Mem. S.A.It. Suppl. Vol. 15, 13

Memorie della
Supplementi

Studying the complex spectral line profiles in the spectra of hot emission stars and quasars

E. Danezis[1], E. Lyratzi[1,2], A. Antoniou[1], L. Č. Popović[3], and M. S. Dimitrijević[3,4]

[1] University of Athens, Faculty of Physics Department of Astrophysics, Astronomy and Mechanics, Panepistimioupoli, Zographou 157 84, Athens, Greece;
e-mail: edanezis@phys.uoa.gr
[2] Eugenides Foundation, 387 Sygrou Av., 17564, Athens, Greece
[3] Astronomical Observatory of Belgrade, Volgina 7, 11160 Belgrade, Serbia
[4] Laboratoire d'Étude du Rayonnement et de la Matiére en Astrophysique, Observatoire de Paris-Meudon, UMR CNRS 8112, Bâtiment 18, 5 Place Jules Janssen, F-92195 Meudon Cedex, France

Abstract. Some Hot Emission Stars and AGNs present peculiar spectral line profiles which are due to DACs and SACs phenomena. The origin and the mechanisms which are responsible for the creation of DACs/SACs is an important problem that has been studied by many researchers. This paper is a review of our efforts to study the origin and the mechanisms of these phenomena. At first we present a theoretic ad hoc picture for the structure of the plasma that surrounds the specific category of hot emission stars that present DACs or SACs. Then we present the mathematical model that we constructed, which is based on the properties of the above ad hoc theoretical structure. Finally, we present some results from our statistical studies that prove the consistency of our model with the classical physical theory.

Key words. Hot Emission Stars: spectral lines; Quasars: spectral lines

1. Introduction

One of the main characteristics of hot emission stars, which also distinguish them from the classical hot stars, is the presence of strong PCygni profiles in their Balmer series (Curtiss 1916). When the UV spectral region of these stars was studied, some emission lines were observed in that spectral region too (Underhill & Doazan 1982).

Additionally, 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). We call these absorption spectral lines, which do not correspond to any known absorption line of the same spectral type stars, Discrete Absorption Components (DACs) (Bates & Halliwell 1986).

The mechanisms which are responsible for the creation of DACs is an important problem that has been studied by many researchers. Some of them have suggested mechanisms that allow the

Send offprint requests to: E. Danezis

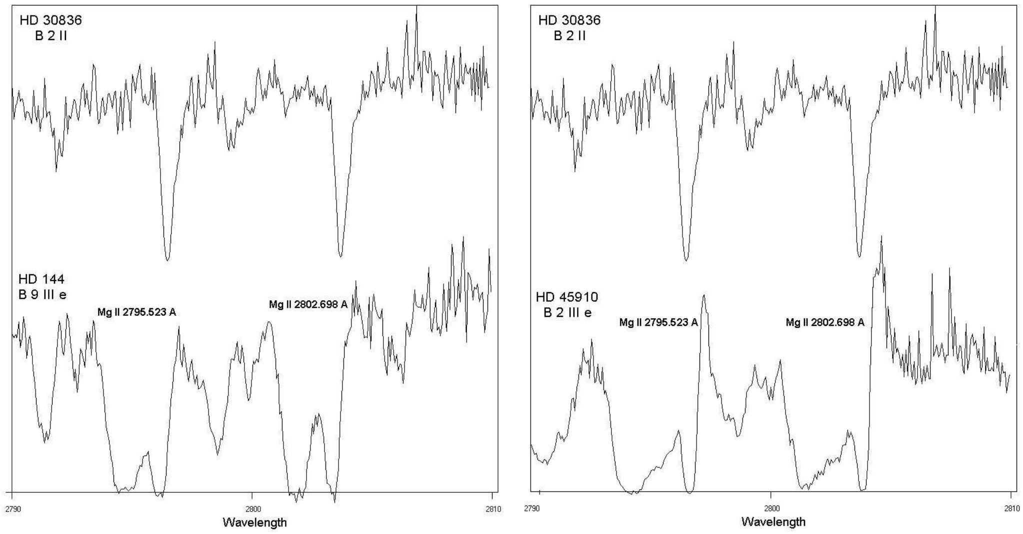

Fig. 1. Comparison of the Mg II resonance lines between the spectrum of a normal B star and the spectra of two active Be stars that present complex and peculiar spectral lines. As we can observe the Be stars present some absorption components that do not appear in the spectrum of the classical B star.

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, 1994; Cranmer & Owocki 1996; Rivinius et al. 1997; Kaper et al. 1996, 1997, 1999; 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 (Cranmer & Owocki 1996; Kaper et al. 1996, 1997, 1999; Mulan 1984a,b, 1986; Prinja & 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.

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 1983, 1987; Danezis et al. 1991, 2003; Lyratzi & Danezis 2004).

Another problem of the hot emission stars that present DACs is the presence of very complex profile of the main or the discrete components of the spectral lines that we can't reproduce theoretically. This means that we can't fit these line profiles with a known distribution, such as Gaussian, Voight, or Lorenzian. As a result 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 profiles Danezis et al. (2003, 2007a); Lyratzi & Danezis (2004); Lyratzi et al. (2007a) proposed the phenomenon of SACs (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 1983, 1987; Sahade et al. 1984; Sahade & Brandi 1985; Danezis et al. 2003, 2006, 2007a; Lyratzi & Danezis 2004). The existence of SACs results to the formation of the complex structure of the observed spectral features.

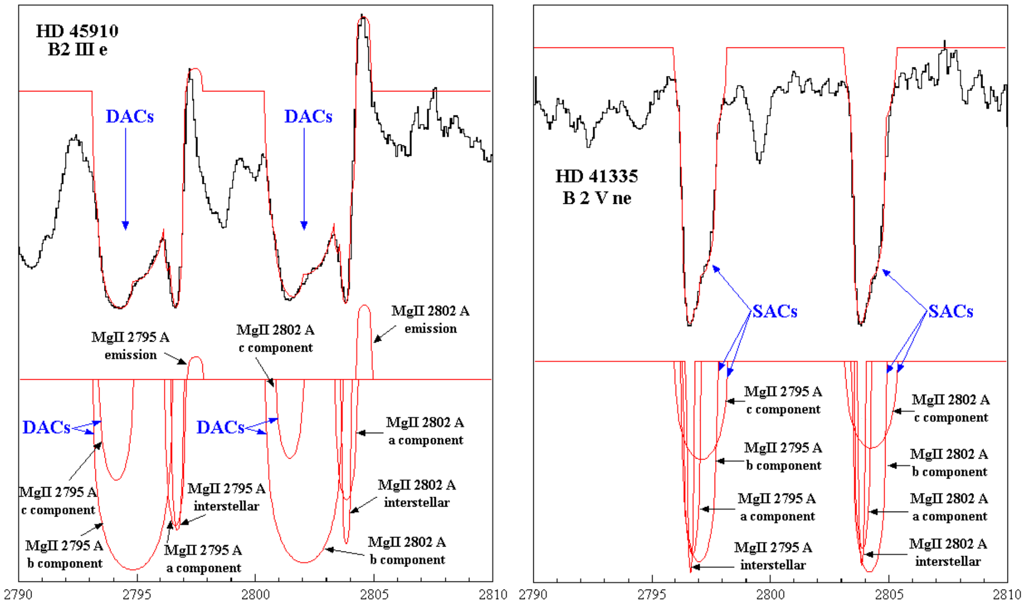

Fig. 2. DACs of the Mg II UV resonance line profiles of the Be star AX Mon (HD 45910) and SACs of the Be star HD 41335 are produced in the same way. The black line presents the observed spectral line's profile and the red one the model's fit. All the components which contribute to the observed features are shown separately.

