9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Turbulence localization in zonal flows in Hasegawa-Wakatani model

Lei Yao[1], T-H Watanabe[2]
[1 2] Department of physics, Nagoya University
e-mail (speaker):
yao.lei.r4@s.mail.nagoya-u.ac.jp

Abstract

Plasma turbulence, arising from the nonlinear interaction of waves and instabilities in magnetized plasmas, plays a crucial role in determining energy and particle transport within fusion devices and astrophysical systems. This study is based on the Hasegawa-Wakatani (H-W) model, a two-dimensional fundamental framework for investigating drift wave turbulence in magnetized plasmas[1].

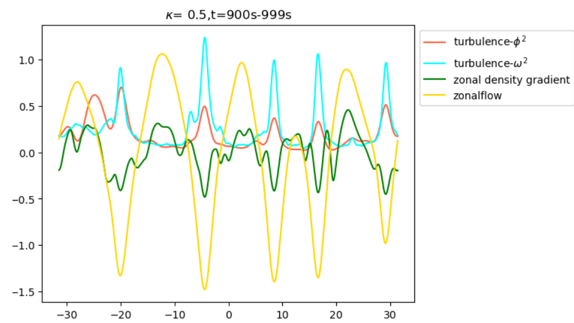
A drift wave is a wave-like motion driven by the interplay between the plasma's density gradient and the effects of the magnetic field. Its propagation is perpendicular to both the density gradient and the magnetic field. The drift wave becomes unstable when the density gradient exceeds a critical threshold. When amplitudes of the drift waves are large enough, the nonlinear interactions of drift waves lead to turbulence. This turbulence can give rise to secondary structures, such as zonal flows—meso-scale, band-like flows that move perpendicular to both the magnetic field and the plasma's density gradient.

This study investigate the influence of both self-generated zonal flows and externally imposed shear flows on the behavior of plasma turbulence and the evolution of vortex structures within the H–W model framework. The simulation results show that zonal flow exhibits relatively greater strength when the density gradient decreases. For small density gradient and strong zonal flows, turbulence localize in regions where zonal flows have opposite direction to the drift wave propagation. Also, while externally imposed shear flow has a relatively weak influence, with limited effects on turbulence intensity and vortex formation, the impact of zonal flows become significant as the strength of the externally imposed shear flow increases for large density gradient.

These findings contradict the conventional theory of turbulence trapping, which predicts that turbulence should localize in regions where zonal flow has the same direction with drift wave propagation[2]. This suggests a complex interaction between zonal flows and turbulent structures under such conditions. A potential explanation for this phenomenon may lie in the influence of zonal structure of plasma density generated by the turbulence on the drift wave instability growth rates.

In summary, this work provides new insights into the multi-scale interaction between turbulence and large-scale flow structures—including zonal flows and externally imposed shear flows—and has potential implications for predicting and controlling turbulent transport in magnetically confined fusion plasmas.

Reference:
[1]Hasegawa, A., & Wakatani, M. (1983). A theory of the nonlinear dynamics of the ion-temperature-gradient-driven instability. Physics of Fluids, 26(2), 464-470.
[2]Sasaki, M., Itoh, K., Hallatschek, K., Kasuya, N., Lesur, M., Kosuga, Y., & Itoh, S.-I. (2017). Enhancement and suppression of turbulence by energetic-particle-driven geodesic acoustic modes. Scientific Reports, 7, 16767.



$\kappa = 0.5$, turbulence localize in regions of negative zonal flow and zonal density gradient.