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Global gyrokinetic simulation of energetic particle-driven instabilities in 3D systems

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Instabilities driven by energetic particle (EP) components are of interest to magnetic fusion concepts since they can lead to decreased heating efficiency, high heat fluxes on plasma-facing components, and decreased ignition margins in reactor systems. Since 3D magnetic field perturbations will be present to some extent in all toroidal configurations, the analysis of EP instabilities in 3D systems will be an important component of whole device modeling. To address this, the GTC global gyrokinetic PIC model has been adapted to the VMEC 3D equilibrium model, and 3D effects included in the field solvers and particle push. This model has been applied to several stellarators (LHD, W7-X, TJ-II) and tokamaks with 3D fields (NSTX with RWM). Also, a new code has been developed for the analysis of wave-particle resonance locations in phase space in 3D systems. The results indicate that Alfvén modes similar to those observed in LHD are obtained from the GTC simulations. The calculations also show a sensitivity as to which Alfvén gap mode is excited, depending on the shape of fast ion pressure profile. This feature allows diagnostic inferences for profiles, such as the fast ion pressure, that cannot be directly measured. Other parameter and profile sensitivities have been observed that are unique to 3D configurations. Initial nonlinear calculations have demonstrated the interplay between fast ion redistribution and zonal flows/currents in reaching a saturated state. Predicting the onset and effects of these instabilities is of significant importance due to their impact on heating efficiency, plasma-facing component heat loads, and possible diagnostic use. The importance of non-axisymmetric effects in all toroidal devices motivates development of comprehensive new gyrokinetic simulation methods that can apply across the full range of symmetry-breaking perturbation levels.

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