On the role of drifts in the divertor power load distribution in ASDEX Upgrade

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Introduction

Dissipation of the exhaust power in the tokamak scrape-off layer (SOL) is one of the key challenges for divertor operation in ITER and DEMO. Of particular concern is the mitigation of strongly peaked or asymmetrically distributed power loads on the low- and high-field-side target plates. In this contribution, we discuss the role of cross-field drifts in modifying the divertor power load distribution in the ASDEX Upgrade tokamak. A medium-density L-mode discharge exhibiting a typical, high level of asymmetry in normal field configuration (ion $\nabla \mathbf{B}$ drift towards the lower divertor) is chosen for a detailed analysis.

Effects of drifts in medium-density L-mode discharges

SOLPS5.0 simulations [1] have been carried out to understand the highly asymmetric divertor conditions typically observed in medium-density ASDEX Upgrade discharges [2]. The composition of divertor power fluxes has been analysed for discharge #27691. The technical parameters of this discharge are line-averaged density of 4.0×10^{19} m^{-3}, plasma current of 1.0 MA and toroidal magnetic field of -2.5 T. The heating power was kept just below the L–H transition power by applying 0.4 MW ECRH heating in addition to 0.6 MW ohmic heating. The discharge had low-recycling conditions in the outer divertor, with a peak electron temperature $T_e \sim 40$ eV, in contrast to the partially detached inner divertor conditions with peak $T_e \sim 5$ eV. The outer target power load was ∼0.45 MW, accounting for ∼95% of the total target power load measured by the Langmuir probes. In the modelling, the free parameters such as the radial transport coefficients have been adjusted to simultaneously match the measured conditions at the outer target and outer midplane when all drift terms and currents are activated in the simulations. The inner divertor conditions are obtained as a result of the code calculations assuming ballooning-like transport with B^{-1} dependence.

We separate the analysis of drift effects into two regions: the main SOL above the X-point and the divertor below the X-point. Table 1 shows the modelled in–out power flux asymmetries at the divertor entrance and at the divertor targets, as well as the asymmetry in the peak target T_e. The asymmetries at the divertor entrance must be connected with processes in the main SOL,

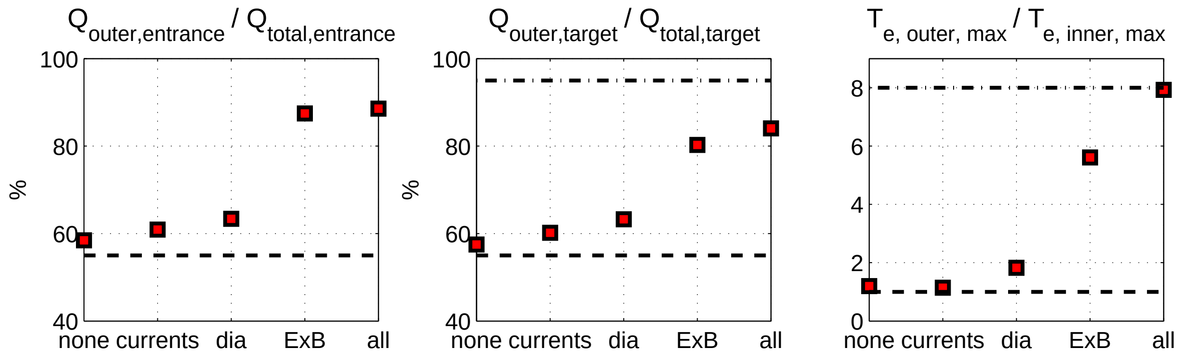

Figure 1: Calculated outer divertor power flux fractions at the divertor entrance, Q_{entrance}, and at the target, Q_{target}, and the asymmetry in the peak target T_{e}, according to SOLPS5.0 modelling for discharge #27691. Different physics ingredients are included in the simulations (**none**: no drifts or currents; **currents**: only currents activated; **dia**: dimagnetic drifts and currents activated; **ExB**: $\mathbf{E}\times\mathbf{B}$ drifts and currents activated; **all**: all drifts and currents activated). The dotted lines represent equal power sharing (considering the different toroidal lengths of the two targets) and temperature symmetry. The dash-dotted lines indicate the experimental levels.

