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STARK BROADENING OF In III LINES IN ASTROPHYSICAL AND LABORATORY PLASMA

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Abstract. Besides the need of Stark broadening parameters for a number of problems in physics, and plasma technology, in hot star atmospheres the conditions exist where Stark widths are comparable and even larger than the thermal Doppler widths. Using the semiclassical perturbation method we investigated here the influence of collisions with charged particles for In III spectral lines. We determined a number of Stark broadening parameters important for the investigation of plasmas in the atmospheres of A-type stars and white dwarfs. Also, we have compared the obtained results with existing experimental data. The results will be included in the STARK-B database, the Virtual Atomic and Molecular Data Center and the Serbian Virtual Observatory.

Key words: stars: atmospheres, spectral lines, Stark broadening

1. INTRODUCTION

Stark broadening parameters of indium spectral lines are of interest for a number of problems in astrophysics, physics, and plasma technology. For example indium is identified in the spectrum of HD110066, an A-type chemically peculiar star (Cowley et al. 1974).

Dimitrijević & Sahal-Bréchot (1999) determined, using semiclassical perturbation theory (Sahal-Bréchot 1969a,b) Stark broadening parameters due to collisions with electrons, protons and helium ions of 20 In III multiplets, for the temperatures from 20000 K to 50000 K. Djeniže et al. (2006) obtained experimentally Stark widths for sixteen In III spectral lines at a temperature of 13000 K without citation of Dimitrijević & Sahal-Bréchot (1999).

In order to make a better comparison with their experimental results and to provide the data of interest for hot stellar plasma research, we recalculated Stark broadening parameters for ten In III spectral lines using the semiclassical perturbation method (Sahal-Bréchot 1969a,b), within four previously considered multiplets (Dimitrijević & Sahal-Bréchot 1999), for which the experimental data

(Djeniže et al. 2006) exist. Differently with the previous work, we calculated the data for each line separately, and we increased the temperature range from 20 000 K - 50 000 K to 10 000 K - 100 000 K to cover the temperature of the experimental investigation. The obtained results are used to investigate the influence of Stark broadening of the In III lines in the A-type stellar atmospheres.

2. RESULTS AND DISCUSSIONS

The calculations have been performed within the semiclassical perturbation formalism, developed and discussed in detail in Sahal-Bréchot (1969a,b). This formalism, as well as the corresponding computer code, have been optimized and updated several times (see e.g. Sahal-Bréchot 1974; Dimitrijević & Sahal-Bréchot 1984; Dimitrijević et al. 1991; and the review by Dimitrijević 1996). The needed atomic energy levels for Stark broadening calculations were taken from Bhatia (1978).

Table 1. shows the Stark broadening parameters for electron, proton, and helium impacts (full widths at half intesity maximum, and shifts) for ten In III lines, obtained by using the semiclassical perturbation method for a perturber density of 10^{17}cm^{-3} and temperatures from 10 000 K up to 100 000 K. The quantity C (given in Å cm^{-3}), when divided by the corresponding FWHM, gives an estimate for the maximum perturber density for which tabulated data may be used.

In Table 2. we show a comparison between experimental (Djeniže et al. 2006) and our theoretical results for Stark line widths. One can see a large disagreement between both results. Ratio of experimental and theoretical widths changes from 0,25 to 0.52, i.e. the experimental widths are two to four times smaller than theoretical. A new experimental determination of Stark widths for In III spectral lines would be important.

In order to investigate the influence of Stark broadening mechanism for In III lines in stellar plasma conditions, we calculated Stark widths for the Kurucz's (1979) model of the A-type atmosphere with T_{eff} = 10 000 K and log g = 4.5 and compared them with the Doppler broadening (see Figure 1). We found that the photospheric layers exist where the Doppler and Stark widths are comparable and even where the Stark width is dominant.

Additionally, we compared thermal Doppler and the total Stark widths and the contribution of different collisional processes for In III 6199.3 Å line for the same model atmosphere. The contribution of elastic collisions is leading in the total Stark widths (see Figure 2). The strong collisions, inelastic collision inducing transition from or to upper atomic energy levels and inelasic collisions for lower levels are less important.

