The complex structure of the Si IV λλ 1393.755, 1402.77 Å regions of 68 Be-type stars

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Introduction

As it is already known, the spectra of many Oe and Be stars present Discrete Absorption Components (DACs) which, due to their profiles' width as well as the values of the radial velocities, create a complicated profile of the main spectral lines (Bates & Halliwell, 1986). In this poster paper we detect the presence of this phenomenon (DACs or SACs) in the Si IV resonance lines in the spectra of 68 Be-type stars of all the spectral subtypes and luminosity classes.

In our study we apply the method proposed by Danezis et al. (2003) on the spectra of 68 Be stars, taken with I.U.E. and we examine the variations of the physical parameters, stated below, as a function of the spectral subtype.

We found that the absorption atmospherical regions where the Si IV resonance lines originated may be formed of one to five independent density layers of matter which rotate with different velocities, producing one to five Satellite Absorption Components (SACs or DACs, Lyratzi & Danezis 2004). With the above method we calculate the values of the apparent rotational and radial velocities, as well as the optical depth of the independent regions of matter which produce the main and the satellites components of the studied spectral lines.

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

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

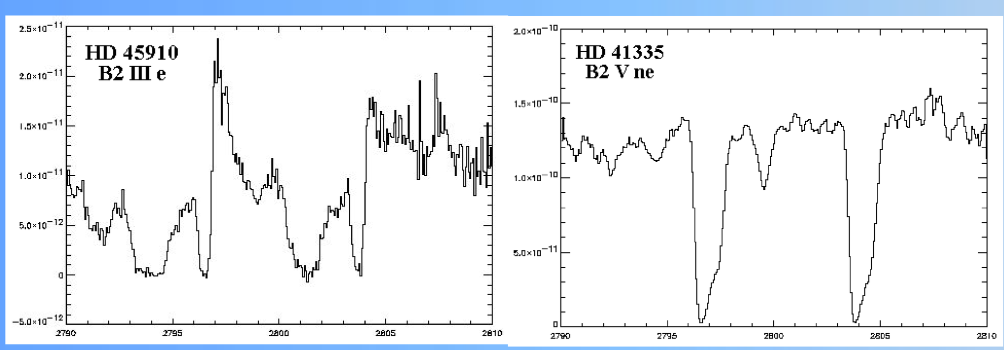
In the spectra of many Oe and Be stars some spectral lines are accompanied by **Discrete Absorption Components (DACs)** (Bates & Halliwell 1986, Prinja 1988, Willis et al. 1989, Bates & Gilheany 1990, Gilheany et al. 1990, Waldron et al. 1994, Henrichs et al. 1994, Telting et al. 1993, Telting & Kaper 1994, Cranmer & Owocki 1996, Prinja et al. 1997, Fullerton et al. 1997, Kaper et al. 1996, 1997, 1999, Cranmer et al. 2000) or **Satellite Absorption Components (SACs)** (Peton 1974, Lamers et al. 1982, Sahade et al. 1984, Sahade & Brandi 1985, Hutsemékers 1985, Danezis 1987, Danezis et al. 1991, 2003, Laskarides et al. 1992a,b, Lyratzi et al. 2004).

Definition of DACs – SACs

The DACs were considered to be unknown spectral lines, which accompanied some spectral lines (Si IV, C IV, N IV, N V, Mg II) in the spectra of Oe and Be stars (Bates & Halliwell 1986, Prinja 1988, Willis et al. 1989, Bates & Gilheany 1990, Gilheany et al. 1990, Kaper et al. 1990, Waldron et al. 1994, Henrichs et al. 1994, Telting et al. 1993, Telting & Kaper 1994, Cranmer & Owocki 1996, Prinja et al. 1997, Fullerton et al. 1997, Kaper et al. 1996, 1997, 1999, Cranmer et al. 2000).

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

If the regions that create such lines rotate quickly and move radially slowly, the produced lines are quite broadened and little shifted. So, they may not be discrete absorption spectral lines, but blended among themselves. In such a case, they are not observable, but we can detect them through the analysis of the profile. As Peton (1974) first pointed out, these components appear as "satellites" in the violet or in the red side of a main spectral line, as a function of the time or the phase, in the case of a binary system. For these two reasons and in order to include all these components, either they are discreet of not, to a unique name, we prefer to name them **Satellite Absorption Components (SACs)** and not Discrete Absorption Components (DACs).