whereas at the targets they can be sensitive to the dissipation processes by neutrals and impurities in the divertor [3]. The results are shown for simulations with the $\mathbf{E}\times\mathbf{B}$ drifts, diamagnetic drifts and currents switched on or off. In the cases with activated drift terms, also the currents are calculated. With the full physics model (all drifts and currents calculated), a strong in–out asymmetry is observed already at the divertor entrance. The individual drifts affect the asymmetries as follows: The diamagnetic drift, directed towards the X-point in the main SOL, gives an overall increase to the power fluxes entering the divertor, compared to simulations without drifts. The effect on the in–out asymmetry is, however, negligible, as observed when comparing to the simulations without drifts: both cases yield an in/out power flux ratio of 3/5. In contrast, the $\mathbf{E}\times\mathbf{B}$ drifts alone change this ratio to 1/7 at the divertor entrance, largely accounting for the asymmetry observed with the full physics model. Activation of currents alone does not have a strong influence on the solutions.

In order to better understand the mechanisms behind the asymmetries at the divertor entrance, the various components of the poloidal heat fluxes have been calculated as shown in Figure 1. In the absence of drifts, the asymmetry in the heat fluxes at the divertor entrance is due to the asymmetric heat conduction, which is responsible for 50% of the total heat flux to the two divertor legs. The contribution of currents is small, as identified already in the analysis above. However, as the $\mathbf{E}\times\mathbf{B}$ drift terms are activated, a significant increase in the convective heat fluxes due to both currents and $\mathbf{E}\times\mathbf{B}$ drifts are observed. The plasma current increases because a temperature asymmetry is established at the targets, which reduces the peak T_{e} at the inner target from 20 eV to 6 eV while increasing it at the outer target from 22 eV to 33 eV. The

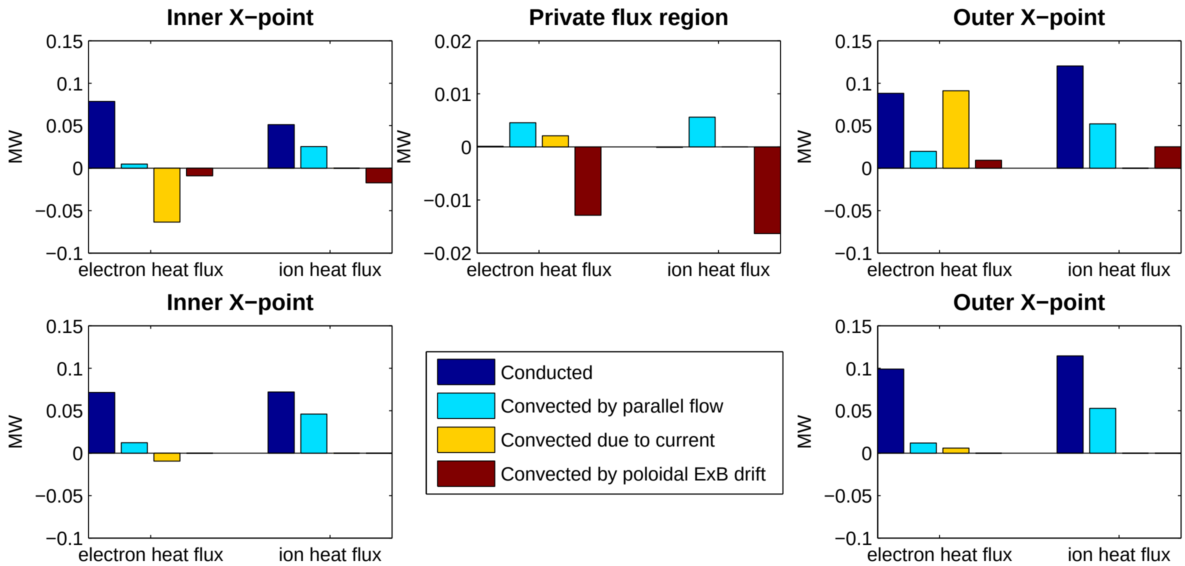

Figure 2: Calculated poloidal heat flux components for discharge #27691 at the divertor entrance and through the private flux region in the outer divertor. The top row shows the results obtained with activated $\mathbf{E}\times\mathbf{B}$ drifts and currents. The bottom row shows the results from simulations with only currents activated. The heat fluxes are calculated separately for the electron and ion channels. The positive direction is always towards the target (inner target on the high-field side and outer target on the low-field side.).

currents carry 10 % of the total divertor heat flux from the inner divertor to the outer divertor. The poloidal $\mathbf{E}\times\mathbf{B}$ drift in the main SOL is directly responsible for moving 5 % of the heat to the outer divertor, and the rest is due to smaller changes in the conducted and convected heat fluxes.

