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FULLY GYROKINETIC MODELING OF BEAM-DRIVEN ALFVÉN EIGENMODES IN DIII-D USING GYRO

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Fully Gyrokinetic Modeling of Beam-Driven Alfvén Eigenmodes in DIII-D Using GYRO TH-W

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Linear properties of a spectrum of beam-driven Alfvén eigenmodes (AEs) have been investigated in a benchmark DIII-D discharge using the gyrokinetic code GYRO [1]. GYRO solves the coupled gyrokinetic equations on a continuum grid for all three species: thermal ions and electrons and driving beam energetic particles (EPs). A gyrokinetic global eigenvalue solver tracks the linearly interacting spectrum of two toroidal Alfvén eigenmodes (TAEs) and a reverse-shear Alfvén eigenmode (RSAE) at $n = 3$ as they evolve over a short time slice of the discharge. Results agree well with the experiment and shed light on details of the spectrogram controlled by interaction of observed unstable modes and more weakly driven modes not visible in the experiment. The present fully kinetic solution also reveals kinetic corrections to eigenfunction structure over MHD predictions, notably a twist in the poloidal plane and a broadening of TAE radial extent. Both effects, confirmed in experiments [2], have likely implications for mode stability and EP confinement [3] in ITER and future fusion devices.

Simulated mode structure and frequency sweeping behavior agree well with experimental measurements. The investigated DIII-D discharge (142111, near $t = 725$ ms) resembles the advanced tokamak regime in that it features a non-monotonic safety factor q profile. The RSAE appears near the minimum q_{min} in the q profile and can only be unstable in such a reversed shear configuration. A population of EPs with a radial pressure gradient drives both the TAE and RSAE unstable. The driving EPs can be fusion-produced alpha particles or, as in the present case, come from neutral beam injection (NBI). As q_{min} evolves with the discharge, decreasing in time, the RSAE frequency sweeps up and down, interacting with one or more TAEs over the sweep. Subdominant modes revealed by GYRO's global eigenvalue solver illustrate how individual eigenmodes exchange identity, going from RSAE-like to TAE-like (or vice versa) or taking on a hybrid, double peaked structure over

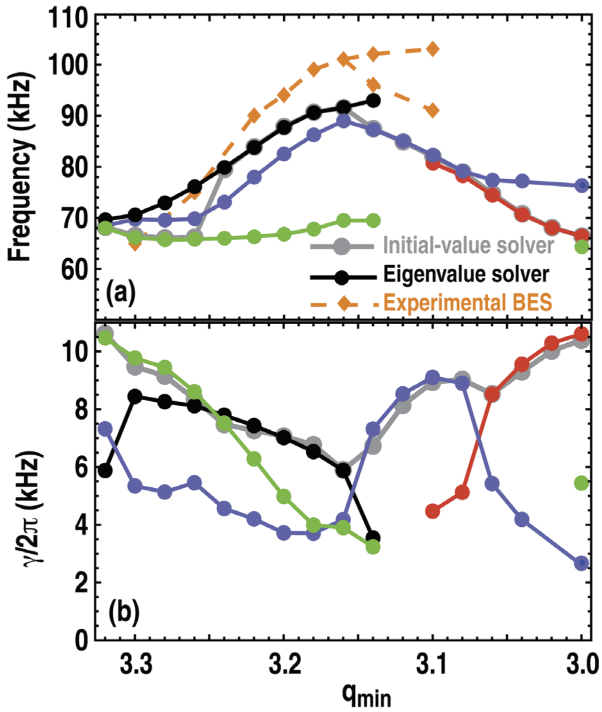

Fig. 1. Frequency (a) and growth rate (b) of unstable n=3 AEs in DIII-D discharge 142111 near t = 725 ms. q_{min} decreases in time. GYRO predictions (dots) omit an approximately 7 kHz Doppler shift seen in experiment (diamonds).

the sweep. Figure 1 shows the spectrum of rates over one complete $n = 3$ RSAE frequency sweep $10/3 \le q_{\min} \le 9/3$, with points from the experimental beam emission spectrogram for comparison. If an approximate Doppler shift is added to the un-shifted simulation result, the dominant GYRO mode predicts the experimentally observed spectrogram quite well, especially at the low $q_{\min}$ end.

A twist in the eigenfunction as viewed in the poloidal plane (Fig. 2) appears as a universal feature of all unstable AEs. This twisting pattern is precluded in MHD in an up-down symmetric discharge such as 142111 and appears to derive from self-consistent inclusion of EP kinetics [2]. However, a range of experiments and simulations suggest that the details of the twisting pattern do not depend sensitively on the EP profile [4]. The present GYRO results consistently agree with experiment on the existence of a reversal in the mode twisting direction roughly at the $q = 10/3$ surface, regardless of EP profile details. A smooth connection between the untwisted MHD prediction and the present kinetic prediction remains unrealized.

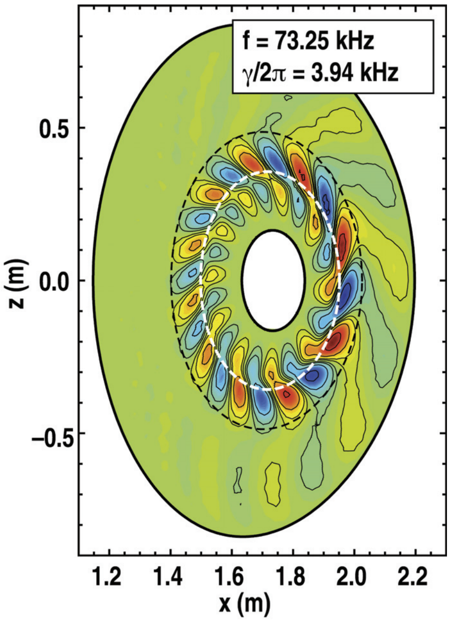

Fig. 2. Fluctuating electrostatic potential ϕ in the poloidal plane of a representative hybrid TAE-RSAE subdominant n=3 mode at $q_{\min}$=3.22. The white dashed oval is the $q_{\min}$ surface. The twist pattern reverses direction near the q=10/3 surface (black dashed oval).

Another kinetic effect shown in the present work is a radial broadening of poloidal harmonics on the scale of EP orbits. In the high shear outer plasma region, this broadening implies a local shift in the parallel wave number $k_{\parallel}$ (with frequency fixed), bringing the EPM-like, orbit frequency-dependent piece of the resonance condition to greater prominence there. This shift in $k_{\parallel}$ is consistent with previous local studies of linear coupling between the TAE and EPM [5] and shows that a single global TAE has both TAE-like and EPM-like velocity space resonance across its radial domain. Such dual-resonance behavior suggests that only self-consistent EP kinetics can account for the large radial extent of TAEs, with accompanying broad transport footprint, seen in the present work and validated by experiments.

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