Publ. Astron. Obs. Belgrade No. 76 (2003), 215-220 *Contributed paper*

IMPORTANCE OF COLLISIONS WITH CHARGED PARTICLES FOR STELLAR UV LINE SHAPES: Cd III

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Abstract. Stark broadening parameters, widths and shifts, for 84 spectral lines of the doubly-ionized Cadmium (Cd III) have been calculated using modified semiemprical approach (MSE). Influence of collisions with charged particles on Cd III UV stellar lines along HR diagram has been discussed. Compared to the Doppler broadening, influence of Stark broadening mechanism is more important for deeper atmospheric layers and for larger values of log *g*. Influence of the Stark widths for standard models of DA and DB white dwarfs has been also discussed.

1. INTRODUCTION

Spectral lines of multiply charged heavy elements are present in the UV spectra of early-type stars, especially in spectra of chemically peculiar (CP) ones. Investigation of these lines is important for example for spectral lines synthesis, diagnostics and modelling of laboratory and stellar plasma, abundance determination and opacity calculation.

Stark broadening of spectral lines is the dominant pressure broadening mechanism in hot, early-type, stars and white dwarf atmospheres. Spectral lines of Cd I and Cd II are observed in stellar spectra of some CP stars, as e.g. χ Lupi (Leckrone *et al.,* 1999), so that Cadmium in various ionization stages is present in stellar atmospheres. With the development of space born telescopes, spectral instruments like Goddard High Resolution Spectrograph (GHRS) on Hubble Space Telescope provide good resolution spectra of stellar objects so that the need for trace element data, like Cadmium, increases.

2. METHOD OF CALCULATION AND RESULTS

Advanced calculation of the Stark broadening parameters using strong-coupling quantum-mechanical method (Baranger, 1958abc; Kolb and Griem, 1958; Griem, 1974; Dimitrijević *et al.,* 1981; Seaton, 1988; Ralchenko *et al.,* 1999; Zeng-xin *et al.,* 1999) are so complicated that only limited number of data for spectral lines originating from low laying transitions can be calculated in an adequate way. On the other hand, semiclassical method (Sahal-Bréchot, 1969ab; Dimitrijević *et al.,* 1991; see also a review of obtained results in Dimitrijević, 1997) need a set of large number of atomic data, energy levels and oscillator strengths. This method is not applicable in adequate way to the Stark broadening calculation of Cd III because there is no sufficient number of reliable atomic data.

We used the modified semiempirical approach (MSE, Dimitrijević and Konjević, 1980, Dimitrijević and Kršljanin, 1986). The accuracy of the MSE calculations for spectral line widths is around $\pm 50\%$ (Dimitrijević and Konjević, 1980). Error in obtained shifts with MSE calculations is within $\pm 50\%$ of the corresponding widths value.

Doubly-ionized cadmium (Cd III) belongs to Palladium isoelectronic sequence with the ground state electronic configuration $4d^{10}\ ^1S_0$ and ionization potential of 302200 ± 50 cm^{-1}. Atomic data needed for our MSE calculation were taken from Van Kleef *et al.* (1980). They observed Cd III spectra in UV spectral range from 50 to 210 nm with 6.65 and 10.7 meters normal-incidence vacuum spectrograph. Experimental values of energy levels were checked with the least-square level fitting of Hartee-Fock (HF) calculations of atomic parameters. They give more complete analysis of energy level values compared to the first observed spectra of Cd III presented in paper of Shenstone and Pittenger (1949). Van Kleef *et al.* (1980) estimated that the energy levels error for sharp lines is ± 0.5 cm^{-3} and several cm^{-3} for strong and asymmetric lines.

Even if coupling schemes slowly go from LS to jj coupling as we go throughout the isoelectronic sequence from Pd I to Sn V, most of energy levels, without loosing accuracy, can be represented with LS coupling (Van Kleef *et al.,* 1980). Consequently LS coupling scheme is adopted here.

The calculated Stark widths and shifts of Cd III spectral lines for 84 spectral lines, whereat 22 belong to $4d^9$ 5s–$4d^9$ 5p and 62 to $4d^9$ 5p–$4d^9$ 5d transition are given in Milovanović *et al.* (2003).

