Multi-energy SXR characterization of actively stabilized resistive wall modes in NSTX

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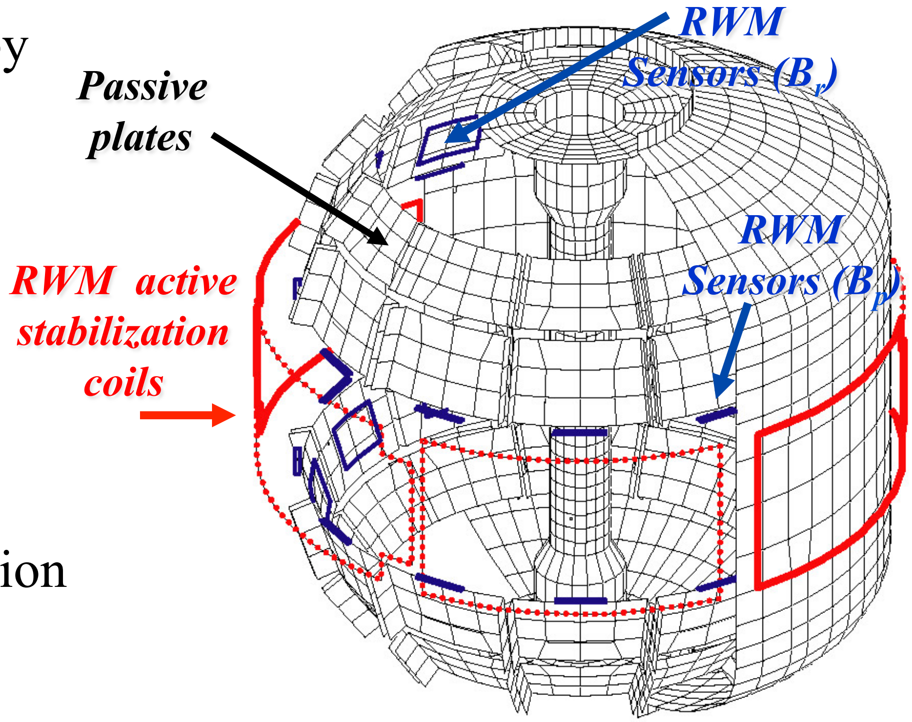
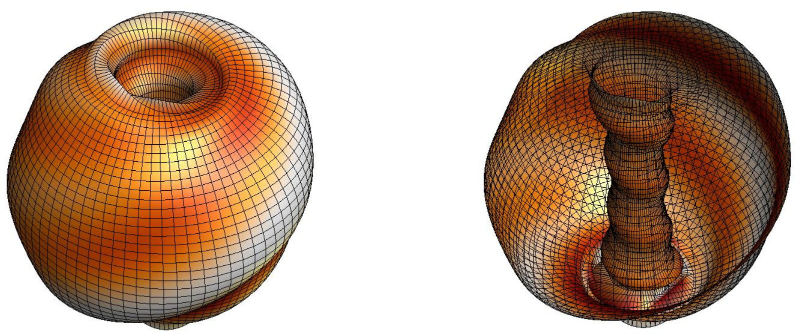
RWM research in NSTX

- RWM is an external kink modified by presence of resistive wall.
- RWM Characteristics:
  - slow growth: $\Gamma \sim 1/\tau_{wall}$
  - slow rotation: $f_{RWM} \sim 1/\tau_{wall}$
  - $\tau_{wall} \sim 10$ ms
  - stabilized by rotation & dissipation
- High toroidal rotation passively stabilizes RWM at high-q.
- **RWM can affect both the outer and inner plasma.**
- ***Long-pulse, high-β_N requires wall stabilization.***

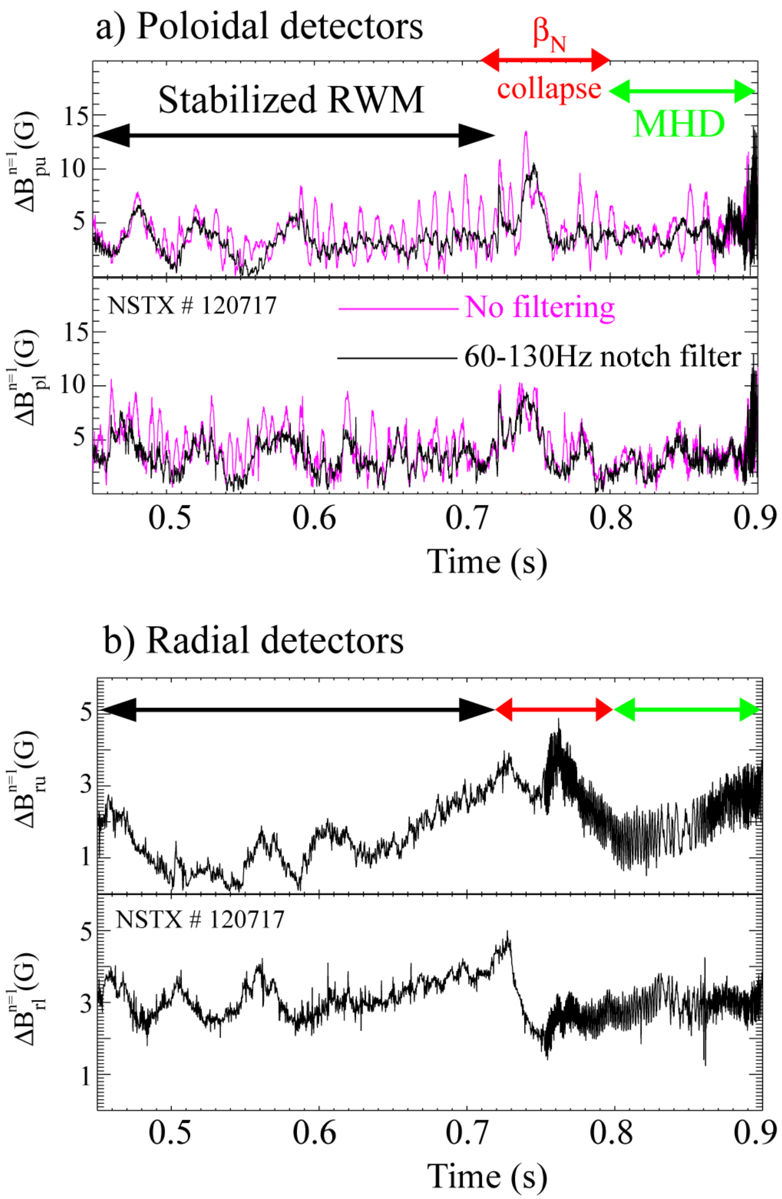




(exterior view) (interior view)

Sabbagh, NF, **46**, 635, (2006).

