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Oxygen impurity profile studies in the EXTRAP T2R reversed field pinch

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I. Introduction

The medium sized reversed field pinch (RFP) EXTRAP T2R [1] has an all metal first wall in contrast to the more common graphite wall found in devices like the RFX reversed field pinch and the previous EXTRAP T2. Recent comparisons of bolometric data [2] between EXTRAP T2R and RFX have suggested very different radial profiles of impurity emission. Oxygen is the main intrinsic plasma impurity in EXTRAP T2R and the vacuum ultra violet (VUV) spectrometer data shows strong emission from OV and OVI.

A radial 5-channel, 0.5 m, Ebert grating spectrometer has been modified and calibrated for use on EXTRAP T2R. It is possible to reconstruct the emission profiles from measurements along several different lines of sight by a technique commonly known as tomography. If the emission is expected to be poloidally symmetric it is possible to make certain simplifications and the reconstruction can be done by Abel transformation [3] or by emission function fitting. Knowledge of impurity profiles is important for modelling and understanding of plasma transport properties as well as the general plasma understanding. In addition to measurements, the impurity emission and density profiles have been computed with an OSCR (Onion Skin Collisional Radiative) model constrained with the finite confinement time of particles. The OSCR code has a small number of free parameters of which all but one are partially set by measurements or external self-consistent codes. This is particularly appealing to experiments with limited spatial information of plasma parameters.

II. Experimental

Oxygen line emission from OII (395.4 nm), OIII (377.4 nm), OIV (338.6 nm), OV (278.1 nm) and OVI (529.1 nm) has been studied along five lines of sight (LOS) for a series of discharges (#18333-#18360). The spectrometer previously used on EXTRAP T2 [4] has been modified and recalibrated for this use. In the new configuration the five LOS partly intersect and also measure further out towards the edge (the impact parameters are 0.0, 0.21, 0.41,

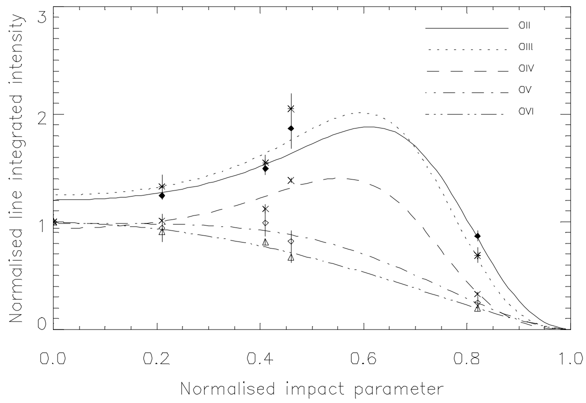

Fig 1. Spectrometer line integrated intensity.

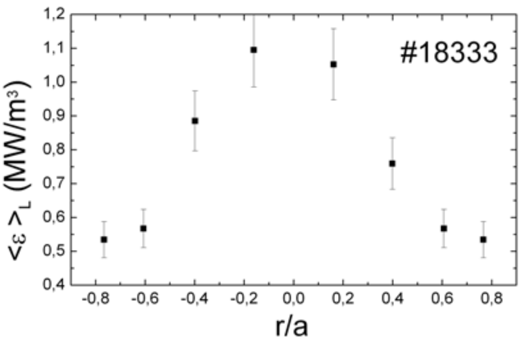

Fig 2. Bolometer line-averaged emissivity

0.46 and 0.82). The absolute intensity calibration was performed with an integrating sphere in the visible (300-750 nm) and a deuterium lamp in the ultra-violet (230–400 nm). The measured line-integrated signals (averaged 2 - 12 ms) from the spectrometer for different oxygen ionisation stages during standard EXTRAP T2R discharges (80kA, T_e=230 eV, n_e=0.4*10^{19} m^{-3}) are shown in figure 1. During the same series of discharges measurements were also taken from a 8-chord bolometric system and a VUV spectrometer. These data together with main plasma parameters are essential as input to the OSCR model. The VUV spectrometer is absolute intensity calibrated and the density of OVI ions was determined to be 1.2*10^{11} cm^{-3} for the discharges. Experimental data from the bolometers shows a peaked emissivity profile (figure 2) and a total radiated output power of 0.7 MW.

III. Modelling

Reconstruction of the emission profiles has been performed following two approaches, Abel inversion (Eq. 1a) and emission function fitting (Eq. 1b).

$$\varepsilon(r) = -\frac{1}{\pi}\int_r^a \frac{dI}{dy}\cdot\frac{dy}{\sqrt{y^2-r^2}} \qquad \text{(Eq.1a)}$$

$$\varepsilon(r) = C_1 \cdot e^{-\left(\frac{r-c_2}{c_3}\cdot(r+0.25)\right)^2} \cdot \left(1-r^4\right) \qquad \text{(Eq. 1b)}$$

Although both gave similar results the emission function fitting of the free parameters c_1, c_2 and c_3 was generally more stable. Several emission functions could come in question but the chosen

