Linear Excitation and Nonlinear Saturation of Low Frequency Alfven Eigenmodes in DIII-D

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Summary

Here, we report results of recent global gyrokinetic simulations of low-frequency Alfven eigenmodes (AEs) and neoclassical tearing mode(NTM) in the presence of energetic particles (EPs) in DIII-D plasmas. Using gyrokinetic toroidal code GTC, we have studied excitation and nonlinear evolution of Beta-induced AE (BAE) and low-frequency mode (LFM), EP interactions with NTM, as well as nonlinear evolution of Reversed Shear AE (RSAE) & Toroidal AE (TAE) with microturbulence in DIII-D experiments.

GTC simulation model

- GTC: global electromagnetic gyrokinetic δf PIC code for multiple kinetic-MHD processes (turbulence, MHD and EP, neoclassical, RF wave).
- Equilibrium current and parallel magnetic compression can be considered.
- Hybrid-kinetic electron scheme (conservative scheme is available).
- Single-fluid simulation is available: incompressible MHD, resistive MHD.

1. Linear excitation of BAE and LFM and nonlinear evolution

By G.J. Choi

Motivation

In recent DIII-D L-mode experiments, BAE and LFM with neutral beam (NB) has been observed. LFM was tought to be a Beta-induced Alfven-Acoustic Eigenmode (BAAE). However, LFM persists long after turning-off the NB.

GTC finds BAE with EP, and LFM without EP

GTC simulations of DIII-D #178631 find the most unstable BAE with EP, and LFM inside BAAE gap without EP (Fig. 1(a)). LFM has narrower, interchange-like structure. Simulations with various GTC models (Fig. 1(b)) reveal that equilibrium parallel current and kinetic electrons have modest effect, and parallel magnetic compression is crucial on BAE and LFM stabilities.

LFM is an interchange-like mode

Wave-particle energy exchange analyses (Figs. 1(c) and (d)) show that BAE is mostly driven by perpendicular wave-EP resonance, and that LFM is by interchange-type, fluid-like energy exchange. We thus conclude that LFM is a thermal plasma pressure gradient-driven, interchange-like mode.

Nonlinear evolution of BAE

Nonlinear GTC simulations have revealed that zonal flows have significant impact on BAE, and multiple-n BAE is nonlinearly unstable in a colliisonless plasma, i.e., (collisional or nonlinear) dissipation is necessary for saturation.