The slow (~20 Hz) *n=1* mode is measured by the RWM coils.



• This new plots have mode amplitudes that are slightly different than the ones reported in Sabbagh, PRL, 2006 [data showing what was stored in the operations files while running the mode identification algorithms].

• This new data has been revised using the present identification algorithm to the raw data [Levesque].

• A (60-130 Hz) notch filter has also been applied to the data from the poloidal detectors in order to **extract the same slow ~20 Hz *n=1* mode**.

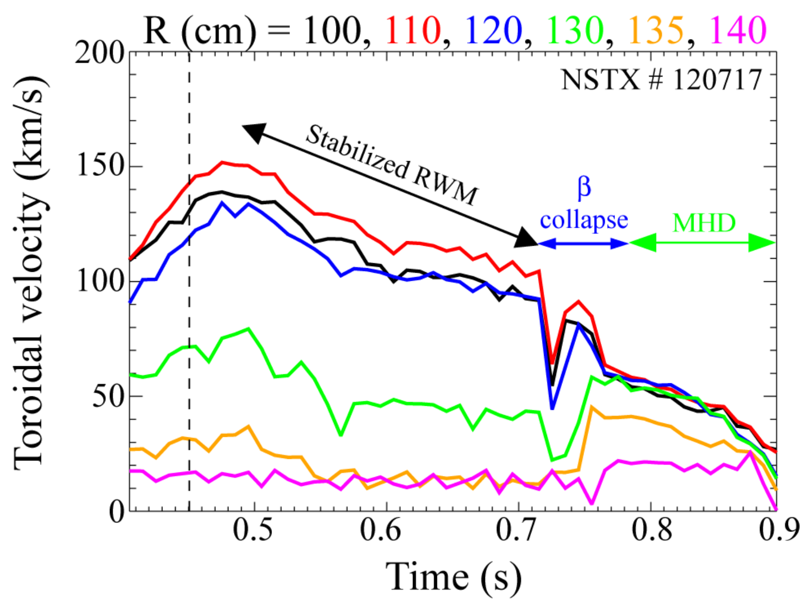
RWM induced by *n=3* braking & stabilized using *n=1* feedback

- RWM active stabilization has been successfully tested in the National Spherical Torus Experiment at the Princeton Plasma Physics Laboratory.

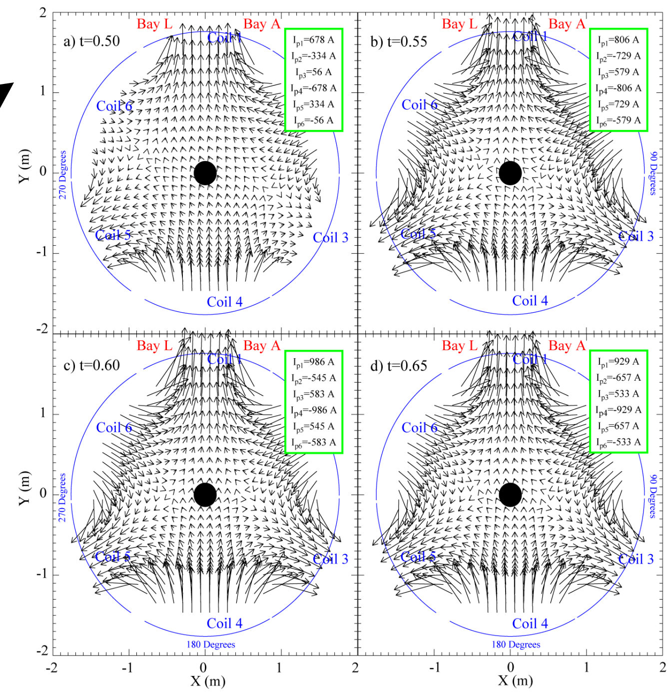
- Such experiment is made by applying both:

 a) a non-resonant *n=3* magnetic braking [that reduces the toroidal rotation (ω_ϕ) significantly below a critical rotation ($\Omega_{\phi,c}$)] and,

 b) a *n=1* active feedback stabilization field.



