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Recent Progress in Transport and Turbulence Research at NSTX

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We discuss recent findings in the understanding of anomalous electron thermal transport: first nonlinear gyrokinetic simulations of micro-tearing turbulence which predict experimentally relevant level of electron thermal transport; the parametric dependence of high-k turbulence measured by a microwave scattering diagnostic and its implication on electron thermal transport; suppression of Electron Temperature Gradient (ETG) driven turbulence correlated with the electron internal transport barrier (eITB) formation in reversed shear L-modes. In addition, first low-k turbulence measurements from a newly implemented Beam Emission Spectroscopy (BES) diagnostic will be presented.

1. Introduction

The National Spherical Torus eXperiment (NSTX) provides a unique laboratory for studying plasma turbulence and its relation to transport due to its high plasma beta, low aspect ratio and large E×B flow shear. A comprehensive understanding of this relation requires not only measurements of both large and small wavenumbers, but also detailed comparisons with nonlinear gyrokinetic simulations. Recent developments in diagnostics and numerical simulations at NSTX enable us to gain further insight to understanding turbulent plasma transport. In this overview, we present recent progress in transport and turbulence research at NSTX, focusing on thermal-gradient driven core transport.

2. Nonlinear microtearing simulations

First non-linear gyrokinetic simulations of microtearing mode turbulence have recently been reported [1] for a high-collisionality NSTX H-mode discharge [2]. Using the Eulerian gyrokinetic code GYRO [3] with finite collisionality (ν_{ei}=1.26 c_s/a, Z_{eff}=2.9) and electromagnetic perturbations ($\delta A_{\parallel}$, $\beta_e=8\pi n_e T_e/B_0^2$= 8.8%), it was shown for NSTX at r/a=0.6 (where only microtearing modes are linearly unstable) that the magnetic "flutter" from the strong δB_r fluctuations is responsible for ~98% of the total electron thermal transport, $\chi_{e,sim}\approx 1.2\ \rho_s c_s^2/a = 6\ m^2/s$, which is in the experimental range $\chi_{e,exp}$=5-8 m^2/s. Estimates using the spectrum of rms saturated amplitudes ($\langle|\delta B_r/B|^2\rangle^{1/2}$~0.15%) predict that island widths should be larger than the minimum separation in rational surfaces $w_{island}/\delta r_{rat}\ \leq 8$, and Poincare plots confirm global stochasticity throughout the entire simulation domain [4]. Most remarkably, Fig. 1 shows that the predicted transport increases with collisionality, $\chi_{e,sim}\sim\nu_e^{1.1}$, roughly consistent with global energy confinement scaling in both NSTX and MAST [5], $\Omega_i\tau_E\sim\nu_*^{-(0.82-0.95)}$. This gives strong evidence for the importance of microtearing modes in determining confinement scaling in this high-beta NSTX plasma, as no other micro-instability is predicted to be unstable for these parameters. However, including the experimental value of E×B shear, $\gamma_{E,exp}\approx 0.17\ c_s/a$ (comparable to the maximum linear growth rate) reduces the predicted transport considerably. Additional simulations are underway to test the influence of numerical and physical parameter variations.

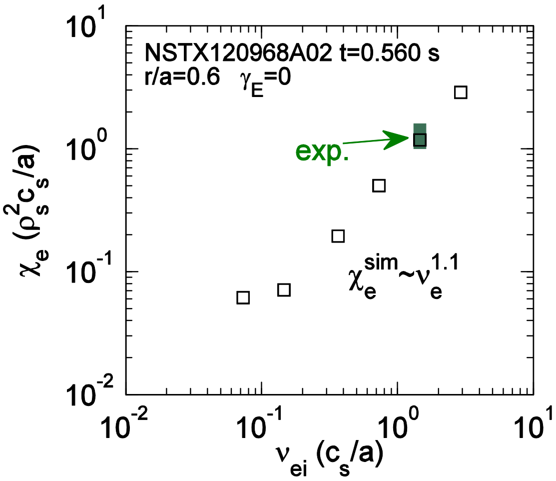

Fig. 1. Predicted χ_e vs. ν_{ei} from microtearing simulations.

