Stabilization of electromagnetic turbulence in the presence of fast particles

A. Di Siena,[1] T. Görler,[1] E. Poli,[1] A. Bañón Navarro,[1] A. Biancalani,[1] R. Bilato,[1]
A. Bock,[1] M. Mantsinen,[2] N. deOliveira-Lopes,[1] M. Reisner,[1] E. Fable,[1] J. Stober,[1]
F. Jenko,[1] The ASDEX Upgrade Team, JET Contributors, and The EUROfusion MST1 Team
[1]*Max Planck Institute for Plasma Physics Boltzmannstr 2 85748 Garching Germany*
[2]*Catalan Institution for Research and Advanced Studies Barcelona Spain*

It is well established that transport generated by plasma micro-turbulence represents one of the most limiting factors for the performance of future fusion reactors. A recent striking observation in many experiments [1, 2], supported by numerical gyrokinetic simulations [3, 4], is the beneficial role of energetic particles which may reduce the ion-driven anomalous transport. Despite the high relevance of this subject for performance optimisation of burning plasmas, a coherent picture of the role of energetic particles in nonlinear plasma scenarios has remained elusive for more than a decade. In this work, the recent findings of Ref. [5–7] are presented and extended further. In particular, a wave-wave coupling between micro-turbulence, axisymmetric zonal flows and energetic particle driven modes has been observed in GENE simulations [5]. Numerical evidence of this nonlinear interaction is shown and the mechanisms which lead to a reduction of the heat fluxes in strong electromagnetic regimes is elucidated for the first time. It is found that linearly stable "Magnetohydrodynamics (MHD)" modes, which (i) deplete the energy content of the turbulent ion-temperature-gradient (ITG) modes and (ii) act as an additional mediator for an increased zonal-flow activity, are marginally destabilised by fast ions in scenarios exhibiting reduced heat fluxes. Moreover, a wave-particle resonant interaction between the bulk-ion-driven instabilities and energetic particles is shown to become relevant if the temperature gradient [1] of the fast-particle species is steeper than the density gradient [6, 7], e.g., as in minority ion-cyclotron-heating (ICRH) schemes. The interplay between the wave-particle and wave-wave nonlinear interaction will be discussed. The GENE results are compared to different JET and ASDEX Upgrade discharges with reduced transport levels attributed to energetic ion effects, obtaining a good quantitative agreement with the transport levels measured experimentally. Extensions such as comparison of fluxtube results with radially global simulations will be considered as well as a discussion on the role of the velocity space anisotropies on the previous findings.

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[1] measured as the second order moment of the background distribution function.