Up-gradient Particle Transport in Magnetically Confined Plasmas

Zhibin Guo

Peking University, Beijing 100871, China

Particle transport is one of the most important is- sues in achieving magnetically controlled nuclear fusion, since the fusion power is proportial to the square of the plasma density. In future fusion reactor, the D-T plasma fueling is mainly at the periphery, therefore an efficient up-gradient particle transport is vital to forming a peaked density profile. In this vein, turbulence equipartition (TEP) is proposed as a robust mechanism that induces an inward pinch. In the TEP, a 'canonical' density $n\lambda$ (n: plasma density; λ: an auxiliary field) is contructed to be a Lagrangian invariant and is assumed to get homogenized through turbulent mixing. Since λ is inhomogeneous, a non-equilibrium (i.e., peaked) density profile forms. The utmost involved auxiliary field is the magnetic field (i.e., $\lambda = 1/B$). Correspondingly, the pinch velocity u is proportional to the magnetic curvature, $u \propto 1/R$, where R is the large radius. Though u is always negative (i.e., an inward pinch), the TEP mechanism based on $\lambda = 1/B$ can only surport a weakly inhomogeneous density profile, $\nabla r \ln n \propto 1/R$. While in the magnetized plasma systems, the core density could be much peaked. Particularly in the edge regime of H-mode (H: high performance), the density gradient is too steep to be explained by the TEP process based on the B-field inhomogeneity. Pragmatically, the relation $u \propto 1/R$ also lowers the controllability of the inward particle transport and it becomes even smaller for a larger fusion device, such as the ITER (International Thermonuclear Experi- mental Reactor).

On the other hand, it is well documented that $E \times B$ flow is essential in regulating various plasma turbulence transports. Not only reducing the turbulence intensity vis $E \times B$ flow shear, recently it is revealed that the $E \times B$ curvature (i.e., mean vorticity gradient) may qualitatively impact the underlying turbulence dynamics by driving vortex waves. In this work, we will show the coupling between particle transport and the vortex dynamics. we also demonstrate that the vorticity fluctuation can induce nonlocal spatial coupling, so that the particle flux at one location may 'slaved' to the thermodynamical force (i.e., gradient of the free energy field) at other locations.