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Abstract

We present in this work Stark broadening calculations for 12 Ar XII and 12 Ar XIV lines. We present also their radiative atomic and collision data (energy levels, radiative decay rates, line strengths, oscillator strengths and collision strengths). Our Stark broadening data have been obtained using our quantum method in the impact approximation frame and including fine structure effects in the structure study. Our results are provided for the range of temperatures from 5×10^5 to 5×10^6 K of interest for plasmas investigations, and at electron density $N_e = 10^{18}$ cm^{-3}. The radiative atomic data have been calculated using the UCL code SUPERSTRUCTURE. The collision strengths have been calculated using the two UCL codes DISTORTED WAVE and JAJOM. Good agreement have been found between our atomic results and other theoretical and experimental ones. Our Stark broadening data are the first to be published, so no comparisons have been performed for them.

Keywords: line profiles- Stark line broadening- white dwarfs- atmospheres- atomic data.

1. Introduction

In the past, trace elements had no significance for the investigation of stellar spectra. Nowadays, with the development of satellite-born spectrographs and space astronomy in general, analysis of the spectrum of some astrophysical objects show spectral lines of different highly charged ions of trace elements. For example, new Ar VI [1] and Ar VII [2] lines have been discovered in hot stars and white dwarfs. Werner et al. [3] detected Br VI, Sb V and Sb VI ions for the first time in helium-rich white dwarfs. The analysis of the spectra needs atomic and line broadening data: for the evaluation of the abundance of Ba V, Ba VI, and Ba VII [4] and of the Se V, Sr IV-VII, Te VI, and I VI ions [5] in the white dwarfs' G191-B2B and RE 0503-289, the authors calculated the oscillator strengths of the emitted lines and included them in their atmosphere-model calculations. Nikiforov et al. [6] have used Stark broadening data of hydrogenic and non-hydrogenic lines to determine the electron density in atmospheric pressure plasma jets. Rauch et al. [1] showed that the lack of atomic and line broadening parameters of many elements presents an obstacle for plasma research, and concluded that the difference between their resonance doublets line profiles of N V, O VI, and S VI and the observation can be explained by the missing of line broadening tables. Better atomic and line broadening data will improve spectral analyses in the future. Barstow et al. [7] have shown that models which neglect the opacity of heavy elements are not well suited for the analysis of DA(O) white dwarfs. Werner [8] showed that when introducing C, N, and O (considered before without significance) and their detailed Stark broadening in the model, the precedent problem vanishes. Consequently, atomic, collision and line broadening data of these ions are prerequisite for the atmosphere-model calculations.

Spectral lines of highly charged argon ions (Ar IX-XVIII) were observed by Zhang et al. [9] when analysing high-resolution spectra in the UV, EUV and X-ray regions obtained for stellar and other astrophysical sources by several space missions such as Chandra, and XMM-Newton. Wang et al. [10] identified and analysed some lines of argon ions from Ar XII to Ar XVI obtained with Texas Experimental Tokamak (TEXT) for temperature about $2.4\times10^6 - 4\times10^6$ K. For Ar XII, the line is $2s^22p^3$ ($^2D_{5/2}$) – $2s2p^4$ ($^2D_{5/2}$) at 193.7 Å and for Ar XIV, the line is $2s^22p$ ($^2P_{3/2}$) – $2s2p^2$ ($^2D_{3/2,5/2}$) at 257.5 Å. Lepson et al. [11] performed experiments on the Ar IX- Ar XVI ions with the Lawrence Livermore electron beam ion traps EBIT-I and EBIT-II, and identified 79 transitions with their wavelengths. Other observations of the spectra of Ar X to Ar XV in the UV range (140–300 Å) were performed in Fawcett et al. [12]. Connerade et al. [13] observed about 60 lines of argon ions from Ar IX to Ar XVIII in the X-ray range (20–40 Å).

The atomic and collision data of Ar XII and Ar XIV ions were studied a long time ago. Since the 1960s, Ar XII lines were studied [14, 15, 16] in ϑ-pinch UV light sources, for instance, Fawcett and Gabriel [15] identified the resonance lines of argon XI and XII in the wavelength range 150 to 200 Å. A beam-foil spectroscopy of highly ionized Argon was performed in Buchet et al. [17], where more than thirty observed lines

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were identified as hydrogenic transitions in Ar X-XV. Oscillator strengths, radiative decay rates, line intensities and electron collision strengths were calculated for the nitrogen isoelectronic sequence (including Ar XII) in Bhatia et al. [18] and for boron isoelectronic sequence (including Ar XIV) in Bhatia et al. [19]. Collision strengths in Bhatia et al. [18, 19] were calculated at one electron energy. Zhang and Sampson [20] used the relativistic distorted-wave method to provide oscillator strengths and collision strengths for the $\Delta n = 0$ transitions with $n = 2$ in Ar XII and N-like other ions with $12 \leq Z \leq 92$. Eissner et al. [21] performed the same calculations as in [18, 19] but collision strengths were provided for five incident electron energies. Zhang et al. [9] calculated the energies of the 204 levels of the Ar XIV ion in the relativistic configuration interaction (RCI) formalism using multi-configuration Dirac–Fock (MCDF) wavefunctions. Rynkun et al. [22] calculated the energies and E1, M1, E2, M2 transition rates for states of the configurations $2s^22p$, $2s2p^2$ and $2p^3$ in boron-like ions between N III and Zn XXVI including Ar XIV. Wang et al. [23] improved the work of Bhatia et al. [18] and used combined relativistic configuration interaction and many-body perturbation calculations to provide energies and transitions rates of Ar XII and (other N-like ions up to Zn XXIV) including configurations with $n = 2, 3$ yielding 359 fine structure levels. The authors in Wang et al. [23] expected that their data sets would be useful for the identification and interpretation of observed spectra, and for modelling and diagnosing of astrophysical and fusion plasmas. Transitions of type $2s^22p^3-2s2p^4$ in Ar XII were prominent in tokamak plasmas and $2s^22p^3-2s^22p^23d$ transitions were typically intense in high density laser-produced plasmas [18]. Transitions in B-like Ar XIV were observed in the spectra from tokamak plasmas [19]. Mattioli et al. [24] analysed the experimental spectra of argon in the wavelength range 23–34 Å from jet tokamak plasmas and simulated them using collisional–radiative models constructed for Ar XII–Ar XVI ions. The argon ions were injected as impurities into tokamak plasmas [9].

No line broadening results have been found in the literature for the ions Ar XII and Ar XIV. The present work is an effort to provide Stark broadening data for these two ions using our quantum method. The expression giving the electron impact broadening of spectral lines was established in Elabidi et al. [25, 26], where configuration interactions and relativistic effects for the atomic structure were taken into account in intermediate coupling. This method was applied many times in the last ten years: the first applications of our method were performed for the Be-like [26] and Li-like [27] ions, where extensive comparisons were done with many theoretical and experimental results. Satisfactory agreement was found. The Stark broadening of Si IV was calculated using our method in Elabidi et al. [28] and comparisons with the experimental results of Bukvić et al. [29] showed acceptable agreements. Extensive study of the influence of strong collisions on Stark broadening was performed in [30] for the calculations of Ar VII line widths. Recently, this method was used by Elabidi and Sahal-Bréchot [31] to provide scaling of Stark broadening with electron temperature and by Elabidi and Sahal-Bréchot [32] to provide scaling with electron density. Calculations of Stark widths of some Ar VIII and Ar IX lines of astrophysical interest were performed in Aloui et al. [33], where a comparison between the importance of Stark and Doppler broadening in the atmospheric conditions of DO white dwarfs was performed.

