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Stark Broadening Mechanism in Hot Stellar Atmospheres

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Abstract. Stellar spectroscopy needs atomic and line-broadening parameters for a very extensive list of line transitions for various elements in neutral and ionized states. With the development of space-born observational techniques data on trace elements become more and more important for astrophysical problems as stellar plasma analysis and modelling, stellar opacity calculations and, interpretation and numerical synthesis of stellar spectra. In several works we investigated Stark broadening mechanism in atmospheres of A type stars and DB and DA white dwarfs. Here, we present a review of our work on the importance of Stark broadening data for stellar atmospheres plasma research on the basis of our results for spectral line widths of Cd I, F III, Cu III, Zn III and Se III transitions, obtained within the modified semiempirical approach and semiclassical perturbation method.

1 Introduction

Data on Stark broadening of, for example, neutral cadmium and doubly ionized fluorine, copper, zinc and selenium spectral lines are of interest not only for laboratory but also for astrophysical plasma research as *e.g.* for stellar spectra analysis and synthesis, for abudance determination and opacity calculations. We note also that in hot star atmospheres Stark broadening mechanism is the main pressure broadening mechanism [1,2].

Abudance analysis for A type stars showed the presence of neutral cadmium in stellar spectra of *e.g.* 68 Tauri [3,4] and V816 Centauri [5], in distinction from fluorine which cosmic abundance is lower. We note as well that the line 6438.4696 Å, 5p $^1P^\circ_1$ – 5d $^1D_2$ is the fundamental wavelength standard used as the basis for other standards.

With the development of new techniques, importance of data on trace element spectra like Se or Cu increases. For example, from the analysis of 11 Hg-Mn star spectra [6], where Stark broadening is the main pressure broadening mechanism, it follows that copper is clearly present and overabundant in 10 of there investigated stars.

Zinc spectral lines are also present in stellar spectra [3–5,7,8]. Moreover, doubly charged zinc ion is a member of the nickel isoelectronic sequence, known to include possible candidates for development of ultraviolet lasers [9].

Selenium, a trace element without an astrophysical significance before, is now detected in the atmospheres of cool DO white dwarfs [10, 11].

Here, we will present a review of our work on the the importance of Stark broadening data for stellar atmospheres plasma research on the basis of our results for spectral line widths of Cd I, F III, Cu III, Zn III and Se III transitions [12–14], obtained within the modified semiempirical approach [15] and semiclassical perturbation method [16, 17].

2 Results and Discussions

We have calculated within the semiclassical perturbation approach [16, 17] the Stark broadening parameters of 11 Cd I singlets and 13 triplets in ultra-violet and visible, and 24 Cd I triplets in infra red spectral ranges, for temperatures between 2500 K and 50000 K, and for perturber density of 10^{16} cm^{-3} [12]. Also, we have calculated within the same approach these parameters for F III $2p^3$ $^4S^\circ$ – 3s ^4P resonant line [13]. Moreover, for 10 F III multiplets, line widths have been obtained within the modified semiempirical approach [15], for temperatures between 10000 K and 300000 K, and for perturber density of 10^{17} cm^{-3} [13]. Atomic energy levels needed for calculations of Cd I and F III have been taken from [20], for Cu III from [18], for Zn III from [19] and ones for Se III from [20]. The oscillator strengths have been calculated within the Coulomb approximation [21, 22]. For higher levels, the method from [23] has been used.

One of our aims here is to use the obtained results for the investigation of the influence of Stark broadening within a spectral series in A type star atmospheres. Consequently, Stark widths within $5s^2$ ^1S – np $^1P^\circ$ spectral series have been compared in Figure 1 with Doppler widths for a model ($T_{\mathrm{eff}} = 10000$ K, $\lg g = 4$) of A type star atmosphere [24], close to the conditions for 68 Tauri ($T_{\mathrm{eff}} = 9025$ K, $\lg g = 3.95$) where Stark broadening is of interest for the atmosphere modelisation [3, 4]. We note also that one of the line (2288.7 Å) within the first member of this series, the multiplet $5s^2$ ^1S – 5p $^1P^\circ$, has an intensity of 1500 according to the NIST Atomic Spectra Database. Our results are presented as a function of Rosseland optical depth – $\lg \tau$. As one can see, with an increase of the principal quantum number the importance of Stark broadening in comparison to the Doppler one increases as well. For lines with higher initial quantum number Stark broadening is more than one magnitude larger than Doppler mechanism.

