Understanding and Predicting Microtearing Instabilities in the ST

K. Tritz, D. Stutman, L. Delgado-Aparicio, M. Finkenthal
Department of Physics & Astronomy, Johns Hopkins University

I. Current Status

Electron thermal transport is believed to be the dominant heat loss mechanism in present STs. Therefore, understanding and controlling electron thermal transport is crucial for predicting confinement and performance for any future devices based on the ST concept. The two dominant instabilities affecting electron transport on NSTX [1] and MAST [2] are predicted to be microtearing and ETG modes. There are some indications that between these two instabilities, microtearing modes may primarily responsible for electron heat loss because global thermal confinement scaling on NSTX scales strongly with collisionality, ν^{-1}. Of the microinstabilities that can contribute to electron heat loss, the microtearing mode is one of the more difficult to investigate as evidence of its presence, δB, δTe fluctuations, are quite challenging to diagnose on the frequency and spatial scales of the mode. Additionally, while linear stability calculations have indicated that microtearing modes can be destabilized in present ST discharges, nonlinear simulations of these modes using the current crop of gyrokinetic codes (e.g. GYRO, GS2, GEM) have proved problematic.

II. Diagnosing the Microtearing Mode

Microtearing instabilities are magnetic field fluctuations that cause the formation of small island chains near rational magnetic surfaces. The width of the islands increase as the mode amplitude grows and saturates according to analytic predictions at $\delta B/B \sim \rho_e/L_T$ ($\sim 10^{-3}$ on NSTX) [3]. Significant electron thermal transport occurs when either the resistive layers near the rational surfaces overlap, or when the island width is large enough such that successive island chains begin to overlap [4]. When this occurs, the nested flux surfaces in the overlap region break down into a stochastic region of magnetic flux, and electron heat can be transported radially, carried by parallel motion of electrons streaming along the field.

To directly measure this turbulent activity, one must detect the magnetic fluctuations with spatial resolution sufficient to resolve modes with $k_\theta\rho_s \sim 0.1$-1 [1], enough sensitivity to detect the mode amplitudes estimated above, and with a bandwidth sufficient to measure the Doppler-shifted frequency spectrum (10's of kHz). Possible diagnostics to measure these magnetic fluctuations are as follows:

II.A Magnetic fluctuation diagnostics

Motional Stark effect (MSE) measures equilibrium magnetic field pitch, and can measure magnetic field fluctuations, though it may be challenging to measure fluctuations at the level of microtearing mode amplitudes.

Polarimetry measures magnetic field and fluctuations line-integrated along a chord through the plasma. Though some localization has been achieved on the MST RFP due in part to strong density peaking [5], density profiles on low-A tokamaks tends to be much broader, so spatial resolution is unlikely to be sufficient.

Cross-polarization scattering using RF mode conversion has been used to diagnose magnetic fluctuations on tokamaks, but the wave number is more suited to higher-k turbulence $k\rho_s > 10$, which is more relevant to ETG activity [6].

A heavy ion beam probe (HIBP) has been used to measure magnetic fluctuations in LHD and CHS though in addition to signal contributions from fluctuations along the line path, sensitivity to other plasma fluctuations, such as electric potential, can also complicate the measurement interpretation [7,8]. Additionally, due to the cost, size, and complexity of the diagnostic itself, there are no current plans to implement the HIBP on either of the main ST devices.

II.B Non-magnetic fluctuation diagnostics

While investigations into magnetic fluctuation diagnostics should continue to determine applicability to the measurement of microturbulence, other diagnostics that measure quantities indirectly related to the magnetic fluctuations may also prove useful, especially when coupled to nonlinear simulations incorporating the relevant synthetic diagnostics. Specifically, electron density and temperature fluctuations may also be driven by the microtearing modes; therefore, diagnostics that can measure these quantities with the appropriate spatial and temporal capabilities should detect the presence of these modes. The detection of associated fluctuations will need to be compared to predictions from nonlinear simulation codes to distinguish the underlying turbulent mechanism from other electrostatic fluctuations. However, in present ST devices it is predicted that low-k electrostatic turbulence is suppressed by strong ExB shear, which should help isolate both the presence and the effect of electromagnetic microturbulence.

One method of detection is to measure localized X-ray emission from the plasma in an attempt to image the impact of the turbulent fluctuations on plasma emissivity, which is a function of electron temperature and density. Shown in Figure 1 is an X-ray diagnostic that is spectrally resolved to image Carbon VI emission which is radially localized in a narrow shell near the outer plasma region where T_e ~150-250eV. This radial localization allows the measurement of both a large 5kHz 2/1 tearing mode, as well as smaller, turbulent filaments with characteristic frequencies ~50-80kHz, which is consistent with small, higher-m/n islands formed along nearby rational surfaces. If this type of diagnostic is coupled with a measurement of the density fluctuations, such as beam emission spectroscopy (BES), it should be possible to have separate measurements of the electron density and temperature fluctuations.

