Tools for spectral data analysis of arbitrary emitters in edge plasmas

Y. Marandet[1], P. Genesio[1], M. Koubiti[1], L. Godbert-Mouret[1], B. Felts[1],
R. Stamm[1], H. Capes[2], P. Lotte[2], C. Lowry[2], R. Guirlet[2]

[1]PIIM, UMR6633 CNRS/Université de Provence, centre St-Jérôme,13397 Marseille, France
[2]DRFC, Euratom-CEA, CEA Cadarache, 13108 Saint Paul lez Durance cedex, France

1. Introduction

Line radiation has long been used for diagnosing edge plasmas in a non perturbative manner. A spectral line shape code including the Stark, Zeeman and Doppler effects has been developed for arbitrary emitters in a magnetized plasma. By retaining all these effects, it allows the study of a wide range of edge plasma conditions, with electron densities 10^{18}-10^{21} m^{-3}, temperatures from a fraction of eV to several hundreds eV, and magnetic fields up to 10 T. In this paper, observations of neutral and ionized carbon lines in the Tore-Supra tokamak edge plasma are fitted using this code. As Zeeman and Doppler effects are dominant for these lines, a temperature diagnosis is done. In addition, inclusion in the line shape code of the motional Stark effect (MSE) experienced by an emitter belonging to an energetic neutral beam is reported. Line shape studies are usually performed using iterative tools which compare experimental spectra to theoretical ones. An alternative and more robust method is to use a genetic algorithm (GA). The use of such an algorithm to the fit of Dα spectra observed in Tore Supra is presented.

2. Carbon lines

In a fusion device it is important to know the main processes by which impurities are released from plasma facing components (PFCs). As all the Tore Supra PFCs are covered with graphite or CFC, the main impurity is carbon. Therefore, spectra of two C I and C II multiplets have been analyzed to infer temperatures and determine the nature of the dominant sputtering processes, and to determine the position of the emission zone from the Zeeman splitting. For that purpose, the non-perturbative model was fitted to the measured spectra of both the C II doublet at 6578-6583 Å and the C I multiplet in the wavelength range 9060-9115 Å as shown in Fig. 1. From the C I spectrum measured in Tore-Supra (instrumental function: Gaussian with FWHM~0.83±0.03Å), a magnetic field B=2.2 T and an effective neutral carbon temperature T_{CI}=6.9±1.4 eV have been obtained. Such a temperature value is indicative of physical sputtering as opposed to chemical sputtering which results in low neutral temperatures ~1 eV [1,2]. In the edge of Tore-Supra, electron temperature and density (T_e>10 eV ; n_e<$2x10^{19}$ m^{-3}) indeed favor physical sputtering [3]. For the measured C II spectrum, the instrumental function was Gaussian too (FWHM~0.43±0.03 Å). The C II line fit (using Maxwellian velocity distribution functions) shown in Fig. 1b, gives B=2.2 T and T_{CII}=12±1.4 eV (for the ionic C II temperature). Note that the electron temperature T_e measured by probes during shot #27276, near the neutralizer plates, was in the range 20-40 eV.

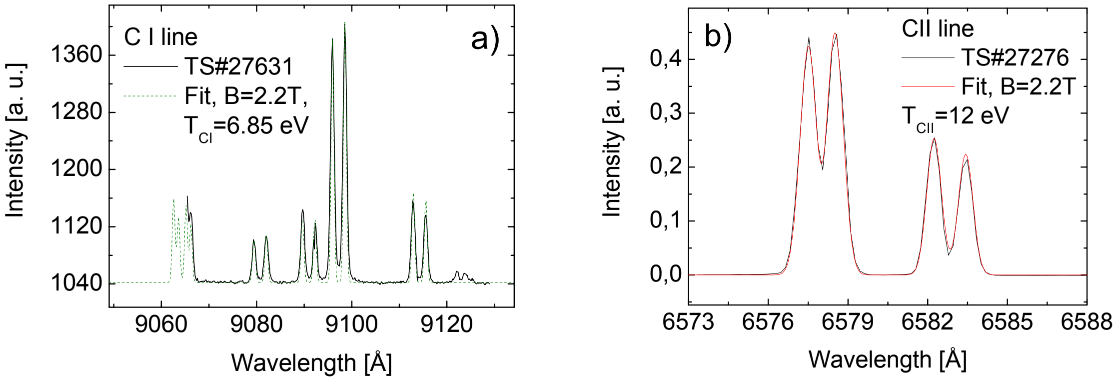

Fig. 1 : a) Fit of a C I line spectrum measured tangentially to the magnetic field lines in the former ergodic divertor of Tore-Supra (shot #27631). b) : Fit of a C II line spectrum (Tore-Supra discharge #27276) .

3. Motional Stark Effect

Theoretical calculations of motional Stark effect spectra of hydrogen have been done for an observation parallel to the magnetic field. Fig. 2a illustrates the MSE features for a Lorentz electric field in the domain 0-3 MV/m, and a magnetic field B=3 T [4]. Increasing the electric field in this interval results in a transition from a pure Zeeman spectrum, to an almost pure Stark spectrum. Spectra calculated for intermediate field values show how the transition between those limiting cases takes place. An experimental MSE spectrum measured in Tore-Supra during discharge #30323 in which a 50 keV hydrogen neutral beam was used is presented in Fig. 2b. For such conditions, one can see that Stark features are red-shifted (Doppler effect) by ~44 Å. Knowing the emitter velocity and the magnetic field in the emission region, one can estimate the angle between the line of sight and the neutral beam. A preliminary fit to the measured MSE spectrum indicates that the value of the magnetic field and Lorentz electric field at the emission zone are B~3.23 T and E_L~9 MV/m. As all the resolved MSE components are Gaussian with the same FWHM, a hydrogen temperature of 17.5 eV can be inferred. It corresponds to the thermal motion of neutrals in their source.