Mechanisms responsible for the SACs' creation

The creation of SACs is due to mechanisms which allow the existence of structures which cover all or a significant part of the stellar disk, such as **shells, blobs or puffs** (Underhill 1975, Underhill & Fahey 1984, Bates & Halliwell 1986, Grady et al. 1987, Lamers et al. 1988, Cranmer & Owocki 1996, Kaper et al. 1996, 1997, 1999, Markova 2000) or interaction of fast and slow wind components, Corrotation Interaction Regions (CIRs), structures due to magnetic fields or spiral streams as a result of the star's rotation (Underhill & Fahey 1984, Mullan 1984a,b, 1986, Prinja & Howarth 1988, Cranmer & Owocki 1996, Fullerton et al. 1997, Kaper et al. 1996, 1997, 1999, Cranmer et al. 2000).

Though we do not know yet the mechanism responsible for the formation of such structures, it is positive that the SACs result from **independent high density regions** in the stars' environment. These regions are formed by the specific ions which create a specific spectral line.

Model

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

Fundamental Hypotheses

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

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

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

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

By solving the equations of radiation transfer through a complex structure as the one described, we conclude to a function for the line's profile, able to give the best fit for the main spectral line and its Satellite Absorption Components in the same time. Such a best fit, through the function of the line's profile, enables us to calculate some parameters (rotational and radial velocities, FWHM, optical depth) of the independent layers of matter, which form the main spectral line and its satellite absorption components.

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

where:

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

Rotation distribution function

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

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

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

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

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

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

Application of the model to the Si IV resonance lines (λλ 1393.755, 1402.77 Å) of 68 Be stars

The data we used are the Si IV resonance lines of 68 Be stars taken from the IUE Archive Search database (http://archive.stsci.edu/cgi-bin/iue). The stellar spectra were observed with IUE satellite using the Short Wavelength range Prime camera (SWP) at high resolution (0.1 to 0.3 Å).

We applied the model on the Si IV resonance lines (λλ 1393.755, 1402.77 Å) in the spectra of 68 Be stars of all the spectral subtypes and luminosity classes.

Our first step is to identify the spectral lines in the studied wavelength range, in order to find out which lines may be blended with the Si IV doublet and, thus, may contribute to the observed features. The identification has been made by NIST Atomic Spectra Database (http://physics.nist.gov/cgi-bin/AtData/lines form), as well as the catalogues of Moore (1968) and Kelly (1979). In the studied spectral range, we identified some spectral lines, which are blended with those of Si IV. This means that the observed profiles consist of the Si IV resonance lines, as well as some blended lines. Thus, in order to accomplish the best fit, we should have in mind the existence of blends and the studied profiles should present some "badly fitted" features. Moreover, as we deal with resonance lines, we know that if one line of the doublet is well fitted, we should apply the same parameters to the other one, even if the fit is not so good. In this case the unfitted regions correspond to blends.

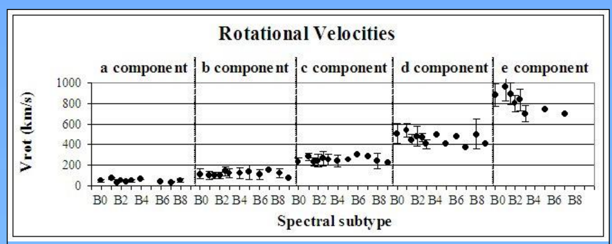


Figure 1: Mean values for each spectral subtype of the rotational velocities of all the SACs as a function of the spectral subtype.

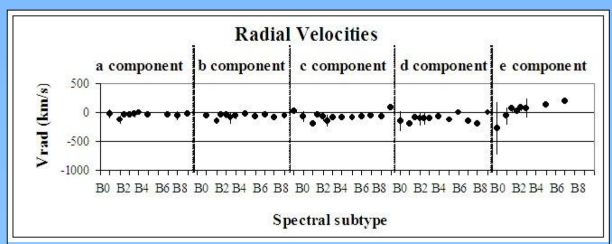


Figure 2: Mean values for each spectral subtype of the radial velocities of all the SACs as a function of the spectral subtype.

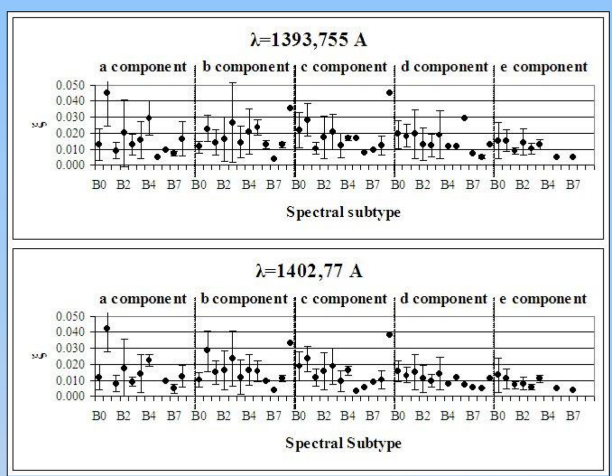


Figure 3: Mean values of the optical depth ξ in the center of the line for all kinematically separated components of each resonance line, as a function of the spectral subtype.

