Contrib. Astron. Obs. Skalnaté Pleso **53/3**, 37 – 50, (2023)
https://doi.org/10.31577/caosp.2023.53.3.37

On the Stark broadening of Al IV spectral lines in stellar atmospheres

Magdalena D. Christova[1] **and Milan S. Dimitrijević**[2,3]

[1] *Department of Applied Physics, Technical University of Sofia, 1000 Sofia, Bulgaria, (E-mail: mchristo@tu-sofia.bg)*

[2] *Astronomical Observatory, Volgina 7, 11060 Belgrade, Serbia, (E-mail: mdimitrijevic@aob.rs)*

[3] *LERMA, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, F-92190 Meudon, France*

Received: September 17, 2023; Accepted: October 9, 2023

Abstract. The influence of Stark broadening on Al IV spectral lines in the visible part of the spectrum of A-type star and DO white dwarf atmospheres is analyzed. It has been demonstrated that it is negligible for considered spectral lines in the case of A-type stars and dominant in the case of DO white dwarfs. Also, regularitis of Stark widths and their temperature dependence have been discussed.

Key words: Stark broadening – spectral line shapes – atomic data – Al IV

1. Introduction

One of the first studies dealing with Stark broadening of aluminum spectral lines is presented in Mazing *et al.* (1964) and since than a great number of studies of Stark broadening of spectral lines of aluminum in different ionization degrees, witnessing on its importance, have been published. The needs for Stark broadening data for spectral lines of aluminum ions in astrophysics stimulated particularly the efforts on that subject (Dimitrijević; Sahal-Bréchot, 1994; Elabidi, 2021). For example results for 7 Al XI spectral lines for perturber densities 10^{18} cm^{-3} – 10^{23} cm^{-3} and temperatures: 500 000 K – 4 000 000 K are provided in Dimitrijević and Sahal-Bréchot (1994). Elabidi (2021) calculated Stark broadening parameters for 20 Al IV lines in UV, belonging to 2p^6–3s, 3s–3p and 3p–3d transitions. For calculations he used quantum mechanical theory (Elabidi, 2004; Elabidi *et al.*, 2008), while in Dimitrijević and Sahal-Bréchot (1994), the semiclassical perturbation formalism (Sahal-Bréchot, 1969 a b) is applied.

Aluminum is the twelfth most common chemical element in the cosmos and its spectral lines are largely presented in the observed stellar spectra. That implies the astrophysical importance of aluminum. Aluminum abundances in giants and dwarfs are for example determined in Smiljanic *et al.* (2016) within the Gaia-ESO Survey. Carretas *et al.* (2018) determine aluminum abundances for red giant branch (RGB). For a total of 108 RGB stars in NGC 2808 [Al/Fe] ratios are gathered. The atmospheric abundance of aluminum is derived for a sample of normal, superficially normal and HgMn–type main–sequence late–B stars (Smith, 1993). According to Fernández–Trincado *et al.*, stars with higher levels of aluminium and nitrogen enrichment are often key pieces in the chemical makeup of multiple populations in almost all globular clusters (GCs). With the help of APOGEE spectra, they reported the discovery of 29 mildly metal–poor stars wich atmospheres have overabundance of aluminum (Al–rich stars).

Plasma diagnostics using spectral line profiles and line broadening is a powerful tool to understand the interactions in the plasma environment. Such data are significant to obtain reliable modelling of plasma processes. Interactions between emitters (atoms or ions) and surrounding particles results in broadening and shifting of spectral line profiles known as pressure broadening. Stark broadening is a type of pressure broadening where the interactions between emitters and charged particles are of interest. Stark broadening data are applicable in fundamental research as astrophysics (Beauchamp *et al.*, 1997), investigations of laboratory plasma (Konjević, 1999; Belostotskiy *et al.*, 2010; Zhou *et al.*, 2022), laser produced plasma (Gornushkin, 1999; Nicolosi *et al.*; Sorge *et al.*, 2000), inertial fusion experiments (Griem, 1992; Iglesias *et al.*, 1887) and others. They find application also in technological and industrial plasma (Yilbas *et al.*, 2015; Hoffman *et al.*, 2006), as well as for laser design and development (Wang *et al.*, 1992).

Recently, we calculated Stark widths at half maximum (FWHM) for 23 Al IV multiplets using modified semiempirical method (Dimitrijević; Christova, 2023). The studied lines belong to the visible part of the spectrum. Values for the temperature are 10 000 K, 20 000 K, 40 000 K, 80 000 K and 160 000 K, and the perturber density is 10^{17} cm^{-3} .

In this work, we perform an analysis of the Stark broadening influence on the Al IV spectral lines in the visible part of A-type star and DO white dwarf spectra, by comparison of Stark and Doppler widths versus Rosseland optical depth, with the help of Kurucz (1979) and Wesemael (1981) models of stellar atmospheres. Additionally, temperature dependence of Stark broadening for spectral lines within one multiplet, one spectral series and one supermultiplet will be discussed and the similarities of Stark widths (Wiese; Konjević, 1982) for spectral lines within a multiplet will be considered.

