Impurity transport studies in RFX-mod and MST RFPs

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Introduction

Impurity behaviour is a growing topic in fusion science studies. Radiation, transport, plasma-wall interaction and first wall conditioning are key aspects – where impurities play important roles – which need to be controlled and understood. A critical issue in a reactor perspective is the understanding of the (heavy) impurity behaviour, especially the impurity profile, and the control of the impurity peaking.

Here the results of an impurity transport study on RFX-mod and MST Reversed-Field Pinches (RFPs) are presented and discussed. In MST impurity diffusion coefficient D and pinch velocity v are obtained through reproducing experimental C^{+6} density time evolution and radial profiles with a 1-D impurity transport code [1], for both improved confinement pulsed poloidal current drive (PPCD) and standard regimes. In RFX-mod transient experiments with solid C and Li pellets have been performed. Their analysis by the impurity transport code confirms transport coefficients previously estimated for intrinsic impurities C and O.

Impurity transport in MST

Transport coefficients are estimated through comparing C^{+6} density measurements from charge-exchange recombination spectroscopy (CHERS) [2] with simulated carbon ion abundances for both standard and PPCD discharges in D plasmas.

Standard discharges in MST are characterized by quasi-continuous sawtooth oscillations. Magnetic field lines have a high degree of stochasticity and transport is therefore predominantly stochastic. Radial profiles of the fully stripped carbon are nearly flat at the equilibrium (away from sawteeth) (see Figure 1) [3]. To reproduce this impurity profile a high outward convective velocity and high central D are assumed in the simulation (Figure 2).

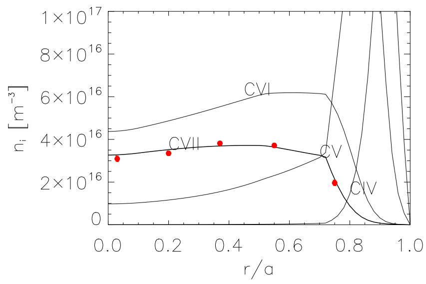

Figure 1 C IV-VII population profiles away from sawteeth computed by the transport code (lines) and C VII density measured by CHERS (red circles).

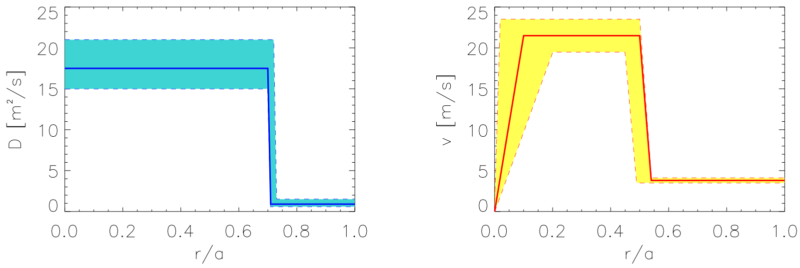

Figure 2 Transport coefficients estimated for standard discharge with uncertainty ranges indicated by the respective coloured areas.

During PPCD magnetic fluctuations are reduced, core electron temperature and confinement greatly increase [4]. C^{+6} CHERS measurements made at medium current (400 kA) PPCD discharges show that the impurity core content is decreasing after the transition to improved confinement, while, in the outer region, the density is slowly increasing (Figure 3a). The profile in the core region ($0 \leq r/a \leq 0.6$) approaches a hollow shape towards the end of the PPCD (Figure 3b) [5]. This behaviour is reproduced by the code with transport coefficients which are low and close to classical values (Figure 4) [6]. Convective velocity is outward in the core region and then reverses its direction at r/a ~ 0.7. Diffusion coefficient is lower in the core and higher in the edge region. The estimated coefficients agree within a factor lower than 2 with the classical model.

