Line Shape Modelling for Tokamak Edge Plasma Conditions

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1. Introduction

The broadening of spectral line shapes has long been used in the past as a non-interfering probe to obtain information on the plasma parameters of the emitter environment. It is therefore a useful tool to analyze the sources and radiating species in high density, highly radiative Tokamak experiments. Precise information can generally be obtained with the help of a complete modelling of the radiating particles and their environment. A general line shape code PPP [1] developed by the Marseille group for modelling the Stark broadening of both neutral and charged emitters, has recently been modified to take into account the Zeeman effect due to the magnetic field present in Tokamak devices. Line broadening calculations for different emitters have been performed in the conditions of Tore-Supra edge plasmas during ergodic divertor operation, and Alcator C-Mod divertor plasmas.

2. Spectral line analysis during ergodic divertor operation in Tore-Supra

An in situ optical fiber is used, which views the plasma edge near a divertor neutralizer plate, tangentially to the magnetic field lines and in the counter direction of the plasma current [2]. An equatorial viewing line in the poloidal plane, crossing the plasma between two ergodic divertor modules, is also used. The Deuterium and ionized Helium temperatures near the neutralizer plate are obtained by modeling the D_α line and both the n=4→n=3 (4685.7Å) and n=6→n=4 (6560 Å) transitions of HeII. For the plasma conditions considered here (Te~10 eV, Ne~2 10^{19} m^{-3}), the Zeeman-Doppler broadening mechanism is dominant. For a line shape study of the D_α line, it is first necessary to estimate the intensity of the nearly coincident n=6→n=4 transition of HeII. This calculation is done by using the measured intensity of the Paschen-α line of HeII and the assumption that the three-body recombination as well as the quasi-resonant charge exchange between D and He^{2+} are negligible. The result shows that the intensity of the n=6→n=4 transition of HeII deduced from a collisional-radiative model [3] cannot contribute significantly to the blue wing of the D_α line.

An overview of the Tore-Supra spectroscopic database reveals that the D_α line shapes observed tangentially to the magnetic field lines do not vary strongly during a shot and are of two types. In the first type, the D_α profiles (like shot #26676 on Fig. 1) exhibit two well separated and symmetric σ components. The line profile analysis shows that the major fraction of D_α emission results from the Franck-Condon population (T=3 ± 0.5 eV). A good fit of the line blue side requires the inclusion of a hot (T=50±10 eV) but minor (~10%) deuterium population due to charge exchange. The remaining discrepancy on the red wing is probably due to the H_α line which is not taken into account here. In the second type of profiles (like shot #22316 on Fig. 2), the same line is asymmetric and does no longer exhibit separate σ components. Such a profile cannot result from the emission of a single Franck-Condon population. Our analysis shows that this profile results from a superposition of two populations, with one of them emitting a blue shifted component. This suggests that in addition to the cold Franck-Condon deuterium atoms, a hot emitter population flowing toward the emission spectrometer contributes significantly to the line. Such a population is most likely to relate to deuterium atoms which are thermalized through charge exchange.

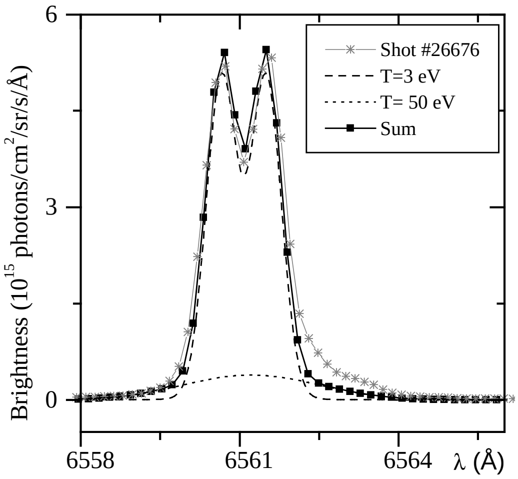

Fig. 1 : *Symmetric spectrum of D_α for ICRF or ohmically heated plasma in Tore-Supra. Synthetic profiles are computed for 2 values of the neutral temperature with B=2 Teslas.*