The data on Al IV Stark broadening parmeters will be of interest for a number of research topics in astronomy, in particular for white dwarf spectra analysis and synthesis and modelling of their atmospheres, for abundance determination and radiative transfer and opacity calculations. They will be also useful for laboratory, fusion and laser-produced plasmas investigation and modelling.

2. Theory

The modified semiempirical method (MSE - Dimitrijević, Konjević, 1980, for the applications see Dimitrijević, 2020) has been described many times so that only basic details will be presented here. In this method, the full width at half intensity maximum (FHWM) is given as:

$$W_{MSE} = N\frac{8\pi}{3}\frac{\hbar^2}{m^2}\Big(\frac{2m}{\pi kT}\Big)^{1/2}\frac{\pi}{\sqrt{3}}\frac{\lambda^2}{2\pi c}\times$$

$$\times\Big\{\sum_{\ell_i\pm1}\sum_{L_{i'}J_{i'}}\vec{R}^2[n_i\ell_iL_iJ_i, n_i(\ell_i\pm1)L_{i'}J_{i'}]\widetilde{g}(x_{\ell_i,\ell_i\pm1})+$$

$$+\sum_{\ell_f\pm1}\sum_{L_{f'}J_{f'}}\vec{R}^2[n_f\ell_fL_fJ_f, n_f(\ell_f\pm1)L_{f'}J_{f'}]\widetilde{g}(x_{\ell_f,\ell_f\pm1})+$$

$$+\Big(\sum_{i'}\vec{R}^2_{ii'}\Big)_{\Delta n\neq0}g(x_{n_i,n_i+1})+\Big(\sum_{f'}\vec{R}^2_{ff'}\Big)_{\Delta n\neq0}g(x_{n_f,n_f+1})\Big\}. \quad (1)$$

Here, the index i is for the initial and index f for the final atomic energy level. The square of the matrix element $\{\vec{R}^2[n_k\ell_kL_kJ_k, (\ell_k\pm1)L_{k'}J_{k'}], \quad k=i,f\}$ may be expressed as:

$$\vec{R}^2[n_k\ell_kL_kJ_k, n_k(\ell_k\pm1)L'_kJ'_k] =$$

$$\frac{\ell_>}{2J_k+1}Q[\ell_kL_k,(\ell_k\pm1)L'_k]Q(J_k,J'_k)[R^{n_k^*(\ell_k\pm1)}_{n_k^*\ell_k}]^2. \quad (2)$$

Here, $\ell_> = \max(\ell_k, \ell_k\pm1)$ and

$$\Big(\sum_{k'}\vec{R}^2_{kk'}\Big)_{\Delta n\neq0} = \Big(\frac{3n_k^*}{2Z}\Big)^2\frac{1}{9}(n_k^{*2}+3\ell_k^2+3\ell_k+11). \quad (3)$$

In Equation (1)

$$x_{\ell_k,\ell_{k'}} = \frac{E}{\Delta E_{\ell_k,\ell_{k'}}}, \quad k=i,f$$

$E=\frac{3}{2}kT$ is the electron kinetic energy and $\Delta E_{\ell_k,\ell_{k'}} = |E_{\ell_k}-E_{\ell_{k'}}|$ is the energy difference between levels ℓ_k and $\ell_k\pm1$ $(k=i,f)$,

$$x_{n_k,n_k+1} \approx \frac{E}{\Delta E_{n_k,n_k+1}},$$

where for $\Delta n\neq0$, the energy difference between energy levels with n_k and n_k+1, $\Delta E_{n_k,n_k+1}$ is represented by the following equation:

$$\Delta E_{n_k,n_k+1} = 2Z^2E_H/n_k^{*3}, \quad (4)$$

where $n_k^* = [E_H Z^2/(E_{ion} - E_k)]^{1/2}$ is the effective principal quantum number, N the electron density, T the temperature, Z the residual ionic charge (e.g. Z=4 for Al IV), E_{ion} the appropriate spectral series limit, $Q(\ell L, \ell' L')$, multiplet factor and $Q(J, J')$ line factor (Shore, Menzel, 1965). The needed Gaunt factors are $g(x)$ (Griem, 1968; Griem, 1974) and $\widetilde{g}(x)$ (Dimitrijević, Konjević, 1980). For radial integrals $[R_{n_k^*\ell_k}^{n_k^*\ell_k \pm 1}]$ the Coulomb approximation Bates, Damgaard, 1949) was applied with the help of tables in Oertel and Shomo (1968).

