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A Possible Explanation for Doubly Peaked Profiles at the Divertor Target in JET

A V Chankin[1], G Corrigan, S K Erents, G F Matthews, J Spence, P C Stangeby[2].

EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxfordshire, OX14 3DB, UK.
[1]Russian Scientific Centre "Kurchatov Institute", Institute for Nuclear Fusion, Kurchatova sq.46, Moscow 123182, Russia.
[2]University of Toronto, Institute for Aerospace Studies, Ontario, M3H 5T6, Canada.

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ABSTRACT

Doubly peaked target density profiles have been obtained in the EDGE2D modelling of JET plasmas with drifts included. Their appearance is related to the divergence of the radial E×B drift particle flow along the surface of the target. The modelling results may provide a possible physical mechanism for doubly peaked target profiles observed earlier in some JET experiments.

1. INTRODUCTION

An observation of doubly peaked target profiles has been previously reported at JET [1,2] in JET Mark I divertor configuration on the horizontal target in discharges with normal toroidal field (B_t) direction. Figure 1 replicates the original figure from [1], for an Ohmic density ramp discharge. The second peak appeared during the transition from low recycling to high recycling regime, and then gradually disappeared during the detachment. EDGE2D calculations without drifts could not reproduce this feature of the profiles. In the EDGE2D modelling with drifts included, however, doubly peaked profiles could be obtained. The present paper presents one particular example and provides the physical interpretation of an EDGE2D solution exhibiting doubly peaked feature of the target profiles.

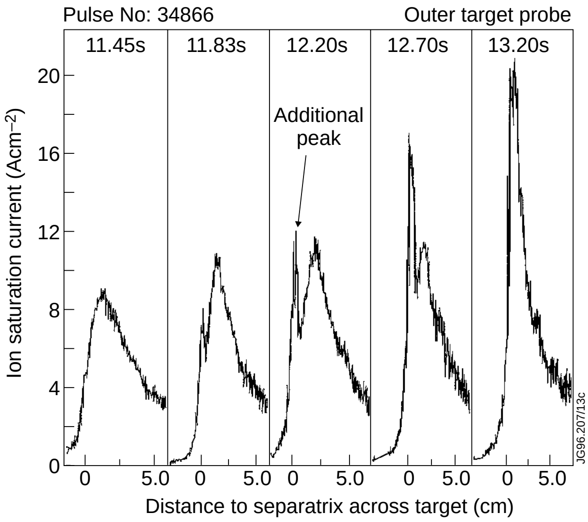

Fig.1: Ion flux profiles at the outer target showing the growth of the additional peak as the density is increased during an Ohmic discharge. Replicated from ref. [1].

2. EDGE2D MODELLING WITH DRIFTS

The main equations of the EDGE2D code with drifts have been reported in [3]. Numerical solutions of the drifts implemented into the code are based on guiding centre equations. Boundary conditions at the targets, set at the entrance to the magnetic pre-sheath, are also modified by inclusion of the contribution of the poloidal E×B drift, in accordance with [4]. Some results of the modelling of JET experimental data have been reported in [5-7]. Although only a pure hydrogen/deuterium version of this code has been realised so far (with the radiated power inside the

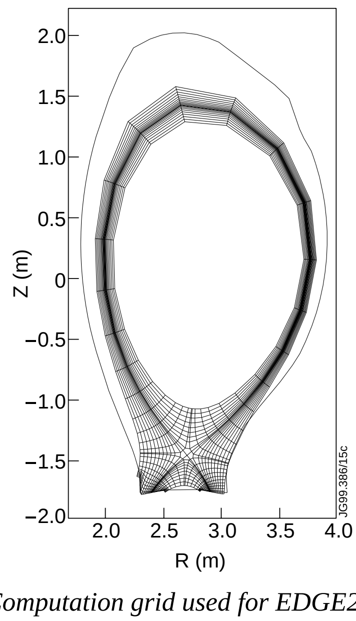

Fig.2: Computation grid used for EDGE2D cases.

computational grid calculated according to [8]), the code has demonstrated its ability to satisfactorily match experimental target profiles simultaneously for both (normal and reverse) toroidal field (B_t) directions (see e.g. [6,7]).

