DPP15-2015-000123

Abstract for an Invited Paper
for the DPP15 Meeting of
the American Physical Society

Toward integrated multi-scale simulations for a full ELM cycle with ELM dynamics[1]

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The high-fidelity BOUT++ two-fluid and Gyro-Landau-Fluid code suites have demonstrated significant recent progresses toward integrated multi-scale simulations for a full ELM cycle with ELM dynamics. In order to improve the computational efficiency for a full ELM cycle with ELM dynamics, the basic set of dynamical equations has been separated into equations in the fluctuating and averaged parts over binormal direction. The two parts are advanced together in time but with different time steps, and dynamically exchange the turbulence fluxes and averaged profiles. Nonlinear ELM simulations show three stages of an ELM event: (1) a linear growing phase; (2) a fast crash phase; and (3) a slow inward propagation phase lasting until the core heating flux balances the ELM energy loss and the ELM is terminated. To better understand the inter-ELM pedestal dynamics during the pedestal recovery, BOUT++ simulations started from a kinetic equilibrium reconstruction using measured plasma profiles from DIII-D show that quasi-coherent fluctuations (QCFs) can provide the necessary transport to limit and saturate the H-mode pedestal gradient. The simulations predict that (1) QCFs are localized in the pedestal region as observed on DIII-D; (2) the QCFs are near marginal instability for ideal ballooning modes combined with drift-Alfven wave modes; (3) the dominant mode is around n=15, $k_\theta \rho_i$ =0.034, comparable to the measured value of 0.04; (4) the frequency of the mode is around 80kHz, close to that of the measured QCF; and (5) particle transport is smaller than the heat transport. BOUT++ simulations have also been performed to elucidate the nature and underlying physics mechanisms of the weakly-quasi-coherent mode (WCM) with higher collisionality, which causes particle transport in I-mode pedestals of Alcator C-Mod. Key simulation results are that (1) there is no ideal peeling-ballooning mode instability for the I-mode studied; (2) a strong instability exists at $n \geq 20$; (3) the mode propagates in the electron diamagnetic direction; (4) the predicted frequency of the n=20 mode agrees with the measured WCM peaking around 300kHz; (5) the predicted χ_e agrees with the χ_{eff} from the experiment; and (6) the predicted particle transport is larger than the predicted heat transport.

[1]USDOE by LLNL under Contract DE-AC52-07NA2734. LLNL-ABS-674450

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