3. DISCUSSION

Behavior of Stark and Doppler spectral line widths in stellar atmospheres were calculated for Cd III 5p $^3F^o_3$ – 5d $^3G_3$ (λ=144.754 nm), a strong spectral line in various atmospheric models. These calculations were performed for solar element abundance atmospheric models given in Kurucz (1979) and Kurucz's web site (http://kurucz.harvard.edu). Each model is characterized by the effective temperature $T_{\rm eff}$, logarithm of gravity log g and turbulent velocity v_t and each atmospheric layer within the model is characterized by electron density N and temperature T.

In hot stars atmospheres besides electron-impact broadening (Stark broadening) the important broadening mechanism is Doppler (thermal) one as well as the broadening due to the turbulence and stellar rotation. Other types of spectral line broadening, as Van der Waals, resonance and natural broadening, are usually negligible.

Importance of Stark broadening in hot stars atmospheres is illustrated in Figs. 1-3. In Fig. 1 Stark (FWHM) and Doppler widths for Cd III 5p $^3F^o_3$ – 5d $^3G_3$ (λ=144.754 nm) spectral line as a function of atmospheric layer temperatures are shown. Stark widths are shown for 8 atmospheric models with effective temperatures $T_{\rm eff}$=7000 - 30000 K, corresponding to spectral classes (Sp) from F0 to B0, logarithm of surface gravity log g=4 and turbulent velocity v_t=0 km/s. In Fig. 1 one can see that Stark widths are larger than Doppler ones for stars with lower effective temperatures. For stars with higher effective temperatures Stark broadening is more important than Doppler one for deeper atmospheric layers (higher layer temperature T). For example, for stars with effective temperature $T_{\rm eff}$=30000 K (B0 stars) Stark and Doppler widths are equal for layer temperature $T\approx$35000 K and for stars with $T_{\rm eff}$=7000 K (F0 stars) they are equal for $T\approx$5000 K.

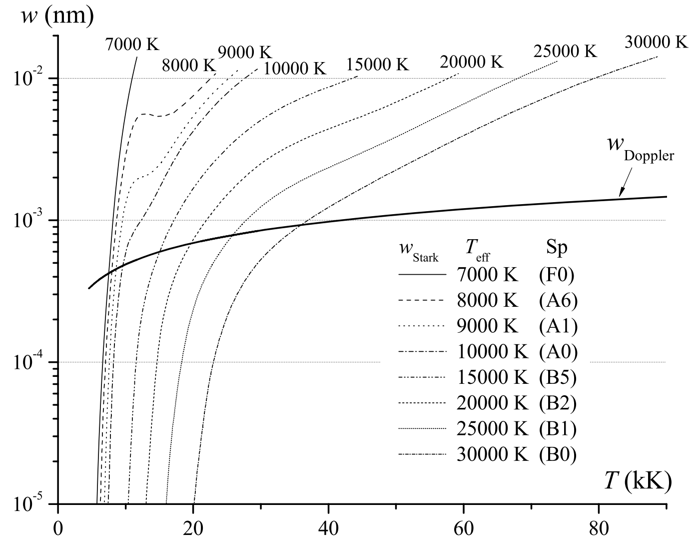

Fig. 1: Stark widths (FWHM) (thinner lines) and Doppler width (thicker line) for Cd III 5p $^3F^o_3$ – 5d $^3G_3$ (λ=144.754 nm)spectral line as a function of atmospheric layer temperatures. Stark widths are shown for 8 atmospheric models with effective temperatures T_{eff} =7000 - 30000 K, corresponding to spectral classes (Sp) from F0 to B0, log g=4 and turbulent velocity v_t =0 km/s.