The computational grid used for running EDGE2D cases with drifts is shown on Fig.2. The detailed mapping out of the input parameter space of the region where such profiles are observed has not been done yet. In this paper, an analysis of the distribution of plasma parameters in the divertor, near the target, has been performed for the case with 6 MW of input power into the grid, shared equally between ion and electron channels, radiated power of 2 MW and separatrix density $n_e=1.2\times10^{19}m^{-3}$. Transport coefficients, constant in the magnetic flux space, were used with values at the midplane: $D_\perp=0.1\ m^2s^{-1}$, $\chi_e=\chi_i=0.5\ m^2s^{-1}$, pinch velocities $V_{pinch}=3\ ms^{-1}$ and $0.5\ ms^{-1}$ in the SOL and core, respectively. This has previously been analysed in [7]. Target profiles of n_e, T_e, target electric current density j_{target} and power flux, P_{target}, which includes recombination power, are presented in Fig.3, replicated from [7]. Density asymmetries introduced by the drifts are accompanied by T_e asymmetries, with the plasma being much cooler at the inner target in the normal B_t case, consistent with direct experimental observations, as pointed out in [7].

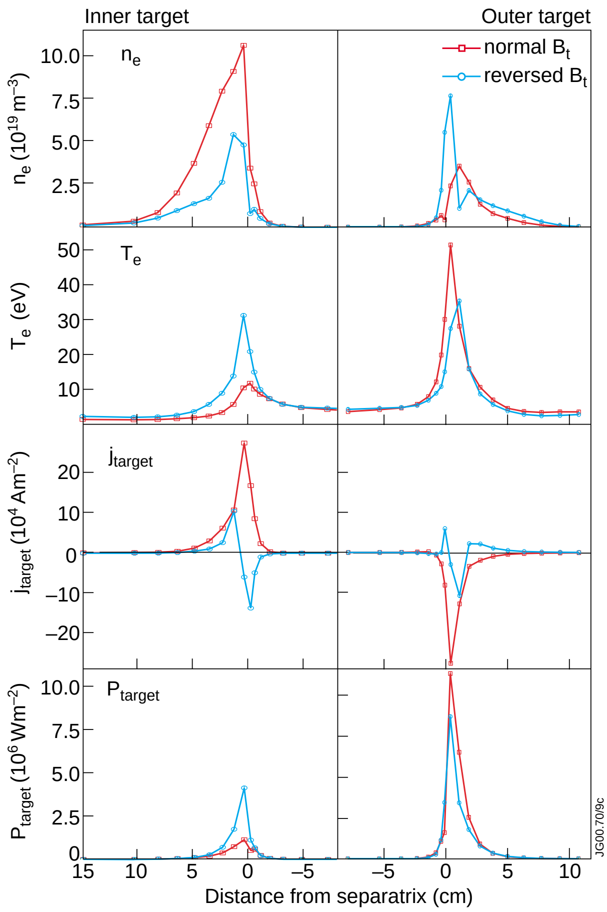

Fig.3: n_e, T_e, target current and power density profiles for normal and reversed B_t cases. Replicated from ref. [7].