Complementary simulations of high current (550 kA) PPCD discharges are performed, reproducing density measurements of different impurity ions: B^{+5}, C^{+6} and O^{+8}. These simulations are performed using the same transport coefficients previously estimated for medium current PPCD discharge, thus implying that the impurity transport is not strongly dependent on mass/charge for species with similar Z, such as B, C and O. Instead, classically, the convective velocity increases with Z, whereas D has no dependence on the atomic number [6].

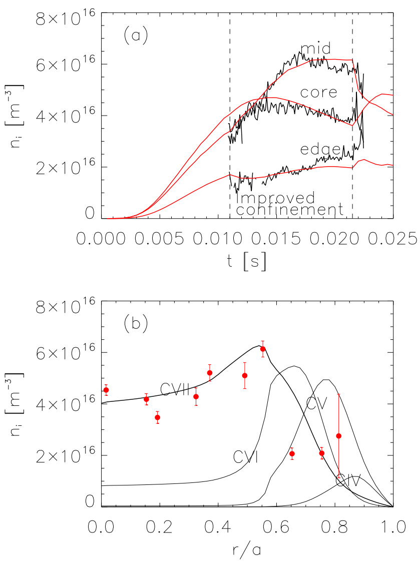

Figure 3 (a) C VII population time evolution at r/a ~ 0.15 (core), 0.55 (mid), 0.76 (edge), measured (black) and simulated (red). (b) C IV-VII population profiles at the end of PPCD computed by the transport code (lines) and C VII density measured by CHERS (red circles) with corresponding error bars.

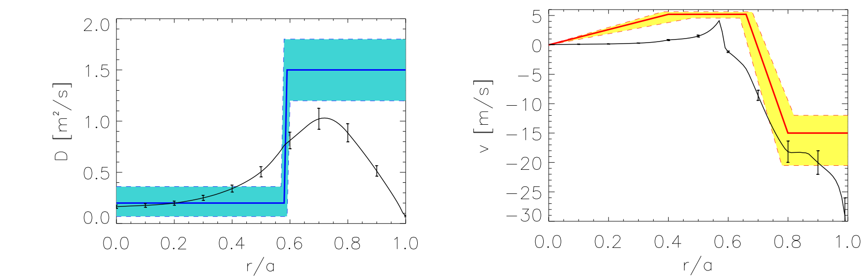

Figure 4 Transport coefficients estimated for PPCD discharge with uncertainty ranges indicated by the respective coloured areas. In black the classical coefficients with ±10% error bars.

Impurity transport in RFX-mod

In RFX-mod, past Ni Laser Blow Off and Ne gas puffing experiments in Multiple Helicity (MH) and Quasi-Single Helicity (QSH) regimes evidenced an outward convective flux in both regimes with a more effective impurity screening in the QSH case [7]; the diffusion coefficient is at least one order of magnitude greater than both classical and stochastic values [8]. The emission patterns of intrinsic impurities (C and O) in high current discharges were also simulated in MH and QSH regimes, with *D* and *v* close to those deduced for Ni and Ne [7]. In the work presented here, transient experiments with C and Li solid pellets confirm these findings.

The impurity transport code simulates the pellet ablation, through a model developed by Garzotti [9], and reproduces the enhancement in plasma emission (SXR) and electron density following the pellet injection.

C pellet injections in He discharge are simulated by varying transport parameters in MH and QSH phases, according to the periodic transitions from QSH to MH which occur throughout the discharge (Figure 5). The code well reproduces the enhancement in electron density and in the SXR emission (due to the pellet ablation) using *D* and *v* found for intrinsic impurities in RFX-mod, so confirming previous estimations based on brightness profiles of C ion lines.

