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

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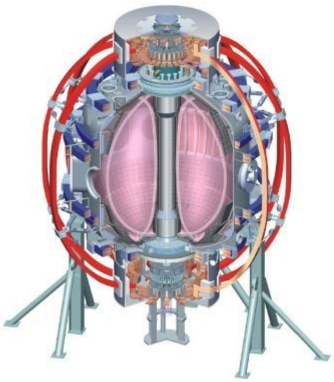

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Motivation

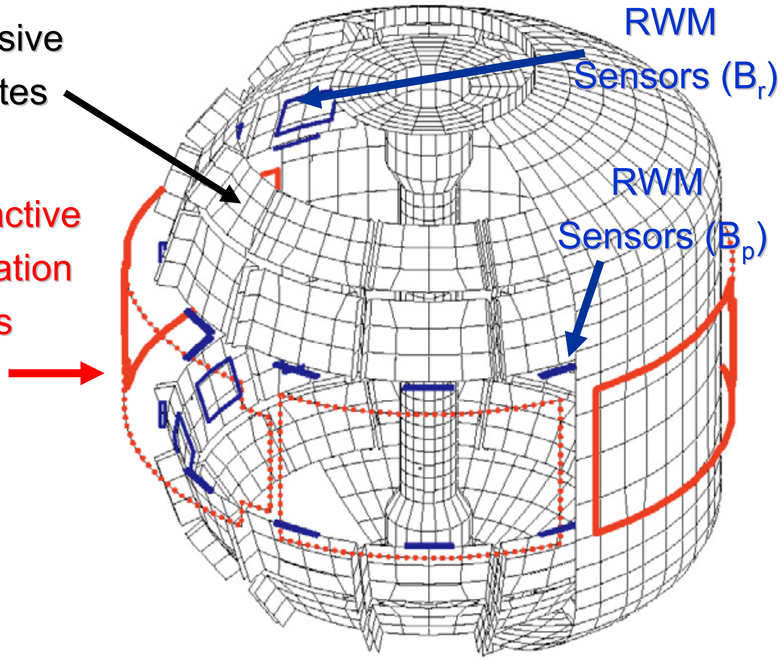
Contribute to the understanding of the physics of RWM stabilization and control, especially, on the effects of the actively-stabilized RWMs on the background plasma and the correlation between magnetic and kinetic measurements.

Previous observations in DIII-D, JT-60 and NSTX:

- Investigation of RWM Internal Structure (DIII-D).
  [I. N. Bogatu, APS-06].
- Dynamics and Stability of RWM in the JT-60U High-β Plasmas.
  [Matsunaga, 22nd IAEA-08, PRL-09].
- Kinetic characterization of actively-stabilized RWMs in NSTX.
  [S. A. Sabbagh, NF-06]
  [L. Delgado-Aparicio, APS-08-09, EPS-09, submitted to PPCF-10].

RWM research in NSTX

- RWM is an external kink modified by presence of resistive wall.
- RWM Characteristics:
  - *slow growth:* $\gamma \lesssim 1/\tau_{wall}$
  - *slow rotation:* $f_{RWM} \lesssim 1/2\pi\tau_{wall}$
  - τ_{wall}*~5-10 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 stabilization.

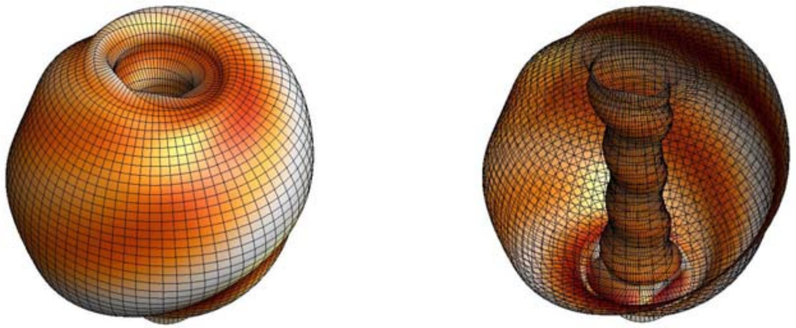


Passive plates

RWM active stabilization coils

RWM Sensors (B_r)

