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Interpreting the complex line profiles in the stellar spectra

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ABSTRACT

In this review we present our recent investigation of the complex absorption lines in spectra of hot emission stars. The lines are created in a material ejected from stars (here we call it density regions around the objects). Particularly we present a model (GR model) which is developed to study satellite or discrete absorption components (SACs or DACs). Using the model we are able to extract kinematical parameters (rotational, radial and random velocity) and some physical parameters (full width at half maximum, optical depth in the center of the line, column density and absorbed or emitted energy) of the density regions.

1. Introduction

The definition of hot emission stars is that they present emission lines of the Balmer series, which, superposed with the respective absorption lines, construct PCygni profiles. Besides that, they may also present PCygni profiles in the UV region (such as in the case of the resonance lines of Si IV, C IV, N V, Mg II, and the N IV spectral line) and IR excess in their spectra. Additionally, another characteristic of hot emission stars, which also distinguish them from the classical hot stars, is the violent mass ejection, like flares, from active regions. Specifically, hot emission stars are rapid rotators and when the rotational velocity takes a critical value, the star ejects plasma violently from a zone around the equator (Underhill and Doazan, 1982, Part II, Chapter 10). The ejected plasma maybe evolves to a thin spherical shell around the star (Meilland et al., 2006). Some times we have repeated ejection of mater (Danezis, 1984). This means that we can detect not one, but many successive thin and independent spherical shells around the star. These spherical shells rotate rapidly because they lie near the rapidly rotating star and they are the origin of the very broad spectral lines that present rotational velocities with values about the critical. The mass ejection may last for quite long time and results to the fact that near the stars the ejected plasma could form spiral streams due to turbulence and the stellar rotation. These structures form density regions such as shells, blobs or puffs (Underhill, 1975; Henrichs, 1984; Underhill and Fahey, 1984; Bates and Halliwell, 1986; Grady et al., 1987; Lamers et al., 1988; Waldron et al., 1992; Waldron et al., 1994; Cranmer and Owocki, 1996; Rivinius et al., 1997; Kaper et al., 1996; Kaper et al., 1997; Markova, 2000). These spherical blobs, arising from spiral streams or turbulences, are the origin of a group of satellite spectral lines with intermediate or low broadening. The thin spherical shells evolve to an equatorial disk (Meilland et al., 2006) that far away from the star becomes a classical stellar wind. As a result, the material that comes from the star, has not the form of a classical stellar wind near the star. Consequently, the stellar wind models may be used for the outer regions of the equatorial disk, but not for the inner layers.

Additionally, near hot emission stars we can detect density regions that have the characteristics of chromospheres, corona and post-coronal regions (Franco and Stalio, 1983, Part II, Chapter 13; Franco et al., 1983; Underhill and Doazan, 1982). Besides, we detect the corona of hot emission stars in X-rays and in UV we detect the post-coronal regions (Si IV, C IV, N IV, N V lines etc.). Investigations of line profiles of UV lines, can give us more information about these regions, as e.g. the velocity of outflow, rotation of sub-regions, etc.

Here, we give an overview of our recent investigations of complex UV lines in hot emission stars. We study the density regions which are formed due to violent mass ejection from the star, lie near the star and cannot be considered as regions of a classical stellar wind. These density regions are the ones that create the observed complex profiles of the spectral lines.

This paper is organized as follows: In Section 2 we discuss observational facts and problems connected with peculiar and complex spectral line profiles of hot emission stars; in Section 3 we describe GR model, in Section 4 we give some results of our recent investigation and in Section 5 we outline our conclusions.

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2. Peculiar and complex spectral line profiles – observations and problems

Almost all the stars of the same spectral type and luminosity class present the same absorption lines in their spectra. However, in the UV spectral region, some hot emission stars (Oe and Be stars) present some absorption components that should not appear in their spectra, according to the classical physical theory (Fig. 1).

In the case of hot emission stars we call the absorption spectral lines, not corresponding to any known absorption line of the same spectral type stars, discrete absorption components (DACs) (Bates and Halliwell, 1986).

However, 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 in different density regions which rotate and move radially with different velocities (Danezis, 1984; Danezis, 1987; Danezis et al., 1991; Danezis et al., 2003; Lyratzi and Danezis, 2004).

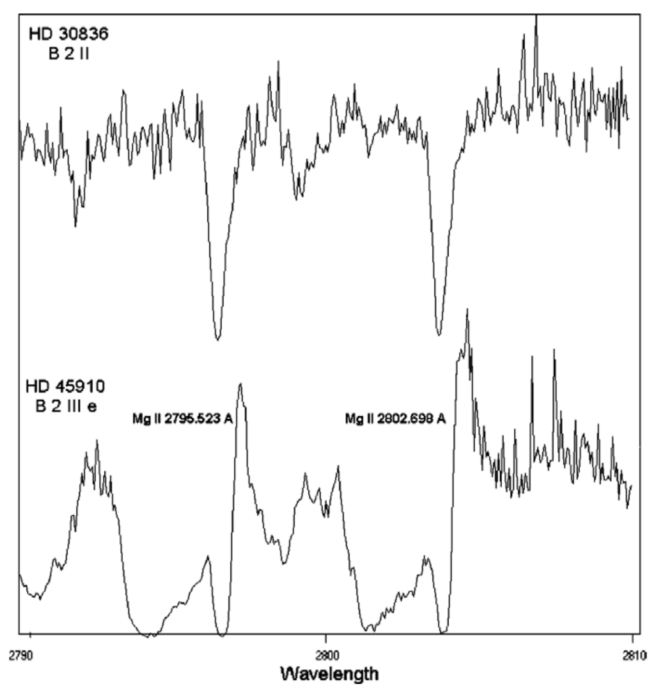

Fig. 1. Comparison of Mg II resonance lines between the spectrum of a normal B star and the spectrum of an active Be star that presents complex and peculiar spectral lines. As we can observe the Be star presents some absorption components that do not appear in the spectrum of the classical B star.

