

## Multi-energy SXR measurements of Resistive Wall Mode behavior in NSTX

L. Delgado-Aparicio<sup>1</sup>, D. Stutman<sup>2</sup>, S. A. Sabbagh<sup>3</sup>, K. Tritz<sup>2</sup>, R. Bell<sup>1</sup>, J. Berkery<sup>3</sup>, J. Bialek<sup>3</sup>, M. Finkenthal<sup>2</sup>, S. Gerhardt<sup>1</sup>, J. Menard<sup>1</sup> and L. Roquemore<sup>1</sup>

<sup>1</sup>*Princeton Plasma Physics Laboratory, Princeton, NJ, USA*

<sup>2</sup>*The Johns Hopkins University, Baltimore, MD, USA*

<sup>3</sup>*Columbia University, New York, NY, USA*

The active control of the long-wavelength resistive wall mode (RWM) instability is expected to significantly improve the performance of future burning plasmas. We present here a study, which contributes to the understanding of the physics of RWM stabilization and control, especially, on the effects of the actively stabilized RWMs on the background plasma and the correlation between magnetic and kinetic measurements.

### RWM KINETIC DIAGNOSTIC

The main diagnostic used for describing the effects of the actively stabilized RWM on the background plasma is a tangential multi-energy soft X-ray array [1-5] (see Figure 1) we operate at the National Spherical Torus eXperiment (NSTX) [6] at the Princeton Plasma Physics Laboratory. This diagnostic has three identical groups of overlapping sightlines that view the same plasma volume at various energies using beryllium foils of different thickness. Due to the toroidal asymmetric nature of the RWM, the 1D Abel-inversion gives only an approximate description of the SXR emissivity profile. Modulations in the time-history of the ME-SXR emissivity profiles (see Figure 2) have indicated the existence of edge density and core temperature fluctuations in good agreement with the slow evolution of the  $n=1$  magnetic perturbation measured by the poloidal and radial RWM coils [5]. The characteristic 20-30 Hz frequency in the kinetic diagnostics is approximately that of the  $n=1$  stable

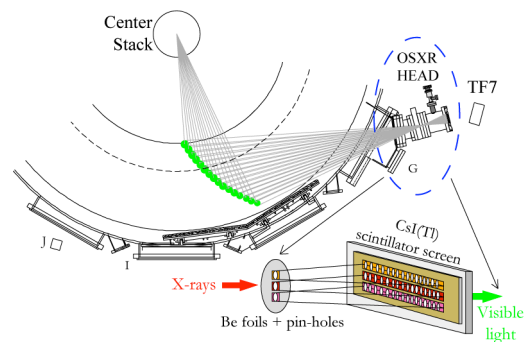


Fig. 1. Top-view of tangential multi-energy OSXR array installed in NSTX.

RWM, which is also near the measured peak of the resonant field amplification (RFA) [7] and inversely proportional to the wall time. The use of this diagnostic system has been paramount in the description of impurity density and temperature fluctuations found to be associated with a driven and stable RWM.

## NEW OBSERVATIONS

Three new experiments are confirming the presence of this driven stable mode. The first observation was made in high  $\beta_N \sim 5-6$  NSTX H-modes, indicating also good agreement between magnetic and kinetic diagnostics. The low-frequency (20-30 Hz) mode activity in the low- and high-energy SXR emissivities shown in

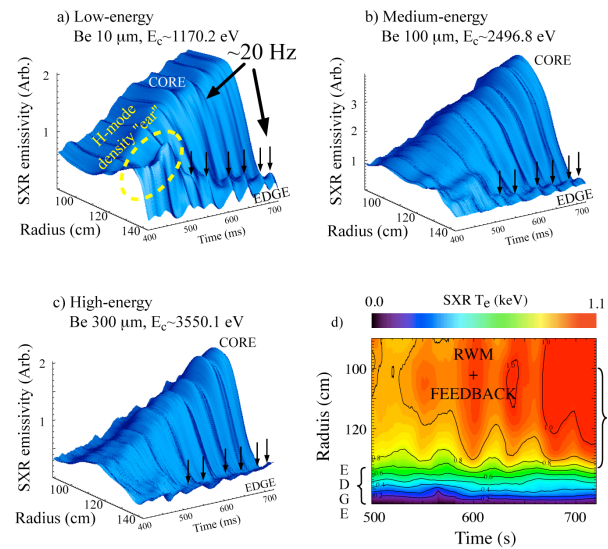


Fig. 2. Plots of the three ME-SXR emissivities and SXR-inferred  $T_e(R,t)$  measurement indicating a stable RWM.