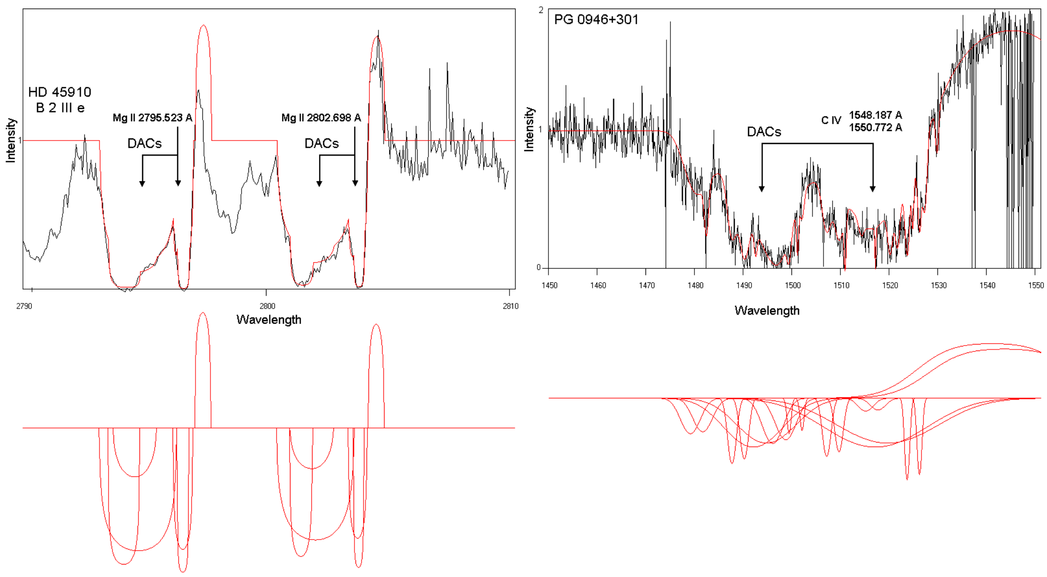

Fig. 3. DACs phenomena in AGNs spectra: Similarity of DACs phenomenon in Be star's HD 45910 spectrum (Mg II UV resonance lines) with AGNs' PG 0946+301spectrum (C IV doublet). In the case of the C IV doublet, the two discrete features do not correspond to the two resonance lines, as the two members of the doublet have small difference in wavelength (1548.187Å and 1550.772 Å) and they both lie at the right feature.

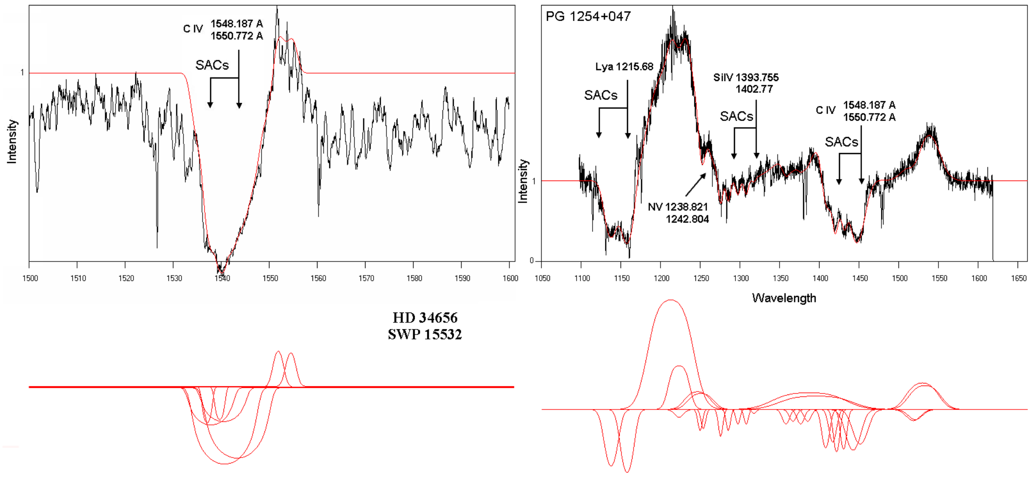

Fig. 4. SACs phenomena in AGNs spectra: Similarity of SACs phenomenon in Oe star's HD 34656 spectrum (C IV doublet) with AGNs PG 1254+047 spectrum (Lya and Si IV and C IV doublets).

As we can deduce from the above, the DACs and SACs are two aspects of the same phenomenon. In Fig. 2 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.

It is very important to point out that we can detect the same phenomenon in the spectra of some Active Galactic Nuclei (AGN) (Danezis et al. 2006). In Fig. 3 (right) we can see the CIV UV doublet of an AGN (PG 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 (e.g. HD 45910). Since the DACs phenomenon is present in some AGNs spectra, we also expect the presence of SACs phenomenon, which is able to explain the observed absorption lines complex profiles (Fig. 4). 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 (Fig. 5) (Danezis et al. 2006).

- Based on the above mentioned observational facts, our first step was the composition of a theoretic ad hoc picture for the structure of the plasma that surrounds the hot emission stars, which present DACs or SACs. This theoretic ad hoc picture should cover all the regions (and thus all ionization potentials) around hot emission stars, from the photosphere to the outer atmospherical regions (e.g. the Fe II, Mg II regions). Our second step was the construction of a mathematical model which, based on the properties of the described theoretical structure, should be able to:

- Reproduce the complex (due to DACs and SACs) profiles of the spectral lines and calculate a series of physical parameters of the regions where the spectral lines are created.

Be consistent with the physical theory. This means that statistically, the calculated values should lead to common physical properties of the studied atmospherical regions for all the studied stars that produce similar spectral lines.

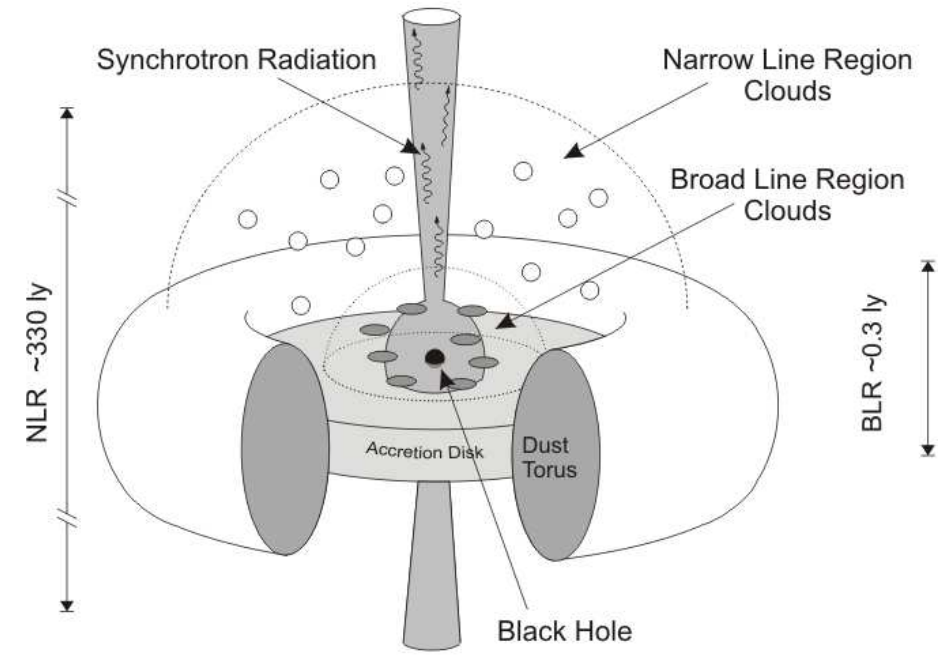

Fig. 5. The origin of DACs/SACs phenomenon in AGNs.

