NSTX

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SXR measurements of Resistive Wall Mode behavior in NSTX

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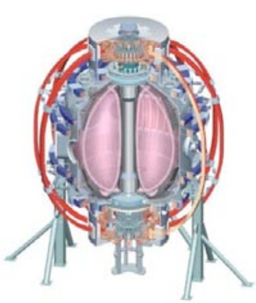

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Motivation

Address the NSTX 2009 research milestone of understanding the physics of RWM stabilization and control, especially on the effects of the actively stabilized RWMs on the background plasma

a) Modification of kinetic profiles (T_e, n_e & n_Z)

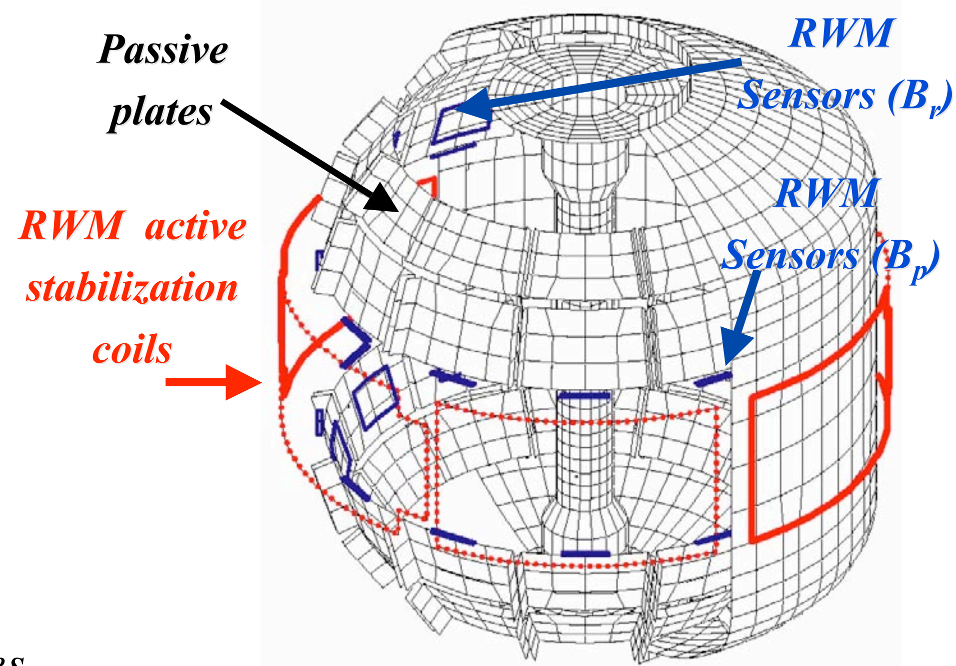
b) T_e and $n_e n_Z$ fluctuations.

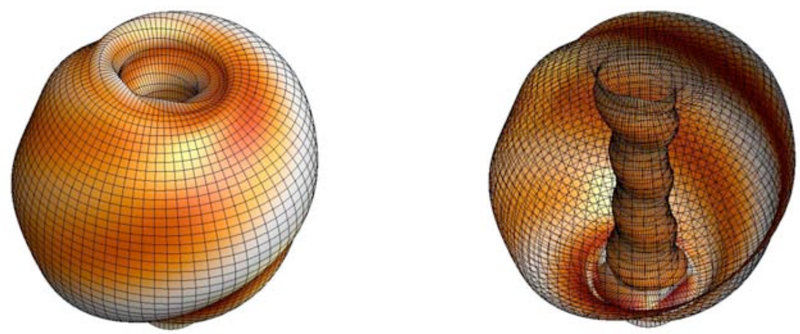
Previous observations in NSTX, DIII-D and JT-60:

1. *Multi-energy SXR characterization of actively stabilized resistive wall modes in NSTX.* [L. Delgado-Aparicio, APS-DPP-2008].
2. *Investigation of Resistive Wall Mode Internal Structure (work done at DIII-D).* [I. N. Bogatu, APS-DPP-2006].
3. *Dynamics and Stability of Resistive Wall Mode in the JT-60U High-β Plasmas.* [Matsunaga, 22nd IAEA-2008].

