1st Asia-Pacific Conference on Plasma Physics, 18-22, 09.2017, Chengdu, China

Validating gyrokinetic predictions using NSTX and NSTX-U plasmas

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Core transport in conventional aspect ratio tokamaks is often predicted to be determined by electrostatic ion temperature gradient (ITG) and trapped electron mode (TEM) turbulence at ion gyroradius scales, with possible contributions from electron temperature gradient (ETG) turbulence at electron gyroradius scales. More recently, electromagnetic instabilities like microtearing mode (MTM) and kinetic ballooning mode (KBM) have also been predicted in H-mode core and edge conditions (e.g. [1,2]), simultaneously with ITG/TEM instabilities. The spherical tokamak offers a unique opportunity to validate gyrokinetic simulations as a broad range of parameter space (e.g. beta, collisionality) can be spanned within one machine to access and isolate different microstability regimes, specifically in the core [3]. To illustrate this, we will provide examples of where gyrokinetic codes are being validated using both L and H mode plasmas from NSTX as well recent NSTX-Upgrade operations [4].

Previous validation efforts have focused on high-beta NSTX H-mode plasmas where only MTM [5,6] or KBM [3] are predicted to be unstable. These simulations predict significant transport due to magnetic fluctuations that are very sensitive to beta. For NSTX core parameters, the MTM simulations were also found to be susceptible to suppression via E×B shear. However, demonstrating sufficiently resolved, saturated turbulence simulations at high beta is especially challenging due to stringent numerical resolution requirements. It is therefore desirable to provide an intermediate validation condition that bridges high aspect ratio, low beta (R/a~3, β_N~1-2) where the bulk of gyrokinetic validation studies exist, and low aspect ratio, high beta (R/a~1.5, β_N~5) where GK simulations are less tested and challenged by stronger electromagnetic, equilibrium, and non-local effects (at large $\rho_*=\rho_i/a$). To provide such a scenario, previous analysis has utilized NSTX L-mode plasma at lower beta (R/a~1.5, β_N=1-2.5), but under transient conditions [7]. The analysis found that ITG, TEM and ETG can all provide significant transport, although demonstrating quantitative agreement with experimental fluxes has been elusive for both local and non-local [8,9] simulations. To supplement the NSTX analysis, a variety of L-mode plasmas were successfully developed during the first run campaign of the NSTX-U project with normalized beta values between β_N~1-2 (R/a~1.6) [10]. In contrast to the NSTX L-modes, the NSTX-U L-mode plasmas are stationary for periods of 0.5-1.0 sec, allowing for long-time averaging of transport and turbulence measurements. Ion scale fluctuation data from Beam Emission Spectroscopy (BES) in these plasmas increase in amplitude at increasing radii, where ITG is predicted to be strongest, and exhibit bimodal turbulence phase velocities that propagate in both electron and ion diamagnetic direction. However, measured turbulence amplitude, as well as predicted ion scale growth rates and E×B shearing rates, vary significantly over a narrow width, ~30 ρ_i (ρ=0.5-0.75) due to the relatively large values of $\rho_*=\rho_i/a\sim1/120$, illustrating the desire for global ion-scale simulations. Furthermore, in regions where E×B shearing rates are larger than ion scale growth rates, local nonlinear ETG simulations (at electron scales) predict significant electron heat flux, suggesting a potential interplay between global ion-scale turbulence and local electron scale turbulence. The potential necessity and feasibility of the global multiscale simulations that would be required to simulate these conditions will be examined.

This work is supported by US DOE contract DE-AC02-09CH11466, and used resources of the National Energy Research Scientific Computing Center, supported by US DOE contract DE-AC02-05CH11231.

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