RELATION BETWEEN LOW Z IMPURITY POLOIDAL EMISSION PROFILES AND TRANSPORT IN TORE SUPRA ERGODIC DIVERTOR PLASMAS

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1. Background

The Tore Supra grazing incidence VUV spectrometer (duochromator) provides poloidally resolved brightness profiles of emission from peripheral light impurity ions, scanning the lower half of the plasma with a 3 cm spatial resolution [1]. Such profiles should provide, when inverted, radial impurity profiles complementary to those measured with charge-exchange spectroscopy, and thus permit analysis of transport properties. However, the duochromator profiles exhibit a very complex spatial structure during ergodic divertor (ED) operation. The observed profiles clearly have both core plasma (symmetric) and scrape-off layer and ergodic zone (asymmetric) sources, requiring a somewhat complicated inversion. Our approach is to simulate the observed profiles: the axi-symmetric contribution with a 1D radial impurity transport code and the asymmetric component with the BBQ 3D Monte Carlo code. This approach has proven more illuminating in practice than the alternative Maximum Entropy fitting procedure. An example for Tore Supra outboard limiter conditions is discussed in [2]. Here we apply the technique to Tore Supra ED discharges positioned close to the inner wall. The profile behavior in this configuration shows regular modulations clearly related to the applied ED field; simulation of the signals should therefore provide information about its effect on impurity transport. We briefly summarize the main observations, the elements of the simulation, and the comparison of the simulations with the measurements.

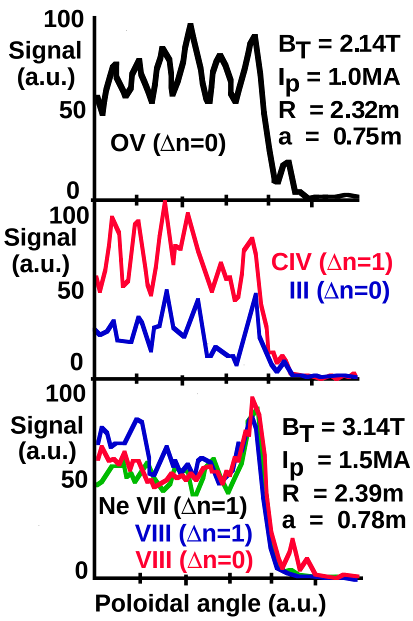

FIG. 1 Observed poloidal duochromator profiles of oxygen (OV, top) carbon (CIII, CIV, middle), and neon (NeVII, NeVIII, bottom) emission with ED (I_{ED}=45kA).

2. Observations

Previous observations of inner-wall influenced Tore Supra ED plasmas, under detached (MARFE-like)

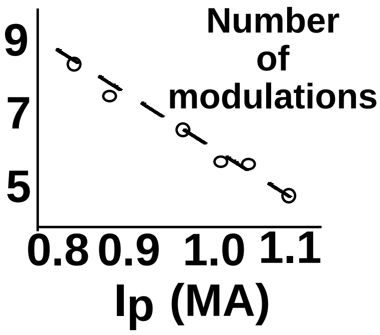

FIG. 2 Variation in number of oscillations in duochromator poloidal profile with I_p, for I_{ED}=45kA

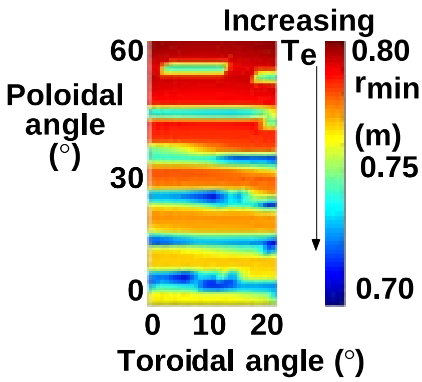

FIG. 3 MASTOC calculation of the poloidal and toroidal distribution of the minimum minor radius linked to observation volume (r_{min} , thus T_e) at the inner wall location.