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.***

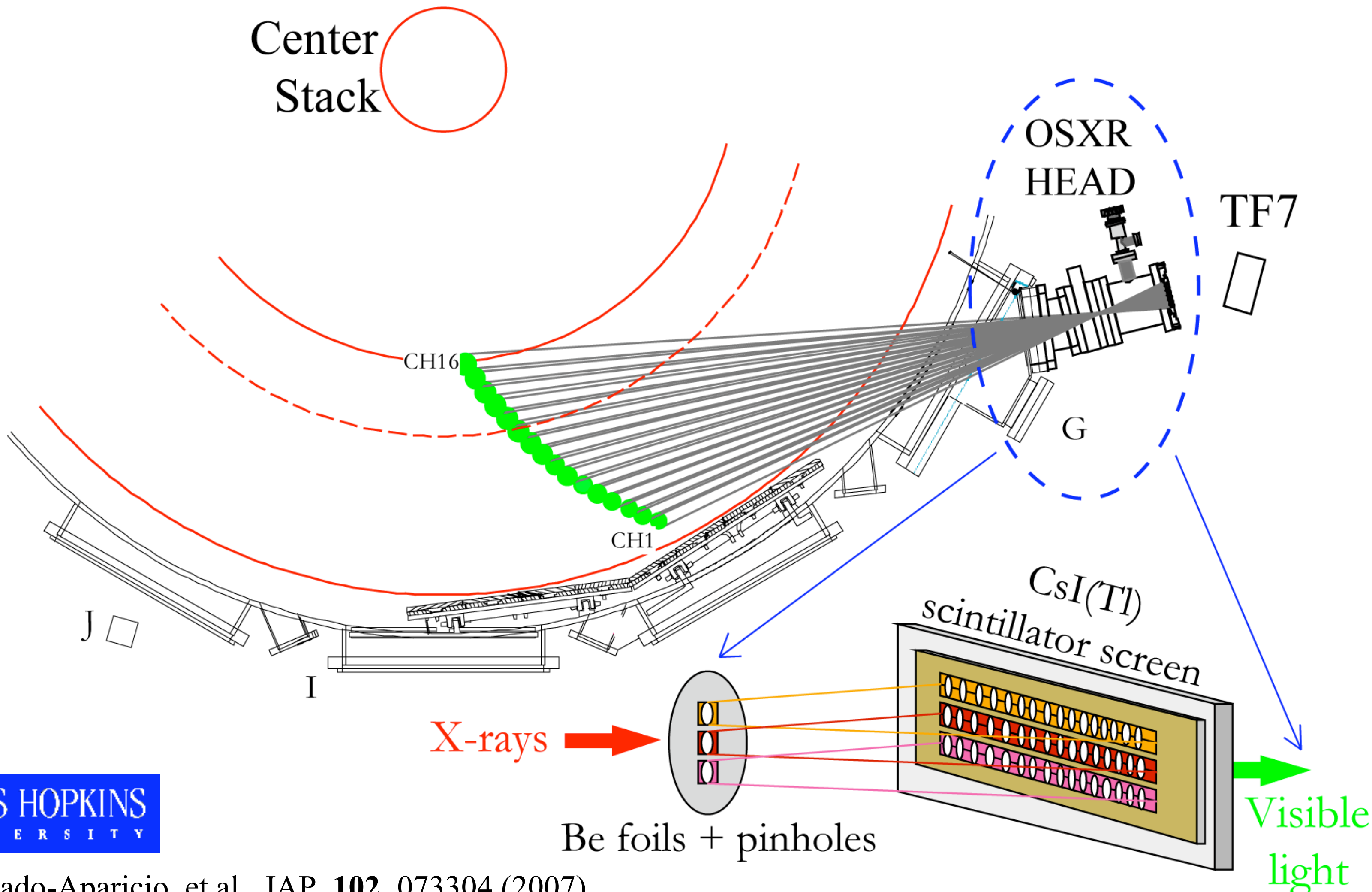




(exterior view) **(interior view)**

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

Main diagnostic: Multi-energy “optical” SXR array



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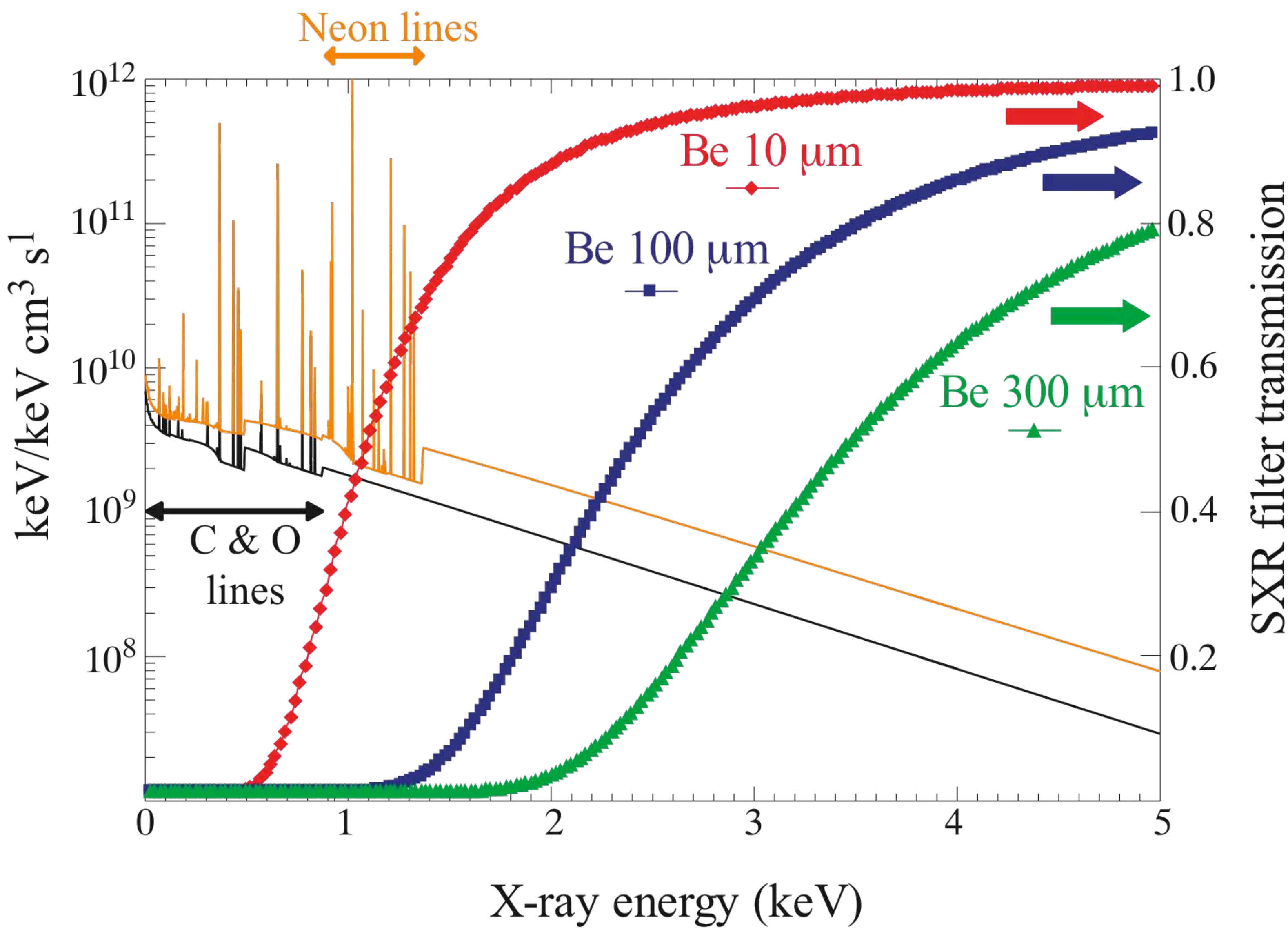
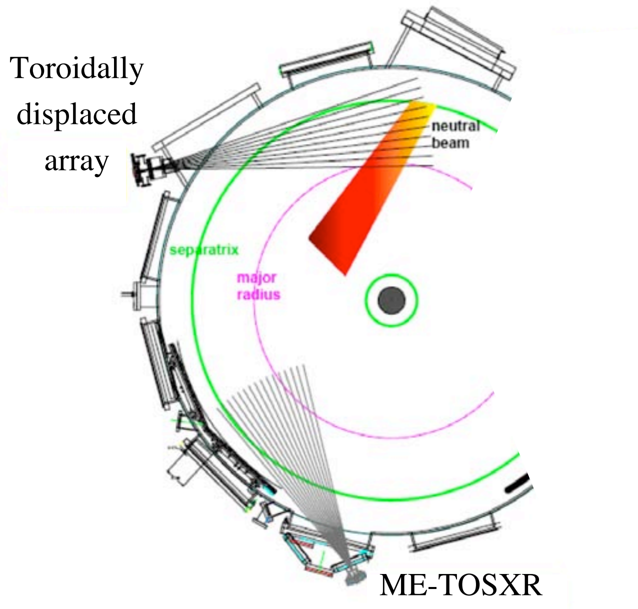
L. Delgado-Aparicio, et al., JAP, **102**, 073304 (2007).
L. Delgado-Aparicio, et al., PPCF, **49**, 1245 (2007).
L. Delgado-Aparicio, et al., NF, **49**, 085028, (2009).

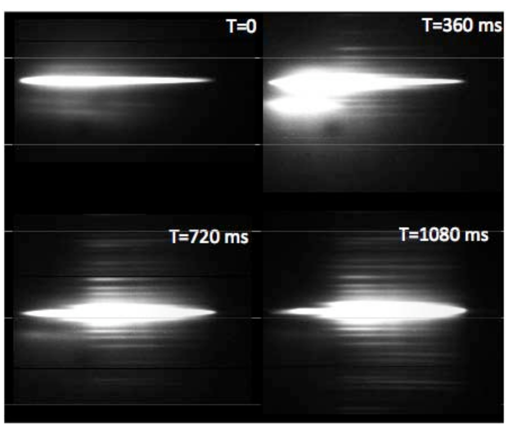
SXR filtering for MHD and transport studies



Benefits of ME-SXR diagnostic method



Transmission grating spectrometer (TGS)