The power flux asymmetry observed at the divertor entrance is largely preserved at the targets. Nevertheless, some redistribution of power is observed in the divertor below the X-point with activated $\mathbf{E}\times\mathbf{B}$ drifts, leading to a small reduction of the power flux asymmetry at the targets compared to the divertor entrance, despite a higher level of radiation in the inner divertor compared to the outer. Figure 1 illustrates the power transfer mechanism between the two divertor legs: a strong poloidal $\mathbf{E}\times\mathbf{B}$ drift in the private flux region moves 5 % of the heat from the outer to the inner divertor leg. This is possible due to the radial fluxes of particles and heat into the private flux region in the outer divertor, similarly caused by the $\mathbf{E}\times\mathbf{B}$ drifts. As illustrated in Figure 2, such radial fluxes are also observed in the inner divertor, where they lead to a broadening of the heat and particle loads.

Summary and discussion

In medium-density ASDEX Upgrade discharges, the asymmetry in divertor power sharing has been observed to significantly increase due to the $\mathbf{E}\times\mathbf{B}$ drifts. This is in line with other 2D simulation studies [4, 5], which have emphasized the role of $\mathbf{E}\times\mathbf{B}$ drifts in defining the

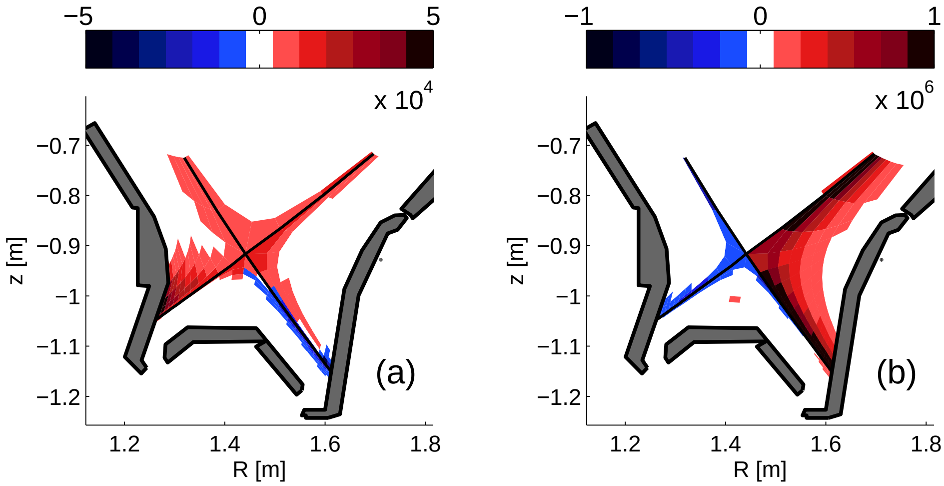

Figure 3: Modelled power fluxes (W/m^2) in the radial (a) and poloidal (b) directions in discharge #27691 with activated $\mathbf{E} \times \mathbf{B}$ drifts and currents. The positive directions are radially outwards and poloidally clockwise, towards the outer divertor.

divertor conditions in single-null configurations. In this work, we have provided a quantitative assessment of the various heat flux components. In agreement with [5], parallel currents were observed to strongly influence the divertor heat flux asymmetries. For the currents to arise, an initial target temperature asymmetry was required, which in the present case was only obtained due to the $\mathbf{E} \times \mathbf{B}$ drifts. The poloidal $\mathbf{E} \times \mathbf{B}$ drift carries heat from the inner to the outer divertor across the main SOL, increasing the asymmetry in the power fluxes entering the two divertor legs. In the divertor, both the radial and the poloidal drifts redistribute the particles and heat but, due to the low temperatures in the private flux region, the heat transfer to the inner divertor is small compared to the main SOL processes transferring heat to the outer divertor. Nevertheless, the drifts transfer particles across the private-flux region to the inner divertor. Therefore, the inner divertor becomes cooler and denser, which gives rise to the thermal current and leads to the experimentally observed strong target power load asymmetry.

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