II.C Indirect diagnostics

In the presence of stochastic magnetic transport, it is expected that higher energy electrons will be preferentially lost as they stream parallel to the stochastic magnetic field. This loss should result in a deviation from Maxwellian of the electron distribution and corresponding X-ray emission energy. Therefore, another method of diagnosis could be that of the measurement of the inferred electron distribution function by measuring the X-ray spectrum using pulse height analysis. While such measurements are only an indirect measurement of the existence if not amplitude of the microtearing fluctuation activity, in the absence of more direct measurements, PHA or other X-ray spectral measurement methods may be sufficient to correlate the inferred existence of microtearing modes with changes in the calculated electron confinement.

III. Proposed Research Thrust – Validation of microtearing physics using synthetic and physical diagnostic comparisons

Though analytic theoretical models for microtearing modes have existed for some time, recent studies have indicated that these previous works may not adequately describe the microtearing instability in the ST. Linear numerical studies have uncovered dependencies that are inconsistent with the analytic predictions, and are due, perhaps, to operation at higher β and the increased magnetic drifts from the smaller radius of curvature of the plasma [2].

Therefore, developing a physics-based understanding of microtearing modes, and specifically how they manifest at low aspect ratio may be crucial for a confident prediction and scaling to future ST devices. Specifically, understanding the role of magnetic and ExB shear on mode stabilization, the effects of ν, β, β', and operation at low A on microtearing modes are all important topics that should be included in this research thrust.

Barring direct measurement of the thermal fluxes, translating fluctuation measurements to knowledge about electron thermal transport requires the comparison to simulations; therefore, these codes need to produce predicted mode amplitudes and fluctuation power k-spectra using synthetic diagnostics that can be compared to the full range of diagnostics in use to experimentally measure the fluctuations. Given the difficulty of direct magnetic measurements, using a combination of other measurements, such as BES, localized X-ray imaging, or X-ray spectral diagnostics, to compare with predictions from nonlinear gyrokinetic calculations should be an important first step to understanding and validating the physics behind microtearing modes.

[1] K. L. Wong *et al.*, Phys. Rev. Lett. **99** (2007) 135003
[2] D. J. Applegate *et al.*, Plasma Phys. Control. Fusion **49** (2007) 1113
[3] J. F. Drake *et al.*, Phys. Rev. Lett. **44** (1980) 994
[4] J. F. Drake and Y. C. Lee, Phys. Fluids **20** (1977) 1341
[5] T. F. Yates *et al.*, Rev. Sci. Instrum. **79** (2008) 10E714
[6] A. B. Altukhov, *34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, P-2.135 (2007)*
[7] A. Shimizu *et al.*, Rev. Sci. Instrum. **79** (2008) 10F317
[8] A. Fujisawa *et al.*, Plasma Phys. Control. Fusion **49** (2007) 845

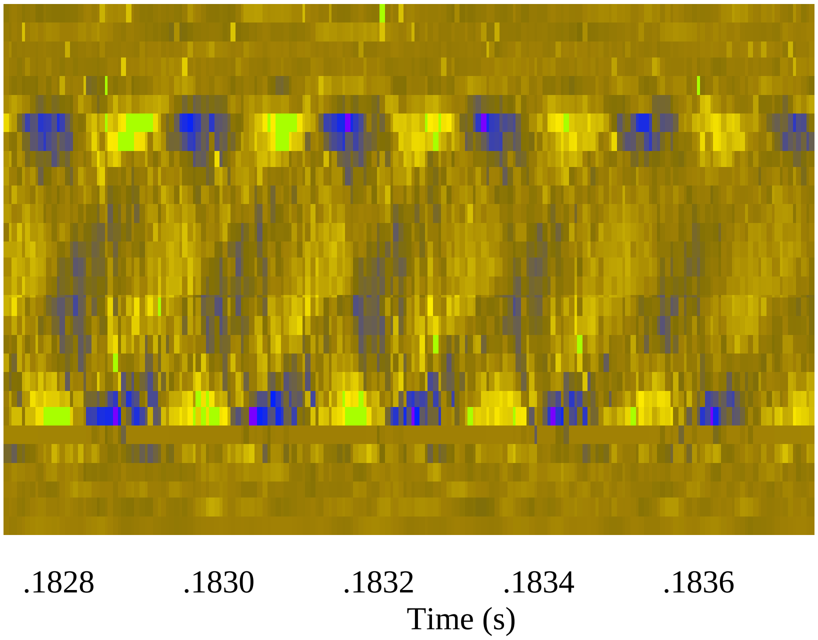

Fig. 1: X-ray imaging of a 2/1 tearing mode and underlying turbulent filaments.