The origin of DACs is an important problem that has been studied by many researchers. Some of them have suggested mechanisms that allow 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 and Fahey, 1984; Bates and Halliwell, 1986; Grady et al., 1987; Lamers et al., 1988; Waldron et al., 1992; Waldron et al., 1994; Cranmer and Owocki, 1996; Rivinius et al., 1997; Kaper et al., 1996; Kaper et al., 1997; Markova, 2000), interaction of fast and slow wind components, co-rotation interaction regions (CIRs), structures due to magnetic fields or spiral streams as a result of the stellar rotation (Underhill and Fahey, 1984; Cranmer and Owocki, 1996; Kaper et al., 1996; Kaper et al., 1997; Kaper et al., 1999; Mullan, 1984a,b; Mullan, 1986; Prinja and Howarth, 1988; Fullerton et al., 1997; Cranmer et al., 2000). According to these ideas, DACs result from independent high density regions in the stellar environment, which have different rotational and radial velocities.

Our proposition is that since hot emission stars are surrounded by thin spherical envelopes which evolve to a disk in the equatorial plane, the density regions which create the observed DACs in the stellar spectra may be either the thin spherical shells around the star or apparent spherical density regions that lie in the disc around the star (Fig. 2).

Another problem of this group of hot emission stars is the presence of very complex profile of the spectral lines that we cannot produce theoretically. This means that we could not know the physical conditions that exist in the high density regions that construct these spectral lines. In order to explain this complex line profile our scientific group proposed the SACs phenomenon (satellite absorption components). If the regions that construct the DACs rotate with large velocities and move radially with small velocities, the produced lines have large widths and small shifts. As a result, they are blended among themselves as well as with the main spectral line and thus they are not discrete. In such a case the name discrete absorption components is inappropriate and we use the name: satellite absorption components (SACs) (Danezis, 1984; Danezis, 1987; Lyratzi and Danezis, 2004; Danezis et al., 2006; Sahade et al., 1984; Sahade and Brandi, 1985). The existence of SACs results to the formation of the complex structure of the observed spectral feature.

As we can deduce from the above, the DACs and SACs are two aspects of the same phenomenon. In Fig. 3 it is clear that the Mg II line profiles of the star AX Mon (HD 45910), which presents DACs and the star HD 41335, which presents SACs are produced in the same way. The only difference between them is that the components of HD 41335 are much less shifted and thus they are blended among themselves.

Similar phenomena can also be detected as an effect of the ejected plasma around peculiar stars. Around the Wolf-Rayet star

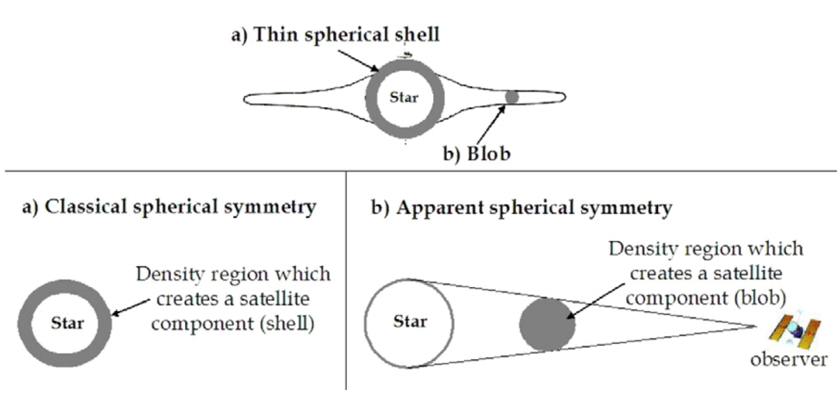

Fig. 2. DACs arise from (a) the thin spherical envelope around hot emission stars or (b) (apparent) spherical density regions in the disc around the stars.

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WR 104 we can detect density regions of matter, quite away from the stellar object, able to produce peculiar profiles (Fig. 4).

It is very important to point out that we can detect the same phenomenon in the spectra of some active galactic nuclei (AGN). In Fig. 5 (down) we can see the C IV UV doublet of an AGN (PG

