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On the Stark broadening in hot stars

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Abstract. In hot star atmospheres exist conditions where Stark widths are comparable and even larger than the thermal Doppler widths, so that the corresponding line broadening parameters are of importance for the hot star plasma investigation. Here, we investigated theoretically the influence of collisions with charged particles on heavy element spectral line profiles for Te I, Cr II and Sn III in spectra of A stars and white dwarfs. We applied semiclassical perturbation theory. When it can not be applied in an adequate way, due to the lack of reliable atomic data, we used modified semiempirical theory.

Key words. Stark broadening – line profiles – atomic data – stellar atmospheres

1. Introduction

With the development of new space techniques, the quality and quantity of spectroscopic data for trace elements has increased. For example, Yuschenko & Gopka (1996), identified one line of tellurium in the Procyon photosphere spectrum. Chayer et al. (2005) observed tellurium spectral lines in ultraviolet spectra of the cool DO white dwarf HD199499. They report as well presence of tellurium lines in the cool DO dwarf HZ21.

Chromium lines are interesting due to their presence in stellar atmospheres, so that they give possibility to determine chromium abundance and investigate chromium stratification in stelar atmospheres (Dimitrijević et al. 2005, 2007) and to be used for the diagnostics of stellar plasma and for more rafined synthesis of stellar spectra. They have been identified in A-type star spectra, as e.g. o Peg (Adelman 1994), 7 Sex (Adelman & Philip 1996), ϕ Aqu (Caliskan & Adelman 1997) which are all and chemically peculiar stars.

Spectral lines of neutral tin are present in the spectra of A type stars, for example γ Equ (Adelman et al. 1979). Also, a Sn II spectral line is observed in Przybylski's star by Cowley et al. (2000).

Here we use the semiclassical perturbation method (Sahal-Bréchot 1969a,b) to calculate the Stark broadening parameters. When it can not be applied in an adequate way, due to the lack of reliable atomic data, we used modified semiempirical theory (Dimitrijević & Konjević 1980).

2. Results and discussions

For Te I, Cr II and Sn III spectral line Stark broadening parameters, the full

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semiclassical perturbation approach (Sahal-Bréchot 1969a,b) has been applied. A summary of the formalism for ionized emitters is given in Dimitrijević et al. (1991) and Dimitrijević & Sahal-Bréchot (1996). Also, for Sn III spectral line Stark width, modified semiempirical approach (Dimitrijević & Konjević 1980) has been applied. The needed energy levels have been taken from Moore (1971) and Wiese & Musgrove (1989). The oscillator strengths have been calculated by using the method of Bates & Damgaard (1949), and the tables of Oertel & Shomo (1968). For higher levels, the method of van Regemorter et al. (1979) has been used.

There are no experimental and other theoretical data for the 2 Te I and 4 Cr II multiplets. For the considered Sn III 6s $^1S_0$ – 6p $^1P^o_1$ spectral line, Kieft et al. (2004) measured Stark width and they also, obtained the first theoretical result by using semiempirical (Griem 1968) approach.

For example, we investigated the influence of Stark broadening on Te I spectral lines in DB white dwarf atmospheres for 6s $^5S^o$ - 7p ^5P (5125.2 Å) and the 6s $^5S^o$ - 6p ^5P (9903.9 Å) multiplet by using the corresponding model with T_{eff} = 15000 K and log g = 7 (Wickramasinghe 1972). For the model atmosphere of the DB white dwarfs the prechosen optical depth points at the standard wavelength λ_s=5150 Å(τ_{5150}) are used in Wickramasinghe (1972). As one can see in Fig. 1, for the plasma conditions in the DB white dwarf atmospheres, thermal Doppler broadening is much less important compared to Stark broadening.

Stark broadening parameters, line widths and shifts for 4 Cr II 3d^5 - 3d^{4}4p multiplets are shown in Table 1. This table shows electron-, and proton-impact broadening parameters for Cr II, for a perturber density of 10^{17} cm^{-3} and temperatures from 5000 up to 100000 K. The quantity C (given in Å cm^{-3}), when divided by the corresponding full width at half maximum, gives an estimate for the maximum perturber density for which tabulated data may be used.

