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Analysis of Ly_α in B-Type Stars

D. Nowak and H. Cugier

Astronomical Institute of the Wrocław University, Kopernika 11, 51-622 Wrocław, Poland, E-mail:nowak@astro.uni.wroc.pl

Abstract. The hydrogen Ly_α line is the most pronounced absorption feature in spectra of B-type stars. Two effects play the dominant role in observed behavior of Ly_α: the Stark broadening of the line absorption coefficient and interstellar absorption. These two effects may be separated by considering late B and early B-type stars. We search for the best description of the Stark effect using observations collected by *Copernicus*, *IUE* and *HST* satellites.

Having a credible description of the broadening mechanisms of Ly_α we determined interstellar component of the observed line profiles of early B-type stars. The interstellar column densities, N(H I), are derived and correlations with various signatures of interstellar extinction are also examined.

1 Model Calculations

Theoretical profiles of the hydrogen Ly_α line are calculated for Kurucz's (1979) models of atmospheres corresponding to B-type stars. The line absorption coefficient is a convolution of the Voigt and Stark profiles. We search for the best description of the broadening mechanisms of the line absorption coefficient using various data for the Stark effect. We found that Vidal's et al. (1973) and Clausset's et al. (1994) results are almost identical for $\Delta\nu > 10^{11}$ s^{-1}. Feautrier's (1976) exact quantum calculations indicate significantly stronger line wings, cf. Fig. 1 where two examples are shown (cf. also Tran Minh et al., 1980 and Hubený 1981).

Figure 2 illustrates how the interstellar H I Ly_α absorption influences the photospheric spectra of Ly_α 1216 Å, Si III 1204 Å and C III 1175 Å.

2 Comparison with Observations

We analyze archival observations of Ly_α line collected by *Copernicus*, *IUE* and *HST* satellites. The basic stellar parameters T_{eff} and log g as well as color excess $E(b-y)$ are derived from $uvby\beta$ photometry using Kurucz's (1991) grids of $uvby$ colors and β indices calibrated by Smalley & Dworetsky (1995). Following to Shobbrook (1978) we adopted the relations $(b-y)_0 = 0.099c_0 - 0.117$ and $E(c_1) = 0.24E(b-y)$ in the de-reddening procedure. The results are shown in Table 1.

Figure 3 displays the observations of α Lyr and α CMa A in comparison with the predicted photospheric spectra near Ly_α 1216 Å, Si III 1204 Å and C III 1175 Å. As one can see, only line profiles with Feautrier's et al. (1976) data for the hydrogen Stark effect are able to reproduce the observations. The same is true for the remaining late B-type stars investigated. Thus having a good description of the Stark effect we investigated early B-type stars, where interstellar absorption may play an important role. A few examples are show in Fig. 4 (IUE observations) and Fig. 5 (HST observations).

The dotted lines in Figs. 4 and 5 mean only the photospherical fluxes, whereas the synthetic spectra with the interstellar component of H I Ly_α line are shown as the solid lines. The stellar rotational broadening does not influence strongly the Ly_α profile due to large widths of this line