3. Results and Discussion

In order to investigate and demonstrate the importance of Stark broadening of Al IV lines for modelization of stellar atmospheres, we took one atmosphere model of an A-type star (Kurucz, 1979) and one of a DO white dwarf (Wesemael, 1981) and three spectral lines in the visble part of the spectrum, since such lines are particularly important for astronomy. The corresponding transitions are: $2s^2$ $2p^5$ $(^2P^o_{3/2})4p^2[1/2]_1$ – $2s^2$ $2p^5$ $(^2P^o_{3/2})4d^2[1/2]^o$, λ = 3279.6 Å, $2s^2$ $2p^5$ $(^2P^o_{3/2})4p^2[1/2]_0$ – $2s^2$ $2p^5$ $(^2P^o_{3/2})4d^2[1/2]^o$, λ = 4210.3 Å and $2s^2$ $2p^5$ $(^2P^o_{3/2})4p^2[5/2]$ – $2s^2$ $2p^5$ $(^2P^o_{3/2})4d^2[3/2]^o$, λ = 3411.8 Å. Two first lines belong to the same multiplet and all three belong to the same supermultiplet. Using the modified semiempirical method (Dimitrijević, Konjević, 1980), we calculated Stark widths (FWHM) for Roseland optical depths, temperatures and electron densities in different points of the model. The obtained results, together with the corresponding thermal Doppler widths, are presented in Table 1, for A-type star atmosphere and in Table 2 for DO white dwarf. In order to beter investigate similarities and regularities of Stark widths within multiplet, supermultiplet and spectral series, Stark and Doppler widths are given in angstroms as well as in angular frequency units.

Comparison of Stark and thermal Doppler widths of three Al IV lines 3279.6 Å, 4210.3 Å, and 3411.8 Å, are presented in Figs. 1-4, as a function of Rosseland optical depth for conditions corresponding to atmospheres of an A–type star (Figures 1 and 2) and DO white dwarf (Figures 3 and 4). Figures 1 and 3 illustrate the case when widths are expressed in angstrom units and Figure 2 and 4, when they are in angular frequency units.

The model of stellar atmosphere for A-type star is taken from Kurucz (1979) with the effective temperature T_{eff} = 8 500 K and logarithm of surface gravity log g = 4.5, and for DO white dwarf from Wesemael (1981), with parameters T_{eff} = 60 000 K and log g = 8.0. In the case of A-type star, the Doppler broadening of all three lines dominates in the whole temperature interval and it changes very slowly. The Doppler widths for 3279.6 Å and 3411.8 Å spectral lines coincide if angstroms (Fig. 1) or angular frequency units (Fig. 2) are used. The same width for 4210.3 Å is larger 28% than those of both lines in angstrom units and lower 28 % than them in angular frequency units. Except for the first value of Rosseland optical depth (τ), three curves of Stark widths in angstroms

Table 1. Dependence of Stark (We) and Doppler (WDop) full width at half intensity maximum of Al IV ($^2P^o_{3/2}$) $4p^2[1/2]_1$ – ($^2P^o_{3/2}$) $4d^2[1/2]^o$ λ = 3279.6 Å, ($^2P^o_{3/2}$) $4p^2[1/2]_0$ – ($^2P^o_{3/2}$) $4d^2[1/2]^o$ λ = 4210.3 Å and ($^2P^o_{3/2}$) $4p^2[5/2]$ – ($^2P^o_{3/2}$) $4d^2[3/2]^o$ λ = 3411.8 Å spectral lines, on the Rosseland optical depth (τ_{Ross}) in the atmosphere of an A-type star. Model of stellar atmosphere (Kurucz, 1979) with parameters T_{eff} = 8 500 K and log g = 4.5. T is temperature and Ne electron density.

τ_{Ross}	**T** [K]	**Ne** [cm^{-3}]	**We** [Å]	**WDop** [Å]	**We** [10^{12}s^{-1}]	**WDop** [10^{12}s^{-1}]
			3279.592 Å			
0.106E-03	6164.	1.25E+12	0.939E-06	0.014	0.164E-05	0.024
0.481E-03	6410.	3.24E+12	0.238E-05	0.014	0.417E-05	0.025
0.204E-02	6616.	7.10E+12	0.514E-05	0.014	0.901E-05	0.025
0.846E-02	6826.	1.25E+13	0.890E-05	0.015	0.156E-04	0.026
0.366E-01	7101.	3.51E+13	0.245E-04	0.015	0.430E-04	0.026
0.166	7602.	1.05E+14	0.708E-04	0.015	0.124E-03	0.027
1.21	8930.	6.05E+14	0.377E-03	0.017	0.661E-03	0.029
4.34	11980.	3.36E+15	0.182E-02	0.019	0.319E-02	0.034
25.2	17938.	5.31E+15	0.244E-02	0.024	0.426E-02	0.042
118.	26137.	1.58E+16	0.624E-02	0.029	0.109E-01	0.050
			4210.296 Å			
0.106E-03	6164.	1.25E+12	0.156E-05	0.018	0.165E-05	0.019
0.481E-03	6410.	3.24E+12	0.395E-05	0.018	0.419E-05	0.019
0.204E-02	6616.	7.10E+12	0.853E-05	0.019	0.906E-05	0.020
0.846E-02	6826.	1.25E+13	0.148E-04	0.019	0.157E-04	0.020
0.366E-01	7101.	3.51E+13	0.407E-04	0.019	0.432E-04	0.020
0.166	7602.	1.05E+14	0.117E-03	0.020	0.125E-03	0.021
1.21	8930.	6.05E+14	0.625E-03	0.022	0.664E-03	0.023
4.34	11980.	3.36E+15	0.302E-02	0.025	0.321E-02	0.027
25.2	17938.	5.31E+15	0.403E-02	0.031	0.429E-02	0.032
118.	26137.	1.58E+16	0.103E-01	0.037	0.110E-01	0.039
			3411.782 Å			
0.106E-03	6164.	1.25E+12	0.587E-06	0.014	0.950E-06	0.023
0.481E-03	6410.	3.24E+12	0.149E-05	0.015	0.241E-05	0.024
0.204E-02	6616.	7.10E+12	0.322E-05	0.015	0.520E-05	0.024
0.846E-02	6826.	1.25E+13	0.556E-05	0.015	0.900E-05	0.025
0.366E-01	7101.	3.51E+13	0.153E-04	0.016	0.248E-04	0.025
0.166	7602.	1.05E+14	0.442E-04	0.016	0.716E-04	0.026
1.21	8930.	6.05E+14	0.237E-03	0.017	0.384E-03	0.028
4.34	11980.	3.36E+15	0.116E-02	0.020	0.187E-02	0.033
25.2	17938.	5.31E+15	0.154E-02	0.025	0.250E-02	0.040
118.	26137.	1.58E+16	0.398E-02	0.030	0.645E-02	0.048

