Non-local structure and transport in toroidal flux-driven ITG turbulence
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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/zonal flow 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 made the following new findings;

- Flux-driven turbulent transport is dominated by three processes: (a) fast-scale avalanches, (b) explosive global transport and (c) slow-scale radial convection of temperature corrugation coupled with $E \times B$ staircase [4].
- Explosive global transport (b) is triggered by the instantaneous formation of radially extended potential vortices, whose size ranges to even macro-scale ($\sim L_T$). The neoclassical mean flow shear plays an important role in forming such a global ballooning structure through the cancelation of global profile variation effect, i.e. diamagnetic shear.
- Ascribed to these events with long correlation lengths, a self-organized resilient profile keeping the exponential function form is established even in the presence of zonal/mean flow. Such a resilience is also confirmed from step-up/down switching test for heat input power, which justifies a self-organized critical type transport is dominant in flux-driven ITG turbulence.
- A break of resilience is observed in outer region, where radial convection of temperature corrugation coupled with $E \times B$ staircase (c) occurs, exhibiting a weak transport barrier formation in high power regime. Radial convection (c) is similar to typical avalanches (a), but the heat flux is sustained by neoclassical counterpart since turbulence is suppressed.