The obtained Stark broadening parameters will supplement the STARK-B database (http://stark-b.obspm.fr), dedicated for modelling of stellar atmospheres, analysis and synthesis of stellar spectra, as well as for investigations of laboratory plasma, inertial fusion plasma, laser development and for plasmas in technology. This database is a part of a FP7 project Virtual Atomic and Molecular Data Center - VAMDC (P.I. Marie Lise Dubernet), with the following aims: (i) to build a secure, flexible and interoperable e-science environment based interface to the existing Atomic and Molecular databases; (ii) to coordinate groups involved in the generation, evaluation, and use of atomic and molecular data, and (iii) to provide

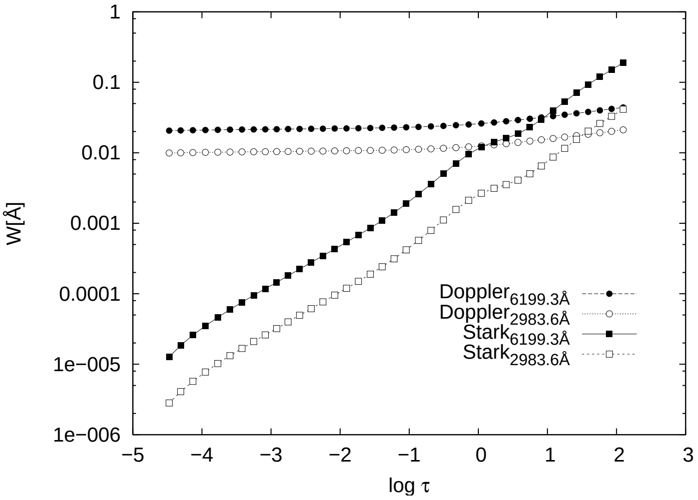

Fig. 1. The Doppler and Stark widths for two In III lines at 2983.6 and 6199.3 Å as functions of the Rosseland optical depth for an A-type star atmosphere (T_{eff} = 10 000 K, log g = 4.5). One can see that the Stark broadening mechanism is absolutely dominant in comparison with the thermal Doppler mechanism in deeper layers of the stellar atmosphere (log $\tau > 1.0$).

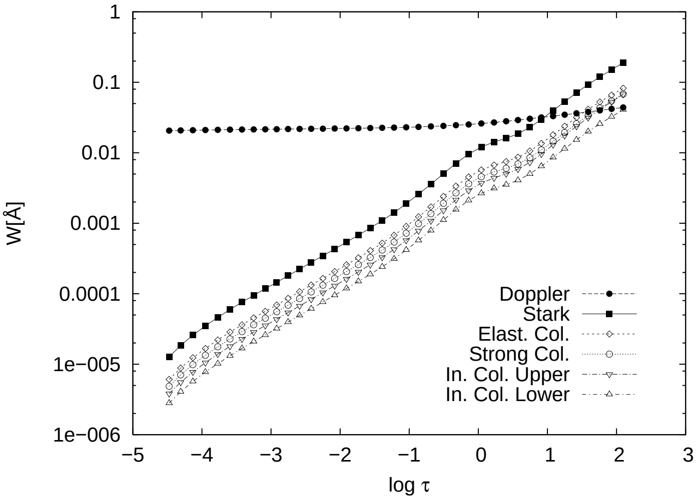

Fig. 2. The thermal (Doppler), total Stark width and contributions of different collisional processes to the total Stark width for the In III 6199.3 Å line as a function of the Rosseland optical depth for a model atmosphere of A-type star (T_{eff} = 10000 K, log g = 4.5).

a forum for training of potential users (Dubernet et al. 2010, Rixon et al. 2011).

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Table 1. Stark broadening parameters: widths (FWHM) and shifts for In III spectral lines obtained within semiclasical approach for a perturber density of 10^{17} cm^{-3} and temperatures from 10000 K up to 100000 K.