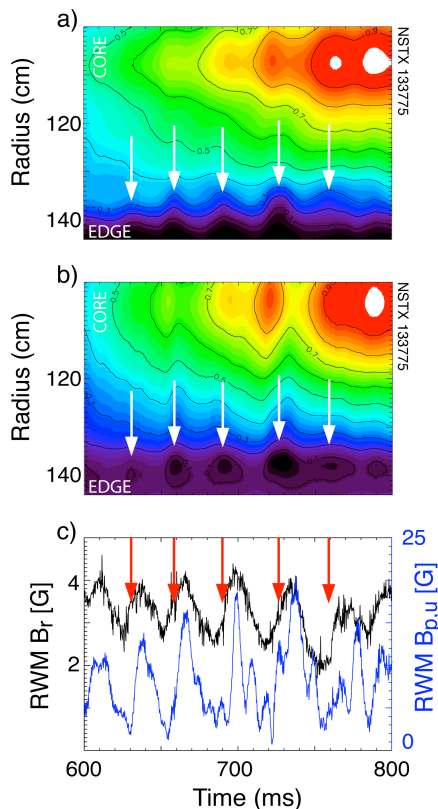


Fig. 3. Plots of the low- and high-energy emissivities together with radial and poloidal  $n=1$  fields.

Figure 3-a) and -b), correlate well with the radial and poloidal magnetic fields measured by the RWM coils right after the  $n=1$  mode active-feedback was turned off at 600 ms; this fluctuation has a frequency of few tens of Hz which differs from that of a fast (several kHz to few tens of kHz) toroidally-rotating kink or tearing modes. The fluctuating ME-SXR emissivities indicate that the mode activity at the edge appears to be driven or saturated (not growing), especially when compared to a typical wall-time ( $\tau_{\text{wall}}$ ) of the order of 5-10 ms. Although the ME-SXR reconstructions show low frequency mode activity mainly at the edge, these perturbations are rather global affecting also NSTX core. Moreover, the  $n=1$  frequency of interest ( $\sim 30$  Hz) is near the natural resonant field amplification (RFA) resonance [7]. The stability of this driven mode is currently being investigated using a newly-

developed multi-mode VALEN code in which the multi-mode response is theoretically computed to be significant when  $\beta_N > 5$  [8].

A second observation involves the coexistence of the driven stable (20-30 Hz) mode and that of fast (20-40 kHz) core (e.g. fishbone-like) MHD activity as depicted in Figure 4. It has been reported elsewhere that the resonance between the mode and the precession drift frequency of hot ions can lead to a significant improvement of the RWM stability limits [6]. A preliminary experimental study in JT-60 indicated that this resonance can lead to a significant improvement of the RWM stability limits [7], and that fast core MHD could re-distribute the fast ion density in such a way as to destabilize and/or trigger RWMs. However, the loss and/or redistribution of fast ions in the NSTX core due to the  $n=1,2$  fishbone-like activity shown in Figure 4-c) seems not to affect the presence of the stable driven mode [11].

A third experiment aimed at investigating the role of resonant field amplification (RFA) near marginal stability, used an  $n=1$  traveling (co-rotating) waveform (see Figure 5). Signals from lock-mode (LM) and RWM coils indicating the traveling-wave toroidal-phase and plasma response are shown in Figures 5-a) and -b). The perturbation induced by the  $n=1$  traveling waveform also shows up as a radial perturbation in the low- and medium energy SXR emissivities. The kinetic perturbation seems to have the same response as the radial RWM fields but a time-dependent offset with respect to the poloidal fields.

