

Edge transport analysis of JET H-mode discharges and the possible influence of radial drift velocities

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Introduction

The edge plasma transport under H-mode conditions varies considerably within radial scales of a few mm due to the presence of the Edge Transport Barrier (ETB). While the radial ion fluxes can be described within a fluid model and the use of appropriate transport parameters (D , v), the fact that ions are neutralised at the walls and re-released as neutrals requires to address neutral transport as well. If radial ion fluxes originate from the region outside the separatrix, the neutral backflow produced at the wall may penetrate inside the separatrix and cause a coupling of these regions. This effects the pedestal temperature and density, determining plasma conditions even up to the center for conditions of stiff temperature profiles. This paper describes the edge transport analysis of well diagnosed H-mode discharges performed over the JET experimental campaigns C1-C5 using the EDGE2D/NIMBUS fluid/Monte Carlo code package [1]. Special emphasis is placed on the fast transport region extending in the scrape-off layer (SOL) outside the ETB towards the wall. Radial particle fluxes in this region may be partly caused by intermittent events [2] and are connected to flattening of the density profile in the outer SOL and strong wall recycling [3] [4]. A parameter study comparing EDGE2D predictions with actual measurements investigates the significance of the radial ion fluxes and their impact on the edge profiles from pedestal to the wall boundary.

Modelling the radial structure of the H-mode edge

Fig. 1 compares EDGE2D calculations with T_e (edge LIDAR), n_e (Lithium beam diagnostic, edge LIDAR) and T_i (CXRS) mapped to the outer midplane for a JET H-mode discharge. ELM-averaged conditions are considered. The transport coefficients χ , D and an additional convective term v for the particle transport have been parametrized in 2 radial steps as suggested by the analysis of edge Thomson scattering measurements with high spatial resolution in ASDEX Upgrade [4]: the ETB characterised by a very low diffusivity starts about 1.5 cm inside the separatrix and extends about 1 cm into the SOL. The high transport in the outer SOL is approximated by an outward pinch velocity. The code calculations are matched to various experimental data. The gas puff used in the code is set to the steady state situation in the experiment, namely the gas puff rate complemented by the wall sources as derived from the difference of injected and pumped particle flux.

The need to introduce particle pinch velocities results from the radial mismatch of the particle source profile and the measured electron density profiles, in particular the steepness of the measured electron density profile inside the separatrix, where the source has decayed to a low value. The two pinch terms inside and outside the separatrix are associated with different physics: the outward directed term in the SOL resembles intermittent or 'blobby' transport, which is understood as the fast ExB radial drift of polarized plasma filaments. Since sources are present, a larger value of the diffusivity could describe the measurements equally well.