In the present paper, we use our quantum mechanical method for calculating electron impact widths of Ar XII and Ar XIV lines for electron temperature ranging from 5×10^5 to 5×10^6 K and electron density $N_e = 10^{18}$ cm^{-3}. We provide also energy levels, radiative decay rates, oscillator strengths, line strengths and collision strengths of the considered ions. These parameters are used in our line broadening calculation. We have used the University College London (UCL) packages: the SUPERSTRUCTURE code [34] for the structure study, and the codes DISTORTED WAVE [35] and JAJOM [36] for the collision study. We find that our atomic and collision data are close to other theoretical and experimental results. The acceptable agreement of atomic and collision data indicates that our line broadening results have a sufficient accuracy. We expect that our calculations could fill the lack of Ar XII and Ar XIV line broadening data.

2. Outline of our line broadening method

We have used our quantum mechanical method to calculate Ar XII and Ar XIV electron Stark broadening, where the impact approximation has been assumed. More details can be found in Elabidi et al. [25, 26]. The expression of the full width at half-maximum W is valid at the temperatures and densities studied and it is given by:

$$W = 2N\left(\frac{\hbar}{m}\right)^2\left(\frac{2m\pi}{k_BT}\right)^{\frac{1}{2}} \times\int_0^\infty \Gamma_w(\varepsilon)\exp\left(-\frac{\varepsilon}{k_BT}\right)d\left(\frac{\varepsilon}{k_BT}\right), \quad (1)$$

where the integration is over the Maxwellian velocity distribution. k_B is the Boltzmann constant, m the electron mass, T and N are the electron temperature and density, respectively. ε is the incident electron energy ans $\Gamma_w(\varepsilon)$ is given by:

$$\Gamma_w(\varepsilon) = \sum_{J_i^T J_f^T l K_i K_f}\frac{\left[K_i, K_f, J_i^T, J_f^T\right]}{2} \times\left\{\begin{array}{ccc} J_i & K_i & l \\ K_f & J_f & 1\end{array}\right\}^2\left\{\begin{array}{ccc} K_i & J_i^T & s \\ J_f^T & K_f & 1\end{array}\right\}^2 \times\left[1-\left(\mathrm{Re}\,(\mathbb{S}_i)\mathrm{Re}\,(\mathbb{S}_f)+\mathrm{Im}\,(\mathbb{S}_i)\mathrm{Im}\,(\mathbb{S}_f)\right)\right], \quad (2)$$

where $L_j + S_j = J_j$, $J_j + l = K_j$ and $K_j + s = J$. S and L designate the spin and orbital angular momenta of the target and l is the electron orbital momentum. $\mathbb{S}_i$ ($\mathbb{S}_f$) represent the scattering matrix elements for the initial (final) levels in intermediate coupling, Re ($\mathbb{S}$) and Im ($\mathbb{S}$) are the real and the imaginary parts of the $\mathbb{S}-$matrix. The terms in braces represent the 6–j symbols and we make use of the notation $[x, y, ...] = (2x + 1)(2y + 1)...$ Both $\mathbb{S}_i$ and $\mathbb{S}_f$ computed using the same incident electron

energy $\varepsilon = mv^2/2$. The expression (1) of electron impact width W includes relativistic effects of the target in intermediate coupling. The atomic structure calculations are performed using the SUPERSTRUCTURE (SST) code [34]. The radial wave functions are determined by diagonalization of the non relativistic Hamiltonian using orbitals calculated in a scaled Thomas–Fermi–Dirac Amaldi (TFDA) potential. The potential depends on scaling parameters λ_l that have been obtained by a self–consistent energy minimization on the term energies included in our calculations. This code takes into account configuration interactions and relativistic (one–body, spin–orbit, mass and Darwin) corrections. These effects are introduced according to the Breit–Pauli approach [37]. The SST code provides energy levels, radiative data (decay rates, oscillator strengths, line strengths, ...) and the Term Coupling Coefficients (TCC) which will be used after by the JAJOM code. The electron-ion scattering calculations in LS coupling are performed using the DISTORTED WAVE (DW) code [35] to produce the reactance matrices $\Re$ between terms ^{2S+1}L. The JAJOM code [36] is used to treat the scattering calculations in intermediate coupling: it makes use of the TCC -supplied by the code SST- to transform the $\Re$ matrices (provided by DW) from LS coupling to the intermediate one and calculates fine structure collision strengths.

Many years ago, the three codes SST/DW/JAJOM were used until the step of providing collision strengths. We have adapted them to our line broadening expression (1): The code JAJOM was transformed into the code JAJPOLARI (Dubau, unpublished results) to produce the reactance matrices $\Re$. Our code RtoS (Elabidi & Dubau, unpublished results) calculate the scattering matrices $\mathbb{S}$ from the $\Re$ matrices and their real and imaginary parts in an adequate order to be used as input data suitable for the formula (2). Re ($\mathbb{S}$) and Im ($\mathbb{S}$) are given by:

$$\mathrm{Re}\,(\mathbb{S}) = \left(1-\Re^2\right)\left(1+\Re^2\right)^{-1}, \mathrm{Im}\,(\mathbb{S}) = 2\Re\left(1+\Re^2\right)^{-1} \quad (3)$$

3. Results and discussions

3.1. Structure and radiative data

For Ar XII, 6 configurations have been used in our study: $1s^2$ ($2s^22p^3$, $2s2p^4$, $2p^5$, $2s^22p^23s$, $2s^22p^23p$ and $2s^22p^23d$). This set of configurations gives rise to 34 terms and 72 fine structure levels. For Ar XIV, we have used 8 configurations: $1s^2$ ($2s^22p$, $2s2p^2$, $2p^3$, $2s^23s$, $2s^23p$, $2s^23d$, 2s2p3s, and 2s2p3p). These configurations give rise to 23 terms and 45 fine structure levels. The code SST provides also the scaling parameters: $\lambda_s = 1.3425$, $\lambda_p = 1.2481$ and $\lambda_d = 1.3268$ for Ar XII, and $\lambda_s = 1.4216$, $\lambda_p = 1.2885$ and $\lambda_d = 1.5300$ for Ar XIV. In Table 1, we present our energy levels E (in cm^{-1}) for the Ar XII and compare them with NIST [38], with the experimental results (Edl) of Edlén [39] and with those calculated by Bhatia et al. [18] using the code SST but with low angular momenta $l < 8$ (SST_7). The difference between our energies and those of the references [18, 38, 39] varies from nearly 0% to 4% with an average value less than 2%. In Table 2, we present the energy levels for Ar XIV expressed in cm^{-1} and compared with NIST [38] values, with the results calculated by Liang et al. [40] using the AUTOSTRUCTURE (AS) code [41] and with those of Aggarwal et al. [42] using the General Purpose Relativistic Atomic Structure Package (GRASP) of Dyall et al. [43]. As it is shown in Table 2, the percentage errors varies from 0.28% to nearly 5% (the value 5% is only with NIST values and for two levels 2s2p3s $^2\mathrm{P}^{\mathrm{o}}_{1/2,3/2}$). The averaged value is about 2%. In the cases where we found an error of about 5% with NIST, there is a good agreement with the AS and the GRASP results (less than 0.5%).

