

The complex structure of the expanding gaseous envelope of the Be star HD 45910 (AXMon).

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Abstract. In this paper we present a first analysis of the complex structure of the gaseous envelope of the Be 2 III star HD 45910 (AX Monocerotis). Our study is based on the coronal model proposed by Danezis et al., announced for the first time at the JENAM 1998 in Prague, also presented in IAU Symposium 210 (Uppsala, 2002). This model suggests that the regions where the ions that present DACs are created, are not continuous but they consist of many independent absorbing density layers of matter, followed by an emitting and finally by an external general absorption region. The model reproduces the profiles of all the spectral lines of Oe and Be stars, that we have studied until now. In this paper we intend to test the proposed model by comparing the results deriving from it with the result of previously published papers, as well as to extract some first general conclusions about the accurate values of the expansion / contraction velocities and the rotation velocities of the atmospheric shells of the star.

1. Introduction

AX Monocerotis (HD45910 = $BD + 5^\circ, 1267 = \text{SAO}13974$, $\alpha=6^h27^m52^s$, $\delta = +5^\circ, 54', 1$ (1950), $V=6,59-6,88$ mag) is a binary system (Merrill 1952), consisting of a B2e III star and a somewhat fainter K0 III star, with an orbital period of 232.5 days (Magalashvili & Kumsishvili 1969; Papoušek 1979) and a variable spectrum (Merrill 1923; Plaskett 1923, 1927).

Cowley (1964) observed the P Cygni profile of hydrogen lines and variability in absorption lines which also are blended. There is a metallic shell spectrum with sharp absorption lines of FeII, TiII, CrII, MnII and NiII. Some of them exhibit faint emission lines in both sides of the lines. She also, proposed the existence of a gaseous region of great density and a mass transfer between the two stars with a velocity of 25 kms^{-1} . Elias et al. (1997), also, derived a mass-loss rate of order $10^{-7} M_\odot \text{ yr}^{-1}$, if the radio emission is thermal.

Peton (1974) announced the existence of a satellite component at the red or violet side of Fe II at 4233 \AA and proposed a model with two absorbing shells, an external hydrogen shell and an internal metallic shell. Sahade et al. (1984) and Sahade & Brandi (1985) identified many absorption lines and indicated the

existence of satellite components of many ions in high dispersion IUE spectra at phase 0.095. Today, these satellite components are named discrete absorption components (DACs).

Harmanec & Tarasov (1990) suggested that the overall profiles derive from the merging of many local profiles of circumstellar gas elements. This means that the line profiles are much smaller and the rotation velocity cannot be calculated by the lines' width. They, also, noted that the line profiles are phase dependent and consistent with asymmetric mass motions, which means that the star's shell is not symmetric.

Danezis (1984, 1986), Danezis et al. (1991), and Laskarides et al. (1992) studied the UV spectrum of the system at 0.568 and detected the existence of DACs in a great number of spectral lines of different ionization potential. Each of these spectral lines presents two satellite components (DACs) at the violet side and one at the red side of a main component. This fact led Danezis et al. to conclude to the existence of independent density layers of matter in the regions where these spectral lines are created. These layers of matter can rotate and move with different apparent velocities. The existence of these layers as well as the existence of the spectral lines of C IV and Si IV, led them to accept a model for the structure of the envelope, which presupposes the existence of a corona layer (Doazan 1982) as well as a number of regions of different ionization potential, where DACs are created. Danezis et al. (2000a,b,c, 2001) suggested a model of the regions where the spectral lines that present DACs are created and concluded to a function which reproduces successfully the complex profile of the spectral lines that present DACs.

In this paper we apply the above mentioned model, which is also presented at IAU Symposium 210 (Danezis et al. 2002), to the star HD 45910 (AX Mon) and we present some first results deriving from this application.