2. The theoretical model

According to Hubert - Delplace (1981), the existence of emission lines can be a repeated phenomenon for a star and we should consider as a fact that the ability of a B star to become Be is a function of the spectral subtype. However, we should always have in mind that there is no definite spectral classification in UV, as the spectral classification is based on the optical spectral range (Henize et al. 1981; Prinja 1990). As a result, the mechanisms of mass ejection from Be stars depend on the factors which classify the star to a specific spectral type. First, Struve (1931a,b) proposed that the Be stars are rapid rotators with velocities up to some hundreds km/s. According to Struve's model, these rapid rotators eject mass, forming a nebulous ring, when the rotational velocity takes the critical value at which the centrifugal force becomes equal to the gravitational force at the equator. However, Collins & Harrington (1966); Slettebak (1976, 1979); Friedjung (1968); Stoeckley (1968); Hardorp & Strittmater (1968) were opposed to this assumption of critical rotational velocity. They proposed that according to observations, Be stars rotate with velocities near, but not equal, to the critical one. Marlborough & Snow (1976), studying UV spectra of B stars, found a relation between the projected rotational velocity of B0-B4 stars and the results of mass loss and they proposed that the mass loss from Be stars could lead to the existence of stellar winds of large velocity, only if the rotation is able to diminish the apparent gravity near the equator. Our proposition is that in the case of Be stars that present DACs or SACs phenomena the rotational velocity could increase to greater values than the critical one, in such a way that Struve's model can be applied. This means that the Be stars of this kind may

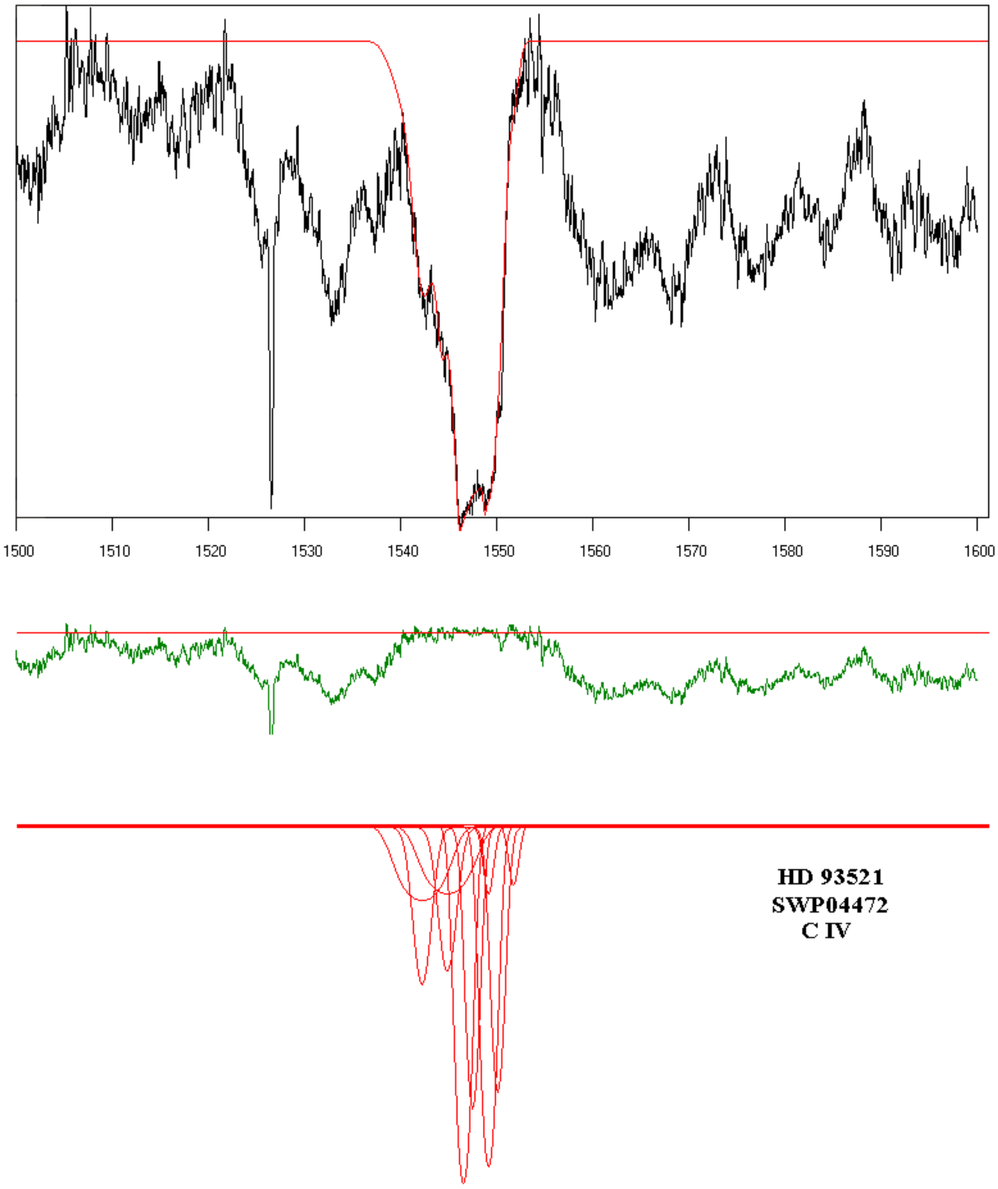

Fig. 6. Fitting of the C IV resonance lines ($\lambda\lambda$ 1548.187, 1550.772 Å) of the Oe star HD 93521, with the proposed model. The SACs phenomenon is able to explain the observed shape. Below the fitting one can see the difference graph (green), which indicates the differences between the observed and the theoretical line profile, as well as the analysis of the observed profile in its SACs (red).

eject mass from the regions around the equator, through a physical instability of the star, which disappears right after the mass ejection (Huang 1977).

The plasma which is ejected from the equatorial active regions in small but different angles, constructs a dense and expanding spherical envelope around the active star. According to the

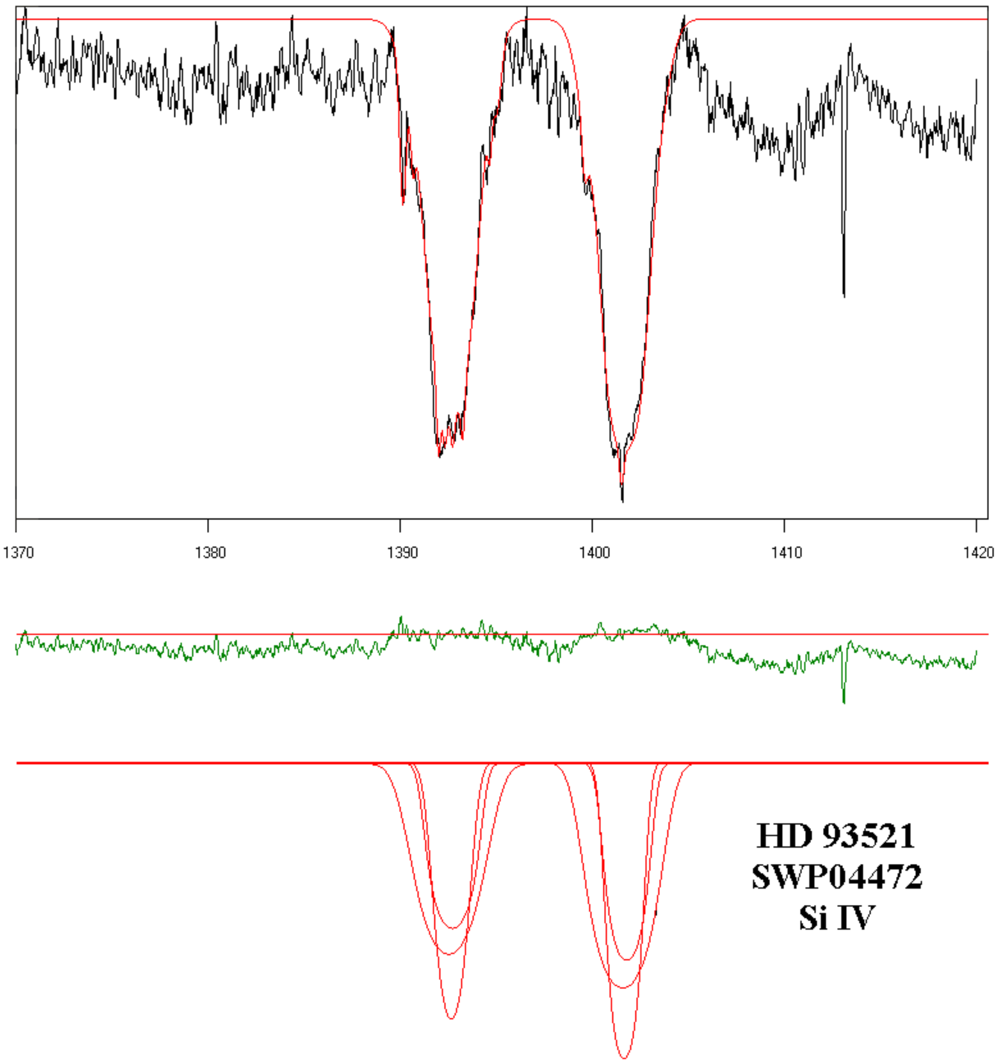

Fig. 7. Fitting of the Si IV resonance lines ($\lambda\lambda$ 1393.755, 1402.77 Å) of the Oe star HD 93521, with the proposed model. The SACs phenomenon is able to explain the observed shape. Below the fitting one can see the difference graph (green), which indicates the differences between the observed and the theoretical line profile, as well as the analysis of the observed profile in its SACs (red).

