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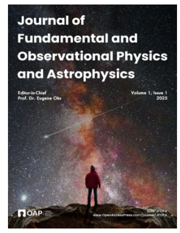

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Comments on Recent Papers on the Stark Broadening of Hydrogenic Spectral Lines in Plasmas

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Abstract The Stark broadening of hydrogenic spectral lines is one of the primary tools for spectroscopic diagnostics of various laboratory and astrophysical plasmas in a very wide range of electron densities Ne and a wide range of electron temperatures Te. There is a rich physics behind this phenomenon because in laboratory and astrophysical plasmas there are different types of the electric fields acting together on radiating hydrogenic atoms/ions. However, there is a lot of confusions in some recent papers on the subject. In the present paper we clarify those confusions for the benefit of the theorists working in this area, for the benefit of the experimentalists using the corresponding methods of spectroscopic diagnostics of laboratory plasmas, as well as for the benefit of astrophysicists employing the corresponding methods of spectroscopic diagnostics of astrophysical plasmas.

Keywords Stark broadening; hydrogenic spectral lines; strongly-magnetized plasmas; helical trajectories of electrons; laboratory plasmas; astrophysical plasmas

1. Introduction

The Stark broadening of hydrogenic spectral lines is one of the primary tools for spectroscopic diagnostics of various laboratory and astrophysical plasmas in a very wide range of electron densities Ne and a wide range of electron temperatures Te. This is because hydrogenic atoms/ions are much more sensitive to the variety of electric fields in plasmas compared to non-hydrogenic atoms/ions. The variety of the electric fields can be subdivided in three groups: the random fields of individual plasma electrons and ions, electric fields of the broadband or quasimonochromatic electrostatic waves generated in plasmas, and quasimonochromatic electric fields penetrating into a plasma from the outside (e.g., laser radiation).

The rich physics of the Stark broadening of hydrogenic spectral lines by different types of the electric fields (acting together) in plasmas, as well as numerous practical applications for spectroscopic diagnostics of the key parameters of the plasmas and of the fields in various laboratory and astrophysical plasmas, are described, e.g., in books [1-5] listed in the reverse chronological order.

However, there is a lot of confusions in some recent papers on the subject. In the present paper we clarify those confusions for the benefit of the theorists working in this area, for the benefit of the experimentalists using the corresponding methods of spectroscopic diagnostics of laboratory plasmas, as well as for the benefit of astrophysicists employing the corresponding methods of spectroscopic diagnostics of astrophysical plasmas.

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2. Critical analysis of some recent papers on the subject

2.1. Paper [6]

In 2021, Alexiou published paper titled "Methods for line shapes in plasmas in presence of external electric fields" [6]. However, first, in this paper he ignored most of the general principles for spectroscopy of plasmas containing external electric fields, formulated already in 2009 in paper [7]. Alexiou's ignorance of the majority of the general principles for spectroscopy of plasmas containing external electric fields made his 2021 paper practically useless.

The general principles for spectroscopy of plasmas containing external, particularly Quasimonochromatic Electric Fields (QEF), first formulated in paper [7] and later reiterated in the review [8] are as follows.

"The broadening of spectral lines in plasmas containing the QEF depends on a large set of characteristic times and frequencies, resulting in a very complex, rich physics. It is possible to single out seven characteristic frequencies serving as "building blocks" for more complicated constructs.

1. The frequency ω of the QEF.
2. The width (the homogeneous width)

$$\gamma = 1/\tau_F \qquad (1)$$

of the power spectrum of the QEF, where τ_F is the coherence time of the QEF.

3. The instantaneous Stark shift $\delta_s(E_0)$ calculated at the amplitude value E_0 of the QEF, the shift being either

$$\delta_s(E_0) = a_1E_0 \qquad (2)$$

for the linear Stark effect or

$$\delta_s(E_0) = a_2E_0^2 \qquad (3)$$

for the quadratic Stark effect). In Eqs. (2) and (3), $a_1(k)$, $a_2(k)$ are the corresponding Stark constants; k denotes the set of quantum numbers of the radiator states.

4. The typical frequency of the variation of the electron microfield

$$\Omega_e(N_e, T_e) = v_{Te}/\min(\rho_{Ne}, \rho_{We}). \qquad (4)$$

In Eq. (4), $v_{Te} = (T_e/m_e)^{1/2}$ (the thermal velocity of plasma electrons), $\rho_{Ne} \sim 1/N_e^{1/3}$ (the mean separation between plasma electrons), $\rho_{We} \sim n^2\hbar/(m_e v_{Te})$ (the electron Weisskopf radius, n being the principal quantum number).

