Gyrokinetic simulation of internal kink and fishbone instabilities: verification and validation using DIII-D experiments, and prediction for ITER plasmas

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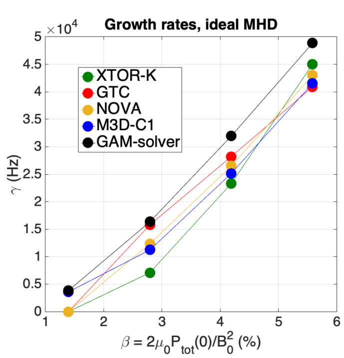
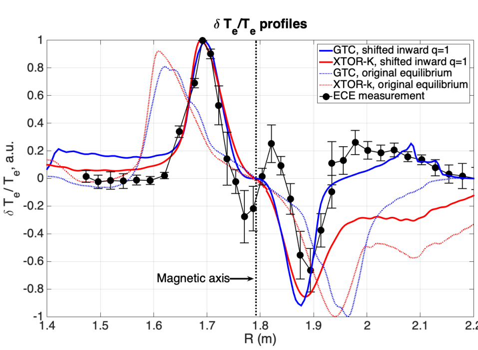
The global gyrokinetic code GTC is applied for the simulations of the internal kink and fishbone instabilities in DIII-D and ITER plasmas. GTC capability at simulating current-driven MHD modes is first demonstrated by performing a verification and validation of the internal kink instability in DIII-D plasmas using gyrokinetic (GTC) and kinetic-MHD codes (GAM-solver, M3D-C1/K, NOVA, XTOR-K). Using realistic magnetic geometry and plasma profiles from the DIII-D discharge, these codes exhibit excellent agreements for the growth rate and mode structure of the n=1 internal kink mode in the ideal MHD limit by suppressing all kinetic effects. The simulated radial mode structures, obtained from linear simulations, are in reasonable agreement with the electron cyclotron emission (ECE) measurement after adjusting, within the experimental uncertainty, the q=1 flux-surface location in the equilibrium reconstruction. Furthermore, kinetic effects of thermal ions are found to decrease the kink growth rate in kinetic-MHD simulations, but increase the kink growth rate in gyrokinetic simulations, due to the additional drive of the ion temperature gradient and parallel electric field.

The validated MHD capability of GTC is then applied to study the fishbone instability in ITER plasmas. A prefusion ITER baseline scenario is first considered in this analysis as part of the ITPA activities. An associated DIII-D discharge is selected for experimental validation of the simulations results, the selection being made in terms of similar q profile, normalized beta and plasmas profiles. The selected discharge exhibits clear n=1 fishbone bursts driven by fast ions from neutral beam injection (NBI). Fishbone modes are found to be triggered by energetic particles for both the DIII-D and ITER configurations, with similar mode structures. Nonlinear GTC results recover mode frequency down-chirping associated with resonant EP transport for both ITER and ITER scenarios, that are key signatures of the fishbone instability. Finally, the fishbone-induced transport of energetic particles and the mode frequency down-chirping obtained in GTC nonlinear simulations will be compared with the experimental measurements.



(a)



(b)

Figure 1: (a) On-axis beta-scan of the internal kink growth rate for the DIII-D discharge, obtained from the different codes, in the ideal MHD limit. (b) Linear eigenmode structures ($\delta T_e/T_e$) obtained from GTC (blue) and XTOR-K (red) ideal MHD simulations, and from the ECE measurement in DIII-D (black solid line with error bar). Material submitted for publication in Nuclear Fusion.