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Verification and Validation of Integrated Simulation of Energetic Particles in Toroidal Plasmas

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Energetic particle (EP) pressure gradients in fusion plasmas can readily excite mesoscale EP instabilities such as the Alfven eigenmodes (AEs) and energetic particle modes that drive large EP transport, which can degrade overall plasma confinement and threaten the machine's integrity. EP could strongly influence thermal plasma dynamics including the microturbulence and macroscopic magnetohydrodynamic (MHD) modes. In return, microturbulence and MHD modes can affect EP confinement. We have developed first-principles capability for global integrated simulation of nonlinear interactions of multiple kinetic-MHD processes by treating both EP and thermal plasmas on the same footing. Verification and validation have been carried out for the gyrokinetic toroidal code (GTC) simulations of EP interactions with thermal plasmas in a DIII-D NBI-heated plasma.

GTC kinetic-MHD simulations of EP interactions with thermal plasmas focus on the DIII-D discharge #159243, which is a NBI-heated plasma with many small-amplitude reversed shear Alfven eigenmodes (RSAE) and toroidal Alfven eigenmodes (TAE), significant flattening of the EP profile, and large amplitude microturbulence. GTC linear simulations using EFIT equilibrium and experimental profiles find that the most unstable AE is RSAE with significant growth rate for toroidal mode number n=3-6. The most unstable RSAE is n=4 and has a radial domain of =0.3 - 0.6 (square-root of normalized toroidal flux function). These results are in good agreement with other gyrokinetic and gyrokinetic MHD-hybrid codes, as well as experimental data. Consistent with experimental observation, GTC simulations also find that weaker TAE exist at the outer radial domain of =0.6 - 0.9. The most unstable TAE mode is n=5. Finally, GTC simulations find strong driftwave instability excited by thermal plasma pressure gradients in the core. The most unstable ion temperature gradient (ITG)-like mode is n=20. The linear ITG-like mode amplitude peak at =0.3, but large fluctuations nonlinearly spread to the whole radial domain. These results indicate that RSAE and TAE in this DIII-D experiment could interact nonlinear with each other and with the microturbulence.

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Primary author: LIN, Zhihong (UC Irvine)

Co-authors: DONG, G (Princeton University); Dr BAO, J (University of California, Irvine); Dr LIU, L (Peking University); Mr HE, R (Peking University); Mr TAIMOURZADEH, S (University of California, Irvine); Mr LIU, Z (Peking University)

Presenter: LIN, Zhihong (UC Irvine)

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