conditions, showed strongly modulated carbon and oxygen poloidal profiles varying coherently with the safety factor (q), but only for Δn=1 (i.e., T_e-dependent) emission lines [3]. The conclusion was drawn that this was evidence of T_e-modulations due to the well known connection provided by the ED to the hot core region, and that modulation in the impurity density profile by the ED did not play an important role. New observations have been made for inner wall configurations under lower density, attached, conditions. As with the previous MARFE-like cases, systematic modulation of the poloidal profiles is observed, on low-Z peripheral impurities (carbon, oxygen and neon), figure 1. The number of modulations is well correlated with q (Fig. 2). However, in this case, novel features are observed: (1) for the modulations to occur, the clearance between the last closed flux surface and the inner wall (Δ_{IW}), calculated without ergodic divertor current (I_{ED} =0), must be less than 0.06m; (2) the modulations are observed on emission lines with both Δn=0 and 1 (i. e., the T_e sensitivity is reduced or absent); (3) the modulation does not depend as sensitively on the radial position of the emitting impurity; and (4) modulations are seen on emission from ions with a relatively large ionization potential (NeVII and VIII) whose radial position is at the inner limit of the ED layer. Thus the interpretation fitting the observations in MARFE-like conditions [3] requires modification for these new conditions.

3. Simulation models

The BBQ 3-D scrape-off layer impurity transport code has been modified to study this problem. An ED background plasma model originally developed to treat the ED neutralizer plate region [4] has been extended to calculate the impurity distributions in an annular region bounded by the inner and outer limits of the ergodic zone (0.65<r<0.8 m) and by the poloidal and toroidal angular limits of the zone viewed by the duochromator. The background plasma parameters (3D spatial distributions of n_e, T_e and magnetic field **B**) are calculated in this annular region with a suitably modified version of the MASTOC mapping procedures [4].

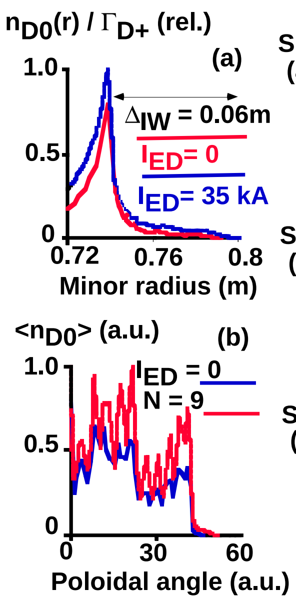

FIG 4. (a, top) BBQ calculation of radial neutral deuterium density with and without edge T_e profile due to ED; (b, bottom) neutral density averaged over duochromator sight lines with no ED and with a background plasma with 9 poloidal modulations in the T_e profile.

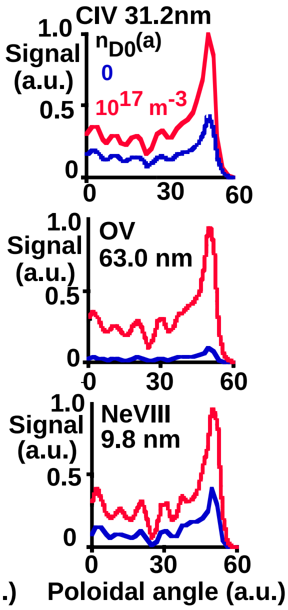

FIG. 5 Simulated poloidal profiles of carbon (a, top), oxygen (b, middle) and neon (c, bottom) emission for cases with n_0=0, and with $n_0 = 10^{17}\,m^{-3}$

Neutral deuterium density distributions are also required in this region, and the same background plasma model is used with a deuterium version of BBQ.

