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Charge exchange contribution to the Doppler spectra emitted by neutrals in tokamak edge plasmas

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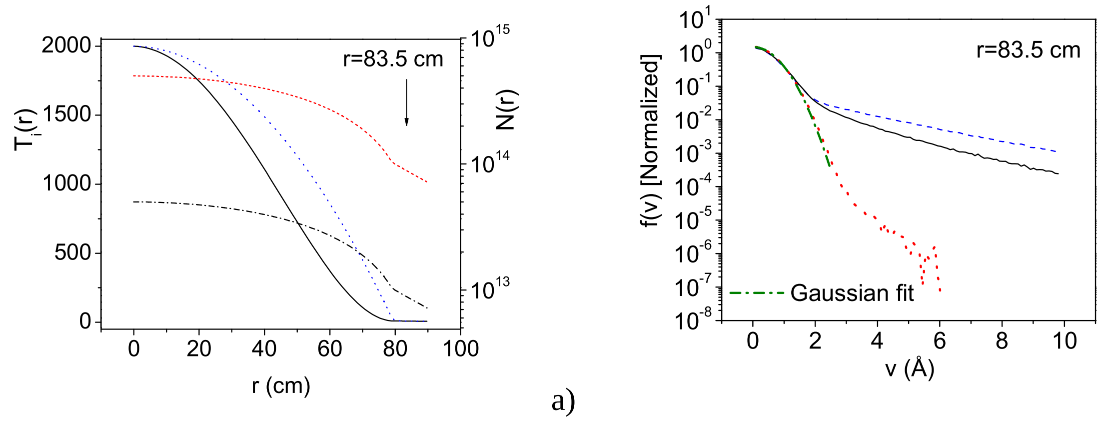
Introduction

Studies of the Balmer α line of deuterium have so far given precious information on the neutral velocity distribution in tokamak edge plasmas (e.g. [1]). While previous works focused on the central part of the Doppler spectra, here we investigate their tails. The existence of hot populations having temperatures up to several hundreds of eV has been reported, and interpreted as charge exchange (CX) components. The temperatures thus obtained have to be treated with care, because this effective multi-gaussian behaviour is actually related to contributions of regions of the plasma characterized by different ion temperatures. In fact, energetic CX neutrals have long mean free paths, and their velocity distribution function (VDF) has to be obtained from the Boltzmann equation. Analysis of the CX component should therefore yield information on the ion temperature profile, in a way reminiscent of Neutral Particle Analysers. Furthermore, it has been suggested that these parts of the spectra might also be used to retrieve information on the statistical properties of turbulent fluctuations, in particular the Probability Density Function (PDF) of ion temperature fluctuations, through neutrals created locally by charge exchange [2]. The aim of this work is to assess the contribution of hot CX neutrals to the wings of Doppler spectra, and the extent to which the neutral VDF reflects the local ion VDF, disregarding turbulence as a first step. Doppler profiles are simulated with the EIRENE Monte Carlo code [3], and discussed. Finally, we present a first qualitative comparison to measurements obtained with a high resolution ($R \simeq 100000$) Littrow spectrometer in the TEXTOR tokamak.

Neutral Velocity distribution in a model case

The EIRENE code solves the Boltzmann equation in any specified geometry. In order to focus on the physics of the problem, and remove most of the complications introduced by the tokamak toroidal geometry, EIRENE was first run in a slab case. The gross features of the model have been chosen so as to be consistent with a medium size tokamak such as TEXTOR, or more specifically Tore Supra (TS). Model plasma profiles are prescribed analytically, assuming



a) b)

Figure 1: a) Density profiles (dashed-dotted black and short dash red, log. scale) and temperature profiles (solid black and dotted blue) used in the simulations. b) Calculated VDF at $r = 83.5$ cm. The velocity is expressed in terms of the equivalent Doppler shift (Å) for the Dα line. The green dashed-dotted line is a Gaussian fit, giving a temperature very close to the local T_i.