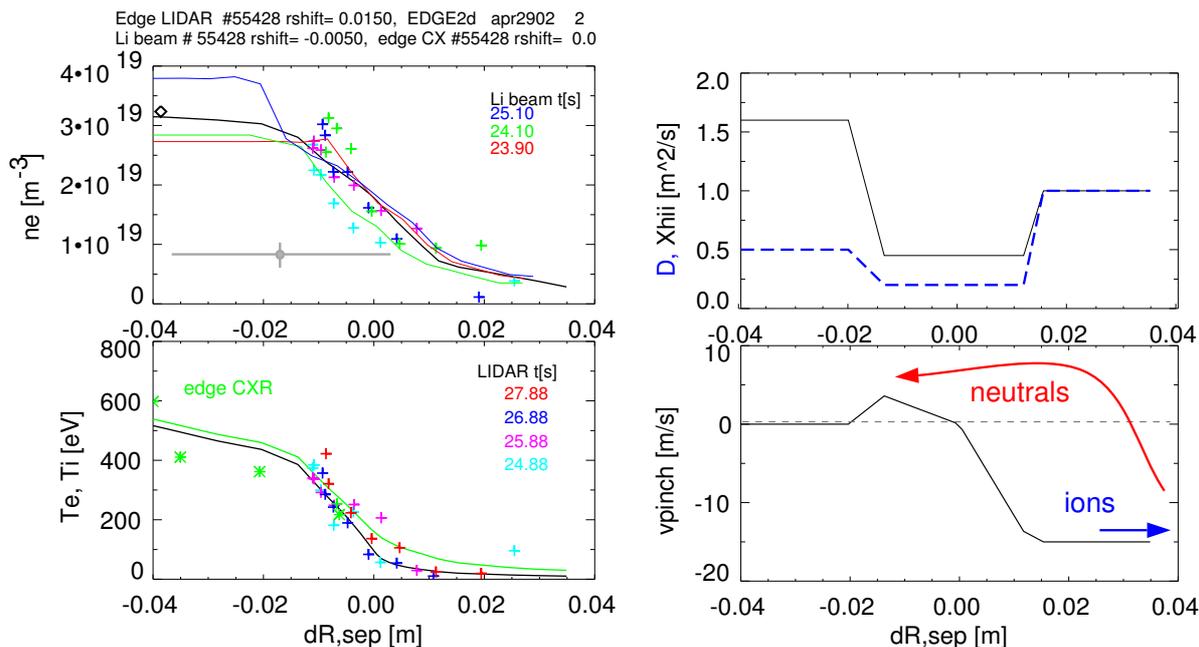


Figure 1: Electron density (black line), T_e (black) and T_i (green) from EDGE2d modelling versus experimental data from edge LIDAR (+), edge CXR (stars) and Lithium beam diagnostics. The diamond is the pedestal density estimate as $0.8 \times$ the line-averaged density from interferometry. Some diagnostic data had to be shifted with respect to the separatrix position to take into account EFIT mapping uncertainties of up to ± 2 cm. Also shown are the transport coefficients used for modelling. Ion flux towards the wall is expected to cause neutral fuelling around the separatrix. $I_p = 1.2$ MA, $B_t = 1.2$ T.

However, an outward drift (typically 10–20 m/s) describes the underlying physics possibly better. The inward term inside the separatrix is also arbitrary and models the assumed change of transport with sources, e.g., the stiffness of the edge density profile in terms of the normalized gradient ratio $\eta_e = d \log(T_e) / d \log(n_e) \approx 2$ as recently observed in ASDEX Upgrade [4]. The absolute values corresponding to the prescribed functional radial dependence of the transport coefficients are obtained by matching the calculated values to the available experimental measurements. Radial position uncertainties caused by equilibrium mapping and instrumental limitations of the spatial resolution have to be taken into account via radial shifts of up to 2 cm for the comparison with the midplane density and temperature measurements. The thermal conductivity (χ_i is taken equal to χ_e) inside the separatrix is quite well determined by the power flux, the diffusivity D has values a factor 1.5–4 smaller depending on the choice of v_{in} . The transport coefficients for carbon are taken similar to the fuel ions, but a larger inward pinch for C (associated with neoclassical transport) is usually necessary to obtain realistic core carbon concentrations. The inward drift used inside the separatrix cannot be linked to a particular transport process or instability so far, but it appears to be necessary for a correct description of the experimental data. Modelling the edge density profile with a moderately varying, smaller $D(r)$ and $v=0$ leads to curved density profiles around and inside the separatrix, in contrast to the Lithium beam measurements. The combination of inward drift and D may also resemble a different type of transport in the pedestal region, where the underlying transport mechanism fixes gradients or gradient parameters. In this case, the diffusivity is expected to change according to the variations of the source distribution.