We present in Table 3 the radiative data for some Ar XII lines up to the level 15. Our radiative decay rates A_{ij} and weighted oscillator strengths gf are compared to the relativistic distorted-wave calculations (ZS99) of Zhang and Sampson [20], to the many-body perturbation theory (MBPT) calculations (M97) obtained by Merkelis et al. [44] and reported in Eissner et al. [21], and to the calculations of Bhatia et al. [18] who used the code SUPERSTRUCTURE (SST_7) with $l \leq 7$. Our gf and A_{ij} values are very close to those of Bhatia et al. [18] (about 2%), but the comparison with (ZS99) and (M97) results gives a higher error but still acceptable: about 14%. The error for A_{ZS99} of the transition $(10-1)$ can reach 84%. If we remove this value, the average error becomes about 9%. We provide also some line strengths (S), but no comparisons have been performed, because we did not find other results to compare them. The radiative data for some Ar XIV lines (up to level 14) have been reported in Table 4. We compare our results to the Multiconfiguration Dirac–Hartree–Fock (MCDHF) method of Grant [45] performed by Rynkun et al. [22] using the code GRASP2K [46]. The differences between the two results are about 16% for A_{ij}, approximately equal to 14% for gf and S values. The error values can reach 50% for the transitions $2p^3\ ^4\mathrm{S}^{\mathrm{o}}_{3/2}$–$2s2p^2\ ^2\mathrm{D}_{3/2}$ $(11-6)$, $2p^3\ ^4\mathrm{S}^{\mathrm{o}}_{3/2}$–$2s2p^2\ ^2\mathrm{S}_{1/2}$ $(11-8)$ and $2p^3\ ^2\mathrm{D}^{\mathrm{o}}_{3/2}$–$2s2p^2\ ^4\mathrm{P}_{5/2}$ $(12-5)$, which are spin-forbidden transitions.

3.2. Electron-ion scattering

The collision strength can be defined as the measure of strength for a binary collision. It contains the information about this collision. It is a dimensionless quantity and is related to the collision cross section σ_{if} (i and f are the initial and final levels, respectively) by the following relationship:

$$\Omega_{if} = \frac{k_i^2 g_i}{\pi a_0^2}\sigma_{if}, \quad (4)$$

where k_i^2 is the incident electron energy in Ryd and g_i is the statistical weight of the initial level. We can say also that both collision strength and cross section describe the intrinsic probability of collisional excitation and de-excitation in an atomic transition at a particular electron energy.

We present in Table 5, collision strengths for several Ar XII lines at three electron energies ε: 35, 70 and 105 Ryd and compare them to the results of Eissner et al. [21]. For Ar XIV, we present collision strengths at one electron energy 40 Ryd, and compare them with the calculations of [19]. The relative errors for Ar XII collision strengths are about 3% for $\varepsilon = 35$ Ryd, 9% for $\varepsilon = 70$ Ryd and 16% for $\varepsilon = 105$ Ryd. Our Ar XIV collision strengths agree well with those of [19] (about 4%).

Table 1: Present fine structure energy levels E (in cm^{-1}) for the Ar XII ion compared to the NIST values [38], to the experimental results (Edl) of Edlén [39], and to the results of Bhatia et al. [18] using the SST code with $l < 8$ (SST$_7$).

k	Level	E	NIST	Edl	SST$_7$	$\Delta_{\rm NIST}$	$\Delta_{\rm Edl}$	$\Delta_{\rm SST_7}$
1	$2s^22p^3\ ^4S^\circ_{3/2}$	0.0	0.0	0.0	0.0	–	–	–
2	$2s^22p^3\ ^2D^\circ_{3/2}$	99057.	94824.	94815	98694	4.27	4.28	0.37
3	$2s^22p^3\ ^2D^\circ_{5/2}$	102883.	98155.7	98162	102577	4.59	4.59	0.30
4	$2s^22p^3\ ^2P^\circ_{1/2}$	149743.	149186.	149175	149188	0.37	0.38	0.37
5	$2s^22p^3\ ^2P^\circ_{3/2}$	155056.	154061.	154050	154551	0.64	0.65	0.33
6	$2s(^2S)2p^4(^3P)\ ^4P_{5/2}$	446673.	445931.	445932	444555	0.17	0.17	0.47
7	$2s(^2S)2p^4(^3P)\ ^4P_{3/2}$	458993.	458106.	458100	456653	0.19	0.19	0.51
8	$2s(^2S)2p^4(^3P)\ ^4P_{1/2}$	465310.	464058.	464043	462868	0.27	0.27	0.52
9	$2s(^2S)2p^4(^1D)\ ^2D_{3/2}$	626680.	613833.	613803	623875	2.05	2.05	0.45
10	$2s(^2S)2p^4(^1D)\ ^2D_{5/2}$	627743.	614466.	614431	624902	2.11	2.12	0.45
11	$2s(^2S)2p^4(^1S)\ ^2S_{1/2}$	728384.	715379.	715277	724882	1.79	1.80	0.48
12	$2s(^2S)2p^4(^3P)\ ^2P_{3/2}$	767374.	745762.	745738	764830	2.82	2.82	0.33
13	$2s(^2S)2p^4(^3P)\ ^2P_{1/2}$	783733.	761838.	761797	780830	2.79	2.80	0.37
14	$2p^5\ ^2P^\circ_{3/2}$	1203351.	1166700.	1166585	1198170	3.05	3.06	0.43
15	$2p^5\ ^2P^\circ_{1/2}$	1224440.	1186244.	1186193	1218881	3.12	3.12	0.45
16	$2s^22p^2(^3P)3s\ ^4P_{1/2}$	2877392.	2867000.	–	2882081	0.36	–	0.16
17	$2s^22p^2(^3P)3s\ ^4P_{3/2}$	2885722.	2875200.	–	2890248	0.36	–	0.16
18	$2s^22p^2(^3P)3s\ ^4P_{5/2}$	2897052.	2883920.	–	2901387	0.45	–	0.15
19	$2s^22p^2(^3P)3s\ ^2P_{1/2}$	2909658.	–	–	2914248	–	–	0.16
20	$2s^22p^2(^3P)3s\ ^2P_{3/2}$	2922856.	2912070.	–	2927228	0.37	–	0.15
21	$2s^22p^2(^1D)3s\ ^2D_{5/2}$	2969949.	2956650.	–	2973839	0.45	–	0.13
22	$2s^22p^2(^1D)3s\ ^2D_{3/2}$	2970712.	2958030.	–	2974586	0.43	–	0.13
23	$2s^22p^2(^3P)3p\ ^4D_{1/2}$	2997407.	–	–	3001934	–	–	0.15
24	$2s^22p^2(^3P)3p\ ^2S_{1/2}$	3003227.	–	–	3007678	–	–	0.15
25	$2s^22p^2(^3P)3p\ ^4D^\circ_{3/2}$	3006437.	2996300.	–	3010901	0.34	–	0.34
26	$2s^22p^2(^3P)3p\ ^4D_{5/2}$	3014426.	–	–	3018750	–	–	0.14
27	$2s^22p^2(^3P)3p\ ^4P^\circ_{1/2}$	3021348.	3010700.	–	3025651	0.35	–	0.14
28	$2s^22p^2(^3P)3p\ ^4P^\circ_{3/2}$	3022117.	3011700.	–	3026450	0.34	–	0.14
29	$2s^22p^2(^3P)3p\ ^4D^\circ_{7/2}$	3024837.	3011470.	–	3028996	0.44	–	0.14
30	$2s^22p^2(^3P)3p\ ^4P^\circ_{5/2}$	3028695.	–	–	3032908	–	–	0.14
31	$2s^22p^2(^3P)3p\ ^2D_{3/2}$	3037364.	–	–	3041562	–	–	0.14
32	$2s^22p^2(^3P)3p\ ^2D^\circ_{5/2}$	3051869.	–	–	3055790		–	0.13
33	$2s^22p^2(^3P)3p\ ^2P^\circ_{3/2}$	3062921.	–	–	3066868	–	–	0.13
34	$2s^22p^2(^3P)3p\ ^2P^\circ_{1/2}$	3064996.	–	–	3068888	–	–	0.13
35	$2s^22p^2(^3P)3p\ ^4S^\circ_{3/2}$	3069689.	3059000.	–	3074109	0.35	–	0.14
36	$2s^22p^2(^1S)3s\ ^2S_{1/2}$	3072782.	–	–	3075853	–	–	0.10
37	$2s^22p^2(^1D)3p\ ^2F^\circ_{5/2}$	3097254.	–	–	3100983	–	–	0.12
38	$2s^22p^2(^1D)3p\ ^2F^\circ_{7/2}$	3100806.	–	–	3104508	–	–	0.12
39	$2s^22p^2(^1D)3p\ ^2D^\circ_{3/2}$	3133354.	–	–	3137108	–	–	0.12
40	$2s^22p^2(^1D)3p\ ^2D^\circ_{5/2}$	3134758.	3124840.	–	3138442	0.32	–	0.12
41	$2s^22p^2(^1D)3p\ ^2P^\circ_{1/2}$	3144705.	3133800.	–	3148104	0.35	–	0.11
42	$2s^22p^2(^3P)3d\ ^4F_{3/2}$	3152201.	–	–	3158121	–	–	0.19
43	$2s^22p^2(^1D)3p\ ^2P^\circ_{3/2}$	3155822.	3142510.	–	3158989	0.42	–	0.10
44	$2s^22p^2(^3P)3d\ ^4F_{5/2}$	3156342.	–	–	3162167	–	–	0.18
45	$2s^22p^2(^3P)3d\ ^4F_{7/2}$	3162712.	–	–	3168409	–	–	0.18
46	$2s^22p^2(^3P)3d\ ^4D_{3/2}$	3170960.	–	–	3176405	–	–	0.17
47	$2s^22p^2(^3P)3d\ ^4F_{9/2}$	3171344.	–	–	3176890	–	–	0.17
48	$2s^22p^2(^3P)3d\ ^4D_{1/2}$	3172100.	–	–	3177624	–	–	0.17
49	$2s^22p^2(^3P)3d\ ^4D_{5/2}$	3175790	–	–	3181224	–	–	0.17
50	$2s^22p^2(^3P)3d\ ^2P_{3/2}$	3179808.	3276700.	–	3185054	3.05	–	0.16
51	$2s^22p^2(^3P)3d\ ^4D_{7/2}$	3180482.	–	–	3185910	–	–	0.17
52	$2s^22p^2(^3P)3d\ ^2F_{5/2}$	3187457.	3175950	–	3192699	0.36	–	0.16