$T_e(r) = T_i(r)$, and are plotted on Fig. 1a. The high density profile (short-dashed red curve) is not realistic for TEXTOR or TS, but allows to investigate an interesting limiting case. The VDF calculated along the magnetic field, i.e. normally to the radial direction, is plotted on Fig. 1b, first for a reference case. The latter is defined by a temperature profile (solid black line on Fig. 1a), and a density profile (dashed-dotted black line). The bulk of the VDF has a Gaussian-like behaviour, which can be interpreted as the local CX contribution. Indeed, at high densities, namely 10 times higher than the reference case, the VDF (Fig. 1b, red dotted line) can be fitted to a maxwellian at the local ion temperature (green dashed-dotted) over several orders of magnitude. The agreement in the bulk of the VDF is also satisfying for the reference case at $r = 83.5$ cm, but would be far less good at these lower densities in regions of steep gradients (short gradient length L_∇). Furthermore, the tails decrease only exponentially because of the contribution of non local CX neutrals. They are sensitive to the shape of the ion temperature profile, as can be seen on the VDF calculated for a steeper ion temperature profile (dashed blue line on Fig. 1a). These non gaussian features are much weaker at higher density, when the CX neutral mean free path $\lambda \propto N^{-1}$ becomes shorter than L_∇. In fact, the contribution at point $\mathbf{r}$ of non local CX neutrals created at point $\mathbf{r}'$ roughly scales as $e^{-|\mathbf{r}-\mathbf{r}'|/\lambda}$. As a conclusion, careful modelling is required for TEXTOR or TS plasmas, where one might have $\lambda > L_\nabla$.

First comparison to experimental spectra

We now use a cylindrical geometry relevant to the TEXTOR tokamak. Fig. 2a shows a poloidal cross section including the test limiter. The plasma profiles are assumed to have poloidal and toroidal symmetry. The simulated Dα spectra are integrated along a set of 3 chords, corresponding to the experimental set-up (horizontal view at LL1 [4]), which provides radial resolution ($\Delta r \sim 1$ cm), see Fig. 2a.

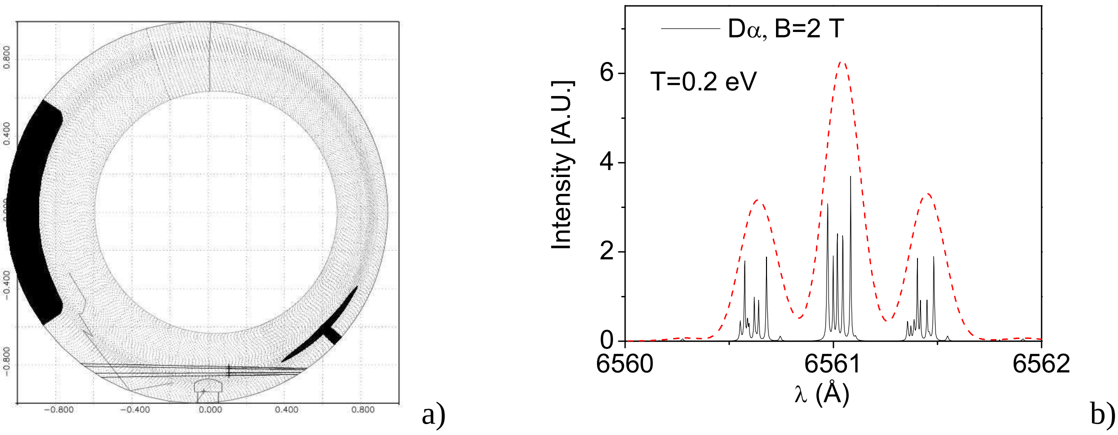


Figure 2: a) Plot of a poloidal cross section of the TEXTOR case. The bumper limiter is on the high field side (left), and the ALT limiter is on the low field side. The black solid lines figure the chords observing above the test limiter, which is positioned at $r = 48$ cm. b) Line shape retaining Zeeman, Stark and fine structure effects, with (dashed) and without Doppler broadening (solid).