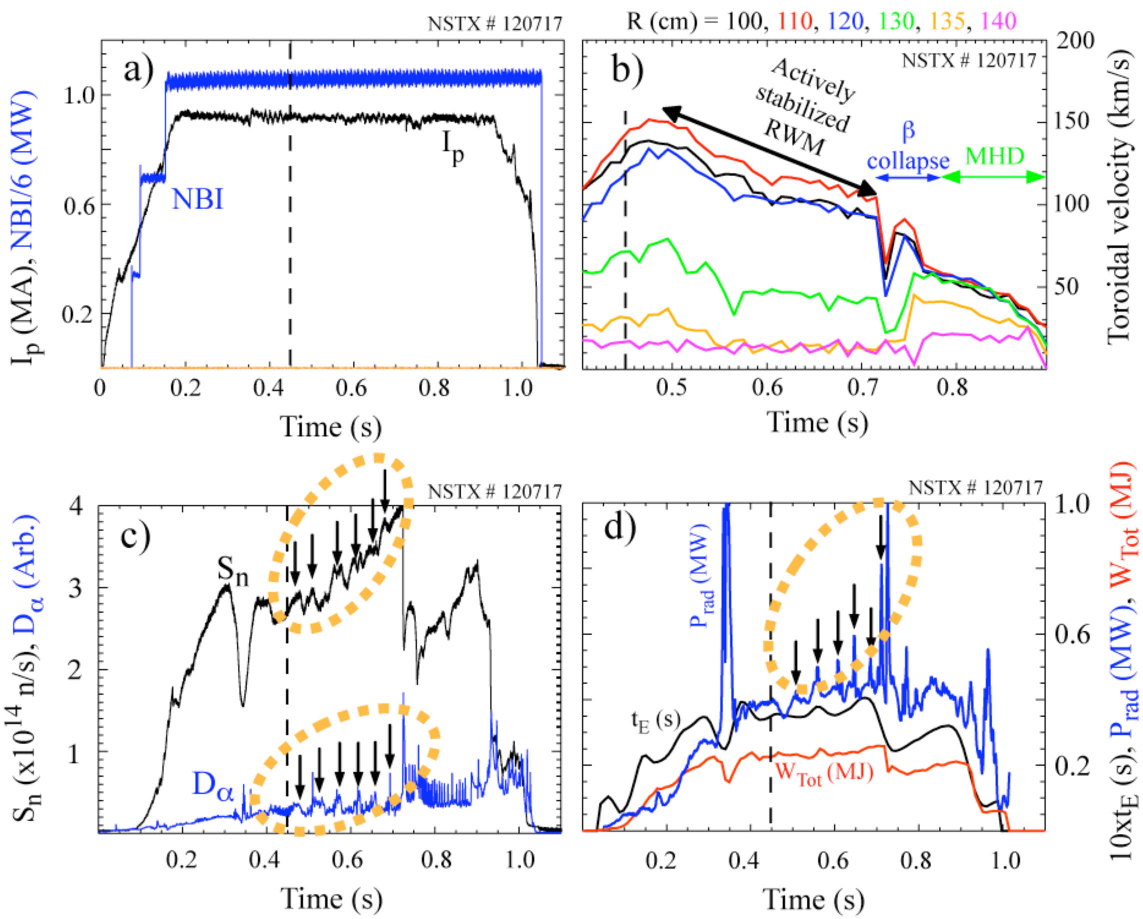


a) Compact design allows ***multiple toroidally displaced arrays*** ⇒ important for MHD mode identification and plasma control.

b) Spatial resolution could be as small as ~1 cm from edge to core [see K. Tritz].

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.

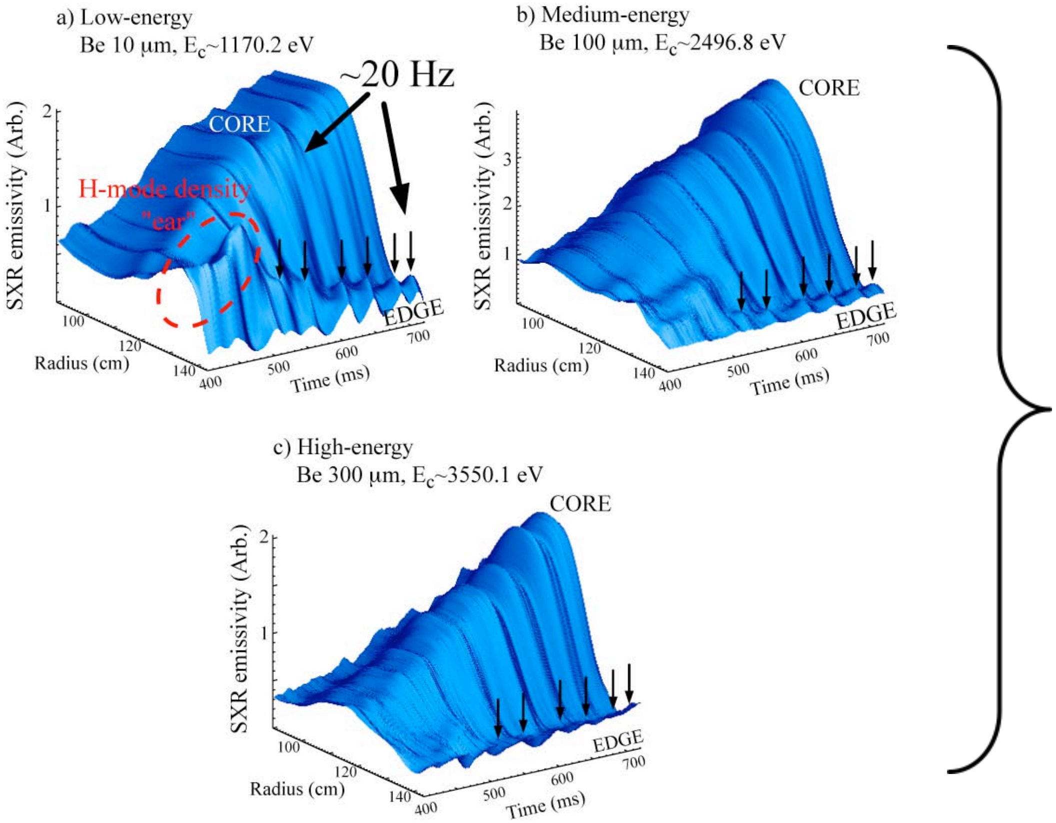
Actively-stabilized RWM plasmas show *n=1* mode



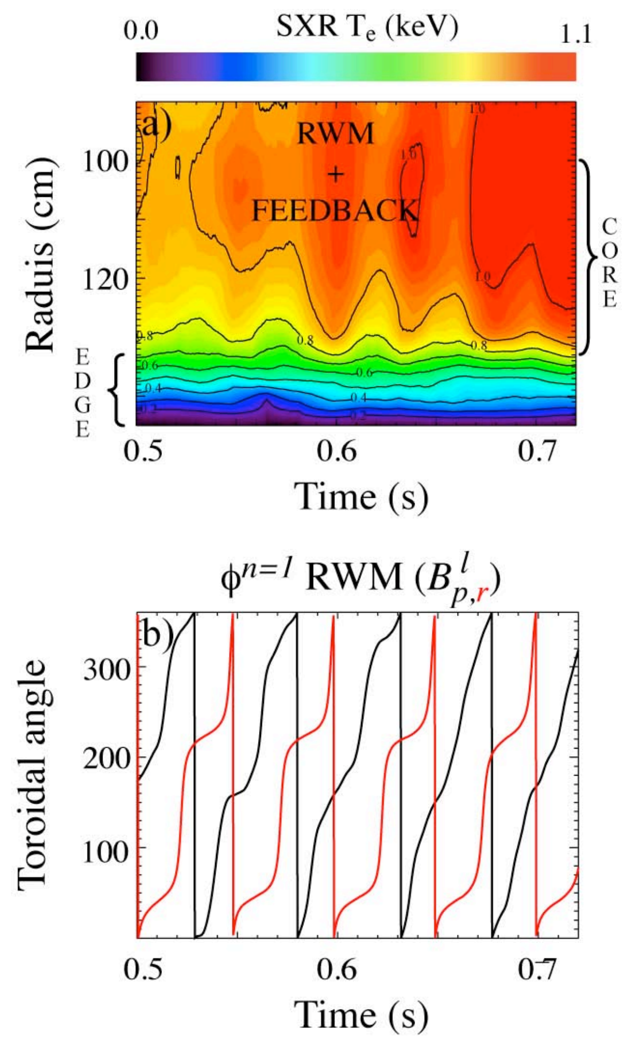
- ***The arrows indicate perturbations in the neutron rate (S_n), D_α light and total radiated power that will be correlated with the slow (~20 Hz) n=1 component of the RWM.***

- ***These signals will also be correlated with edge and core density and temperature fluctuations of the same kind.***