2. The model – Mathematical expression

Considering an area of gas consisting of i independent absorbing shells followed by a shell that both absorbs and emits and an outer shell of general absorption, we conclude to the function:

$$I_{\lambda} = [I_{\lambda 0} \prod_i \exp\{-L_i \xi_i\} + S_{\lambda e} (1 - \exp\{-L_e \xi_e\})] \exp\{-L_g \xi_g\}$$

where:

$I_{\lambda 0}$: the initial radiation intensity,

L_i, L_e, L_g : functions of the rotation and the expansion/contraction velocities
($v \sin i, v_{ex}/c$),

$\xi = \int_0^s \Omega \rho ds$ is an expression of the optical depth τ , where Ω is an expression of k_{λ} and has the same units k_{λ} ,

$S_{\lambda e}$: the source function, which, at the moment when the spectrum is taken, is constant and

$$L = \begin{cases} \sqrt{1 - \cos^2 \theta_0} & , \text{if } \cos \theta_0 < 1 \\ 0 & , \text{if } \cos \theta_0 \geq 1 \end{cases} ,$$

where $\cos \theta_0 = \frac{-\lambda_0 + \sqrt{\lambda_0^2 + 4\Delta\lambda^2}}{2\Delta\lambda z_0}$, where $2\theta_0$ is the angular width of the equatorial disk of matter, λ_0 is the wavelength of the center of the spectral line and $\lambda_0 = \lambda_{lab} + \Delta\lambda_{exp}$, with λ_{lab} being the laboratory wavelength of the spectral line produced by a particular ion and $\Delta\lambda_{exp}$ the radial Doppler shift and $\frac{\Delta\lambda_{exp}}{\lambda_{lab}} = \frac{V_{exp}}{c}$

$z_0 = \frac{V_{rot}}{c}$ where V_{rot} is the apparent rotation velocity of the i density shell of matter and

$\Delta\lambda = |\lambda_i - \lambda_0|$, where the values of λ_i are taken in the wavelength range we want to reproduce.

The spectral line's profile, which is formed by the i density shell of matter, must be accurately reproduced by the function $e^{-L_i \xi_i}$ by applying the appropriate values of V_{roti} , V_{expi} and ξ_i . Using the best model's fit for a complex spectral line, we can calculate the apparent expansion (or contraction) velocity (V_{expi}), the apparent rotation velocity (V_{roti}) and an expression of the optical depth (ξ_i) of the region in which the spectral line and its satellite components are constructed.

3. Data

The data we used are the spectrographs SWP 04762 and LWR 04131 of the star HD 45910 (AX Mon), taken with IUE satellite on March 27, 1979. By the study of the interstellar lines we concluded to the fact that the lines appear to be displaced about +10 km/s in the SWP 04762 spectrograph and +123 km/s in the LWR 04131 spectrograph. Our results have undergone the appropriate corrections.

4. Application of the model to the spectral lines of the Be star HD 45910 (AX Mon)

4.1. The model's fit

In figures 1 and 2 we present two of the spectral lines we studied (black line) as well as their fitting as it derived from the model (grey line). The differences between the real spectra and their fittings are hard to see, as we have accomplished the best fit. Above each spectral range of the star we studied, we give the same spectral range of a classic star of the same spectral type and luminosity class, in order to indicate the lines blended with the ones we study.