Transition	T(K)	W_{e^-} (Å)	d_{e^-} (Å)	W_{p^+} (Å)	d_{p^+} (Å)	W_{He^+} (Å)	d_{He^+} (Å)
	10000	0.358	0.637E-02	0.118E-01	0.244E-02	0.158E-01	0.232E-02
In III	13000	0.319	0.698E-02	0.144E-01	0.317E-02	0.181E-01	0.291E-02
5d $^2D_{3/2}$ – 4f $^2F^o_{5/2}$	20000	0.268	0.632E-02	0.181E-01	0.451E-02	0.222E-01	0.401E-02
2983.6 Å	30000	0.231	0.608E-02	0.220E-01	0.575E-02	0.242E-01	0.500E-02
C= 0.77E+20	50000	0.197	0.680E-02	0.248E-01	0.747E-02	0.267E-01	0.626E-02
	100000	0.167	0.636E-02	0.282E-01	0.921E-02	0.297E-01	0.748E-02
	10000	0.365	0.638E-02	0.120E-01	0.244E-02	0.161E-01	0.232E-02
In III	13000	0.326	0.695E-02	0.147E-01	0.316E-02	0.185E-01	0.291E-02
5d $^2D_{5/2}$ – 4f $^2F^o_{5/2}$	20000	0.273	0.626E-02	0.185E-01	0.450E-02	0.226E-01	0.401E-02
3009.7 Å	30000	0.236	0.602E-02	0.225E-01	0.575E-02	0.247E-01	0.500E-02
C= 0.79E+20	50000	0.201	0.672E-02	0.252E-01	0.747E-02	0.272E-01	0.627E-02
	100000	0.170	0.627E-02	0.287E-01	0.921E-02	0.303E-01	0.751E-02
	10000	0.365	0.639E-02	0.120E-01	0.244E-02	0.161E-01	0.233E-02
In III	13000	0.326	0.696E-02	0.147E-01	0.317E-02	0.184E-01	0.291E-02
5d $^2D_{5/2}$ – 4f $^2F^o_{7/2}$	20000	0.273	0.628E-02	0.185E-01	0.451E-02	0.226E-01	0.402E-02
3008.9 Å	30000	0.236	0.604E-02	0.225E-01	0.576E-02	0.247E-01	0.501E-02
C= 0.78E+20	50000	0.201	0.674E-02	0.252E-01	0.749E-02	0.272E-01	0.628E-02
	100000	0.170	0.629E-02	0.287E-01	0.923E-02	0.303E-01	0.753E-02
	10000	1.26	-0.112	0.426E-01	-0.133E-01	0.554E-01	-0.122E-01
In III	13000	1.12	-0.701E-01	0.516E-01	-0.167E-01	0.640E-01	-0.153E-01
6s $^2S_{1/2}$ – 6p $^2P^o_{1/2}$	20000	0.946	-0.710E-01	0.649E-01	-0.231E-01	0.774E-01	-0.196E-01
5250.3 Å	30000	0.824	-0.599E-01	0.782E-01	-0.287E-01	0.841E-01	-0.248E-01
C= 0.48E+21	50000	0.721	-0.635E-01	0.876E-01	-0.363E-01	0.929E-01	-0.294E-01
	100000	0.626	-0.622E-01	0.100	-0.436E-01	0.103	-0.355E-01
	10000	1.49	-0.158	0.472E-01	-0.177E-01	0.616E-01	-0.161E-01
In III	13000	1.33	-0.135	0.575E-01	-0.221E-01	0.711E-01	-0.201E-01
6s $^2S_{1/2}$ – 6p $^2P^o_{3/2}$	20000	1.12	-0.118	0.727E-01	-0.303E-01	0.867E-01	-0.258E-01
5646.9 Å	30000	0.967	-0.867E-01	0.883E-01	-0.378E-01	0.944E-01	-0.324E-01
C= 0.51E+21	50000	0.842	-0.888E-01	0.996E-01	-0.470E-01	0.105	-0.381E-01
	100000	0.726	-0.852E-01	0.115	-0.563E-01	0.117	-0.459E-01
	10000	1.09	0.461	0.386E-01	0.389E-01	0.418E-01	0.324E-01
In III	13000	0.996	0.408	0.454E-01	0.455E-01	0.502E-01	0.387E-01
6p $^2P^o_{1/2}$ – 7s $^2S_{1/2}$	20000	0.860	0.338	0.630E-01	0.591E-01	0.625E-01	0.481E-01
4024.8 Å	30000	0.785	0.285	0.763E-01	0.689E-01	0.711E-01	0.564E-01
C= 0.13E+21	50000	0.728	0.251	0.918E-01	0.816E-01	0.825E-01	0.667E-01
	100000	0.666	0.196	0.114	0.976E-01	0.982E-01	0.777E-01
	10000	1.19	0.491	0.435E-01	0.426E-01	0.474E-01	0.354E-01
In III	13000	1.09	0.434	0.511E-01	0.498E-01	0.568E-01	0.424E-01
6p $^2P^o_{3/2}$ – 7s $^2S_{1/2}$	20000	0.942	0.358	0.705E-01	0.648E-01	0.703E-01	0.528E-01
4253.8 Å	30000	0.864	0.302	0.853E-01	0.757E-01	0.799E-01	0.619E-01
C= 0.15E+21	50000	0.804	0.267	0.102	0.896E-01	0.920E-01	0.729E-01
	100000	0.741	0.208	0.126	0.108	0.110	0.852E-01
	10000	1.62	-0.358E-01	0.681E-01	-0.112E-01	0.876E-01	-0.106E-01
InIII	13000	1.45	-0.365E-01	0.811E-01	-0.145E-01	0.101	-0.133E-01
5d $^2D_{3/2}$ – 6p $^2P^o_{1/2}$	20000	1.23	-0.426E-01	0.102	-0.206E-01	0.120	-0.182E-01
6199.3 Å	30000	1.06	-0.372E-01	0.120	-0.261E-01	0.130	-0.228E-01
C= 0.61E+21	50000	0.916	-0.456E-01	0.133	-0.339E-01	0.142	-0.283E-01
	100000	0.781	-0.449E-01	0.149	-0.416E-01	0.157	-0.339E-01
	10000	1.35	-0.173E-01	0.604E-01	-0.685E-02	0.774E-01	-0.658E-02
InIII	13000	1.21	-0.169E-01	0.716E-01	-0.896E-02	0.895E-01	-0.836E-02
5d $^2D_{3/2}$ – 6p $^2P^o_{3/2}$	20000	1.03	-0.233E-01	0.895E-01	-0.129E-01	0.105	-0.117E-01
5724.6 Å	30000	0.896	-0.210E-01	0.105	-0.170E-01	0.114	-0.145E-01
C= 0.56E+21	50000	0.776	-0.271E-01	0.116	-0.219E-01	0.125	-0.187E-01
	100000	0.666	-0.269E-01	0.130	-0.275E-01	0.137	-0.225E-01
	10000	1.40	-0.187E-01	0.626E-01	-0.728E-02	0.801E-01	-0.698E-02
InIII	13000	1.26	-0.182E-01	0.741E-01	-0.951E-02	0.927E-01	-0.885E-02
5d $^2D_{5/2}$ – 6p $^2P^o_{3/2}$	20000	1.07	-0.248E-01	0.928E-01	-0.136E-01	0.109	-0.124E-01
5821.2 Å	30000	0.929	-0.224E-01	0.109	-0.180E-01	0.118	-0.154E-01
C= 0.57E+21	50000	0.805	-0.288E-01	0.120	-0.231E-01	0.129	-0.198E-01
	100000	0.692	-0.287E-01	0.135	-0.290E-01	0.142	-0.237E-01

