Highly collisional two-fluid and gyrokinetic simulations of tokamak edge turbulence and the transition between kinetic and fluid regime

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To arrive at a common basis, the gyrokinetic code CGYRO [1] and the non-local two-fluid code NLET [2] have both been applied to identical parameters sets ranging from highly collisional, resitive ballooning turbulence scenarios - which approach the fluid limit - relevant to the edge of a tokamak, up to the ITG turbulence at higher temperatures in the core-edge transitional regime.

Earlier attempts with a less sophisticated collision operator in the gyrokinetic code were unsuccessful to come close to the expected transport values in the edge regime. Surprisingly, it has been much easier to match fluid and gyrokinetic results in the lower collisionality ITG regime in the core-edge transitional region. Even in the collisionless core the transport difference between fluid and gyrokinetic results for non-marginal instabilities are $\lesssim 30\%$ [3].

A non-trivial, novel result is that the linear growth rate and nonlinear transport agree between the codes in the fluid limit of *high* collision numbers ($\nu_e \sim 500 - 2000 c_i/R$), not least, because the kinetic code treats the collisions fully implicit and employs the Sugama collision operator with momentum and energy conservation, Galileian invariance and numerically exact self-adjointness property.

For example, runs with resistive ballooning turbulence in the edge regime using the CGYRO and the NLET code were performed at the parameters $R/L_n = 10$, $R/L_T = 0$, $\varepsilon = r/R = 0$, $q = 3.2$, $T_i = T_e$, $\nu_{ee} = 586 c_i/R$. For the fully developed turbulence the amplitude, pattern, time- and length-scales of the turbulence agree within the statistical errors, indicating that the proper fluid limit has been obtained. E.g., the gyro-Bohm particle diffusivities in the mentioned case are $\chi_{CGYRO} = 772$, $\chi_{NLET} = 796$ (in units of $\rho_i^2 c_i/R$). The cross ion and electron heat diffusivities are slightly less then 3/2 times that, $\chi^{i,Q}_{CGYRO} = 1047$, $\chi^{i,Q}_{NLET} = 1131$, $\chi^{e,Q}_{CGYRO} = 1034$, $\chi^{e,Q}_{NLET} = 1120$.

Regarding the structure of the turbulence the typical fluid-like Kelvin-Helmholtz plumes appear in the simulations, which is very different from the case of collisionless turbulence, with its strongly dispersive behaviour and rather diffuse and random perturbations

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