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Nonlinear Frequency Chirping of β-induced Alfven Eigenmode
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The β-induced Alfven eigenmode (BAE) have been observed in many tokamaks. The BAE oscillates with the GAM frequency ω_0, and therefore, has strong interactions with both thermal and energetic particles. In this work, linear gyrokinetic particle simulations show that nonperturbative contributions by energetic particles and kinetic effects of thermal particles modify BAE mode structure and frequency relative to the MHD theory. Gyrokinetic simulations have been verified by theory-simulation comparison and by benchmark with MHD-gyrokinetic hybrid simulation. Nonlinear simulations show that the unstable BAE saturates due to nonlinear wave-particle interactions with thermal and energetic particles. Wavelet analysis shows that the mode frequency chirping occurs in the absence of sources and sinks, thus it complements the standard "bump-on-tail" paradigm for the frequency chirping of Alfven eigenmodes. Analysis of nonlinear wave-particle interactions shows that the frequency chirping is induced by the nonlinear evolution of coherent structures in the energetic particle phase space of (ζ,$\omega_{\rm d}$) with toroidal angle ζ and precessional frequency $\omega_{\rm d}$. The dynamics of the coherent structures is controlled by the formation and destruction of phase space islands of energetic particles in the canonical variables of (ζ,$\rm P_\zeta$) with canonical angular momentum $\rm P_\zeta$. Our studies use the gyrokinetic toroidal code (GTC) recently upgraded with a comprehensive formulation for simulating kinetic-MHD processes. In collaborations with GTC team and SciDAC GSEP Center.

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