A New Approach For DACs And SACs Phenomena In The Atmospheres Of Hot Emission Stars

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Abstract

DACs and SACs phenomena in Hot Emission Stars

In this paper we present a mathematical model reproducing the complex profile of the spectral lines of Oe and Be stars that present DACs or SACs. This model presupposes that the regions, where these spectral lines are formed, are not continuous but consist of a number of independent absorbing or emitting density layers of matter and an external general absorption region. In this model we assume that the line broadening is due to the random motion of the ions and the rotation of the density regions that produce the spectral line and its satellite components. With this method we can calculate the values of the apparent rotational and radial velocities, the Gaussian standard deviation of the random motions of the ions, the random velocities of these motions, as well as the optical depth, the Full Width at Half Maximum (FWHM), the absorbed and the emitted energy and finally the column density of the independent regions of matter which produce the main and the satellites components of the studied spectral lines.

1. Introduction

DACs (Discrete Absorption Components) are discrete spectral lines which appear in the spectra of hot emission stars (Bates & Halliwell, 1986). These absorption spectral lines are not unknown. They are 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 et al. 2003).

DACs are lines, easily observed, when the regions that give rise to such lines, rotate with low velocities and move radially with high velocities. However, if the regions that give rise to such lines 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 Component is inappropriate and we use only the name SACs (Satellite Absorption Components).

2. The line function

Danezis et al. (1991, 1998, 2002, 2003) proposed a new model to explain the complex structure of the density regions of hot emission stars, where the spectral lines that present SACs or DACs are created.

The main hypothesis of this model is that the stellar envelope is composed of a number of successive independent absorbing density layers of matter, a number of

emission regions and an external general absorption region.
By solving the equations of radiation transfer through a complex structure, as the one described, we conclude to a function for the line profile, able to give the best fit for the main spectral line and its Satellite Components at the same time.
In the case of spherical symmetry around the star or around the density regions which produce the SACs, the line profile function takes the following form:

$$I_\lambda = \left[I_{\lambda 0} \prod_i e^{-L_i \xi_i} + \sum_j S_{\lambda ej} \left(1 - e^{-L_j \xi_j}\right) \right] e^{-L_g \xi_g} \tag{1}$$

where:
$I_{\lambda 0}$ is the initial radiation intensity, L_i, L_{ej}, L_g are the distribution functions of the respective absorption coefficients, ξ_i, ξ_{ej}, ξ_g are the optical depths in the center of the respective spectral line components and $S_{\lambda ej}$ is the source function which is constant during the observation.

3. The calculation of the distribution functions *L*

In order to calculate the distribution functions *L* we suppose that the line broadening is a function of the rotational velocity of the density regions which create the SACs and the random velocities of the ions within these regions.
Let us consider a spherical shell moving radially and a point A_i in its equator. If the laboratory wavelength of a spectral line that arises from A_i is λ_{lab}, the observed wavelength will be $\lambda_0 = \lambda_{lab} + \Delta\lambda_{rad}$ where $\Delta\lambda_{rad}$ is the radial displacement.
If the spherical density region rotates, we will observe a displacement $\Delta\lambda_{rot}$ and the new wavelength of the center of the line λ_i is $\lambda_i = \lambda_0 \pm \Delta\lambda_{rot}$, where $\Delta\lambda_{rot} = \lambda_0 z \sin\varphi$ and $z = \frac{V_{rot}}{c} = \frac{\Delta\lambda_{rot}}{\lambda_0 \sin\varphi}$, where V_{rot} is the observed rotational velocity of the point A_i.

This means that $\lambda_i = \lambda_0 \pm \lambda_0 z \sin\varphi = \lambda_0 (1 \pm z \sin\varphi)$ and if $-\frac{\pi}{2} < \varphi < \frac{\pi}{2}$ then $\lambda_i = \lambda_0 (1 - z \sin\varphi)$.

If we consider that the spectral line profile is a Gaussian distribution we have: $P(\lambda) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\left[\frac{\lambda-\kappa}{\sigma\sqrt{2}}\right]^2}$ where κ is the mean value of the distribution and in the case of the line profile it indicates the center of the spectral line that arises from A_i. This means that $P(\lambda) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\left[\frac{\lambda-\lambda_0(1-z\sin\varphi)}{\sigma\sqrt{2}}\right]^2} = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{[\lambda-\lambda_0(1-z\sin\varphi)]^2}{2\sigma^2}}$.

For all the semi-equator we have $L(\lambda) = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{[\lambda-\lambda_0(1-z\sin\varphi)]^2}{2\sigma^2}} \cos\varphi d\varphi$.