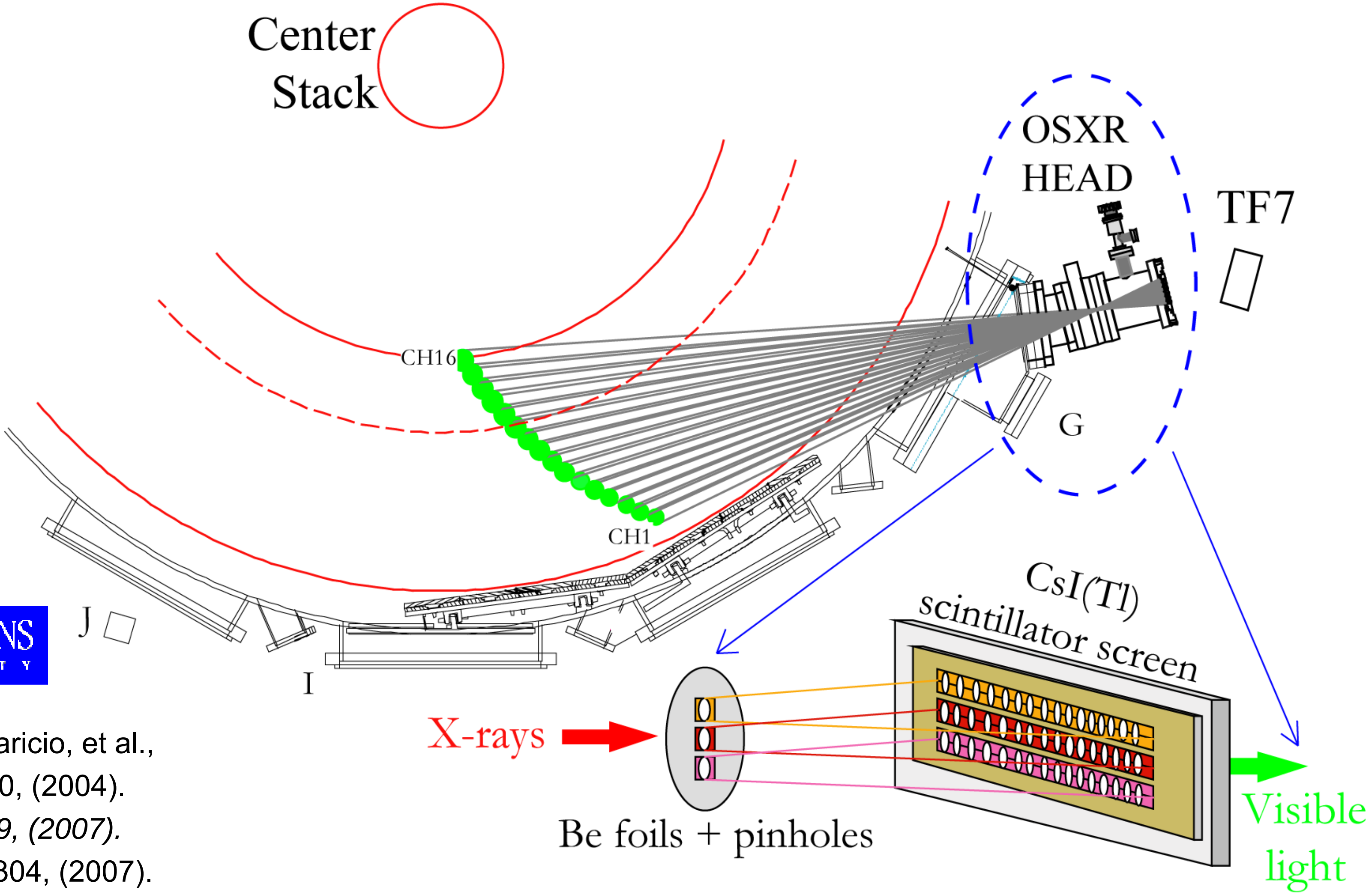
RWM Sensors (B_p)



(exterior view) ***(interior view)***

S. A. Sabbagh, et al., NF, **46**, 635, (2006).

Main diagnostic: multi-energy soft X-ray (ME-SXR) array



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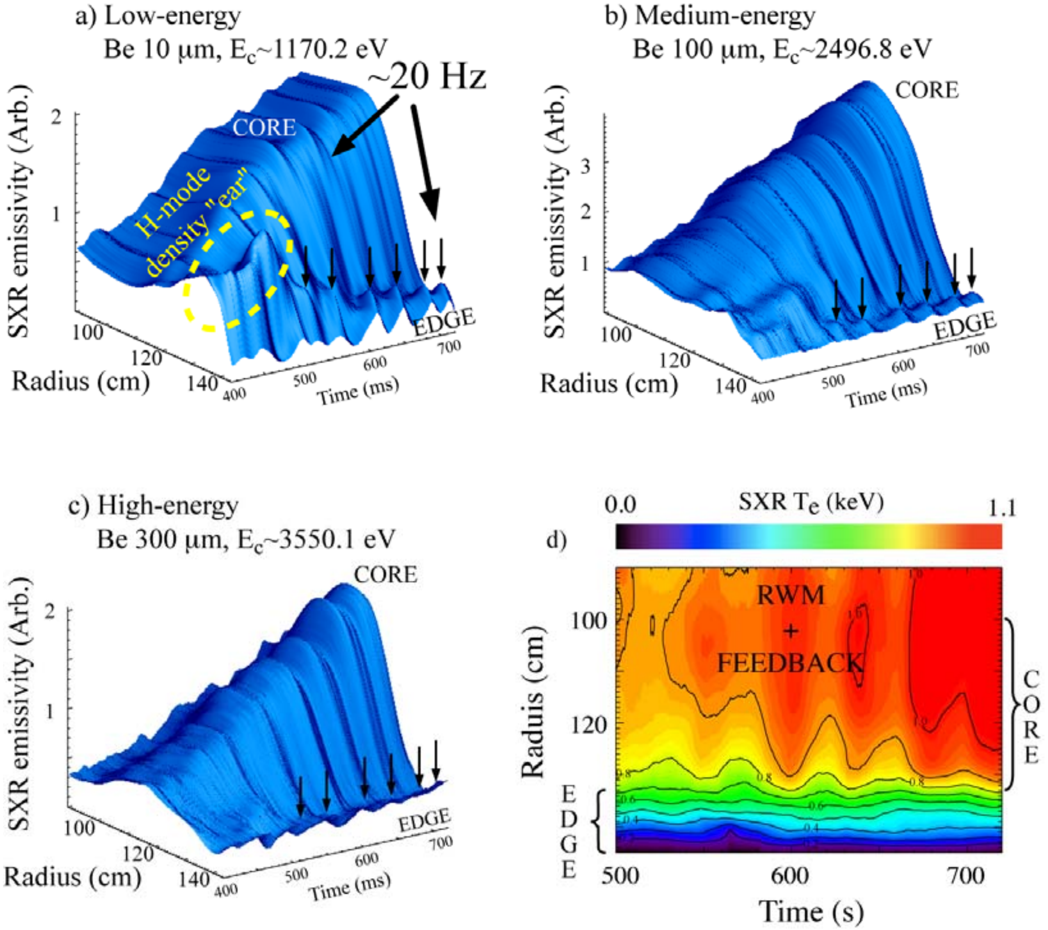
L. Delgado-Aparicio, et al.,
RSI, **75**, 4020, (2004).
AO, ***46**, 6069, (2007).*
JAP, **102**, 073304, (2007).
PPCF, **49**, 1245 (2007).
NF, **49**, 085028, (2009).

Multi-energy SXR measurements indicate stable RWM

ME-SXR reconstructed emissivity profiles and SXR-inferred fast $T_e(R,t)$ measurement.



Peripheral mode shows as:

☐ Increased edge n_Z perturbation during active stabilization (agreement with CHERS).

☐ Good correlation with drops in T_{e0} and neutrons.

☐ Good correlation between kinetic and magnetic diagnostics.

