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Investigating the double scale length of limited plasmas with nonlinear simulations of the TCV Scrape Off Layer

F. Nespoli, B. Labit, I. Furno, F.D. Halpern, P. Ricci

Ecole Polytechnique Fédérale de Lausanne, Centre de Recherches en Physique des Plasmas, 1015 Lausanne, Switzerland

Introduction

Heat loads onto the limiter for inboard limited plasmas have been measured recently in TCV using infrared thermography [1]. The parallel heat flux profile in the Scrape Off Layer (SOL) exhibits a double scale length, confirming previous results from other tokamaks [2]. A short scale length of the order of several millimeters is always present in the vicinity of the Last Closed Flux Surface (LCFS), while in the main SOL the heat flux decay length is typically ten times longer. Even though the ITER first wall design was recently changed to handle the extra heat flux associated with such a narrow feature [3], the physics underlying is not well understood yet.

Nonlinear simulations of the TCV SOL

To improve our understanding, numerical simulations of the TCV SOL are performed for the first time using the GBS code [4]. This code solves the drift-reduced Braginskii equations in a 3D geometry. The resulting plasma turbulence determines self-consistently both the equilibrium profiles and their fluctuations. The simulations include the effects of magnetic shear $\hat{s} = 1.5$, finite aspect ratio $\epsilon = 0.24$ and ion temperature $\tau = 1$. The reference case is based on experimental parameters from the TCV discharge #49170, the electron density $n_{e,0} = 5\ 10^{18} m^{-3}$ and temperature $T_e = 25$ eV at the LCFS are estimated from flush mounted Langmuir probe (LP) data, located on the central column of TCV, acting as the limiter. This values determine the size of the simulation $\rho^* = \rho_s/R_{ax}$ and the normalized Spitzer resistivity $\nu = e^2 n_e R_{ax}/(m_i \sigma_{||} c_s)$, where ρ_s is the ion Larmor radius computed with the sound speed c_s, and $R_{ax} = 0.84$ m is the position of the magnetic axis. The toroidal field on axis is $B_t = 1.45$ T. The value of $q_{edge} = 3.2$ is computed by the equilibrium reconstruction. The geometry of the toroidal limiter in the simulations is shown in Fig.1, together with the main simulation parameters and a snapshot of the resulting electron density. Also, in this first simulations

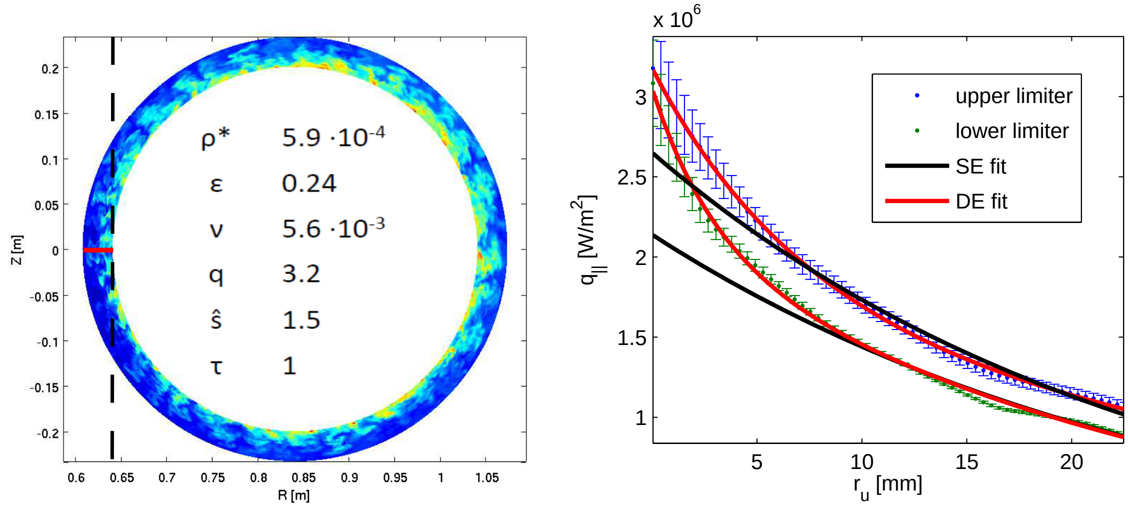

Figure 1: Left: snapshot of the electron density resulting from the numerical simulation, together with simulation (red) and TCV (black) limiter geometry. Right: fit of a radial $q_{||}$ taken along the limiters (blue, green) with a single exponential (SE, black) and with a sum of two exponentials (DE, red).

the magnetic field and plasma current are antiparallel in the simulation, contrary to the experiment.