If we make the transformation $\sin\varphi = x$ and $u = \frac{\lambda - \lambda_0(1-zx)}{\sqrt{2}\sigma}$, then

$$L(\lambda)=\frac{1}{\lambda_0 z\sqrt{\pi}}\int_{\frac{\lambda-\lambda_0(1+z)}{\sigma\sqrt{2}}}^{\frac{\lambda-\lambda_0(1-z)}{\sigma\sqrt{2}}} e^{-u^2}du \qquad \text{or} \qquad L(\lambda)=\frac{1}{\lambda_0 z\sqrt{\pi}}\left[\int_0^{\frac{\lambda-\lambda_0(1-z)}{\sigma\sqrt{2}}} e^{-u^2}du-\int_0^{\frac{\lambda-\lambda_0(1+z)}{\sigma\sqrt{2}}} e^{-u^2}du\right]$$

and $L(\lambda)=\frac{\sqrt{\pi}}{2\lambda_0 z}\left[erf\left(\frac{\lambda-\lambda_0(1-z)}{\sqrt{2}\sigma}\right)-erf\left(\frac{\lambda-\lambda_0(1+z)}{\sqrt{2}\sigma}\right)\right]$.

The distribution function from the semi-spherical region is

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

4. Testing the model

In order to check the above spectral line function, we calculated the rotational velocity of He I λ 4387.928 Å absorption line in the spectra of five Be stars, using two methods, the classical Fourier analysis and our model. The results are favorable for our model.

The values of the rotational velocities, calculated with Fourier analysis, some time, are a little higher than the values calculated with our method, as in Fourier analysis the whole broadening of the spectral lines is assumed to represent the rotational velocity.

In contrary, our model accepts that a part of this broadening arises from the random motion of the ions.

We point out that with our model, apart from the rotational velocities, we can also calculate some other parameters, such as the standard Gaussian deviation (σ), the velocity of random motions of the ions, the radial velocities of the regions producing the studies spectral lines, the full width at half maximum (FWHM), the optical depth, the column density and the absorbed or emitted energy.

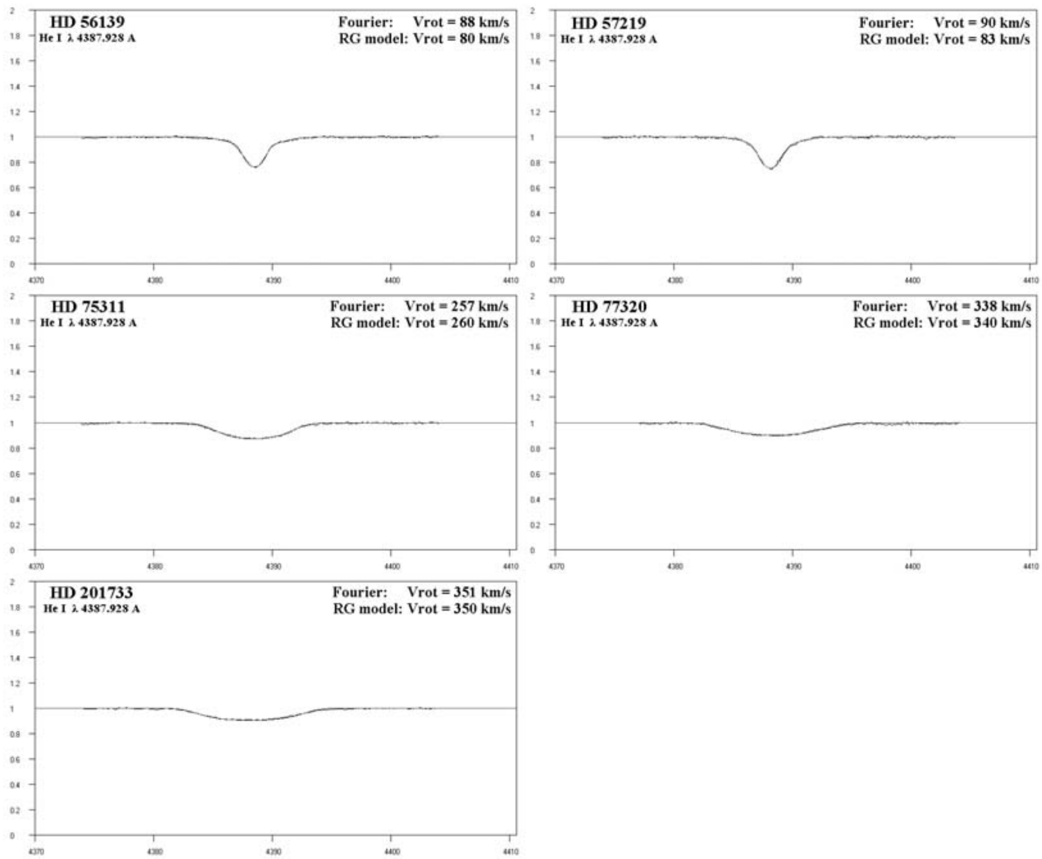

Fig. 1. The five He I λ4387.928 Å fittings for the studied Be stars and the measured rotational velocities with both methods. The results are favorable for our model. The thick line presents the observed spectral line profile and the thin one the model fit. The differences between the observed spectrum and its fit are hard to see, as we have accomplished the best fit.