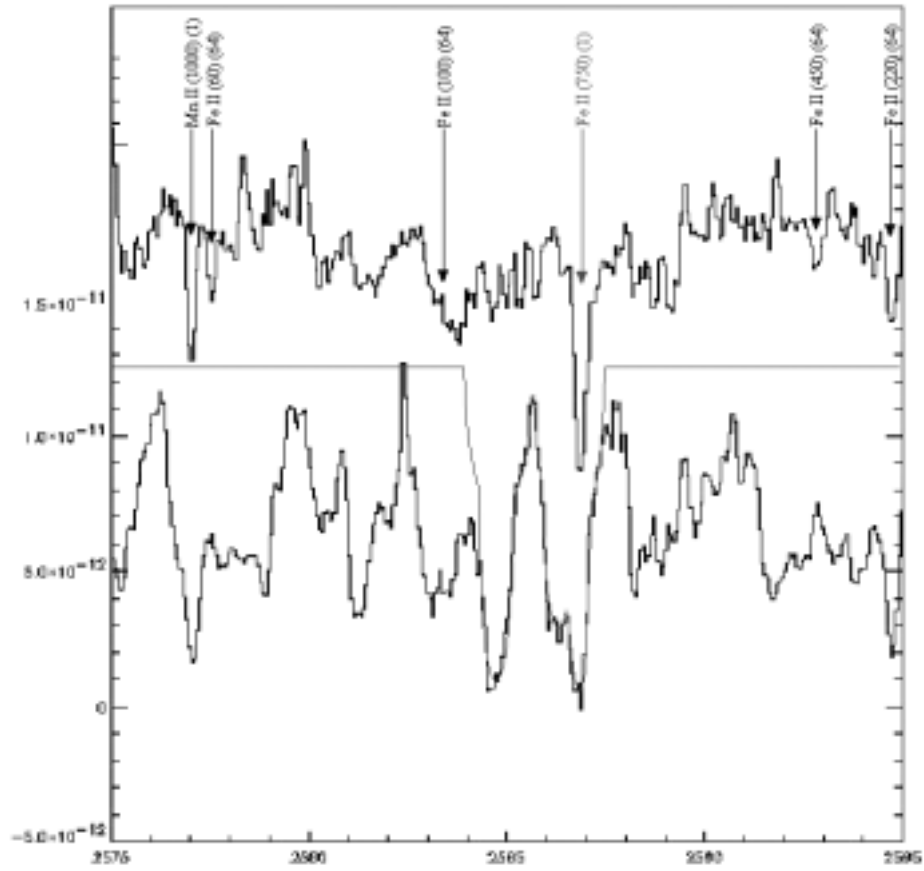


Figure 1. The Fe II λ 2585.876 Å spectral line is formed as a composition of three independent absorption components.