Comparison with experimental data

The parallel heat flux is computed from the plasma density n_e, the electron and ion temperature T_e, T_i as $q_{||} = \gamma n_e \sqrt{\dfrac{T_e + T_i}{m_i}} T_e$, where all the quantities are averaged in time and in the toroidal direction, and $\gamma = 7$ is the sheath power transmission factor. In order to compare with experimental data, $q_{||}(r_u, \theta)$ has been averaged for $\theta_l < \theta < \pi$ nad $-\pi < \theta < -\theta_l$, where θ_l is the angle where the whole GBS profile crosses the TCV-like limiter, resulting in two radial profiles, for the upper and lower part of the limiter respectively. The narrow feature observed in the experiments is also seen in the simulations. Indeed, the limiter profiles are well fitted by the sum of two exponentials

$$q_{||}(r_u) = q_s \exp(-r_u/\lambda_s) + q_l \exp(-r_u/\lambda_l) \tag{1}$$

while the fit with a single exponential is clearly unsatisfactory as shown in fig.1. The fitted values of $\lambda_s = 4.9, 3.9$ mm and $\lambda_l = 28.3, 30$ mm for the upper and lower limiter respectively are similar with the experimental ones $\lambda_{s,exp} = 2.9$ mm , $\lambda_{l,exp} = 36.7$ mm. Furthermore, $q_{||}(r_u)$ has been analyzed at every fixed θ, revealing a strong poloidal variation of the fitted parameters (Fig.2). Above the midplane ($\theta \geq 0$), both scale lengths are observed to increase.

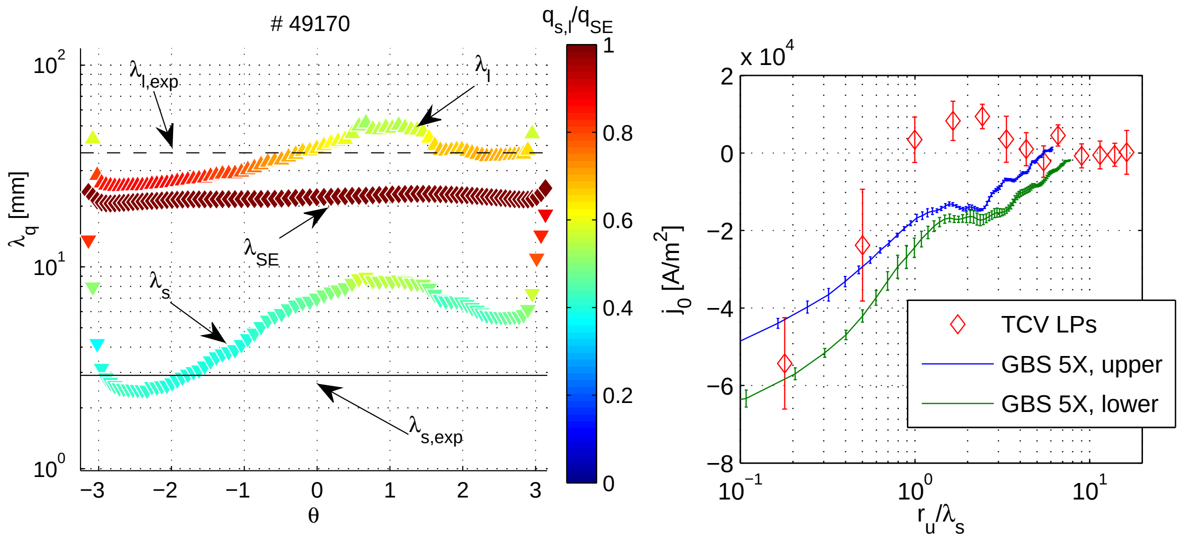

Figure 2: Left: poloidal variation of the fitted decay lengths of the heat flux, color-coded with their relative magnitude. The value resulting from a single exponential fit is shown, together with the experimental values. Right: density current flowing to the grounded limiter measured by LP in TCV discharge #49170 (red diamonds), and average profile calculated from the GBS simulation (5X magnification) for the upper and lower limiter (blue and green, respectively).

