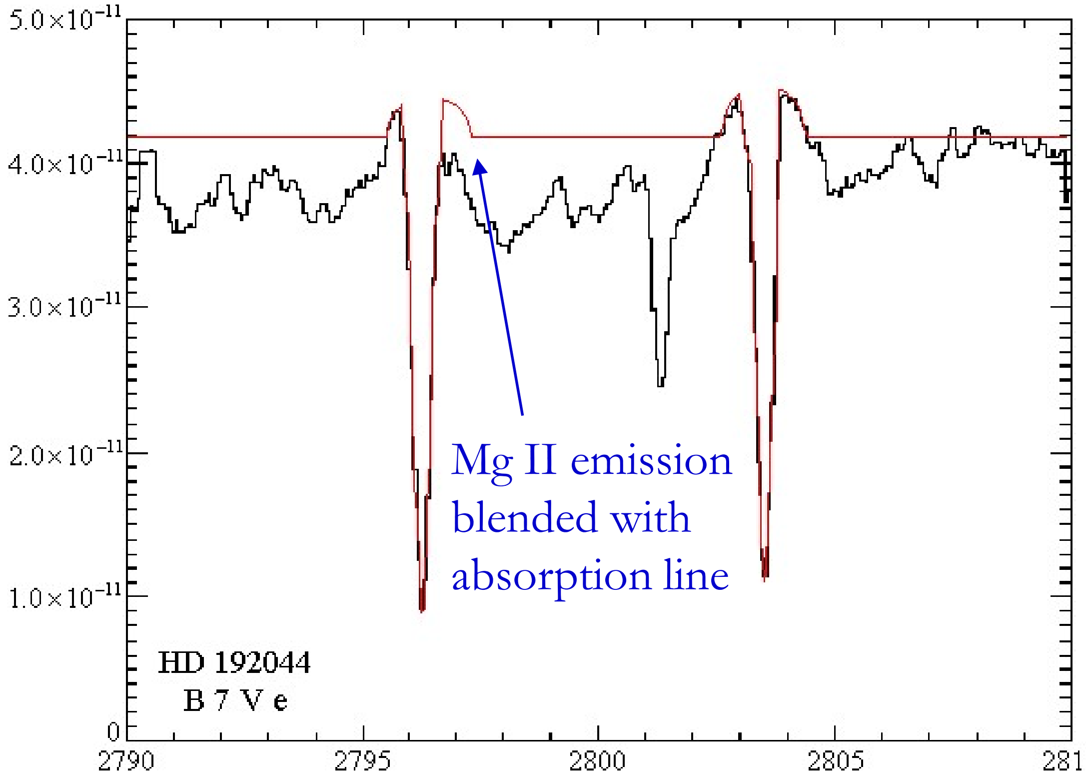
1. By applying the proposed by Danezis et al. (2003), model we are able to reproduce, with great accuracy, the profiles of the MgII doublet of the 40 BeV stars we studied. This means that the model allowing the existence of successive, independent density shells of matter represents accurately the structure of the MgII region of the Be stars. This result verifies the proposition of de Jager et al. (1979) that “there are concentrations of low-ionization species in the stellar wind as a result of the occurrence of significant density variations”, as well as the fact that there are “significant absorption features” shortward of each resonance absorption, which, according to Morgan et al. (1977) are attributed to “additional absorption within the stars’ extended atmosphere”. These “significant absorption features” are the Satellite Absorption Components (SACs) that appear in the spectra of the early type stars. Danezis et al. (2003) explained that the peculiar phenomena observed in the spectra of Oe and Be stars, such as the SACs, are due to independent density regions in the stars’ environment.