Table 1: Continued.

k	Level	E	NIST	SST_7	Δ_{NIST}	Δ_{SST_7}
53	$2s^22p^2(^3P)3d\ ^2P_{1/2}$	3190465.	3271350.	3195372	2.54	0.15
54	$2s^22p^2(^3P)3d\ ^4P_{5/2}$	3198865.	3187350.	3203320	0.36	0.14
55	$2s^22p^2(^3P)3d\ ^2F_{7/2}$	3202525.	3189920.	3207518	0.39	0.16
56	$2s^22p^2(^3P)3d\ ^4P_{3/2}$	3203183.	3190100.	3207531	0.41	0.14
57	$2s^22p^2(^3P)3d\ ^4P_{1/2}$	3205386.	–	3209682	–	0.13
58	$2s^22p^2(^1S)3p\ ^2P^\circ_{1/2}$	3216498.	–	3219498	–	0.09
59	$2s^22p^2(^1S)3p\ ^2P^\circ_{3/2}$	3217330.	–	3220280	–	0.09
60	$2s^22p^2(^3P)3d\ ^2D_{3/2}$	3238702.	3221580.	3242310	0.53	0.11
61	$2s^22p^2(^3P)3d\ ^2D_{5/2}$	3240595.	3226750.	3244179	0.43	0.11
62	$2s^22p^2(^1D)3d\ ^2G_{7/2}$	3251209.	3258510.	3255926	0.22	0.15
63	$2s^22p^2(^1D)3d\ ^2G_{9/2}$	3253192.	–	3257851	–	0.14
64	$2s^22p^2(^1D)3d\ ^2D_{3/2}$	3268759.	–	3272678	–	0.12
65	$2s^22p^2(^1D)3d\ ^2D_{5/2}$	3271306.	–	3274957	–	0.11
66	$2s^22p^2(^1D)3d\ ^2F_{7/2}$	3276720.	–	3279841	–	0.10
67	$2s^22p^2(^1D)3d\ ^2F_{5/2}$	3281986.	3264720.	3285089	0.53	0.09
68	$2s^22p^2(^1D)3d\ ^2P_{1/2}$	3285581.	3271350.	3289124	0.43	0.11
69	$2s^22p^2(^1D)3d\ ^2P_{3/2}$	3291020.	3276700.	3294359	0.43	0.10
70	$2s^22p^2(^1D)3d\ ^2S_{1/2}$	3297762.	–	3301242	–	0.11
71	$2s^22p^2(^1S)3d\ ^2D_{5/2}$	3368328.	3226750.	3371651	4.20	0.10
72	$2s^22p^2(^1S)3d\ ^2D_{3/2}$	3371236.	3221580.	3374427	4.43	0.09

The comparisons performed for our atomic and collision data show an acceptable overall agreement between the experimental and the other theoretical results. As it has been mentioned before, these parameters represent intermediate input data for our line broadening calculations, and their comparisons are very important for the evaluation of the accuracy of line broadening results. The good agreement found can indicate that we can trust the intermediate data used in the calculations of Stark broadening.

3.3. Line broadening results

We perform Stark broadening calculations for 12 Ar XII and 12 Ar XIV lines. Ar XII calculations are shown in Table 6 and the results of Ar XIV are shown in Table 7. Results are presented for the range of electron temperature form 5×10^5 to 5×10^6 K and at electron density $N_e = 10^{18}$ cm^{-3}. Quantum results W are calculated using the expression (1) using 6 configurations for Ar XII and 8 configurations for Ar XIV. There are no other Stark widths results for all these lines to compare with. The acceptable agreements found between our atomic and collision parameters and other results show that our line broadening data are calculated with an acceptable accuracy. Measurements or new calculations of Ar XII and Ar XIV line broadening would be very helpful to confirm our conclusions.

4. Conclusions

We have calculated in the present paper quantum mechanical Stark widths for 12 Ar XII and 12 Ar XIV lines for the range of electron temperature from 5×10^5 to 5×10^6 K and at electron density $N_e = 10^{18}$ cm^{-3}. We have used our quantum method developed in Elabidi et al. [25, 26] together with the UCL packages (SST/DW/JAJOM). Radiative and collision parameters have been also calculated and compared to other results, and good agreement has been found. This can give an idea about the accuracy of our line broadening calculation. To the best of our knowledge, no other results for the Stark broadening have been found to perform comparisons. New theoretical or experimental evaluations of line widths for these ions maybe interesting for checking our calculations.

