Comprehensive analytical and numerical study of beam-driven sub-cyclotron frequency Alfvén eigenmodes in spherical tokamaks

J.B. Lestz[1,2], E.V. Belova[2], N.N. Gorelenkov[2]
[1)] Department of Astrophysical Sciences, Princeton University, Princeton, NJ, USA
[2)] Princeton Plasma Physics Lab, Princeton, NJ, USA

Beam-driven sub-cyclotron compressional (CAE) and global (GAE) Alfvén eigenmodes are routinely excited in spherical tokamaks (STs) such as NSTX(-U) and MAST, have been observed on DIII-D, and can be excited in ITER. Their presence has been linked to the anomalous flattening of electron temperature profiles at high beam power in NSTX [1]. A detailed understanding of CAE/GAE excitation, therefore, is vital to predicting (and ultimately controlling) their effects on plasma confinement. A comprehensive set of 3D simulations has been performed for a wide range of beam parameters, providing a database of information on CAE and GAE stability. This study is unique in that it uses a full orbit kinetic description of the beam ions in order to capture the cyclotron resonances which drive the modes. Hybrid MHD/particle simulations, performed with the HYM code, are complemented with an analytical study of linear stability properties of GAEs and CAEs. New analytic conditions for fast ion drive for realistic NBI distributions have been derived. Linear simulations show that the excitation of CAEs vs GAEs has a complex dependence on the fast ion injection velocity and central pitch. Strong energetic particle modifications of GAEs are found, indicating the existence of a new type of high frequency energetic particle mode [2]. A cross validation between the improved theoretical stability bounds, simulation results, and experimental measurements shows excellent agreement for the unstable GAE spectrum's dependence on fast ion parameters. The analytic results accurately explain the recent experimental discovery of GAE stabilization with small amounts of off-axis NBI [3]. Additional mechanisms for stabilization of CAEs and GAEs with multi-beam distributions are investigated, suggesting new avenues for control of these instabilities in future experiments.

[1] D. Stutman et al, PRL 102, 115002 (2009)
[2] J. Lestz et al, POP 25, 042508 (2018)
[3] E. Fredrickson et al, PRL 118, 265001 (2018)