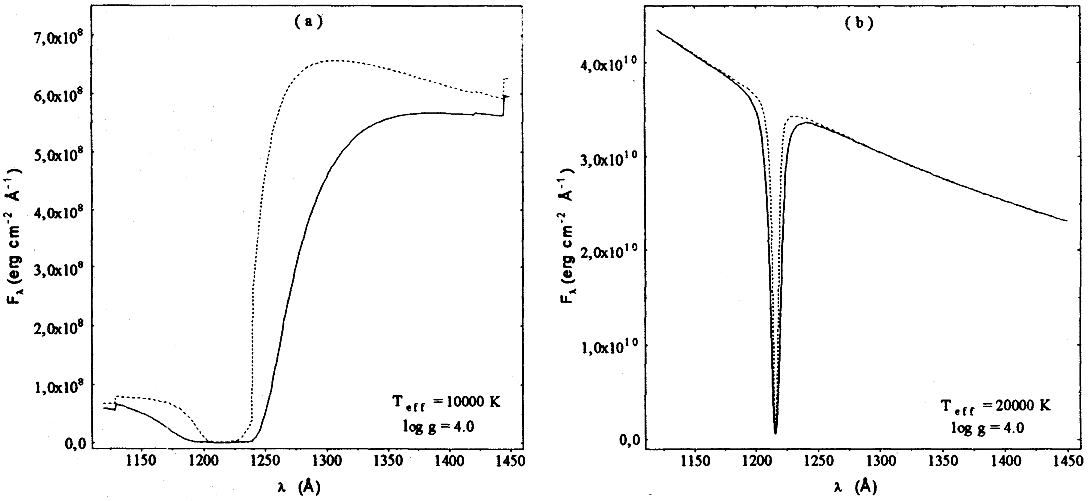

Figure 1. (a) Predicted Ly_α line profiles for model atmospheres of $T_{eff} = 10000K$, $\log g = 4.0$. The Ly_α profile corresponding to Feautrier's et al. (1976) description of the Stark effect (solid curve) is markedly stronger than that of calculated using Vidal's et al. (1973) or Clausset's et al. (1994) (dotted line) data. (b) The same as Panel a but for stellar model of $T_{eff} = 20000K$ and $\log g = 4.0$.

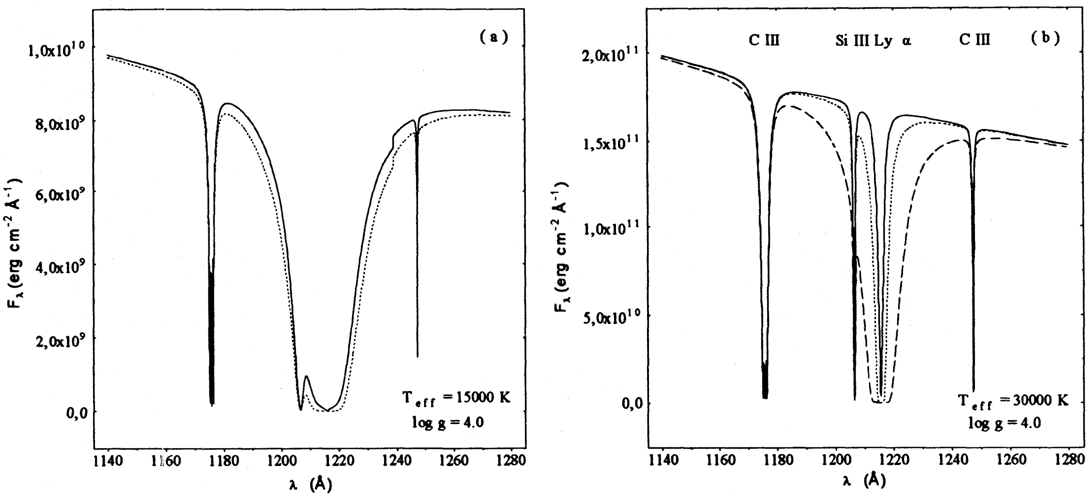

Figure 2. (a) The photospherical flux for $T_{eff} = 15000K$, $\log g = 4.0$ (solid line) and the synthetic profile with the interstellar component corresponding to the hydrogen column density equal to $N(H\,I) = 10^{21}cm^{-2}$ (dotted line). (b) The same as Panel a but for the model atmosphere of $T_{eff} = 30000K$, $\log g = 4.0$ (solid line), and $N(H\,I) = 10^{20}cm^{-2}$ (dotted line) and $10^{21}cm^{-2}$ (dashed line), respectively.

and, therefore, we do not include this effect in our calculations. Note that in the case of δ Pic (HD 42933) the photospherical spectrum is shifted relative to Ly_α line to long wavelength side (cf. Fig. 5) supporting the interpretation of this line as mainly produced by interstellar gas. For α Gru there are two pieces of the *HST/GHRS* spectrum which does not cover the whole profile of Ly_α, cf. Fig. 5.