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Table 2: Our fine structure energy levels E (in cm^{-1}) for the Ar XIV ion compared to those of NIST [38], to those of Liang et al. [40] (AS) obtained using the code AUTOSTRUCTURE [41] and to those of Aggarwal et al. [42] using the GRASP code [43] (GRASP).

k	Level	E	NIST	AS	GRASP	$\Delta_{\rm NIST}$	$\Delta_{\rm AS}$	$\Delta_{\rm GRASP}$
1	$2s^2 2p\ ^2P^\circ_{1/2}$	0.0	0.0	0.0	0.0	–	–	–
2	$2s^2 2p\ ^2P^\circ_{3/2}$	22821.	22656.	22408.36	22551.10	0.72	1.81	1.18
3	$2s2p^2\ ^4P_{1/2}$	223345.	230296.	224818.81	226081.61	3.11	0.66	1.23
4	$2s2p^2\ ^4P_{3/2}$	232122.	238954.	233400.26	234608.23	2.94	0.55	1.07
5	$2s2p^2\ ^4P_{5/2}$	244681.	250423.	245701.81	246053.87	2.35	0.42	0.56
6	$2s2p^2\ ^2D_{3/2}$	415525.	410254.	413610.86	414786.56	1.27	0.46	0.18
7	$2s2p^2\ ^2D_{5/2}$	416843.	411205.	414905.76	415675.43	1.35	0.46	0.28
8	$2s2p^2\ ^2S_{1/2}$	519855.	514401.	519298.85	522175.87	1.05	0.11	0.45
9	$2s2p^2\ ^2P_{1/2}$	557136.	545244.	551539.67	554054.67	2.13	1.00	0.55
10	$2s2p^2\ ^2P_{3/2}$	568721.	554678.	561986.67	563854.25	2.47	1.18	0.86
11	$2p^3\ ^4S^\circ_{3/2}$	716725.	718925.	717780.71	719341.60	0.30	0.15	0.37
12	$2p^3\ ^2D^\circ_{3/2}$	822104.	810387.	817586.78	818917.59	1.42	0.55	0.39
13	$2p^3\ ^2D^\circ_{5/2}$	824973.	812956.	820330.21	820673.39	1.46	0.56	0.52
14	$2p^3\ ^2P^\circ_{1/2}$	921826.	908793.	918435.36	920501.78	1.41	0.37	0.14
15	$2p^3\ ^2P^\circ_{3/2}$	926564.	913056.	923077.25	924638.89	1.46	0.38	0.21
16	$2s^2 3s\ ^2S_{1/2}$	3452445.	–	3417360.	3410220.	–	1.02	1.22
17	$2s^2 3p\ ^2P^\circ_{1/2}$	3570636.	3533890.	3530740.	3524080.	1.03	1.12	1.30
18	$2s^2 3p\ ^2P^\circ_{3/2}$	3576283.	3534840.	3537000.	3530310.	1.16	1.10	1.29
19	$2s2p3s\ ^4P^\circ_{1/2}$	3651843.	–	3649360.	3646140.	–	0.07	0.16
20	$2s2p3s\ ^4P^\circ_{3/2}$	3659152.	–	3656480.	3653220.	–	0.07	0.16
21	$2s2p3s\ ^4P^\circ_{5/2}$	3672972.	–	3670260.	3667470.	–	0.07	0.15
22	$2s^2 3d\ ^2D_{3/2}$	3682658.	3640470.	3644120.	3636450.	1.15	1.05	1.25
23	$2s^2 3d\ ^2D_{5/2}$	3684537.	3641780.	3646022.	3638180.	1.16	1.05	1.26
24	$2s2p(^3P^\circ)3s\ ^2P^\circ_{1/2}$	3716193.	3705800.	3707520.	3705890.	0.28	0.23	0.28
25	$2s2p(^3P^\circ)3s\ ^2P^\circ_{3/2}$	3731468.	3720820.	3722740.	3721360.	0.29	0.23	0.27
26	$2s2p3p\ ^4D_{1/2}$	3751754.	–	3750890.	3746090.	–	0.02	0.15
27	$2s2p3p\ ^4D_{3/2}$	3757322.	–	3757280.	3752320.	–	1E-4	0.13
28	$2s2p3p\ ^4D_{5/2}$	3766442.	–	3767910.	3763070.	–	0.04	0.09
29	$2s2p(^3P^\circ)3p\ ^2P_{3/2}$	3775532.	–	3766880.	3762740.	–	0.23	0.34
30	$2s2p(^3P^\circ)3p\ ^2P_{1/2}$	3777347.	–	3764540.	3760380.	–	0.34	0.45
31	$2s2p3p\ ^4D_{7/2}$	3778746.	–	3780130.	3775700.	–	0.04	0.08
32	$2s2p3p\ ^4S_{3/2}$	3789084.	–	3789170.	3784860.	–	0.00	0.11
33	$2s2p3p\ ^4P_{1/2}$	3799410.	–	3796720.	3796940.	–	0.07	0.06
34	$2s2p3p\ ^4P_{3/2}$	3807087.	–	3805110.	3804980.	–	0.05	0.06
35	$2s2p3p\ ^4P_{5/2}$	3812981.	–	3810490.	3810380.	–	0.07	0,07
36	$2s2p(^3P^\circ)3p\ ^2D_{3/2}$	3822328.	–	3816280.	3814330.	–	0.16	0.21
37	$2s2p(^3P^\circ)3p\ ^2D_{5/2}$	3835998.	3828850.	3829960.	3828830.	0.19	0.16	0.19
38	$2s2p(^3P^\circ)3p\ ^2S_{1/2}$	3863078.	–	3859670.	3858310.	–	0.09	0.12
39	$2s2p(^1P^\circ)3s\ ^2P^\circ_{1/2}$	3904496.	–	3887130.	3884950.	–	0.44	0.50
40	$2s2p(^1P^\circ)3s\ ^2P^\circ_{3/2}$	3905759.	–	3887480.	3889710.	–	0.47	0.41
41	$2s2p(^1P^\circ)3p\ ^2D_{3/2}$	4012579.	–	–	4000850.	–	–	0.29
42	$2s2p(^1P^\circ)3p\ ^2D_{5/2}$	4015738.	–	–	4004080.	–	–	0.29
43	$2s2p(^1P^\circ)3p\ ^2P_{1/2}$	4017499.	–	–	3998960.	–	–	0.46
44	$2s2p(^1P^\circ)3p\ ^2P_{3/2}$	4023117.	–	–	4005390.	–	–	0.44
45	$2s2p(^1P^\circ)3p\ ^2S_{1/2}$	4051416.	–	–	4031960.	–	–	0.48

Table 3: Present Ar XII radiative decay rates A_{ij} and weighted oscillator strengths gf are compared to those of Zhang and Sampson [20]: ZS99, to those of Merkelis et al. [44]: M97 and to those of Bhatia et al. [18] using the SST code with $l < 8$: SST_7. Our line strengths S are also presented. i and j label the levels of Table 1.