## SUMMARY AND FUTURE WORK

Compared to magnetic measurements, the ME-SXR technique has advantages for low-frequency MHD detection, such as spatial localization and insensitivity to stray

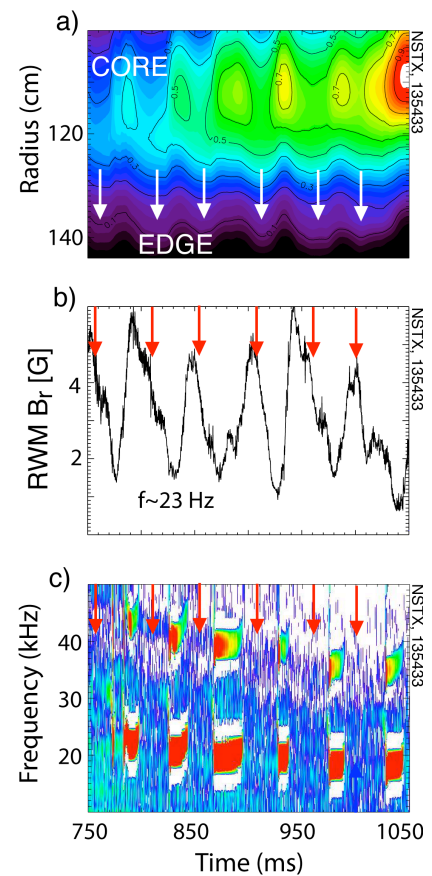


Fig. 4. Plots of the a) low-energy SXR emissivity, b) the radial  $n=1$  fields measured by the RWM coils and c) Mirnov spectrogram.

magnetic fields. Due to its compact design, the ME-SXR diagnostic could be installed in different toroidal locations for proper identification and future control of RWMs. High  $\beta_N \sim 5-6$  NSTX H-mode plasmas exhibit low frequency activity in magnetic and kinetic diagnostics indicating the presence of a stable/driven RWM which co-rotates at a frequency near the measured  $n=1$  RWM and covers a greater radial extent as  $\beta_N$  is increased. The stable/driven RWM is apparently a separate mode from the so-called unstable RWM. This work was supported by U.S. DoE Contract No. DE-AC02-09CH11466 at PPPL and DoE grant No. DE-FG02-99ER5452 at Johns Hopkins University.

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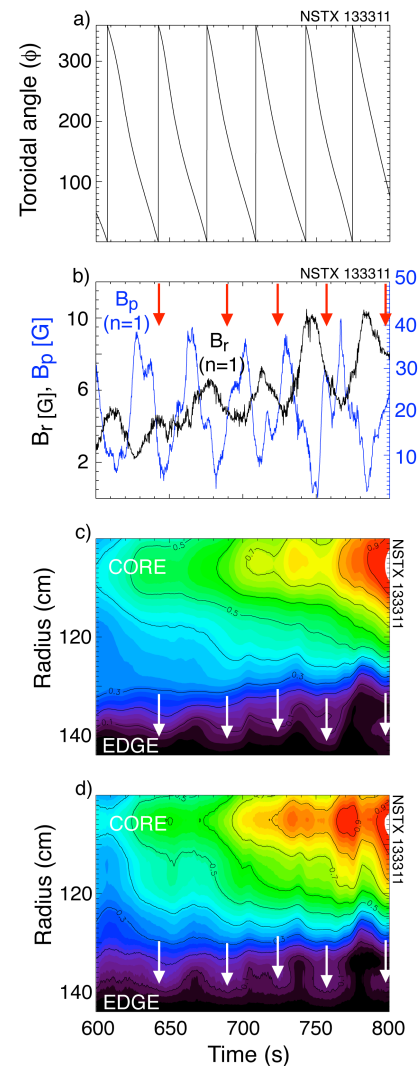


Fig. 5. Signals from the a) lock-mode and b) RWM coils, together with the low- and medium-energy SXR emissivities during the RFA experiment.