statistical study of Hubert - Delplace (1981), the e (emission) phenomenon can be repeated in the case of B stars. According to Huang (1977), sometime after the first mass ejection, the star may become unstable again and thus it may eject mass again from the equatorial regions, as its rotational velocity's value may become larger than the critical value. According to that, when we construct the mathematical model, we should also consider that the star ejects mass from the equatorial zone not once, but successively and repeatedly. In such a case, independent and successive spherical density plasma regions would surround the star (Danezis 1983). These inde-

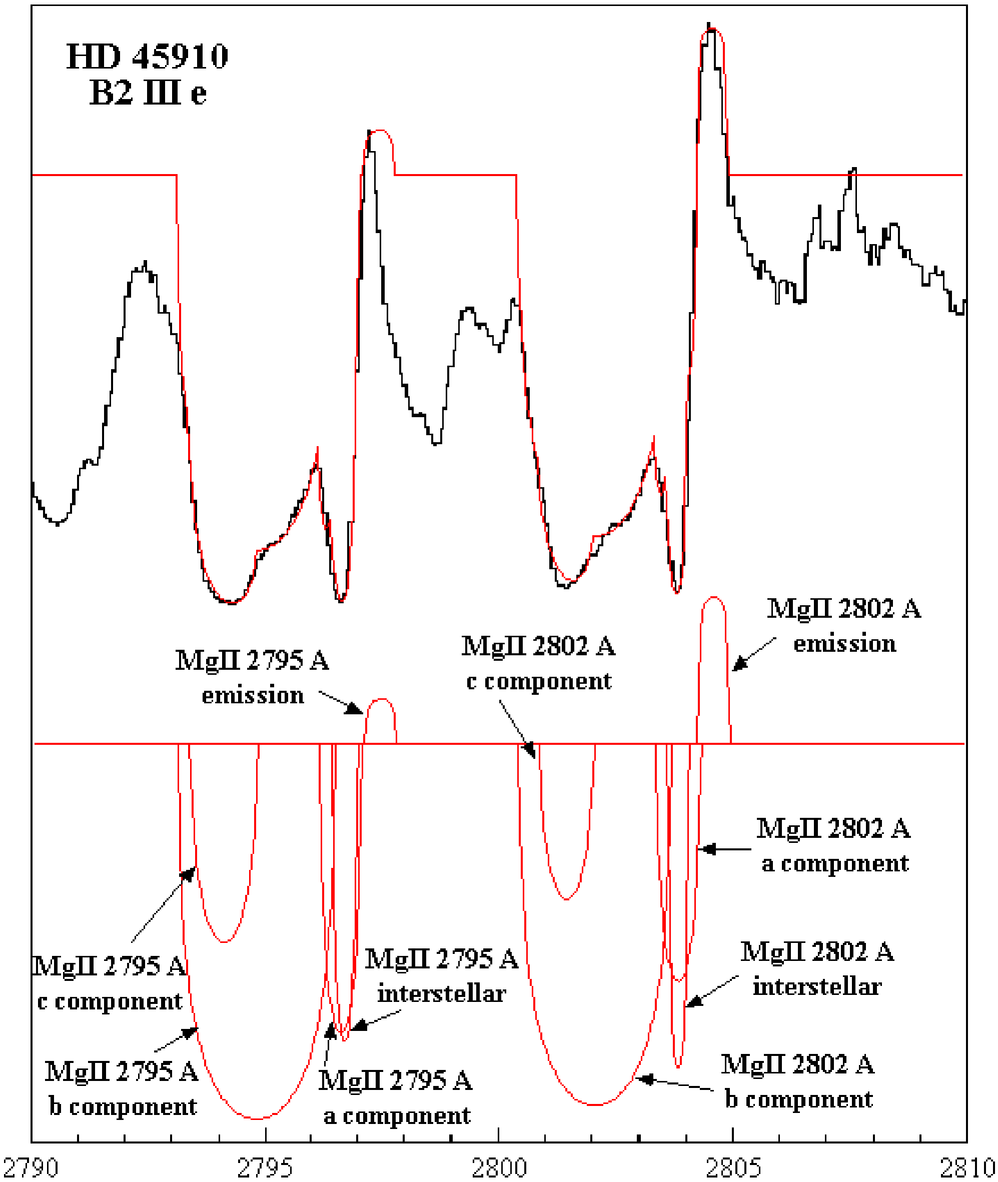

Fig. 8. Fitting of the Mg II resonance lines ($\lambda\lambda$ 1393.755, 1402.77 Å) of the Be star HD 45910, with the proposed model. The DACs and SACs phenomena is able to explain the observed shape. Below the fitting one can see the analysis of the observed profile in its DACs and SACs.

pendent density regions which move and rotate with different velocities create discrete absorption or emission components of the same spectral line in the stellar spectra. A similar phenomenon is also observed in the spectra of super novae.

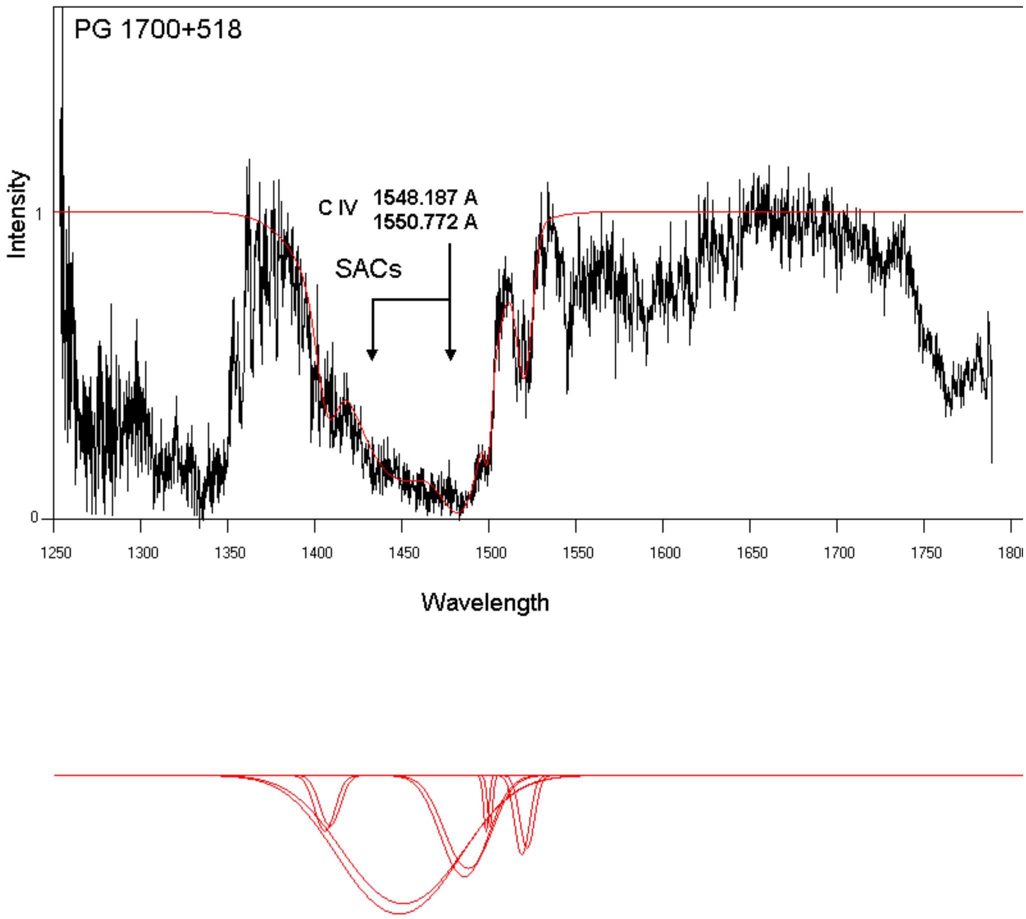

Fig. 9. Fitting of the C IV resonance lines ($\lambda\lambda$ 1548.187, 1550.772 Å) of the AGN PG 1700+518, that present SACs, with the proposed model. The SACs phenomenon is able to explain the observed shape.

