Progress in simulating turbulent electron thermal transport in NSTX TH-C

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Developing a predictive capability for spherical tokamaks (STs) is an important goal for informing the design of future low aspect ratio fusion devices, such as an ST-based Fusion Nuclear Science Facility (FNSF). One of the complications of developing an integrated understanding of transport in STs is the broad range of parameter space and therefore wide-range of instabilities that are possible. As an example, Fig. 1 shows the values of electron beta and collisionality (at r/a=0.6) for a number of NSTX discharges that are part of two separate ν_* scaling experiments [1,2]. These scans operated at different line-averaged densities, and therefore beta. The higher beta discharges are calculated to be unstable to microtearing instability with β_e above the linear threshold (determined using linear calculations based on one high-ν, high-β discharge). On the other hand, the low beta discharges are below the microtearing threshold, and instead the ETG instability is predicted to be unstable. To help differentiate instability mechanisms and to improve confidence in predictive modeling, nonlinear gyrokinetic simulations have been pursued to calculate the magnitude and scaling of both microtearing and ETG transport.

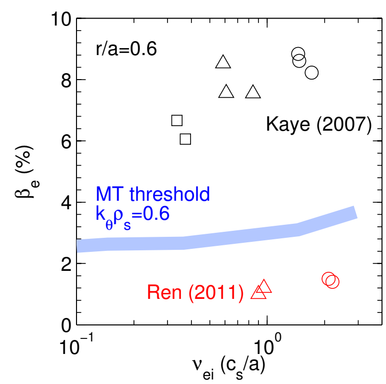

Fig. 1. Electron beta and collisionality (at r/a=0.6) for different NSTX shots (symbols), and calculated microtearing threshold using parameters from one discharge (line).

First nonlinear gyrokinetic simulations of microtearing turbulence in NSTX [3] (based on a high-ν, high-β discharge) predict experimental levels of transport. The magnetic turbulence leads to stochastic field line trajectories and the corresponding magnetic flutter is responsible for almost all (~98%) of the transport. Remarkably, the predicted transport increases with collisionality (Fig. 2) with a scaling ($\chi_{e,sim}\sim\nu_e^{1.1}$) that is roughly consistent with the experimental energy confinement scaling, $\Omega_i\tau_E\sim\nu_*^{-0.95}$ [1], providing evidence for the importance of microtearing modes in determining confinement scaling in the high-beta NSTX plasmas. The predictions are also sensitive to electron temperature gradient, beta, and E×B shear, complicating this simple interpretation.

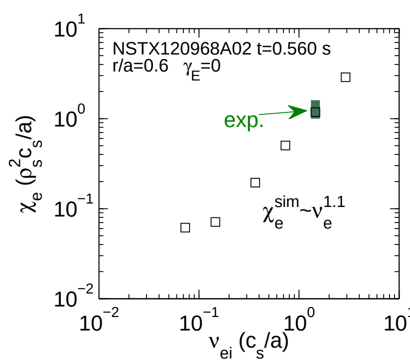

Fig. 2. Normalized χ_e vs ν_{ei} for microtearing simulations.

For the low beta discharges in Fig. 1, nonlinear simulations predict that ETG transport is a significant fraction of the experimental transport. However, the simulations predict negligible dependence of transport with collisionality, in contrast to the experimental confinement scaling $\Omega_i\tau_E\sim\nu_*^{-0.8}$ [2] (which is similar to the high beta scan). In this case we speculate that the accumulation of small differences in other parameters may lead to the overall change in confinement. For example, simulations at slightly different radii illustrate the predicted ETG transport is sensitive to local variations in density gradient.

RF-heated L-mode plasmas (at relatively low beta) have also been used to investigate the physics of ETG turbulence. Electron internal transport barriers (e-ITBs) have been found to occur with strong negative magnetic shear ($s<-0.5$). For a large collection of discharges, both the large local electron temperature gradients (much larger than the linear ETG threshold) and the small measured turbulence intensity from "high-k" scattering are strongly correlated with the largest magnitudes of negative magnetic shear [4]. Non-local GYRO simulations verify that the ETG turbulence and transport is suppressed with strong negative magnetic shear in the region of the e-ITB ($r/a\approx0.3$), as shown in Fig. 3 [5]. Outside the e-ITB the predicted ETG flux reaches experimental levels but turbulence cannot propagate past the barrier. Additional local simulations verify that this suppression results predominantly from a nonlinear stabilizing effect that occurs in the absence of strong E×B shear, confirming that negative magnetic shear alone is sufficient for ETG suppression. This nonlinear effect is very strong, with the threshold for significant transport approaching three times the linear critical gradient in some cases.

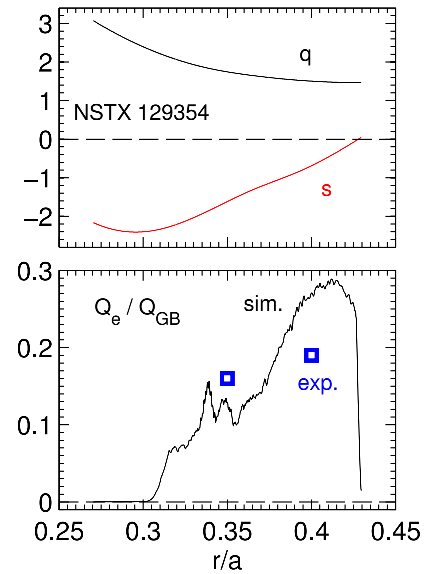

Fig. 3. (top) Safety factor (q) and magnetic shear (s) profiles for e-ITB discharge. (bottom) Predicted normalized electron heat flux.

Beyond the aforementioned dependencies, other predicted parametric scalings may be useful in distinguishing the different instabilities. For example, additional linear and nonlinear simulations predict that microtearing growth rates and transport increase with beta, s/q (for positive shear, $s>0$), and possibly even Z_{eff} [6,7]. On the other hand, ETG turbulence is often weakly dependent or stabilized with beta, and tends to be stabilized by increasing s/q (for $s>0$) and Z_{eff} [5]. Both ETG and MT can also be stabilized with sufficiently strong density gradient [6,8].

The complicated dependence of simulated transport with multiple parameters motivates the development of reduced models for use in predictive transport simulations. To this end, initial tests of the TGLF model [9] have been performed based on NSTX experiments. For the H-mode discharges investigated ETG instability is often predicted, and in limited cases unstable tearing parity modes have also been identified. Both the magnitude and scaling of the TGLF linear stability and transport will be validated with the gyrokinetic simulations. If proven successful, TGLF will be used for predictive transport modeling.

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