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

Mg II $\lambda$ 2795.523 (400) (1)
2802.698 (300) (1)

HD 30386 B2 III
LWR 09251

HD 45910 B2 III e
LWR 06234
• **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


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 $\xi$.

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

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 ($V_{\text{rot}}, V_{\text{exp}}$),
- $\xi = \int_{0}^{s} \Omega \rho ds$ is an expression of the optical depth $\tau$, where $\Omega$: an expression of $k_{\lambda}$ and has the same units as $k_{\lambda}$,
- $S_{\lambda_e}$: 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 $\Delta \lambda$, 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?
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).

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By the study of the interstellar lines we calculated a systematical error which leads to a displacement of about $+98\pm18$ km/s. Our results have undergone the appropriate corrections.
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 $31\pm7$ km/s whereas in the case of the second SAC the dispersion increases around the greater value $64\pm18$ km/s. The third SAC’s rotation velocity increases more and presents a greater dispersion around the value $153\pm24$ 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 $\xi$ values of each SAC as a function of the spectral subtype. For the first SAC the values of $\xi$ lie between 0.011 and 0.172, while for the second SAC the values of $\xi$ 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 $\xi$ and the apparent rotation velocities ($\text{Vrot}\xi$) as a function of the spectral subtype, presented separately for each SAC. The product $\text{Vrot}\xi$ is an expression of the absorbed energy. It appears that $\text{Vrot}\xi$ 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 $\xi$. For small values of $\xi$ the Vrot lies in the range of 16 to 100 km/s. As the value of $\xi$ 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 $\xi$ (between 0.007 and 0.057).
Expansion/contraction velocities of all the SACs as a function of the respective value of $\xi$. For small values of $\xi$ the expansion/contraction velocity lies in the range of -21 to +47 km/s. As the value of $\xi$ 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).

![Graph showing emission velocities as a function of spectral subtype](image)

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

![Graph showing expansion velocities as a function of rotation velocities](image)

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.
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.
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.
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.
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 calculated separately 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.
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!!!