"Steady" n=3 magnetic braking

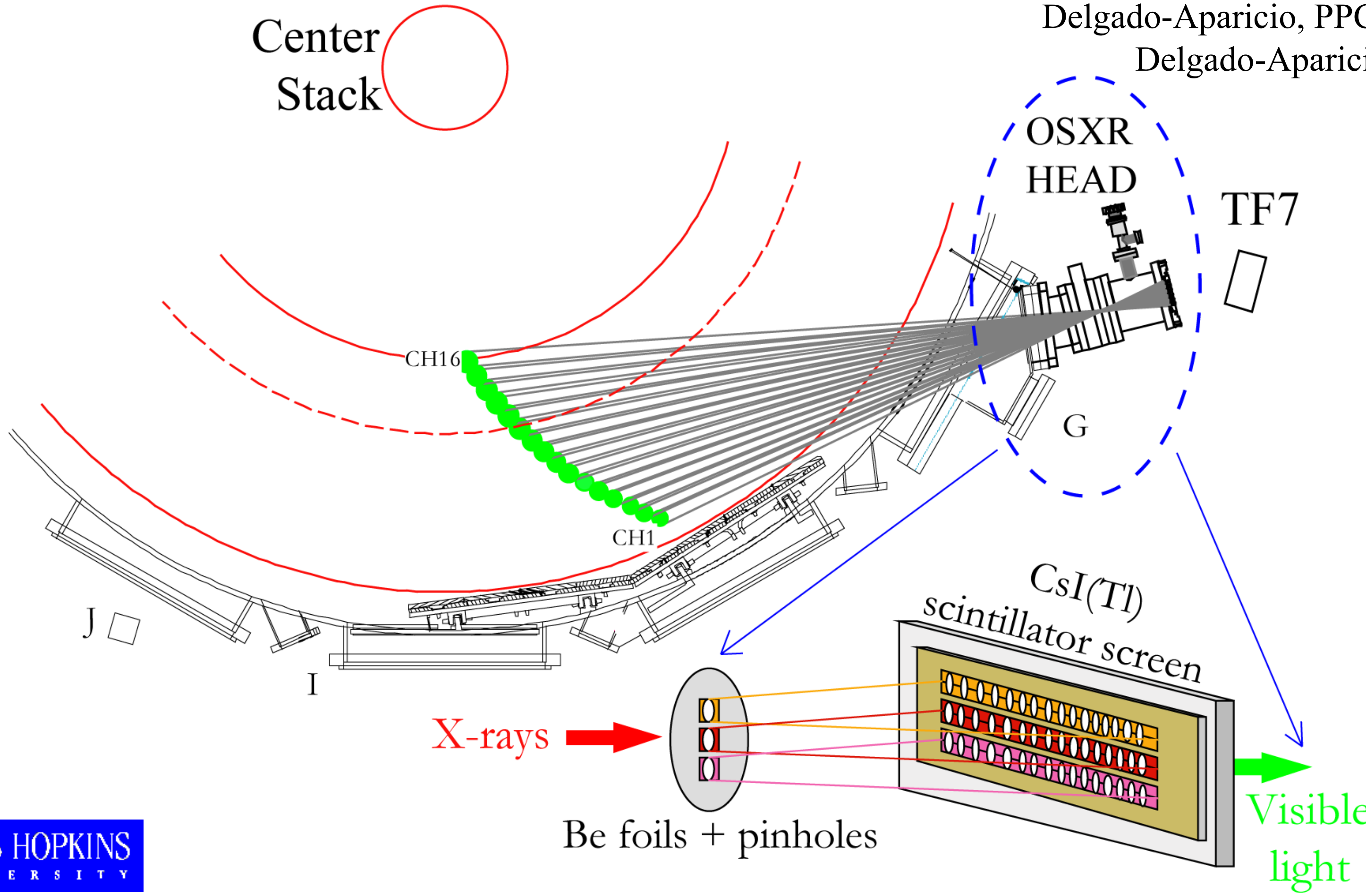


- This process successfully stabilized the RWM for up to seven energy confinement times (τ_E).

Sabbagh, PRL, **97**, (2006), Sontag, NF, **47**, (2007).

Main diagnostic: tangential multi-energy "optical" SXR array

Delgado-Aparicio, JAP, **102**, 073304 (2007).
Delgado-Aparicio, PPCF, **49**, 1245 (2007)
Delgado-Aparicio, NF, July (2009).



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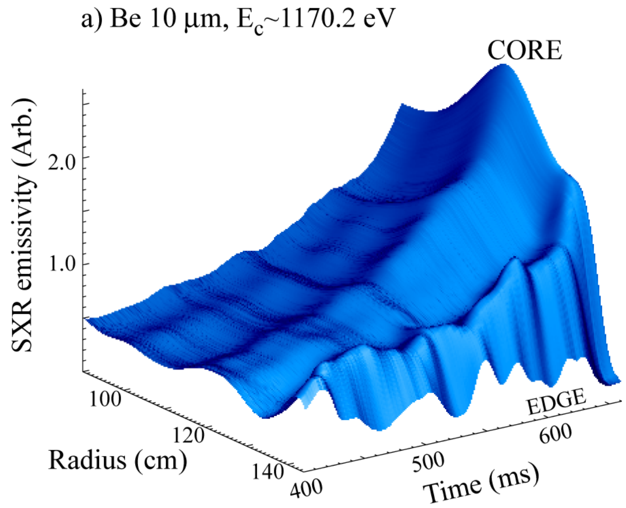
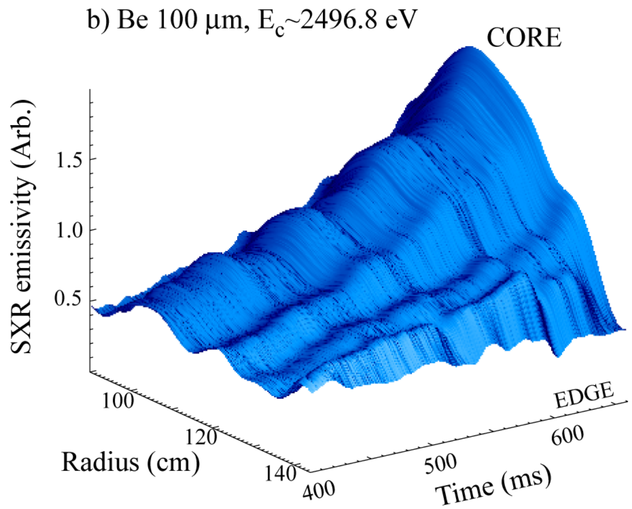
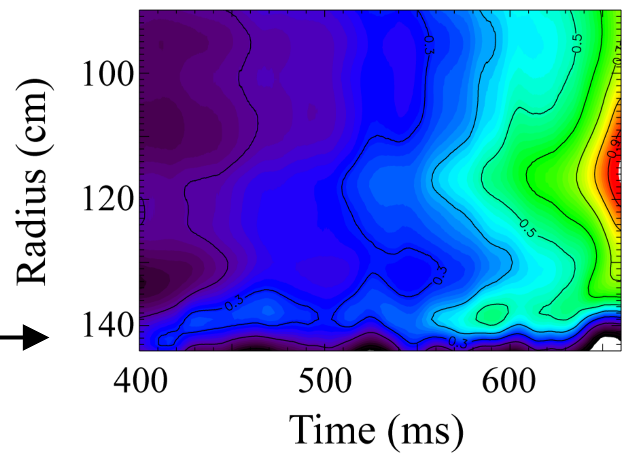
The motivation for the construction of this "multi-energy" soft X-ray (SXR) instrument is the development of simple, low-cost, stable, multi-chordal and versatile diagnostics which can serve a wide range of magnetically confined fusion (MCF) experiments for a number of critical simultaneous profile measurements (e.g. T_e, n_e, n_Z).

