Gyrokinetic electromagnetic simulation of single poloidal harmonic instability

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Previous gyrokinetic simulations demonstrate an ITG-KIM transition as β increases for DIII-D like Cyclone parameters with reversed safety factor profile.[1,2] In this work, it is identified that in the low to moderate β ($\beta\sim$ 0.2%) regime, when $q_{\min}$ coincides with a mode rational surface, an instability characterized by a dominant single m (poloidal harmonic) component is destabilized rather than the conventional ITG, which is widely expected to emerge in this region.

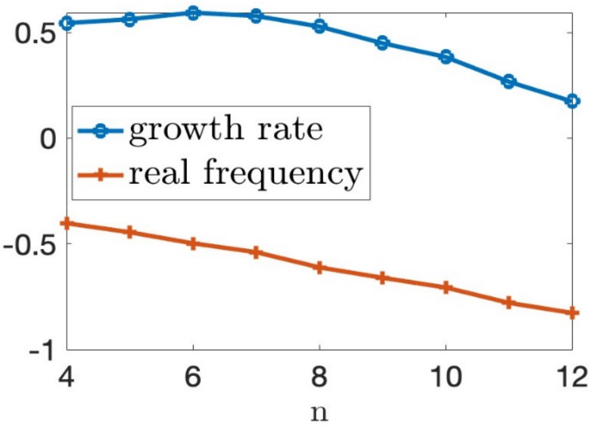
Gyrokinetic simulations of this single m instability have been carried out using the electromagnetic gyrokinetic particle code TRIMEG-GKX.[3] The ITG-KIM transition benchmark ($\beta \in [0.2\%, 2\%]$) has been reproduced. In addition to previous studies, it is found that the ion-electron mass ratio m_i/m_e affects not only the growth rate, but also the radial location of the mode structure. Specifically, as m_i/m_e increases from 100 to 400, the peak of the radial mode structure shifts from the location of $q_{\min}$ to the mode rational surface nearest to the $q_{\min}$ position. Therefore, $m_i/m_e = 400$ is adopted for the simulations in this work.

The newly identified single m instability has been investigated in terms of its frequency, dispersion relation, mode structure and polarization compared with the ITG mode. The real frequency of this instability is much higher than that of an ITG mode, while the growth rates are comparable. The dispersion relation of this instability shown in the left figure is similar to that of the conventional ITG mode.[4] The two-dimensional mode structure indicates that the instability also appears on the high field side, instead of only on the low field side. The global polarization analysis is illustrated in the right figure, where the solid line represents $-\mathbf{b}\cdot\nabla\delta\phi$, and the dashed line represents $\frac{1}{c}\frac{\partial A_\parallel}{\partial t}$. As shown in this figure, the magnetic vector potential perturbation is much smaller than the electrostatic potential perturbation, suggesting that this instability is electrostatic. The polarization and dispersion relation indicate that this instability is most likely an ITG mode, while the two-dimensional mode structure and real frequency suggest that it belongs to the slab branch of ITG.

Furthermore, the different effects of plasma β both on the traditional ITG and this single m mode are demonstrated. In the electrostatic limit ($\beta = 0.01\%$), the toroidal ITG mode is dominant while for moderate β ($\beta \sim 0.2\%$), this single m mode is dominant, suggesting the different influence of $A_\parallel$. This finding contributes to an understanding of different ITG branches with the electromagnetic effects.

References

[1] Ishida Y et al., Phys. Plasmas 27, 092302 (2020).
[2] Li G et al., arXiv:2405.10568 (2024), submitted to Nucl. Fusion.
[3] Lu Z et al., J. Comput. Phys. 440, 110384 (2021).
[4] Rewoldt G et al., Comput. Phys. Commun. 177, 775–780 (2007).



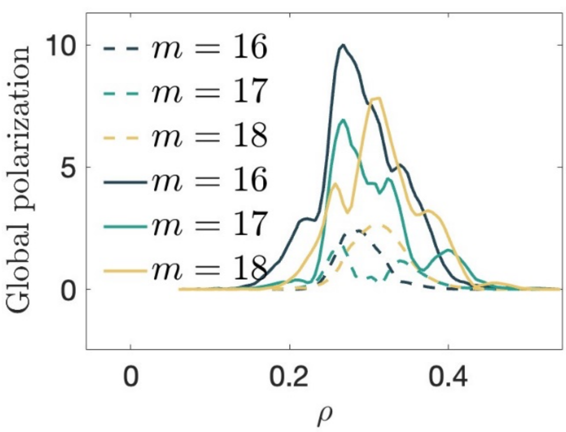


Figure. Left: Dispersion relation of the single m mode, blue circle line represents the growth rate γ and red plus line represents the real frequency $\omega/4$. **Right:** The global polarization of the single m mode. The solid line denotes $-\mathbf{b}\cdot\nabla\delta\phi$ and the dashed line denotes $\frac{1}{c}\frac{\partial A_\parallel}{\partial t}$.