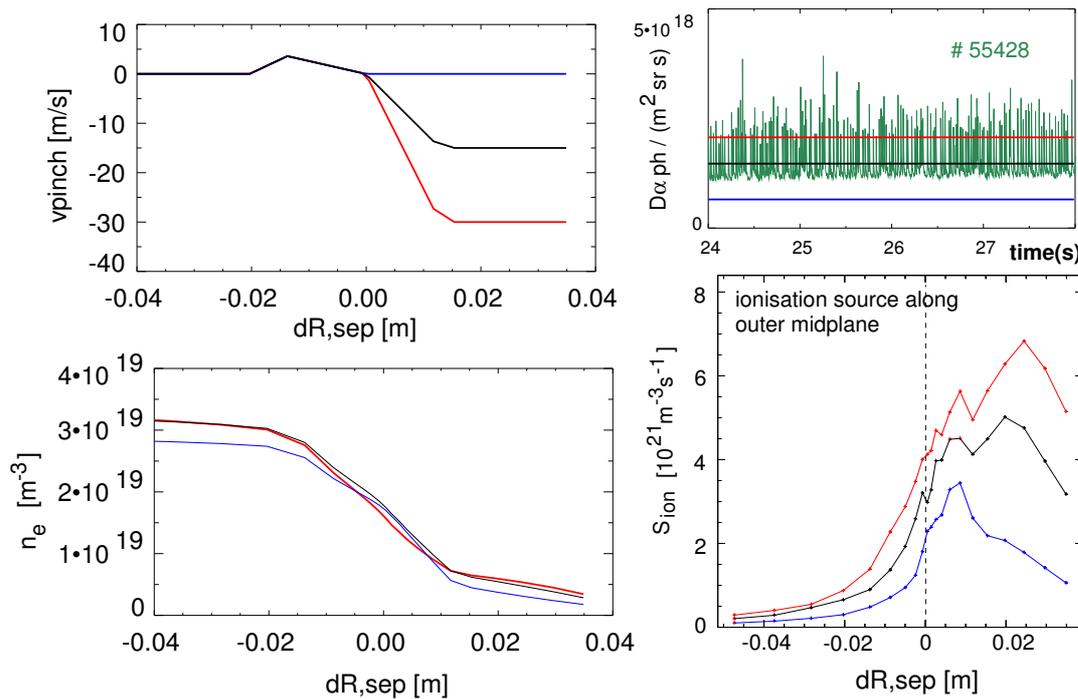


Figure 2: EDGE2d-NIMBUS calculations for the discharge shown in Fig. 1 with different values of the outward drift velocity and comparison to the D_α radiation along a radial midplane view.

Evidence for such a behaviour was found in an investigation of the parameter dependence of the relation of recycling and line density in JET and ASDEX Upgrade: A strong increase of the line density for given recycling flux with plasma current and upper triangularity suggests the impact of stability related effects on particle transport [5].

Position of the outer barrier foot

Due to the large particle sources and the strong variation of parallel conductivity with temperature, the outer foot position of the ETB is not obvious. The best means to determine this position is to compare modelling results with Langmuir probe measurements at the target. Fig. 3 shows a comparison of Langmuir probe measurements in the outer divertor with EDGE2d calculations for 2 different positions of the outer barrier foot. To match the absolute values of the Langmuir probe data in this high power (12 MW) H-mode discharge, the power input into the edge plasma had to be reduced to 5 MW in the code. This may be explained by the power loss due to fast ions emerging from the ETB region [6]. Figure 3 suggests that the outer barrier foot is situated about 1 cm outside the separatrix, with an uncertainty of a few mm. Its radial position appears to be a sensitive parameter in particular with respect to the particle sources. If the barrier would be situated further outside, radial particle fluxes from the source region would be inhibited, which would be in contrast to the measured values of wall recycling. It is also impossible that the barrier already ends at the separatrix. In this case, a contradiction would arise with the low densities measured with the target Langmuir probes. The ETB outside the separatrix allows for the temperature and density gradients necessary to cause the strong radial pressure drop in the first cm outside the separatrix.

