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Theory of Sub-cyclotron Instabilities of Alfvén Eigenmodes due to Energetic Ions in Low Aspect Ratio Plasmas

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Abstract

Spherical tokamaks present new regimes for fast particle confinement, which include low Alfvén speed, large FLR and orbit width, low aspect ratio, high plasma and fast ion betas.

Recent observations of rich sub-cyclotron frequency MHD activity in NSTX suggest that Alfvén eigenmodes (AE) are destabilized in the presence of $80keV$ NBI [1, 2], which has an injection velocity three times larger then the Alfvén velocity. The frequency of observed AEs correlates with the characteristic Alfvén velocity as shown in Fig. 1 (a). A new theory is developed to identify the observed instabilities as Compressional Alfvén Eigenmodes (CAE) and Global shear Alfvén Eigenmodes (GAE frequency is shown in Figure 1) and a comparison of the CAE and GAE dispersions with experimental measurements is made. These AEs are destabilized by free energy in the energetic ion velocity space via Doppler shifted cyclotron resonances with beam ions. CAEs are typically localized at the edge whereas GAEs are localized near the center. The local growth rates of these modes are derived and shown to be small with $\gamma_b/|\omega| \simeq n_{bt}/n_i \leq 1\%$. A broad spectrum of these AEs may be excited at the same time, providing a channel for the energy transfer from the beam ions to the modes and then to the background ions [3]. The main damping mechanism is the continuum damping of GAEs which is small if poloidal mode numbers are high with $m \geq 5$. We have also performed nonlinear simulations of GAE/CAEs with the hybrid kinetic MHD code HYM. The mode structure and frequencies agree with the analytical theory and with the measured frequencies and are shown in figure 1 (b).

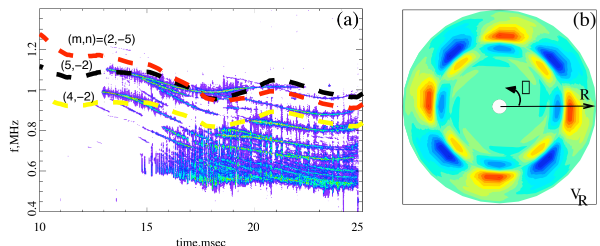

Figure 1: *High frequency spectrum of magnetic coil signal from NSTX plasma showing correlation of simplified GAE dispersion for different* (m, n) *pairs*, $\omega_{GAE} \simeq v_{A0}(m - nq_0)/q_0R$, and *frequency peaks of the instabilities (a). Figure (b) shows the perturbed plasma velocity of GAE mode as modeled by HYM.*

[1] FREDRICKSON, E., et. al., Phys. Rev. Lett. 87 (2001) 145001.

[2] GORELENKOV, et. al., Nucl.Fusion 42 (2002) 977.

[3] GATES, D. A., et. al., Phys. Rev. Lett. 87 (2001) 205003.