4. Profile simulation: CX effect

Early Tore Supra outer limiter particle exhaust studies showed a strong plasma interaction with the inner wall when Δ_{IW} < 0.1m. Comparison of inner wall heat fluxes with observation also found large scrape-off layer decay lengths (λ_Γ~ 0.05–0.1m)[5]. Significant inner wall deuterium recycling thus occurs under these conditions, such that the effect of charge exchange with neutral deuterium on impurity emission profiles is important. Charge exchange cross sections for carbon and oxygen have been known for some time to affect the ionization balance, and a detailed model for carbon and oxygen charge exchange processes is now available [6, 7]. Although charge exchange rates are not available for neon, magnitudes are expected to be similar. Further, the details of inner wall construction (faceted graphite blocks, tangent to the plasma minor radius at only one point) provide another possible source of periodic modulation, through modulation of the charge exchange rates. The BBQ deuterium transport code is used to calculate this effect. Calculations with the MASTOC field line following code show that the poloidal distribution of T_e at the inner wall should also be modulated when I_{ED} > 0 (Fig. 3). The incident D^+ flux on the inner wall is therefore modulated via the sheath potential, leading to modulated deuterium density in the plasma. Further, T_e is reduced in the ergodic zone, increasing the ionization path length for recycled deuterium neutrals. Ergodic zone T_e profiles similar to those measured for I_{ED}=35kA [8] are used in the simulation. The radial deuterium atom density, and neutral density averaged over the duochromator sight lines (BBQ deuterium model calculation) is shown in Fig. 4a, b. There can be an interference effect between the modulation due to faceted tiles and the systematic variation with I_{ED}. However, even in cases with an incoherent poloidal modulation, a strong

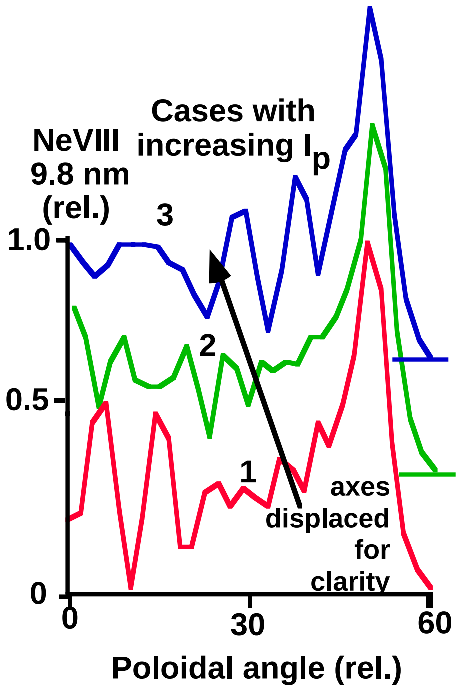

FIG. 6 Simulated poloidal profiles of NeVIII, emission vs I_p (see Fig. 2) with ED (I_{ED}=45kA).

neutral deuterium density is present in the ergodic zone. Figure 5a,b,c shows calculated modulation in carbon, oxygen and neon lines from the BBQ simulation. Figure 6 shows a simulation of the variation of the number of modulations with I_p. Background 3-D distributions of T_e and n_0 are modulated using the relation between poloidal mode number and I_p [3].

5. Conclusions

Reviewing the novel observed features: (1) Simulation suggests that profile modulation is indeed related to modulations of T_e, but also of the neutral density, which is important in the ergodic zone precisely under these conditions (Δ_{IW}< 0.06m). (2) Modulations occur with both Δn=0 and Δn=1 lines, because, besides the local T_e, neutral charge exchange also modulates the ionization stage. (3) The modulation does not depend as sensitively on the radial position of the emitting impurity, since T_e in the ergodic zone is relatively flat with I_{ED}>0, and the charge exchange rate also helps to determine the ionization stage. (4) Modulations are seen on emission from ions with a relatively large ionization potential because charge exchange increases the apparent ionization potential of impurity ions, leading to the appearance of emission from NeVII and VIII. A direct line-by-line fitting simulation is thus feasible, even in this complex situation, and can provide information about the underlying transport.

References

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