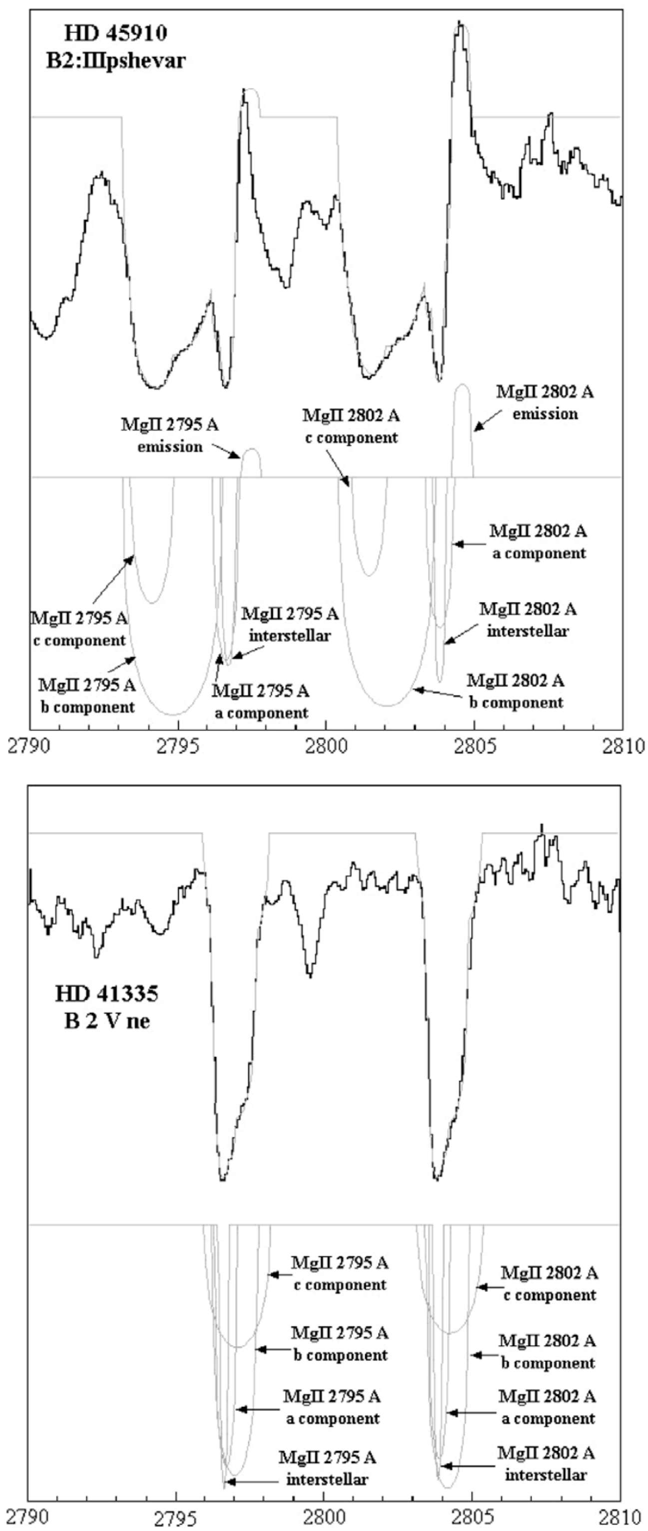

Fig. 3. DACs of the Mg II line profiles of the star AX Mon (HD 45910) and SACs of the star HD 41335 are produced in the same way. The black line presents the observed spectral line's profile and the grey one the model's fit. All the components which contribute to the observed features are shown separately.

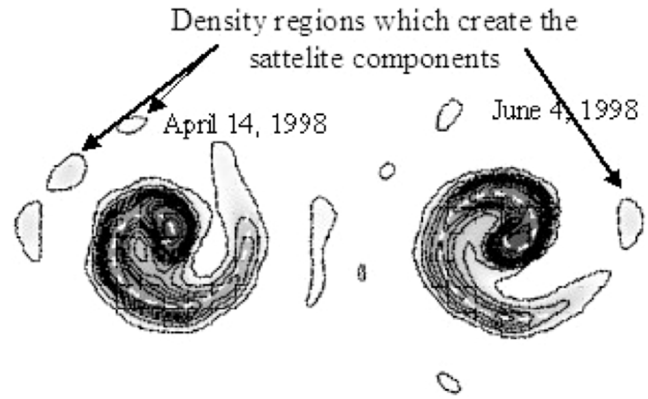

Fig. 4. Density regions of matter, able to produce peculiar profiles can be detected around the Wolf-Rayet star WR 104. (This figure is taken from (Tuthill et al., 1999)).

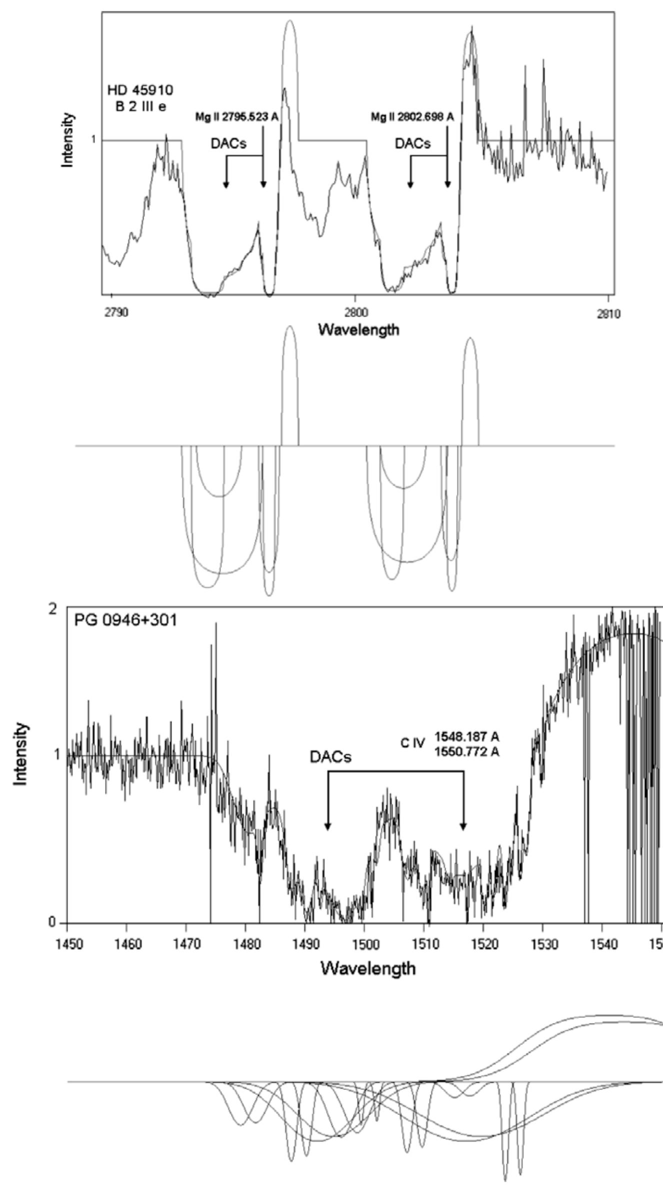

Fig. 5. DACs phenomena in AGNs spectra: similarity of DACs phenomenon in Be star's HD 45910 spectrum (Mg II doublet) with AGNs PG 0946+301spectrum (C IV doublet).

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0946+301). The values of radial displacements and the ratio of the line intensities indicate that the two observed C IV shapes present DACs phenomenon similar with the DACs phenomenon that we detect in the spectra of hot emission stars (HD 45910, up).

Since the DACs phenomenon is present in AGNs spectra, we also expect the presence of SACs phenomenon which is able to explain the observed absorption lines complex profiles (Fig. 6). In the case of AGNs, accretion, wind (jets, ejection of matter etc.), BLR (broad line regions) and NLR (narrow line regions) are the density regions that construct peculiar profiles of the spectral lines.