As Struve's model considers, the spherical density regions that may exist around the star, evolve to an equatorial disk (Struve 1931a,b, 1942).

The plasma jets which are ejected from the equatorial active regions form blobs or structures due to magnetic fields or spiral streams resulting from the stellar rotation, which evolve in the regions where DACs and SACs are created (Cranmer & Owocki 1996; Kaper et al. 1996, 1997, 1999; Mulan 1984a,b, 1986; Prinja & Howarth 1988; Fullerton et al. 1997; Cranmer et al. 2000), These structures are local regions of high density, which have spherical symmetry around their own center and not around the star. These density regions result to the existence of absorption or emission spectral lines in the stellar spectra.

Near the hot emission stars we can detect density regions that have the characteristics of chromosphere, corona and post-coronal regions (Franco et al. 1983; Franco & Stalio 1983; Underhill & Doazan 1982, Part II, chapter 13). The corona of hot emission stars is detected in X-rays and the post-coronal regions (Si IV, C IV, N IV, N V lines e.t.c.) in UV. All the

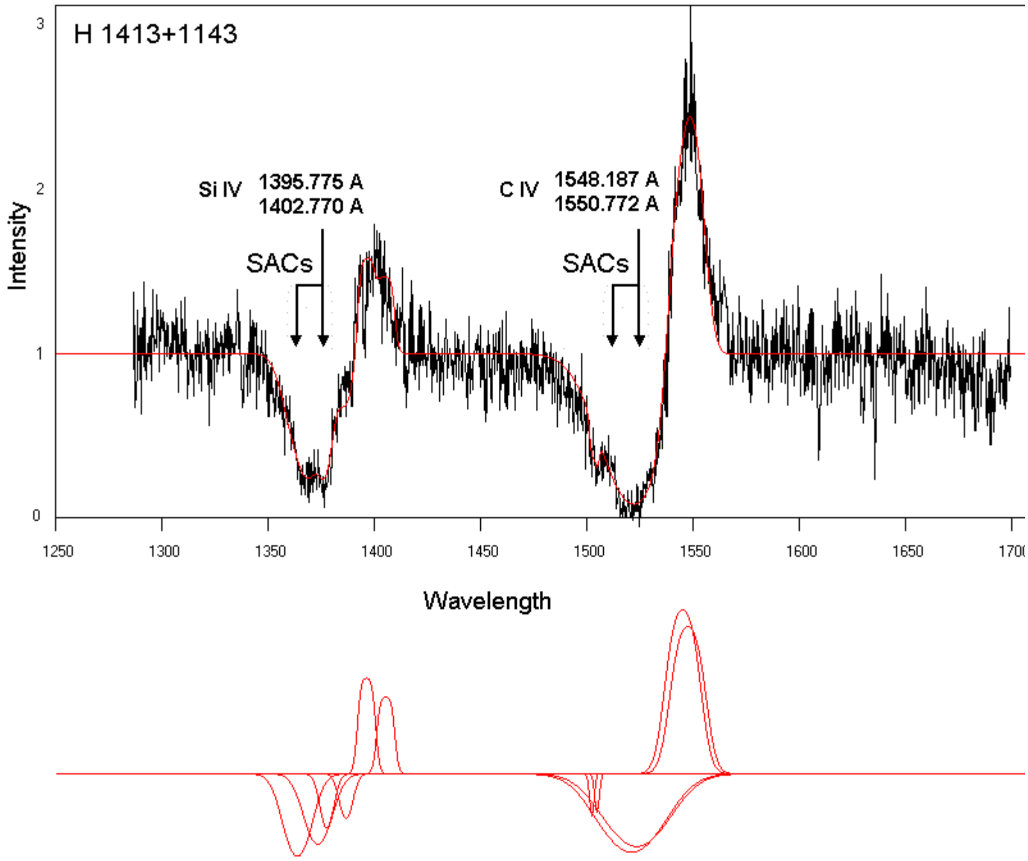

Fig. 10. Fitting of the Si IV ($\lambda\lambda$ 1393.755, 1402.77 Å) and C IV resonance lines ($\lambda\lambda$ 1548.187, 1550.772 Å) of the AGN H 1413+1143, that present SACs with the proposed model. The SACs phenomenon is able to explain the observed shape.

above lead us to the connection of Struve's model with the corona model of Thomas-Doazan (Underhill & Doazan 1982), which suggests the existence of coronal and post coronal regions.

Many ad hoc models have been proposed that do not accept the existence of chromosphere and corona. These models were constructed to represent only the observations made in the optical and infrared regions and point out that they all produce good agreement between the observed and computed spectra. We should also remind that all the models that have been proposed are ad hoc; as such, they cannot and do not pretend to be physically self-consistent. In this respect, one must keep in mind the arbitrary nature of certain hypotheses on which their construction is based, and one must not expect this picture of reality to closely describe a real star (Underhill & Doazan 1982).

All the above lead us to the conclusion that in the inner regions of the stellar atmosphere (from the photosphere to the first regions of the disk) of the stars that present DACs or SACs, the plasma is violently deranged and it does not have the form of calm stellar wind, for as long

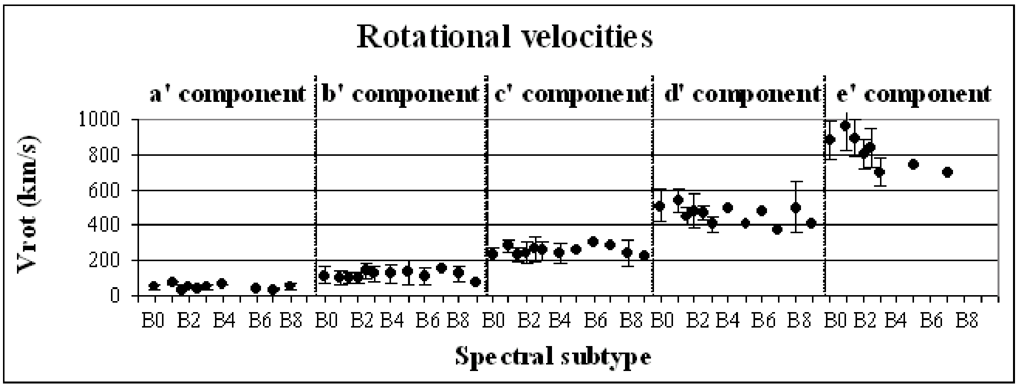

Fig. 11. Mean rotational velocities of the independent density regions of matter which create the SACs of the Si IV resonance lines ($\lambda\lambda$ 1393.755, 1402.77 Å) as a function of the spectral subtype, in a sample of 68 Be stars (Lyratzi et al. 2007b).

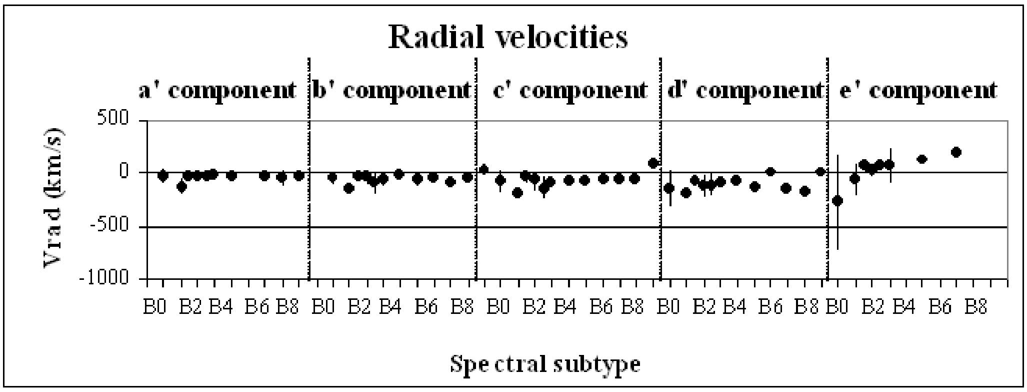

Fig. 12. Mean radial velocities of the independent density regions of matter which create the SACs of the Si IV resonance lines ($\lambda\lambda$ 1393.755, 1402.77 Å) as a function of the spectral subtype, in a sample of 68 Be stars (Lyratzi et al. 2007b).

as the e phenomenon lasts. During the e phenomenon, in the regions where the DACs or SACs are created, the majority of plasma is distributed in the density regions of spherical symmetry around the star or around their own centers. These density regions were created as a result of the violent mass ejection during the period of e phenomenon. The ejected matter takes the form of stellar wind as it goes away from the disturbed area of the inner atmospherical layers of the hot emission stars. Among the density regions, the rest of the matter has the form of stellar wind, but its density is very low compared with the matter of the density regions and thus we considered it negligible when we constructed the mathematical model.