Table 2. Dependence of Stark and Doppler full width at half intensity maximum of Al IV ($^2P^o_{3/2}$) $4p^2[1/2]_1$ – ($^2P^o_{3/2}$) $4d^2[1/2]^o$ $\lambda = 3279.6$ Å, ($^2P^o_{3/2}$) $4p^2[1/2]_0$ – ($^2P^o_{3/2}$) $4d^2[1/2]^o$ $\lambda = 4210.3$ Å- and ($^2P^o_{3/2}$) $4p^2[5/2]$ – ($^2P^o_{3/2}$) $4d^2[3/2]^o$ $\lambda = 3411.8$ Å spectral lines, on the Rosseland optical depth τ_{Ross} in the atmosphere of a DO white dwarf. Model of stellar atmosphere (Wesemael, 1981) with parameters T_{eff} = 60 000 K and log g = 8.0. T is temperature and Ne electron density.

τ_{Ross}	**T** **[K]**	**Ne** **[cm^{-3}]**	**We** **[Å]**	**WDop** **[Å]**	**We** **[10^{12}s^{-1}]**	**WDop** **[10^{12}s^{-1}]**
			3279.592 Å			
0.101E-07	38426.	6.31E+11	0.222E-05	0.035	0.389E-05	0.061
0.140E-05	38632.	6.59E+13	0.232E-03	0.035	0.406E-03	0.061
0.103E-03	42308.	1.21E+15	0.412E-02	0.037	0.721E-02	0.064
0.108E-01	46360.	1.54E+16	0.513E-01	0.038	0.898E-01	0.067
0.131	50908.	5.87E+16	0.190	0.040	0.333	0.070
1.32	66476.	2.64E+17	0.792	0.046	1.39	0.080
13.6	108902.	1.76E+18	4.76	0.059	8.34	0.103
23.1	123731.	2.54E+18	6.66	0.062	11.7	0.109
62.9	159279.	4.54E+18	11.3	0.071	19.8	0.124
98.9	179107.	6.73E+18	16.5	0.075	28.8	0.132
			4210.296 Å			
0.101E-07	38426.	6.31E+11	0.368E-05	0.045	0.391E-05	0.047
0.140E-05	38632.	6.59E+13	0.384E-03	0.045	0.408E-03	0.048
0.103E-03	42308.	1.21E+15	0.682E-02	0.047	0.724E-02	0.050
0.108E-01	46360.	1.54E+16	0.849E-01	0.049	0.902E-01	0.052
0.131	50908.	5.87E+16	0.315	0.051	0.334	0.055
1.32	66476.	2.64E+17	1.31	0.059	1.39	0.062
13.6	108902.	1.76E+18	7.87	0.075	8.37	0.080
23.1	123731.	2.54E+18	11.0	0.080	11.7	0.085
62.9	159279.	4.54E+18	18.7	0.091	19.9	0.097
98.9	179107.	6.73E+18	27.2	0.096	28.9	0.102
			3411.782 Å			
0.101E-07	38426.	6.31E+11	0.139E-05	0.036	0.225E-05	0.059
0.140E-05	38632.	6.59E+13	0.145E-03	0.036	0.235E-03	0.059
0.103E-03	42308.	1.21E+15	0.257E-02	0.038	0.415E-02	0.061
0.108E-01	46360.	1.54E+16	0.318E-01	0.040	0.514E-01	0.064
0.131	50908.	5.87E+16	0.117	0.042	0.189	0.067
1.32	66476.	2.64E+17	0.486	0.048	0.786	0.077
13.6	108902.	1.76E+18	2.85	0.061	4.60	0.099
23.1	123731.	2.54E+18	3.98	0.065	6.45	0.105
62.9	159279.	4.54E+18	6.77	0.074	11.0	0.119
98.9	179107.	6.73E+18	9.88	0.078	16.0	0.126