Conclusions

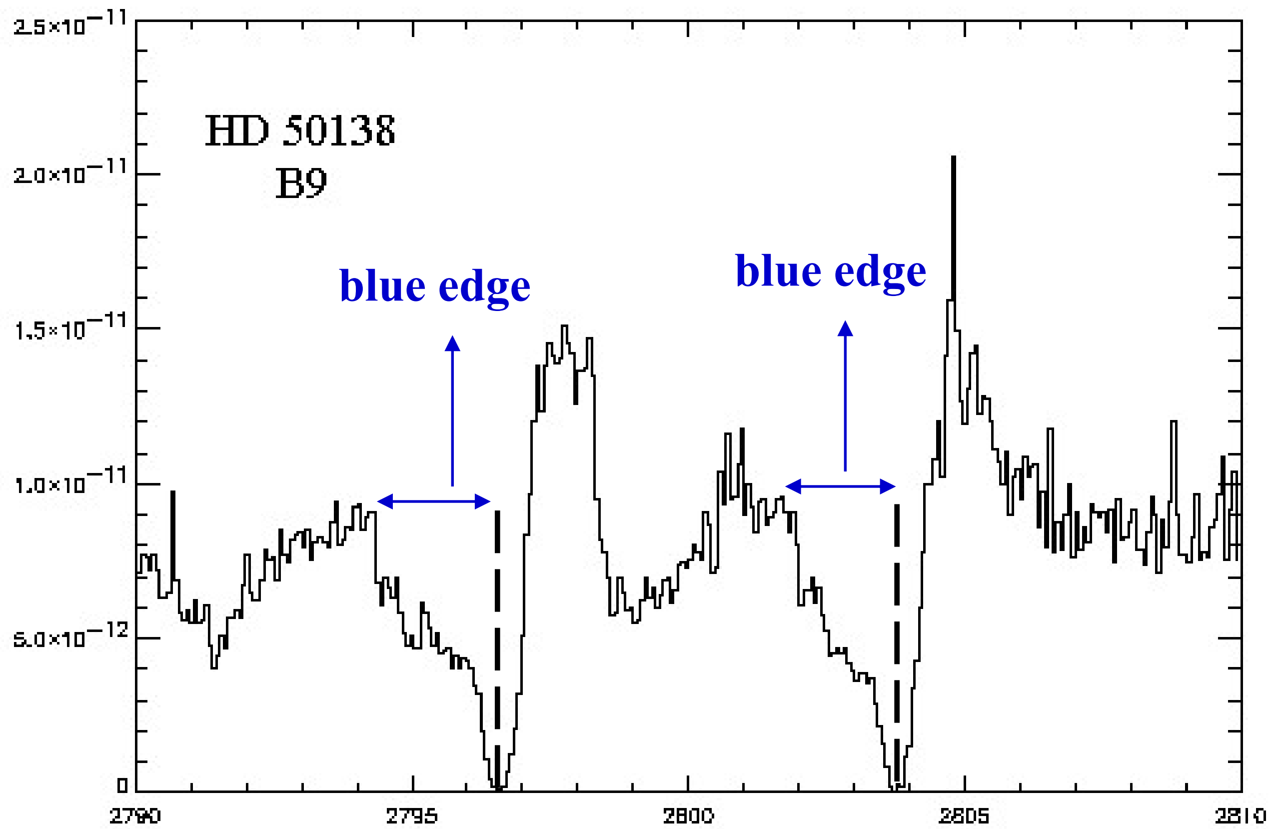
2. The SACs phenomenon appears to be a classical one for the Be stars. All the 40 Be V stars present SACs, though, they are not presented as intensively as they are in the case of the Be III stars, where the SACs appear as discrete lines (DACs). In the case of the Be V stars, the relatively small values of the expansion/contraction velocities result to the SACs being blended among them as well as with the main spectral line, making it difficult for the observer to detect them.

Conclusions

3. The emission component presents positive or negative expansion velocities. The calculated values correspond to the regions where the emission component is created (strings, blobs, puffs, bubbles), and not to a uniform region around the star. This means that the emission region may approach or move away from the observer and its different position and motion around the star is responsible of whether this value is positive or negative. At this point, we would like to point out that the emission component is blended with absorption lines of other ions, making difficult the evaluation of the apparent rotation and expansion/contraction velocity. As a result the calculated values present greater statistical error than the absorption components.