3. ETG stabilization with density gradient

We have recently demonstrated the stabilization of electron-scale turbulence [6] due to a large density gradient increase induced by an ELM event. Fig. 2 shows the normalized $k_\perp$ spectra measured by high-k microwave scattering [7] before (498, 515 ms) and after (532 ms) a fivefold increase in local density gradient in the vicinity of r/a=0.6. It is clear that after the ELM event (532 ms) the fluctuation power for $k_\perp \rho_s \leq 15$ is reduced, most significantly at smallest wave numbers, $k_\perp \rho_s \leq 10$.

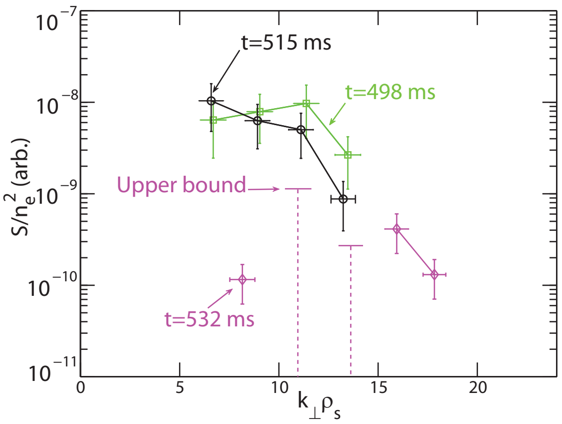

Fig. 2. Measured high-k scattering intensity vs. $k_\perp \rho_s$, before (498, 515 ms) and after (532 ms) an ELM event that causes a large increase in density gradient.

Before the ELM event (498, 515 ms) the measured T_e gradients from Thomson Scattering are larger than the threshold for the Electron Temperature Gradient (ETG) instability (determined from GS2 simulations) over most of the high-k measurement region. However, after the ELM event (532 ms), the threshold T_e gradients are much larger due to the large density gradient (as expected from theoretical considerations [8]). The resulting stabilization of ETG modes is consistent with the reduced fluctuation intensity in Fig. 2 and the corresponding reduction in effective thermal diffusivity [6]. Non-linear ETG simulations appear to predict this trend at some of the measurement locations. While the microtearing mode is stable in this plasma, the trapped electron mode (TEM) is driven unstable by the large density gradient. However, the growth rates are weaker than the E×B shear rates. Additional nonlinear simulations will test whether TEM turbulence can survive the strong flow shear and contribute to the electron thermal transport in this plasma.

4. ETG stabilization with reverse shear

In RF-heated NSTX L-mode plasmas, negative magnetic shear is found to suppress electron turbulence and improve electron thermal transport. Fig. 3 (left) shows an example of a strongly peaked T_e profile indicative of an electron internal transport barrier (e-ITB). The steep gradient region in the e-ITB coincides with the region of most negative magnetic shear ($s \approx -2$, Fig. 3, right). A correlation has been found between the maximum observed electron temperature gradient and magnitude of negative magnitude shear for a collection of discharges [9]. High-k microwave scattering measurements are largest in intensity for the weakest shear (s>-0.4) and become smaller or bursty in nature for the strongest negative shear values (-2.5<s<-0.4), suggesting it is correlated with reduced transport and corresponding stronger temperature gradients. GYRO simulations verify that the ETG instability is suppressed at strong negative magnetic shear, resulting from both linear and nonlinear stabilizing effects. This suppression occurs in the absence of strong E×B shear confirming that negative magnetic shear alone is sufficient for ETG suppression in these e-ITB discharges.

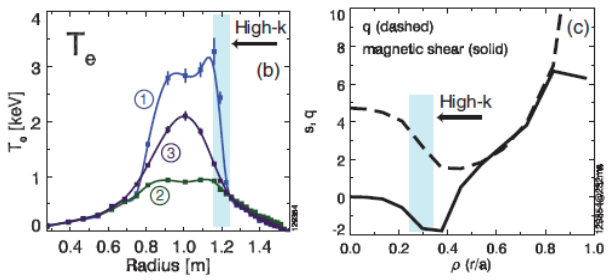

Fig. 3. (left) Measured T_e profiles at different times in a reverse shear plasma. (right) Safety factor and magnetic shear profiles for a reverse shear plasma.

5. First BES measurements

First Beam Emission Spectroscopy (BES) measurements have recently become available on NSTX [10]. These measurements have shown reduction of ion scale turbulence during the L-H transition from edge to core, and large edge poloidal correlation lengths.

Acknowledgements

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