In order to study and explain the spectral lines that have complex profiles due to the existence of DACs or SACs and the atmospherical regions where these lines originate, we have to calculate a line function that will be able to reproduce theoretically the observed spectral line profiles. The term line function corresponds to the function that relates the intensity with the wavelength. This function includes as parameters all the physical conditions that construct the line profile. By giving values to these parameters we try to find the right ones in order to have the best

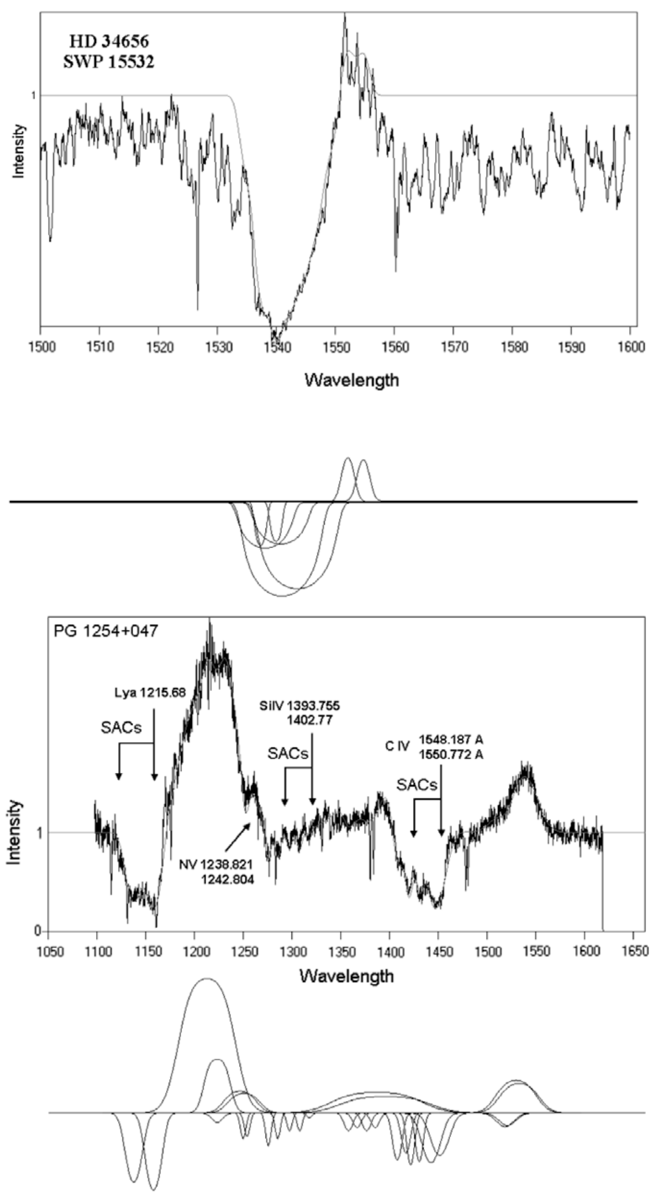

Fig. 6. SACs phenomena in AGNs spectra: similarity of SACs phenomenon in Oe star's HD 34656 spectrum (C IV doublet) with AGNs PG 1254+047 spectrum (Lya and Si IV and C IV doublets).

theoretical fit of the observed line profile. If we accomplish the best fit, we accept that the theoretical values of the physical parameters are the actual ones that describe the physical conditions in the region that produces the specific spectral line. However, the calculation of a line function is not simple and includes many problems, such as the following. A line function able to reproduce theoretically any spectral line of any ion should include all the atomic parameters. As a result the line function would be very complex. Also, if we wanted a time dependent line function, we should include as parameter the time. The existence of many parameters makes the solution of the radiation transfer equations problematic. Another problem is to choose the correct values of so many parameters.

In order to eliminate some of these problems we considered that in the calculation of a line function we should not include variation with time, as our purpose was to describe the structure of the regions where the SACs are created at the specific moment when a spectrum is taken. 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. Additionally, we needed a line function with which we could study a specific spectral line of a specific ion. This means that we did not need to include the atomic parameters, as in such a case the atomic parameters remain constant. In this way, we were able to solve the radiation transfer equations and to find the correct group of parameters that give the best fit of the observed spectral line.

3. GR (Gauss-rotation) model – the line function

We considered that in the stellar atmosphere the radiation passes through a number of successive independent absorbing and/or emitting density regions of matter until it arrives at the observer. By solving the radiation transfer equations through such a complex structure we obtain a line function (Eq. (1)) for the line profile, able to give the best fit for the main spectral line and its DACs/SACs at the same time (see Danezis et al. (2003), and Danezis et al. (2007a)).

$$I_\lambda = \left[I_{\lambda 0} \prod_i \exp\{-L_i \xi_i\} + \sum_j S_{\lambda ej}(1 - \exp\{-L_{ej}\xi_{ej}\}) \right] \times \prod_g \exp\{-L_g \xi_g\} \quad (1)$$

where, $I_{\lambda 0}$ is the initial radiation intensity, L_i, L_{ej}, L_g are the distribution functions of the absorption coefficients $k_{\lambda i}, k_{\lambda ej}, k_{\lambda g}$, ξ is the optical depth in the center of the spectral line, $S_{\lambda ej}$ is the source function that is constant during one observation.

The geometry and the physical conditions of the region that produces the spectral line are included in the factors L_i, L_{ej}, L_g and not in the calculation of I_λ. So, the decision on the geometry and the physical conditions is essential for the calculation of the distribution function that we use for each component. Specifically, the physical conditions indicate the exact distribution that we must use. This means that for a different geometry and different physical conditions we have a different analytical form of L_i, L_{ej}, L_g and thus a different shape for the spectral line profile of each SAC.