Such an asymmetry might be due to the $\mathbf{E} \times \mathbf{B}$ drift velocity, whose main component is in the positive θ direction.

The current in the SOL flowing to the limiter is computed from the simulation as $j_{||} = q_e n_e (v_{i,||} - v_{e,||})$, where $v_{i,||}, v_{e,||}$ are the ion and electron parallel velocity. Two profiles are obtained for the limiter with the same procedure used for $q_{||}$. The result is compared in Fig. 2 with the current measured by the LPs biased at the limiter potential. The presence of electronic currents in the region $r_u \leq \lambda_s$ is found in both experiments and simulations, suggesting a correlation between the narrow feature and such non-ambipolar currents, as already observed in COMPASS [5].

The role of resistivity

Experimentally, it has been shown that the excess heat load in the SOL scales with $\Delta P_{SOL} \equiv 4\pi R_{LCFS} B_\theta / B_\phi \int_0^\infty [q_{||}(r_u) - q_{||,main}(r_u)] dr_u \propto T_e^{1.43} n_e^{-1.01}$ [1], i.e. approximately with $1/\nu$. Three more simulations have been performed, in which the resistivity is increased by a factor 10, 20, 40 respectively. Increasing ν, the profiles flatten in the main SOL (Fig.3), and the poloidal asymmetry is reduced. The narrow feature is still present, but its im-

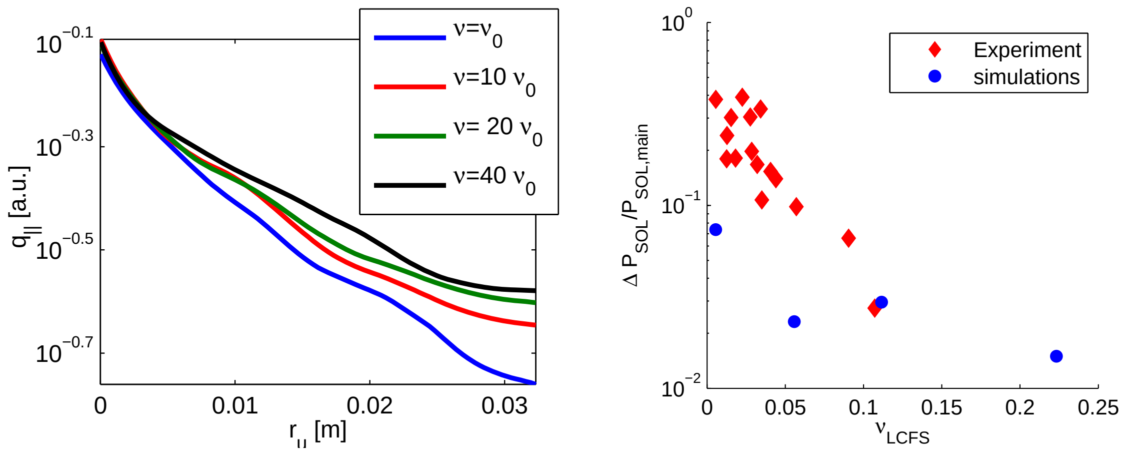

Figure 3: Left: change in the (poloidally averaged) $q_{||}$ profiles increasing the resistivity. Right: relative importance of the narrow feature variation with normalized resistivity. TCV experiments shown as red diamonds, GBS simulation shown as blue points.

portance with respect to the main SOL is decreased. The latter can be estimated as $\Delta P_{SOL}/P_{SOL,main} = q_s\lambda_s/q_l\lambda_l$. The variation of this parameter with resistivity is shown in Fig. 3, where $q_s, q_l, \lambda_s, \lambda_l$ are obtained fitting the poloidally averaged $q_{||}$ profiles with eq.(1). The experimental trend is qualitatively recovered herein. A more detailed analyses of the statistical properties of plasma density and potential fluctuations are ongoing and will be compared with the experiments. Moreover, another simulation with a different safety factor $q_edge = 5.2$ is being performed and experiments in TCV are planned for the MST-1 campaign at the end of 2015. In particular, experiments in helium plasmas are foreseen.

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