3. The mathematical model – The line function

As we have already mentioned, in order to accept, even theoretically, all the above, we should construct a mathematical model which should include all the above ideas. This means that by solving the radiation transfer equations through a complex structure as the one described, we

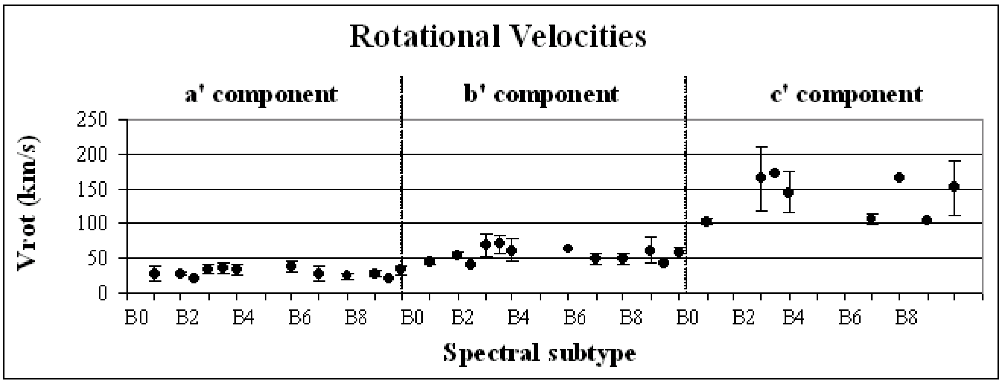

Fig. 13. Mean rotational velocities of the independent density regions of matter which create the SACs of the Mg II resonance lines ($\lambda\lambda$ 2795.523, 2802.698 Å) as a function of the spectral subtype, in a sample of 64 Be stars (Lyratzi et al. 2007b).

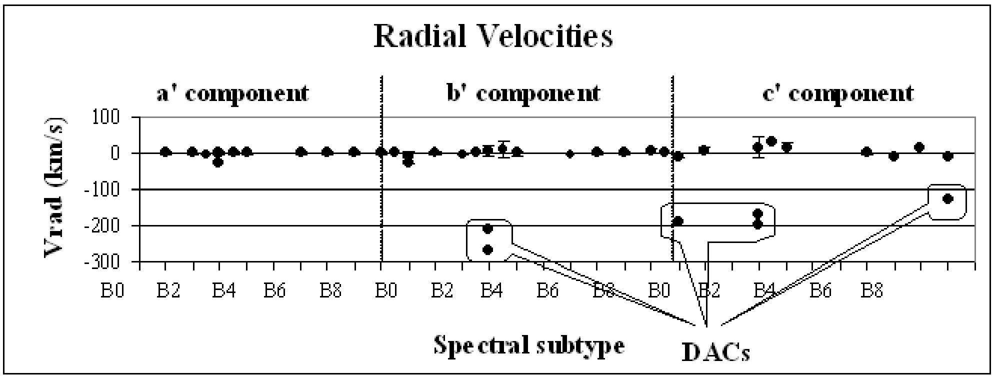

Fig. 14. Mean radial velocities of the independent density regions of matter which create the SACs of the Mg II resonance lines ($\lambda\lambda$ 2795.523, 2802.698 Å) as a function of the spectral subtype. The existence of DACs is clearly indicated, in a sample of 64 Be stars (Lyratzi et al. 2007b).

should calculate a line function, 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 many 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 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.

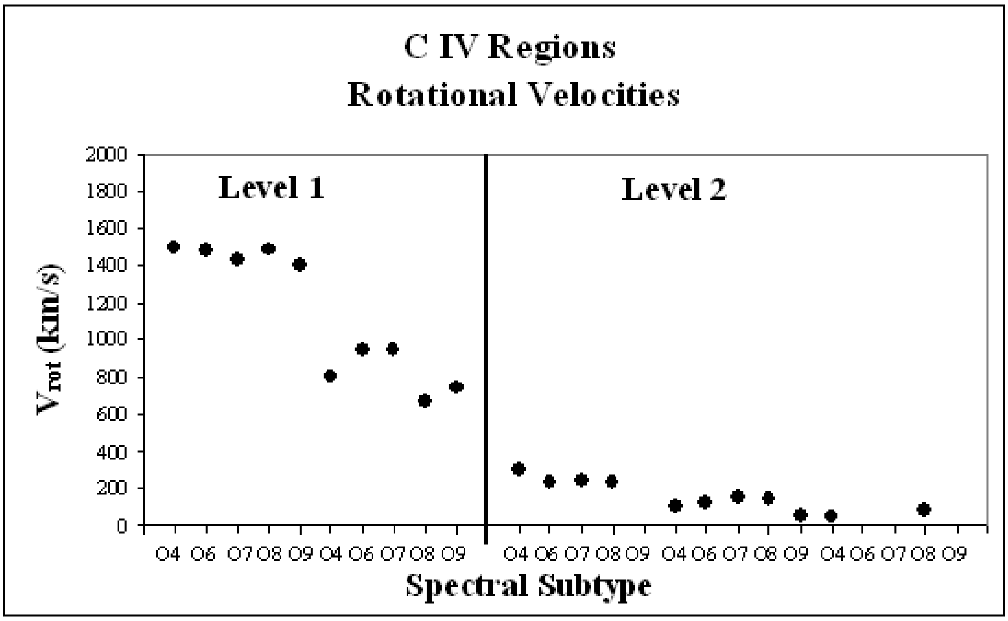

Fig. 15. Rotational velocities (V_{rot}) in the C IV region as a function of the spectral subtype, in a sample of 20 Oe stars. We detect two levels of rotational velocities (Antoniou et al. 2007a).

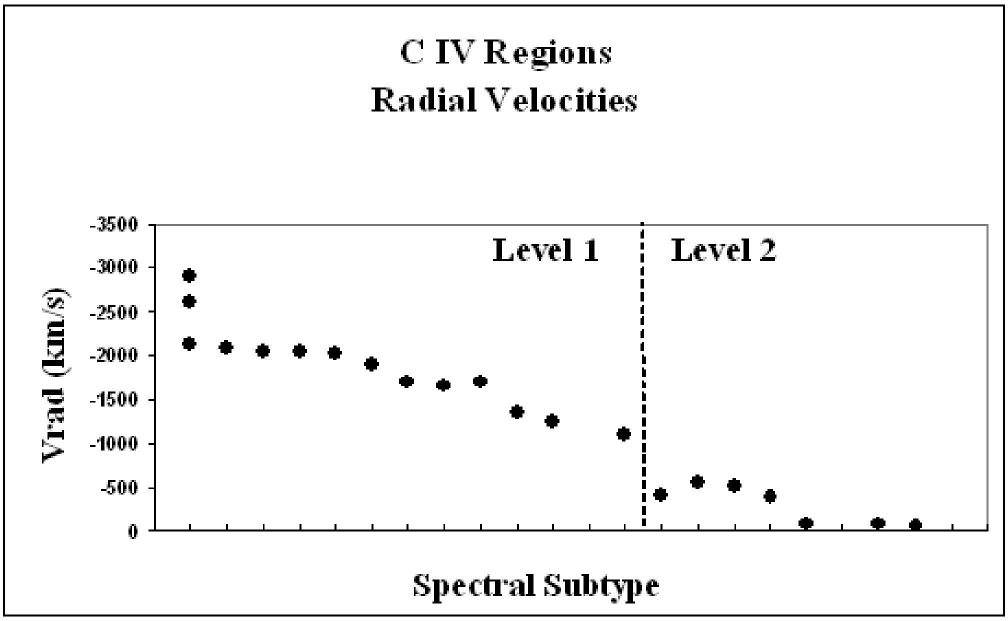

Fig. 16. Radial velocities (V_{rad}) in the C IV region as a function of the spectral subtype, in a sample of 20 Oe stars. We detect two levels of radial velocities (Antoniou et al. 2007a).