In the case of rapidly rotating hot emission stars, it is very important to insert in the line function the rotational and the radial of the regions that produce each one of the satellite components, as well as the random velocities of the ions. In this case we must define the geometry for the corresponding regions.

3.0.1. Geometry

In our model we considered the spherical geometry. In order to decide on the appropriate geometry we took into consideration

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that the spectral line profile is reproduced in the best way when we consider spherical symmetry for the independent density regions. Such symmetry has been proposed by many researchers (Waldron et al., 1992; Rivinius et al., 1997; Kaper et al., 1996; Kaper et al., 1997; Kaper et al., 1999; Markova, 2000; Lamers et al., 1982; Bates and Gilheany, 1990; Gilheany et al., 1990; Cidale, 1998). However, the independent layers of matter, where a spectral line and its SACs are created, could lie either (i) around the star, in which case spherical symmetry is justified, or (ii) at a greater distance from the star, where the spherical symmetry can not be justified (see also Lyratzi et al., 2007).

(i) Independent density regions of matter that lie around the star (see Fig. 2a): In this case we consider the existence of a classical spherical symmetry of the thin spherical envelope around hot emission stars.
(ii) Independent density regions of matter that lie at a greater distance from the photosphere (see Fig. 2b): we consider the existence of independent density regions such as blobs, which cover all or a substantial fraction of the stellar disk, which exist in the disc around hot emission stars. These regions, do not present spherical symmetry around the star, but they may present local spherical symmetry around their own center and they form spectral line profiles which are identical with those deriving from a spherically symmetric structure. So, even if the density regions are not spherically symmetric, through their effects on the line profiles, they appear as spherically symmetric structures to the observer.

The way the density regions of the second case are formed is shown in Fig. 4. The star ejects mass with a specific radial velocity. The stream of matter is twisted, forming density regions such as co-rotating interaction regions (CIRs), structures due to magnetic fields or spiral streams as a result of the stellar rotation (Underhill and Fahey, 1984; Cranmer and Owocki, 1996; Kaper et al., 1996; Kaper et al., 1997; Kaper et al., 1999; Mullan, 1984a,b; Mullan, 1986; Prinja and Howarth, 1988; Cranmer et al., 2000). This means that hydrodynamic and magnetic forces take effect as centripetal forces, resulting to the outward moving matter twisting and moving around the star. Some parts of these streams cut off and form the observed high density regions (shells, blobs, puffs, spiral streams).

3.0.2. Physical conditions

Depending on the physical conditions that we consider for the calculations of the factors L_i, L_{ej}, L_g, the functions $e^{-L_i\xi_i}$ and $S_{\lambda ej}(1-e^{-L_{ej}\xi_{ej}})$ that correspond to the absorption and the emission satellite component, respectively, may take the form of different distribution functions, such as Gauss, Lorentz or Voigt distribution function. However, a very important point is that in this case we do not use the pure mathematical distributions that do not include any physical parameter, but the physical expression of these distributions that are the following.

1. If L_i has the form $L_\lambda = e^{-\alpha(\lambda-\lambda_0)^2}$, where $\alpha = \frac{1}{2(\Delta\lambda_{width})^2}$, the line function $e^{-L_i\xi_i}$ that defines well an absorption line, has the form of a Gauss distribution.
2. If L_i has the form $L_\lambda = \frac{1}{1+\beta(\lambda-\lambda_0)^2}$, where $\beta = \frac{1}{2(\Delta\lambda_{width})^2}$, the line function $e^{-L_i\xi_i}$ that defines well an absorption line, has the form of a Lorentz distribution.
3. If L_i has the form $L_\lambda = \frac{\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} f(x,(\lambda-\lambda_0)\sqrt{a},K)\,dx}{V_0}$, where $\alpha = \frac{1}{2(\Delta\lambda_{width})^2}$, $V_0 = \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} f(x,0,K)\,dx$ and $0 \leqslant K$, the line function $e^{-L_i\xi_i}$ that defines well an absorption line, has the form of a Voigt distribution. Similarly, if we put the above expressions of L_i (cases 1–3) in the emission line function $S_{\lambda ej}(1-e^{-L_{ej}\xi_{ej}})$, it will take the form of a Gauss, Lorentz or Voigt distribution.

Besides the above distribution functions, we had to consider the fact that hot emission stars are rapid rotators and present violent mass ejection, producing density regions that create the observed DACs or SACs and which also rotate quickly around their own center. According to this, we should accept that the rapid rotation of the density regions is one of the main broadening factors of the spectral lines originating from them. This means that the rotation of the density regions should be included in the calculations of our model, in order to be able to reproduce the observed spectral lines.

As a first step, our scientific group constructed a distribution function L that considers as the only reason of the line broadening the rotation of the regions that produce the spectral lines. We called it rotation distribution (see Danezis et al., 2003; Lyratzi et al., 2007). However, it is known that in a gaseous region we always detect random motions, which must be taken into consideration as a second reason of line broadening (Doppler broadening). The distribution function that expresses these random motions is the Gaussian. This means that in order to have a spectral line that has as broadening factors the rotation of the regions and the random motions of the ions, we should construct a new distribution function L that would include both of these reasons (rotation and random motions). Our scientific group constructed this distribution function L (Eq. (2)) and named it Gaussian-rotation distribution (GR distribution).

$$L_{final}(\lambda) = \frac{\sqrt{\pi}}{2\lambda_0 z}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\left[erf\left(\frac{\lambda-\lambda_0}{\sigma\sqrt{2}}+\frac{\lambda_0 z}{\sigma\sqrt{2}\cos\theta}\right) - erf\left(\frac{\lambda-\lambda_0}{\sigma\sqrt{2}}-\frac{\lambda_0 z}{\sigma\sqrt{2}\cos\theta}\right)\right]\cos\theta\, d\theta \quad (2)$$

where, λ is the wavelength of each point of the spectral line profile, $\lambda_0 = \lambda_{lab} \pm \Delta\lambda_{rad}$, where λ_0 is the wavelength of the center of the observed spectral line which is shifted from the laboratory wavelength λ_{lab} of the spectral line at $\Delta\lambda_{rad}$, from which we calculate the radial velocity V_{rad} of the density region, $z = \frac{V_{rot}}{c}$, from which we calculate the rotational velocity V_{rot} of the density region, σ is the Gaussian typical deviation from which we calculate the random velocity V_{rand} of the ions as $V_{rand} = \frac{\sigma c\sqrt{2\ln 2}}{\lambda_0}$ and $erf(x) = \frac{2}{\pi}\int_0^x e^{-u^2}du$, is the known error function (see also Danezis et al., 2007a).

