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Carbon impurity transport studies in the TCV tokamak using spatially resolved ultrasoft X-ray spectroscopy

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Introduction

An important topic in fusion research is the study of the light impurities transport character in tokamak plasma periphery. An identification of the impurity sources and a description of impurity behaviour play a important role in getting high temperature plasmas and at last in design of the future thermonuclear reactor. In global, analysis of particle transport is required for the explanation and predication of reactor plasma confinement.

The transport coefficients could be evaluated by measuring and modelling of the spatial and temporal behavior of the emission line profiles in different confinement regimes. It is well known, the radial distribution of the line emission density is influenced by the transport phenomena and differs from those calculated using a pure coronal equilibrium. In some tokamak plasma regimes, the ion recombination time is comparable to the characteristic time of the particle transport. This fact leads to a distribution of ionised states, which are not in equilibrium with the electron temperature, as it would be expected according to the coronal model. The broadening of the radial profile for each ionised species is the typical effect of transport phenomena and can be examined by radial profile measurements of the intensity of the selected line.

Carbon transport studies using 4-channel USX multimonochromator

The TCV tokamak is equipped with a 4-channel ultrasoft X-ray (USX) multimonochromator based on use of multilayer mirrors. Recently the instrument was refurbished and new oriented to allow measurements of radial profiles of the CV (308 eV) or CVI (368 eV) line intensities in specially designed discharges. In the usual TCV plasma configurations, the four channels of the USX monochromator span only 40 % of the plasma radius at the outboard side and there is normally no chord passing just inside the plasma edge where the line radiation profile depends most strongly on position.

Fortunately, the shaping capabilities of the TCV tokamak allows us to slowly compress a plasma towards the HFS inner wall, thereby sweeping the low field side flux surfaces across

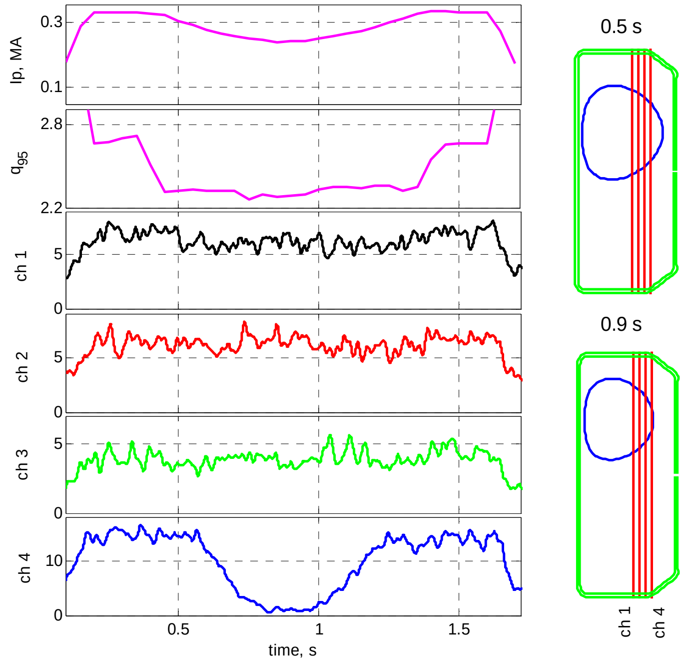

Fig 1. On the left: plasma current, edge safety factor and time traces from digital counters of USX in TCV discharge #24429. On the right: contours of LCFS (blue) and the position of the USX chords (red) before compression and after maximum compression.

the USX viewing lines with good spatial resolution in a single discharge. Such experiments were performed in several Ohmic L-mode limited discharges with plasma currents I_p ranging between 130kA and 300kA, line averaged electron densities in the range $2.10^{19} \le <n> \le 4.3\cdot10^{19} m^{-3}$, central electron temperatures about 700-1100 eV, average elongation κ~1.25 and average triangularity δ~0.25. The plasmas were compressed by some 10% of plasma crossection while keeping q_{95} constant. An example of temporal behaviour of current, safety factor and signals from digital counter of USX in the discharge with $<n_e>$~$3\cdot10^{19}$ m^{-2} is shown in Fig. 1. All four channels measured CV radiation at 308 eV. The contours of last closed flux surfaces (LCFS) before the start of the compression and final LCFS contour at the end of the compression, when the plasma current is minimal, are shown in Fig. 1, at the right. The vertical lines indicate the lines of sight of the multimonochromator. During the 300 ms of compression, each channel scans about 4 cm in the radial direction, resulting for the four channels in 80% coverage of the distance from the plasma centre to the low field side edge. It is seen that at the end of the compression the plasma edge is resolved up to the LCFS and the signal of the detector closest to the edge drops practically to zero.

In order to derive a steady state profile of line emission, the main plasma parameters such as profile of the density and plasma safety factor at the edge were kept constant during the compression. It was assumed that current changes during the compression do not significantly affect the impurity transport parameters as long as edge safety factor remains constant [1].