ME-SXR reconstruction of actively stabilized RWMs

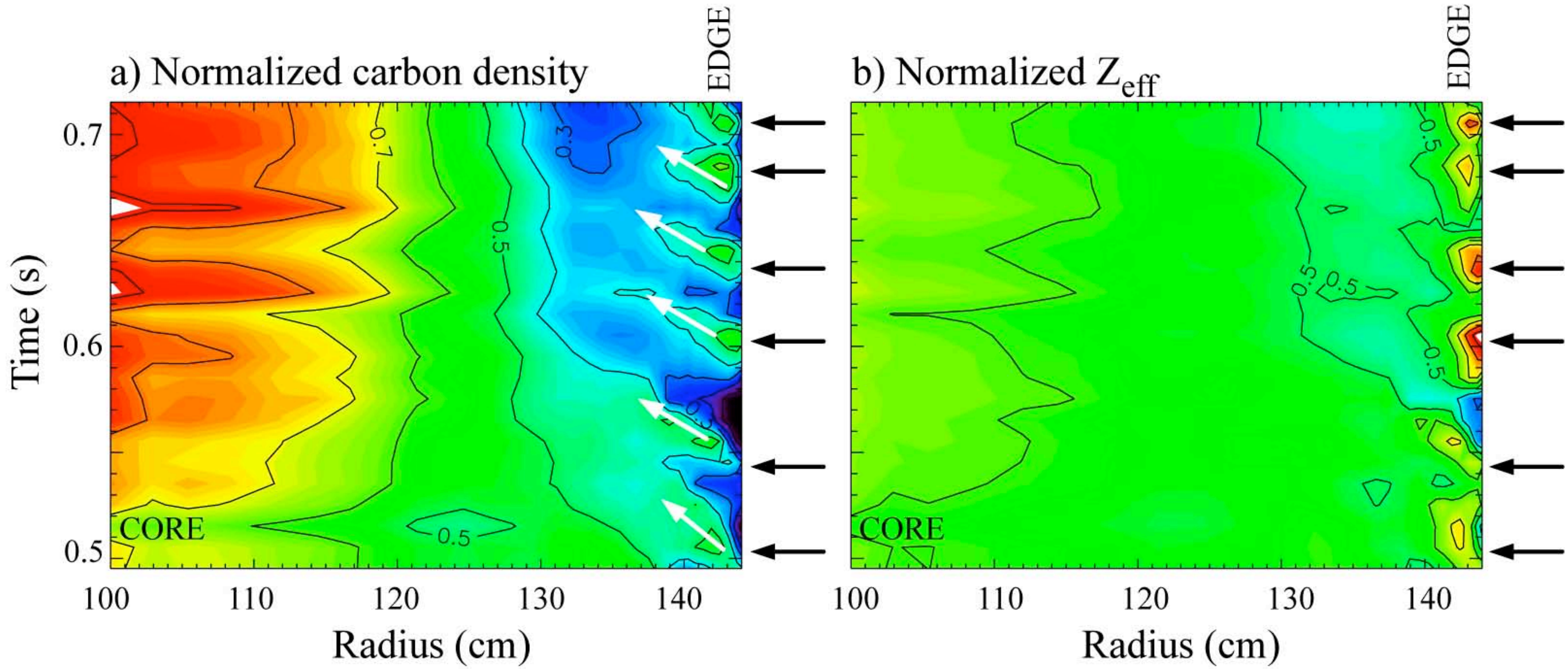


Fast SXR-based $T_e(R,t)$ measurememts



- Increased edge n_Z during RWM active stabilization.
- Good correlation with drops in T_{e0} (MPTS & SXR) & S_n.
- **Good correlation between kinetic and magnetics.**
- **Identified a stable RWM near the natural RFA resonance.**

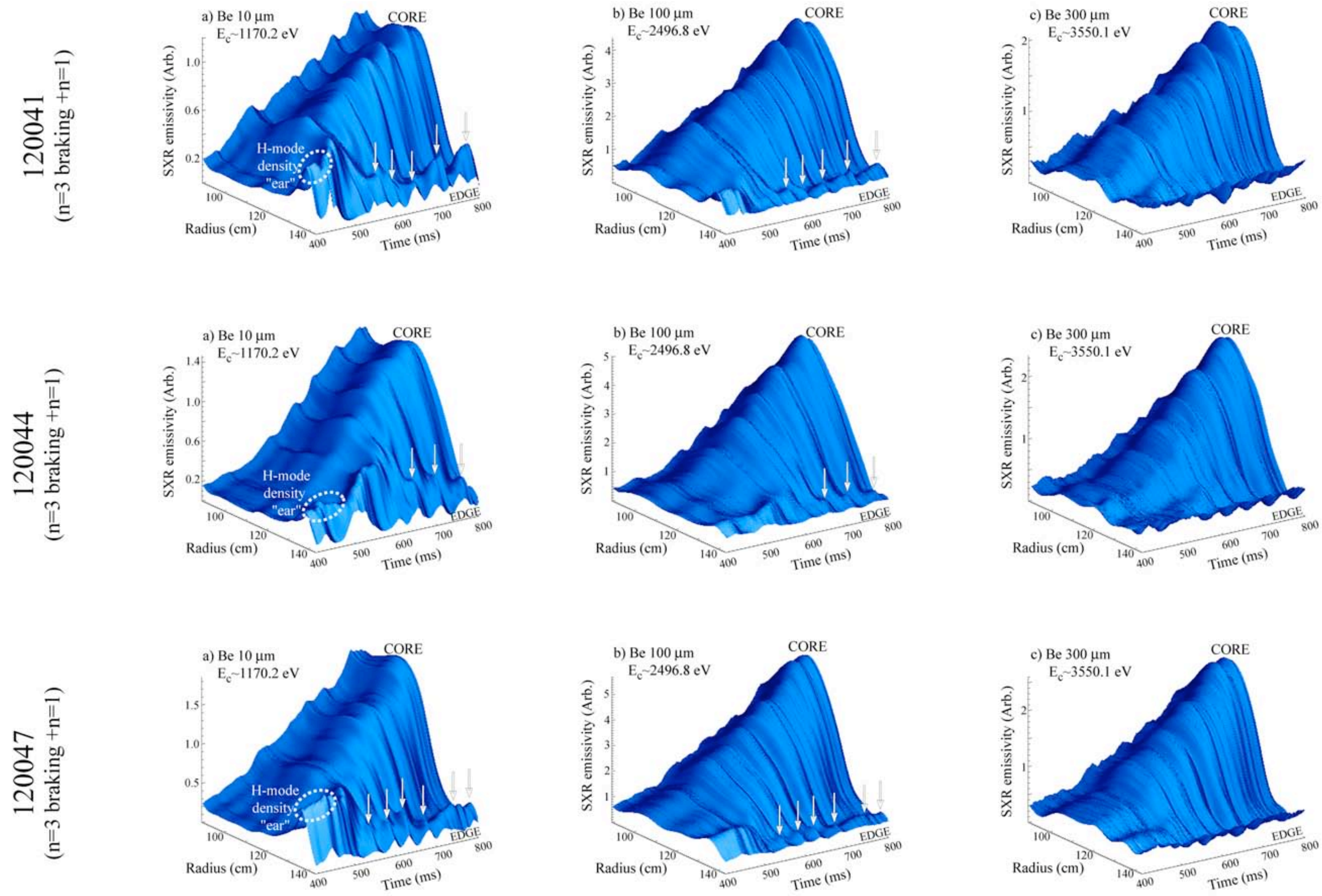
n_Z pertubation with the same rotating *n=1* frequency



• The out-of-phase edge and core n_C show the ~20-30 Hz mode ($n=1$).

• $T_i(r,t)$ does not show $n=1$ activity.

This is not a singled-out event ⇒ reproducible!