The analytical form and the calculations of the GR distribution function can be found in Danezis et al. (2007a).

Using the GR model, we can calculate some important parameters of the density region that construct the DACs/SACs. Directly, we can calculate the apparent rotational velocities of absorbing or emitting density layers (V_{rot}), the apparent radial velocities of absorbing or emitting density layers (V_{rad}), the Gaussian typical deviation of the ion random motions (σ) and the optical depth in the center of the absorption or emission components (ξ). Indirectly, we calculate the random velocities of the ions (V_{rand}), the full width at half maximum (FWHM), the absorbed or emitted energy (Ea, Ee) and the column density (CD) (see also Danezis et al., 2005).

3.1. Main aspects of the GR model

First of all, we should point out that with GR model we can study and reproduce specific spectral lines. This means that we can study specific density regions in the plasma surrounding the studied object. These density regions lie near the star and are formed by the plasma which is violently ejected from the stellar active regions. This means that the material that comes from the star has not the form of a classical stellar wind. In order to construct a general model we need to study with the proposed model many density regions that produce spectral lines of different ionization potential, meaning different temperature and thus different distance from the studied object.

3.1.1. The simple case of only one component (simple spectral lines)

The line function of the GR model (Eq. (1)) is able to reproduce any spectral line profile, regardless of the number of the line's components (DACs or SACs). This means that it can be used for any number of absorbing or emitting regions. As a result it may also be used in the simple case that $i = 1$ and $j = 0$ or $i = 0$ and $j = 1$, meaning when we deal with simple, classical absorption or emission spectral lines, respectively. This means that we can calculate all the important physical parameters, such as the rotational, the radial and the random velocities, the optical depth, the column density and the absorbed or emitted energy, for all the simple and classical spectral lines in all the spectral ranges.

3.1.2. The case of many absorption or emission components

In the GR line function (Eq. (1)) the final profile that is produced by a group of absorption lines is given by the product of the line functions of each SAC. On the other hand, the final profile that is produced by a group of emission lines is given by the addition of the line functions of each SAC. The addition of a group of functions is completely different than the multiplication of functions. The spectral line profile that results from the addition of a group of functions is exactly the same with the profile that results from a composition of the same functions. On the contrary, the product of a group of functions is completely different from the composition of the same functions. As a result, we can use the composition of functions for the emission lines, but not for a group of absorption components. This means that in such a case we can not refer to the law of reversion of the spectral lines.

The function $I_{\lambda i} = e^{-L_i \xi_i}$ reproduces the spectral line profile formed by the i density region (profile of one component). In the case of the GR distribution function (Eq. (2)), for each quadruplet of the parameters $V_{rot(i)}, V_{rad(i)}, V_{rand(i)}$ and $\xi_{(i)}$ we have a different profile. This results to the existence of only one quadruplet able to give the best fit of the i component.

3.1.3. Fitting criteria

In order to accept as best fit of the observed spectral line, what is given by the quadruplet $(V_{rot(i)}, V_{rad(i)}, V_{rand(i)}, \xi_{(i)})$ of all the calculated SACs, we must adhere to all the physical criteria and techniques.

First of all, it is necessary to have the superposition of the spectral region that we study with the same region of a classical star of the same spectral type and luminosity class, in order to identify the existence of spectral lines that blend with the studied ones and the existence of SACs.

The resonance lines, as well as those that form in regions close to each other (small difference in ionization potential), must have the same number of SACs and the same values for V_{rot}, V_{rad} and V_{rand}. Besides, in the cases of resonance lines and of lines of the same ion and the same multiplet, the ratio of the values of ξ must be the same as the ratio of the respective intensities.

The final criterion to accept or reject a best fit is that the calculated values of the physical parameters should not go against the classical physical theory.

3.1.4. Method for the fitting of a spectral line

In order to conclude to the group of the parameters which give us the best fit, we use the model by the following two methods:

- In the first method we consider that the main reason of the line broadening of the main line and the satellite components is the rotation of the region which creates the components of the observed feature and a secondary reason is the thermal Doppler broadening. This means that we start fitting the line using the maximum V_{rot}. Then, we include Doppler broadening, in order to accomplish the best fit (rotation case).
- In the second method, we consider the opposite. This means that in this case the main reason of the line broadening of the main line and the satellite components is supposed to be the thermal Doppler broadening and the secondary reason is the rotation of the region which creates the components of the observed feature. This means that we start fitting the line using the maximum Doppler broadening. Then we include the rotation of the region, by increasing V_{rot}, in order to accomplish the best fit (Doppler case).

In both of the above cases (rotation case and Doppler case) we check the correct number of satellite components that construct the whole line profile. First we try to fit with one component. We add another one only when we see that we cannot fit with only one component. We keep adding components until we accomplish the best fit. Finally, we fit using the number of the components that give the best difference graph between the fit and the real spectral line (step by step, component by component). Then we fit using one component less than in the previous fit. The *F*-test between them allows us to take the correct number of satellite components that construct in the best way the whole line profile.

The *F*-test between these two cases indicates the best way to fit the spectral lines. When the *F*-test cannot give definite conclusion on which case we should use, we still could obtain information about the limits of V_{rot} and σ. If the *F*-test gives similar values, then the rotation case defines the maximal V_{rot} and the minimal σ and the Doppler case defines the minimal V_{rot} and the maximal σ.

