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The Stark broadening effect in hot star atmospheres: Tl II

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Abstract. In order to provide spectroscopic data for singly ionized Thallium spectral lines we present Stark broadening parameters for Tl II spectral lines calculated within the modified semiempirical approach. Calculations were performed in a temperature range 5 000 K - 50 000 K and for an electron density of 10^{23} m^{-3}. The influence of collisions with charged particles on Tl II UV stellar lines along HR diagram and in DA white dwarf atmospheres is discussed.

Key words. Atomic data: Stark broadening – Stars: atmospheres – Stars: chemically peculiar – Stars: white dwarf

1. Introduction

Electron-impact broadening is the main broadening mechanism in A and B type star atmospheres (see e.g. Popović et al. 1999). Electron-impact broadening data are needed to solve various problems in astrophysics and physics, for example, diagnosis and modeling of laboratory and stellar plasma, investigation of its physical properties and for abundance determination. These investigations provide information useful for modeling of stellar evolution, e.g. abundance studies in stellar atmospheres provide evidence of the chemical composition of the stellar primordial cloud, of processes occurring in the stellar interior, and the dynamic processes occurring in the stellar atmosphere.

Present abundance analyses for early-type stars show that 10% - 20% of A and B stars have abundance anomalies, including anomalies in isotopic composition (Leckrone et al. 1993). The abundance anomalies in these stars, called CP stars, could be caused by diffusion occurring in the presence of selective radiative acceleration. The chemical species that absorb more of outgoing photons are dragged by photons to the stellar surface (see e.g. Michaud & Richter 1997).

2. The method of calculation

We use the modified semi-empirical approach (Dimitrijević & Konjević 1980) which includes explicitly only levels with $\Delta n = 0$ and $l'_{if} = l_{if} \pm 1$, where n is the principal quantum number, l is the orbital quantum number and i and f denote the initial and final level, respectively. Levels with $\Delta n \neq 0$ are combined and approximately estimated, so that for Stark broadening parameter calculations we need less atomic data then in the semi-classical method. We note that the needed dipole ma-

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Table 1. Stark widths (FWHM) for two astrophysicaly important Tl II spectral lines. Electron density is $N = 10^{23}$ m^{-3}.

T [K]	FWHM [nm] λ=132.171 nm	FWHM [nm] λ=253.165 nm
5000	0.2195E-2	0.1963E-1
10000	0.1552E-2	0.1388E-1
15000	0.1267E-2	0.1133E-1
20000	0.1097E-2	0.9817E-2
25000	0.9818E-3	0.8781E-2
30000	0.8963E-3	0.8016E-2
35000	0.8298E-3	0.7503E-2
40000	0.7763E-3	0.7139E-2
45000	0.7319E-3	0.6844E-2
50000	0.6944E-3	0.6602E-2

trix elements have been calculated using the Coulomb approximation method described in Bates & Damgaard (1949), Shore & Menzel (1965) and Oertel & Shomo (1967).

The modified semi-empirical method is applicable under the following conditions:

1. That the line is isolated, i.e. non-degenerate energy levels broadened by collisions do not overlap (Sahal-Bréchot 1969; Dimitrijević & Sahal-Bréchot 1984).
2. That the minimal distance of the perturbing electron from an emitter is significantly smaller than distances between two perturbing electrons, i.e. that the probability that two or more electrons are close to the emitter particle is negligible (see e.g. Griem 1974).
3. That we can assume an impact approximation, which requires that the collision volume $V \sim \rho^3$ multiplied by the electron density is much less than 1 (Sahal-Bréchot 1969).
4. That the plasma is ideal. With the increase of the density the number of particles in the Debye sphere decreases and the plasma becomes non-ideal (Konjević & Uzelac 1990). The idealness of the plasma can be checked by calculating the number of perturbers in the Debye sphere which must be larger than 1 (Dimitrijević et al. 1991).

The accuracy of the MSE calculations for spectral line widths is around ±50% (Dimitrijević & Konjević 1980). The average ratio of calculated and experimental widths, determined in Dimitrijević & Konjević (1980) for 36 multiplets of 7 different doubly- charged ions is 1.06±0.32 and for 7 multiplets for 4 triply-charged ions 0.91±0.42. For 71 multiplets of 7 singly-charged ions with various couplings schemes Popović (1994) found that the overall average ratio of experimental to calculated widths is 1.4±0.3. Even for relatively complex spectra of Xe II and Kr II with mixed jK and LS couplings, the accuracy is about ±30% (Popović & Dimitrijević 1996).

3. Results and discussion

We used MSE method for Tl II spectral lines calculations. Here we present results for two astrophysically important spectral lines, while other results will be published elsewhere (see Milovanović et al. 2005). Stark widths as a function of the temperature for Tl II λ=132.171 nm (6s^2 $^1S_0$ - 6p $^1P^o_1$) and λ=253.165 nm (6p $^1P^o_1$ - 6d $^1D_2$) for electron density $N = 10^{23}$ m^{-3} are shown in Table 1. These two spectral