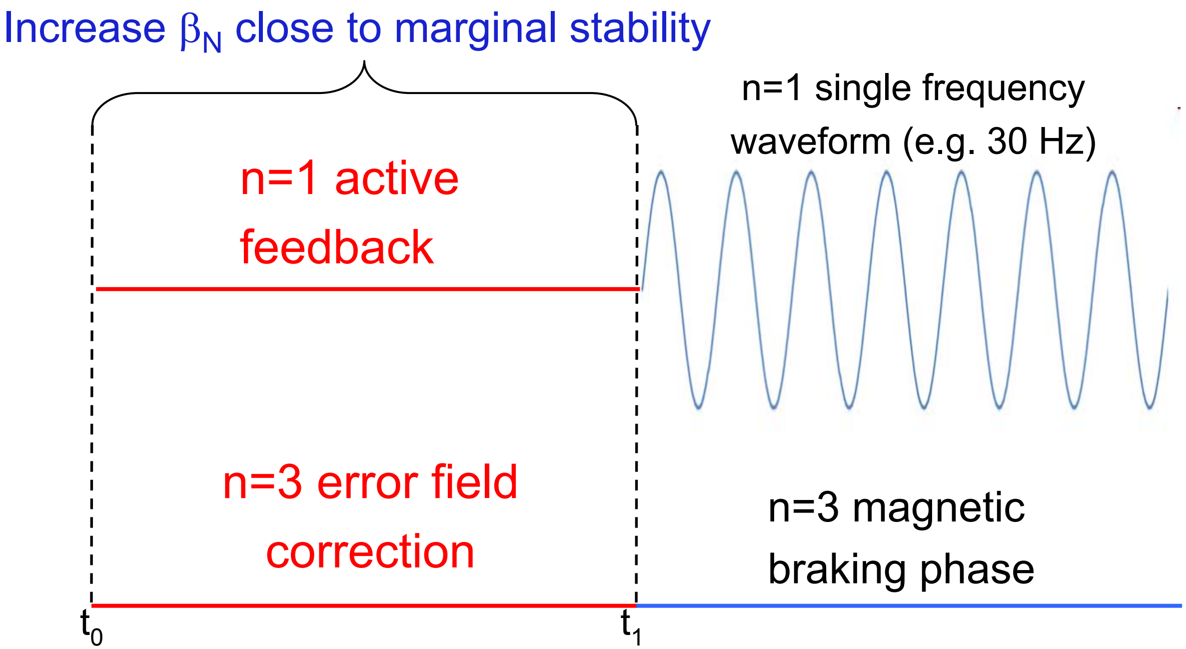
☐ Stable RWM with a frequency near the natural RFA resonance.

L. Delgado-Aparicio, et al., APS-08-09, EPS-09-10, submitted to PPCF-10.

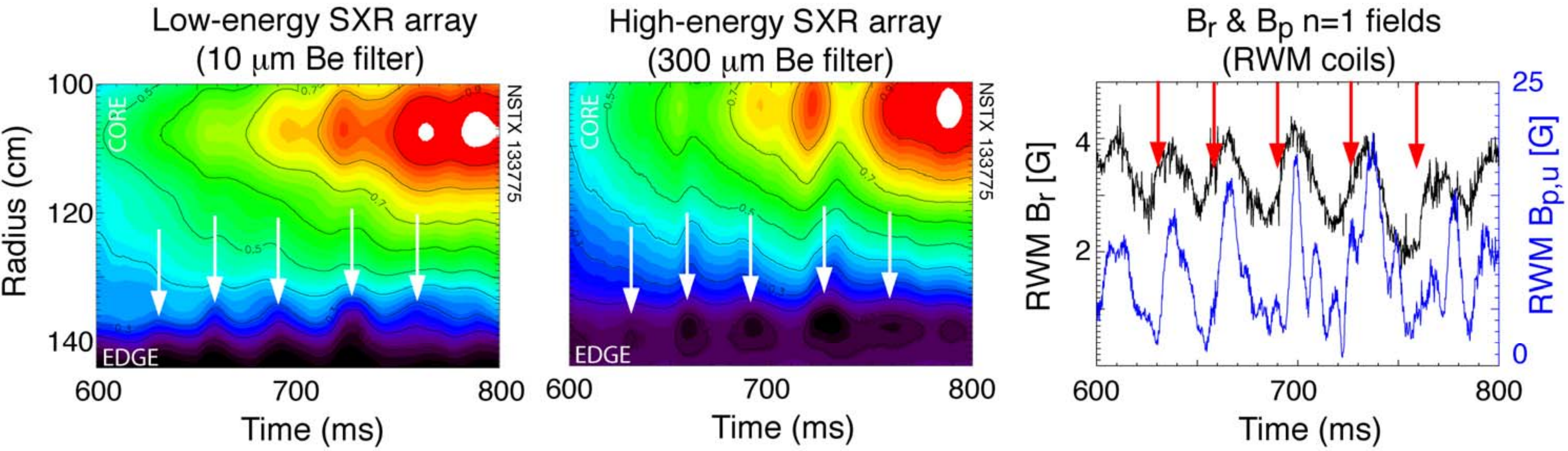
New experiments confirm the existence of stable driven mode

- High β_N H-modes exhibit low-f mode activity in magnetic and kinetic diagnostics.
- Interaction between driven/stable mode and fast MHD (e.g. fishbones).
- The role of RFA near marginal stability was investigated using an *n=1* traveling (co-rotating) waveform (see below).

NSTX control system waveforms for RFA experiments



High β_N H-modes exhibit low frequency mode activity in magnetic and kinetic diagnostics


Low-energy SXR array (10 μm Be filter)

High-energy SXR array (300 μm Be filter)

B_r & B_p n=1 fields (RWM coils)

- Mode activity in RWM frequency range (~30 Hz) coincident in both magnetics and kinetic diagnostics.

- ME-SXR reconstructions show low frequency mode activity is rather global.