New research targets

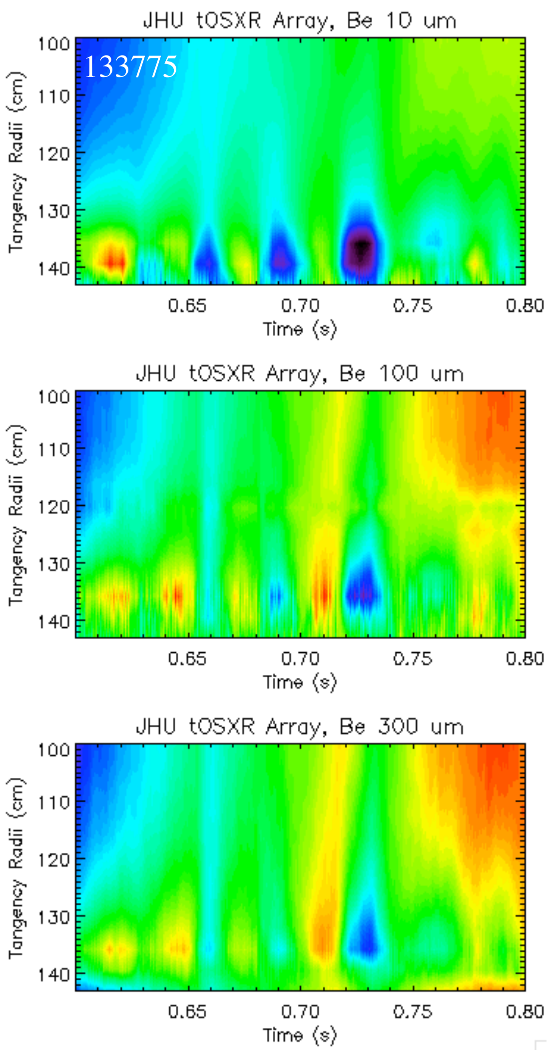
a) ***The modification of the kinetic plasma profiles by the use of the (n=3 braking and the n=1 active feedback) external fields.***

b) ***The role of the resonant field amplification and its kinetic response near the marginal stability.***

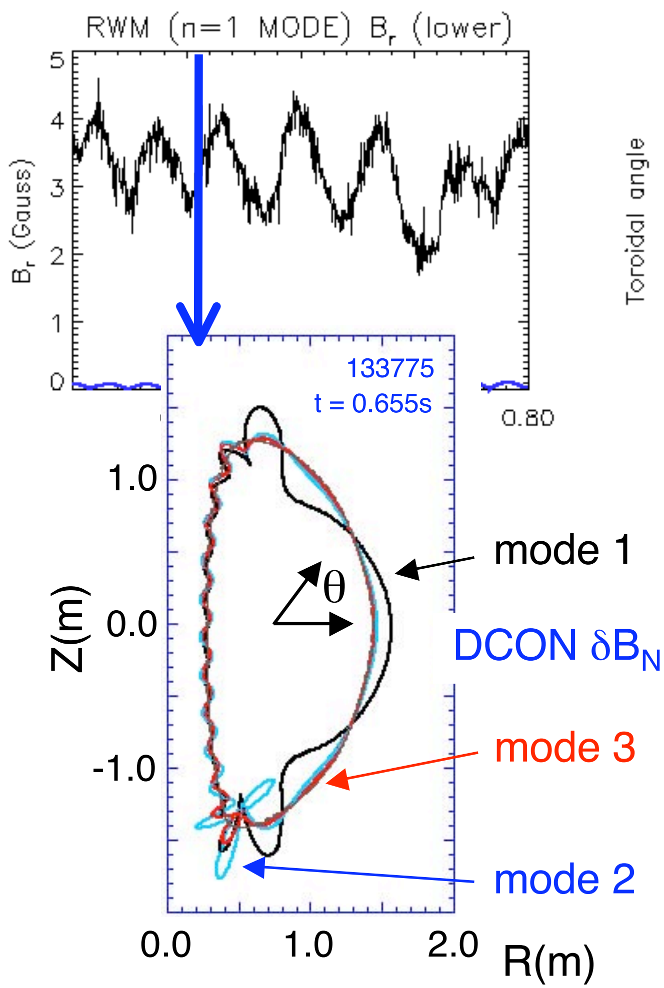
c) ***Study of the plasma profiles during fast-MHD (e.g. fishbones) and RWMs.***

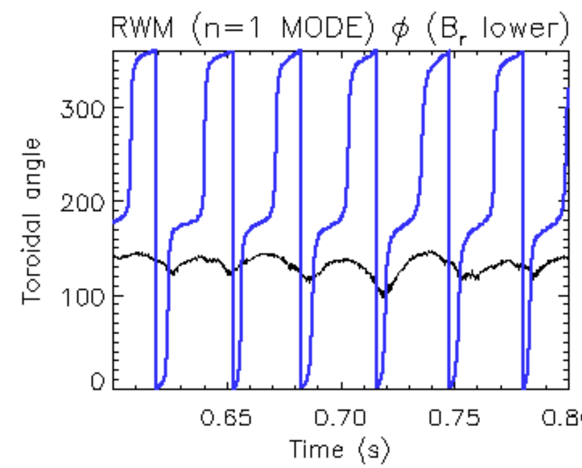
a) Imaging the ~20-30 Hz slow mode

~20-30 Hz RWM
Line-integrated ME-SXR signals



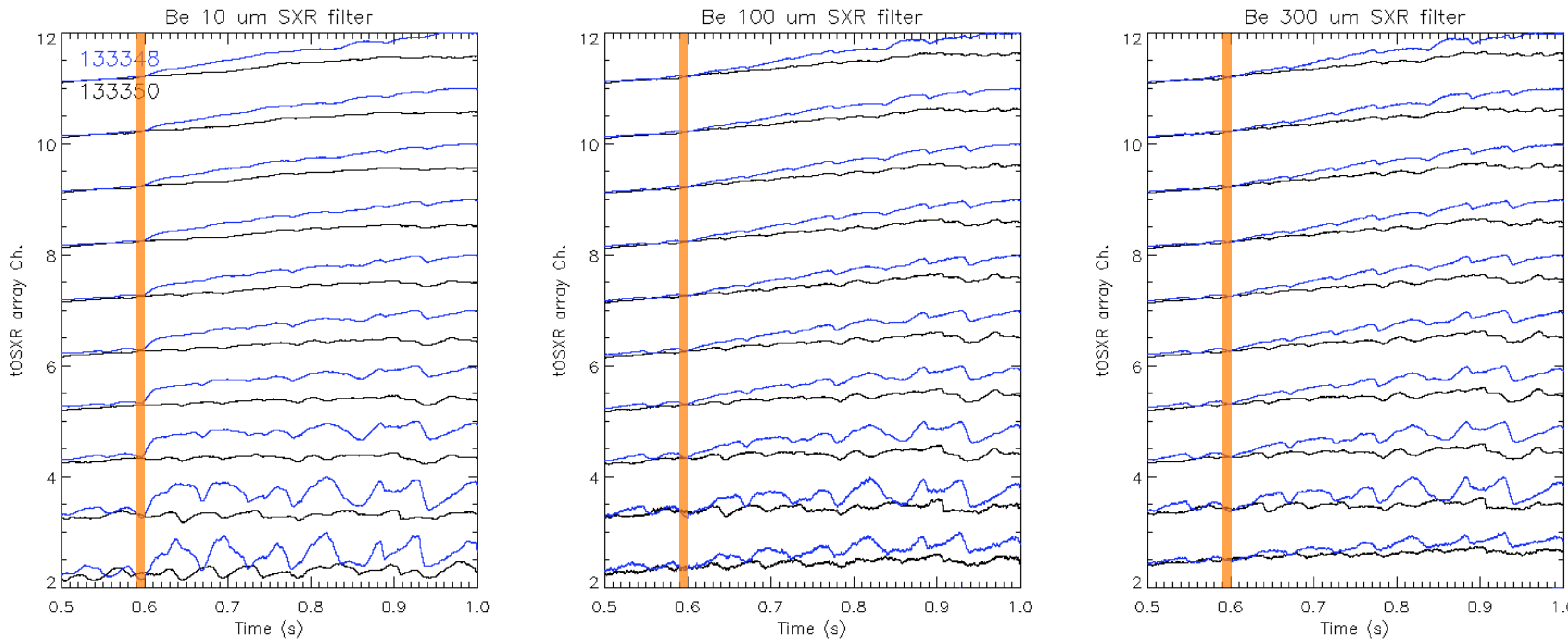
High β_N~6 plasmas exhibit low frequency activity in magnetic and kinetic diagnostics





DCON analysis indicated that multi-mode response is theoretically expected to be significant at high β_N.

