Impact of the plasma-wall contact position on edge turbulent transport and poloidal asymmetries in tokamaks in 3D global turbulence simulations

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Research in magnetic confinement fusion plasmas explores the possibility of producing power by using fusion in deuterium-tritium plasmas heated to temperatures of up to 10^7-10^8K. Particles are confined by magnetic field in machines of toroidal shape known as tokamaks. Fusion requires optimizing temperature and density in order to maximize the fusion yield, while also minimizing the heat load on vessel wall. This optimization requires understanding and control of the main heat and particles transport mechanisms in the machine, namely turbulence. It was showed that turbulent transport in the edge plasma exhibits large poloidal asymmetries, both regarding parallel flows and thermal pressure, as well as on turbulent fluctuations levels [1-3]. Experimental and theoretical evidence suggest that the ballooned character of radial turbulent transport [3-5] is a key player in establishing these asymmetries. Capturing these effects in numerical models requires the use of global 3D turbulence codes.

In this work, we analyse turbulent flows in the well-defined Mistral base case [4,6] in order to characterize the physical mechanisms at play as well as the role of the plasma-wall contact point location on these symmetry breakings. The TOKAM3X 3D fluid global (full torus, flux-driven) turbulence code is used [5], in a limiter geometry covering both the Scrape-Off-Layer (plasma region in direct contact with the wall) and outermost open flux surfaces. The Mistral base case covers a set of discharges run in the Tore Supra tokamak in which strong changes of the poloidal asymmetries and flows were observed depending on poloidal position of the plasma-limiter contact point. The detailed measurements provided by the Mistral base case and the sensitivity of the observations to the position of the limiter constitute a demanding test bench to assess the degree of accuracy and validity of numerical models.

TOKAM3X simulations globally recover poloidal asymmetries observed in experiments without adjusting any free parameters, suggesting that the mechanisms at the origin of the asymmetries are well captured by the full-torus electrostatic interchange model used. As the position of the limiter is moved in the poloidal direction, the parallel flow velocity $M_{//}$ observed at the top of the machine (experimental position of the measurement) is strongly impacted. In particular, a flow reversal is found when the limiter is moved from +30° ($M_{//} \approx -0.8$ towards the limiter) to -30° ($M_{//} \approx 0.4$ away from it) with respect to the outboard mid-plane. The density radial decay length, and consequently most likely of the width of the heat channel, is also found dependent on the poloidal position of the limiter, with a change of more than a factor of 2 between the ±30° cases. As suggested by experiments, the ballooning character of edge turbulent transport explains most of these observations although additional symmetry breaking mechanisms are identified. Simulations also show that turbulent transport itself is impacted with variations of a factor of 2 of the poloidal width of the ballooning region. The unprecedented match of TOKAM3X simulations with experimental results clearly indicates that the SOL and edge region, including the geometry of wall components, must be addressed globally to determine the turbulent transport. This would explain the difficulty in establishing scaling laws to describe these edge phenomena.

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