Table 2. Comparison between experimental-$\mathrm{W_m}$ and theoretical-$\mathrm{W_{th}}$ results.

Transition	λ_m (Å)	$\mathrm{W_m}$(Å)	$\frac{\mathrm{W_m}}{\mathrm{W_{th}}}$
5d $^2\mathrm{D}_{3/2} - 4\mathrm{f}\ ^2\mathrm{F}^\mathrm{o}_{5/2}$	2982.8	0.240	0.51
5d $^2\mathrm{D}_{5/2} - 4\mathrm{f}\ ^2\mathrm{F}^\mathrm{o}_{5/2}$	3008.1	0.250	0.52
5d $^2\mathrm{D}_{5/2} - 4\mathrm{f}\ ^2\mathrm{F}^\mathrm{o}_{7/2}$	3008.8	0.210	0.44
6s $^2\mathrm{S}_{1/2} - 6\mathrm{p}\ ^2\mathrm{P}^\mathrm{o}_{1/2}$	5248.8	0.717	0.43
6s $^2\mathrm{S}_{1/2} - 6\mathrm{p}\ ^2\mathrm{P}^\mathrm{o}_{3/2}$	5645.2	0.520	0.27
6p $^2\mathrm{P}^\mathrm{o}_{1/2} - 7\mathrm{s}\ ^2\mathrm{S}_{1/2}$	4023.8	0.545	0.37
6p $^2\mathrm{P}^\mathrm{o}_{3/2} - 7\mathrm{s}\ ^2\mathrm{S}_{1/2}$	4252.7	0.480	0.30
5d $^2\mathrm{D}_{3/2} - 6\mathrm{p}\ ^2\mathrm{P}^\mathrm{o}_{1/2}$	6197.7	0.800	0.37
5d $^2\mathrm{D}_{3/2} - 6\mathrm{p}\ ^2\mathrm{P}^\mathrm{o}_{3/2}$	5723.2	0.450	0.25
5d $^2\mathrm{D}_{5/2} - 6\mathrm{p}\ ^2\mathrm{P}^\mathrm{o}_{3/2}$	5819.5	0.520	0.28