are parallel and slowly increase with τ. The largest values are for 4210.3 Å- and the lowest for 3411.8 Å and their ratio is almost 2.6. The Stark widths of 3279.6 Å are in the middle, 1.7 times lower than the widths of 4210.3 Å and 1.6 times larger than the values of 3411.8 Å. Concerning the trend of Stark widths in angular frequency units (Figure 2), the behavior of three curves is the same. The values of two lines from the same multiplet (3279.592 and 4210.296 Å) coincide in the whole temperature interval which is in accordance with the conclusion in Wiese and Konjević (1982). The Stark widths of 3411.8 Å spectral line are 1.7 times lower. We can conclude that for the considered Al IV spectral lines, thermal Doppler broadening is the main broadening mechanism in the atmosphere of an A-type star.

For the conditions corresponding to atmosphere of DO white dwarfs, Stark widths of three spectral lines dominate for all optical depths, being approximately three orders of magnitude higher than the Doppler widths. Figures 3 and 4 confirm that the main broadening mechanism of spectral lines in atmospheres of DO white dwarfs is usually Stark broadening. Three Stark width curves are parallel to each other in angstrom units. Their gradient is lower in comparison to the case of A-type stars. The largest values are for 4210.3 Å and the lowest for 3411.8 Å in which casee, the variation is within 1.67 times. The Stark width values of 3279.6 Å are in the middle. The same dependence in angular frequency units confirms that lines from one multiplet have close Stark widths. In our case, they practically coincide in the whole examined Rosseland optical depth interval. The Stark width values of 3411.8 Å are 29% lower.

Our analyzis confirms the importance of Stark broadening for reliable analysis and investigation of physical nature of DO white dwarfs. The three considered lines are suitable for application in modelling of DO white dwarf atmospheres, particularly since they are in the visible part of the spectrum.

Additionally, we studied the temperature dependence of Stark widths (full width at half maximum of intensity (W)) of Al IV spectral lines belonging to six multiplets. In Figure 5 we present this dependence for spectral lines within the multiplet Al IV 4p $^2[1/2] - 4d\,^2[3/2]^o$ with parent term $^2P^o_{1/2}$. The corresponding transitions and wavelengths are: 4p $^2[1/2]_1$ – 4d $^2[3/2]^o_2$, λ = 3485.1 Å; 4p $^2[1/2]_1$ – 4d $^2[3/2]^o_1$, λ = 3279.5 Å; 4p $^2[1/2]_0$ – 4d $^2[3/2]^o_2$, λ = 4550.5 Å. Stark widths for lines with λ = 3485.1 Å and λ = 3279.5 Å coincide. In the examined temperature interval, the relative variation of Stark width (in Å) of lines within this multiplet is 94% in the whole temperature interval. The relative variation of the same width expressed in angular frequency units increases from 8% for lower temperatures to 13% for higher ones. This is in accordance with the conclusion of Wiese and Konjević (1982), that the variation of Stark width in angular frequency units for lines from one multiplet is of the order of several percent.

In the next two figures Stark widths within two spectral series are presented. Figure 6 shows the temperature dependence of three spectral lines belonging to

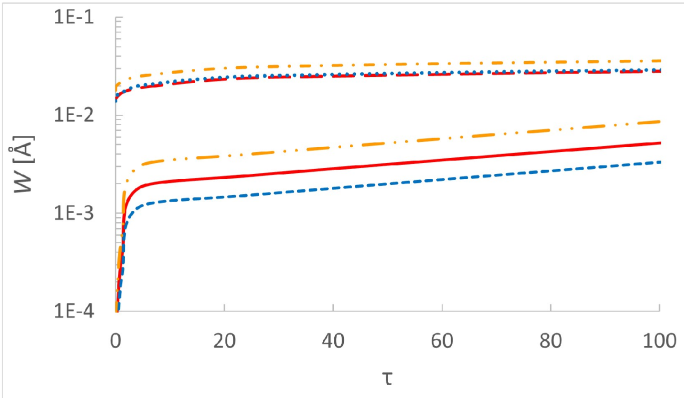

Figure 1. Dependence of Stark and Doppler full width at half intensity maximum (W - in angstroms) of Al IV 3279.6 Å (red, Stark – solid line, Doppler – long dashes), 4210.3 Å (blue, Stark – dashes, Doppler – dots), and 3411.8 Å (orange, Stark – dash dot dot, Doppler – short dash dot) spectral lines, on the Rosseland optical depth (τ) in the atmosphere of an A-type star. Model of stellar atmosphere (Kurucz, 1979) with parameters T_{eff} = 8 500 K and log g = 4.5.