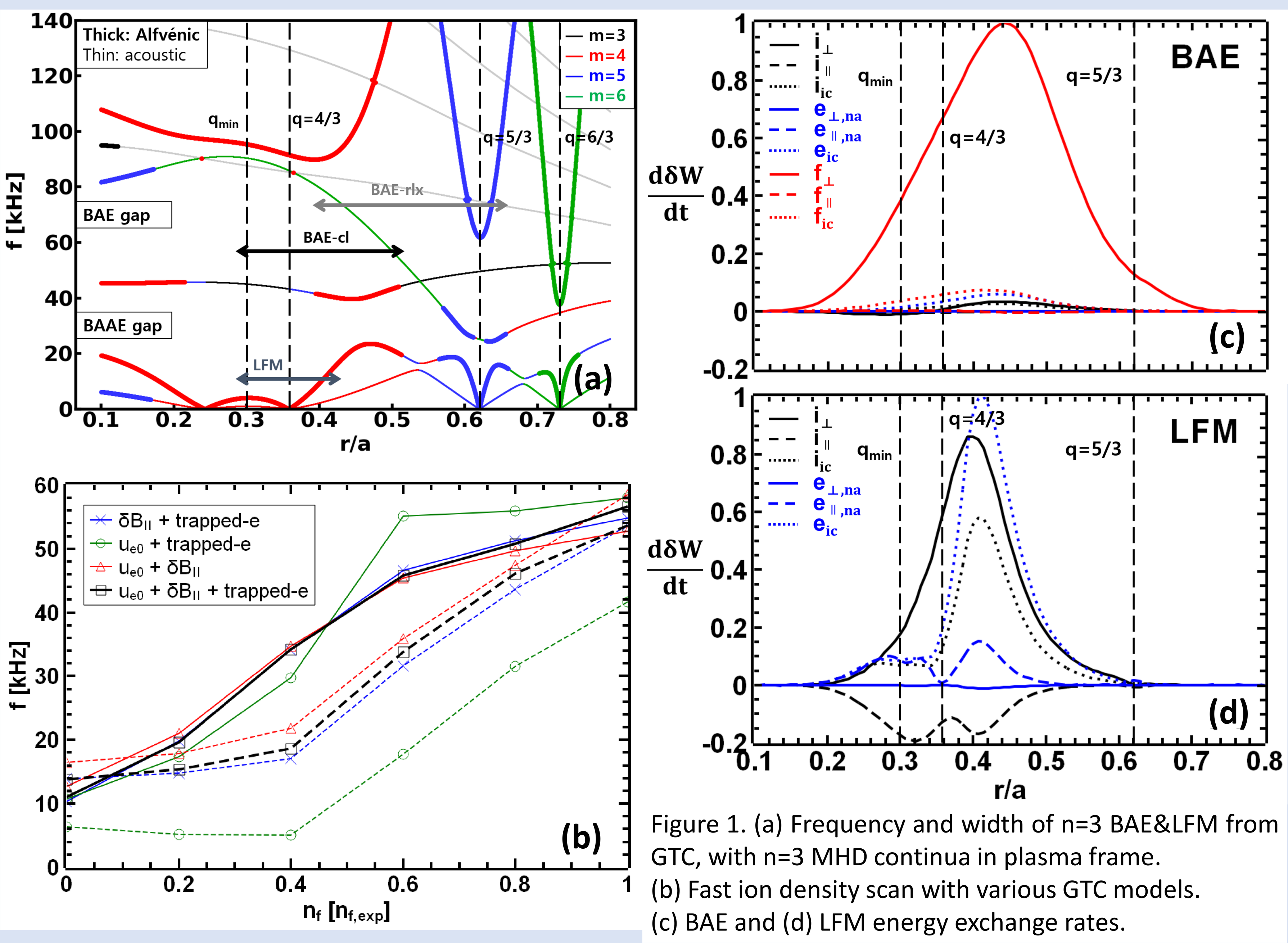

Figure 1. (a) Frequency and width of n=3 BAE&LFM from GTC, with n=3 MHD continua in plasma frame.
(b) Fast ion density scan with various GTC models.
(c) BAE and (d) LFM energy exchange rates.

2. Interaction between EP and NTM

By X. Tang

NTM island-induced EP re-distribution

GTC gyrokinetic simulations of EP with the main 2/1 NTM island found that EP profile is partially flattened within the island. EP flux is induced around the island due to stochasticity in phase space. Stochastic magnetic field regions by multiple-island effect are smaller than EP orbit width in our target discharge DIII-D #157402, resulting in weak change in EP flux.

EP effect on NTM stability

From GTC simulations using resistive MHD model, we found that perturbed EP current induced by NTM island has a weakly stabilizing effect on NTM stability. It is consistent with an observation that the NTM island width was decreased about 1 cm by fast ions in our target DIII-D experiment.

