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Spatially resolved H_α study of hydrogen recycling at a limiter and neutral density profiles obtained with EIRENE in ECRH plasmas of TJ-II

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Introduction

H_α-emission analysis has been the key in understanding the dominant atomic processes during fuel recycling. Doppler line broadening studies to measure the excited atom energy as input for Monte-Carlo codes (mainly EIRENE and DEGAS) were used in the past to identify the dissociation, ionization and excitation reactions, since the kinetic energy of the emission precursor helps in identifying the exact reactions, well characterised from laboratory experiments (see e.g. [1-4]). Here, a simple 1-D model for recycling of neutrals and the EIRENE Monte-Carlo code are used to simulate the H_α-emission image of a tangential viewing camera equipped with a H_α-filter looking at a poloidal limiter [4]. The radial emission profiles were well simulated with both, a simple 1-D model and EIRENE, which is next used to calculate the absolute neutral density profiles of atomic and molecular hydrogen in the complex 3-D stellarator geometry. The code is also used to infer the H_α-emission along the camera-viewing chord, important to know from where and from what precursor the light comes.

Experimental set-up

The experiments have been performed in the medium sized stellarator TJ-II, with 200 ms, 400 kW ECRH power producing bean shaped, 20 cm sized plasmas with $n_e(0) \approx 0.5 – 1.2 \times 10^{19}$ m^{-3} and $T_e(0) \approx 1 – 1.5$ keV at the centre and $n_e(a) = 1.5 \times 10^{18}$ m^{-3} and $T_e(a) = 40$ eV at the L.C.F.S. The T_e-profile stays at the plasma edge from r/a = 1 to r/a = 0.7 nearly constant and than increases strongly towards the centre and n_e increases nearly linear from $n_e(a) = 1.5 \times 10^{18}$ m^{-3} to $n_e(r/a=0.5) = 10 \times 10^{18}$ m^{-3} and than is somewhat hollow at the plasma centre. Hydrogen recycling is studied in front of one poloidal limiter, which is positioned 1 cm inside the L.C.F.S. as defined by the helical limiter. A fast digital CMOS camera, operated at 10^4 frames per second with 64 x 128 pixel resolution, coupled to the view-port with a coherent fibre bundle and an interference filter centred at the H_α-line, captures the images with a tangential line of view, so that the chord each pixel observes is nearly parallel to the magnetic field within the bright light cloud in front of the poloidal limiter (figure 1).

Results and Discussion

Figure 2 shows one of the main results disclosed with more detail in [4]: the solid line is the radial H_α-emission intensity profile I(r) divided by the electron density profile n_e, which should be proportional to the sum of the emission precursor $n_j(r)$ multiplied by k_j, its respective electron collision excitation rates of the precursor to the principal quantum number sate n = 3 normalised to the H_a-branching ratio:

(1) $$I(r) = c \; n_e(r) \sum_j n_j(r) \; k_j \;, \quad \text{or} \quad I(r) \;/\; n_e(r) \;=\; c \sum_j n_j(r) \; k_j \;.$$

Since most H_α-emission is localised in front of the limiter and the view is tangential to the magnetic fields, the profiles correspond in a first approximation to radial profiles (as will be demonstrated later). Further, the excitation rate coefficients k_j can be considered approximately constant since they do not vary sensibly with 40 eV < T_e < 500eV for the here studied plasma edge (true within 20%). With the help of a simple 1D model, the penetration of the neutrals into the plasma were calculated, their radial velocity being a free parameter. A very good adjustment of the modelled neutral profiles with the experimental $I(r)/n_e(r)$ profile was obtained assuming two main precursors (dashed lines in figure 2): 1.) dissociative excitation of H_2 molecules producing H in the n = 3 excited state leaving the limiter surface with the thermal surface temperature of about 0.03 eV and 2.) H atoms produced near the limiter by dissociation with energies of about 0.3 eV and which are excited in a second step. These are the so called slow atoms, produced by dissociation of super excited H_2 which produces H atoms in n > 1 states and more detailed discussion on this will be presented next.

In order to confirm this result we tried to simulate the same H_α-emission profiles with the recently implemented EIRENE code. The fit between experimental and simulated profile was very good: for 12 camera chords covering the whole plasma radius the agreement was better than 10% (not shown). Once the EIRENE code was validated with the emission simulation we used the code to calculate the absolute molecular and atomic hydrogen density radial profiles in front of the limiter. These are shown in figure 3 together with the emission precursor profiles as obtained with the simple 1-D model, obtained by dividing the profiles of figure 2 by the corresponding excitation rate coefficients (see eq. 1): the direct molecular dissociative excitation to the level n = 3 for the 0.03 eV profile and the excitation of atomic hydrogen from the ground state to the n = 3 level to the 0.3 eV profile. Since the experimental data were not absolutely calibrated, the modelled profiles were first calculated in arbitrary units and than normalised to the value at r/a = 1 as obtained from EIRENE's profiles absolute values. A good agreement between EIRENE and the simple 1-D model is obtained. It should be remarked that the absolute data obtained with EIRENE strongly depend on the particle confinement time, which is an input parameter with considerable error.

