Zonal flows governed by density gradients in gyrokinetic simulations of slab ITG turbulence

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The fusion power in ITER is estimated from an empirical scaling law for the energy confinement time. It is also sensitive to the density profile, for which a large uncertainty remains. Predictions for turbulent transport, based on first principles, are thus crucial to bridge the gap between present experiments and ITER. This paper reports on non-linear gyrokinetic simulations of heat and particle turbulent transport in a 4D model for the slab branch of the Ion Temperature Gradient (ITG) driven turbulence in a cylinder. In the limit $k_\perp\rho_i<<1$ ($k_\perp$ the transverse wave vector, ρ_i the thermal ion Larmor radius), the distribution function is 3D in space and 1D in the velocity, namely $v_{//}$. The **E**×**B** drift governs the transverse dynamics, while the parallel motion is governed by $\mathbf{E}_{//}$. The electron response is adiabatic. The Vlasov-Poisson like system is solved on a fixed grid with a semi-Lagrangian scheme for the entire distribution function. The number of particles and the energy are typically conserved within less than one percent in the non-linear regime. The initial profiles of density, electron and ion temperatures are essentially hyperbolic tangents. The driving force of the system consists of different densities and ion temperatures at the boundaries. Slab ITG modes become unstable when the ion temperature gradient exceeds a threshold which increases with the density gradient. Two cases with different initial conditions are considered. The trajectories of the central radial point of the system are plotted on fig. 1 in a Ω^*_T, $\langle V_\theta\rangle'$ diagram. The diamagnetic frequency is $\Omega^*_T = (k_\theta\rho_i)\, v_T\, \partial_r \log T_i$, with k_θ the poloidal wave vector and v_T the ion thermal velocity. Circles refer to a finite initial density gradient. Square symbols correspond to the same case with a flat density initial profile. The central region is initially unstable in both cases. The flat density case relaxes towards marginality by decreasing the temperature gradient. A strong heat outflow at the beginning of the non-linear phase leads to an almost flat T_i profile, with strong gradients at the edges (fig. 2). Conversely, in the other case, a mean sheared flow $\langle V_\theta\rangle'$ is self generated, leading to a transport barrier on the temperature profile. This comes from the fact that, at lowest order, the magnitude of the Reynolds stress is proportional to the density gradient, namely Ω^*_n. To sum up, the system relaxes preferentially either via heat transport or via mean sheared flows, depending on the initial conditions. A strong density gradient appears to be stabilizing both linearly, by increasing the instability threshold, and non linearly, by activating sheared flows. Such a mechanism provides a way to sustain – and possibly to trigger – pressure transport barriers.

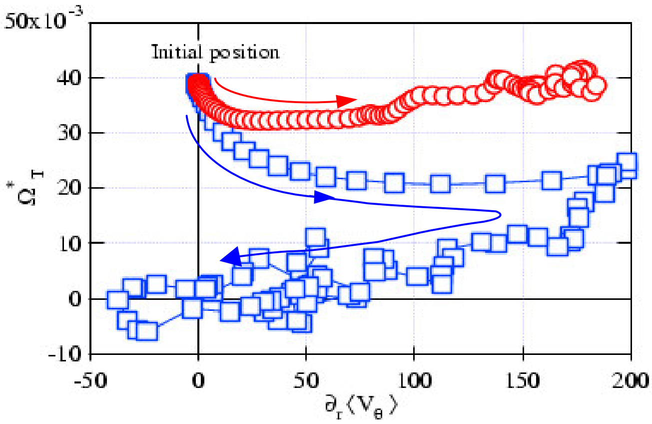

Fig.1: *Trajectories at mid radius for an initially flat (squares) or shaped (circles) density profile .*

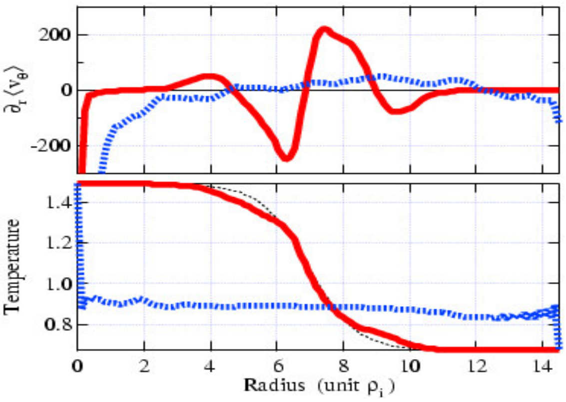

Fig.2: *Final profiles when the initial density profile is flat (dashed) or shaped (plain).*