Multi-scale issues in fusion plasmas: synergy between turbulence & neoclassical transports

Y. Sarazin, Y. Asahi, P. Donnel, X. Garbet, E. Caschera, G. Dif-Pradalier, C. Ehrlacher, Ph. Ghendrih, V. Grandgirard, G. Latu, and C. Passeron

CEA, IRFM, Saint-Paul-lez-Durance, F-13108, France

In tokamak plasmas, the radial transport of matter, momentum and energy, governed by collisions and turbulence, is intrinsically multi scales. While neoclassical transport results from stationary large scale structures, namely static (m,n) = (1,0) modes (m,n = poloidal, toroidal Fourier wave numbers), turbulence develops fluctuating small scale modes m,n >> 1. Here, neoclassical refers to the collisional transport driven by axisymmetric modes (n = 0), turbulent transport being governed by non-axisymmetric modes ($n\neq0$). On the basis of this apparent scale separation, it is usually assumed that both contributions are additive. In turn, these two transport channels are often modelled with different dedicated codes. Yet, on the one hand, turbulence is long known to generate meso- to large-scale structures such as zonal flows or avalanches, or the more recently reported staircases. On the other hand, neoclassical coefficients can exhibit small-scale variations, e.g. due to the strong variation of the collisionality at the edge. One of the key questions is therefore whether this assumption is valid, or whether neoclassical and turbulent transports exhibit synergetic effects.

This fundamental issue has been recently addressed by means of self-consistent nonlinear simulations of both turbulent and neoclassical transports with the full-f and flux-driven gyrokinetic code GYSELA [1]. There, a simplified version of the multi-species collision operator – valid for trace thermal impurities – has been implemented and successfully benchmarked against neoclassical theory [2,3]. A clear example of this synergy comes from the observation that the tungsten impurity flux is not the sum of turbulent and neoclassical fluxes computed separately [3], as usually assumed. Actually, it is found that the synergy partly results from the turbulence-driven in-out poloidal asymmetry of tungsten density. Indeed, large scale poloidal structures of the impurity density are generated by turbulence large scale (m,n) = (1,0) modes of the electric potential. These add-up and/or compete with those governed by neoclassical physics, so that neoclassical and turbulent transports are not additive. Interestingly, it is also found analytically – dedicated numerical simulations are in progress, with scrape-off layer like boundary conditions – that these poloidally asymmetric large scale convective cells also impact momentum transport [4]. Last but not least, evidence of flow poloidal asymmetries was found in measurements on the Tore Supra tokamak [5].

The conditions for the onset and sustainment of these turbulence-driven m=1 cells have been clarified and will be exposed. It turns out that Landau damping is small at low frequency, so that the amplitude of quasi-steady cells is mainly dictated by shielding polarization effects. It is also found that poloidal asymmetries of the distribution function driven by these cells produce a flux of toroidal momentum via the magnetic drifts of particle guiding-centers. This flux partially balances the contribution of $E\times B$ drift velocity fluctuations to the turbulent residual stress. Also the resulting poloidal asymmetries of the density modify deeply the neoclassical flux of impurity. It will be shown that the neoclassical thermal screening of heavy impurities is reduced because of this effect. Finally turbulence self-regulation through the generation of poloidal convective cells and feed-back via vortex shearing will be discussed.

References

[1] V. Gandgirard et al., Comp. Phys. Commun. 207, 35 (2016)
[2] D. Estève et al., Phys. Plasmas 22 (2015) 122506; see also P. Donnel et al., this conference
[3] D. Estève et al., to appear in Nuclear Fusion (2017) https://doi.org/10.1088/1741-4326/aa6ebb
[4] X. Garbet et al., New J. Phys. 19, 015011 (2017)
[5] A. Storelli, PhD thesis Ecole Polytechnique, Palaiseau, (2015) https://www.theses.fr/189107685; L. Vermare et al., to be presented at the 44th EPS conference on plasma physics (2017)