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Trapping and de-trapping bifurcation of drift wave turbulence by zonal flows based on a reduced fluid model

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Turbulence in magnetically confined plasmas dominates the plasma profiles and performance. Turbulence simulations, including gyro-kinetics and fluids, have universally shown the ballistic propagation and spatial localization of the turbulence [1-3]. Understanding these dynamic phenomena is an inherently important issue for detailed plasma distribution control. The turbulence intensity is spatially modulated by the zonal flow and takes a wavelength same as that of the zonal flow. On the other hand, according to conventional turbulence suppression theory, turbulence is suppressed by the shear intensity of the flow, so the turbulence intensity is expected to be half the wavelength of the zonal flow. This does not explain the observations from the simulations [4]. Therefore, an extension of the picture regarding to the interaction of the turbulence and zonal flows is needed.

According to the wave-kinetic theory, it is theoretically pointed out that the turbulence trapping mechanism by zonal flows appears [5-7]. Wave-kinetic theory deals with the distribution function of turbulence in the phase space, which consists of real and wavenumber spaces. Turbulence trapping occurs as a result of non-linear resonance between zonal flows and turbulence. When turbulence trapping by zonal flows occurs, turbulence accumulation and exclusion occurs at specific spatial phases of the zonal flow, and the spatial phase relationship is maintained for a long time. If the zonal flow is spatially propagating, the turbulence propagates ballistically at the phase velocity of the zonal flow with keeping the phase relationship [8]. If the zonal flows do not propagate in space, the turbulence is also spatially localized and involves corrugation of the plasma profiles due to the localization of the turbulence driven fluxes [6]. Thus, the turbulence trapping mechanism by zonal flows could have a key to understand the spatio-temporal behavior of turbulence.

In this study, therefore, turbulence simulations are used to investigate the presence or absence of turbulence trapping mechanisms. Turbulence simulations based on the Hasegawa-Wakatani model are performed in the two-dimensional space shown below. Periodic boundaries are employed as boundary conditions. Here, simulations are performed with α (adiabatic coefficient) as a parameter, varying from shot to shot, to investigate the behavior of zonal and turbulent flows.

Figures 1 shows the time evolutions of the radial distributions of the turbulence-driven particle flux, turbulence intensity and zonal flow evaluated from the turbulence data obtained in the simulations. Here, all physical quantities are poloidally averaged. The upper and lower panels of Fig. 1 correspond to cases with adiabatic coefficients of 1 and 0.1, respectively. From the upper panel of Fig. 1, the drift wave turbulence begins to grow linearly at time t=0 and reaches nonlinear saturation around

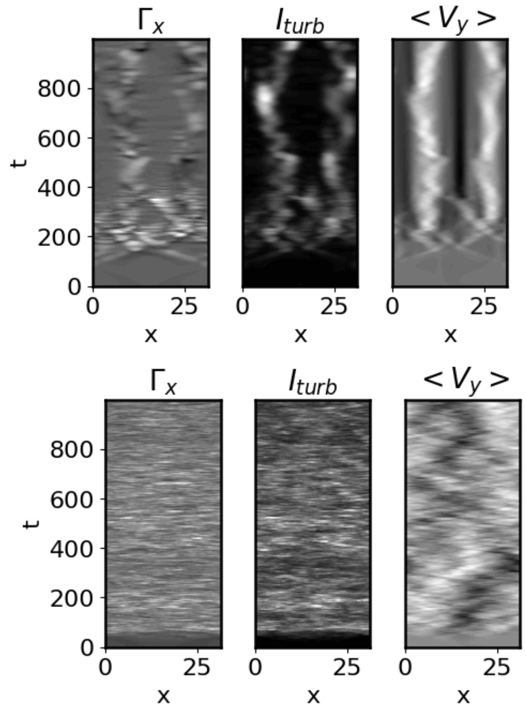

Fig. 1: Time evolutions of radial profiles of particle flux, turbulence intensity and zonal flows in the cases of α=1 (upper) and α=0.1 (bottom).

t~200. In the nonlinear saturated state, zonal flows develop and spatially modulate the turbulence intensity can be observed. The turbulence intensity is strong in the region where the zonal flow is positive (negative radial second-order derivative, so curvature). This phase relationship is consistent with the relationship predicted by wave-kinetic theory in [5-7]. On the other hand, for small adiabatic coefficients, the zonal flow energy itself is found to be large, but the lifetime of the zonal flow is short and turbulent trapping doesn't occur. It is found that the turbulence characteristics and zonal flows change as the adiabatic coefficient changes, and the turbulence itself self-selectively transitions between trapping and non-trapping states.

References

[1] G. Dif-Pradalier, Phys. Rev. Lett., 114, 085004 (2015).
[2] M. Nakata, 53, 113039 (2013).
[3] B. F. McMillan, Phys. Plasmas, 16, 022310 (2009).
[4] H. Biglari, Phys. FluidsB, 2, 0899 (1990).
[5] P. Kaw, Plasma Phys. Control. Fusion, 44, 51 (2001).
[6] M. Sasaki, Phys. Plasmas, 28, 112304 (2021).
[7] X. Garbet, Phys. Plasmas, 28, 042302 (2021).
[8] M. Sasaki, Sci. Rep. , 7, 16767 (2017).