We synthesized Cr II 4588.2 Å line profile using SYNTH code Piskunov (1992) (Fig. 3) and, DIPSO program package, for the corresponding equivalent width, for a model atmosphere with T_{eff} = 8 750 K and log g =4.0 as a function of chromium abundance. One can see in Fig. 3 that the influence of Stark broadening increases in line wings and with chromium abundance as expected. From Figs. 3 and 4. one can see that in A type CP stars exist atmospheric layers where Doppler and Stark widths are comparable, so that the influence of Stark broadening is important.

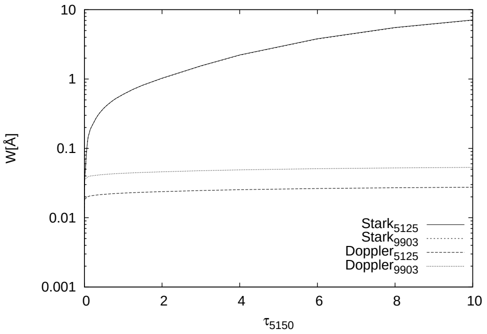

Fig. 1. Thermal Doppler and Stark widths for Te I 5125.2 and 9903.9 Åspectral lines for a DB white dwarf atmosphere model: T_{eff} = 15000 K, log g = 7 (Wickramasinghe 1972), as a function of optical depth τ_{5150}.

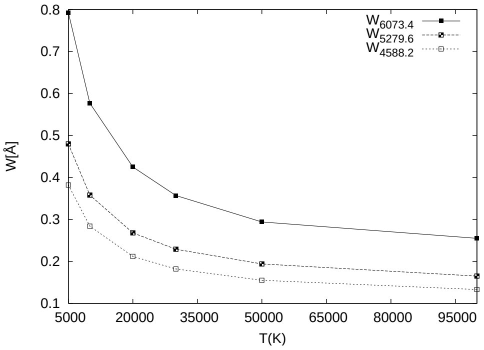

Fig. 2. Stark widths for resonant Cr II spectral lines as a function of temperature.

One can see from Table 2, a good agreement with experimental value of both our results for Stark width for Sn III 6s $^1S_0$ – 6p $^1P^o_1$ obtained by using semiclassical and modified semiempirical approach. Obviously, this ratio is better for our values than for

Table 1. Stark broadening parameters for Cr II, $3d^5$ - $3d^44p$ spectral lines.With *W* is denoted Full width at half maximum (FWHM) (e - electrons,p - protons) and with d shift.

TRANSITION	T(K)	W_e(Å)	d_e(Å)	W_p(Å)	d_p(Å)
	5000	0.514E-01	-0.334E-03	0.148E-02	-0.542E-04
CrII	10000	0.382E-01	-0.379E-03	0.268E-02	-0.120E-03
^6S-$^6P^o$	20000	0.282E-01	-0.438E-03	0.382E-02	-0.232E-03
2060.4 Å	30000	0.238E-01	-0.425E-03	0.431E-02	-0.311E-03
C=0.15E+21	50000	0.196E-01	-0.460E-03	0.473E-02	-0.405E-03
	100000	0.157E-01	-0.515E-03	0.528E-02	-0.547E-03
	5000	0.382	0.718E-01	0.102E-01	0.117E-02
CrII	10000	0.284	0.491E-01	0.175E-01	0.244E-02
^4F-$^4D^o$	20000	0.212	0.378E-01	0.244E-01	0.416E-02
4588.2 Å	30000	0.182	0.319E-01	0.268E-01	0.505E-02
C=0.40E+21	50000	0.155	0.265E-01	0.295E-01	0.639E-02
	100000	0.133	0.219E-01	0.329E-01	0.770E-02
	5000	0.480	0.743E-01	0.120E-01	0.874E-03
CrII	10000	0.358	0.514E-01	0.209E-01	0.188E-02
^4F-$^4F^o$	20000	0.268	0.399E-01	0.293E-01	0.337E-02
5279.6 Å	30000	0.229	0.338E-01	0.325E-01	0.425E-02
C=0.53E+21	50000	0.194	0.274E-01	0.357E-01	0.546E-02
	100000	0.165	0.229E-01	0.398E-01	0.679E-02
	5000	0.793	0.264	0.144E-01	0.411E-02
CrII	10000	0.577	0.197	0.258E-01	0.806E-02
^4F-$^4P^o$	20000	0.425	0.155	0.368E-01	0.127E-01
6073.4 Å	30000	0.357	0.134	0.414E-01	0.156E-01
C=0.70E+21	50000	0.294	0.110	0.459E-01	0.184E-01
	100000	0.255	0.920E-01	0.521E-01	0.221E-01

Table 2. Comparison between W_m-experimental Stark width with theoretical: W_{se}-semiempirical, W_{sc}-semiclassical and W_{mse}-modified semiempirical.