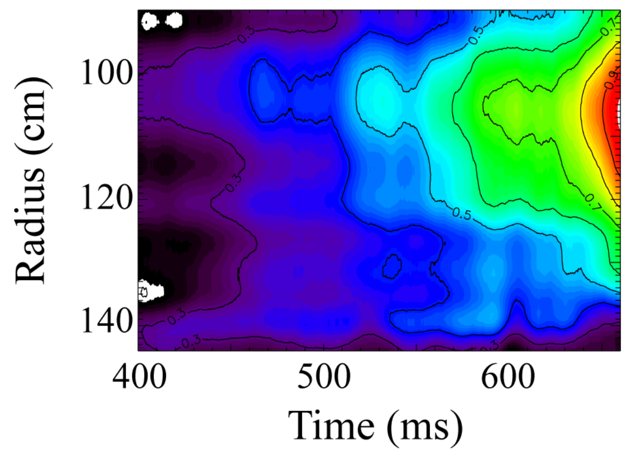
SXR reconstruction of non-stabilized RWM





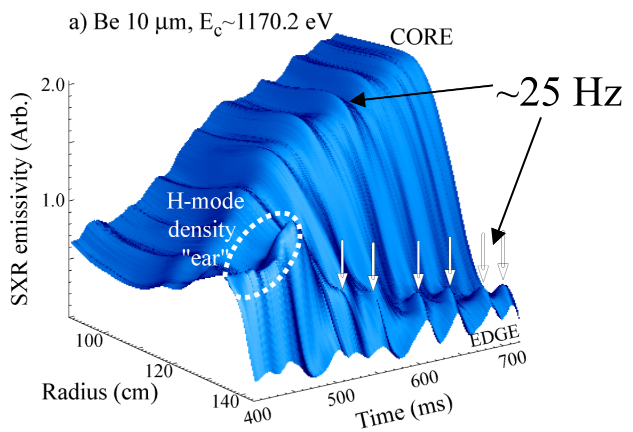
Peripheral modulation

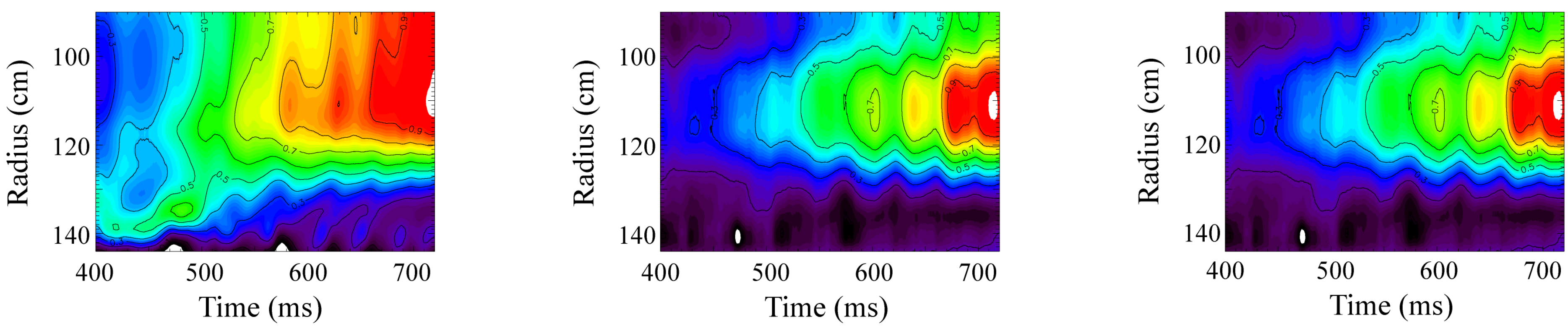




• Without stabilization the mode structure is ***peripheral*** and the plasma disrupts.
• The plasma core seem ***unaffected*** by the edge modulation.