Conclusions

We applied the method developed in Danezis et al. (2003) and Lyratzi & Danezis (2004) on the Si IV resonance lines of 68 Be stars in order to investigate the kinematical properties of the Si IV resonance lines forming region. We obtained the rotational and radial velocities which allow us to extract some general physical properties for the Si IV regions of Be stars. Some interesting results inferred from the investigations are the following:

1. The proposed line function $I_\lambda = \left[I_{\lambda 0} \prod_i e^{-\tau_i} + \sum_j S_{\lambda ej}\left(1 - e^{-\tau_j}\right) \right] e^{-\tau_g}$ is able to reproduce accurately the complex profiles of the Si IV resonance lines of all the 68 studied Be-type stars. This means that the regions where the Si IV resonance lines are created are not continuous, but they consist of successive independent density regions. The important advantage of this method is that we are able to accomplish the best fit of the observed spectral lines, by applying a line function, to which we conclude after the solution of the radiation transfer equations, through a complex atmospherical structure, and not by a graphical composition of mathematical distribution functions with no physical meaning.

2. The absorption atmospherical region where the Si IV resonance lines are created presents a complex structure. It tends to be composed by more than one kinematically independent regions. We found that the kinematically independent regions rotate with different velocities: 40±16 km/s, 114±38 km/s, 251±52 km/s, 469±82 km/s and 828±119 km/s. The respective radial velocities are -38±60 km/s, -53±70 km/s, -87±89 km/s, -116±103 km/s and +25±145 km/s. These calculated values lead us to accept that the Si IV resonance lines of the Be stellar spectra present Satellite Absorption Components. This means that the existence of SACs is a general phenomenon in the spectra of Be-type stars.

3. The profiles of the studied Si IV resonance lines appear to be peculiar and complex, as they do not present only one spectral line, but a number of SACs, which are created in independent density regions. **All the studied stars do not present the same number of independent density regions**.