The VDF simulated by EIRENE is first convolved with the line shape profile calculated by the PPP code [5], which retains fine structure, Zeeman, and Stark effects (see Fig. 3b, $T = 0.2$ eV is a typical value for the temperature of neutrals created by molecular dissociation), and then with the apparatus function. Measurements have been carried out using a specifically built Littrow spectrometer ($f = 1.25$ m focal length, $R \simeq 10^5$). This resolution is reached for the Dα line using a 220×110mm^2, 79 grooves.mm^{-1} echelle grating in the 37th order. The spectrometer is coupled to a 1024×256 pixels CCD camera ($19 \times 19\mu$m^2 pixels) featuring a high dynamic range (18-bits digitalization). Successive spectra taken during the flat-top phase of a stationary discharge are averaged to increase the signal to noise ratio (SNR). Fig. 3a shows an example of radially resolved experimental Dα/Hα spectra, plotted on a logarithmic scale. The CX component, which is seen on the line wings, becomes broader and broader as one looks deeper and deeper in the plasma. This is physically sound, the CX component being closely related to the ion temperature. The SNR is highest closest to the limiter, because of the radial localisation of the emission. Here gas (D2) was injected at the limiter to enhance emission. These results show that the CX component can be measured with a reasonable SNR. Here we present a preliminary comparison between these measurements and the first results obtained with the simulation, plotted on Fig. 3b. The behaviour of the tail of the distribution as a function of the radius is in qualitative agreement with the experimental results.

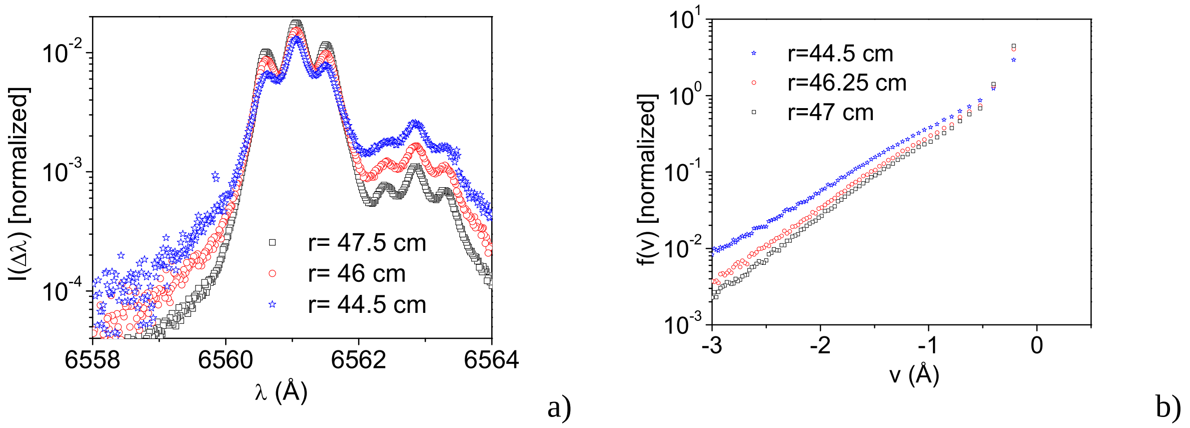


Figure 3: a) High resolution Dα/Hα spectra measured in TEXTOR. b) Simulated VDF for 3 different chords providing radial resolution.

Conclusion and perspectives

In tokamak edge plasmas, the bulk of the velocity distribution function of charge exchange neutrals (CX) can as a first approximation be described by a maxwellian at the local ion temperature, which makes for the local CX component considered in Ref. [2]. This approximation becomes however questionable in regions of steep gradients. Furthermore, the tails exhibit an exponential like decay, because of non local CX neutrals, and are strongly density dependent. In the near future, further work should allow to perform quantitative comparisons between experiments and simulation, and finally reach a conclusion about the possibility to obtain information on turbulence from line shapes. According to our results, performing density and radial scans would be very helpful to understand the origin of a non Gaussian tail on experimental spectra.

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