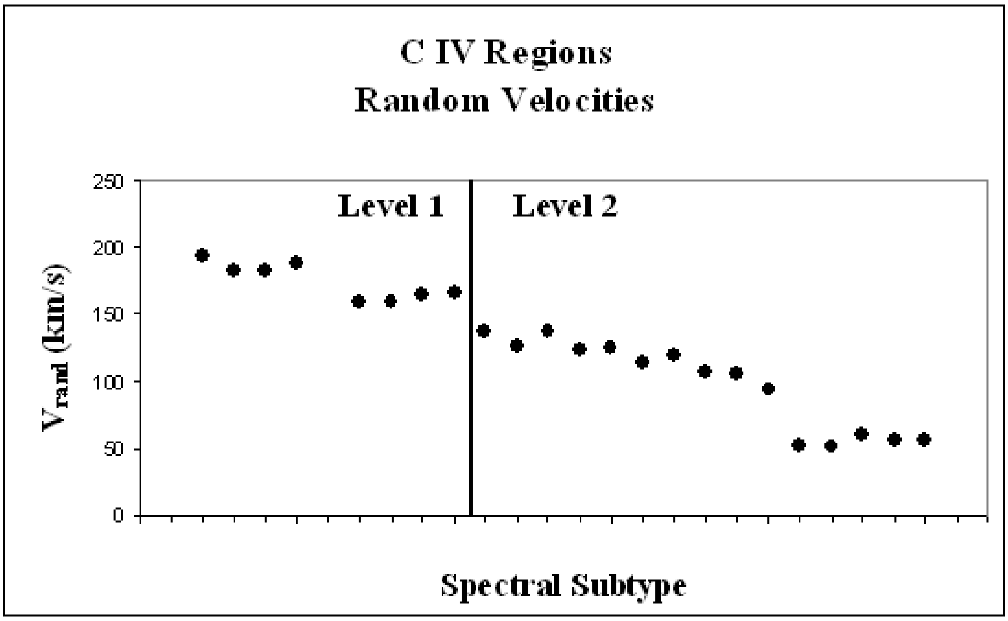

Fig. 17. Random velocities (V_{rand}) in the C IV region as a function of the spectral subtype, in a sample of 20 Oe stars. We detect two levels of random velocities (Antoniou et al. 2007a).

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 DACs/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.

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, 2007a).

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

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 many physical conditions of the region that produces the spectral line are included in the factors L_i,

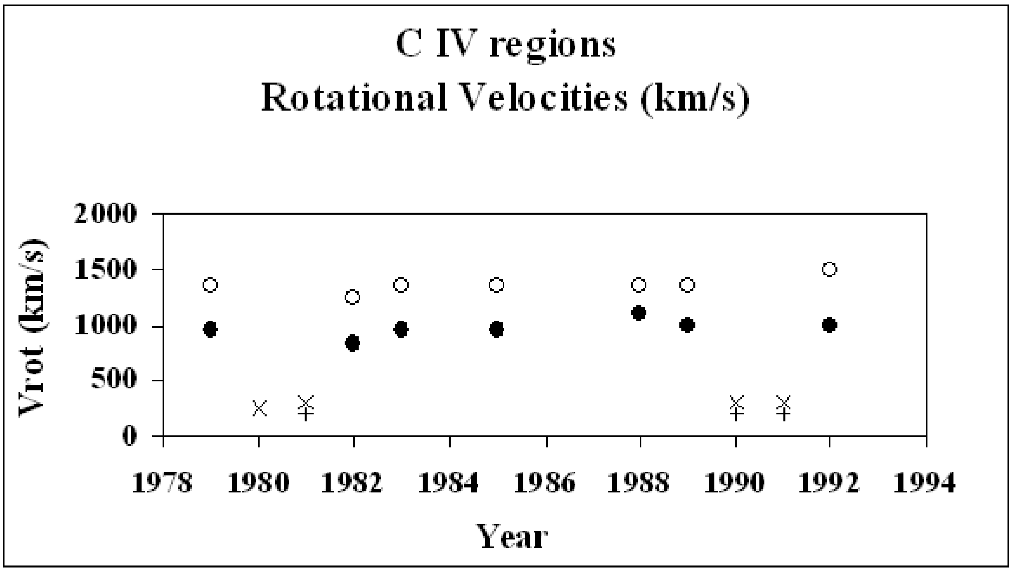

Fig. 18. Variation of the rotational velocities of the C IV density regions of the Oe star HD 149757, as a function of time (Antoniou et al. 2007c).

L_{ej} and 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 our model we considered the spherical geometry. In order to decide on the appropriate geometry we took into consideration 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; Markova 2000; Lamers et al. 1982; Bates & Gilheany 1990; Gilheany et al. 1990; Cidale 1998). Besides, 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. 2007a). 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 Gauss-Rotation distribution (GR distribution) (Danezis et al. 2007a).

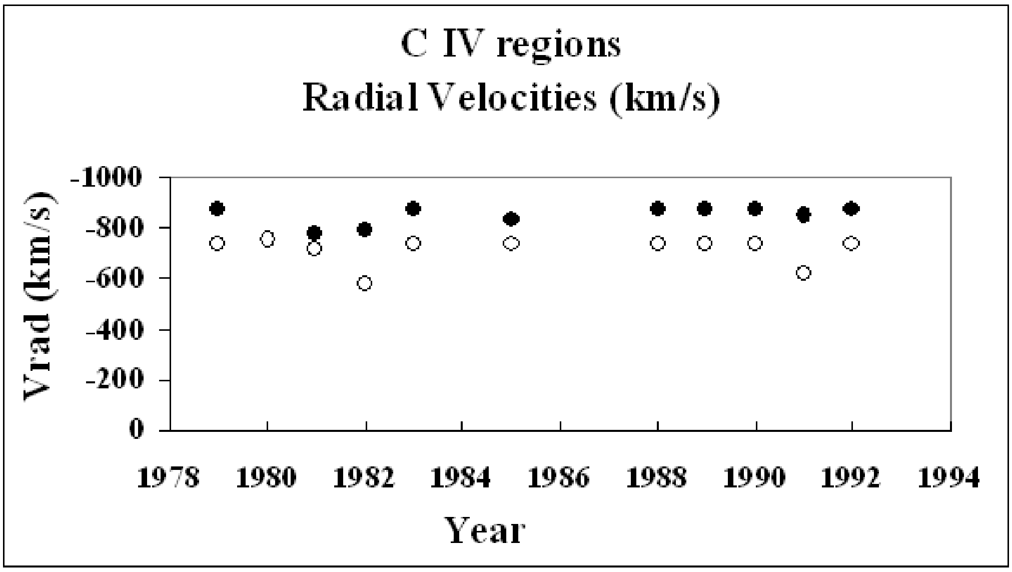

Fig. 19. Variation of the radial velocities of the C IV density regions of the Oe star HD 149757, as a function of time (Antoniou et al. 2007c).

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

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

$erf(x) = \frac{2}{\pi} \int_0^x e^{-u^2} du$, 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).

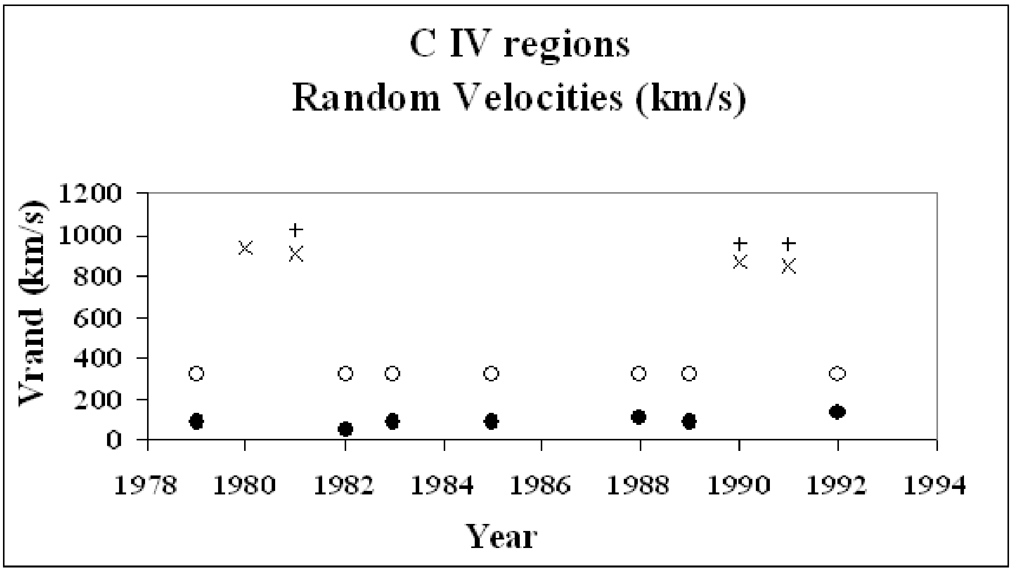

Fig. 20. Variation of the random velocities of the C IV density regions of the Oe star HD 149757, as a function of time.