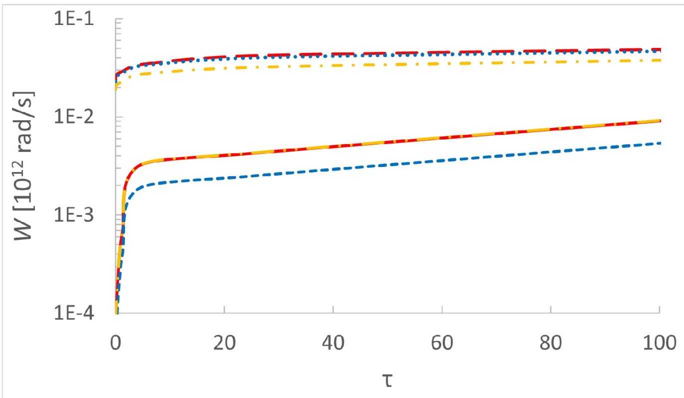

Figure 2. Dependence of Stark and Doppler full width at half intensity maximum (W - in angular frequency units) of Al IV 3279.6 Å (red, Stark – solid line, Doppler – long dashes), 4210.3 Å (blue, Stark – dashes, Doppler – dots), and 3411.8 Å (orange, Stark – dash dot dot, Doppler – short dash dot) spectral lines, on the Rosseland optical depth (τ) in the atmosphere of an A-type star. Model of stellar atmosphere (Kurucz, 1979) with parameters T_{eff} = 8 500 K and log g = 4.5.

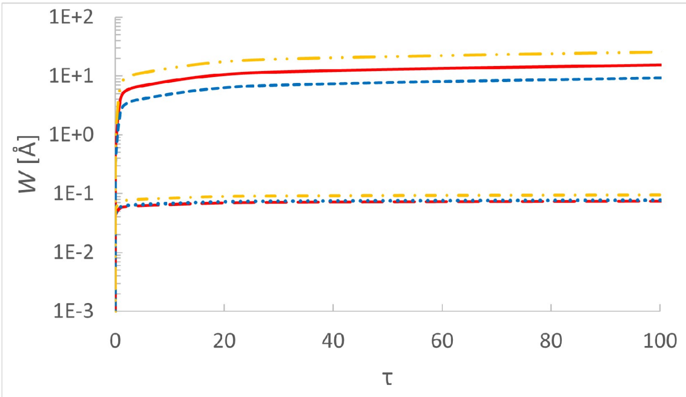

Figure 3. Dependence of Stark and Doppler full width at half intensity maximum (W- in angstroms) of Al IV 3279.6 Å (red, Stark – solid line, Doppler – long dashes), 4210.3 Å (blue, Stark – dashes, Doppler – dots), and 3411.8 Å (orange, Stark – dash dot dot, Doppler – short dash dot) spectral lines, on the Rosseland optical depth (τ)in the atmosphere of a DO white dwarf. Model of stellar atmosphere (Wesemael, 1981) with parameters T_{eff} = 60 000 K and log g = 8.0.

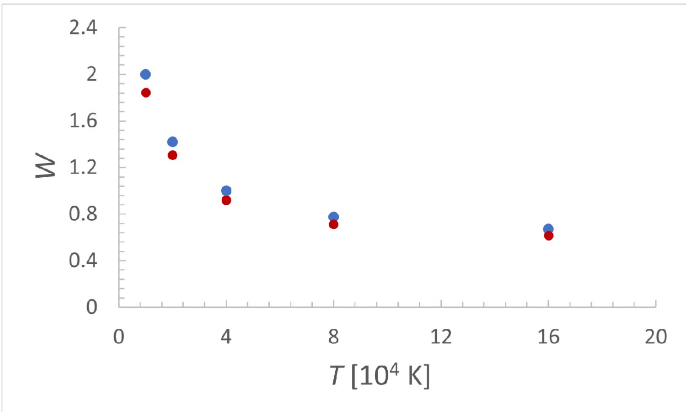

Figure 4. Dependence of Stark and Doppler full width (W - in angular frequency units) at half intensity maximum of Al IV 3279.6 Å (red, Stark – solid line, Doppler – long dashes), 4210.3 Å (blue, Stark – dashes, Doppler – dots), and 3411.8 Å (orange, Stark – dash dot dot, Doppler – short dash dot) spectral lines, on the Rosseland optical depth (τ) in the atmosphere of a DO white dwarf. Model of stellar atmosphere (Wesemael, 1981) with parameters T_{eff} = 60 000 K and log g = 8.0.

three multiplets from one spectral series with parent term $^2P^o_{1/2}$. The corresponding transitions and wavelengths are as follows: $2s^2\ 2p^5\ (^2P^o_{1/2})4s\ ^2[1/2]^o$ – $2s^2\ 2p^5\ (^2P^o_{1/2})4p\ ^2[1/2]$, λ = 4515.6 Å; $2s^2\ 2p^5\ (^2P^o_{1/2})4s\ ^2[1/2]^o$ – $2s^2\ 2p^5\ (^2P^o_{1/2})4p\ ^2[3/2]$, λ 4520.2 Å; $2s^2\ 2p^5\ (^2P^o_{1/2})4p\ ^2[1/2]$ – $2s^2\ 2p^5\ (^2P^o_{1/2})4d\ ^2[3/2]^o$, λ = 3485.1 Å. The three curves are almost parallel in the examined T-interval. The widths of 4515.6 Å and 3485.1 Å are close and the width of 4520.2 Å is almost twice times larger. This line has the largest Stark width values of all studied lines in this work. It could be very useful for spectroscopic diagnostics and abundance determinations. The width variation in angstrom units between 4515.6 Å and 3485.1 Å is from 43% for lower temperatures to 19% for higher ones. The largest relative change of W in angular frequency units within the series, i.e between 4520.2 Å and 3485.1 Å varies from 59% to 35% with increase of the temperature. Elastic collisions determine Stark broadening of 4515.6 Å and 4520.2 Å for lower temperatures while inelastic dominate for higher ones.

