Non-local structure and dynamics of flux driven turbulent transport

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Non-local turbulent transport and profile stiffness/resilience are long standing problems, which have been observed in magnetically confined fusion plasmas. In 1990s, full-kinetic simulation demonstrated that the toroidal ITG modes impose a strong constraint on the functional form of the profile, leading to a self-similar relaxation [1]. On the other hand, recent advanced flux-driven gyrokinetic simulations have also revealed that stiff ion temperature profiles are sustained with a critical gradient, and a significant part of the heat flux is carried by avalanches with $1/f$ type spectra [2, 3]. However, the underlying mechanism which impose such a constraint even in the presence of mean flow determined self-consistently by evolving equilibrium profiles has not been clarified yet.

In order to understand such a mechanism, we have newly developed a 5D toroidal global gyrokinetic code with heat source/sink and collision. This enables us to simulate flux-driven ITG turbulence coupled with neoclassical ion heat transport, where the radial electric field is determined consistently through radial force balance with pressure profile and toroidal rotation. Full-order FLR effect is also properly taken into account and the validity is well demonstrated through several linear and nonlinear benchmark tests such as linear/nonlinear ITG instability and collisionless damping of zonal flow.

Based on this code, we investigated the non-local characteristics of flux-driven ITG turbulence to clarify the underlying mechanism of avalanches, profile resilience and their dynamic responses in the presence of mean flow. We found that the transport is dominated by two processes: one is the fast intermittent bursts resulting from the instantaneous formation of radially extended potential vortices, whose size ranges from meso ($\sim \sqrt{L_T \rho_i}$) to even macro ($\sim L_T$) scale across the $E \times B$ staircase [4]. Such potential structures are considered to trigger the non-Gaussian PDF (probability density function) tails of turbulent heat flux, which becomes longer as heat input power increases. The other process is the slow convective propagation (avalanche) of temperature corrugation coupled with the meso-scale $E \times B$ staircase, which propagates from half-minor radius to edge.

Ascribed to these events with long correlation lengths, a self-organized resilient profile keeping the exponential function form is found to be established even in the presence of mean flows. The energy partition of the mean flow to the total fluctuation, i.e. $\eta \equiv E^{(mean)} / (E^{(mean)} + E^{(turb)})$ is found to decrease with P_{in} as $\eta \propto 1/\sqrt{P_{in}}$, so that the profile keeps the same function form even in high input power regime while typical scale length L_T weakly depends on P_{in}.

References

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