F-I10 AAPPS-DPP2020

4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

A unified theory of zonal flow dynamics

Rameswar Singh and Patrick H Diamond
CASS, University of California San Diego
e-mail (speaker): rameswarsingh@gmail.com

Spectral equations for zonal flow, density corrugations and turbulence energy have been derived for the drift wave turbulence[1]. The spectral equation for the zonal flow energy shows two distinct mechanisms of zonal flow excitation- modulational growth (coherent) and zonal noise or polarization noise drive (incoherent). The two are of comparable strength. The synergy of the two mechanisms is stronger than the either element alone. The polarization noise scales as spectral Reynolds stress squared times the triad interaction time. The polarization noise is positive definite and is insensitive to the spectral slope. Polarization nonlinear noise generates the zonal flow even when the drift waves are modulationally stable. Whereas, zonal flow growth by modulation mechanism requires a sufficiently negative spectral slope[2]. Noise eliminates the threshold in the linear growth rate of turbulence for zonal flow excitation within the predator prey model. This is consistent with the observation of zonal flows without a critical power in experiments. The zonal intensity increases and turbulence intensity decreases with the strength of zonal noise.

Spectral equations for density corrugations also show two distinct mechanisms of density corrugations- modulational and convective noise. However, the modulation growth of density corrugations does not require a negative spectral slope. This is consistent with a similar observation made for temperature corrugations in ITG turbulence[3]. So density and temperature corrugations are more ubiquitous than the zonal flows. Both modulational growth and convective noise are weaker in the adiabatic regime than that in the hydrodynamic regime. In contrast, the modulational growth of the zonal flow is stronger in the adiabatic regime than that in the hydrodynamic regime. This means that the zonal flows are dominant in the adiabatic regime and density corrugations are dominant in the hydrodynamic regime. Both zonal flow and corrugations feedback turbulence via random refraction induced diffusion in wave number space.

A variation of KD03 0D model[4] consisting of turbulence energy, zonal flow energy and pressure gradient is advanced to study the effect of zonal noise on L-H and H-L transition dynamics. With noise, substantial zonal flows appear much below the threshold for the modulational excitation without noise. This reduces the predicted threshold power for the transition to the H mode. I-phase persist, but with lower onset threshold and reduced oscillations. The model exhibits hysteresis in a cyclic power ramping. The back transition from H to I-phase occurs at a lower power. The I-phase during power ramp down is more oscillatory than that during power ramp up. The area enclosed by the hysteresis curve is reduced with the zonal noise strength.

This work is supported by US DOE under award number DE-FG02-04ER54738

References

1. A. Hasegawa and W. Wakatani, Phys. Rev. Lett. **50**, 682 (1983).
2. P. H. Diamond, S. I. Itoh, K. Itoh, and T. S. Hahm, Plasma Phys. Controlled Fusion **47**(5), R35-R161 (2005).
3. R. Singh, R. Singh, O. D. Gurcan, P. K. Kaw and P. H. Diamond, Phys. Plasmas **21**, 102306 (2014)
.
4. E. Kim and P. H Diamond, Phys. Rev. Lett. **90**, 185006 (2003)