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Nonlinear excitation of subcritical fast ion-driven modes

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Energetic ions in fusion plasmas can excite the Geodesic-Acoustic Mode (GAM), which is a finite-frequency counterpart of zonal flow. Depending on plasma conditions, GAMs can significantly enhance or mitigate transport. Therefore, understanding and controlling their excitation is of great interest. Recent observations on the LHD have revealed a new phenomenon of abrupt excitation of large-amplitude GAM, triggered by another, weaker GAM. In the present paper, we develop a theoretical model for the nonlinear interactions among fast ions and two coupled GAMs. The model is obtained by combining two descriptions: 1. the kinetic description of resonant interactions between fast ions and a GAM, and 2. the reduced description of modulational-parametric coupling between two GAMs. The model is able to recover key aspects of the experiment, with input parameters which are consistent with measured plasmas parameters and independent calculations. It provides a viable interpretation for the phenomenon of abrupt GAM excitation on LHD, as the result of a new kind of subcritical instability. This subcritical instability is a linearly stable mode which grows from a sustained collaboration between two kinds of nonlinearities: resonant particle trapping and wave-wave coupling. Our analysis suggests that a mechanism of synchronization between the periods of the two waves contributes to the abruptness of the subcritical growth. The model further predicts how this instability may be enhanced or mitigated. The abrupt GAM burst is important for fusion plasmas because of its increased amplitude and reduced frequency (compared to the triggering GAM), which should lead to a stronger coupling with thermal ions. The model can be straightforwardly adapted to other energetic particle-driven modes.

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