Transition	W_m(Å)	Rel. error	$\frac{W_m}{W_{se}}$	$\frac{W_m}{W_{sc}}$	$\frac{W_m}{W_{mse}}$
Sn III 6s $^1S_0$ – 6p $^1P_1^o$ 5226.2 Å	1.22	50%	1.70	0.92	1.15

semiempirical one obtained by Kieft et al. (2004) using Griem (1968) method, not applicable for multiply charged ions, see Dimitrijević & Konjević (1980).

In order to see the influence of Stark broadening mechanism for Sn III spectral line in stellar plasma conditions, we have calculated Stark widths for a Kurucz (1979) A type star ($T_{\rm eff}$ = 10000 K, log g = 4.5) atmosphere model and compared them with Doppler ones. Obtained results in function of the Rosseland optical depth are presented in Fig. 5. One can see, that exist photospheric layers where Doppler and Stark widths are comparable and

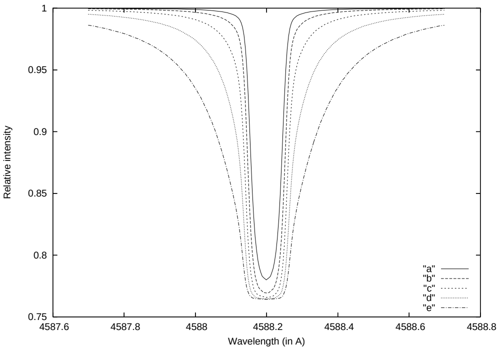

Fig. 3. Comparison of the Cr II 4588.2 Åline profile ("a") without Stark broadening contribution and with this contribution for different Cr abundances log Cr/H: ("b") Solar one, ("c") -3.75, ("d") -3.25 , ("e") -2.75. The atmosphere model: T_{eff} = 8750 K, log g= 4 (Piskunov 1992).

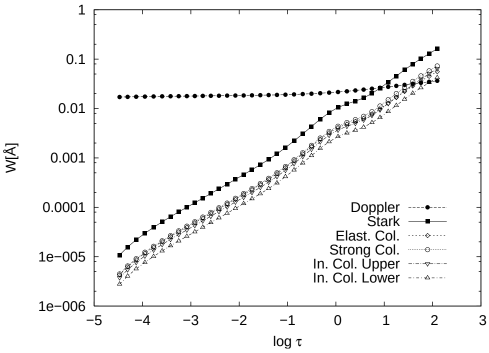

Fig. 5. Thermal Doppler, Stark and contributions of different collision processes to the total Stark width of Sn III 5226.2 Åline as functions of optical depth for an A type star (Kurucz 1979) model: T_{eff} = 10000 K and log g = 4.5.

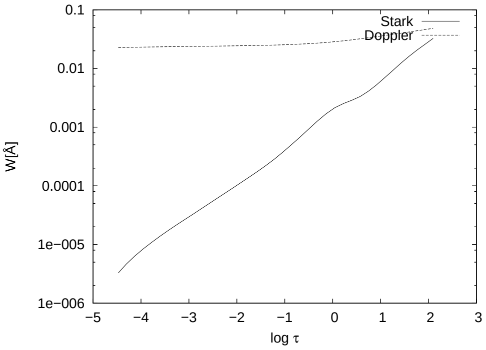

Fig. 4. Thermal Doppler and Stark widths for Cr II 4588.2 Åfor a model: T_{eff} = 10000 K, log g = 4.5 (Kurucz 1979) of an A type star, as a function of the Rosseland optical depth.

even where the Stark width is dominant and must be taken into account. Also, in Fig. 5, for the same atmosphere model, we presented Stark widths and contributions of different collision processes to the total Stark width in comparison with Doppler one. In this case, elastic and strong collisions and inelastic collision from upper levels have a similar contribution to the full Stark width as well as the similar behaviour with temperature.

We note that in all cases considered here Stark broadening influences on line shapes of considered stellar types and should be taken into account.

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