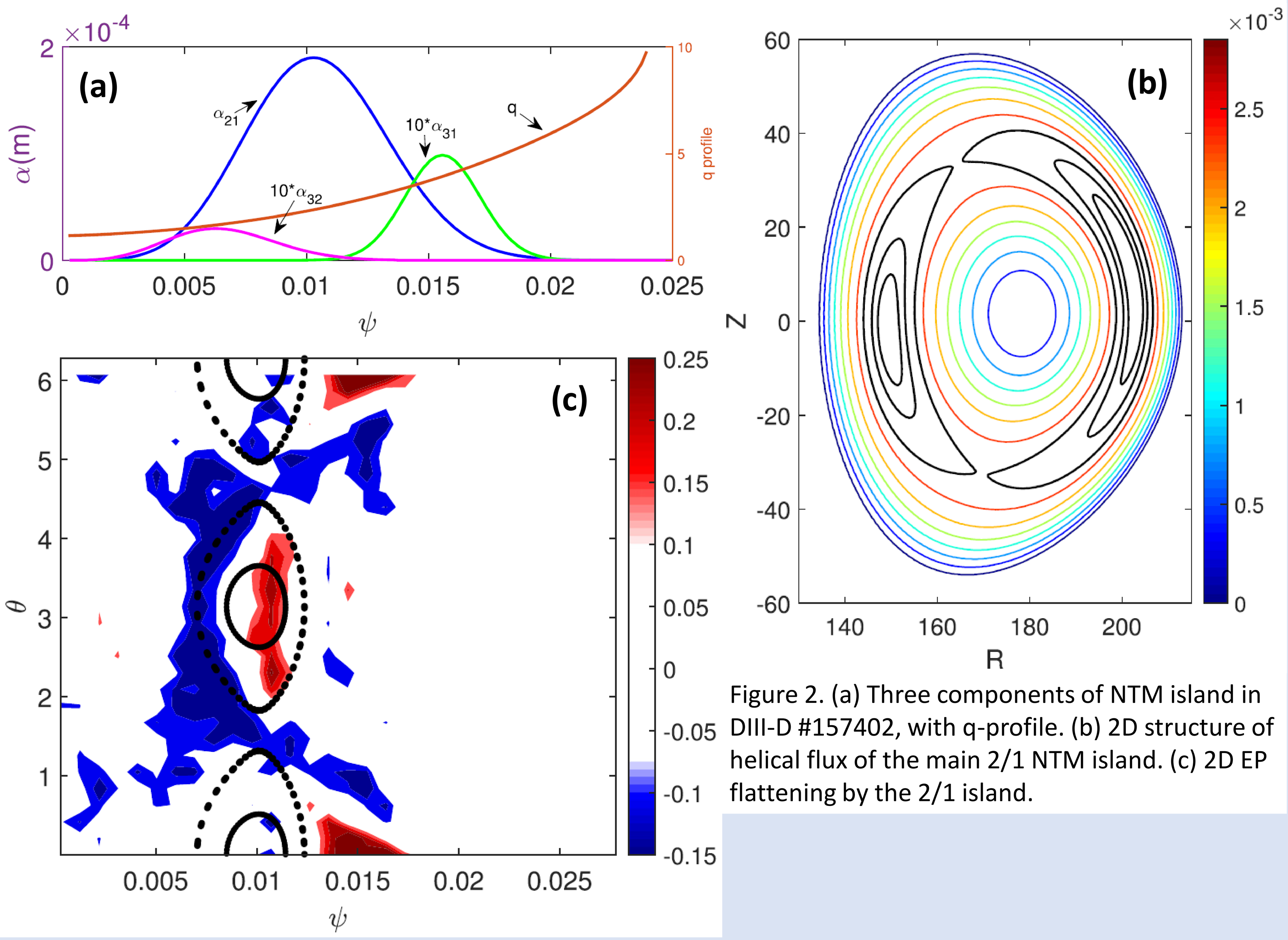

Figure 2. (a) Three components of NTM island in DIII-D #157402, with q-profile. (b) 2D structure of helical flux of the main 2/1 NTM island. (c) 2D EP flattening by the 2/1 island.

3. Nonlinear evolution of RSAE/TAE with turbulence

By H.Y. Wang

Co-existing RSAE/TAE and ITG turbulence

In DIII-D #159243, linear GTC finds that low-n RSAE and high-n ITG modes co-exist having similar linear growth rates. ITG modes are excited in outer region, while RSAE is excited in inner region so that they do not overlap linearly. Also, there is weakly unstable intermediate-n TAE in outer region.

Zonal field-mediated RSAE/TAE-turbulence interaction

Nonlinear simulation without ITG showed that RSAE amplitude and EP transport are greatly reduced by zonal fields. Simulations with ITG showed that zonal fields mediate RSAE-turbulence interaction, as both significantly contribute to zonal field generation and are regulated by the zonal field.

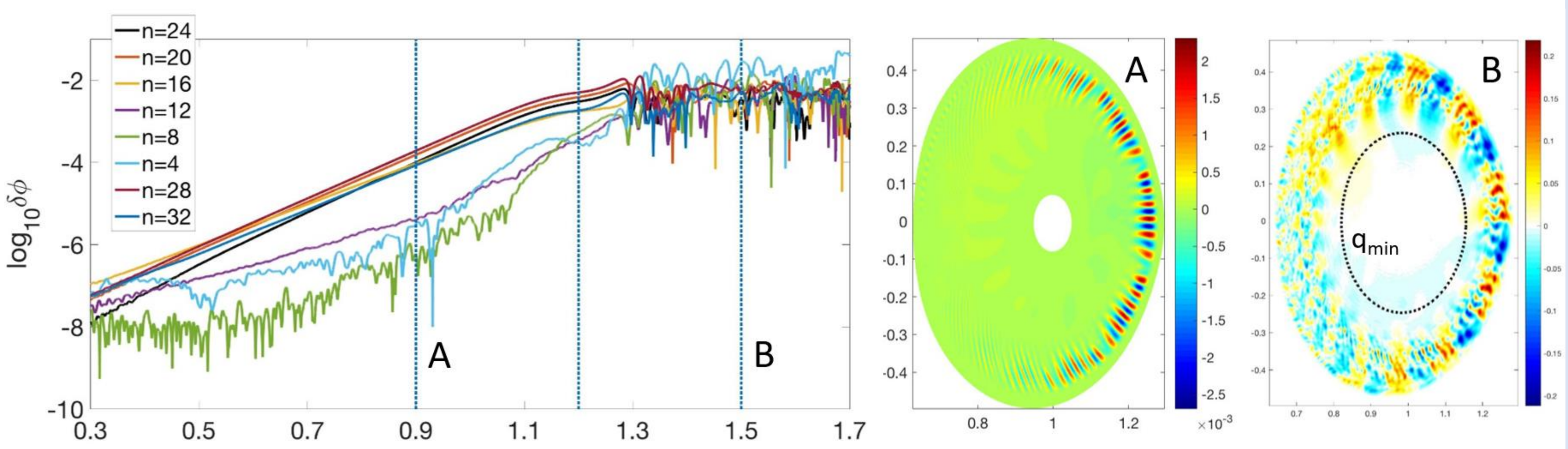

Figure 3. A. Linearly dominant ITG, B. RSAE/TAE with spreaded ITG

Acknowledgment/References

- X. Tang *et al.*, *Phys. Plasmas* **27**, 032508 (2020)
- G.J. Choi *et al.*, *Nucl. Fusion*, in press (2021)
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