Zonal flows isotopic effects on turbulent transport

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In tokamak plasmas, the energy confinement time τ_E is mostly governed by turbulence. Two strategies have been developed in view of predicting τ_E in present and next step devices including ITER. On the one hand, a large database using multi-machines experimental measurements has allowed for the derivation of empirical scaling laws. Focusing on their mass dependency, these laws exhibit a scaling proportional to the square root of the atomic mass number A of the plasma ions: $\tau_{E,scaling\,law} \propto A^{1/2}$ [1]. On the other hand, first principle numerical simulations find that the turbulent transport coefficient $\chi_\perp$ is gyro-Bohm at sufficiently ρ_* values, as expected in ITER: $\chi_\perp \sim \rho_* \chi_B$, with $\chi_B = T/eB$ the Bohm diffusion coefficient and $\rho_* = \rho_i/a$ the ion gyro-radius normalized to the minor radius a. These findings are in good agreement with experimental observations. The resulting energy confinement time is then expected to scale like $\tau_{E,gB} \sim a^2/\chi_\perp \propto A^{-1/2}$. It readily appears that this prediction is nothing but the inverse of the one reported by scaling laws. So far, there is no satisfying explanation for this longstanding discrepancy. One possibility would be that there exists another player in transport issues $-$ in addition to the gyro-Bohm turbulence $-$ which would scale differently with mass so as to counterbalance the gyro-Bohm scaling. Zonal flows (ZFs), which are known to efficiently contribute to turbulence saturation, appear as good candidates in this frame. The present work aims at clarifying their role regarding this critical issue, by means of gyrokinetic nonlinear simulations.

The simulations are performed in the flux-driven regime with the GYSELA (GYrokinetic SEmi-LAgrangian) code [2], which models the electrostatic branch of ITG turbulence with adiabatic electrons. This global code solves the gyrokinetic equation for the full-f ion guiding-center distribution function, coupled to the quasi-neutrality equation. Both micro-scale turbulence and ZFs are self-consistently generated. In the nonlinear regime, the interplay between large scale flows, including ZFs, and turbulent eddies leads to plasma self-organization. In such a full-f code, ZFs cannot be easily removed. However, by modifying the adiabatic electron response from $\tilde{n}_e/n_{eq} = e(\phi - \langle\phi\rangle)/T_e$ to $\tilde{n}_e/n_{eq} = e\phi/T_e$ (with ϕ the electric potential and $\langle\phi\rangle$ its flux surface average), one drastically increases the inertia of ZFs so that they effectively become ignorable. The latter kinds of simulations can be considered as "without ZFs".

The results of 4 simulations are compared, for Hydrogen ($A = 1$) and Deuterium ($A = 2$) plasmas, with and without ZFs. Following a recent analytical calculation [3], the efficiency of turbulence saturation by ZFs is quantified by the turbulence reduction factor $R_{turb} = \chi_\perp/\chi_{\perp,noZF}$, with $\chi_{\perp,noZF}$ the effective transport coefficient without ZFs. These factors are compared for both H and D cases. Last but not least, sufficiently long run simulations reach steady state equilibrium, characterized by steady radial profiles. In this case, the energy confinement time can be directly retrieved, allowing for the direct estimate of τ_E. Its scaling dependency on A will be presented.

References:

[1] ITER Physics basis, *Nucl. Fusion* **47**, S18-S127 (2007)
[2] V. Grandgirard, Y. Sarazin et al., *Plasma Phys. Control. Fusion* **49**, B173 (2007)
[3] T.S. Hahm, Lu Wang et al., *Nucl. Fusion* **53**, 072002 (2013)