5. The typical frequency of the variation of the dynamic part of the ion microfield

$$\Omega_i(N_i, T_i) = v_{Ti}/\min(\rho_{Ni}, \rho_{Wi}). \qquad (5)$$

In Eq. (5), $v_{Ti} = (T_i/m_i)^{1/2}$ (the thermal velocity of plasma electrons), $\rho_{Ni} \sim 1/N_i^{1/3}$ (the mean separation between plasma ions), $\rho_{We} \sim n^2\hbar/(m_e v_{Ti})$ (the ion Weisskopf radius).

6. The electron plasma frequency

$$\omega_{pe}(N_e) = (4\pi e^2N_e/m_e)^{1/2} = 1/\tau_{scr}. \qquad (6)$$

In Eq. (6), τ_{scr} is the typical time, after which the screening by plasma electrons becomes effective.

7. The detuning $\Delta\omega$ from the unperturbed position of the radiator spectral line under consideration. This physical quantity influences the typical value of the argument τ of the correlation function, the Fourier transform of which controls the lineshape.

The term "homogeneous" used above mean that the particular quantity is the same for all radiators. The frequencies from the above items 1 – 3 relate to the subsystem F and its interaction with the subsystem R. The frequencies from the above items 4 – 6 relate to the subsystem P and its interaction with the subsystem R.

There are four characteristic times that can be composed out of the above seven building blocks.

1. The typical time of the formation of quasienergy states:

$$\tau_{QS}(k, E_0, \omega) \sim \min(1/(\omega^2\, \delta_s)^{1/3}, 1/\omega). \qquad (7)$$

Under the QEF, the radiator states can exhibit the oscillatory behavior at the frequency ω, thus constituting the development of the quasienergy states (introduced by Zeldovich [9] and Ritus[10]). Equation (7), derived in paper [11], shows that while for the relatively weak QEF, the quasienergy states become effective after the typical time 1/ω, for the relatively strong QEF, the quasienergy states become effective after the much shorter typical time proportional to $1/E_0^{1/3}$ (for the linear Stark effect) or proportional to $1/E_0^{2/3}$ (for the quadratic Stark effect).

2. The typical time of the formation of the homogeneous Stark broadening by plasma electrons:

$$\tau_e(k, N_e, T_e, \Delta\omega) \sim \min(1/\Omega_e , 1/\omega_{pe} , 1/\Delta\omega). \qquad (8)$$

3. The typical time of the formation of the homogeneous Stark broadening by plasma ions:

$$\tau_i(k, N_i, T_i, N_e, \Delta\omega) \sim \min(1/\Omega_i , 1/\omega_{pe} , 1/\Delta\omega). \qquad (9)$$

4. The lifetime of the exited state of the radiator

$$\tau_{life}(k, N_e, T_e, N_i, T_i, \gamma, \omega, E_0, \Delta\omega) \sim 1/\Gamma, \qquad (10)$$

where

$$\Gamma = \gamma_e(k, N_e, T_e, \Delta\omega)+ \gamma_i(k, N_i, T_i, N_e, \Delta\omega)+ \gamma_F(k, \gamma, \omega, E_0) \qquad (11)$$

is the sum of the homogeneous Stark widths due to the electron microfield, to the dynamic part of ion microfield, and to the QEF, respectively. The QEF caused contribution γF(k, γ, ω, E0) was calculated analytically in paper [12].

It should be underscored that τQS entangles the parameters of the subsystems QEF and the radiator, τe and τe entangle the parameters of the subsystems plasma and the radiator, while τlife entangles the parameters of all three subsystems: the plasma, the QEF, and the radiator."

Thus, the physics behind the Stark broadening of spectral lines in plasmas containing the QEF is indeed very rich: it is a complicated interplay of four characteristic times presented in Eqs. (7) – (10). There was no understanding of this in paper [6].

2.2. Paper [13]

In 2023, Alexiou published simulations titled "Analysis of Plasma Emission Experiments and 'Dips'" [13]. However, that paper had severe flaws that were detailed in papers [14, 15], as follows.

"1. The primary flaw of simulations from paper [13] is the following: there was no understanding of the nature of the emergent phenomenon of Langmuir-wave-caused "dips" as stemming from the multifrequency nonlinear dynamic resonance. This kind of the resonance effects was beyond the code used in his paper. From the outset, that code was tied to Blochinzew satellites (predicted by Blochinzew in paper [16]). What he was called "dips" are in fact just random troughs between the peaks, where the peaks are (shifted) Blochinzew satellites. The definition of the "dips" in his paper has nothing to do with the highly-localized structures in spectral line profiles caused by the multifrequency nonlinear dynamic resonances.