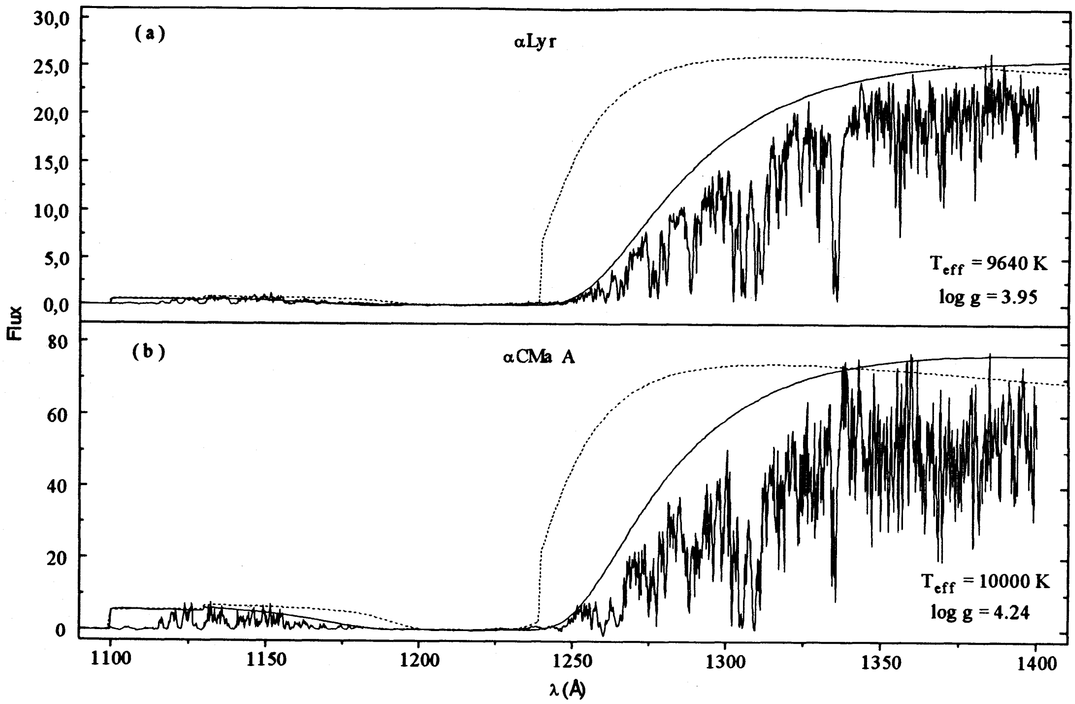

Figure 3. (a) Comparison of the predicted Ly_α line profiles with observations of α Lyr (Vega). The Ly_α profile corresponding to Feautrier's et al. (1976) description of the Stark effect is shown as solid curve, whereas calculations based on Clausset's et al. (1994) data are shown as dotted line. (b) The same as Panel a but for α CMa A (Sirius).