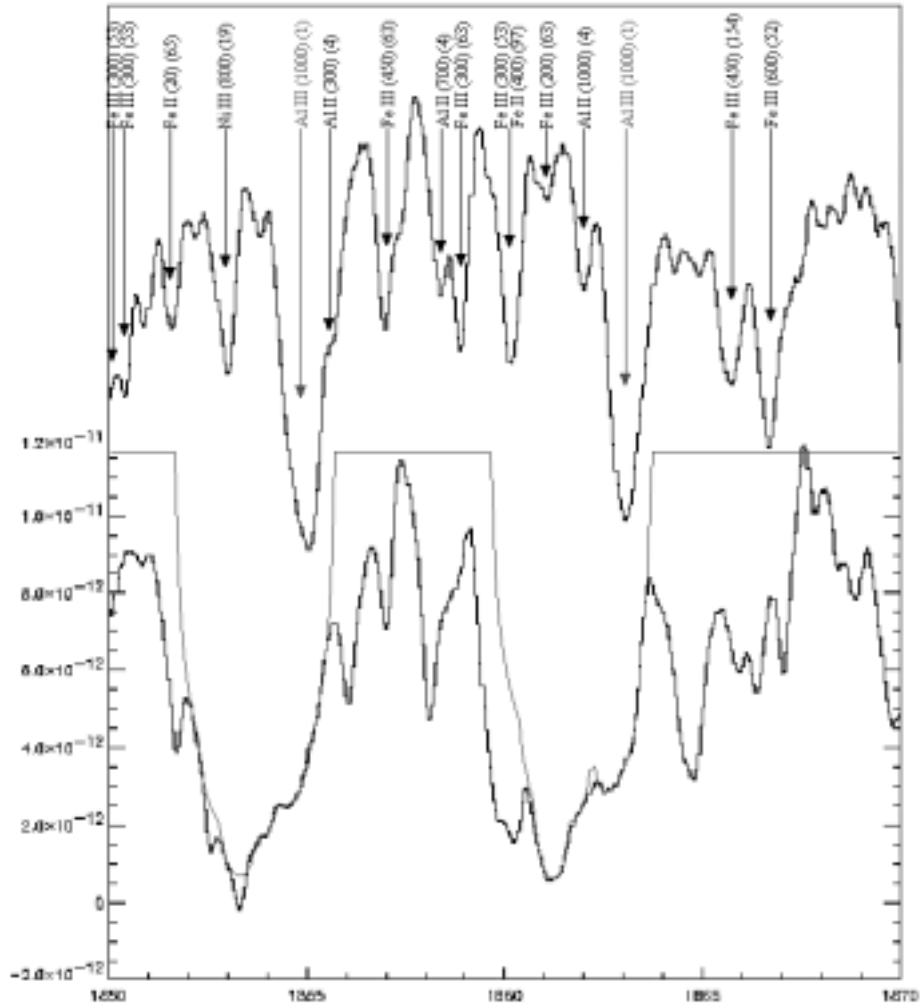


Figure 2. Each of Al III $\lambda\lambda$ 1854.722, 1862.782 Å resonance lines is formed as a composition of three independent absorption components.

4.2. Tables and figures of expansion/contraction and rotation velocities

By applying the model to the spectral lines Ly α , Al II, Mg II, Fe II, C II, Al III and Si IV of HD 45910 we calculated the apparent expansion / contraction and rotation velocities. Our results appear in tables 1 and 2 and in figures 3 and 4.

Table 1.

Expansion/Contraction velocities of the envelope regions of HD 45910 (km/s)							
Spectral line	Ionization potential	a' comp	b' comp	c' comp	d' comp	e' comp	Emission
Ly α	0.000		-160			+185	+31
Al II	5.986	-295		-109	-26		
Mg II	7.646	-291	-233		-15		+58
Fe II	7.870	-265		-70	-22		
C II	11.260	-267		-135	-1	+122	
Al III	18.828	-257	-183		-6		
Si IV	33.492	-321	-215	-101		+74	
Mean		-283 \pm 24	-198 \pm 33	-104 \pm 27	-14 \pm 11	+127 \pm 56	+45 \pm 19

Table 2.

Rotation velocities of the envelope regions of HD 45910 (V _{sini}) (km/s)							
Spectral line	Ionization potential	a' comp	b' comp	c' comp	d' comp	e' comp	Emission
Ly α	0.000		127			46	67
Al II	5.986	59		283	93		
Mg II	7.646	99	245		42		40
Fe II	7.870	101		104	33		
C II	11.260	74		76	91	230	
Al III	18.828	153	325		81		
Si IV	33.492	79	307	469		748	

5. Conclusions

1. By applying the proposed by Danezis et al. (1984, 1991, 2001, 2002), model we are able to reproduce the profiles of the studied spectral lines of the star HD 45910 (AXMon) with great accuracy. This means that the coronal model allowing the existence of successive, independent denser shells of matter represents accurately the structure of the gaseous envelope of AX Mon.
2. We confirm the existence of the three independent shells of matter, proposed by Danezis (1984, 1986), Laskarides, Danezis & Theodossiou (1992) and Sahde & Brandi (1985) in the envelope of AXMon, with similar expansion velocities. The values that derived by the model's application are

