The effects of magnetic shear and plasma temperature gradients on intrinsic rotation generation via parity changes in global electromagnetic ITG modes

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Intrinsic rotation refers to the spontaneously generated toroidal plasma flow that arises in the absence of external momentum input. It is expected to play an important role in future reactor-scale devices, including ITER, where the available external torque will be insufficient to effectively suppress magnetohydrodynamic instabilities. In this work, we extend our previous study to investigate the influence of magnetic shear and plasma temperature gradients on intrinsic rotation driven by electromagnetic (EM) ion temperature gradient (ITG) modes.

Our previous work [1] demonstrated the global EM effects on the ITG modes and the associated generation of intrinsic rotation. The global ITG mode has pure even parity in the electrostatic (ES) regime, but the odd parity component gradually develops due to global EM effects. This parity mixing in the global EM-ITG mode differs from the behavior of local EM-ITG mode, which exhibits a complete parity change from purely even to purely odd. The resulting mixed parity indicates mode asymmetry, so the global EM-ITG mode can generate intrinsic rotation without any other symmetry breakers, such as E×B shear. As the plasma beta (β= thermal energy / magnetic energy) increases, this parity mixing becomes stronger, leading to enhanced EM parallel Reynolds stress.

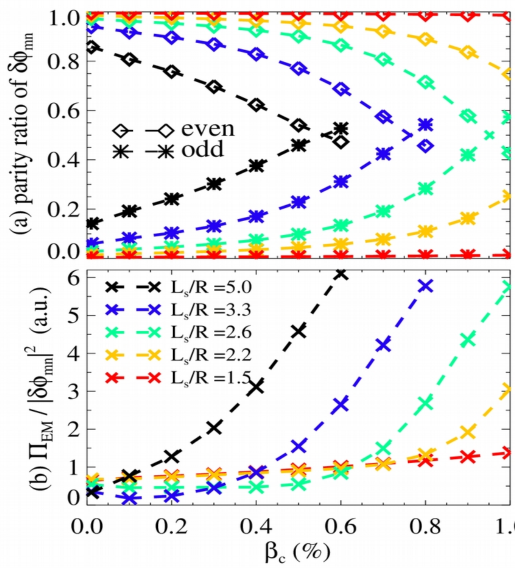

Figure 1. (a) The parity ratios of δφ and (b) EM parallel Reynolds stresses as the functions of β for different L_s/R with R/L_T=5.0.

In this study, we compute the EM-ITG modes for various safety factor (q) and plasma temperature profiles to investigate the profile shear effects. The EM-ITG modes are obtained by solving the five-field fluid equations with the BOUT++ framework, and the parallel Reynolds stress is calculated using linear EM-ITG modes to analyze the generation of the intrinsic rotation in the context of quasi-linear analysis.

Magnetic shear and temperature gradient exert opposing effects on the generation of the intrinsic rotation. As the magnetic shear scaling length ($L_s/R=q/\hat{s}$) increases, the parity ratio changes more rapidly, resulting in greater mode asymmetry [Fig. 1(a)]. As a result, the EM Reynolds stress is enhanced with Ls, especially in high-β regime [Fig. 1(b)]. In contrast, the EM Reynolds stress is also enhanced with R/L_T (rather than L_T/R), where L_T= T/∇T denotes a temperature gradient scale length. As R/L_T increases, the parity ratio again varies more rapidly, leading to a corresponding enhancement in the Reynolds stress.

These results indicate that intrinsic rotation in the high-β regime can be amplified in plasmas characterized by weak magnetic shear (i.e., large Ls/R) and improved confinement (i.e., large R/L_T) [Fig. 2]. Moreover, these findings are consistent with experimental observation [2], although the quasi-linear approach adopted here does not fully capture the nonlinear dynamics of developed turbulence

References

[1] H. Kaang et al, Phys. Plasmas. 25, 012505 (2018).
[2] J. E. Rice et al, Nucl. Fusion 57, 116004 (2017).

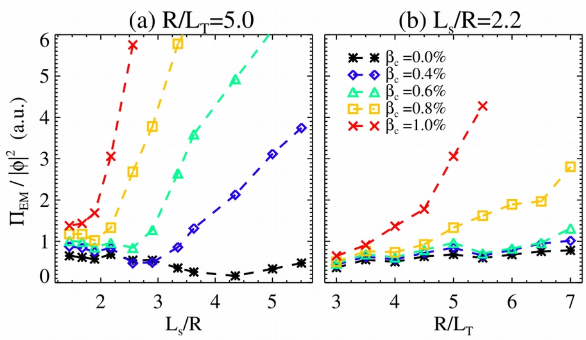

Figure 2. EM parallel Reynolds stresses as functions of (a) L_s/R and (b) R/L_T for different β.