Figure 7 shows the behavior of Stark widths versus temperature of spectral lines from three multiplets within one spectral series with parent term $^2P^o_{3/2}$. The corresponding transitions and wavelengths are: $2s^2\ 2p^5\ (^2P^o_{3/2})4s\ ^2[3/2]^o$ – $2s^2\ 2p^5\ (^2P^o_{3/2})4p\ ^2[1/2]$, λ = 5224.1 Å; $2s^2\ 2p^5\ (^2P^o_{3/2})4p\ ^2[1/2]$ – $2s^2\ 2p^5\ (^2P^o_{3/2})4d\ ^2[3/2]^o$, λ 3279.6 Å; $2s^2\ 2p^5\ (^2P^o_{3/2})4p\ ^2[1/2]$ – $2s^2\ 2p^5\ (^2P^o_{3/2})4d\ ^2[3/2]^o$, λ = 3108.0 Å. Three curves have the same trend with temperature. The largest Stark broadening is manifested for 3279.6 Å spectral line. The temperature sensitivity of the width indicates that this line is suitable for spectroscopic diagnostics. Their widths in Å units are larger from 3.5 to 2.7 times than Stark width of 3108.0 Å line which presents the lowest broadening in the series. The relative width (in angular frequency units) change between 3279.6 Å and 3108.0 Å-decreases from 34% to 27% when temperature increases.

Figure 8 presents temperature dependence of Stark width in both units, angstroms and angular frequency unites for spectral line λ = 4520.2 Å. This line has the largest Stark width in the group of spectral lines considered in this study, as it was written above. The trend of W is the same for both units and decreases almost 3 times in the temperature interval. From the point of view of astrophysical and laboratory plasma diagnostics, the important temperature interval is up to 40 000 K where the Stark broadening is very sensitive to temperature.

4. Conclusions

We calculated Stark widths for Al IV spectral lines originating from three transitions, as a function of Rosseland optical depth for one A-type star atmosphere model and one model of DO white dwarf atmosphere. Stark broadening is negligible in comparison with thermal Doppler broadening in A-type star atmosphere for considered Al IV lines and dominant in the case of DO white dwarfs. It is

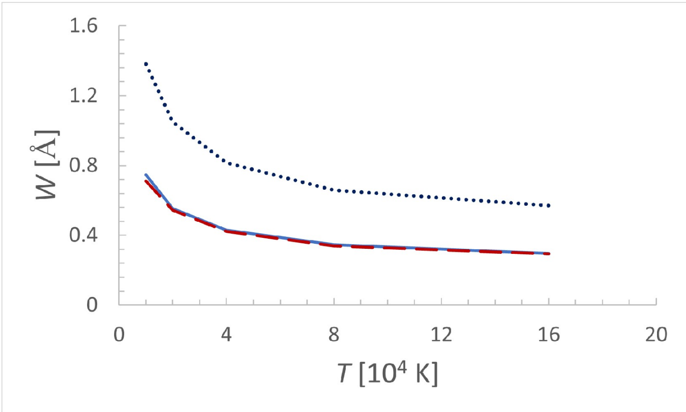

Figure 5. Temperature dependence of Stark width (in angstroms) of spectral lines from one Al IV multiplet 4p $^2[1/2]$ - 4d $^2[3/2]^o$ with parent term $^2P^o_{1/2}$: $\lambda = 3485.1$ Å (blue solid line); $\lambda = 3279.5$ Å (red dashes) and $\lambda = 4550.5$ Å (dark blue dots). Stark widths are due to collisions with electrons. The perturber density is 1.10^{17} cm^{-3}.