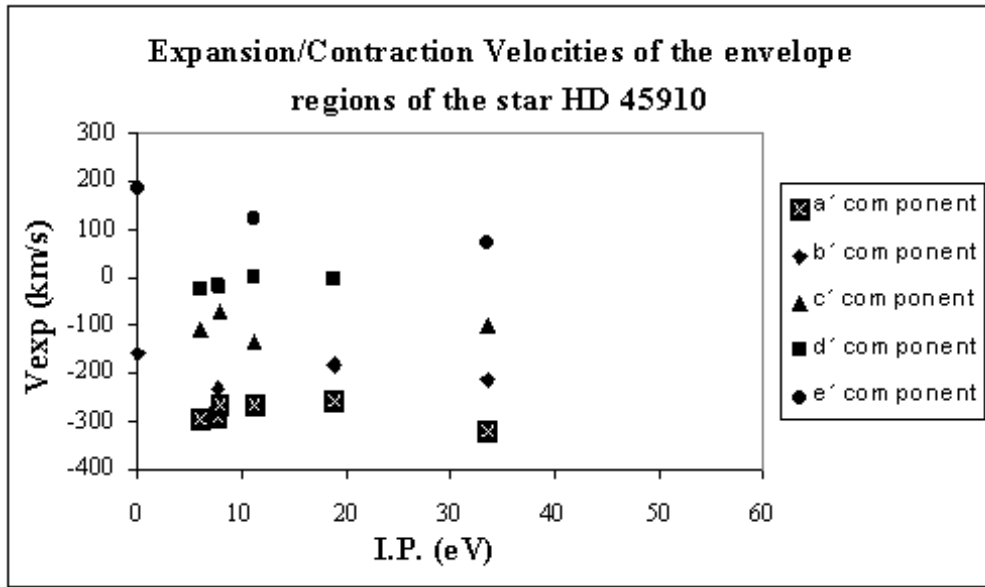


Figure 3. Expansion / contraction velocities of each DAC as a function of the ionization potential (geometrical depth).

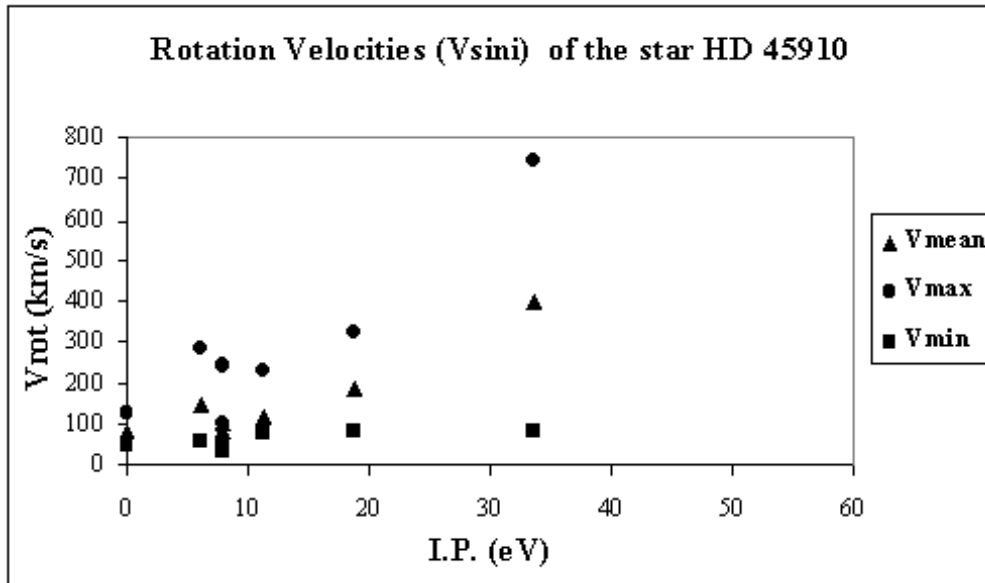


Figure 4. The values of mean, max and min rotation velocity calculated by the spectral lines of each ion as a function of the ionization potential (geometrical depth).

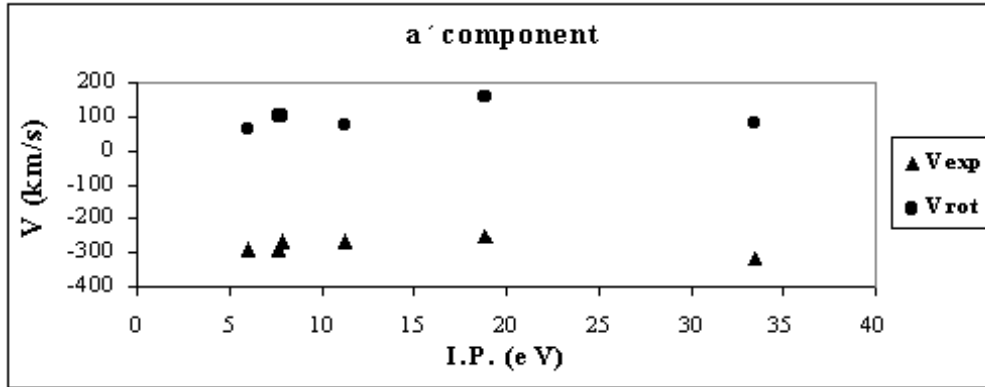


Figure 5. Expansion / contraction (V_{exp}) and rotation velocity (V_{rot}) of the first DAC of each ion as a function of the ionization potential (geometrical depth).