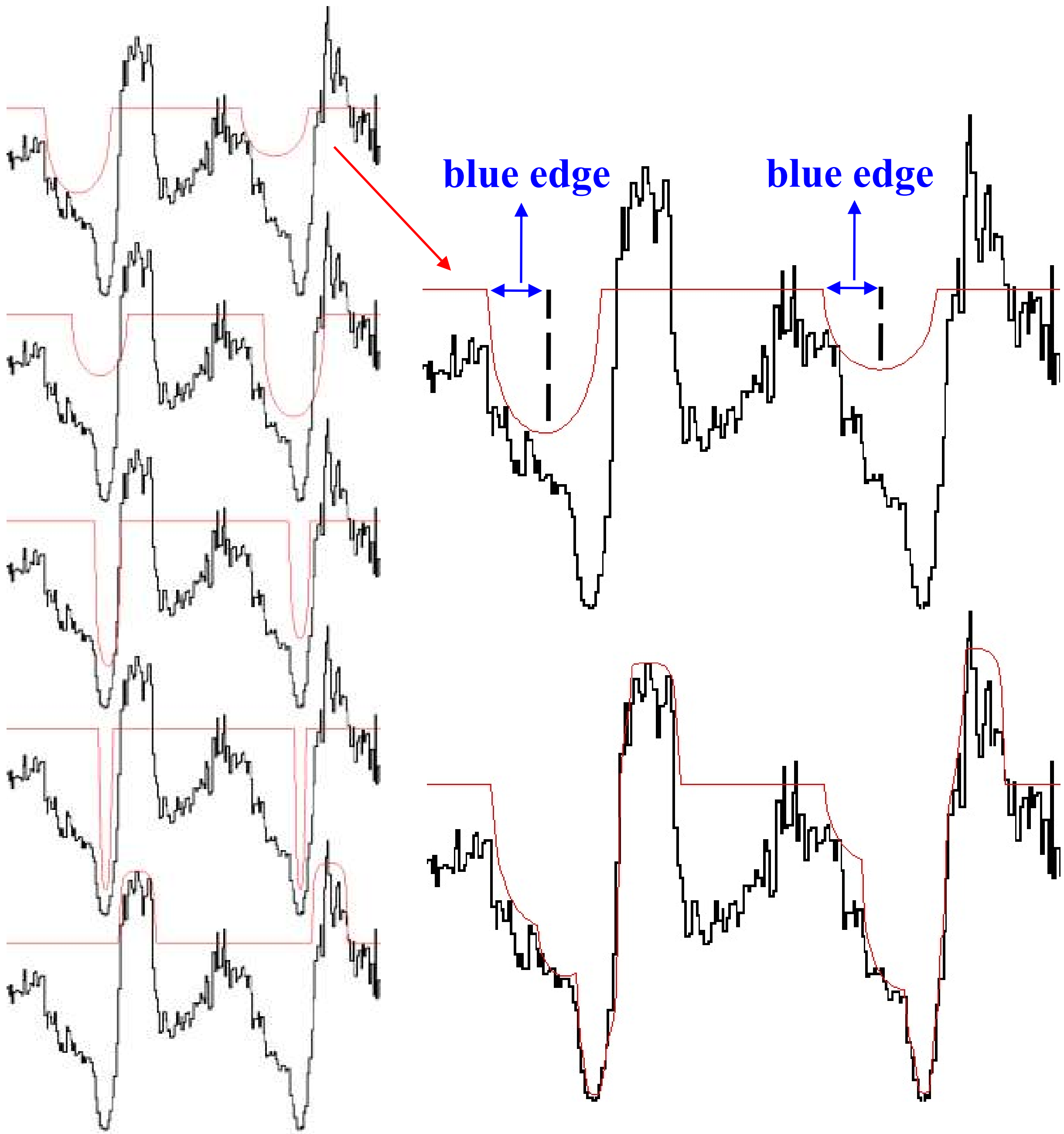


4. Until now, the main idea of the MgII doublet was that the resonance lines were created in a specific region in the star's atmosphere and were consisted of an absorption feature and a possible emission feature. Based on this idea, the equivalent width was calculated supposing that the whole absorption feature represents one absorption line, the rotation velocity was calculated by the width of the blue edge and the expansion velocity was calculated by the line shift, supposing that the deepest point of the feature corresponds to the wavelength at which the absorption appears.



Conclusions

4. According to the model the MgII resonance lines consist of a main absorption line accompanied by a number of SACs and a possible emission line. This fact can be explained, if we accept the existence of density regions (blobs, puffs, strings, bubbles) in the cool envelope. As Henrichs et al. (1988, 1994), Prinja (1991) and Kaper et al. (1996, 1997, 1999) proposed, the edge variability is directly related to the SACs, which have an impact on the position of the edge. Thus, the equivalent width and the rotation and expansion/contraction velocities must be calculatied separatelly for each SAC. In this way we calculate smaller values for the rotation velocity.



5. It is important to make clear that the observed fluctuations of the apparent rotation and expansion/contraction velocities correspond to the regions where the SACs are created (strings, blobs, puffs, bubbles) and do not refer to a uniform shell around the star. Specifically, the calculated velocities correspond to the rotation of the region around itself and not around the star.

Future Work

1. Study of the regions which create the Mg II resonance lines in the UV spectra of Be stars of luminosity classes I to IV

2. Study of the regions which create the Si IV resonance lines (post-coronal regions) in the UV spectra of Be stars of all luminosity classes

3. Study of the H alpha regions (external regions) of Be stars of all luminosity classes

4. Study of the post-coronal regions of Oe stars of all luminosity classes

5. Study of the variation with time of the atmospheric layers, through the study of many ionization potential ions of specific early type emission stars

All the above will enable us to conclude to whether there is a uniform mechanism which can produce the SACs phenomena in the early type emission stars

Thank you!!!