4. Applications

As we have already mentioned, the validity of GR model should be judged by its application and the model should be consistent with the following two points:

- The GR model must be able to reproduce the complex (due to DACs and SACs) profiles of the spectral lines and calculate a series of physical parameters of the regions where the spectral lines are created.

- The results of GR model must be consistent with the physical theory. This means that statistically, the calculated values should lead to common physical properties of the studied atmospherical regions for all the studied stars that produce similar spectral lines.

A series of papers have been published, where the GR model is applied on a great number of stellar and galactic spectra, calculating the physical parameters of the regions where the spectral lines are created and giving consistent results with the classical physical theory (Danezis et al. 2007b, 2009; Lyratzi et al. 2007a,b, 2009; Antoniou et al. 2007a,b,c, 2008). Some of these results are presented in the following figures. In Figs. 6-10 we present the fittings of some peculiar profiles of spectral lines, observed in the spectra of hot emission stars and AGNs. In Figs. 11-17 we present the variation of kinematical parameters of the regions that create DACs or SACs, as a function of the spectral subtype, in samples of Be and Oe stars. In Figs. 18-20, we present the variation of the kinematical parameters of the C IV regions of the Oe star HD 149757, as a function of time.

5. Conclusions

In brief, the results of our study are as follows:

– We proposed a theoretic ad hoc picture for the structure of the plasma that surrounds hot emission stars, which is able to explain the origin of DACs phenomenon and we proposed 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.

- We observed the same phenomenon in the spectra of quasars and we proposed that its origin is similar as in the case of hot emission stars.
- Based on the properties of the theoretic ad hoc picture for the structure of the plasma that surrounds hot emission stars, we constructed a new mathematical model (GR model), able to reproduce theoretically the observed complex spectral line profiles. In order to do so, we calculated for the first time a line function through the solution of the radiation transfer equation.
- We calculated two new distribution functions (Rotation distribution and Gauss-Rotation distribution).
- We constructed a first version of software, in order to reproduce the observed spectral lines and to calculate some physical parameters.
- We applied successfully the GR model in a great number of spectral lines of hot emission stars and quasars. The results of GR model are consistent with the physical theory. This means that statistically, the calculated values lead to common physical properties of the studied atmospherical regions for all the studied stars or quasars that produce similar spectral lines.

Acknowledgements. This research project is progressing at the University of Athens, Department of Astrophysics, Astronomy and Mechanics, under the financial support of the Special Account for Research Grants, which we thank very much. This work also was supported by Ministry of Science Technological Development of Serbia and, through the projects 'Influence of collisional processes on astrophysical plasma line shapes' and 'Astrophysical spectroscopy of extragalactic objects'.

References

Antoniou, A. et al. 2007a, UVAstronomyJD04, 113
Antoniou, A. et al. 2007b, AIPC, 938, 194
Antoniou, A. et al. 2007c, AIPC, 938, 198
Antoniou et al. 2008, JPhCS, 133a, 2028
Bates, B. & Halliwell, D. R. 1986, MNRAS, 223, 673
Bates, B. & Gilheany, S. 1990, MNRAS, 243, 320
Cidale, L. S. 1998, ApJ, 502, 824
Cranmer, S. R. & Owocki, S. P. 1996, ApJ, 462, 469
Cranmer, S. R. et al. 2000, ApJ, 537, 433
Collins, G. W. & Harrington, J. P. 1966, ApJ, 146, 152
Curtiss, R. H. 1916, Publ. Obs. Univ. Michigan, 2, 1
Danezis, E. 1983, The nature of Be stars, PhD Thesis (University of Athens)
Danezis, E. 1987, IAU, Colloq. No 92, Physics of Be Stars (Cambridge University Press)
Danezis, E. et al. 1991, Ap&SS179, 111
Danezis, E. et al. 2003, Ap&SS, 284, 1119
Danezis, E. et al. 2005, MemSAIS, 7, 107
Danezis, E. et al. 2006, AIPC, 876, 373
Danezis, E. et al. 2007a, PASJ, 59, 827
Danezis, E. et al. 2007b, AIPC, 938, 119
Danezis, E. et al. 2009, NewAR, 53, 214
Franco, M. L. et al. 1983, A&A, 122, 9
Franco, M. L. & Stalio, R. 1983, MemSAI, 54, 537
Friedjung, M. 1968, ApJ, 151,779
Fullerton, A. W. et al. 1997, A&A, 327, 699
Gilheany, S. et al. 1990, Ap&SS, 169, 85

Grady, C. A. et al. 1987, ApJS, 65, 673.
Hardorp, J. & Strittmater, P. A. 1968, ApJ, 153, 465
Henize et al. 1981, AJ, 86, 1658
Henrichs, H. F. 1984, Proc. 4th European IUE Conf., ESA SSSP-218, p.43, eds Rolfe, E. & Battrick, B., Rome
Hubert - Delplace, A.M. 1981 in Proc. IAU Symp. 98, Be stars, eds. M. Jaschek and H. G. Groth (Dordrecht: Reidel), p. 125
Huang, S. S. 1977, ApJ, 212, 121
Kaper, L. et al. 1996, A&AS, 116, 257
Kaper, L. et al. 1997, A&A, 327, 281
Kaper, L. et al. 1999, A&A, 344, 231
Lamers et al. 1982, ApJ, 258, 186
Lamers et al. 1988, ApJ, 325, 342
Lyratzi, E. & Danezis, E. 2004, AIPC, 740, 458
Lyratzi, E. et al. 2007a, PASJ, 59, 357
Lyratzi, E. et al. 2007b, AIPC, 938, 176
Lyratzi, E. et al. 2009, NewAR, 53, 179
Markova, N. 2000, A&AS, 144, 391
Marlborough, J. M. & Snow, T. P. 1976, in Proc. IAU Symp. 70, Be and Shell Stars, ed. A. Slettebak (Dordrecht: Reidel), p. 179
Mulan, D. J. 1984a, ApJ, 283, 303
Mulan, D. J. 1984b, ApJ, 284, 769
Mulan, D. J.: 1986, A&A, 165, 157
Prinja, R. K. & Howarth, I. D. 1988, MNRAS, 233, 123
Prinja, R. K. 1990, MNRAS, 246, 392
Rivinius, Th. et al. 1997, A&A, 318, 819
Sahade, J. et al. 1984, A&AS, 56, 17
Sahade, J. & Brandi, E. 1985, Rev. Mex. Astron. Astrofis. 10, 229
Slettebak, A. 1976, in Proc. IAU Symp. 70, Be and Shell Stars, ed. A. Slettebak (Dordrecht: Reidel), p. 123
Slettebak, A. 1979, SSRv, 23, 541
Stoeckley, T. R. 1968, MNRAS, 140, 141
Struve, O. 1931a, ApJ, 73, 94
Struve, O. 1931b, ApJ, 74, 225
Struve, O. 1942, ApJ, 95, 134
Tuthill, P. et al. 1999, Nature, 398, 487
Underhill, A. B. 1975, ApJ, 199, 693
Underhill, A. B. & Doazan, V. 1982, B Stars with and without emission lines, NASA SP–456, Part II, chapter 10
Underhill, A. B. & Fahey, R. P. 1984, ApJ, 280, 712
Waldron, W. L. et al. 1992, nvos.work, 181
Waldron, W. L. et al. 1994, ApJ, 426, 725