The mentioned model for the stellar atmosphere has been also used for two other spectral lines, the first (7400.9 Å) in optical range and the second (59346.5 Å) in IC range (see Figure 2). It is interesting to see, in Figure 2, that the Stark broad-

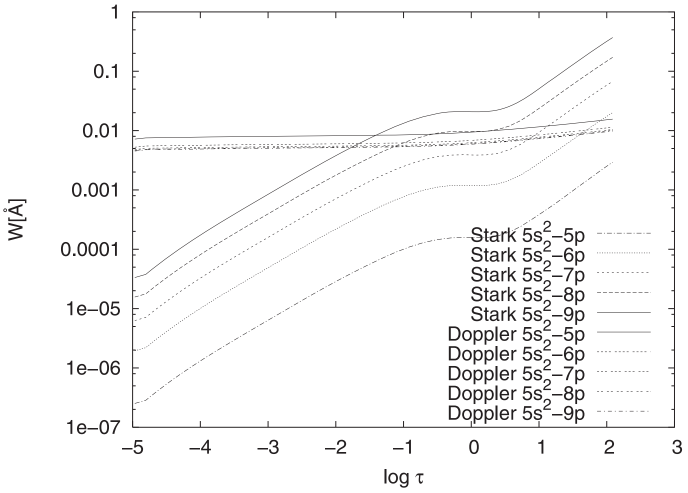

Figure 1. Thermal Doppler and Stark widths for Cd I singlet spectral lines: 5s^2 ^{1}S – 5p ^{1}P$^\circ$ (2288.7 Å), 5s^2 ^{1}S – 6p ^{1}P$^\circ$ (1669.3 Å), 5s^2 ^{1}S – 7p ^{1}P$^\circ$ (1526.9 Å), 5s^2 ^{1}S – 8p ^{1}P$^\circ$ (1469.4 Å), 5s^2 ^{1}S – 9p ^{1}P$^\circ$ (1440.2 Å) as a function of Rosseland optical depth.

ening mechanism is absolutely dominant in comparison with the termal Doppler mechanism throughout the considered layers of stellar atmosphere ($\lg \tau > -3.5$) for the 59346.5 Å line. This is a consequence of the fact that infrared spectral lines originate from more closer transitions than the lines in UV and optical

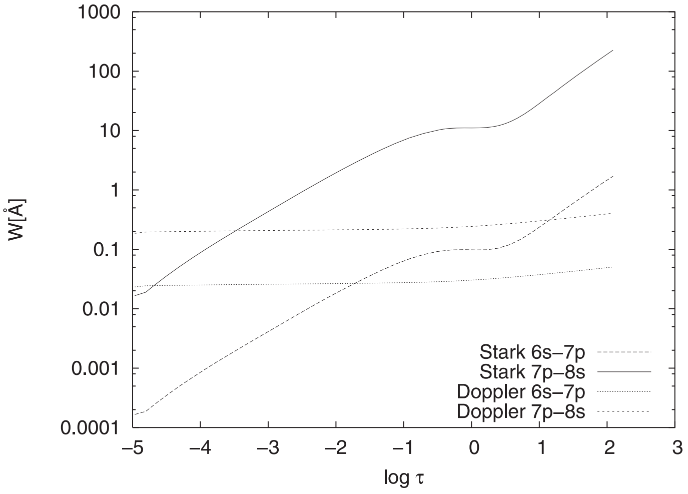

Figure 2. Thermal Doppler and Stark widths for Cd I triplet spectral line: 6s ^{3}S$^\circ$ – 7p ^{3}P$^\circ$ (7400.9 Å) and 7p ^{3}P$^\circ$ – 8s ^{3}S$^\circ$ (59346.5 Å) as a function of Rosseland optical depth.