MHD & transport studies using Neon injection



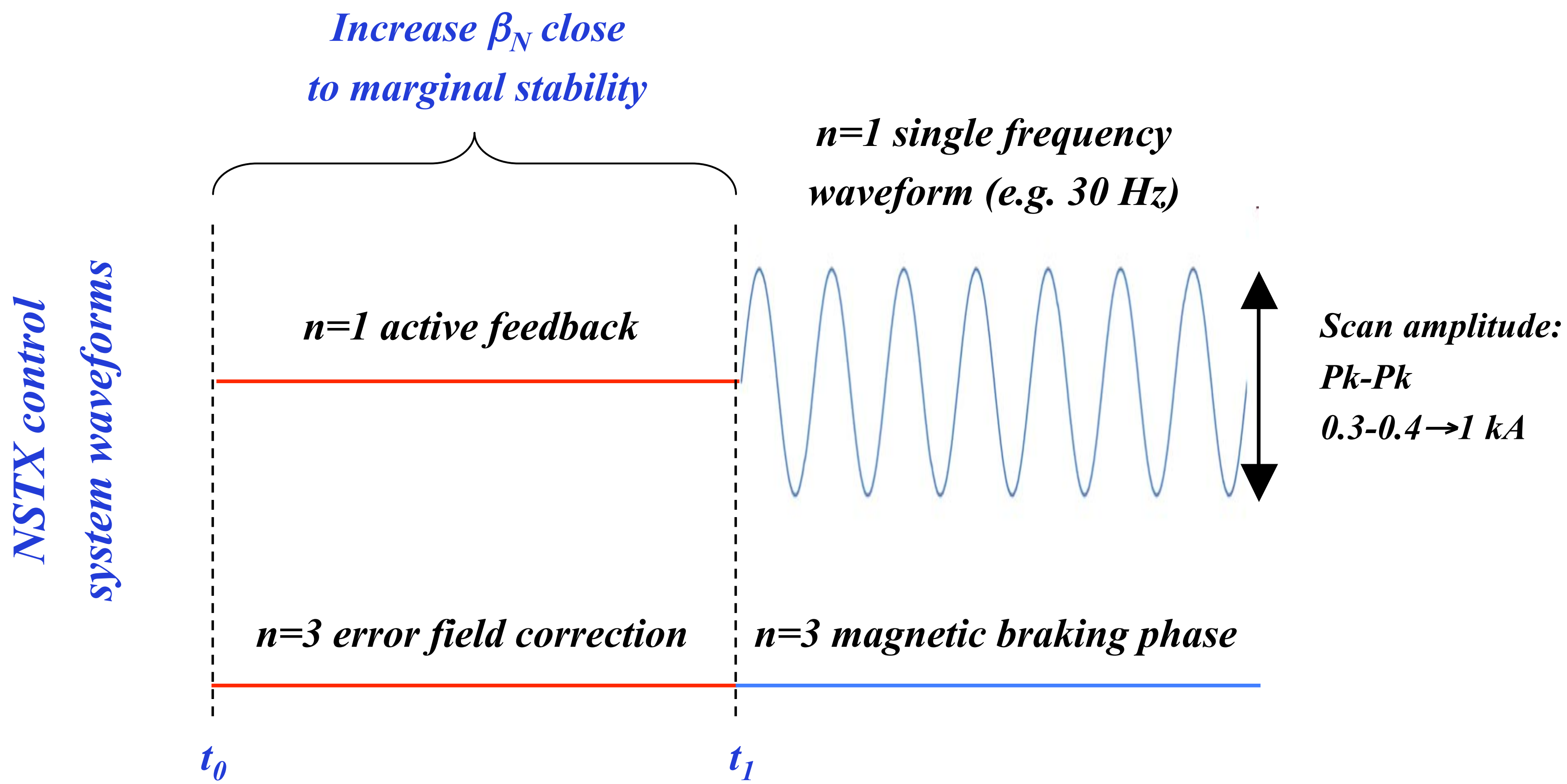
• Neon injections at @ 1.5 Torr·l/s (or less) for a time window ∈ [600-610] ms.

• Very reproducible effect (NSTX #s 133348 and 133351 vs background 133350).

• Background subtracted data is sensitive to helium-like, hydrogen-like and fully-stripped Neon density.

• Neon emission sheds light into the RWM identification as well as in the problem of changing particle transport with the $n=1, 3$ fields.

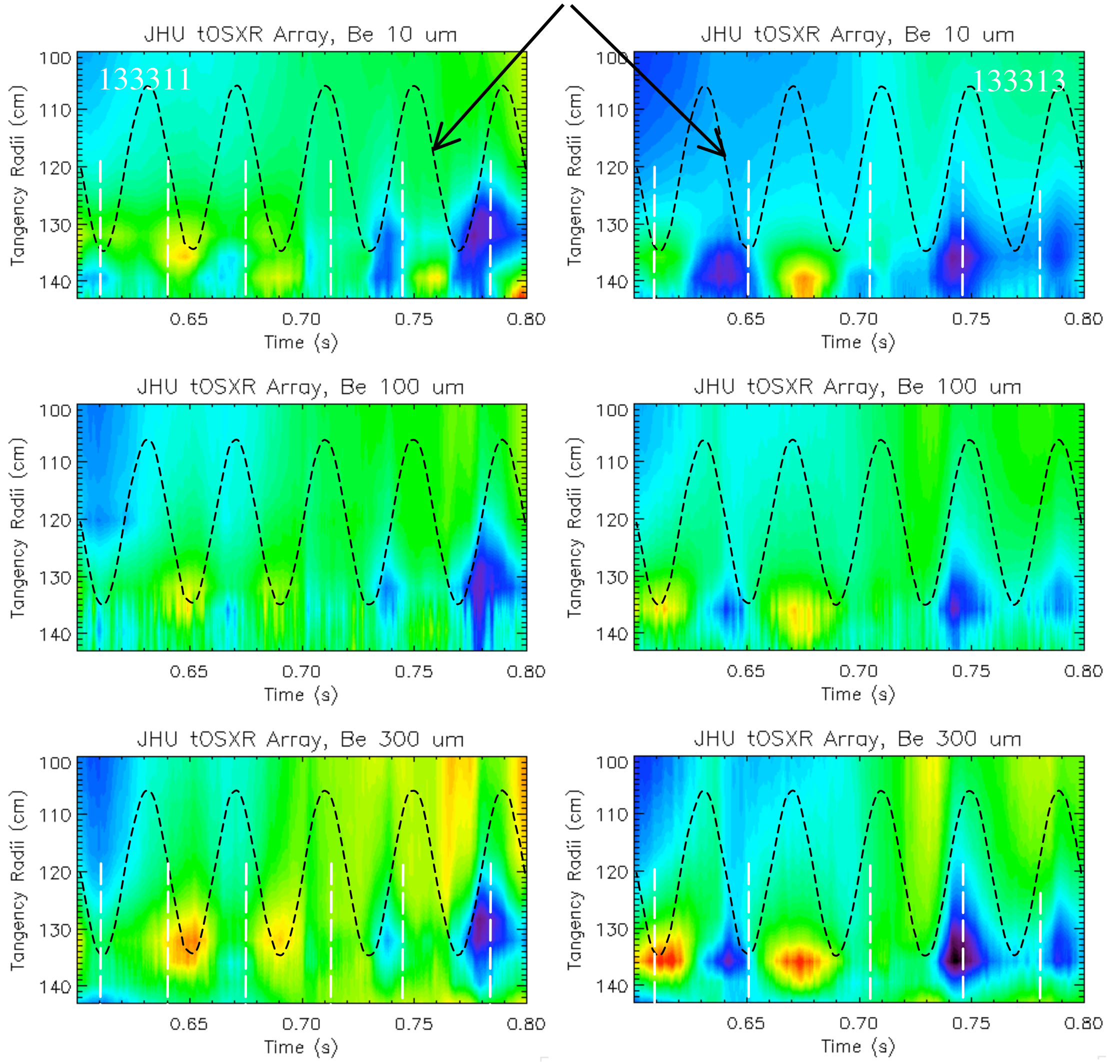
b) The role of RFA near marginal stability was investigated using an *n=1* traveling waveform