3. MECHANISM FOR THE FORMATION OF DOUBLY PEAKED PROFILES

The origin of dips on the n_e profiles becomes clear from Fig.4, where radial profiles of the parallel electric field $E_{||}$ at the outer target are plotted alongside density profiles, for the same cases as on Fig.3. The sign of $E_{||}$ is indicative of the sign of the poloidal electric field E_θ, which creates radial E×B drift of plasma particles directed mostly along the target surface. Parallel electric field can be determined from the parallel Ohm's law:

$$eE_{||} = ej_{||}/\sigma_{||} - \nabla_{||}p_e/n - \alpha\nabla_{||}T_e \qquad (1)$$

where the last term on the r.h.s. describes the electron thermoelectric force, with the coefficient α being of the order unity (0.71 for singly charged ion plasmas). Under the simplified conditions with no parallel currents and constant electron pressure along the field lines, $E_{||}$ is determined only by the parallel T_e gradient. The poloidal electric field $E\theta$ must then be negative, pointing towards the outer target, as is the case for the majority of the rings along the target on Fig.4. One would then expect inward (with respect to the major radius) shifts of the density profiles in normal, and outward – in reversed B_t plasmas. The shifts in n_e profiles on Fig.4 are rather exactly the opposite, owing to the "inversion" of $E_{||}$ (and $E\theta$) at a number of rings near the separatrix position. The dips in the n_e profiles occur near rings where the direction of $E_{||}$ and, hence, of the radial E×B drift, changes in such a way (inward – for inner rings and outward – for outer rings) that it effectively creates particle sinks.

The $E\theta$ "inversion" at the target near the separatrix position can occur due to both current flow and the rise of the electron pressure near the target. The mechanism for the latter is more general and is explained on Fig.5, for the 1st ring outside of the separatrix for normal B_t case. This figure shows plasma parameters profiles against poloidal distance from the target upstream up to the X-point position. Owing to the large local ionisation source, the density exhibits sharp rise near the target. At the same time, T_e stays relatively constant due to high parallel heat conduction (while T_i shows a much steeper drop due to both ionisation and charge-exchange).

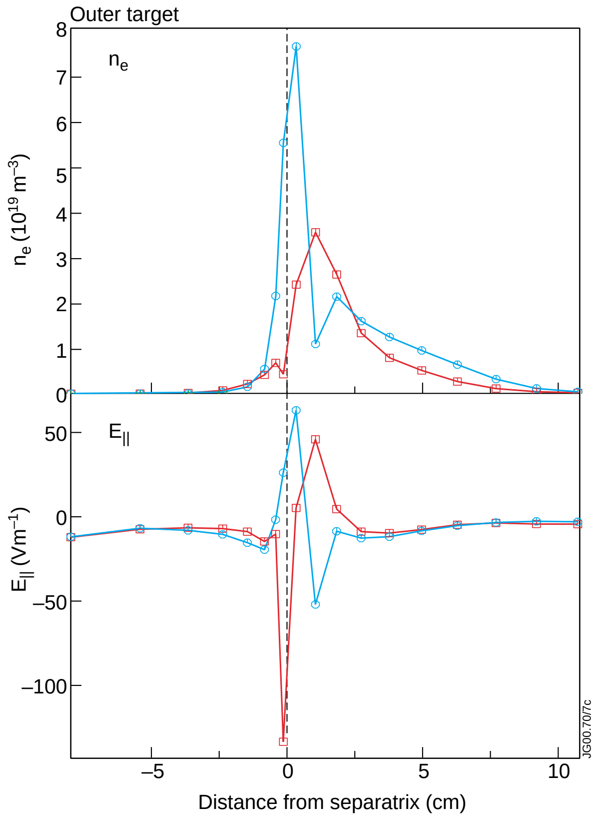

Fig.4: Target profiles of n_e and parallel electric field ($E_{||}$) near the outer target, for the cases with all drifts switched on and both B_t directions. Positive values for j_{target} correspond to the current flow into the target.