SXR reconstructions of actively stabilized RWMs

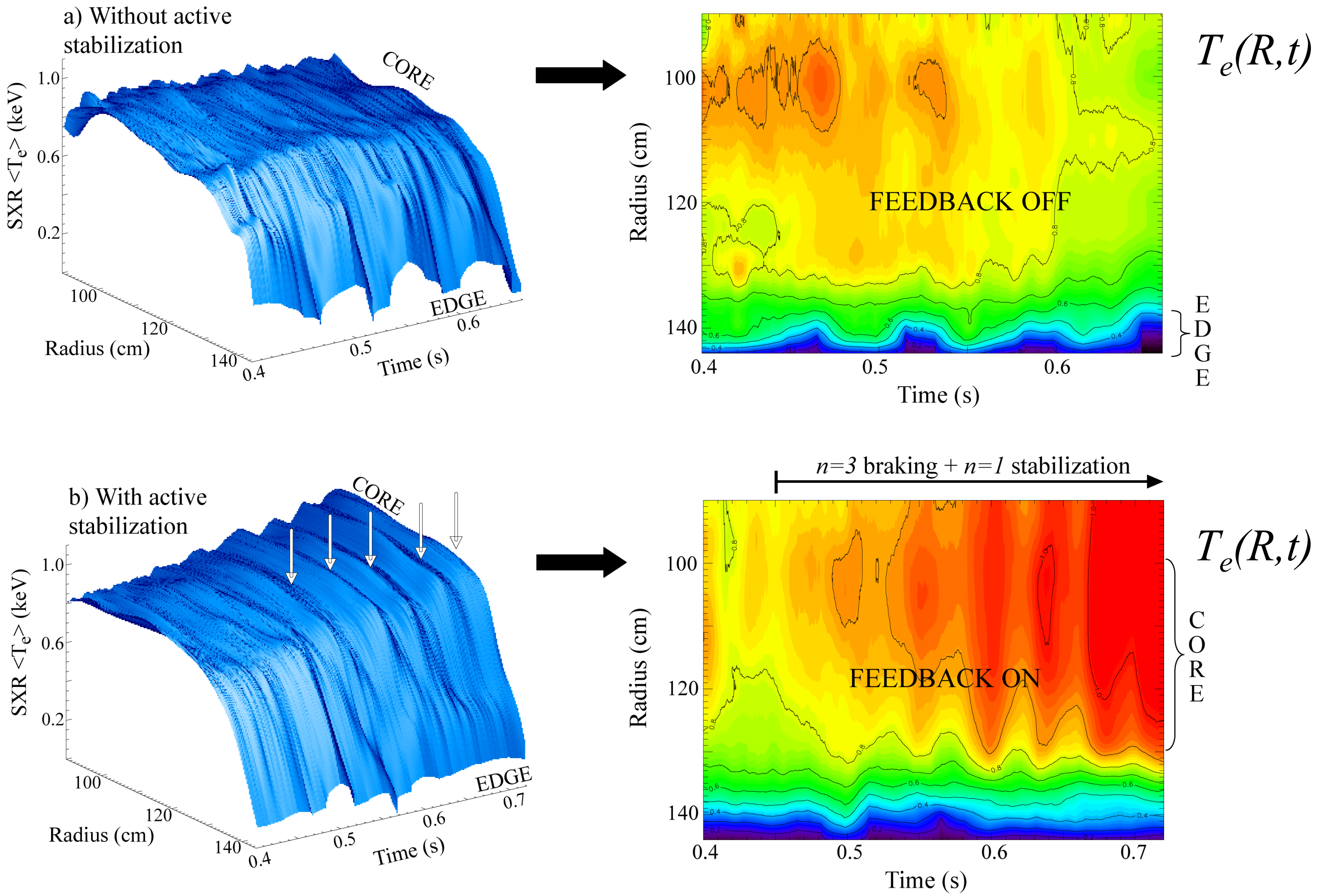




1. *n=3* braking and *n=1* stabilizing fields modified kinetic profiles at early times?
2. Are the RMPs taking out the H-mode density "ears"?
3. Increased edge n_Z blobs during stabilization.
4. Good correlation with drops in $\boldsymbol{T_{e0}}$ & S_n.
5. ***May have identified a stable RWM near the natural RFA resonance.***

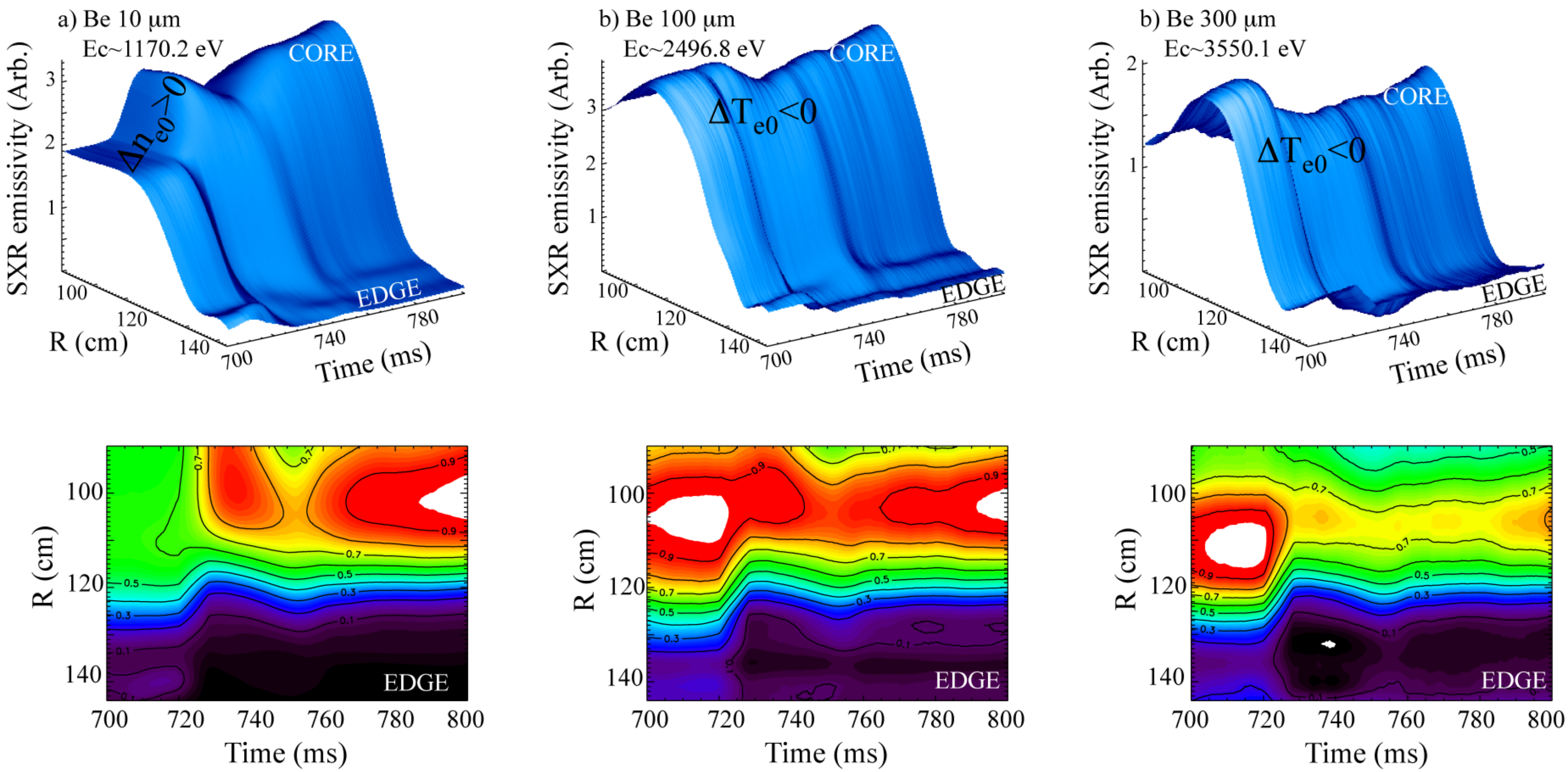
(Delgado-Aparicio, PoP, to be submitted, (2009)).