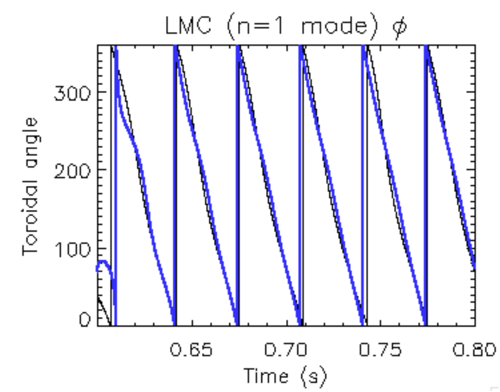
- Scan t_1 to avoid getting “that” close to marginal stability.
- Scan *n=1* amplitude to look for kinetic response of RFA.
- Use neon-injection to increase the SXR-SNR for the *n=1* amplitudes selected.

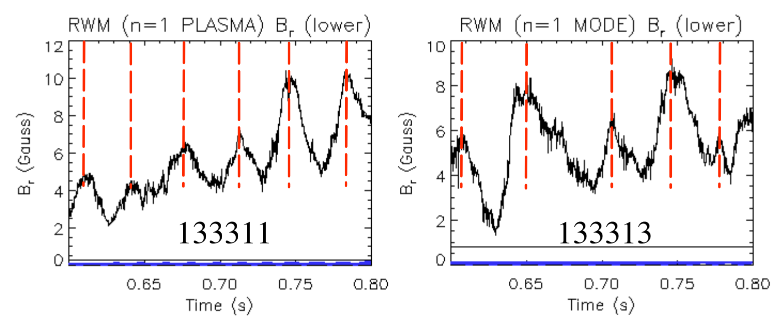
SXR response to the RFA – traveling wave

Line-integrated ME-SXR signals and ~30 Hz 1.5 kA traveling waveform

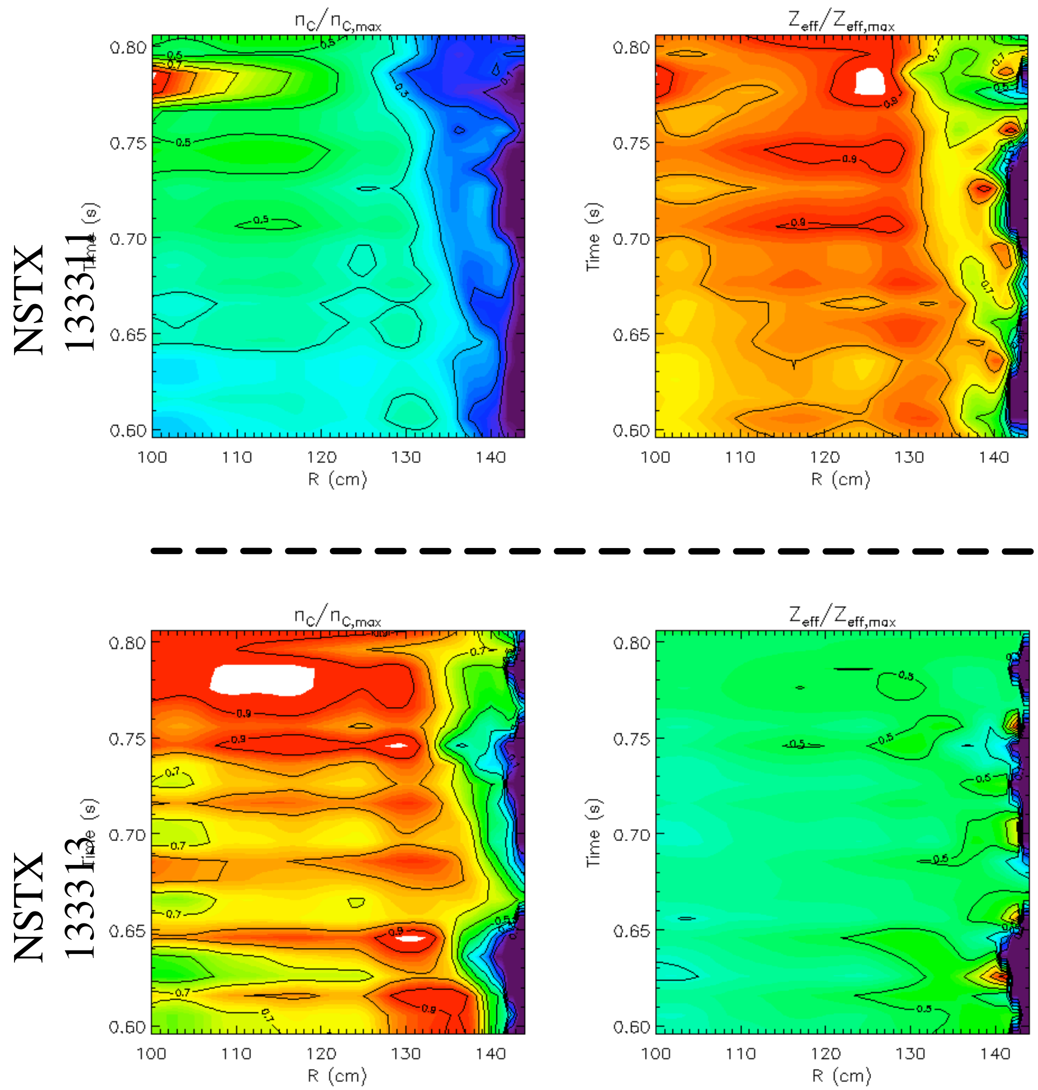


Signals from lock mode (LM) and RWM coils indicating traveling wave toroidal phase and plasma response