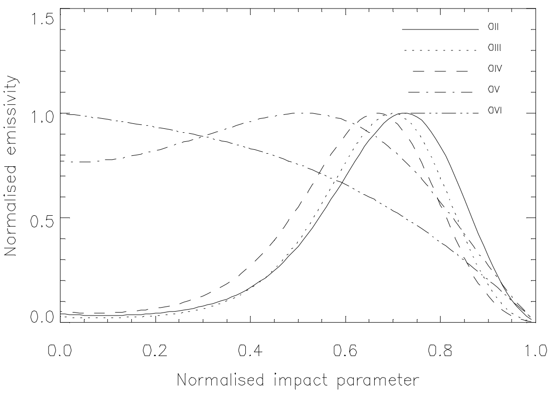

Fig 3. Reconstructed emission profiles

profile was found to generally give good fitting. The reconstructed emission profiles are shown in figure 3. The emission from OV and OVI come from a large part of the radius. Lower ionisation stages (OII, OIII, OIV) are found emitting closer to the edge but still over an appreciable part of the radius. The temperature and density dependent rate coefficients, q_{1j}, are a necessary knowledge for the transition from emission to ion density profiles as seen from the equation below. The atomic data of the radiative transitions in question was determined using the Atomic Data and Analysis Structure (ADAS).

$$\varepsilon_{z,i,\lambda}(r) = n_{z,1}(r) \cdot n_e(r) \cdot q_{1i}(T_e(r), n_e(r)) \cdot \frac{A_{i\lambda}}{\sum_j A_{ij}}$$

The electron density and temperature profiles have been modelled for EXTRAP T2R using interferometer and Thomson measurements. The OVI line is populated by charge exchange from OVII and is treated separately. The OSCR model has recently been used to model the plasma emission at T2R, including both bremstrahlung and line emission to account for the total power received by the bolometers [2]. The model use input data from a VUV spectrometer to fix the amount of OVI in the plasma and use data from ADAS to calculate a plasma *coronal equilibrium* at each spatial position (onion skin) in the plasma. The recirculation of neutral particles as well as their penetration into the plasma is modelled by EDCOLL, a plasma-wall interaction tool, modified to take into account the metal wall. The overall density of oxygen is modelled as constant along the radius and the only free parameter is the particle confinement time, which is poorly known at T2R but expected to be in the range of 100-400 μs. The overall power output calculated by the model is compared to the measured bolometric signal. With a confinement time of 250 μs the model predicts 0.17 MW radiative output power which is a factor 4 lower than the measured value. However, it does manage to model the peaked shape of the radiated power. The ion density profile simulated by the OSCR model is shown in figure 4 and should be compared to the reconstructed density profiles in fig 5.

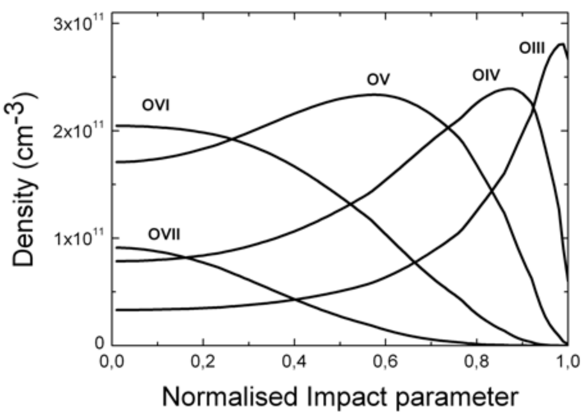

Fig 4. OIII, OIV, OV, OVI and OVII profiles computed with OSCR

IV. Discussion

Both simulation and measurement yield broad density profiles and show that OV and OVII ions are expected to exist at the core. The model predicts a somewhat higher concentration of

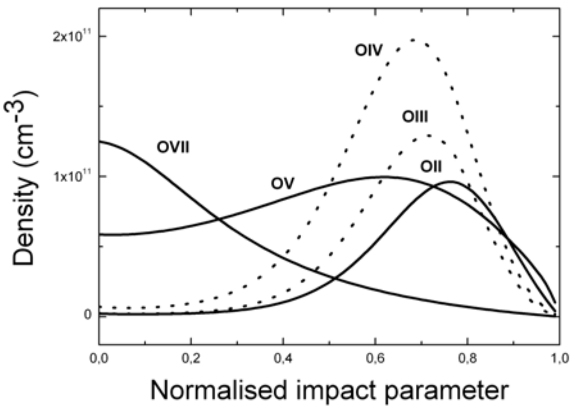

Fig. 5 Ion density profile of OII, OIII (dotted), OIV(dotted), OV and OVII.

OII and OV than is measured. OIII and OIV (dotted lines) have been reduced by a factor 8. The reason behind their high values are yet unknown. The shape and position of the density peak in OV is well correlated. The profile as well as the magnitude of OVII is also well in agreement. The OII and OIII peaks are closer to the edge in the model, and the measured profiles are possibly not accurate this close to the edge. This could partly be explained due to having only one channel with impact parameter>0.5. These results are in contrast to measurements done using the same diagnostic on the previous EXTRAP T2 [5] where a hollow profile was obtained for OV. This difference could be caused by a much larger penetration of neutral particles. The correlation between the two diagnostic methods adds more evidence of the OSCR model's potential in experiments such as EXTRAP T2R where plasma parameters are measured with a limited number of radial channels. The OSCR model fails to account for all the power in the bolometer signal, although the radial shape of the radiated power is similar. The unaccounted radiated power can partly be explained as coming from line emission from metals like Cr, Mo, Fe and Ni. Metals have this far not been included in the OSCR model since they only recently have been observed on EXTRAP T2R. Strong emission lines from neutral metals have been observed in the visible wavelength region by a 1.0 m VIS-spectrometer and in the VUV region lines believed to originate from highly ionised metals have been seen by the VUV-spectrometer. The determination of the ion density and emission profiles on EXTRAP-T2R has already helped to advance the understanding of other plasma properties such as ion flow velocities [6].

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