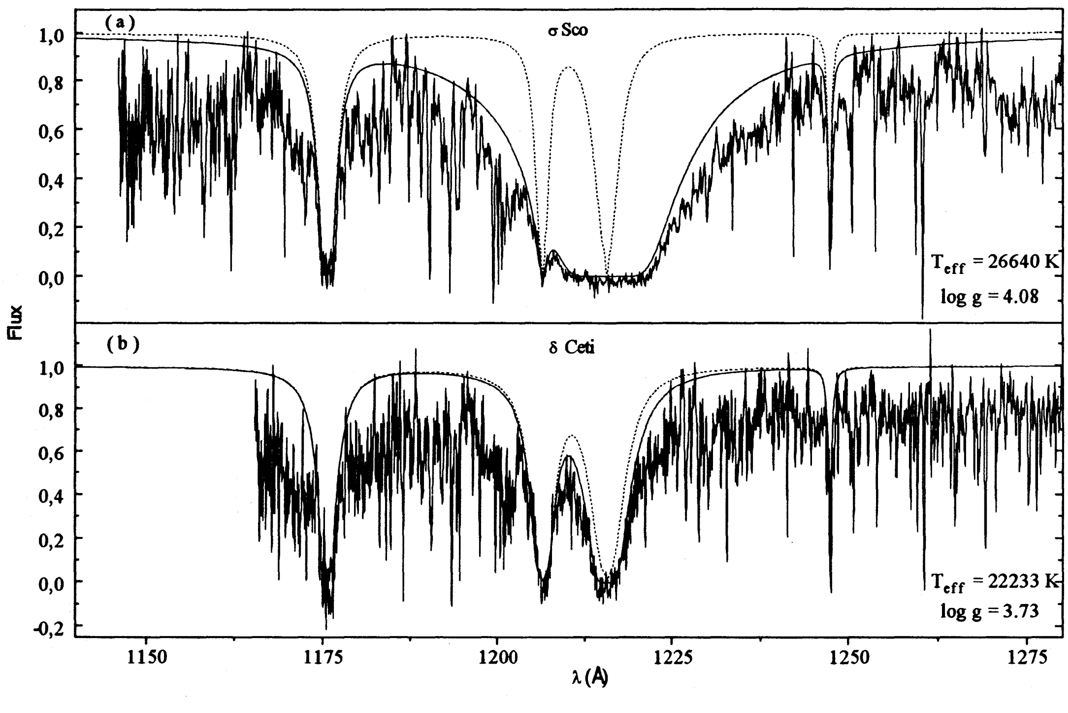

Figure 4. Examples of the *IUE* observations in comparison with theoretical spectra (see text).

Table 1. Basic parameters of the program stars and hydrogen column densities $N(HI)$, $N(H_2)$. (The number 4.8(15) means $4.8 * 10^{15}$).

No.	star	HD	Sp	T_{eff}	$\log g$	E(b-y)	$N(HI)$ $[10^{20}\ cm^{-2}]$	$N(H_2)$ $[cm^{-2}]$
1	κ *Ori*	38771	B0.5 Ia	28600	3.56	0.092	4.0	4.8(15)
2	ϵ *Per*	24760	B0.5 III	26530	3.82	0.048	2.5	3.4(19)
3	θ *Car*	93030	B0.5 Vp	28970	4.31	0.023	1.5	< 4.5(17)
4	τ *Sco*	149438	B0 V	28180	4.06	0.024	3.0	3.2(14)
5	δ *Pic*	42933	B0 IV	27180	4.07	0.016	1.5	
6	139 *Tau*	40111	B1 Ib	27880	3.56	0.156	8.0	5.5(19)
7	ζ *Per*	24398	B1 Ib	24010	3.17	0.265	7.5	4.7(20)
8	β *CMa*	44743	B1 II-III	24390	3.72	0.028	< 0.03	< 2(17)
9	σ *Sco*	147165	B1 III	26640	4.08	0.284	25.0	6.2(19)
10	β *CenA*	122451	B1 III	24480	3.73	0.026	< 0.2	< 1.6(12)
11	*o Per*	23180	B1 III	23300	3.59	0.209	7.5	4.1(20)
12	40 *Per*	22951	B1 IV	26810	4.05	0.176	9.0	2.9(20)
13	α *Vir*	116658	B1 IV	23630	3.80	0.001	< 0.05	8.9(12)
14	π *Sco*	143018	B1 V	23950	3.96	0.047	3.5	2.1(19)
15	λ *Sco*	158926	B1.5 IV	21830	3.67	0.005	< 0.1	5.0(12)
16		33328	B2	22440	3.59	0.038	2.5	
17	ϵ *CMa*	52089	B2 II	22990	3.24	0.037	< 0.1	< 4.6(17)
18	δ *Ceti*	16582	B2 IV	22233	3.73	0.008	1.0	
19	γ *Peg*	886	B2 IV	20790	3.72	0.000	< 0.3	< 1.6(14)
20	υ *Sco*	158408	B2 IV	20430	3.72	0.000	< 0.3	< 1.3(14)
21	ζ *Cen*	121263	B2.5 IV	22550	3.81	0.004	0.3	6.3(12)
22	α *Pav*	193924	B2.5 V	17300	3.73	0.000	< 0.3	< 2(14)
23	23 *Ori*	35149	B3	22840	3.85	0.070	5.0	< 3.4(18)
24	ι *Her*	160762	B3 IV	16960	3.69	0.025	< 1	
25	η *UMa*	120315	B3 V	16820	4.14	0.008	< 0.8	2.4(13)
26		21278	B4 V	15200	4.00	0.050	< 0.5	3.0(19)
27	α *Gru*	209952	B7 IV	13160	3.73	0.000	<< 5	< 4.8(13)
28	α *Leo*	87901	B7 V	12100	3.37	0.006	<< 10	< 9.5(14)
29	20 *Tau*	23408	B8 III	12780	3.22	0.048	<< 5	5.6(19)
30	β *Lib*	135742	B8 V	11820	3.16	0.003	<< 7	< 3.4(14)
31	α *Lyr*	172167	A0 V	9640	3.95	0.014		
32	α *CMa A*	48915	A1 V	10000	4.24	0.016		