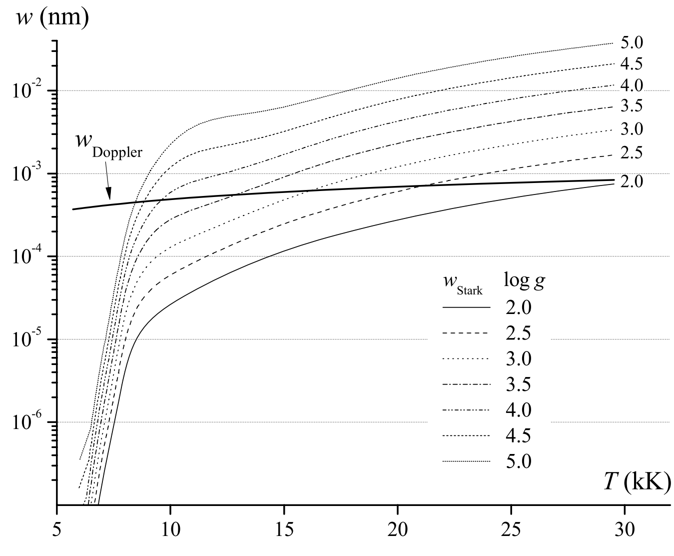

Fig. 2: Same as in Fig. 1 but Stark widths are shown for 7 values of model gravity log g= 2 - 5, T_{eff}=10000 K and v_t =0 km/s.

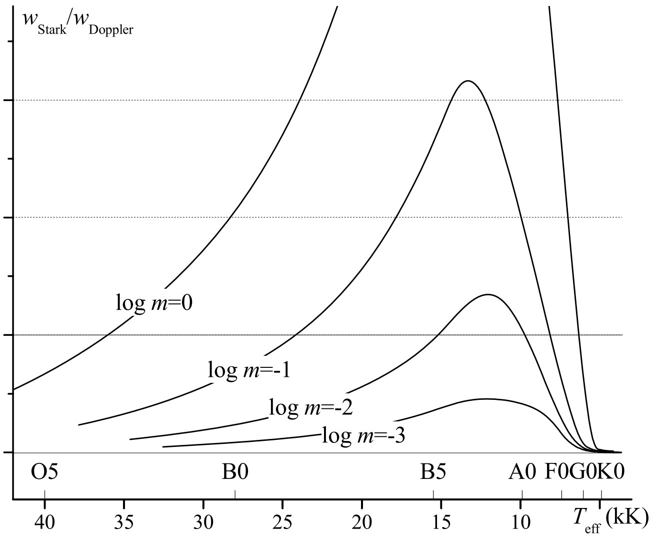

Fig. 3: Ratio of Stark and Doppler widths $w_{Stark}/w_{Doppler}$ as a function of the model effective temperature $T_{\rm eff}$ (upper part of horizontal axis is spectral class). Dependence is shown for 4 values of logarithm of the column mass at temperature minimum log *m* from 0 to -3, log *g*=4 and velocity v_t=0 m/s.

Dependence of Stark and Doppler broadening on atmospheric layer temperature for 7 values of surface gravity is shown in Fig. 2. Model used here has $T_{\rm eff}$ =10000 K and v_t=0 km/s. Stark broadening in stellar atmospheres with higher values of surface gravity is significantly larger than Doppler broadening. For stars with surface gravity log *g*=2 Stark broadening is comparable to Doppler widths only for deeper hot atmospheric layers. For upper parts of stellar atmospheres (T<10000 K) Stark widths rapidly decrease and for layer temperature T≈6000 - 7000 K Stark widths are several magnitudes lower than Doppler ones for all shown values of surface gravity log *g*.

Ratio of Stark and Doppler widths along Hertzsprung-Russell diagram, from K0 to O5 spectral class, and within the range of the column mass at temperature minimum log *m* from -3 up to 0 are shown in Fig. 3. In deeper parts of atmospheres, e.g. log *m*=0, Stark broadening is larger than Doppler one for stars of G, F, A and B spectral type. For log *m*=-3 (upper atmospheric parts) Doppler widths are comparable (approximately one-half) with Stark widths for spectral classes A0 to B5.

In order to compare Stark and Doppler broadening we have calculated spectral line widths for Cd III λ=144.754 nm for DA and DB white dwarfs 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 Figs. 4 and 5 Stark broadening is by one or two order of magnitudes higher than Doppler one. Consequently, with the increases of the pressure, electron density or effective temperature in DA and DB white dwarf models the importance of Stark broadening increases as well.

