Up-gradient Particle Transport Driven by Potential Vorticity Boundary Layer

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Realizing an efficient up-gradient particle transport is crucial to the fueling problem in future nuclear fusion reactor, because the fuels can only be injected into the edge region while the thermal nuclear fusion occurs mainly in the core region. However, the existing up-gradient transport mechanisms are either too mild (e.g., turbulent-equipartition) or too sensitively depends on the excitation of a specific mode (e.g., the ion-mixing-mode)[1].

In this work, we study the Hasegawa-Wakatani system[2], which is PV conserved and extensively used to study the plasma edge turbulence, with cylinder boundary condition. Fig. 1(a) shows that the particle transport is constrained by the PV homogenization in the core plasma region, which is reported in lecture[3] and observed for various parameters. Combine with negative turbulent vorticity viscosity[4], the zonal flow profiles can be fitted by 1st order Bessel function in the PV mixing region, which are shown in Fig. 1(b), and hence the density profile can be determined. The PV mixing inevitably produces a PV boundary layer in a bounded system, in which the positive vorticity gradient drives an up-gradient particle flux (Fig. 1(c)). We also report the nonlocality of turbulent particle flux: In Fig. 1(d), with a typical mean density and a step mean vorticity field, we show that the particle flux is negative in relative broad region, which is induced by vorticity fluctuation at the jumping point of mean vorticity. This work was supported by the National MCF Energy R&D Program (2018YFE0311400).

References

[1] Angioni C, Camenen Y, Casson F J, et al, Nuclear Fusion, 2012, 52(11): 114003.

[2] Hasegawa A, Wakatani M, Physical Review Letters, 1983, 50(9): 682.

[3] Rhines P B, Young W R, Journal of Fluid Mechanics, 1982, 122: 347-367.

[4] Smolyakov A I, Diamond P H, Malkov M, Physical review letters, 2000, 84(3): 491.

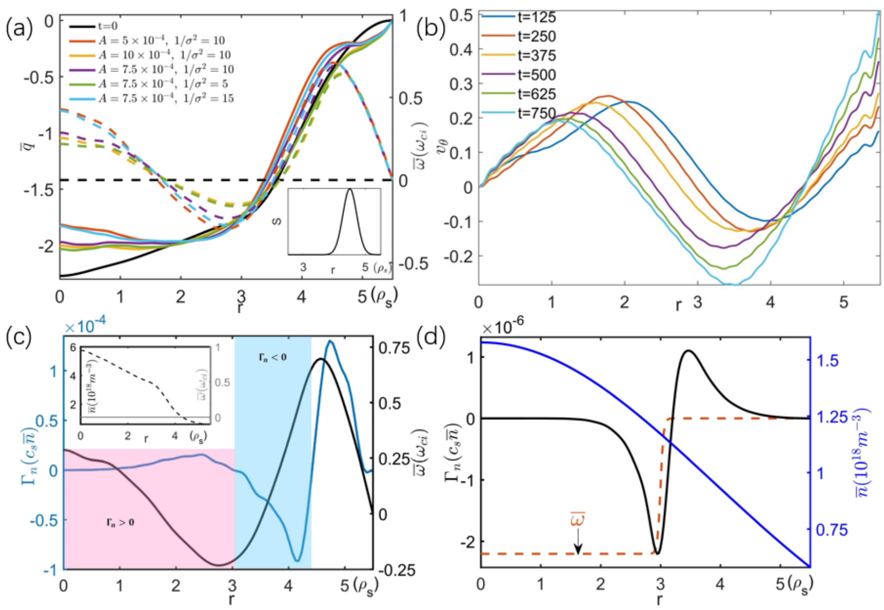

Figure 1: (a) The quasi-steady profiles of mean PV (solid curves) and vorticity (dash curves) for different sources identified by parameters A and σ with the same initial profiles (t=0). (b) Spatial profile of zonal velocity for different times. (c) Relation between mean vorticity profile and the particle flux. The initial profiles of density and vorticity are shown in the subplot. (d) Particle flux (black) with a step vorticity (dash red) and a typical density (blue) profile.