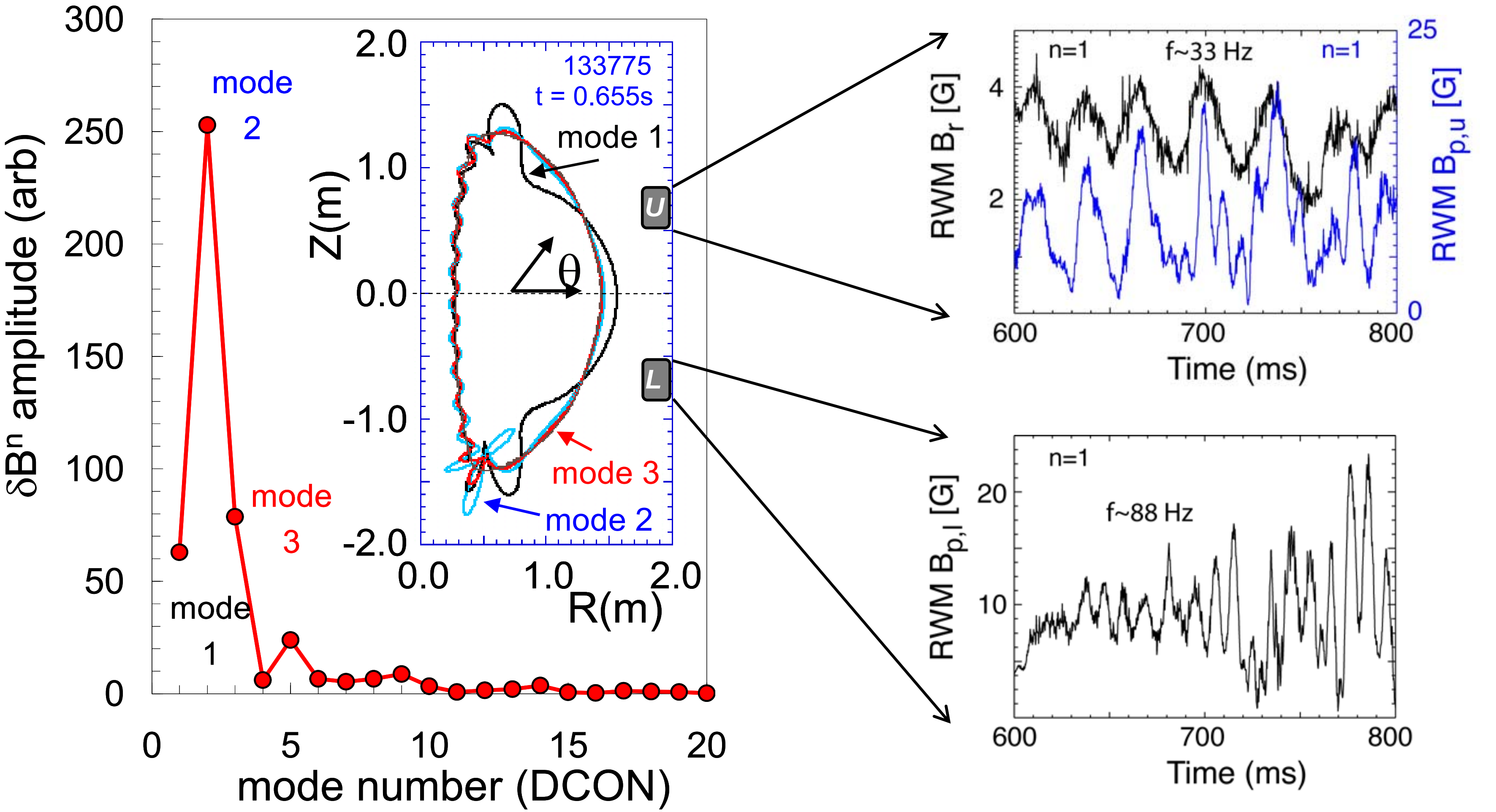
- Without active feedback the low frequency mode grows in time as suggested by kinetic and magnetic diagnostics.

Multi-mode response is theoretically expected at high β_N

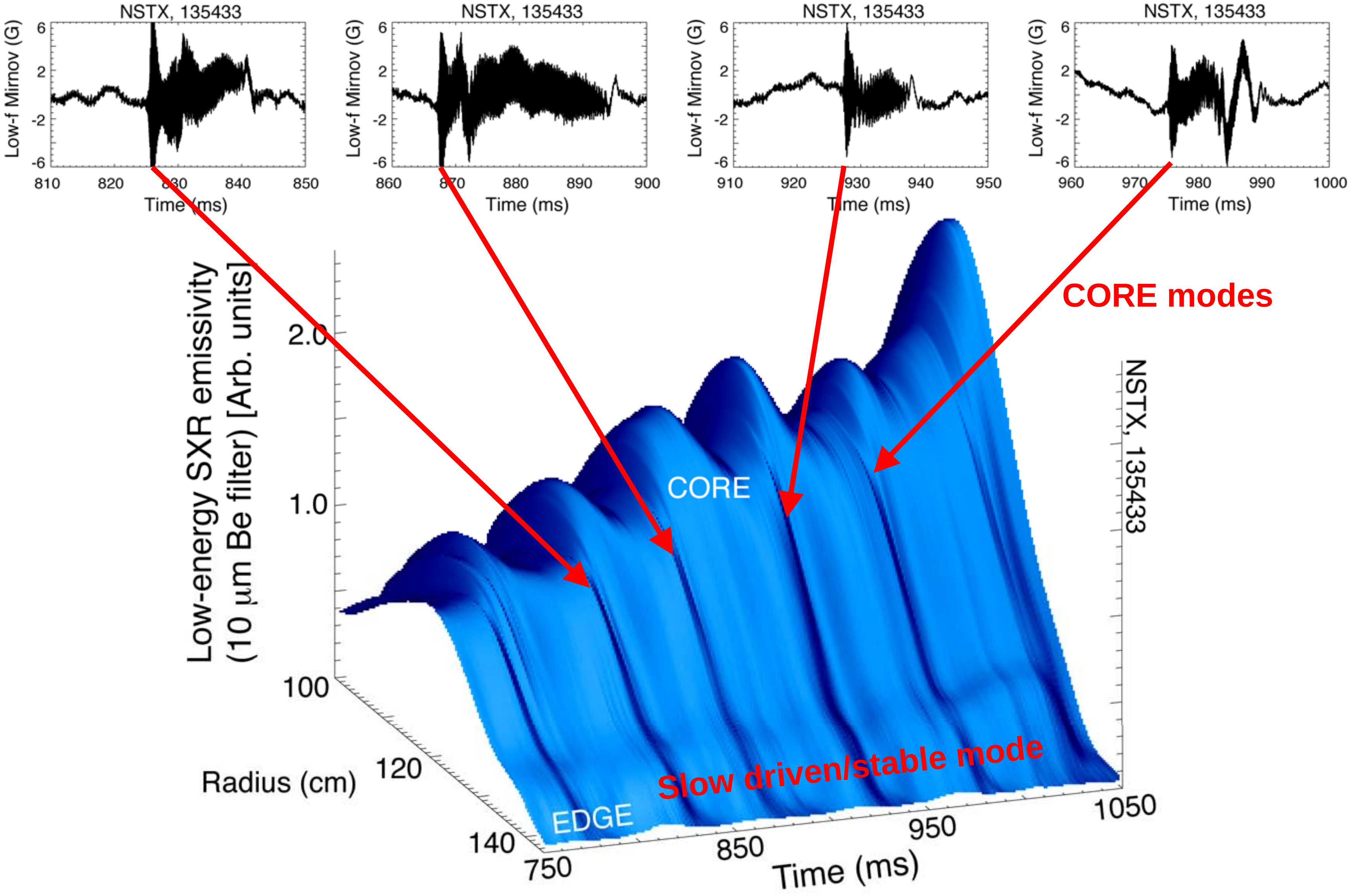
Computed eigenfunction spectrum of the perturbed field in multi-mode RWM analysis.