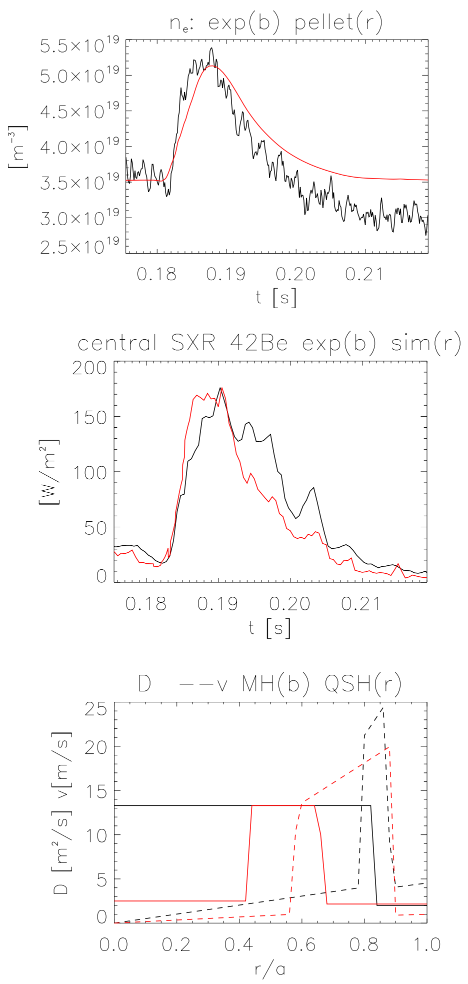

Figure 5 [Top to bottom] Experimental (black) and simulated (red) n_e and SXR emission following C pellet injection. Transport coefficients used in the simulation for MH and QSH phases.

Li pellet injections performed during lithization campaign in H plasmas [10] are also simulated (Figure 6). In this case the discharge is in MH regime after the injection because the large size of Li pellet increases the electron density beyond the QSH threshold ($n_e/n_G = 0.35$). The enhancement in electron density is well reproduced by the code, whereas the time evolution of SXR emission due to lithium ions is reproduced within a factor of two. The simulation is however satisfactory. The outward velocity used to best reproduce n_e and SXR emission results higher than for carbon.

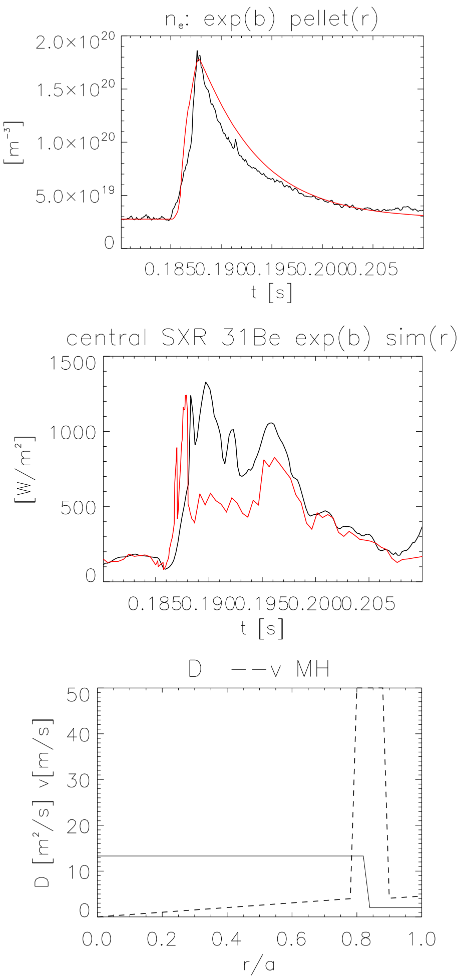

Figure 6 [Top to bottom] Experimental (black) and simulated (red) n_e and SXR emission following Li pellet injection. Transport coefficients used in the simulation for MH phase.

Conclusions

In MST standard discharge, simulations of experimental C^{+6} density are obtained with a D compatible with diffusion through a stochastic magnetic field, and a v outward and one order of magnitude lower than stochastic v. C^{+6} simulations during PPCD discharge show that transport coefficients are much lower in this regime and close to predictions from classical collision theory. In RFX-mod transient experiments with solid C and Li pellets confirm transport coefficients previously estimated for intrinsic impurities, which are not compatible with stochastic or classical expectations. However, a common feature of both RFPs is that impurity accumulation in the core is prevented during improved confinement regimes.

References

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