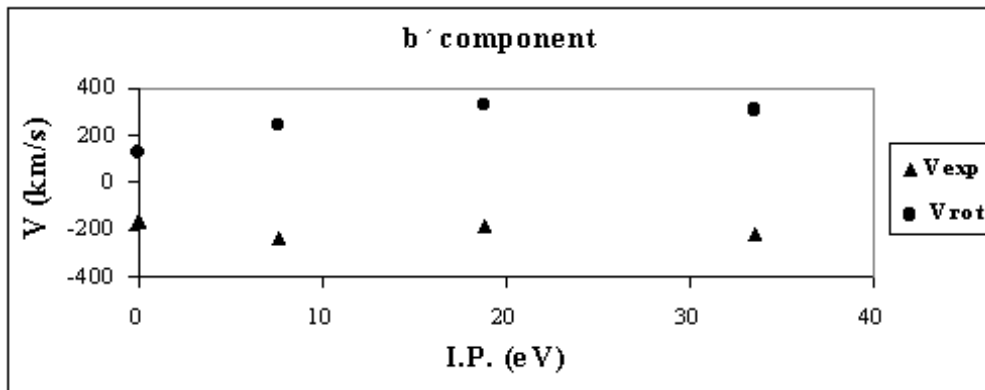


Figure 6. Expansion / contraction (V_{exp}) and rotation velocity (V_{rot}) of the second DAC of each ion as a function of the ionization potential (geometrical depth).

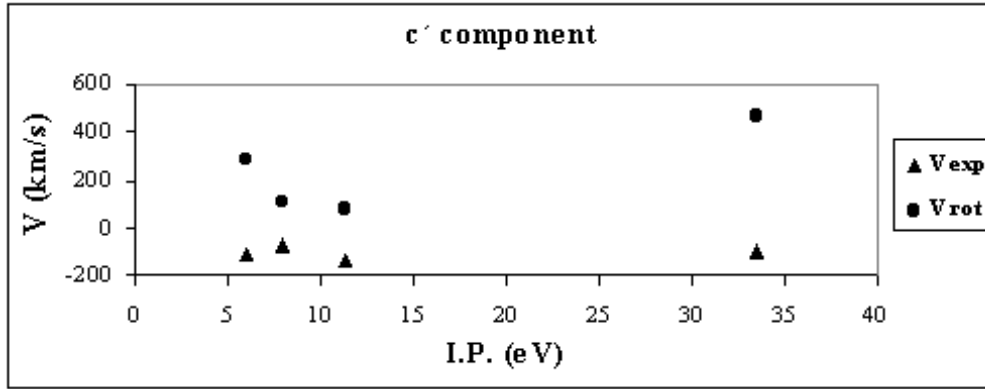


Figure 7. Expansion / contraction (V_{exp}) and rotation velocity (V_{rot}) of the third DAC of each ion as a function of the ionization potential (geometrical depth).

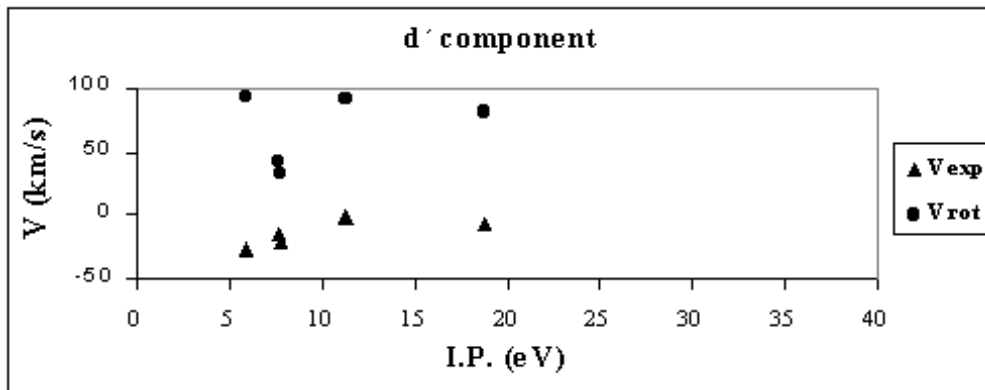


Figure 8. Expansion / contraction (V_{exp}) and rotation velocity (V_{rot}) of the fourth DAC of each ion as a function of the ionization potential (geometrical depth).

