Upper bounds on gyrokinetic instabilities

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For several decades, an enormous effort has been devoted to the gyrokinetic theory of instabilities and turbulence in stellarators and tokamaks. Thousands of papers have been published on this subject, and millions of lines of code have been written for the purpose of numerically solving gyrokinetic equations.

As a result of this effort, a great deal of knowledge about various microinstabilities has accumulated. Ion- and electron-temperature-gradient-driven modes, trapped-electron modes, kinetic ballooning modes and microtearing modes have, for instance, been found to be unstable and cause turbulence in tokamaks and stellarators. However, these instabilities tend to be sensitive to assumptions made about plasma parameters and the magnetic-field geometry. A cylindrical plasma does not have the same stability properties as a plasma slab, toroidal plasmas are different from cylindrical ones, and tokamaks and stellarators are also substantially different. As a result, little is known in general about gyrokinetic microinstaiblities, despite the great effort devoted to their study.

Proceeding from thermodynamic considerations, we derive universal upper bounds on the growth rates of local gyrokinetic instabilities in any magnetised plasma, regardless of the geometry of the magnetic field, the number of particle species, beta, and collisions. A large number of results that have earlier been derived in special cases or observed in numerical simulations are thus brought into a unifying framework. Moreover, these upper bounds hold not only for linear instabilities but also for the nonlinear growth of free energy in a turbulent plasma.

These results are very general and reflect dependencies on plasma parameters that have earlier been derived in special cases. However, they contain no information about the influence of magnetic geometry on instabilities and turbulence, but it is possible to extend the analysis in such a way that some of this information is retained. The result is a family of bounds that do depend on the magnetic geometry, though not as sensitively as gyrokinetic simulations.