Levels	$A_{ij}(s^{-1})$				gf			S
$i-j$	Present	ZS99	M97	SST_7	Present	M97	SST_7	
6 – 1	6.726E+09	7.265E+09	6.106E+09	6.7E+09	3.032E−01	2.780E−01	3.060E−01	0.223502
6 – 2	8.061E+06	7.835E+06	6.693E+06	–	6.001E−04	4.920E−04	–	0.000568
6 – 3	1.383E+07	–	–	–	1.053E−03	9.480E−04	–	0.001008
6 – 5	5.039E+06	–	–	–	5.330E−04	4.520E−04	–	0.000602
7 – 1	7.315E+09	–	–	7.3E+09	2.082E−01	1.910E−01	2.100E−01	0.149350
7 – 3	1.115E+06	8.745E+05	1.074E+06	–	5.275E−05	5.010E−05	–	0.000049
7 – 5	1.257E+07	–	–	–	8.163E−04	6.740E−04	–	0.000884
8 – 1	7.676E+09	–	–	7.6E+09	1.063E−01	9.720E−02	1.070E−01	0.075210
8 – 2	3.576E+06	–	–	–	7.993E−05	7.120E−05	–	0.000072
8 – 4	5.886E+06	–	–	–	1.772E−04	1.470E−04	–	0.000185
9 – 1	7.014E+06	–	–	–	1.071E−04	8.870E−05	–	0.000056
9 – 2	1.697E+10	1.754E+10	1.487E+10	1.7E+10	3.655E−01	3.340E−01	3.680E−01	0.228078
9 – 3	9.149E+08	–	–	9.3E+08	2.000E−02	1.850E−02	2.040E−02	0.012569
9 – 4	1.849E+09	2.007E+09	1.675E+09	1.8E+09	4.875E−02	4.690E−02	4.930E−02	0.033650
9 – 5	4.988E+07	–	–	–	1.345E−03	2.680E−04	–	0.000939
10 – 1	1.029E+06	1.646E+05	6.204E+05	–	2.348E−05	1.490E−05	–	0.000012
10 – 2	2.340E+08	–	–	–	7.531E−03	8.020E−03	–	0.004689
10 – 3	1.559E+10	1.615E+10	1.357E+10	1.6E+10	5.091E−01	4.620E−01	5.130E−01	0.319306
10 – 5	3.036E+09	–	–	3.0E+09	1.222E−01	1.150E−01	1.230E−01	0.085129
11 – 1	8.011E+07	–	–	–	4.527E−04	3.480E−04	–	0.000205
11 – 2	8.414E+09	7.802E+09	7.350E+09	8.2E+09	6.370E−02	5.780E−02	6.260E−02	0.033322
11 – 4	1.643E+10	–	–	1.6E+10	1.471E−01	1.360E−01	1.470E−01	0.083713
11 – 5	1.363E+10	1.445E+10	1.104E+10	1.4E+10	1.243E−01	1.060E−01	1.270E−01	0.071403
12 – 1	1.950E+08	–	–	–	1.986E−03	1.800E−03	–	0.000852
12 – 2	1.017E+10	–	–	1.0E+10	1.365E−01	1.210E−01	1.380E−01	0.067252
12 – 3	5.461E+10	5.235E+10	4.655E+10	5.5E+10	7.417E−01	6.710E−01	7.470E−01	0.367456
12 – 4	3.285E+09	–	–	3.3E+09	5.164E−02	5.010E−02	5.190E−02	0.027525
12 – 5	8.521E+09	–	–	8.5E+09	1.363E−01	1.420E−01	1.370E−01	0.073279
13 – 1	4.119E+07	–	–	–	2.011E−04	1.960E−04	–	0.000084
13 – 2	3.993E+10	3.980E+10	3.470E+10	4.0E+10	2.554E−01	2.360E−01	2.590E−01	0.122817
13 – 4	6.394E+09	–	–	6.5E+09	4.770E−02	4.460E−02	4.920E−02	0.024770
13 – 5	2.934E+10	–	–	2.9E+10	2.226E−01	2.020E−01	2.220E−01	0.116544
14 – 6	1.848E+08	–	–	–	1.936E−03	–	–	0.000842
14 – 7	5.559E+07	–	–	–	6.017E−04	–	–	0.000266
14 – 8	1.705E+07	–	–	–	1.877E−04	–	–	0.000084
14 – 9	4.711E+09	–	–	4.7E+09	8.495E−02	–	8.490E−02	0.048497
14 – 10	2.718E+10	2.560E+10	2.118E+10	2.7E+10	4.920E−01	–	4.960E−01	0.281384
14 – 11	3.253E+09	–	–	3.2E+09	8.648E−02	–	8.570E−02	0.059942
14 – 12	1.902E+10	–	–	1.9E+10	6.001E−01	–	6.040E−01	0.453124
14 – 13	2.540E+09	–	–	2.6E+09	8.649E−02	–	8.820E−02	0.067858
15 – 7	9.441E+06	–	–	–	4.832E−05	–	–	0.000021
15 – 8	6.022E+07	–	–	–	3.133E−04	–	–	0.000136
15 – 9	3.031E+10	–	–	3.0E+10	2.544E−01	–	2.570E−01	0.140089
15 – 11	1.132E+08	–	–	–	1.380E−03	–	–	0.000916
15 – 12	1.065E+10	–	–	1.1E+10	1.528E−01	–	1.530E−01	0.110074
15 – 13	1.766E+10	–	–	1.8E+10	2.727E−01	–	2.740E−01	0.203682

Table 4: Same as in Table 3 but for the Ar XIV ion. Results are compared to the MCDHF calculations of Rynkun et al. [22]. i and j label the levels of Table 2.

Levels	$A_{ij}(\mathrm{s}^{-1})$		S		gf	
$i-j$	Present	MCDHF	Present	MCDHF	Present	MCDHF
3 – 1	2.851E+06	2.922E+06	0.000253	0.000239	1.714E−04	1.665E−04
3 – 2	1.679E+06	1.597E+06	0.000206	0.000179	1.252E−04	1.121E−04
4 – 2	4.756E+05	5.276E+05	0.000102	0.000104	6.511E−05	6.827E−05
5 – 2	2.025E+06	2.385E+06	0.000549	0.000606	3.700E−04	4.171E−04
6 – 1	3.567E+09	3.384E+09	0.098161	0.096710	1.239E−01	1.205E−01
6 – 2	3.031E+08	2.745E+08	0.009881	0.009304	1.179E−02	1.095E−02
7 – 2	3.249E+09	3.050E+09	0.157308	0.153900	1.883E−01	1.817E−01
8 – 1	1.275E+10	1.337E+10	0.089567	0.096770	1.414E−01	1.513E−01
8 – 2	3.724E+09	2.037E+09	0.029939	0.016880	4.520E−02	2.523E−02
9 – 1	1.012E+10	7.480E+09	0.057772	0.045500	9.777E−02	7.539E−02
9 – 2	1.535E+10	1.510E+10	0.099343	0.104300	1.612E−01	1.657E−01
10 – 1	4.285E+09	3.903E+09	0.045993	0.045080	7.945E−02	7.599E−02
10 – 2	2.322E+10	2.131E+10	0.281844	0.279000	4.674E−01	4.510E−01
11 – 3	4.481E+09	4.177E+09	0.073667	0.070660	1.104E−01	1.049E−01
11 – 4	8.460E+09	7.860E+09	0.146762	0.140200	2.160E−01	2.045E−01
11 – 5	1.175E+10	1.095E+10	0.220574	0.210000	3.163E−01	2.989E−01
11 – 6	4.564E+05	6.928E+05	0.000033	0.000047	3.017E−05	4.387E−05
11 – 7	2.130E+05	1.574E+05	0.000016	0.000011	1.420E−05	1.003E−05
11 – 8	3.794E+05	6.541E+05	0.000098	0.000154	5.871E−05	9.483E−05
11 – 9	6.541E+05	7.258E+05	0.000318	0.000279	1.540E−04	1.461E−04
11 – 10	1.789E+06	2.130E+06	0.001089	0.000969	4.897E−04	4.801E−04
12 – 3	5.856E+05	3.406E+05	0.000005	0.000003	9.796E−06	6.034E−06
12 – 4	4.506E+07	4.759E+07	0.000433	0.000499	7.763E−04	8.687E−04
12 – 5	5.927E+05	2.073E+05	0.000006	0.000002	1.066E−05	3.941E−06
12 – 6	5.679E+09	5.087E+09	0.166832	0.156000	2.060E−01	1.899E−01
12 – 7	1.568E+09	1.379E+09	0.046498	0.042590	5.724E−02	5.173E−02
12 – 8	5.984E+08	7.277E+08	0.042790	0.055140	3.929E−02	4.966E−02
12 – 9	1.633E+09	1.333E+09	0.173263	0.140300	1.395E−01	1.132E−01
12 – 10	1.333E+08	1.328E+08	0.016179	0.015600	1.245E−02	1.214E−02
13 – 4	2.593E+06	2.465E+06	0.000037	0.000038	6.637E−05	6.703E−05
13 – 5	8.441E+07	8.541E+07	0.001279	0.001413	2.255E−03	2.419E−03
13 – 6	8.076E+08	7.357E+08	0.034844	0.033360	4.334E−02	4.080E−02
13 – 7	7.062E+09	6.296E+09	0.307615	0.287500	3.814E−01	3.509E−01
13 – 10	1.808E+09	1.667E+09	0.318270	0.287300	2.477E−01	2.252E−01
14 – 3	1.744E+07	1.823E+07	0.000051	0.000057	1.072E−04	1.184E−04
14 – 4	3.495E+06	3.255E+06	0.000011	0.000011	2.203E−05	2.168E−05
14 – 6	1.332E+10	1.180E+10	0.101300	0.093950	1.558E−01	1.423E−01

Table 5: Present collision strengths Ω of some transitions for Ar XII (compared to E05: The results of Eissner et al. [21]) and for Ar XIV (compared to B86: The results of Bhatia et al. [19]).

