§2. Simulation Study of Multi-scale Plasma Turbulent Transport and Structure Formation

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The physics of multi-scale turbulence with wide spectrum due to various linear and nonlinear instabilities in magnetic fusion plasmas has attracted much attention recently. Among various turbulent fluctuations and large-scale structures, shear flows, such as self-generated zonal flows (ZFs) or externally imposed mean flows (MFs), have been found to play an essential role in reducing turbulent transport via 1D flow-shear effects. Especially, the transport suppression by such shear flows has been identified as a fundamental mechanism for the formation of transport barriers, crucially important for a high confinement regime [1]. However, large-scale vortex flows (VFs) varying in both poloidal and radial directions such as long-wavelength Kelvin-Helmholtz (KH) and/or MHD tearing mode, which are also observed in plasmas extensively, may provide a 2D flow-shear effect. Such flows are inevitable due to the inherent poloidal asymmetry features of equilibrium field anisotropy. Transport processes affected by such VFs in regulating micro-turbulence cannot be understood based on the theory of the 1D flow-shear effects. In this study, we investigate the roles of the VFs in the evolution of micro-turbulence by imposing an external VF into the ion temperature gradient (ITG) driven turbulence system for transparence and simplicity.

The nonlinear electrostatic gyrofluid model in slab geometry is adopted for our simulation. The 3-filed nonlinear equations governing the development of the ITG turbulence is employed[2] with coupling with imposed external VFs as follows,

$$\phi_T = \phi_{TX}(x)\sin(k_T y) = \phi_m f(x)\sin(k_T y) \quad , \qquad (1)$$

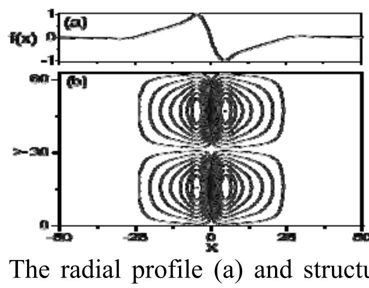

Fig.1 The radial profile (a) and structure contour (b) of VF $\phi_T = \phi_m f(x)\sin(k_T y)$.

where $f(x)$ and k_T are the normalized radial profile and poloidal wave number, respectively, and ϕ_m stands for the VF strength. The representative structure of VFs with two vortices on each side of the rational surface is shown in Fig. 1. The assumption on the time-independence of the VFs should be valid when VFs evolve in a much slower scale than ITG turbulence or are approximately in a stationary state. The VFs may then be understood as a multiplied combination of two anisotropic structures MFs and a streamer-like flows (SFs) with $\phi_T = \phi_m \sin(k_T y)$.

It is found that via the 2D flow-shear effect the VFs can significantly suppress micro-turbulence even with weak flow shear, which is qualitatively different from the usual mean flows that destabilize micro-turbulence in a weak flow-shear regime, as shown in Fig.2. The mechanism is identified as the multiplied effect of both radial and poloidal mode couplings.

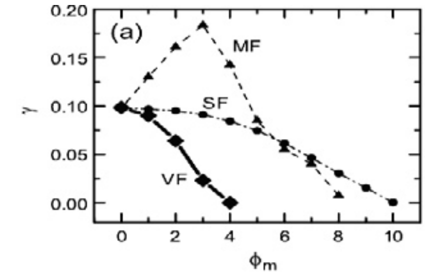

Fig. 2. ITG growth rate vs ϕ_m in 2D linear simulations with magnetic shear $\hat{s} = 0.4$, $\eta_i = 2.2$, $k_T = 0.1$.

Gyrofluid simulations show that VFs can significantly suppress the local transport in the region with strong radial flow-shearing. Meanwhile such flows also lead to an oscillatory ZF component at around weak radial flow-shearing region so that the suppression role of the ZFs in ion transport is reduced locally [3]. The resultant transport structure due to the VFs dynamics behaves similar to the formation of the ITBs in current tokamak experiments. These prominent effects of VF flows are attributed to the structure formation of the ITG fluctuation due to the 2D mode coupling of the VFS, as shown in Fig.3.

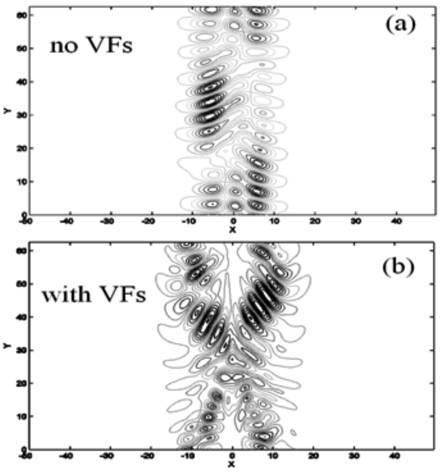

Fig.3 ITG mode structures in the cases without (a) and with (b) external VFs.

1) Diamond P. H. *et al* 2005 Plasma Phys. Control. Fusion **47** R35

2) Li Jiquan and Kishimoto Y., Phys. Plasmas **10**, 683 (2003)

3) Wang Z. X., Li Jiquan, Dong J. Q., and Kishimoto Y., Phys. Rev. Lett. **103**, 015004 (2009)