4. The rotational velocities of the found independent regions present a uniform fluctuation with the spectral subtype.

5. The strength of the Si IV resonance lines decreases towards the latest spectral subtypes of the Be-type stars.

6. We did not detect any emission lines in the studied stellar spectra.

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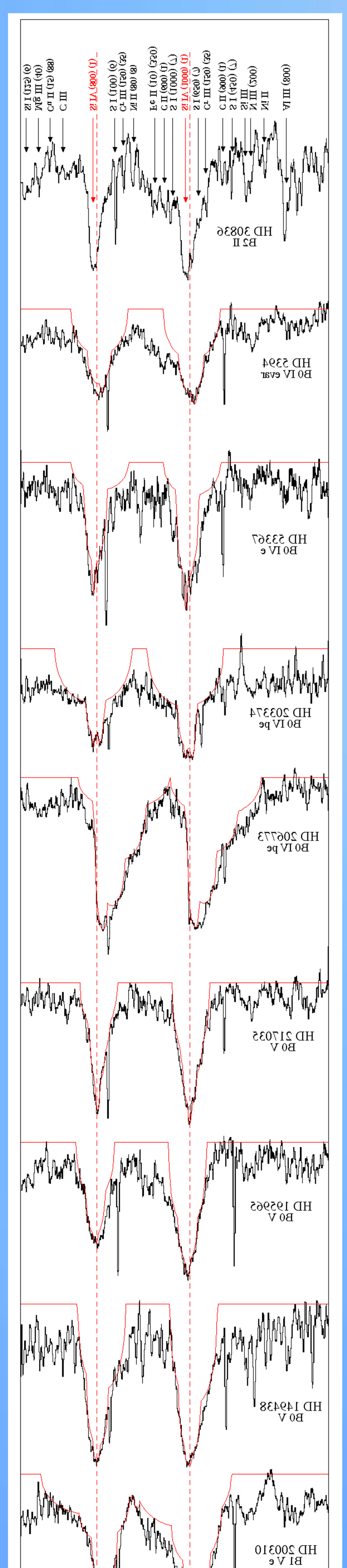
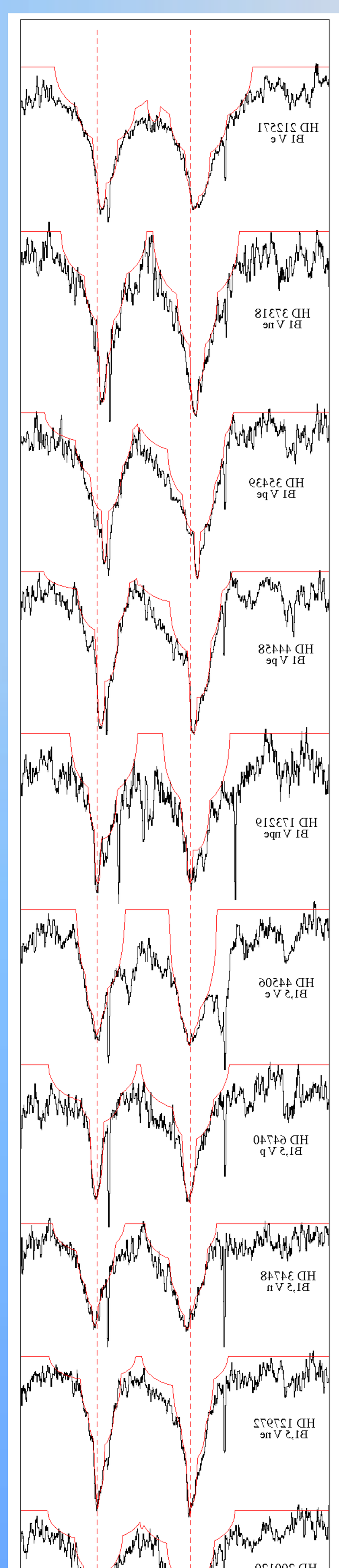
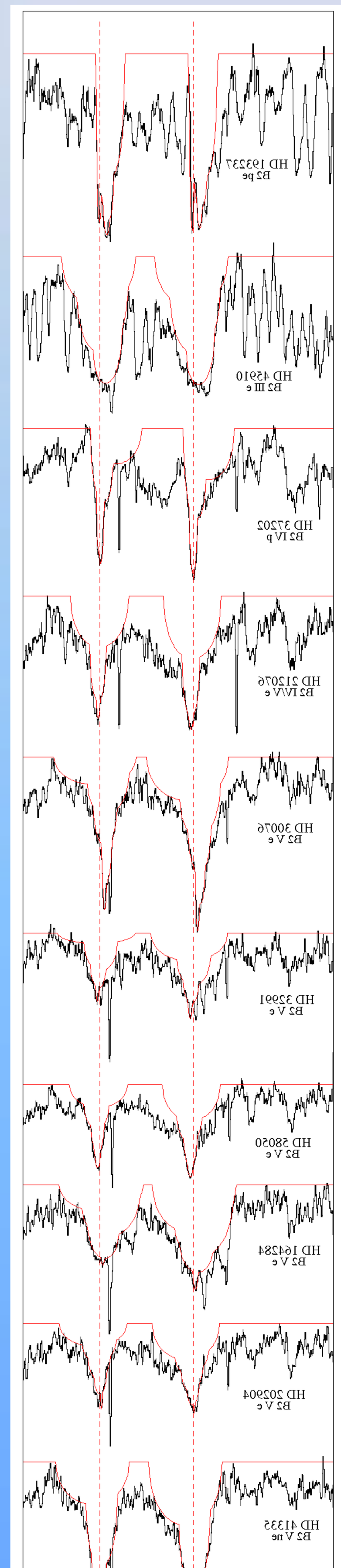
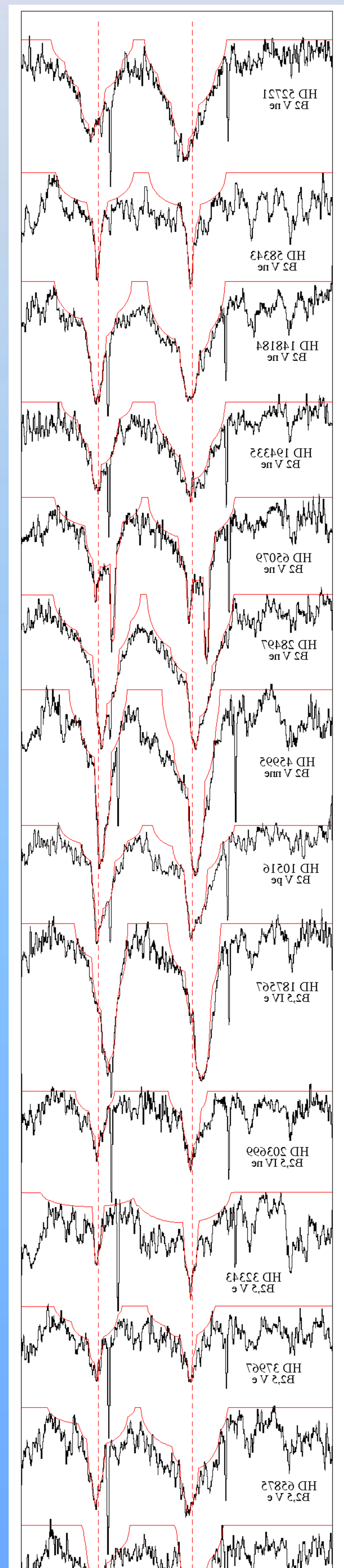
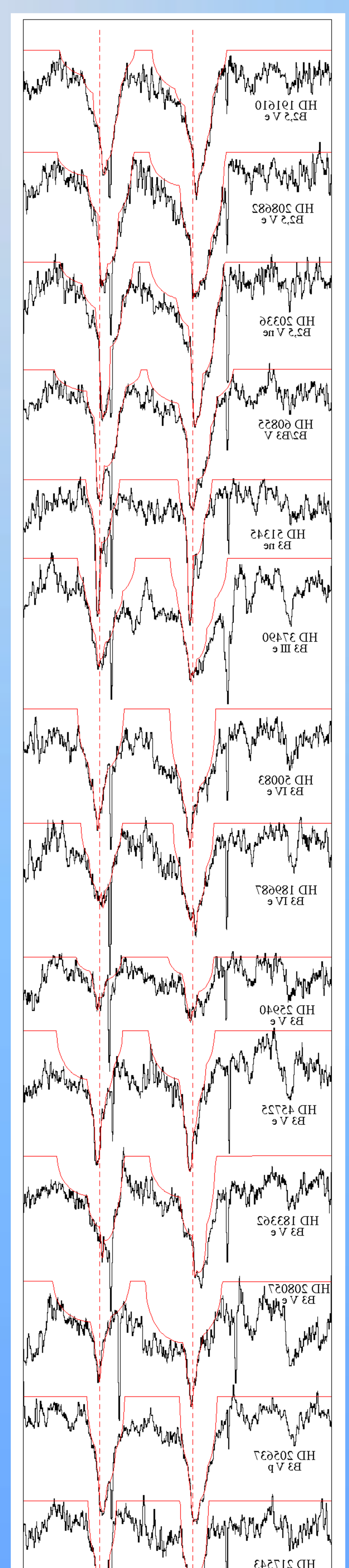
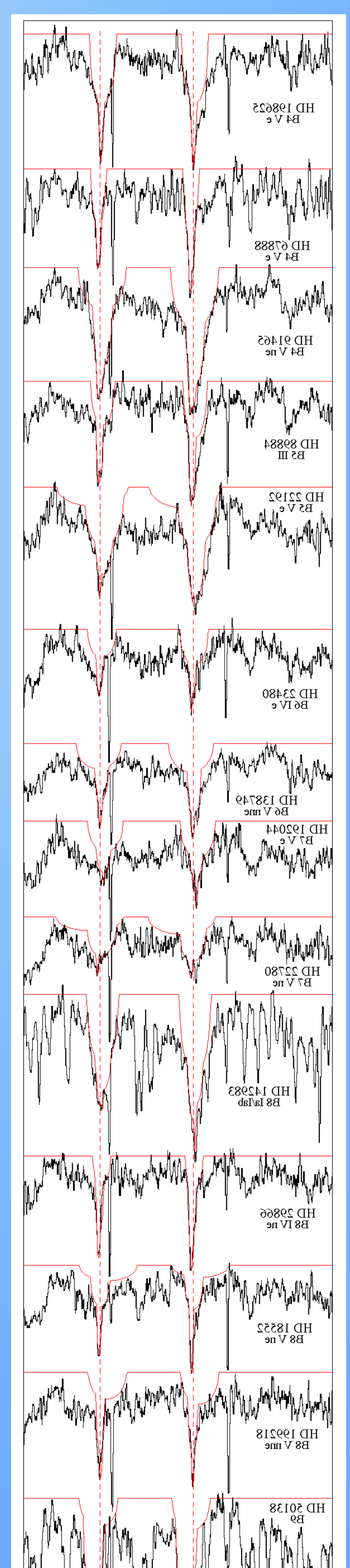

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