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Excitation and Saturation of Low Frequency Alfven Eigenmodes

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In magnetic fusion, energetic particles (EPs) supplied from neutral beam injection or fusion reaction are crucial for high performance operation of present machines and future reactors [1]. Alfven Eigenmodes (AEs), excited by EPs, play an essential role on EP confinement. An AE is excited in a frequency gap between neighboring MHD continua, where continuum damping is absent so that EP drive can easily excite a mode. AEs excited in toroidicity induced gap (TAE), ellipticity induced gap (EAE) and in higher frequency gaps have been extensively studied and are relatively well-understood. However, there has been much less attention to lower-frequency AEs excited in beta-induced gaps [2][3]. There exist two classes of the beta-induced gaps, which correspond to beta-induced AE (BAE) and beta-induced Alfven-Acoustic Eigenmode (BAAE). The latter is excited in the lowest frequency gap induced by coupling of a slow magnetosonic wave with a shear Alfven wave.

Even after theoretical and simulation works in recent three decades, understanding of the low-frequency AEs is not mature. The main reason is that most of theories and simulations have focused on accumulation points or perturbation to damped modes, not seriously considering effects of strong drives. In this work, we have performed gyrokinetic simulations using GTC [4] to study physics of unstable BAE and BAAE in DIII-D #178631. Note that in DIII-D #178631 and in other recent discharges, excited BAAEs have been observed even without neutral beams [5]. Obviously, these BAAEs are not conventional. Therefore, in this work, we call them "Lower-Frequency Modes (LFMs)" instead of "BAAEs", to be cautious on their physics identification. For the GTC simulations, we have used equilibrium and profiles of DIII-D #178631, provided from EFIT and TRANSP/NUBEAM.

Fig. 1 is a primary result of linear GTC simulations of BAE and LFM, with sub-TAE MHD continua calculated from ALCON. The BAE is excited with both relaxed and classical fast ion profiles, having frequency close to the lower continuum in the BAE gap. This is different from a prediction from theories that BAE would be excited near the BAE accumulation point which is local minimum of the upper continuum. GTC finds an excited LFM without fast ions, consistent with experimental observation. Both BAE and LFM have peaks close to qmin, consistent with ECE measurements. Note that GTC finds that LFM as well as BAE is close to ideal MHD, i.e., ratio of parallel electric field to perpendicular one is small. Also note that BAE as well as LFM has large enough parallel magnetic perturbation, comparable to perpendicular one. Previous theoretical and simulation studies, not considering effects from strong drive, did not predict these features.

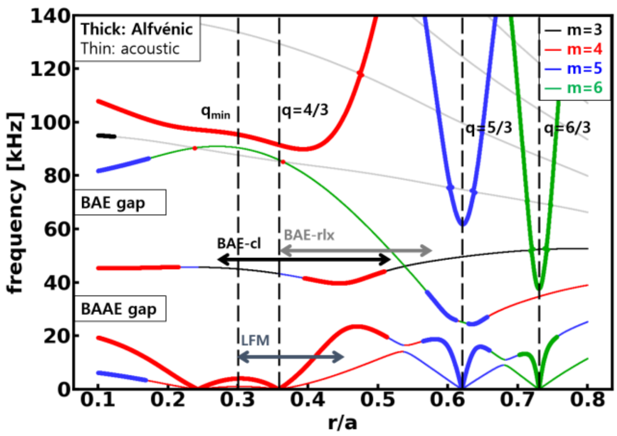

Fig. 1. ALCON plot of n=3 MHD continua in the plasma frame, with BAE and LFM found in linear GTC.

Linear dispersion scans of the most linearly unstable mode with decreasing fast ion density and temperature to zero have showed strong non-perturbative fast ion effect. There is no sudden transition from BAE to LFM, but a continuous change of linear dispersion. Parameter scans and energy exchange analysis have revealed that LFM is a KBM [6] having weak ballooning character. Indeed, we have found an unstable ideal pressure-driven mode in a single-fluid GTC simulation. Both finite Larmor radius and resonance of thermal ions are important for LFM to have a finite frequency.

Nonlinear BAE have showed essential roles of zonal flows and fast ion phase space structure for a two-stage suppression of the BAE. BAE initially saturated by zonal flows is eventually suppressed after robust fast ion loss. This cannot be predicted from linear properties of BAE and fluid-type zonal flow generation mechanism, where Reynolds and Maxwell stresses would cancel with each other due to strong shear Alfvenic polarization.

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References

[1] L. Chen and F. Zonca, Rev. Mod. Phys. **88**, 015008 (2016)
[2] W.W. Heidbrink *et al.,* Phys. Rev. Lett. **71**, 855 (1993).
[3] N.N. Gorelenkov *et al.,* Phys. Lett. A **370**, 70 (2007)
[4] Z. Lin *et al.,* Science **281**, 1835 (1998)
[5] W.W. Heidbrink, M. Van Zeeland and X. Du, 61th APS-DPP Meeting (Fort Lauderdale, FL, 2019)
[6] I. Chavdarovski and F. Zonca, Phys. Plasmas **21**, 052506 (2014)