(see S. Sabbagh poster P4.160)

Upper (U) and lower (L) RWM detectors measure different fields, all of which have an n=1 component



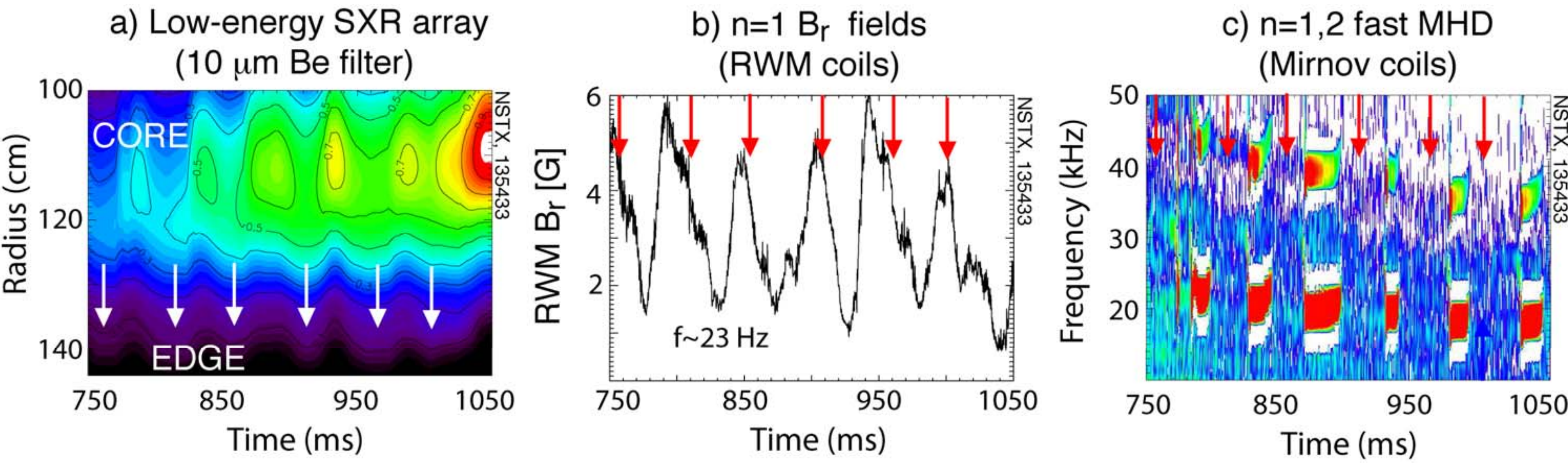
Interaction between wall stable mode and fast core MHD



CORE modes

Slow driven/stable mode

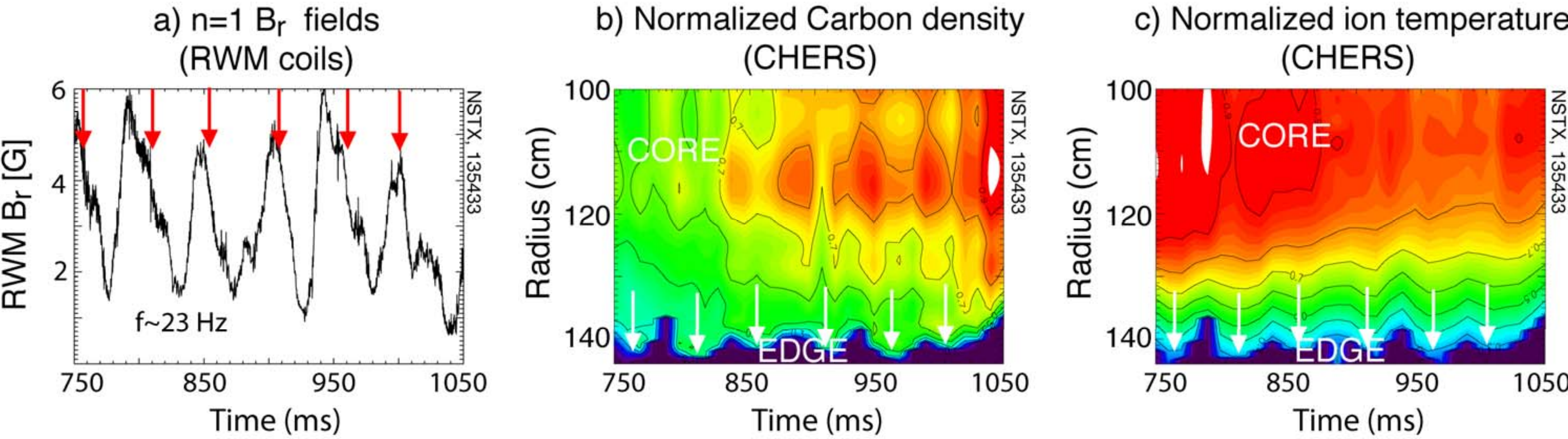
Slow n=1 mode persists in the presence of fast MHD



- A preliminary study (in JT-60 and DIII-D) on the stabilization of the RWM due to fast ions indicated that the resonance between the mode and the precession drift frequency of trapped thermal or energetic ions can lead to a significant improvement of the RWM stability limits (Matsunaga, 22nd IAEA-08, PRL-09).