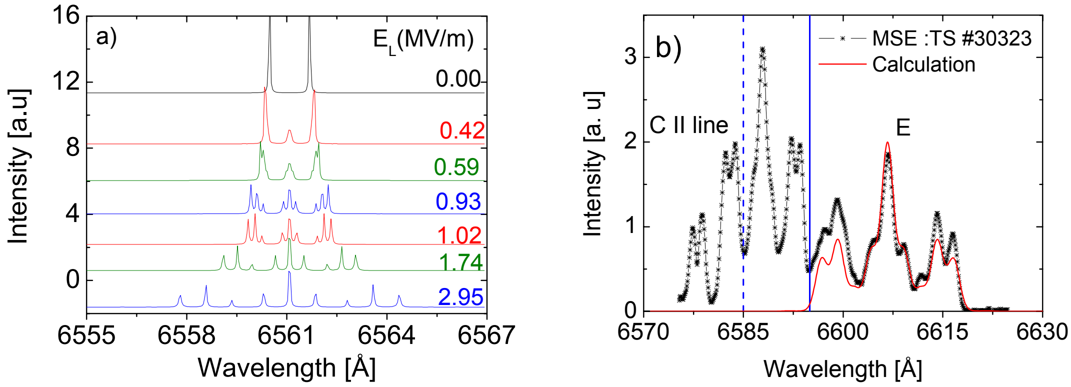

Fig. 2 a) MSE calculations with B=3 T for a Lorentz electric field in the range 0-3 MV/m. For simplicity the observation is chosen parallel to the magnetic field and the Doppler effect is ignored. Line broadening is due to impact of electrons whose density is 5x10^{18} m^{-3}. b) A measured MSE spectrum in Tore-Supra shot #30323. The vertical solid line separate the MSE full energy (E) component (right side) from the ½ and 1/3 energy components (left side). Peaks on the left side of the dashed vertical line represent mainly C II emission.

4. Line shape analysis with a Genetic Algorithm

Comparing between experimental line spectra and theoretical line shape models can be achieved by a Genetic Algorithm (GA) based on an analogy to the mechanics of natural selection. Such an algorithm is able to deal with complex non linear models, and can avoid local minima. The first step of this optimization technique consists in encoding the model parameters in binary strings. In the language of GA, we then have a chromosome containing several genes. For our spectroscopy problem, we consider an initial sample of many individuals (typically about 100). Each individual has a single chromosome and corresponds to a line shape whose fitness is evaluated by comparing the model to the experimental data by a χ^2 statistical estimator. The GA modifies this initial random sample using three operators. Selection is a process during which the fittest individuals have the greatest probability to survive. The chromosome of the best individuals are recombined by crossover of a part of their genes. Mutations are allowed to occur at a very low rate, and consists in the random change of one bit in a binary string (gene). Although mutations generally result in an individual which is less fit, they occasionally produce a change that improves the sample, and helps the whole process in avoiding local minima.

We have used a GA [5] to fit Zeeman $D\alpha/H\alpha$ spectra observed in Tore Supra, broadened by the Doppler effect. The model retains several populations of neutrals [6]: cold neutrals resulting from dissociation of molecules desorbed from the surface, warm neutrals obtained by charge exchange with the plasma ions. Considering that each of these populations leads to a Gaussian line shape with a different temperature, we are thus a priori left with the determination of temperatures and relative fractions of several populations.

Spectra were analyzed from 2 different machine configurations, corresponding to :

1) Recycling from the ergodic divertor (ED) [3], with lines of sight tangential to the magnetic field. 2) Recycling at the Toroidal Pump Limiter (TPL) [7] with vertical lines of sight perpendicular to the magnetic field.

In the ED configuration (shot #28268), the following parameters (contributions to the line emission) have been obtained: 70% from cold deuterium atoms with a temperature T_c=1.6 eV, 17% and 9% respectively from charge exchange atoms with T_{w1}=57 eV and T_{w2}=118 eV. The relative fraction of hydrogen was found to be 4%. In the TPL configuration (shot #30461) cold atoms (T_c=2 eV) are in the minority (23%) and are replaced by warmer charge exchange atoms. Two charge exchange populations are identified: 53% of the atoms have a temperature of 25 eV, and 22% a temperature of 330 eV. This observation could be due to the use of a vertical line of sight, exploring the entire plasma in a poloidal section, but the most emissive region in the visible is clearly located near the limiter. This suggests that the plasma above the TPL contains a larger fraction of warm particles than the ED plasma. A future study of the plasma near the dynamic ergodic divertor of TEXTOR is scheduled for a comparison with Tore Supra results.

5. Conclusion

A line shape code including Stark, Zeeman and Doppler effects has been implemented to include atomic fine structure effects, and the MSE. Genetic algorithms provide an efficient and robust tool for automated analysis of edge plasma line shapes. Preliminary results indicate that the recycling gas is warmer in TPL than in ED configuration of Tore Supra.

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