2. In paper [13], the experimental spectra presented in parts A, B, and C of Fig. 3 from paper [17] – the paper presenting the results of a large-scale international project having 21 authors from 7 countries – were qualified as "noisy". This indicates again the lack of the understanding by Alexiou that the Langmuir-wave-caused "dip" is the structure consisting of the local minimum of the intensity (at the location controlled by the electron density) surrounding by two local maxima ("bumps") plus the secondary minimum. With the understanding of this structure of each "dip", all local minima and maxima of the intensity in parts A, B, and C of Fig. 3 from that experimental paper have been identified, accounted for, and clearly indicated", as can be seen from Fig. 1 below (reproducing the profile of Si XIV Ly-beta from Fig. 3 of paper [17].

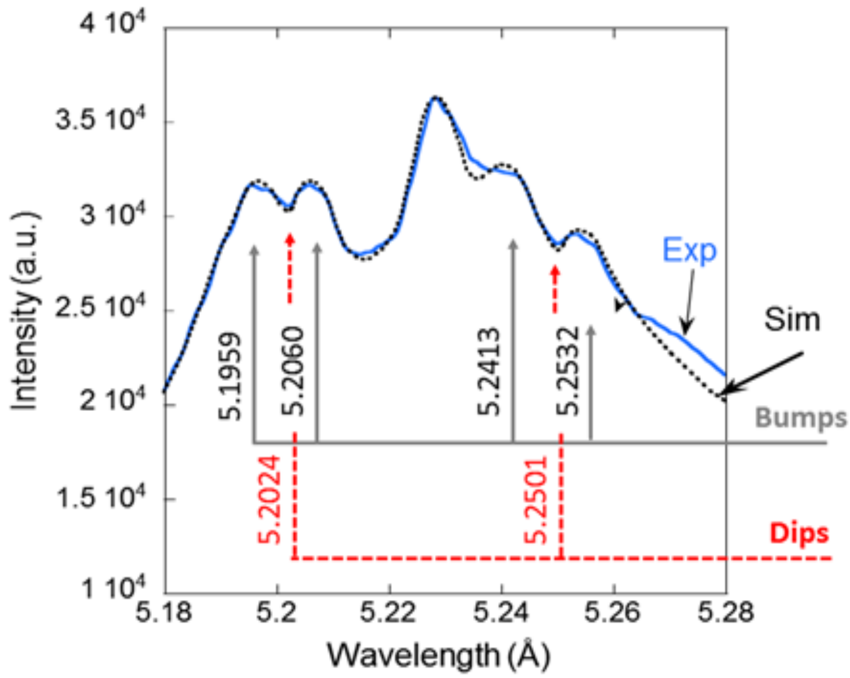

Fig. 1. The profile of Si XIV Ly-beta line from Fig. 3 of paper [17]. The marks "Exp" and "Sim" refer to the experimental and simulated profiles, respectively.

Besides, the bump-to-dip ratio of the intensities was up to 45%, thus exceeding the noise level by at least one order of magnitude. No wonder that the experimental spectra, obtained with a high spectral resolution ($\lambda/\delta\lambda \sim 3000$), easily allowed the reliable and the only one possible identification of the above structures.

3. Another flaw of the simulations from paper [13] is the following. There was the lack of the understanding that regardless of the specific distribution of the quasistatic field F over its magnitude and its direction, there is always a small group of radiators in the ensemble, for which the Stark splitting by the field F is in the multiquantum/multifrequency resonance with the frequency of the Langmuir field E0 cos(ωt) and its harmonics. Therefore, the locations of the resulting highly-localized structures in the spectral line profiles do not depend on the specific distribution of the quasistatic field F – in distinction to the locations of the random troughs between (shifted) Blochinzew satellites, calculated in Alexiou paper.

4. In paper [13], there was also a claim that distribution functions of the turbulent fields are not known. However, in reality the distribution functions of the quasistatic turbulent fields had been derived analytically already in 1976 in paper [18].

5. In paper [13], Alexiou claimed that his paper was the first to reveal that in plasmas containing Langmuir waves, the spectral line profiles exhibit directional/polarization effects. However, already in 1977, in paper [19] it was shown analytically that the highly localized structures in spectral line profiles, emitted from such plasmas due to the above dynamical resonances, exhibit directional/polarization effects. Moreover, in the same year 1977, these polarization effects have been confirmed experimentally and used for plasma diagnostics in paper [20]."