- The loss and/or redistribution of fast ions in the NSTX core due to *n=1,2* fishbone-like activity, seems not to affect the presence of the stable driven mode [see poster contribution by J. Berkery, P4.106].

A suite of diagnostics also shows the slow n=1 component

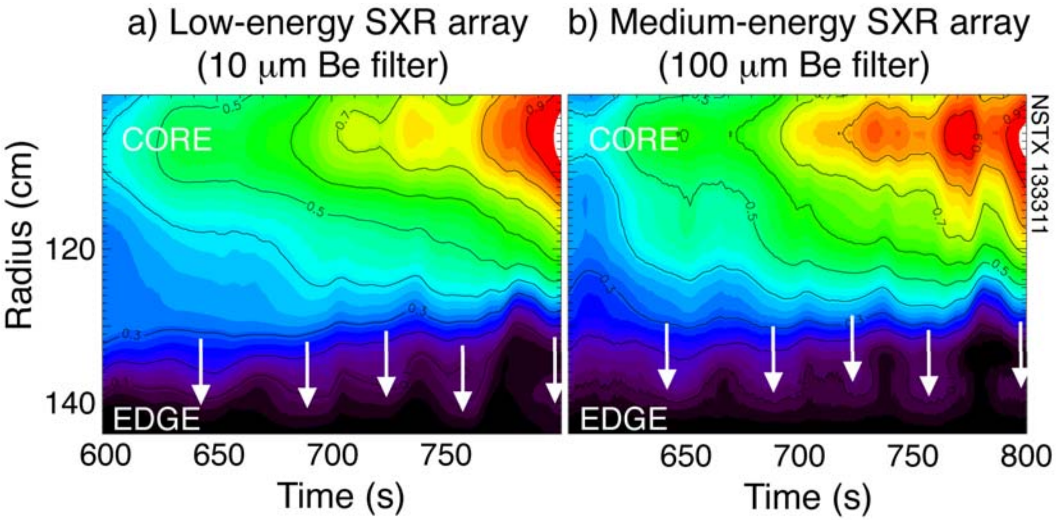


- n_C and T_i at the edge are correlated
- n_C at the edge and core have an offset.
- V_f (CHERS), & β_t, β_N and W_{tot} (EFIT) have the same slow *n=1* modulation.

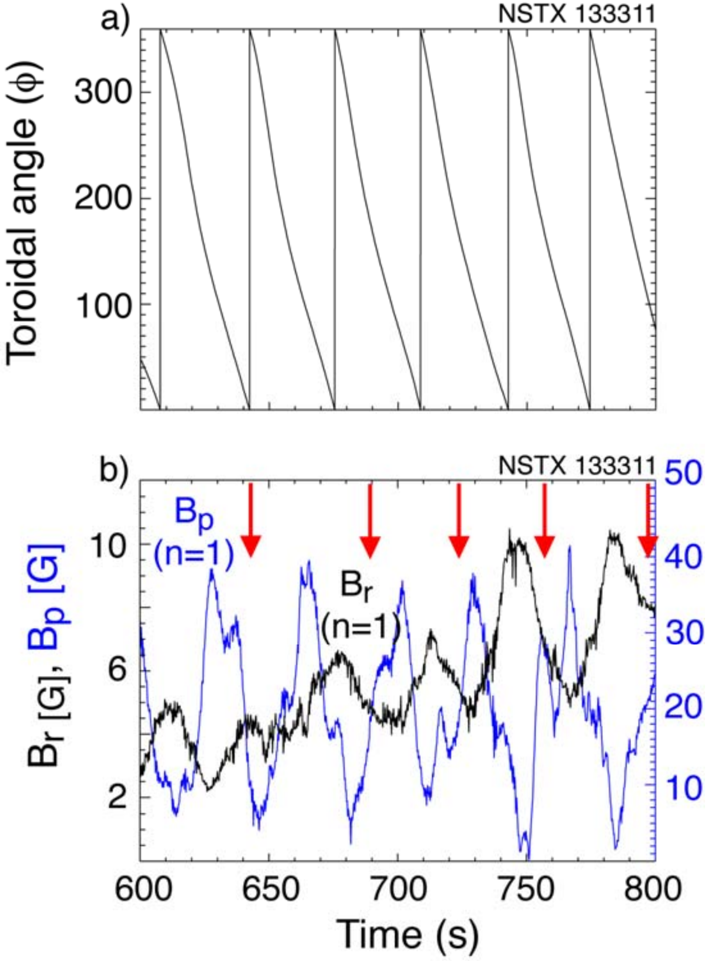
P_{rad}, n_{Fe}/n_e (Bolometer) and Vis-Bremsstrahlung also show *n=1* activity.

