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Interaction between Turbulence, Zonal flow and Magnetic shear

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Turbulent transport driven by drift wave instabilities is widely observed in fusion plasmas. One of the common causes of ion turbulent transport in tokamaks is the ion temperature gradient (ITG) instability, which significantly reduces the efficiency of fusion reactors. It is known than both zonal flow and magnetic shear can directly regulate ITG turbulence in fusion device. Can magnetic shear suppress turbulence indirectly via interacting with zonal flow? This study employs gyrokinetic simulations to investigate ITG turbulence in tokamak plasmas featuring reverse magnetic shear. The weak negative magnetic shear is observed to be more stable for the ITG instability than strong positive shear, primarily stemming the scarcity of mode rational surfaces induced by the weak negative shear. This superiority in suppression for the negative shear persists in nonlinear turbulence with zonal flow artificially eliminated, where the emergence of turbulence solitons is observed and found associated with local condensation mode rational surfaces. However, the difference in transport levels among different magnetic shears diminishes in the presence of self-consistently generated zonal flow, accompanied by the disappearance of turbulence solitons. The nonlinear generation of zonal flow is found to be significantly affected by the magnetic shear. The study reveals that the Dimits shift no longer exists for negative magnetic shear, which is attributed to the weakness of the zonal flow generation near the ITG marginal stability. This phenomenon is quite robust despite plasma shape and residual zonal flow level.

References

[1] D.K. Yang, S.M. Li, Y. Xiao and Z. Lin, Nuclear Fusion, accepted, (2024)

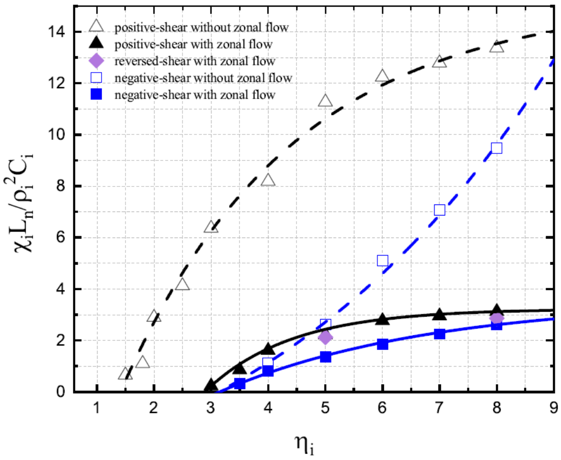

Figure 1. Ion thermal conductivity χi varies with ηi for various magnetic shears with or without zonal flow.

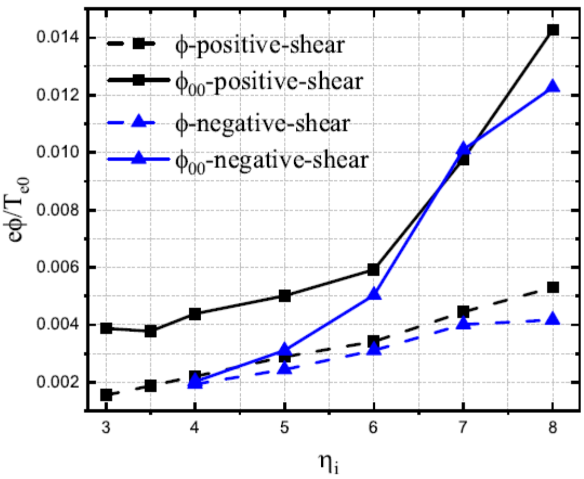

Figure 2. Saturation levels of zonal flow and ITG turbulence