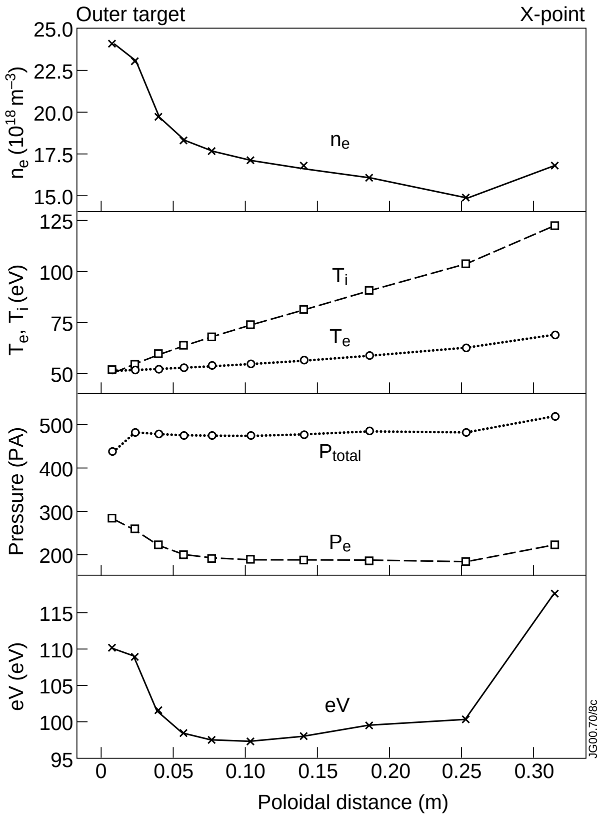

Fig.5: Poloidal profiles of n_e, T_e , T_i, electron pressure p_e, total pressure p_{total} (defined as the sum of ion and electron static, ion non-hydrostatic and ion dynamic pressures), and electric potential V (eV is plotted), for the 1st ring outside of the separatrix, for the case with all drifts switched on in normal B_t direction.

Consequently, electron pressure p_e rises near the target causing the "inversion" of $E_{||}$, as can be seen from the electric potential profile. Since the poloidal position of the "inverted" $E_{||}$, ~5 cm wide near the target, embraces the zone of maximum plasma density, the effect of the "inverted" radial E×B drift in this zone can have a significant impact on the target density profiles. Also shown on Fig.5 is the total pressure, which includes ion and electron static, ion non-hydrostatic (viscous) and dynamic pressures. This pressure shows a drop near the target due to the momentum exchange with neutrals. In some EDGE2D cases, the rise of the total pressure near the target was observed, due mainly to the perpendicular transport of the parallel momentum from one ring to the other, again, mainly by the radial E×B drift.

The role of E×B drifts in the formation of the doubly peaked structure of the profiles has been confirmed by separate EDGE2D runs with these drifts being switched off in the SOL (leaving only ∇B and centrifugal drifts there). Only usual singly peaked profiles could be obtained under such conditions [7].

The above explanation for the origin of doubly peaked profiles requires two conditions. The plasma must be in high recycling regime where the ionisation source near the target is important. At the same time, electron temperature must be sufficiently high for the parallel heat conduction to be effective in maintaining relatively flat T_e profile, providing conditions for the p_e rise towards the target. These two conditions may come in conflict with each other, either in very low density plasmas, where the ionisation source near the target may be insufficient, or in very high density plasmas, where T_e and T_i are both low and equal to each other due to equipartition, and both p_e and p_i drop towards the target.

4. CONCLUSIONS

EDGE2D modelling of JET plasmas with drifts included have produces doubly peaked target density profiles. E×B drifts were found responsible for the appearance of such profiles at the outer target. Dips in the density profiles were found at the positions where the divergence of the radial E×B drift near the target created net particle sinks. Changes in the direction of the radial E×B drift along the target are related to the changes in the sign of the poloidal electric field E_θ (due to the changes in the sign of the parallel field $E_{||}$). The "inversion" of $E_{||}$ near the target (with the expected direction, caused by the electron thermoelectric force, pointing towards the target) may take place in medium density plasmas near the separatrix position, due to the existence of parallel currents and electron pressure rise near the target. The latter is caused by strong ionisation (resulting in n_e rise towards the target) in the presence of relatively flat parallel T_e gradients. Such explanation requires both high recycling and high T_e. It may provide a possible explanation for the earlier experimental observation of the doubly peaked target profiles in JET.

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