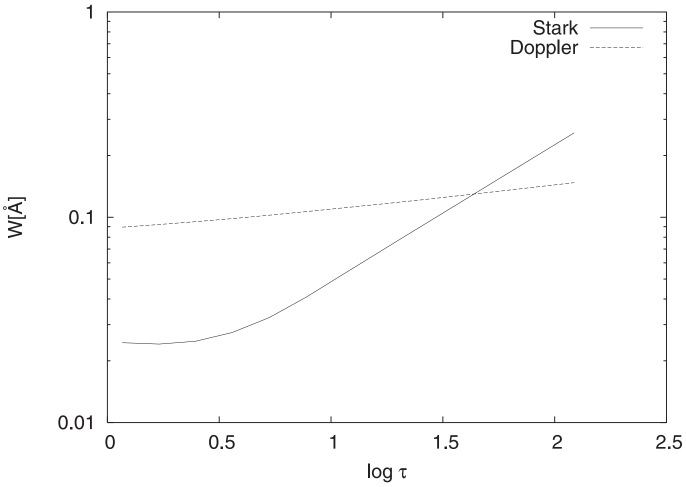

Figure 3. Stark and Doppler widths for F III 4s ^{4}P – 4p ^{4}D° (8890 Å) as a function of Rosseland optical depth, for an A type stellar atmosphere model with $T_{\rm eff} = 10000$ K and $\lg g = 4$.

ranges, and that the corresponding Stark broadening, proportional to the square of the wavelength, is larger in comparison to the Doppler one which is proportional to the wavelength λ.

In Figure 3 we compared line widths for F III due to Stark and thermal Doppler broadening mechanisms as functions of optical depth corresponding to 10000–30000 K temperature range [13], for an A type star atmosphere model ($T_{\rm eff} =$ 10000 K, $\lg g = 4$). One should take into account that due to differences between Lorentz (Stark) and Gauss (Doppler) line intensity distributions, Stark broadening may be more important in line wings in comparison with the thermal Doppler one, even when it is smaller in the central part.

The influence of the Stark broadening on Cu III, Zn III and Se III spectral lines for DB white dwarf plasma conditions was investigated for 4s ^{2}F – 4p ^{2}G° (λ=1774.4 Å), 4s ^{3}D – 4p ^{3}P° (λ=1667.9 Å) and 5s ^{3}P° – 5p ^{3}D (λ=3815.5 Å) by using the corresponding model with $T_{\rm eff} = 15000$ K and $\lg g = 7$ [25]. For the considered 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 [25] and here, as the difference to the A type star model [24], where the Rosseland optical depth scale (τ_{Ross}) was taken. As one can see in Figure 4, for the DB white dwarf atmosphere plasma conditions, thermal Doppler broadening has much less importance in comparison with the Stark broadening mechanism.

Generally, from our results follows that in atmpspheres of A type stars and white dwarfs exist layers where Stark broadening effect should be taken into account for modelling and investigation stellar plasmas.

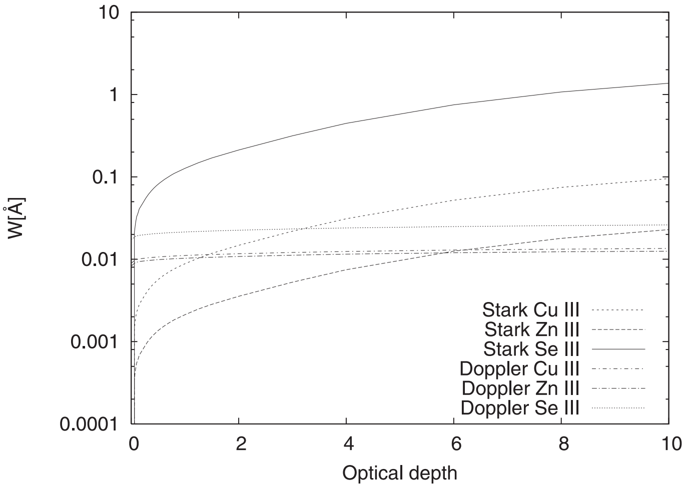

Figure 4. Thermal Doppler and Stark widths for Cu III, Zn III and Se III spectral lines 4s ^{2}F – 4p ^{2}G° (λ=1774.4 Å), 4s ^{3}D – 4p ^{3}P° (λ=1667.9 Å) and 5s ^{3}P° – 5p ^{3}D (λ=3815.5 Å) for a DB white dwarf atmosphere model with $T_{\rm eff} = 15000$ K and lg $g = 7$, as a function of optical depth τ_{5150}.

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