A second test of our model is to calculate the random velocities of the layers that produce the C IV satellite components of 20 Oe stars with different rotational velocities. The values of the random velocities do not depend on the inclination of the rotational axis. As the ionization potential of the regions that create the satellite components for all the studied stars is the same, we expect similar average values of the random velocities for each component for all the studied stars. We apply the model on the C IV line profiles of 20 Oe stellar spectra taken with the IUE satellite (IUE Database http://archive.stsci.edu/iue). We examine the complex structure of the C IV resonance lines (λλ 1548.155 Å, 1550.774 Å). Our sample includes the subtypes O4 (one star), O6 (four stars), O7 (five stars), O8 (three stars) and O9 (seven stars). The values of the photospheric rotational velocities are taken from the catalogue of Wilson (1963). After the study of the C IV spectral lines we detected two components in 9 stars, three in 7 stars, four in 3 stars and five in one star. The results that we present in Figs. 2 and 3 are favorable for our model. The differences between the average values of the random velocities of the satellite components arise from the small variations of the temperature that exist in each one of the regions that produce the satellite components.

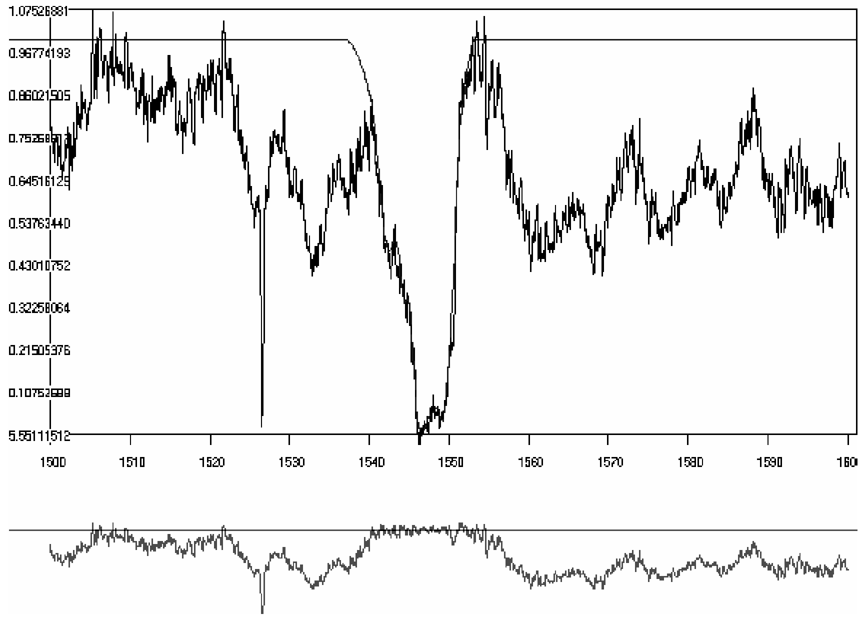

Fig. 2. The best fit of the C IV UV doublet. The green diagram presents the differences between the theoretical and the physical line shape.

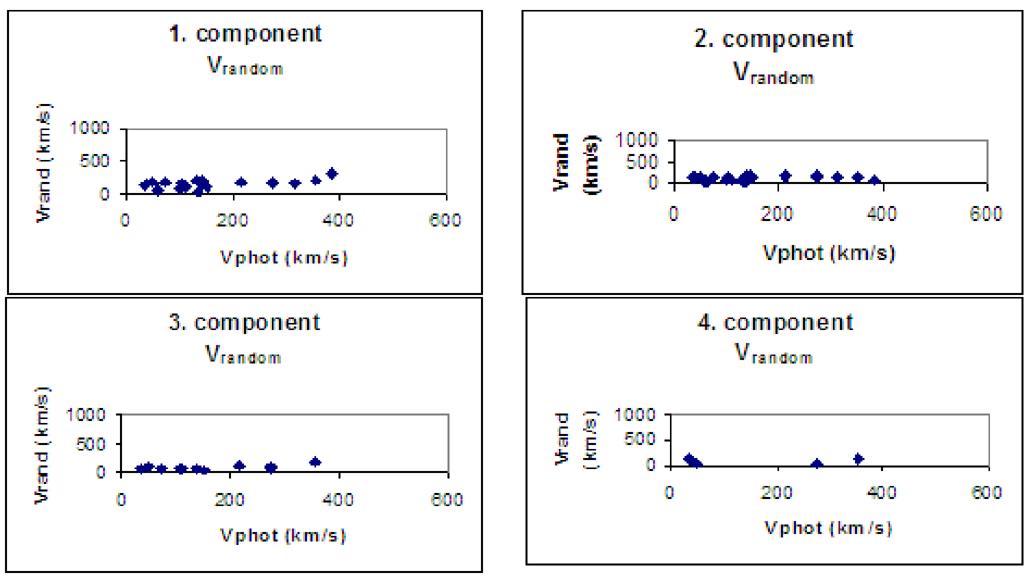

Fig. 3. Relation between the random velocities and the photospheric rotational velocities of the studied stars.

5. Conclusions

In this paper we presented a model that can describe the spectral lines of hot emission stars, which present SACs or DACs. Here we give some of our conclusions: (a) The results obtained from the two tests confirm the theoretical accuracy of the proposed model. (b) The proposed model can explain the peculiar and complex profiles of the spectral lines which present SACs and DACs phenomena, indicating the existence of layers of matter with different physical conditions.

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