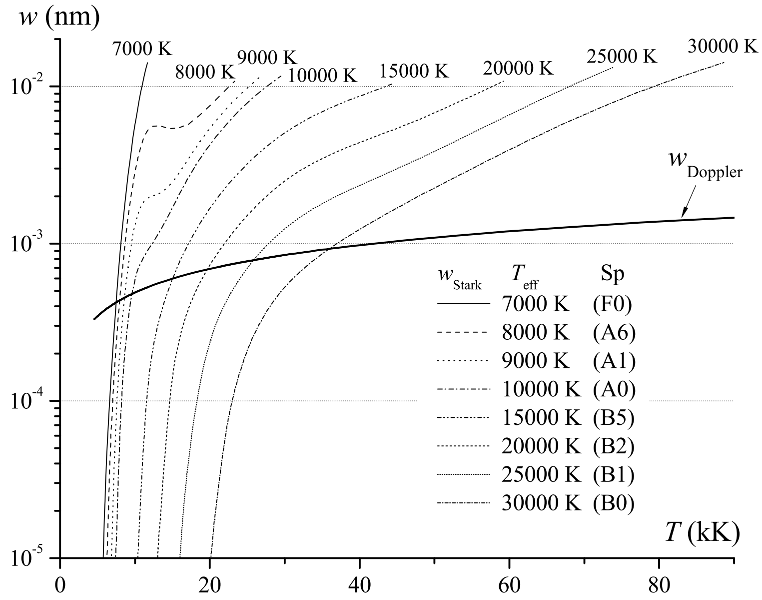

Fig. 1. Stark widths (FWHM) (thin lines) and Doppler width (thick line) for Tl II λ=132.171 nm (6s^2 ^{1}S$_0$ - 6p ^{1}P$^o_1$) spectral line as a function of atmospheric layer temperatures. Stark widths are shown for 8 atmospheric models with effective temperatures T_{eff} = 7 000 – 30 000 K, corresponding to spectral classes (Sp) from F0 to B0, log g = 4.0 and turbulent velocity v_t = 0 km/s.

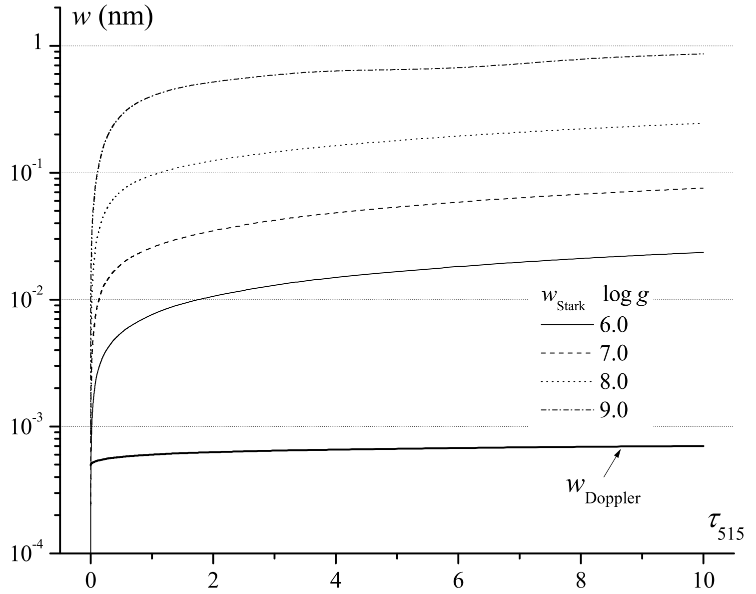

Fig. 2. Stark and Doppler widths for Tl II λ=132.171 nm spectral line as a function of the optical depth for standard wavelength λ_{st} = 515 nm for DA white dwarfs. Widths are given for 4 values of logarithm of surface gravity log g = 6.0 – 9.0. Effective model temperature is T_{eff} = 15 000 K.

lines are discovered in UV spectra of χ Lupi HgMn star (Leckrone et al. 1999).

We used our results for Stark widths given in Table 1 to examine the importance of electron-impact broadening in hot star and white dwarf atmospheres for trace elements like Tl II. Behavior of Stark and Doppler spectral line widths in stellar atmospheres were calculated for Tl II λ=132.171 nm in various atmospheric models.

In Fig. 1 Stark (FWHM) and Doppler widths for Tl II λ=132.171 nm spectral line as a function of atmospheric layer temperatures are shown. Stark widths are shown for 8 atmospheric models with effective temperatures $T_{\rm eff} = 7\,000-30\,000$ K, corresponding to spectral classes (Sp) from F0 to B0, logarithm of surface gravity $\log g = 4.0$ and turbulent velocity $v_t = 0$ km/s. In Fig. 1 one can see that Stark widths are lager than Doppler ones for stars with lower effective temperatures. The similiar results are obtained in the case of Cd III line (Milovanović et al. 2004). For stars with higher effective temperatures, Stark broadening is more important than Doppler one for deeper atmospheric layers. For example, for stars with effective temperature $T_{\rm eff} = 30\,000$ K (B0 stars), Stark and Doppler widths are equal for temperature layer $T \approx 35\,000$ K and for stars with $T_{\rm eff} = 7\,000$ K (F0 stars), they are equal for $T \approx 5\,000$ K.

To compare Stark and Doppler broadening we have calculated spectral line widths for Tl II λ=132.171 nm for DA white dwarf atmospheres. Models were taken from Wickramasinghe (1972). DA dwarfs are helium and metal underabundant and DB white dwarfs are helium and metal overabundant compared to hydrogen.

As one can see in Fig. 2 Stark broadening is by one or two order of magnitudes higher than Doppler one. Consequently, with the increases in pressure, electron density or effective temperature in DA white dwarf models, the importance of Stark broadening increases as well.

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