EFTC 2017

17th European Fusion Theory Conference

9 - 12 October 2017, Athens - Greece

Quantitative study of kinetic ballooning mode theory in magnetically confined toroidal plasmas

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In this work, we report a systematic quantitative comparison of analytical theory and numerical gyrokinetic (GK) simulations of kinetic ballooning modes (KBMs) in a magnetically confined toroidal plasma. A physics-based ordering for beta (the ratio of kinetic to magnetic plasma pressure) with small asymptotic parameters is found. This allows us to derive several simplified limits of previously known theories [1] and to identify regimes where quantitative agreement between theory and numerical simulations can be achieved. We introduce a variational approach which provides explicit dispersion relations in terms of integrals of quadratic forms constructed from numerical eigenfunctions.

For the axisymmetric case, in simple s-α geometry, it is found that, for large pressure gradients, the growth rate and frequencies computed by the gyrokinetic codes GS2 and GENE show excellent agreement with those evaluated by using, in the quadratic forms, a diamagnetic modification of ideal MHD. This is true only if geometric drifts are kept consistent with the equilibrium pressure gradient. For moderate pressure gradients, a new finite-beta formulation of KBM theory is proposed. Also in this case, good agreement between numerical simulations and analytical theory is found.

The theory is also extended to treat the stellarator device Wendelstein 7-X (W7-X) [2]. We show results of finite-beta electromagnetic GK simulations of ion-temperature-gradient-driven modes and KBMs for various W7-X configurations with different ideal MHD stability properties. This is important since, at present, it is not clear how the KBM and the ideal MHD ballooning mode thresholds relate to each other in stellarator geometry.

References

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