3 Comparison with Other Measurements of Interstellar Extinction

The largest collection of hydrogen column densities comes from *OAO-2* and *Copernicus* (*OAO-3*) satellites, cf. e.g., Hobbs (1974), Bohlin et al. (1978) and Shull & Van Steenberg (1985). These data are compared with our results for stars in common. The agreement is satisfactory, cf. Fig. 6, but not perfect.

Figure 7 shows published values of $E(B-V)$ in comparison with our determination of $E(b-y)$ mentioned in Section 2. The linear relation between these quantities is the following: $E(B-V) = 1.26E(b-y) + 0.007\ mag.$ (straight line in Fig. 7).

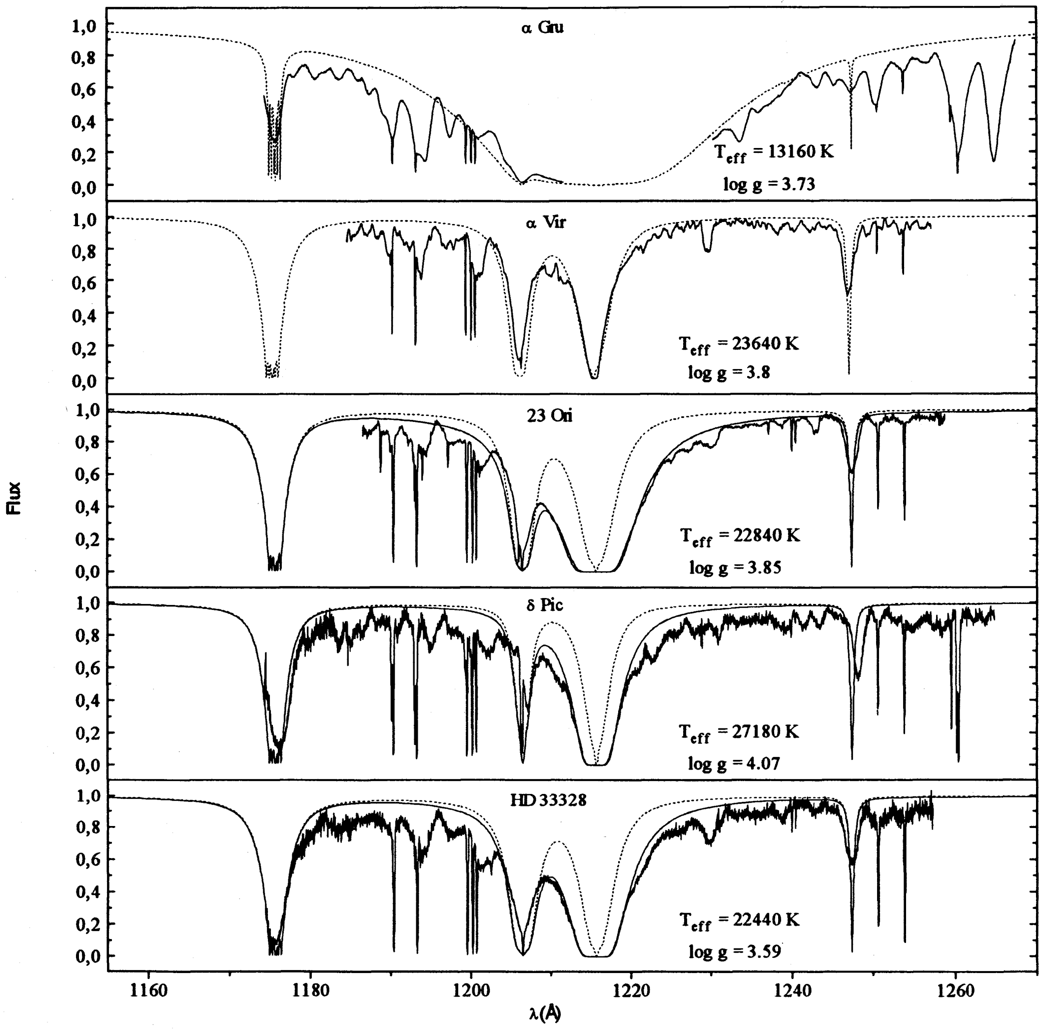

Figure 5. Examples of the *HST* observations in comparison with theoretical spectra.

