Validated GRILLIX Simulations of Edge/SOL Turbulence in H-mode and X-Point Radiator Detached Conditions

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Magnetic confinement fusion reactors must combine high plasma energy confinement with manageable heat exhaust. Both are determined to a large degree by turbulent transport across the magnetic field. Magnetised plasma turbulence is increasingly well understood in the tokamak plasma core [1]. But predicting turbulence in the edge and scrape-off layer (SOL) remains challenging. In particular, better understanding is required for the reduced transport in the plasma edge during operation in the high confinement mode (H-mode), especially in ELM-free regimes [2], as well as the cross-field transport during operation in detached conditions for heat load mitigation.

In this contribution, we report on substantial progress in both aspects. We present first global turbulence simulations of the ASDEX Upgrade tokamak edge and SOL in (ITER baseline similar) H-mode conditions, with reasonable agreement between the simulations and experiment. We compare outboard mid-plane profiles of density, electron/ion temperature and radial electric field, heat transport levels and divertor heat loads. The structure of the significant $E \times B$ flow shear is investigated and the turbulence is characterised. First attempts of L-H transition power scans are discussed. At the same time, we report on turbulence simulations in fully detached regimes with an X-point radiator [3], where most of the heat is radiated away by nitrogen long before reaching the divertor targets, and turbulence characteristics are modified.

These results were obtained with the GRILLIX code [4], which is particularly well suited for efficient turbulence simulations in diverted tokamak and stellarator geometry. Our global drift-fluid plasma model develops turbulence together with background evolution, which cannot be well separated particularly in the SOL. The background must be sustained by realistic sources, in particular neutral gas ionization, for which we include a diffusive 3-moment model. Impurities are implemented with a simple 0D model, in coronal approximation and with a constant concentration. Electromagnetic fluctuations are found to play a critical role in H-mode conditions, stabilizing $E \times B$ and driving magnetic transport themselves. We stress the importance of transcollisional extensions, including neoclassical corrections for the ion viscosity, as well as a Landau-fluid model for the parallel heat conduction. In this context, our work strongly benefits from the close collaboration with the gyrokinetic code GENE-X [5]. Our results pave the way towards predictive simulations of fusion reactors such as ITER.

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