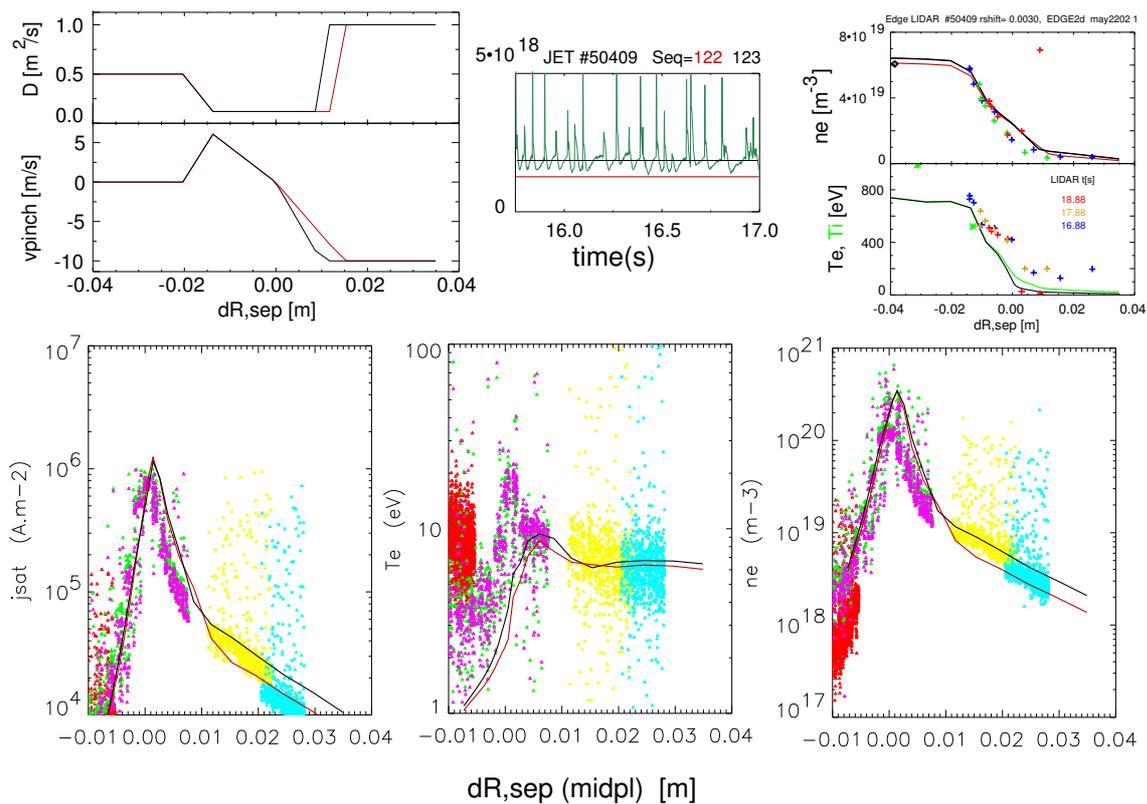


Figure 3: Variation of the outer foot position of the ETB and its effect on midplane D_α and target Langmuir probe measurements. $I_p = 2.5$ MA, $B_t = 2.4$ T

Discussion and conclusions

The fast radial transport taking place in the outer SOL, ≥ 1 cm outside the separatrix, provides coupling of the region outside the ETB with the inner plasma via the backflow of neutrals created at the main chamber wall. In our local transport ansatz, we deal with the time- and space-averaged flux caused by underlying events. The effective outward velocities, typically 10-20 m/s applied to the whole outer SOL plasma, are much less than individual blob velocities of ≈ 1000 m/s obtained from intermittent transport estimations [4, 6]. Intermittent transport caused by the ExB drift of polarized filaments should prevail in outward direction on the low-field side. This should cause enhanced plasma-wall interaction at the low-field side, which is not seen in the experiment so far. Zeeman spectroscopy in JET revealed predominant CIII emission on the HFS for ELMy H-mode conditions [7]. A careful analysis of the carbon source distribution in the main chamber of ASDEX Upgrade also identifies the heat shield on the HFS as the major location of plasma-wall interaction. This means that the plasma filaments must be diminished before reaching the outer wall, or redirected to the HFS by large parallel/poloidal flows.

References

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