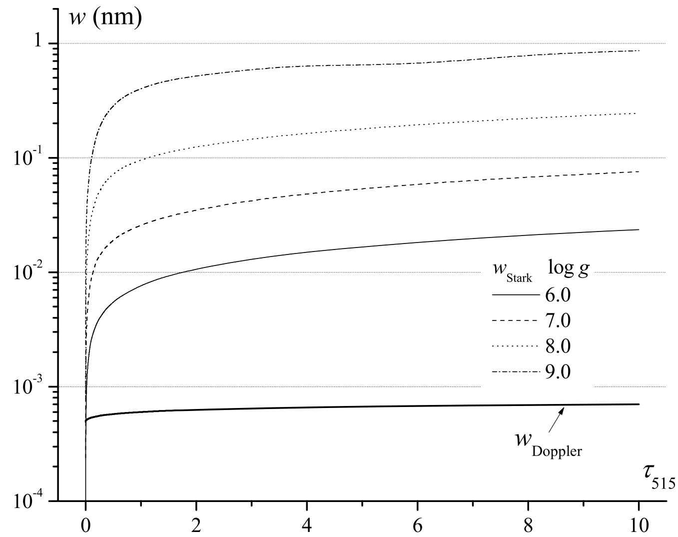

Fig. 4: Stark and Doppler widths for Cd III λ=144.754 nm spectral line as a function of optical depth for standard wavelength λ_{st}=505 nm for DA white dwarfs. Widths are given for 4 values of logarithm of surface gravity log *g*=6 - 9. Effective model temperature is T_{eff}=10000 K.

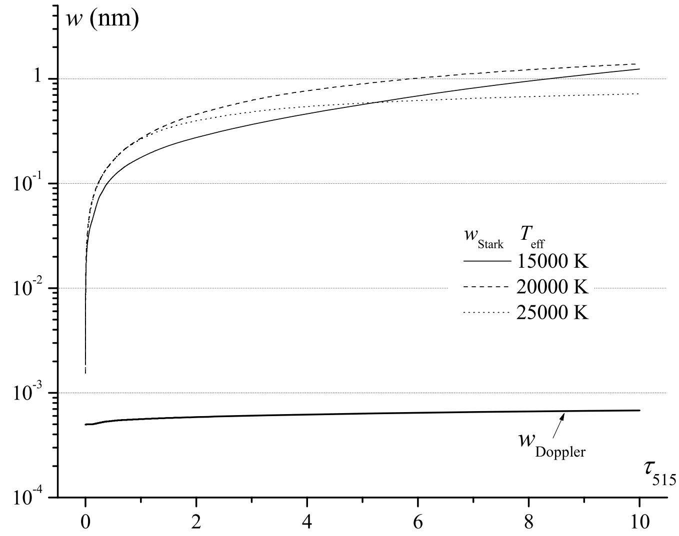

Fig. 5: Same as in Fig. 4 but for DB white dwarfs. Widths are given for T_{eff}=10000, 20000 and 25000 K and log *g*=8.

Here we should mention that the comparison of Stark and thermal Doppler contributions to the line widths is calculated for one line of Cd III (λ=144.754 nm), and that we can expect a similar contribution of the Stark broadening for all UV Cd III lines. The contribution of the Stark effect to line widths increases with the principal quantum number (Vince and Dimitrijević, 1985) and also one should take into account that in some cases, due to close perturbing levels, Stark widths might also be large. In some cases the Stark broadening may significantly contribute to the line widths as well as to the line shapes (see e.g. Dimitrijević *et al.,* 2003, analogous results having been obtained from our similar investigations for Zr II and Zr III in Popović *et al.,* 2001a and Nd II in Popović *et al.,* 2001b).

Acknowledgements. This work is a part of the projects "Influence of collisional processes on astrophysical plasma lineshapes" (GA 1195) and "Astrophysical Spectroscopy of Extragalactic Objects" (GA 1196) supported by the Ministry of Science, Technologies and Development of Serbia.

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