	Ar XII						Ar XIV	
Trans.	35 Ryd		70 Ryd		105 Ryd		40 Ryd	
$i-j$	Present	E05	Present	E05	Present	E05	Present	B86
1−2	3.486E−02	3.358E−02	1.686E−02	1.675E−02	1.005E−02	1.007E−02	5.058E−02	4.733E−02
1−3	5.122E−02	4.925E−02	2.526E−02	2.503E−02	1.537E−02	1.534E−02	6.127E−03	6.382E−03
1−4	9.773E−03	9.588E−03	4.024E−03	4.063E−03	2.091E−03	2.126E−03	6.664E−03	6.484E−03
1−5	1.867E−02	1.834E−02	7.808E−03	7.909E−03	4.111E−03	4.206E−03	4.334E−03	4.207E−03
1−6	1.217E+00	1.265E+00	1.237E+00	1.479E+00	1.194E+00	1.618E+00	5.498E−01	5.380E−01
1−7	8.144E−01	8.407E−01	8.331E−01	9.792E−01	8.058E−01	1.070E+00	6.857E−03	6.185E−03
1−8	4.101E−01	4.223E−01	4.201E−01	4.910E−01	4.064E−01	5.364E−01	4.801E−01	4.401E−01
1−9	4.860E−04	5.406E−04	3.970E−04	4.403E−04	3.550E−04	4.214E−04	2.993E−01	2.973E−01
1−10	1.420E−04	1.804E−04	9.600E−05	8.258E−05	8.100E−05	6.156E−05	2.398E−01	2.263E−01
2−3	7.236E−02	8.525E−02	4.175E−02	5.886E−02	3.008E−02	4.862E−02	3.677E−03	4.028E−03
2−4	5.294E−02	5.168E−02	5.654E−02	5.559E−02	5.913E−02	5.851E−02	8.699E−03	8.598E−03
2−5	5.022E−02	4.991E−02	4.632E−02	4.631E−02	4.596E−02	4.607E−02	2.095E−02	2.095E−02
2−6	9.837E−03	9.980E−03	6.645E−03	7.501E−03	5.197E−03	6.544E−03	6.574E−02	6.485E−02
2−7	7.486E−03	7.457E−03	3.846E−03	3.926E−03	2.350E−03	2.410E−03	8.949E−01	8.954E−01
2−8	4.719E−03	4.724E−03	2.619E−03	2.770E−03	1.742E−03	1.947E−03	1.654E−01	1.641E−01
2−9	1.173E+00	1.189E+00	1.243E+00	1.403E+00	1.218E+00	1.542E+00	5.302E−01	4.894E−01
2−10	3.821E−02	3.848E−02	3.282E−02	3.641E−02	2.944E−02	3.650E−02	1.481E+00	1.399E+00
3−4	4.458E−02	4.349E−02	4.318E−02	4.252E−02	4.375E−02	4.334E−02	3.288E−02	3.189E−02
3−5	1.280E−01	1.273E−01	1.320E−01	1.328E−01	1.365E−01	1.382E−01	3.379E−02	3.145E−02
3−6	2.351E−02	2.348E−02	1.493E−02	1.616E−02	1.118E−02	1.319E−02	1.326E−02	1.276E−02
3−7	5.883E−03	5.906E−03	3.157E−03	3.298E−03	2.030E−03	2.197E−03	7.016E−03	6.786E−03
3−8	7.240E−04	7.432E−04	3.690E−04	3.833E−04	2.250E−04	2.337E−04	2.981E−03	2.853E−03
3−9	8.207E−02	8.488E−02	7.753E−02	8.881E−02	7.248E−02	9.308E−02	5.950E−04	5.700E−04
3−10	1.658E+00	1.684E+00	1.745E+00	1.980E+00	1.705E+00	2.174E+00	1.666E−03	1.621E−03
4−5	2.790E−02	2.713E−02	1.617E−02	1.605E−02	1.170E−02	1.164E−02	7.751E−02	7.355E−02
4−6	2.322E−03	2.357E−03	1.206E−03	1.247E−03	7.420E−04	7.689E−04	1.961E−02	1.896E−02
4−7	4.810E−03	4.828E−03	2.516E−03	2.583E−03	1.556E−03	1.610E−03	2.148E−02	2.066E−02
4−8	4.701E−03	4.720E−03	2.967E−03	3.233E−03	2.204E−03	2.621E−03	5.158E−03	4.988E−03
4−9	1.784E−01	1.861E−01	1.854E−01	2.181E−01	1.804E−01	2.390E−01	2.026E−03	1.911E−03
4−10	6.135E−03	6.226E−03	3.189E−03	3.325E−03	1.954E−03	2.059E−03	3.987E−03	3.841E−03
5−6	1.241E−02	1.300E−02	8.092E−03	9.567E−03	6.158E−03	8.192E−03	1.627E−02	1.542E−02
5−7	1.261E−02	1.306E−02	8.999E−03	1.061E−02	7.295E−03	9.701E−03	4.674E−02	4.500E−02
5−8	4.151E−03	4.175E−03	2.147E−03	2.210E−03	1.318E−03	1.365E−03	6.603E−03	6.421E−03
5−9	1.248E−02	1.263E−02	9.104E−03	1.010E−02	7.468E−03	9.219E−03	5.227E−03	4.974E−03
5−10	4.532E−01	4.708E−01	4.687E−01	5.522E−01	4.550E−01	6.052E−01	6.365E−03	6.106E−03
6−7	9.390E−02	9.333E−02	6.855E−02	6.879E−02	5.986E−02	6.025E−02	4.131E−02	3.912E−02
6−8	3.644E−02	3.611E−02	3.413E−02	3.406E−02	3.404E−02	3.412E−02	4.169E−02	3.804E−02
6−9	2.344E−02	2.280E−02	1.094E−02	1.090E−02	6.355E−03	6.362E−03	1.030E−02	9.923E−03
6−10	6.161E−02	6.018E−02	2.820E−02	2.820E−02	1.622E−02	1.629E−02	1.959E−02	1.922E−02
7−8	4.313E−02	4.302E−02	2.297E−02	2.324E−02	1.526E−02	1.548E−02	6.014E−02	5.523E−02
7−9	2.823E−02	2.752E−02	1.271E−02	1.270E−02	7.135E−03	7.166E−03	2.130E−02	1.958E−02
7−10	2.884E−02	2.811E−02	1.332E−02	1.330E−02	7.682E−03	7.706E−03	2.397E−02	2.422E−02
8−9	1.693E−02	1.655E−02	7.668E−03	7.678E−03	4.365E−03	4.390E−03	5.504E−03	5.382E−03
8−10	1.167E−02	1.134E−02	5.437E−03	5.412E−03	3.142E−03	3.145E−03	9.142E−03	8.623E−03
9−10	4.766E−02	4.773E−02	3.846E−02	3.848E−02	3.560E−02	3.570E−02	4.458E−02	4.210E−02

Table 6: Stark line widths for 12 Ar XII lines at electron density $N = 10^{18}$ cm^{-3} at different temperatures, the wavelengths λ are taken from the SUPERSTRUCTURE (SST) code of Eissner et al. [34].