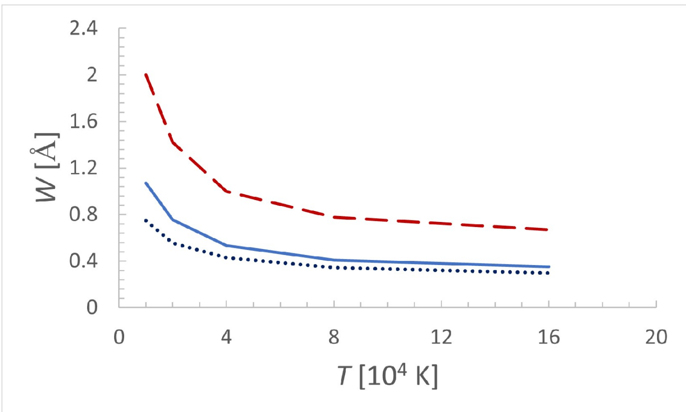

Figure 6. Temperature dependence of Stark width of spectral lines within one spectral series with parent term $^2P^o_{1/2}$ corresponding to three Al IV multiplets: 4s $^2[1/2]^o$ - 4p $^2[1/2]$ $\lambda = 4515.6$ Å (blue solid line); 4s $^2[1/2]^o$ - 4p $^2[3/2]\lambda = 4520.2$ Å (red dashes) and 4p $^2[1/2]$ - 4d $^2[3/2]^o$ $\lambda = 3485.1$ Å (dark blue dots). Stark widths are due to collisions with electrons. The perturber density is 1.10^{17} cm^{-3}.

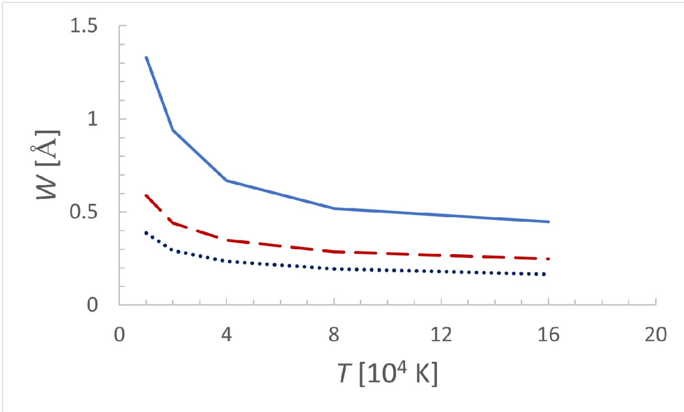

Figure 7. Temperature dependence of Stark width of spectral lines within one spectral series with parent term $^2P^o_{3/2}$ corresponding to three Al IV multiplets: 4s $^2[3/2]^o$ - 4p $^2[1/2]$ $\lambda = 5224.1$ Å (blue solid line); 4p $^2[1/2]$ - 4d $^2[1/2]^o$ $\lambda = 3279.6$ Å (red dashes) and 4p $^2[1/2]$ - 4d $^2[1/2]^o$ $\lambda = 3279.6$ Å (dark blue dots). Stark widths are due to collisions with electrons. The perturber density is 1.10^{17} cm^{-3}.

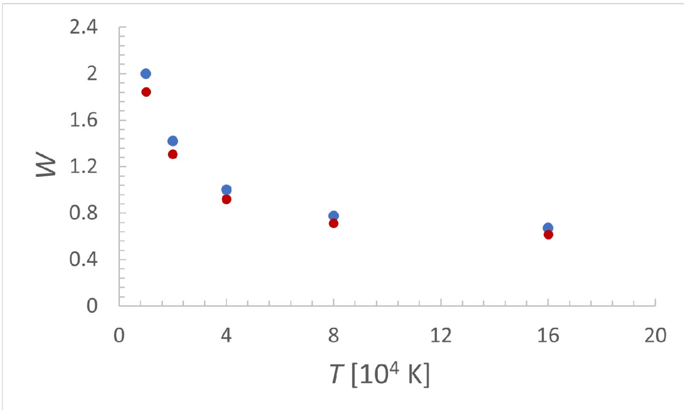

Figure 8. Temperature dependence of Stark width of a spectral lines belonging to Al IV multiplet 4s $^2[1/2]^o$ - 4p $^2[3/2]$ with parent term $^2P^o_{3/2}$ and $\lambda = 4520.2$ Å. Stark width is illustrated in both units: Å (blue solid circle) and 10^{12} s^{-1} (red solid circle). Stark widths are due to collisions with electrons. The perturber density is 1.10^{17} cm^{-3}.

obvious that Stark broadening must enter in the calculation of models of white dwarf atmospheres in order to obtain adequate interpretation of physical processes. The agreement of line widths within a multiplet is much better if they are expressed in angular frequency units than in angstroms, because in that case, they are liberated from the influence of wavelength. Their differences are several percent, as predicted. Also, for two examined spectral series, the variations of Stark widths are much lower when they are expressed in angular frequency units than in angstrom units. Stark broadening of spectral lines 4520.2 Å, 4550.5 Å and 5224.1 Å is sensitive to the temperature changes for temperatures lower than around 40 000 K, so that they could be applied for plasma diagnostics of different plasmas in astrophysics, laboratory and technology.

Acknowledgements. This work has been supported with a STSM visit grant E-COST-GRANT-CA17126-0085105c for M.S.D. within the framework of COST Action CA 17126 "Towards Understanding and Modelling Intense Electronic Excitation, TU-MIEE".

The authors would like to thank the European Union-NextGenerationEU, through the National Recovery and Resilience Plan of the Republic of Bulgaria, project № BG-RRP-2.004-0005 for the financial support for M.D.C. to attend the 14th SCSLSA 2023 and to the Research and Development Sector at the Technical University of Sofia for the financial support covering the conference fee.

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