Mode $T_e(R,t)$ perturbation diagnostic



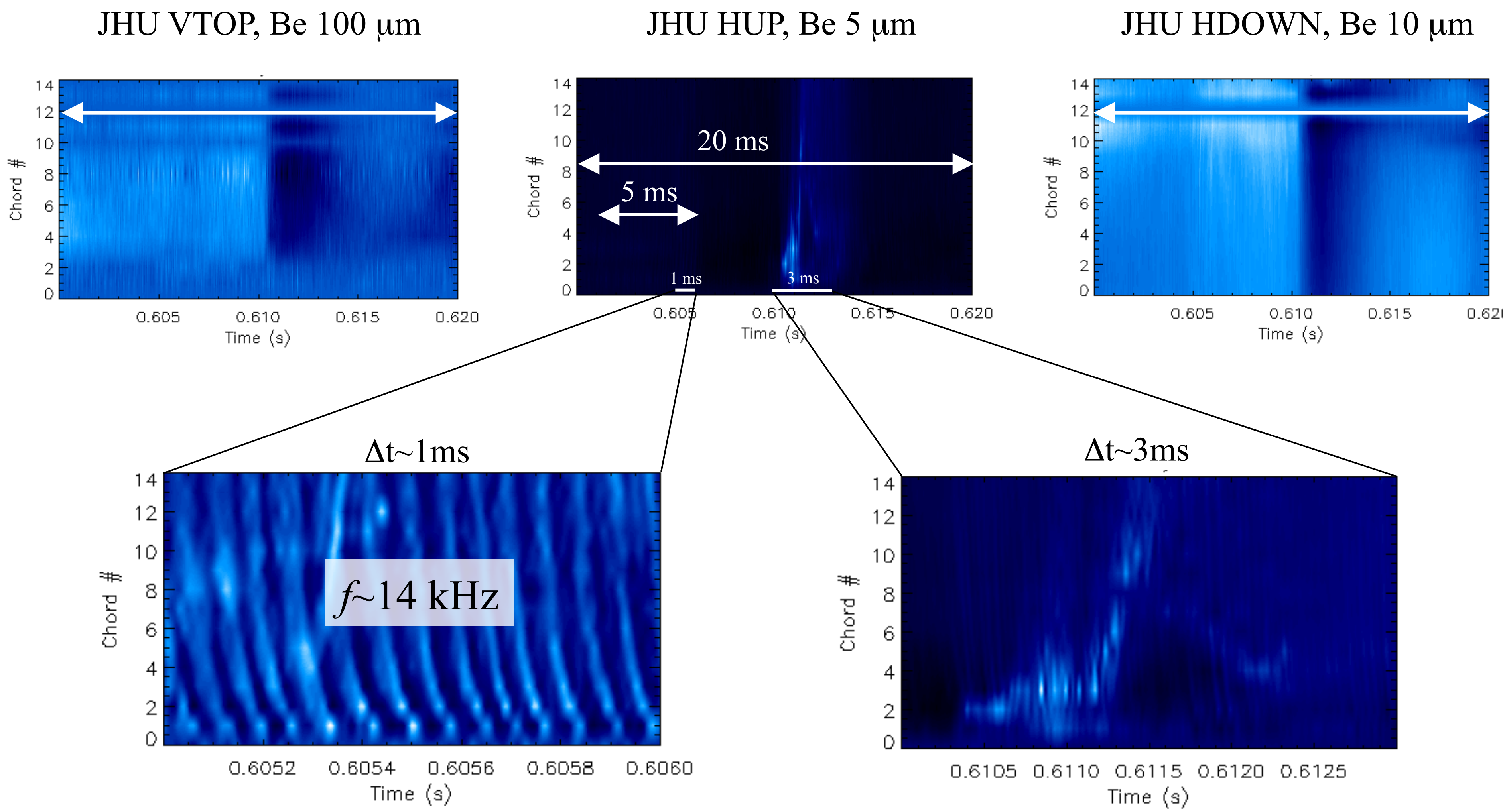
The non-stabilized RWM shows a **peripheral T_e modulation** while the actively stabilized RWM carries a **core T_e perturbation** with the same frequency as the slow $n=1$ mode (~20 Hz).

SXR reconstructions during β_N collapse and plasma recovery



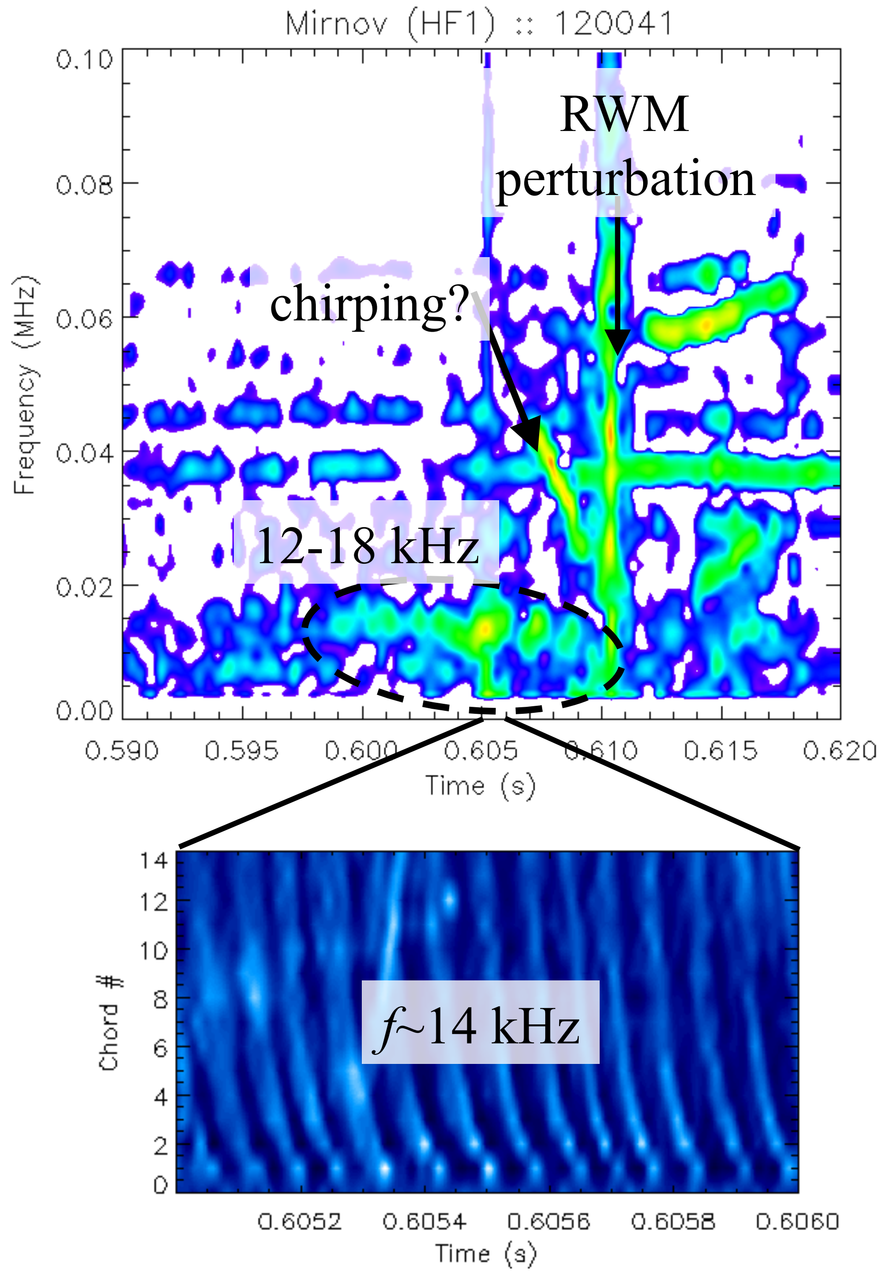
- Both the medium- and high-energy arrays observe the peripheral and core T_e crash.
- The low-energy array shows the effects of the $n_{e,0}$ raise (in agreement with MPTS).
- Possible displacement of plasma center after β collapse (in agreement with LRDFIT).