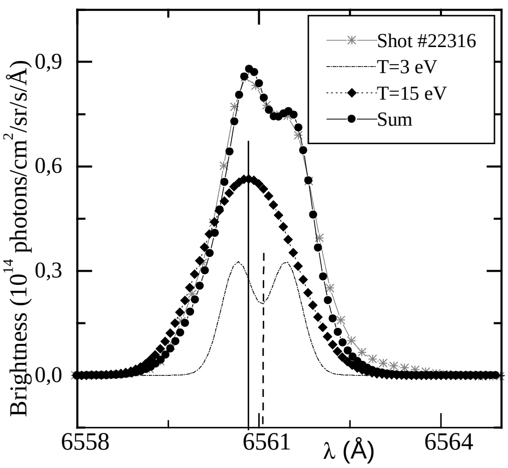

Fig. 2 : *Asymmetric profile of D_α obtained for ohmic plasmas in Tore- Supra. Dashed and solid vertical lines show the positions of the unperturbed and shifted frequencies. Theoretical spectra are calculated with B=2 Teslas.*

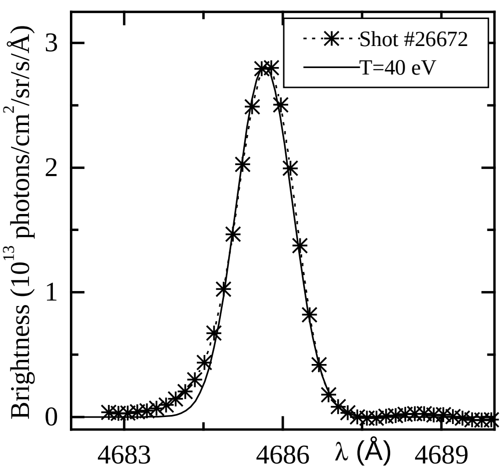

Fig. 3 : *HeII P_α line spectrum. Measured data in Tore-Supra are best fitted for B=2T and an ion temperature of 40 eV.*

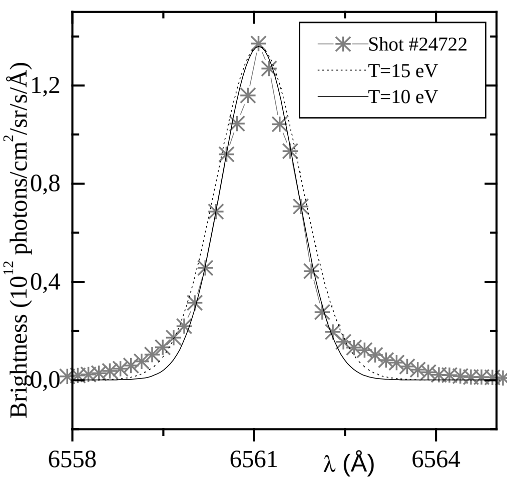

Fig. 4 : *D_α line profile under perpendicular observation of a region located between two divertor modules of Tore-Supra. Theoretical profiles are computed for B=2 T.*

We have found that more than a half of the emission arises from the charge exchange population (Fig. 2), and that the temperature for such atoms reaches 15 eV. The knowledge of the plasma edge and wall conditions influencing the relative importance of the Franck-Condon and charge exchange populations for the D_α emission is in progress. From the blue shifted D_α component, the Mach number of the deuterium flow is estimated to 0.25. This flow direction is corroborated by the HeII Paschen-α spectrum which is slightly asymmetric with most of the emission distributed in the blue side (Fig. 3). The temperature for the charge exchange atoms is consistent with the deuterium temperature deduced from the D_α spectrum measured along the equatorial viewing line between the divertor modules (Fig. 4, shot #24722). In addition, a temperature value of 40 ± 5 eV is deduced for HeII ions from the analysis of the Paschen-α line (Fig. 3).

3. Spectral analysis of D_δ line for a disruptive discharge of Tore-Supra

We also present a study of the D_δ (6→2) line observed with the viewing line tangential to magnetic field lines in disruptive plasmas obtained at the end of a discharge in Tore-Supra (shot #26195). Under such conditions, a high electron density is usually expected. Because Stark effect increases with both the upper quantum number n of the radiative transition and the electron density, this line is dominated by Stark effect. Assuming a Franck-Condon emitter population at 3 eV, and a same temperature of 10 eV for both ions and electrons, we have fitted the D_δ line spectra with Stark-Doppler profiles obtained with our PPP code (Fig. 5). Our calculations indicate that most of the broadening is due to Stark effect by a plasma with an electron density of about 2.2 10^{20} m^{-3}. This line is thus found to be useful for a density diagnostic in disruptive plasmas.