4 Conclusions

In this paper we search for the best description of the Stark effect using observations of late B, A0 and A1 type stars. We found that Feautrier's et al. (1976) exact quantum calculations match well the observations. It can be achieved using atmospheric models with parameters derived from $uvby\beta$ photometry as described in Sect. 3.

Having a credible description of the broadening mechanisms of Ly_α we determined interstellar component of the observed line profiles of early B-type stars. Contrary to previous investigations mentioned in Sect. 3, our approach does not assume that the stellar Ly_α line is much narrower than the interstellar absorption and therefore no limitation for spectral types of about B2 and earlier takes place.

Absorption in the H I Ly_α line provides a fundamental measurement of interstellar gas. For instance, in the direction to stars numbered as 6, 7, 11 and 12 in Table 1, the Hydrogen column densities, N(H I), show almost the same values despite of significant differences in $E(b-y)$. It is interesting to note that in these cases the molecular hydrogen densities (cf. Table 1) achieve the largest values in our sample. The analysis which takes into account a more complete list of stars is in progress.

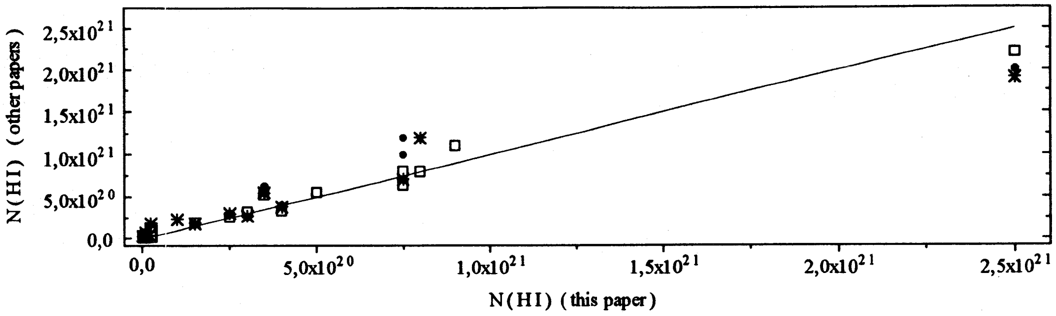

Figure 6. The correlation between hydrogen column densities N (H I) obtained in this paper and other ones, given by Hobbs (1974) (solid circles), Bohlin (1978) (open squares) and Shull (1985) (stars).

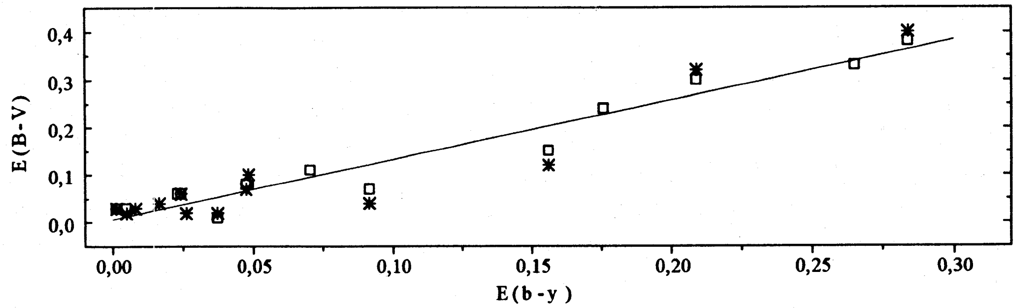

Figure 7. The value of $E(b-y)$ obtained from $uvby\beta$ photometry plotted versus $E(B-V)$ taken from Bohlin (1978) (open squares) and Shull (1985) (stars).

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