Studying Alfvén eigenmodes in realistic conditions using a hierarchy of hybrid-gyrokinetic and fully gyrokinetic models

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Abstract: Alfvén eigenmodes, driven unstable by energetic particles, have the capability to transport particles and energy in a fusion reactor via resonant wave-particle interaction. Whilst it is not expected that the amplitudes of individual saturated Alfvén eigenmodes will be sufficiently large to cause significant transport, in future machines (and especially in burning plasmas) we can potentially expect large numbers of toroidal Alfvén eigenmodes (TAEs) to be driven unstable, and studying the interaction between these modes is of importance, as it can lead to significantly increased transport.

In order to study the effects of TAEs, we value models which include complete physical descriptions, but we also value fast and robust reduced models, in particular for exploratory parameter scans, especially relevant when investigating systems with large numbers of modes present. To this end, we aim for a hierarchy of models, ranging (in this work) from various hybrid-kinetic models to fully gyrokinetic (GK) models against which the simpler models can be verified.

In this work, we focus on two model paradigms, firstly the coupled HAGIS-LIGKA model [1] (linear GK eigenvalue solver/nonlinear perturbative hybrid code), and secondly, the nonlinear gyrokinetic electromagnetic particle-in-cell code ORB5 [2, 3].

In the coupled HAGIS-LIGKA model, the TAE eigenvalues (mode frequency and damping) and eigenvectors (radial mode structure) are calculated using the linear gyrokinetic code LIGKA [4], and evolved with the hybrid HAGIS [5] code. Depending on the physics required, the LIGKA model can perform local or global, MHD or kinetic mode calculations.

In this work, we look at the ITER standard 15MA scenario [6], with three levels of increasing mode-structure fidelity from HAGIS-LIGKA: a gaussian mode structure model combined with analytical estimations for the mode width together with a local ideal MHD calculation, a global eigenvalue calculation in the limit of ideal MHD, and the global kinetic eigenvalue calculation.

In the case of the former two non-kinetic models, we estimate the mode damping using a fast local kinetic eigenvalue calculation. We show that the simpler models match well under certain restrictions, with the simplest model allowing for a surprisingly good measurement of the linear growth rate when the mode is well localized as is true for larger toroidal mode numbers. In this study, we not only focus on the linear properties of large numbers of modes but also assess the validity of analytical estimates for resonance broadening by monitoring the relation between linear growth rates and saturated amplitudes. With this information, the validity of quasi-linear models can be checked with nonlinear multi-mode simulations.

We also present efforts in studying this ITER scenario, also with a realistic equilibrium, using linear runs of ORB5. By applying both paradigms to the same case, we can draw inter-level comparisons across the hierarchy of models.

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REFERENCES