Radial electric fields in core & edge flux-driven turbulence

G. Dif-Pradalier[1], P. Donnel[1], Y. Munschy[1], Y. Sarazin[1], R. Varennes[1,2],
L. Vermare[3], X. Garbet[1,2], Ph. Ghendrih[1], V. Grandgirard[1], O. Panico[1]
[1] CEA, IRFM, France,
[2] Nanyang Technological University, Singapore
[3] LPP, Ecole Polytechnique, France
e-mail (speaker): guilhem.dif-pradalier@cea.fr

Microscale turbulence is known to nonlinearly organise through generation of secondary or tertiary mesoscopic structures such as zonal flows, fronts or staircases. Radial electric field (E_r) evolution underpins these questions and is central to understanding the onset and sustainment of transport barriers. From a modelling standpoint, these questions are sensitive to assumptions of scale separation and thus best understood in a flux-driven framework. This talk tries to articulate recent experimental observations, in particular on the WEST tokamak prior to the H-mode transition and recent results provided by flux-driven turbulence simulations with the gyrokinetic GYSELA code.

Experiments in Tore Supra limited plasmas [1], WEST [2] and MAST [3] diverted L-mode or H-mode discharges have shown a clear role of magnetic ripple and plasma current on radial electric field flow and shear levels in the edge. In particular, the edge E_r well measured using Doppler Backscattering is found to deepen with increasing plasma current I_p (decreasing safety factor q). The physics underpinning this I_p dependence is not straightforward. Plasma current indeed impacts transit times and orbit widths, which are instrumental in a large variety of neoclassical and turbulent processes. Neoclassical transport regimes are affected through modification of the bounce frequency of trapped particles. Turbulence is directly affected through enhancement with q of linear grow rates of electrostatic instabilities. The plasma current may also influence the synergy between neoclassical and turbulent dynamics via flow damping. Dedicated GYSELA numerical experiments point towards subtle trade-offs between collisional flow damping and turbulent flow drive through turbulent Reynolds stresses as I_p is changed [4]. Increasing the safety factor indeed increases turbulent transport, consistently with global scaling laws but decreases edge perpendicular flows. Surprisingly however, neoclassical calculations show no significant effect of the safety factor on flows, which leads to a somewhat counter-intuitive situation: turbulent stresses are clearly responsible for flow drive, but generated flows get weaker (in absolute value) as turbulence intensity increases, therefore emphasising the fact that collisional flow damping wins over flow drive as I_p increases. These observations are qualitatively consistent with the experimental trends albeit not quantitatively. A detailed analysis of these questions will be presented as well as ongoing steps to improve upon them.

In particular, the incidence of realistic Scrape-Off Layer boundary conditions with fully kinetic ion and electron responses is missing in the aforementioned study. This is a topic of great current interest and promise, especially in view of pedestal physics modelling. The important role of a spreading-mediated interplay between core and edge, originating near the magnetic separatrix has recently been shown [5] in flux-driven regimes with a limiter configuration and a simplified Boltzmann electron response. Detailed vorticity balance shows that the diamagnetic component of the Reynolds stress plays a central role in the build-up phase of the E_r well [5] in the L-mode edge as well as in the core shear layers [6] of tokamak plasmas. These findings resonate with recent experimental observations that additional ingredients to the conventional (non diamagnetic) Reynolds stresses are likely required to account for measured flow generation levels [7]. Through SOL—edge interplay, a stable transport barrier self-consistently builds up in GYSELA inside the separatrix. The causal chain that leads to its onset and sustainment has been specifically investigated [5] and will be discussed. At last, current steps towards a fully integrated core to SOL gyrokinetic flux-driven framework will be discussed. In particular, we will discuss strategies to incorporate key aspects of sheath physics [8] in flux-driven gyrokinetics without resolving the Debye sheath. This ongoing step is essential for a comprehensive modelling of the plasma edge.

References:

[1] P. Hennequin et al, 37th EPS conference on Plasma Phys. (2010)
[2] L. Vermare et al, Nucl. Fusion 62:026002 (2022)
[3] H. Meyer et al, J. Phys: Conf Ser. 123:012005 (2008)
[4] R. Varennes, PhD thesis, Aix-Marseille University (2022)
[5] G. Dif-Pradalier et al., Communications Physics 5:229 (2022)
[6] Y. Sarazin et al., Plasma Phys. Control. Fusion 63:064007 (2021)
[7] R. Gerrú et al., Nucl. Fusion 59 106054 (2019)
[8] Y. Munschy et al., submitted to Nucl. Fusion (2023)