Transition	$T(10^5\mathrm{K})$	W(pm)	Transition	$T(10^5\mathrm{K})$	W(pm)
	5	1.709E−03		5	1.045E−03
$2s^22p^3\ {}^4S^\circ_{3/2}-2s^22p^2(^3P)3d\ {}^4P_{5/2}$	10	1.194E−03	$2s^22p^3\ {}^2P^\circ_{3/2}-2s^22p^2(^1D)3s\ {}^2D_{5/2}$	10	7.048E−04
λ = 31.26 Å	15	9.543E−04	λ = 35.53 Å	15	5.592E−04
1−54	20	8.026E−04	5−21	20	4.746E−04
	25	6.946E−04		25	4.179E−04
	50	4.211E−04		50	2.805E−04
	5	1.020E−03		5	1.047E−03
$2s^22p^3\ {}^4S^\circ_{3/2}-2s^22p^2(^3P)3s\ {}^4P_{5/2}$	10	6.821E−04	$2s^22p^3\ {}^2P^\circ_{3/2}-2s^22p^2(^3P)3s\ {}^2P_{3/2}$	10	7.157E−04
λ = 34.52 Å	15	5.419E−04	λ = 36.13 Å	15	5.718E−04
1−18	20	4.604E−04	5−20	20	4.873E−04
	25	4.054E−04		25	4.301E−04
	50	2.712E−04		50	2.899E−04
	5	1.388E−03		5	3.939E−03
$2s^22p^3\ {}^4S^\circ_{3/2}-2s^22p^2(^3P)3s\ {}^4P_{3/2}$	10	8.349E−04	$2s^22p^3\ {}^2P^\circ_{1/2}-2s(^2S)2p^4(^1S)\ {}^2S_{1/2}$	10	3.080E−03
λ = 34.65 Å	15	6.318E−04	λ = 172.82 Å	15	2.888E−03
1−17	20	5.219E−04	4−11	20	2.822E−03
	25	4.512E−04		25	2.766E−03
	50	2.898E−04		50	2.383E−03
	5	1.779E−03		5	5.329E−03
$2s^22p^3\ {}^4S^\circ_{3/2}-2s^22p^2(^3P)3s\ {}^4P_{1/2}$	10	9.961E−04	$2s^22p^3\ {}^4S^\circ_{3/2}-2s(^2S)2p^4(^3P)\ {}^4P_{1/2}$	10	3.840E−03
λ = 34.75 Å	15	7.260E−04	λ = 214.91 Å	15	3.215E−03
1−16	20	5.859E−04	1−8	20	2.859E−03
	25	4.987E−04		25	2.621E−03
	50	3.086E−04		50	2.020E−03
	5	1.078E−03		5	5.453E−03
$2s^22p^3\ {}^2D^\circ_{3/2}-2s^22p^2(^1D)3s\ {}^2D_{3/2}$	10	7.079E−04	$2s^22p^3\ {}^4S^\circ_{3/2}-2s(^2S)2p^4(^3P)\ {}^4P_{3/2}$	10	3.932E−03
λ = 34.82 Å	15	5.583E−04	λ = 217.87 Å	15	3.295E−03
2−22	20	4.728E−04	1−7	20	2.933E−03
	25	4.158E−04		25	2.690E−03
	50	2.785E−04		50	2.074E−03
	5	1.136E−03		5	5.656E−03
$2s^22p^3\ {}^2P^\circ_{3/2}-2s^22p^2(^1D)3s\ {}^2D_{3/2}$	10	7.425E−04	$2s^22p^3\ {}^4S^\circ_{3/2}-2s(^2S)2p^4(^3P)\ {}^4P_{5/2}$	10	4.083E−03
λ = 35.52 Å	15	5.814E−04	λ = 223.88 Å	15	3.425E−03
5−22	20	4.899E−04	1−6	20	3.051E−03
	25	4.293E−04		25	2.801E−03
	50	2.853E−04		50	2.166E−03

Table 7: Same as in Table 6 but for the Ar XIV ion.

Transition	$T(10^5\mathrm{K})$	W(pm)	Transition	$T(10^5\mathrm{K})$	W(pm)
	5	2.044E−04		5	5.923E−03
$2s^22p\ ^2P^\circ_{1/2}-2s^23d\ ^2D_{3/2}$	10	1.442E−04	$2s^22p\ ^2P^\circ_{1/2}-2s2p^2\ ^2S_{1/2}$	10	4.369E−03
λ = 27.15 Å	15	1.174E−04	λ = 192.36 Å	15	3.685E−03
1−22	20	1.013E−04	1−8	20	3.284E−03
	25	9.027E−05		25	3.011E−03
	50	6.273E−05		50	2.298E−03
	5	6.377E−04		5	6.969E−03
$2s^22p\ ^2P^\circ_{3/2}-2s^23d\ ^2D_{5/2}$	10	4.527E−04	$2s2p^2\ ^2D_{3/2}-2p^3\ ^2P^\circ_{1/2}$	10	5.038E−03
λ = 27.31 Å	15	2.036E−04	λ = 197.51 Å	15	4.181E−03
2−23	20	1.437E−04	6−14	20	3.665E−03
	25	1.170E−04		25	3.307E−03
	50	1.010E−04		50	2.378E−03
	5	1.618E−03		5	4.873E−03
$2s2p^2\ ^2D_{5/2}-2s2p(^3P^\circ)3s\ ^2P^\circ_{3/2}$	10	1.144E−03	$2s2p^2\ ^4P_{5/2}-2p^3\ ^4S^\circ_{3/2}$	10	3.490E−03
λ = 30.17 Å	15	5.088E−04	λ = 211.85 Å	15	2.878E−03
7−25	20	3.552E−04	5−11	20	2.512E−03
	25	2.865E−04		25	2.260E−03
	50	2.452E−04		50	1.613E−03
	5	8.238E−03		5	8.087E−03
$2s^22p\ ^2P^\circ_{1/2}-2s2p^2\ ^2P_{1/2}$	10	5.983E−03	$2s^22p\ ^2P^\circ_{1/2}-2s2p^2\ ^2D_{3/2}$	10	6.300E−03
λ = 179.49 Å	15	4.981E−03	λ = 240.66 Å	15	5.407E−03
1−9	20	4.377E−03	1−6	20	4.850E−03
	25	3.960E−03		25	4.457E−03
	50	2.879E−03		50	3.398E−03
	5	8.539E−03		5	8.857E−03
$2s^22p\ ^2P^\circ_{3/2}-2s2p^2\ ^2P_{3/2}$	10	6.207E−03	$2s^22p\ ^2P^\circ_{3/2}-2s2p^2\ ^2D_{5/2}$	10	6.911E−03
λ = 183.18 Å	15	5.178E−03	λ = 253.79 Å	15	5.934E−03
2−10	20	4.563E−03	2−7	20	5.324E−03
	25	4.139E−03		25	4.893E−03
	50	3.038E−03		50	3.728E−03
	5	8.963E−03		5	1.827E−02
$2s^22p\ ^2P^\circ_{3/2}-2s2p^2\ ^2P_{1/2}$	10	6.509E−03	$2s^22p\ ^2P^\circ_{3/2}-2s2p^2\ ^2D_{3/2}$	10	1.454E−02
λ = 187.16 Å	15	5.417E−03	λ = 254.64 Å	15	9.105E−03
2−9	20	4.760E−03	2−6	20	7.081E−03
	25	4.305E−03		25	6.073E−03
	50	3.128E−03		50	5.445E−03

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Conflict of Interest :

Dear Editor;

The authors declare no conflict of interest in this paper.

Thank you

Sincerely,

Rihab Aloui, Haykel Elabidi and Sylvie Sahal-Bréchot