Figure 4a shows the simulated molecular and atomic hydrogen density from EIRENE along a central camera line of view, the coordinate ***dist*** being the distance from the first cell defined in the TJ-II vacuum chamber far outside the separatrix and directed to the poloidal limiter (see figure 1). The normalised plasma radius r/a is also plotted, having a value of about r/a = 0.4 in front of the limiter. The vertical dotted lines represent the points where the lines of view traverse the L.C.F.S., i.e., where r/a = 1. It can be seen that the atomic hydrogen profile is peaked in front of the limiter, but the molecular profile is hollow. This is because at this radius in front of the limiter nearly all molecules have been dissociated or ionised by the plasma, while the atoms can survive due to their higher kinetic energy. Figure 4b shows the simulated H_α-emission along the same line of view. This curve demonstrates that even for ralatively central chords, the emission principally comes from the region in front of the limiter. In fact for this line of view, 80% of the light comes from the section in front of the limiter with $0.4 < r/a < 0.5$. This means that the tangential H_α-images as shown in figure 2a can be approximately regarded as poloidal cuts of the emission in front of the limiter and the vertical emission profiles as radial emission profiles (true within 20% for $r/a > 0.4$).

Conclusions

The recently implemented EIRENE code correctly simulates local H_α-emission in front of a poloidal limiter. This gives confidence on the calculated atomic and molecular hydrogen neutral distribution for the complex TJ-II geometry. The code has been used to correctly interpret the camera lines of view, imortant not only for recycling studies, but also for blob, filament structure, etc. studies. In fact, the responsible excitation mechanism and therefore the corresponding S/XB for H_α is strongly dependent on the line of view. In a next publication the most relevant dissociation, ionisation and excitation reactions involved in recycling-fuelling of hydrogen as a function of plasma radius and plasma parameters will be analysed.

References

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Figure Captions

Figure 1: *Schematic view of the camera with the tangential lines of view.*

Figure 2: *I / n_e (continuous line) and modelled H_α-emission precursor profiles with energies of 0.03 eV and 0.3 eV multiplied by their corresponding k_j (discontinuous lines) and sum of both modelled profiles (circles).*

Figure 3: *Neutral density profiles in front of the limiter as obtained with the simple 1D model (discontinuous traces) and as obtained with the EIRENE code (points).*

Figure 4:a) *Neutral density profiles of H_2 and H for a line of view passing at r/a = 0.4 in front of the limiter as calculated with EIRENE and* ***b)*** *calculated H_α- emission profile.*

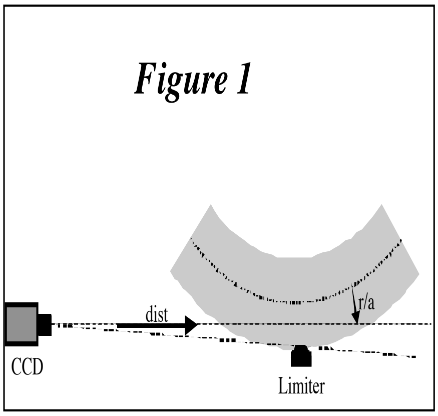

Figure 2

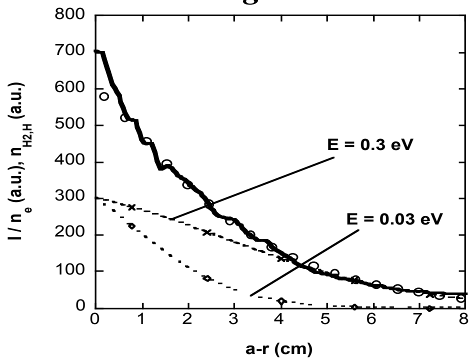

Figure 3

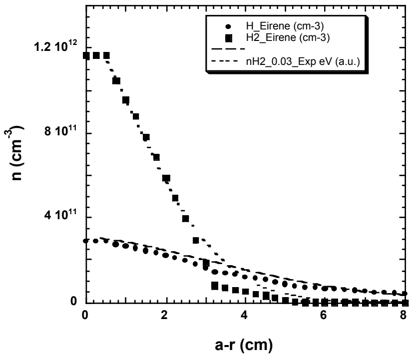

Figure 4a

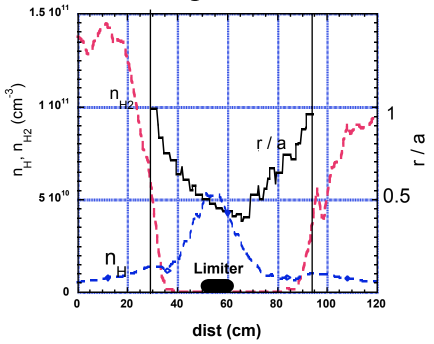

Figure 4b