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Comparison of three-dimensional plasma edge turbulence simulations in realistic double null tokamak geometry with experimental observations

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Understanding the plasma dynamics at the periphery of tokamak devices is a crucial challenge in the path to fusion energy. Most of the heat and particles ejected from the core, transported into the tokamak scrape-off layer (SOL) because of plasma turbulence, is exhausted at the divertor plates. These must be designed to sustain high thermal loads that, in ITER and future fusion devices, are at the edge of or above current material limits. Modelling the particle and heat transport in this region is extremely challenging, as the SOL plasma dynamics involves a large number of nonlinear phenomena occurring on a wide range of spatio-temporal scales. Consequently, state-of-the-art simulations are required to uncover the physics behind the SOL plasma dynamics and to reliably predict the heat flux to the divertor plates.

In the present work, global, three-dimensional edge plasma turbulence simulations of a MAST L-mode plasma discharge are presented. Our study is based on the drift-reduced Braginskii equations, solved with the STORM module [1,2] of BOUT++ [3] for realistic MAST parameters in disconnected lower double null configuration. The three-dimensional plasma profiles are evolved self-consistently, with no separation between equilibrium and fluctuations. The equations are solved on a numerical grid of approximately 14 million points, corresponding to a resolution at the outer mid-plane up to $k_\perp \rho_s \simeq 1$. This allows us to fully resolve SOL plasma turbulence in the tokamak periphery (see Ref. [4] for more details on the simulation setup).

The simulations reveal that plasma turbulence develops inside the last closed flux surface, with fluctuations having a ballooning character (see Fig. 1, left).

Because of the strong magnetic shear near the X-points, fluctuations at the divertor targets are not correlated with the mid-plane near the separatrix. On the other hand, filaments are more homogenous along magnetic field lines in the far SOL (see Fig. 1, right), consistently with theoretical expectations (e.g., see [5]). Moreover, ExB counter flows are observed in the divertor legs near the separatrix. As a result, filaments are generated locally in this region, enhancing the radial transport and widening the radial profiles both in the SOL and in the private flux regions (PFRs).

The numerical results are then validated against experimental measurements both qualitatively and quantitatively. Filaments have previously been observed to exhibit different properties in the SOL, in PFRs and in divertor legs [6]. This is recovered in our simulations. Striations on the divertor plates, as are seen with infrared imaging diagnostics, are also reproduced.

Plasma profiles and statistical properties are validated against Langmuir probe measurements both at the outer mid-plane and at the divertor targets. Moreover, filament properties are investigated exploiting the unique capabilities of the synthetic Dα diagnostic developed by coupling the CHERAB spectroscopy modelling framework [7] to STORM. Overall, the numerical results are in good agreement with experimental observations and theoretical expectations. This study gives a deep insight into the mechanisms that govern the SOL plasma dynamics in diverted configurations, providing a consistent picture of the diverse phenomena observed at the tokamak periphery.

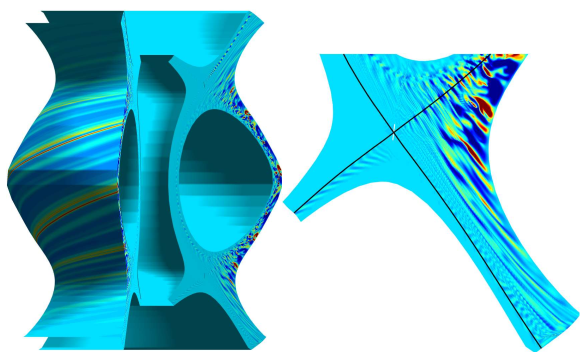

Figure 1: *(left) Relative density perturbations from a three-dimensional STORM simulation of MAST. (right) Zoom on the lower X-point region. The black line denotes the inner separatrix.*

References

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