The role of RFA near marginal stability was investigated using an n=1 traveling waveform

ME-SXR signals indicating kinetic response



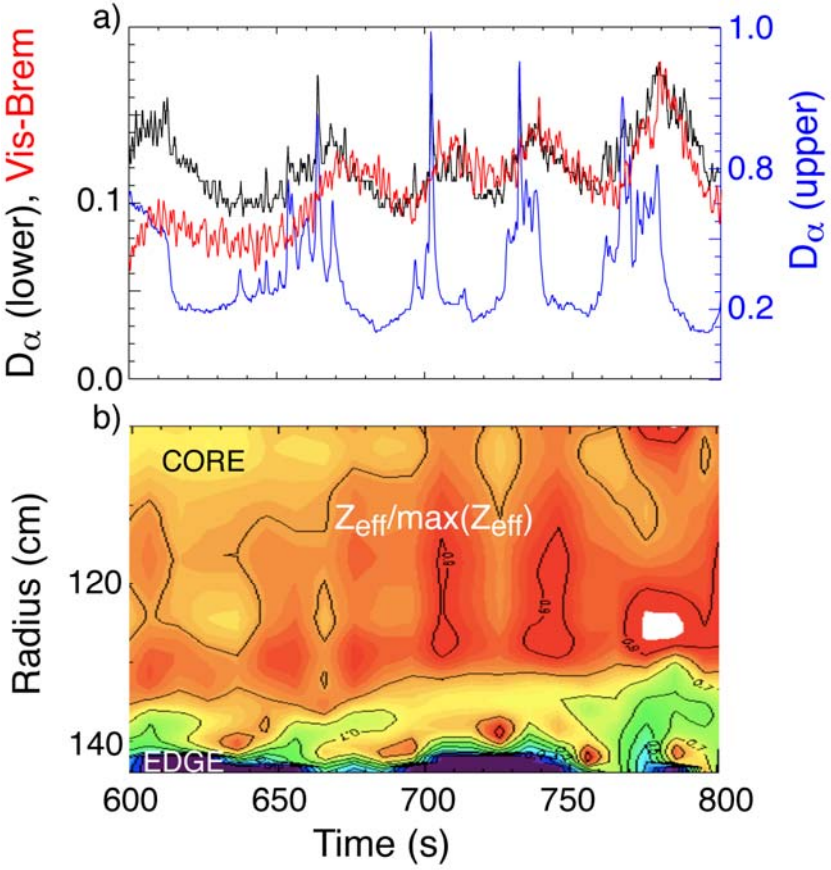
Signals from lock-mode (LM) and RWM coils indicating traveling-wave toroidal-phase and plasma response.



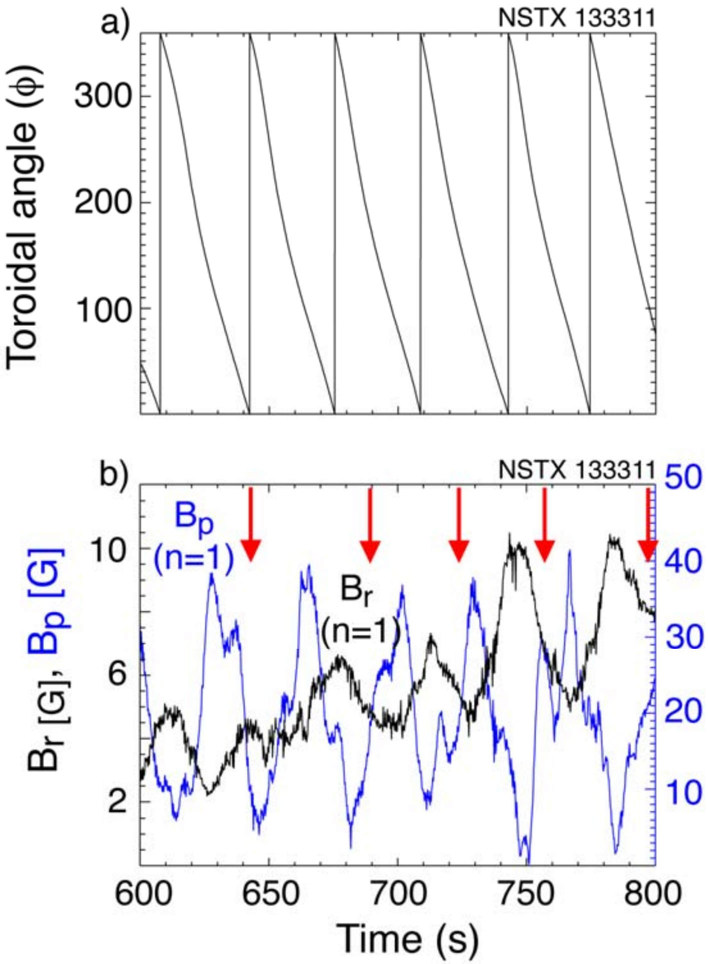
- The perturbation induced by the *n=1* traveling waveform (see the toroidal-phase from the lock-mode coils) also shows up as a radial perturbation in the low- and medium energy SXR emissivities.

- 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

Impurity density also responds to traveling wave



Signals from lock-mode (LM) and RWM coils indicating traveling-wave toroidal-phase and plasma response.



- D_α and Vis-Bremsstrahlung also show *n=1* activity.
- Z_{eff} at the edge and core have an offset.

Summary and future work

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

2. High β_N~5-6 H-mode plasmas exhibit low frequency activity in magnetic and kinetic diagnostics indicating the presence of a stable/driven RWM. Some of its characteristics are:

- Mode is co-rotating at a frequency near the measured n=1 RWM.
- Mode covers greater radial extent as β_N is increased.