Due to the relatively small distance between channels, plasma positions as measured by the poloidal flux based normalised minor radius $\rho_{\text{pol}} = \sqrt{\psi / \psi_{LCFS}}$, seen by one channel in the

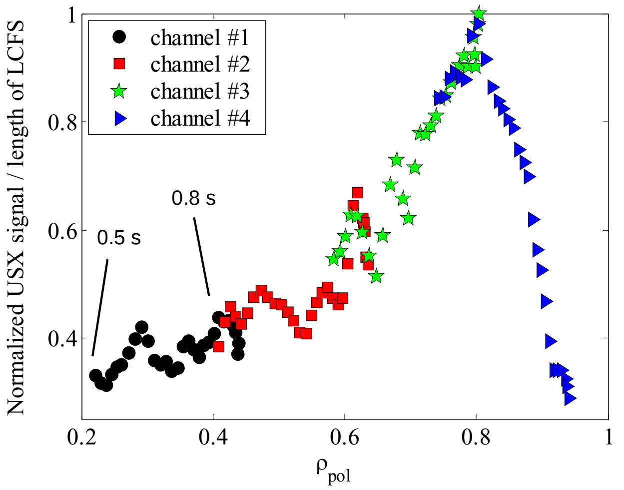

Fig 2. The resulting normalized profile of line emission obtained from USX measurements at 308 eV (He-like carbon) and mapped on the ρ_{pol} grid. The numbers on the graph correspond to the times of measurement for channel 1 (black dots) at the start and at the end of the sweep.

beginning of the compression pass in front of the neighbouring channel at the end of the compression. This overlap allowed us to make a relative calibration of the channels, linking the values of the signal at different stages in the compression. It is essential for such a cross-channel calibration that the total impurity concentration during the compression remains constant. This was indeed ascertained using Z_{eff} derived from soft x-rays. To correctly connect the signals from neighbouring channels one should also take into account the changes in integration length during the sweep. To do so, signals from each channel were renormalised by the corresponding path length inside the LCFS at each time.

The resulting normalised profile obtained from USX measurements at 308 eV, mapped onto the ρ_{pol} coordinate, is shown on the Fig. 2. The profile shown above was deemed to represent a steady state line integrated emission profile of CV and was used to obtain carbon transport parameters by means of the STRAHL code [2].

The background electron temperature and density profiles used in the simulations were taken form the Thomson scattering system and mapped onto the ρ_{pol} grid using the equilibrium code LIUQE. Modelling included profiles of D and υ as a function of ρ_{pol} as input parameters to the transport code and the line brilliance as an output. The line emission profiles from the simulation were then mapped onto the real discharge geometry and integrated along each USX chord. Line integrals were normalised to the corresponding chord length in order to keep the same procedure as for the experimental profile on Fig. 2. The resulting profiles were compared with experimental ones in order to find the D and υ which give the best fit.

In Fig.3 (left) the experimental profile of integrated line emission measured by USX (dots) is plotted together with the simulated one (line) showing a good agreement between

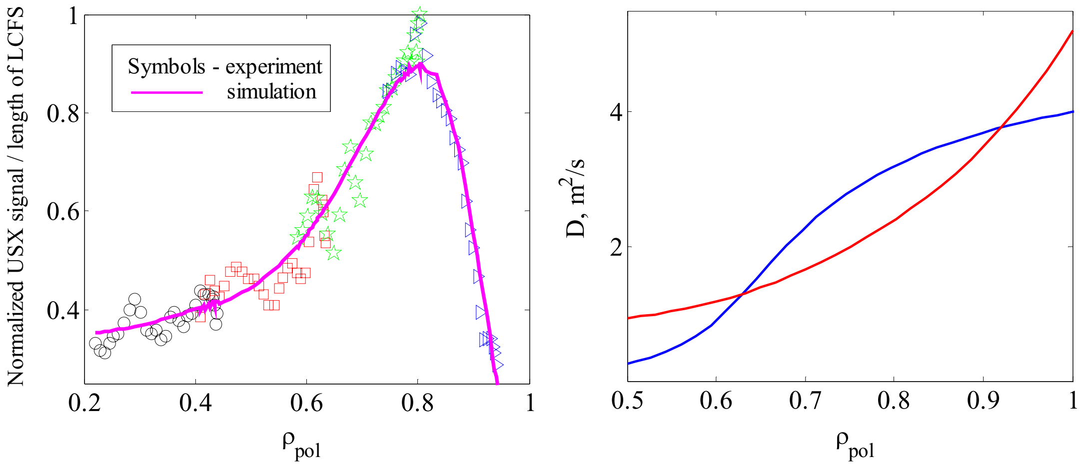

Fig 3. The experimental profile measured by USX (dots) is plotted together with the simulated one (line). The same result is obtained by both profiles of diffusion coefficient shown on the right.

experiment and simulation. The examples of radial profiles of the diffusion coefficients used in simulations are shown in Fig.3 on the right. It was found that there is a range of profiles of the diffusion coefficient, which give a good fit to the final profile of integrated line emission.

Discussion

The 4-channel ultrasoft X-ray (USX) monochromator on TCV was modified for radial emission profile measurements in specially designed radially swept discharges. The results show that the line integrated radial emission profiles provide a significant constraint for determining the diffusion coefficient in the outer part $\rho_{pol}>0.6$ of the discharge. A series of discharges in different conditions show that there is no simple proportionality between the Carbon ion diffusion coefficient and the effective heat diffusivity [3]. The currently used instrument was only intended as a feasibility demonstration and is not adapted for routine measurements of ionisation balance.

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