The profile of every main spectral line and its SACs is fitted by the function $e^{-L_i \xi_i}$, in the case of an absorption component or by $S_{\lambda ej}(1 - e^{-\tau_{ej}})$, in the case of an emission component. These functions produce symmetrical line profiles. However, we know that most of the spectral lines that we have to reproduce are asymmetric. This fact is interpreted as a systematical variation of the apparent radial velocities of the density regions where the main spectral line and its SACs are created. In order to approximate those asymmetric profiles we have chosen a classical method. This is the separation of the region, which produces the asymmetric profiles of the spectral line, in a small number of sub-regions, each of which is treated as an independent absorbing shell. In this way we can study the variation of the density, the radial shift and the apparent rotation as a function of the depth in every region which produces a spectral line with an asymmetric profile. All the above must be taken into account during the evaluation of our results and one should not consider that the evaluated parameters of those sub-regions correspond to independent regions of matter, which form the main spectral line or its SACs. In this case we could use asymmetric

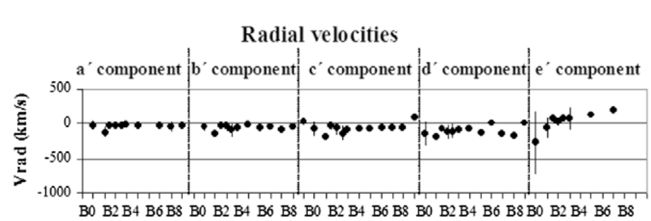

Fig. 7. Radial velocities of the regions that create the Si IV resonance lines as a function of the spectral subtype, in a sample of 68 Be stars (Lyratzi et al., 2007).

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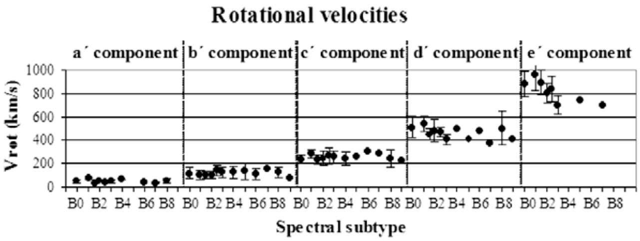

Fig. 8. Rotational velocities of the regions that create the Si IV resonance lines as a function of the spectral subtype, in a sample of 68 Be stars (Lyratzi et al., 2007).

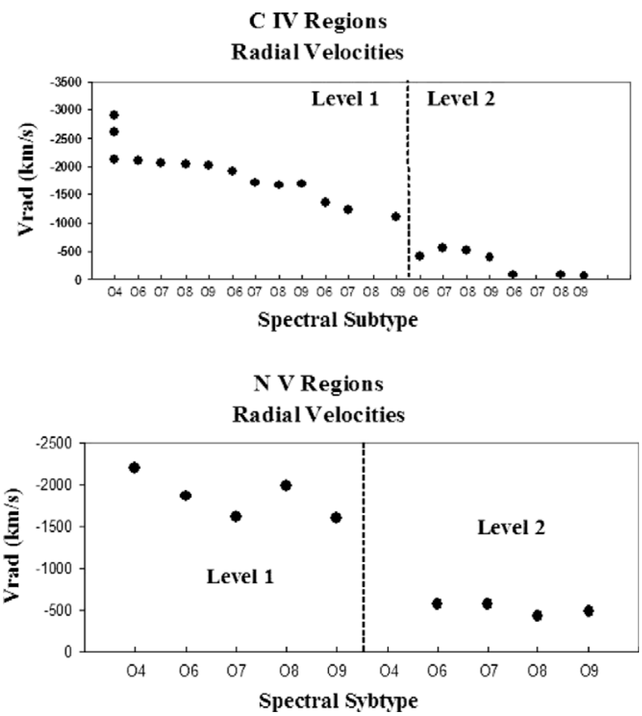

Fig. 9. Radial velocities V_{rad}) in the C IV region (left) and in the N V region (right) as a function of the spectral subtype. We detect two levels of radial velocities in both regions. The first level has high values (between −3000 and −1500 km s^{-1} in the C IV region and between −2300 and −1500 km s^{-1} in the N V region) and the second level has low values (between −500 and −20 km s^{-1} in the C IV region and between −500 and −100 km s^{-1} in the N V region) (Antoniou et al., 2008).

distributions (e.g. Maxwell). This means that we could fit the observed profile with an asymmetric mathematical distribution. However, until now we do not have an expression of the distribution function L_i that would correspond to a Maxwell distribution and which would include physical parameters. As a result, even if we could fit the observed profile with a mathematical asymmetric distribution, we would not be able to calculate any physical parameter. In order to be able to calculate some physical parameters, we use the above mentioned way.

4. Some results from our studies with Gauss-rotational model

As we have already mentioned, with GR model, we can calculate many parameters of the regions where the studied spectral lines are created. Such parameters are the apparent rotational and radial velocities, the random velocities of the ions, as well as the full width at half maximum, the optical depth in the center of the line, the column density and the absorbed or emitted energy of the independent density regions of matter which produce the SACs/DACs of the studied spectral lines. Here we present some results of our studies on hot emission stars (see also Lyratzi et al., 2005; Lyratzi et al., 2007; Danezis et al., 2007b; Antoniou et al., 2008). In Figs. 7 and 8 we give the results of our study of 68 Be stars (Lyratzi et al., 2007). Specifically, Figs. 7 and 8 show the radial and the rotational velocities of the regions that create the Si IV resonance lines as a function of the spectral subtype, respectively. From the calculation of the above mentioned parameters we can study the relations between them. In a study of 20 Oe stars, we calculated