3. The stable/driven RWM is apparently a separate mode from the unstable RWM.

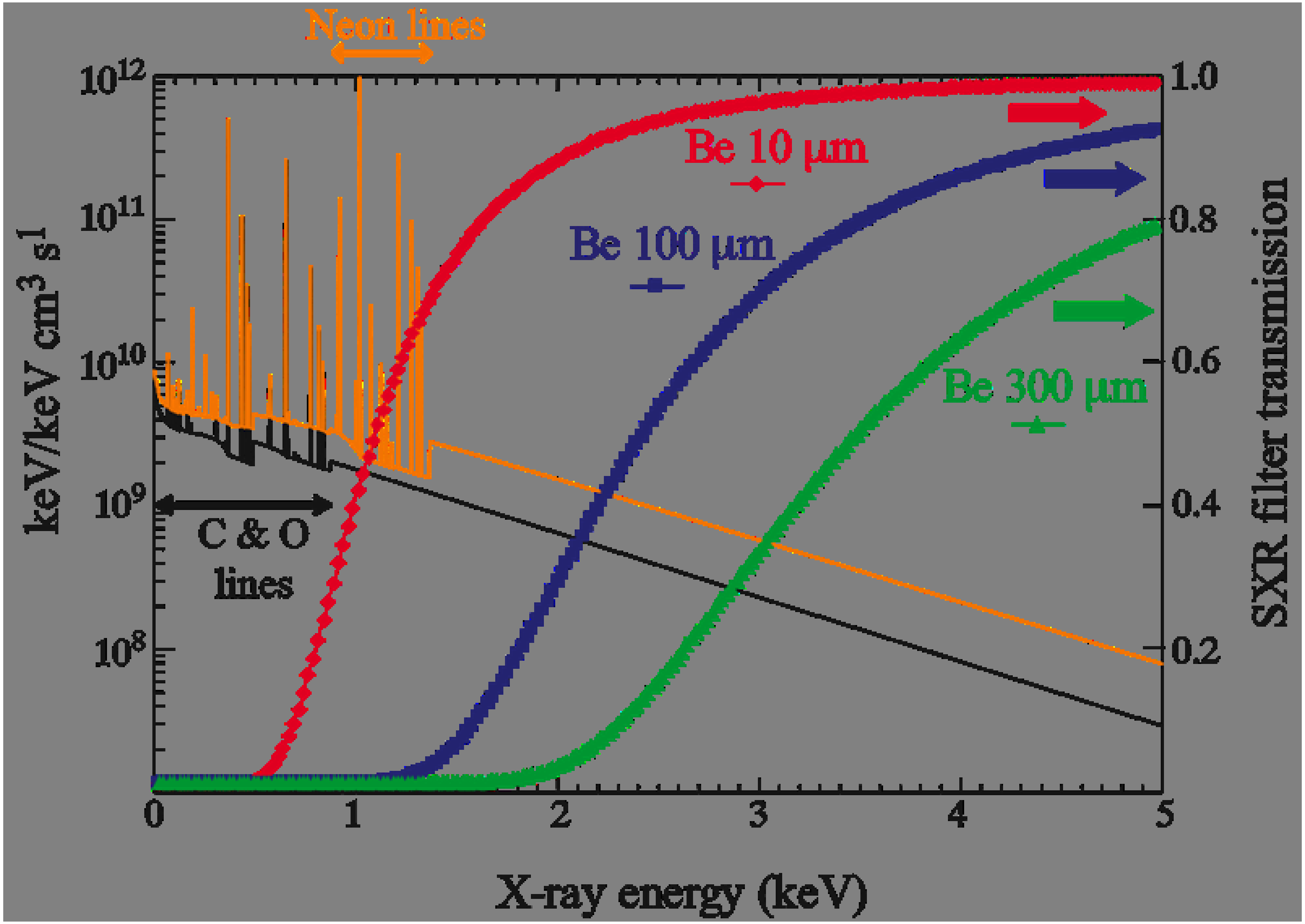
4. New research targets:

a) The modification of the kinetic plasma profiles by the use of external fields.
b) The role of RFA and its kinetic response near the marginal stability.
c) Study of the plasma profiles during fast-MHD (e.g. fishbones) and RWMs.

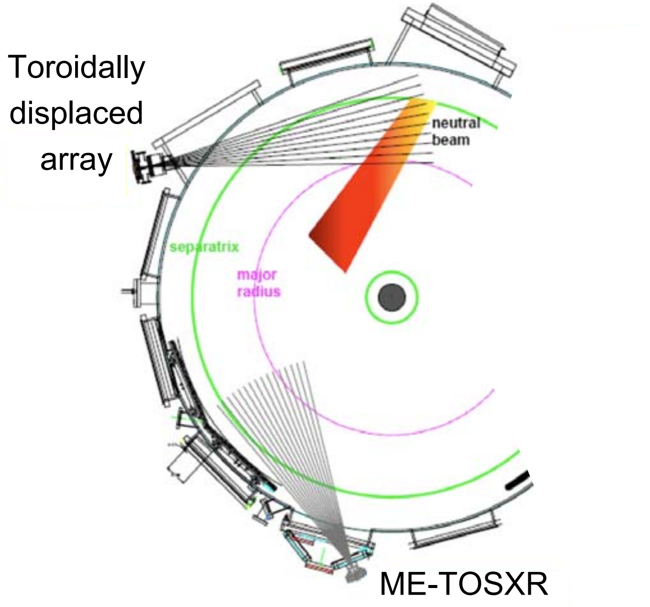
Prints

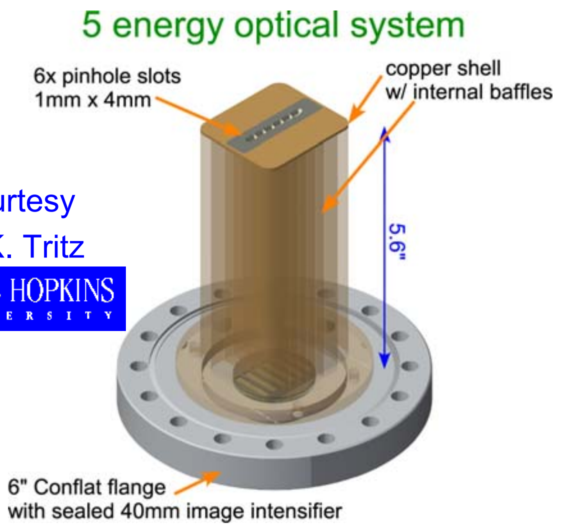
EXTRAS

SXR filtering for MHD and transport studies



Benefits of ME-SXR diagnostic method





Courtesy of K. Tritz

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a) Compact design allows ***multiple toroidally displaced arrays*** □ important for MHD mode identification and plasma control.

b) Spatial resolution could be as small as ~1 cm from edge to core.

c) With additional space and time resolved ***spectroscopic input***, the ME-SXR instrument has the potential for providing ‘***ECE-like’ functionality and more*** to any MCF plasma scheme.