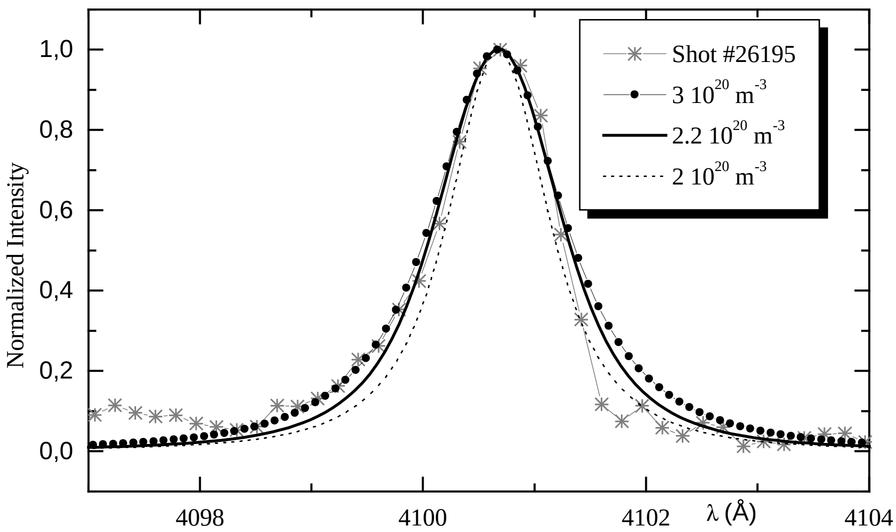

Fig. 5 : D_δ line spectrum observed for disruptive plasmas in Tore-Supra compared with computed profiles.

4. Deuterium Stark broadened high-n Balmer series lines in Alcator C-Mod

If edge plasma conditions reach a recombining regime with high electron density and low temperature, the plasma detaches and Stark broadened Deuterium and Hydrogen high-n Balmer series lines can be observed in the edge and divertor regions. Balmer lines up to n=15-16 were observed in axi-symmetric divertor configurations of several Tokamaks (Alcator C-Mod [4, 5], JET [6] and DIII-D[7]). As Stark effect is the major broadening mechanism which affects the profiles of these lines, electron densities can be deduced by comparing the entire spectrum, not single transitions, to the experimental data. Spectra are computed using a two step method. First, from the best fit of one Balmer line of the experimental spectrum, the electron density is deduced by using an improved model for electron broadening [8], assuming a given electron temperature. Second, the entire spectrum is computed and compared to the experimental one. The density populations of the high levels are calculated assuming a Saha-Boltzmann equilibrium. Fig. 6 shows a synthetic spectrum (transitions n=8→2 to n=12→2) compared to the experimental data from ref. 5 for T_e=4 eV and Ne=9. 10^{20} m^{-3}. Here the density value is obtained from the best fit of the D_9 (n=9→2) line and impurity lines are not fitted.

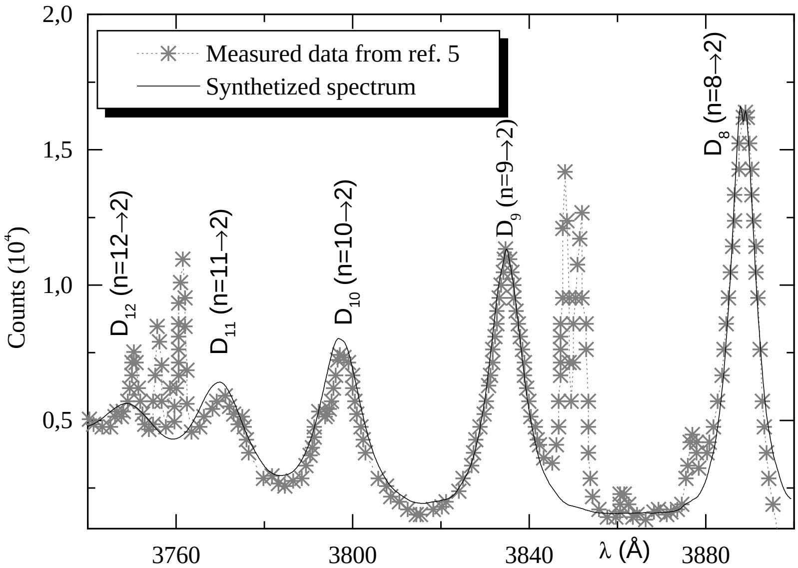

Fig. 6. *Synthetic and experimental spectrum of high-n Balmer line series. The best fit is for* Ne=9.10^{20} m^{-3}.

References

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