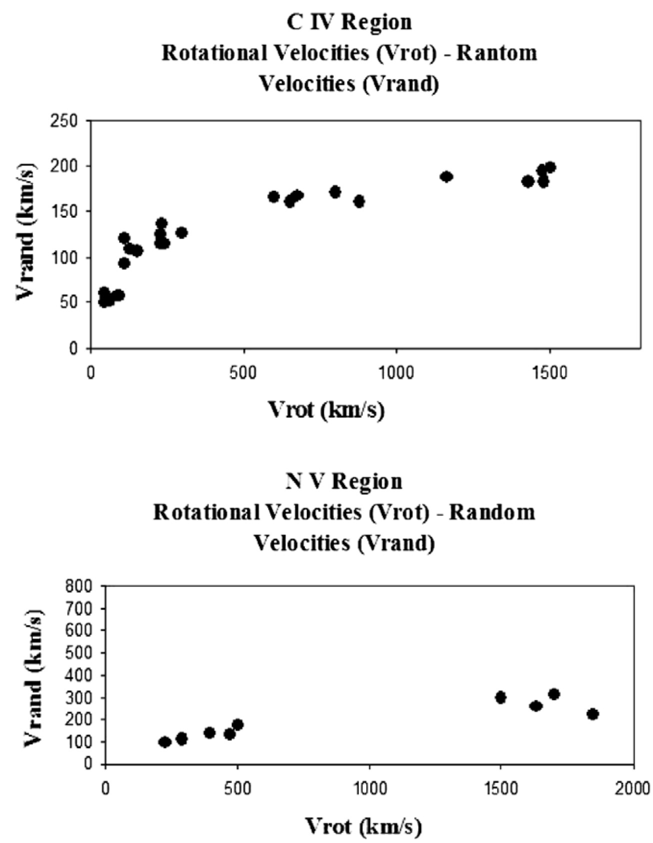

Fig. 10. The random velocities of the CIV and NV density regions, as a function of the apparent rotational velocities, in a sample of 20 Oe stars.

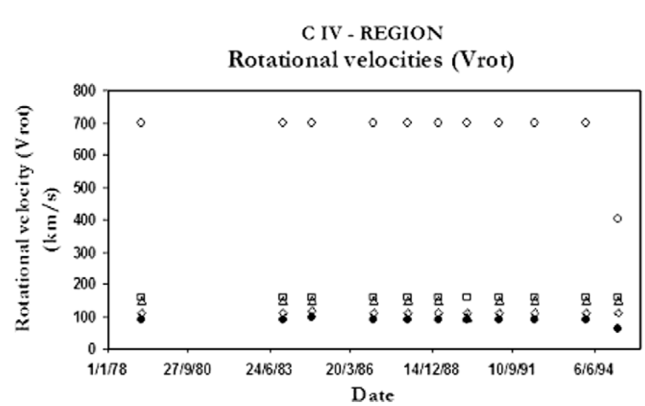

Fig. 11. Timescale changes of the apparent rotational velocities (V_{rot}) (km/s) of the C IV resonance lines ($\lambda\lambda$1548.155, 1550.774 Å) for the independent density regions of matter which create the five satellite components in the spectra of the Oe star HD 93521. The low value (about 400 km/s) in the first component has been tested carefully (Danezis et al., 2007b).

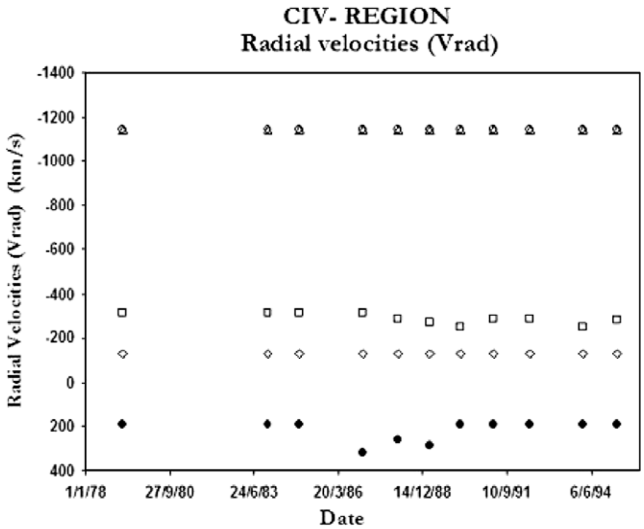

Fig. 12. Timescale changes of the radial velocities (V_{rad}) (km/s) of the $\lambda\lambda$ 1548.155, 1550.774 Å C IV resonance lines for the independent density regions of matter which create the five satellite components in the spectra of the Oe star HD 93521 (Danezis et al., 2007b).

the kinematical parameters of the density regions that create the SACs/DACs (Fig. 9) and the relation among these parameters (Fig. 10). Fig. 9 shows the radial velocities (V_{rad}) in the C IV region (up) and in the N V region (down) as a function of the spectral subtype. We detect two levels of radial velocities in both regions (Antoniou et al., 2008). In Fig. 10 we present the relation between the rotational and random velocities of the density regions that create the C IV (a) and the N V (b) spectral lines, in the studied 20 Oe stars. Finally, in a statistical study of the Oe star HD 93521 (Danezis et al., 2007b) we calculated the timescale changes of the kinematical parameters of the density regions that create the C IV resonance lines (Figs. 11 and 12).

5. Conclusions

In this review we discuss the complex absorption lines in spectra of hot emission stars and quasars. We propose the GR model that can describe such complex spectral line taking into account the ejection of material (radial velocity) as well as rotational and micro-turbulent velocity in the density region around the objects. In brief, the results of our study are as follows:

1. We applied successfully the GR model to a great number of spectral lines of hot emission stars and quasars.
2. We were able to explain the origin of DACs phenomenon and to propose the SACs phenomenon in order to explain the complex structure of the observed profiles of many spectral lines that are created in the environment of hot emission stars. Especially, we were able to reproduce and explain the complex profiles of the spectral lines that are created in the plasma condensations formed in the density regions of hot emission stars (such as the post-coronal regions). These regions lie near the star and are formed by the plasma which is violently ejected from the stellar active regions. This means that the material that comes from the star has not the form of a classical stellar wind.

By the calculation of a number of parameters for the first time, we are able to study the physical laws that exist in the regions where the spectral lines that present DACs and SACs are created.

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