Analysis with multi-energy poloidal USXR system



Modes frequencies ranging 12-18 kHz have been observed throughout RWM stabilization generally before edge perturbations

Is MHD responsible for the trigger/stabilization of RWM ?



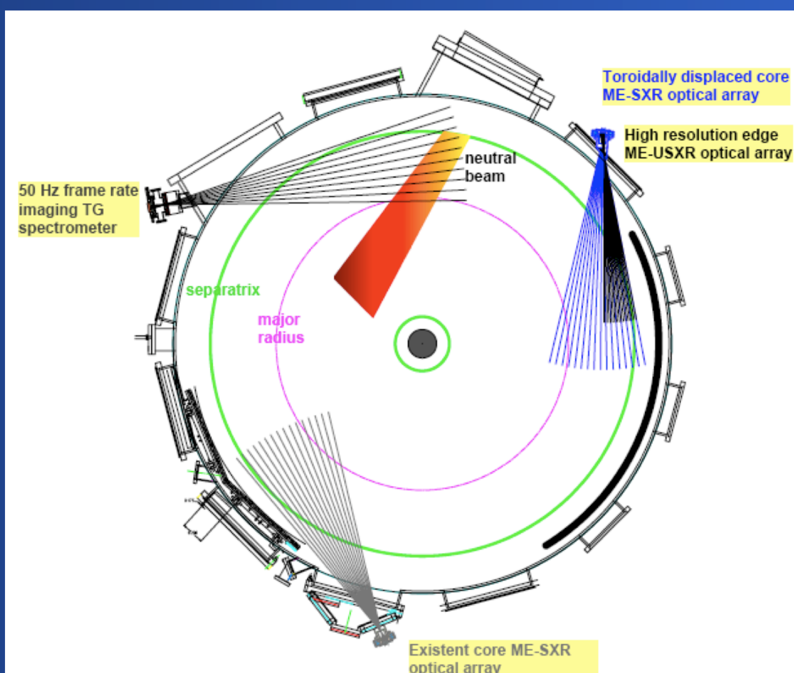
- MHD spectrograms confirm 12-18 kHz mode before edge RWM perturbation.

- High SNR poloidal ME-SXR array also detects this peripheral low-amplitude MHD activity (~ 5 ms before the edge RWM perturbations).

- Preliminary calculations indicate that the precession drift frequencies of energetic ions are of the order of 10-20 kHz.

- The resonance between the mode and the precession drift frequency of hot ions can lead to a significant improvement of the RWM stability limits [Hu & Betti, PRL 04].

Combining existent diagnostic with new edge ME-SXR array at a different toroidal location enables probing new physics:

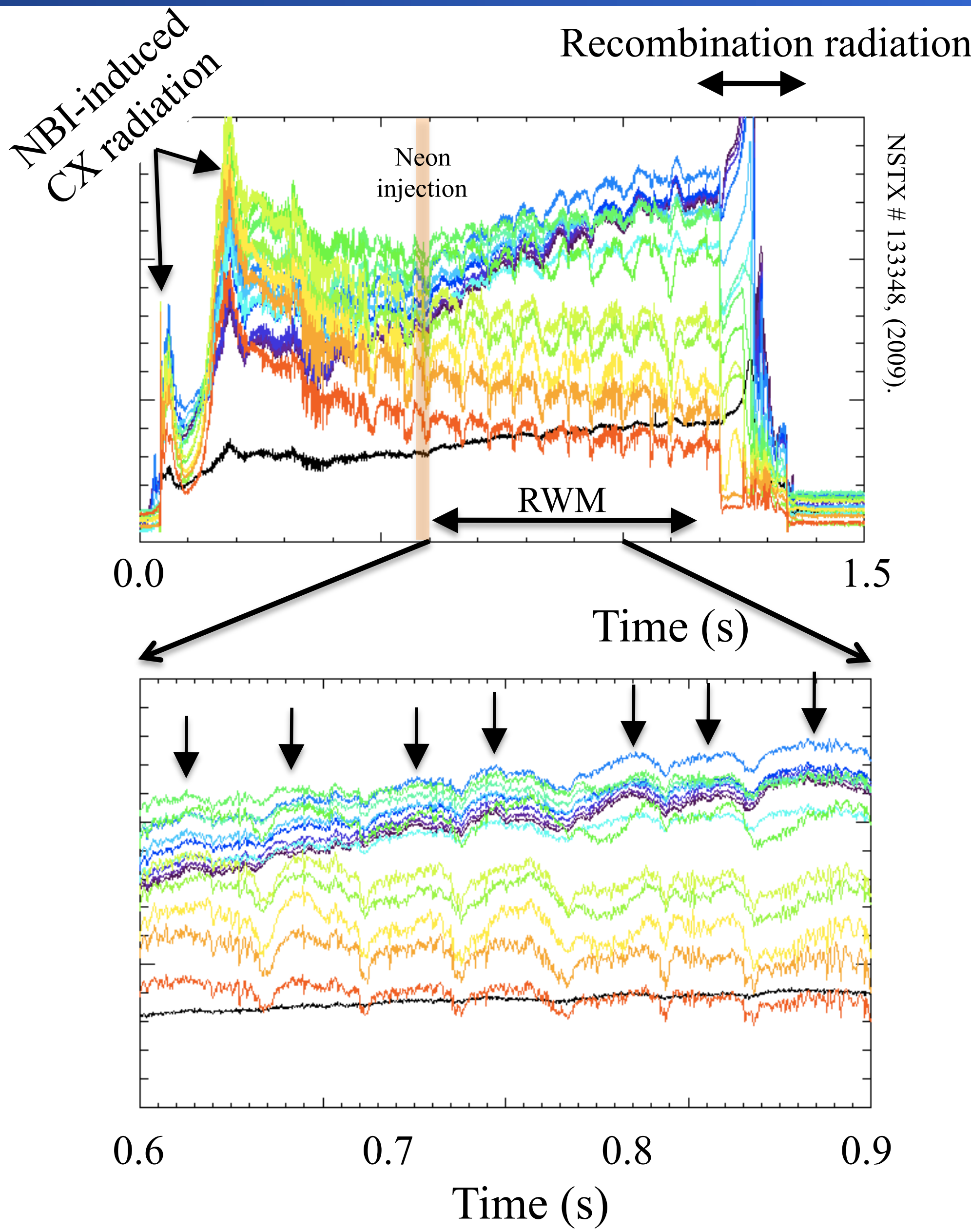


a) accurate n=1 identification

b) hot ion stabilization mechanism

c) possible multi-mode RWM components

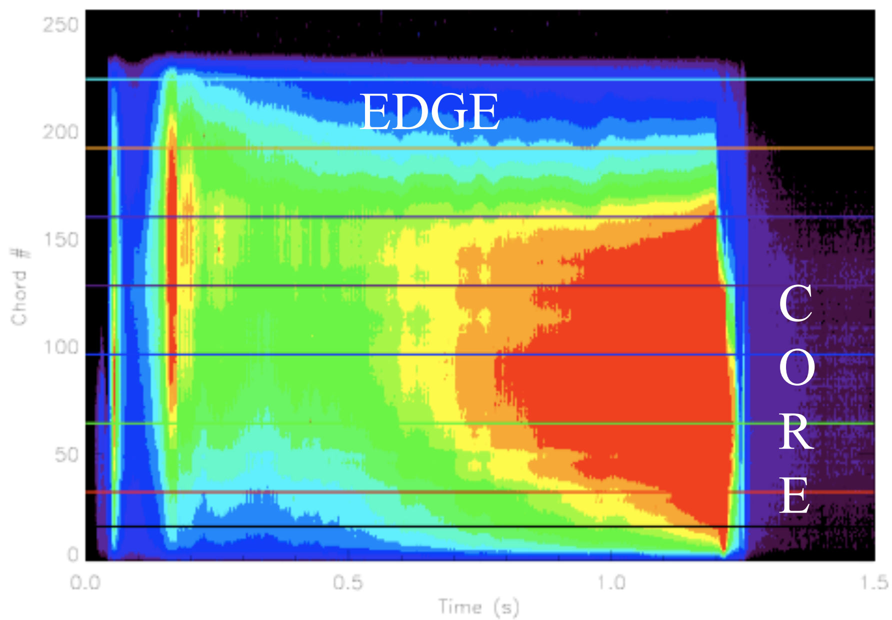
New high spatial resolution diagnostic capability for NSTX



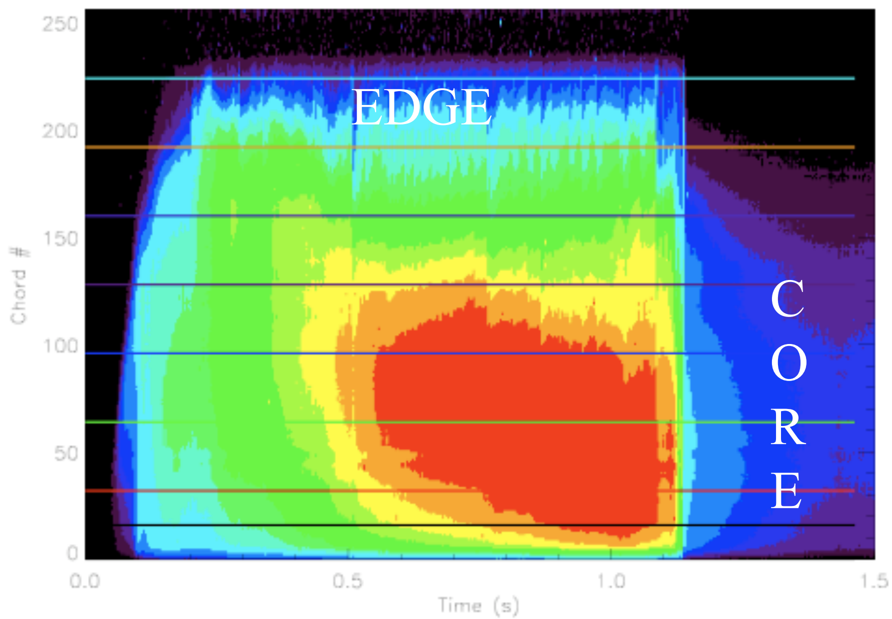
- EDGE ME-SXR array.
- 16 discrete channels with ~1 cm spatial resolution.
- Scintillator + image intensifier + 16-ch diode array + TIA amplifiers
- Use of Ti 0.3 and Be 10 μm foils.
- Capable of observing NBI induced CX-emission.
- Use of Ne-puff to shed light into RWM stabilization mechanisms.
- Effect of impurity penetration will also be decoupled.

Continuous coverage with high resolution at the edge

Ti 0.3 μm



Be 10 μm



- EDGE ME-SXR array.
- Continuous coverage with ~1 cm spatial resolution (oversampling).
- GOAL: sub-cm resolution.

- Scintillator + image intensifier + fiber-bundle + fast camera
- Use of Ti 0.3 and Be 10 μm foils.
- Capable of observing NBI induced CX-emission.

Summary

• The temperature and density profiles at the gradient region are changed due to the presence of the resonant magnetic perturbations (RMPs).

• The non-stabilized RWM shows a peripheral T_e modulation while the actively stabilized RWM carries a core T_e perturbation with the same frequency as the slow $n=1$ mode (~20 Hz).

• The ME-SXR data suggests that the RWM may not be entirely "rigid" and that acting with the stabilizing coils on its external structure may transfer some of the perturbation to the interior of the plasma.

Statement and future plans

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

• Characterization of the RWM internal structure w/o stabilization.

• Establish the impact of hot-ions RWM stabilization and multi-mode RWM physics.

• Measure the helical structure of the RWMs (kink vs. island models).

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