Fundamental physics of the fast ion stabilization of electromagnetic ITG turbulence

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In recent years, it has been observed that both electromagnetic effects and fast particle populations suppress transport from ITG turbulence. This effect was discovered via detailed numerical simulations of JET discharges [1]. Further work has investigated these effects in the context of experimental scenarios [2, 3], but the underlying physics remains somewhat unresolved. However, in pursuit of increased performance, experiments will continue to push to ever-higher β. Similarly, burning plasmas will always have self-generated fast ion populations. Thus, understanding the physics behind this suppression is key to projecting its importance for future devices.

Our analysis of the physical mechanisms comprises two parts: a study of the linear physics, and targeted nonlinear simulations. Firstly, an in-depth study of the linear physics is performed to disentangle the competing effects upon the ITG mode. These effects include dilution of the main ions by fast ions, changes to the magnetic equilibrium, and changes to the pressure gradients in the plasma. To clarify these results we derive a simplified dispersion relation for electromagnetic ITG including a fast ion population, and use it to demonstrate which parameters dominate the linear physics.

Guided by our linear results, we use nonlinear simulations to examine the structure of the turbulence when stabilized by fast ions. Through this study, we show which effects lead to a reduction of stiffness, and why. We also explore which effects lead to changes in the nonlinear upshift of the critical temperature gradient. We enumerate which of these physical mechanisms contribute to the experimentally-observed reduction in heat flux. Given this physical understanding, we identify which class of fast ions contribute most beneficially to this reduction and the conditions under which the electromagnetic stabilization is most effective. We conclude by extrapolating these results towards ITER and DEMO.

References

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