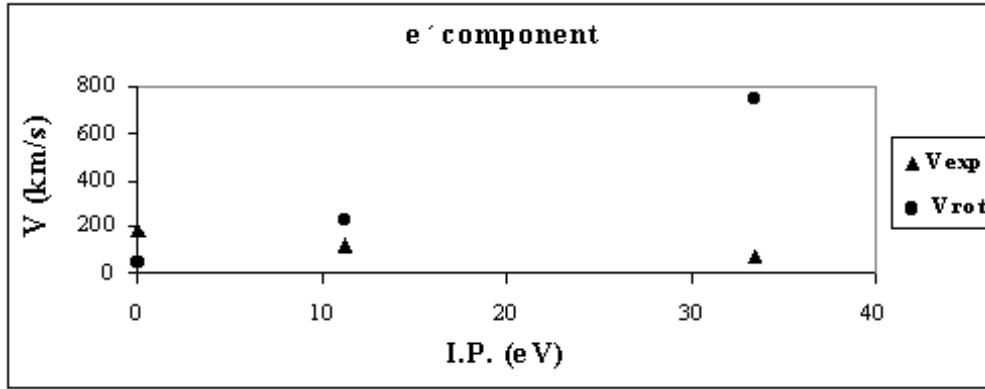


Figure 9. Expansion / contraction (V_{exp}) and rotation velocity (V_{rot}) of the fifth DAC of each ion as a function of the ionization potential (geometrical depth).

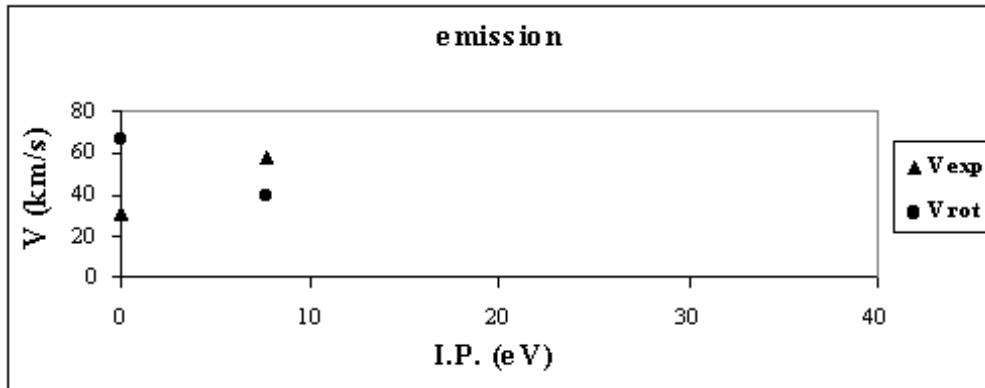


Figure 10. Expansion / contraction (V_{exp}) and rotation velocity (V_{rot}) of the emission component of each ion as a function of the ionization potential (geometrical depth).

-283±24 km/s, -104±27 km/s and -14±11 km/s. We also found one more independent shell with expansion velocity -198±33 km/s.

3. We confirm the existence of the contracting shell which was proposed by Laskarides, Danezis & Theodossiou (1992), with radial velocity of +117 km/s, but the value we calculated is +127±56 km/s. It should be underlined that the emitting shell of MgII is a contracting one moving with +58 km/s, whereas the emitting shell of the Ly α region contracts +31 km/s.
4. The apparent rotation velocities ($v\sin i$) of the independent shells of matter fluctuate between 40 km/s and 748 km/s and, as it was expected, they decrease as the distance of the shell from the star increases. The variability of the apparent rotational velocities of different shells occurring in regions where a particular ion is born is probably due to the different densities of these shells.
5. Finally we confirm Harmanec & Tarasov's suggestion that the overall profiles derive from the merging of many local profiles of circumstellar gas elements, as well as that the edge variability is directly related to the DACs, which actually have an impact on the position of the edge (Kapper et al., 1996, 1999).

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