Thus, paper [13], containing so many false frivolous statements, is pointless.

2.3. Papers [21, 22]

In 2023, Alexiou published paper titled "Effects of Spiralling Trajectories on White Dwarf Spectra: High Rydberg States" [21]. This paper also has severe flaws that were detailed in paper [23].

For example, in paper [21] Alexiou falsely stated that presumably in paper [24] that presented analytical calculations on this subject, there was predicted that the allowance for Helical Trajectories of the Perturbing Electrons (HTPE) leads to a dramatic increase of Stark widths of the lines Balmer-beta, Balmer-delta, and Balmer-epsilon at high densities, while his simulations (performed for only one value of the electron density Ne and only one value of the electron temperature Te) yielded a decrease of the corresponding widths. However, in reality, the ratio of the Stark width γhel(p), calculated with the allowance for HTPE (the superscript "p" stands for "perturbative analytical calculation", as it was such in paper [24]), to the Stark width γrec, calculated in the standard way assuming rectilinear trajectories of electrons was:

$$\gamma_{hel}^{(p)}/\gamma_{rec} = 0.74/[\ln(1/D) - 0.0772], \qquad D = 5.57\times10^{-11}|X_{\alpha\beta}|[N_e(cm^{-3})]^{1/2}/T_e(eV), \quad (12)$$

$X_{\alpha\beta}$ being the standard label of Stark components of hydrogen/deuterium spectral lines:

$$X_{\alpha\beta} = n_a q_\alpha - n_b q_\beta \,, \qquad q_\alpha = (n_1 - n_2)_\alpha \,, \qquad q_\beta = (n_1 - n_2)_\beta, \tag{13}$$

where n1 and n2 are the parabolic quantum numbers. So, according to the perturbative analytical calculations from paper [24] (performed in the second order of the Dyson perturbation expansion), actually, the allowance for HTPE could increase (γhel(p)/γrec > 1) or decrease (γhel(p)/γrec < 1) the width of the Stark components of any hydrogen line, as it can be seen from Eq. (12).

Besides, Alexiou falsely (and ridiculously) stated that the perturbative analytical calculations from paper [24] were performed in frames of the so-called generalized theory of Stark broadening, while in reality they were performed in frames of the standard theory (also known as the conventional theory) of Stark broadening.

In 2024, the author of paper [24] published more advanced, non-perturbative analytical calculations [23], what made Alexiou paper [21] antiquated. The non-perturbative calculations by from paper [23] (equivalent to accounting for all order of the Dyson perturbation expansion) significantly reduced the effect of HTPE on the Stark width compared to the corresponding perturbative calculations from paper [24].

Then Alexiou in paper [22] attempted to criticize paper [23]. However, in paper [22], first Alexiou falsely claimed that presumably paper [23] stated that "the spiralling results should display a significant increase in width compared to the corresponding nonspiralling calculations". In reality, such statement is nowhere to be found in paper [23]: Alexiou lied.

Second, Alexiou in his paper [22] of 2025 did not compare his new simulations with the most advanced – non-perturbative – analytical calculations from paper [23] of 2024. Perhaps, he compared but did not publish – because he found that his simulations confirmed the non-perturbative analytical calculations from paper [23] and this undermined the reason for publishing his paper [22].

For the above reasons, the results of Alexiou papers [21, 22] are pointless.

3. Conclusions

We pointed out that there is a lot of confusions in some recent papers on the Stark broadening of hydrogenic spectral lines in plasmas. We clarified those confusions for the benefit of the readers.

Specifically, we demonstrated that Alexiou papers [6, 13, 21, 22] contain many false frivolous statements and/or are antiquated (due to the more advanced papers of other authors). Besides, it seems that over many years by now, he was able to perform only simulations, but unable to work by analytical methods – despite analytical methods provide physical insight that simulations lack.

Last but not least: some Alexiou codes are deficient, as had been shown in the literature in the past. For example, compared to the benchmark experiment by Büscher et al [25] in the gas-liner pinch, commonly accepted as the most reliable of all benchmark experiments at the electron densities Ne ≥ 1018 cm-3, Alexiou simulations [17] dramatically underestimate the width of the H-alpha line – by 30% for the lowest electron density.

In summary, for many years by now, Alexiou published only futile failed attempts to discredit works of other authors, but did not produce/publish any fresh ideas in plasma spectroscopy in particular and in atomic physics in general.

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