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Role of Zonal Flow in Intermediate-Scale Electron Temperature Gradient Turbulence

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Electron temperature gradient (ETG) turbulence is regarded as a candidate for electron heat transport in tokamaks. However, due to its extremely fine scale, the associated electron heat transport from dimensional analysis is limited to electron gyro-Bohm level. Since observed numerically in early 2000s, radially elongated streamers have been proposed to enhance electron heat transport in ETG turbulence. Zonal flow (ZF) generation, meanwhile, is thought to be weak. To the best of our knowledge, there is no experimental evidence as yet for the existence of streamers.

Here, we develop a nonlinear gyrokinetic theory of ZF generation in intermediate-scale (shorter than ion gyroradius but longer than electron gyroradius) ETG turbulence [1], which is connected with long-time saturation. Both plasma nonuniformity and continuous radial spectrum effects are properly included. The resultant Schrodinger equation for ETG amplitude is characterized by a Navier-Stokes type nonlinearity, which is typically stronger than the Hasegawa-Mima type nonlinearity in fluid limit. Therefore, ZFs can be more easily excited in intermediate-scale than in the short wavelength regime. A novel ETG saturation picture is proposed that, in the early nonlinear phase, strongly unstable short wavelength ETGs are saturated by inverse cascading, with streamers being well preserved; as spectrum downshifts, the ZF generation becomes more important, and will ultimately break up streamers, leading to isotropic eddies. Therefore, streamers cannot exist in realistic experimental devices. Gyrokinetic simulations are applied to verify theoretical predictions.

References

[1] H. T. Chen, et al., Nucl. Fusion, 61, 066017 (2021).