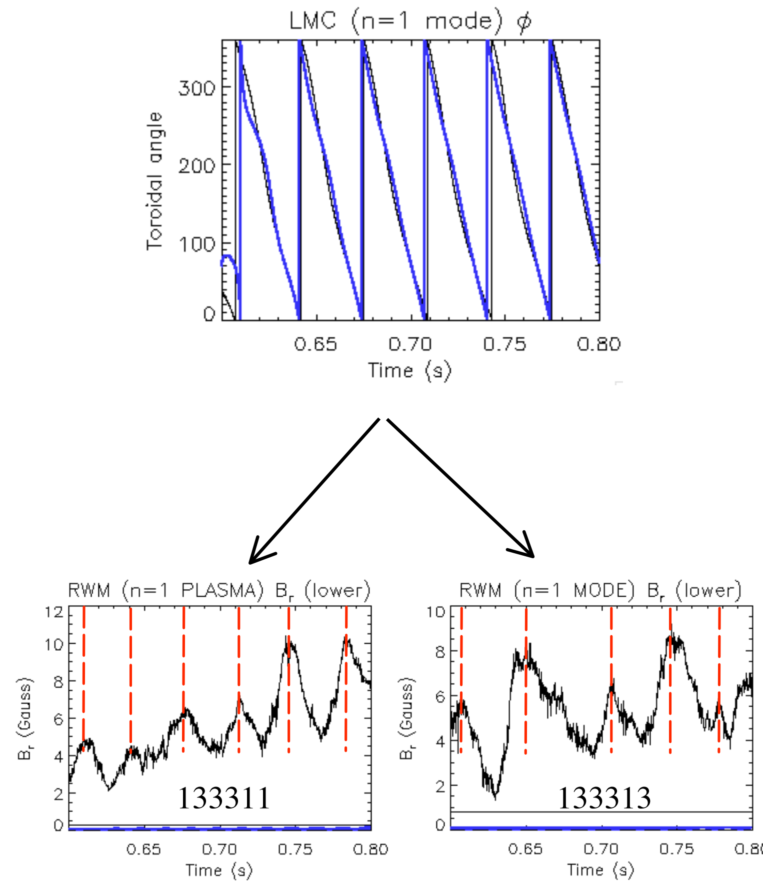




Impurity density also respond to traveling wave



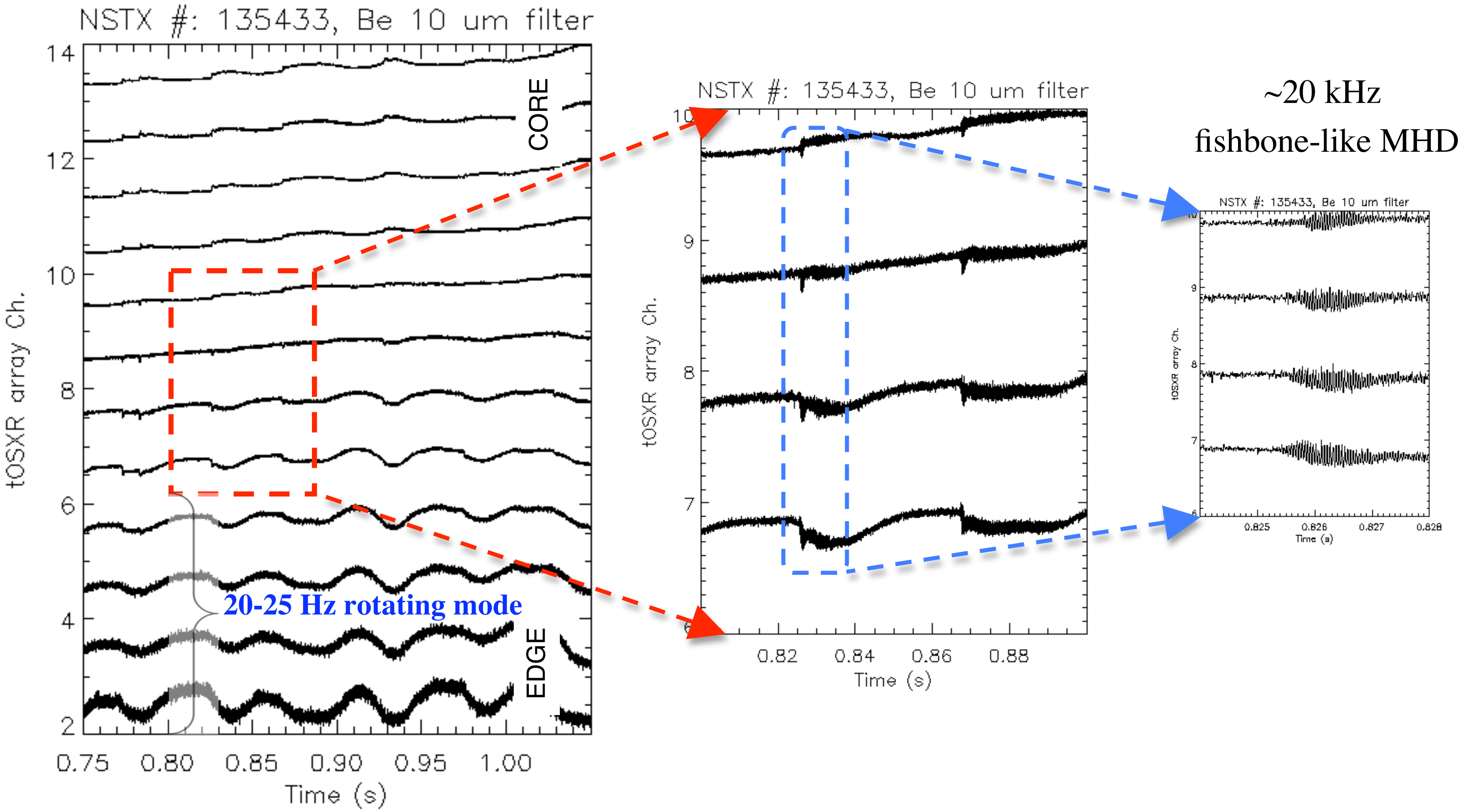
Signals from lock mode (LM) and RWM coils indicating traveling wave toroidal phase and plasma response



c) Interaction between slow mode and fast MHD

~20-25 Hz RWM, Be 10 μm foil

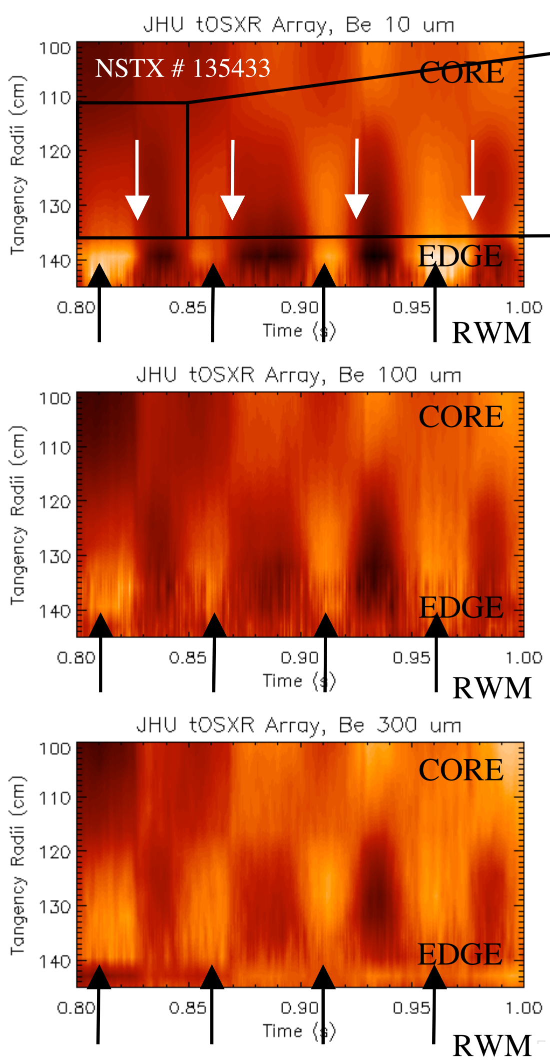
Line-integrated ME-SXR signals



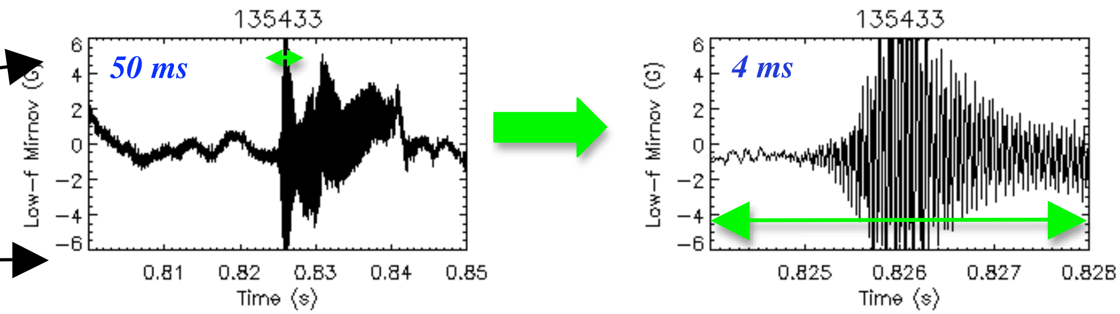
Slow *n=1* mode persists in the presence of fast MHD

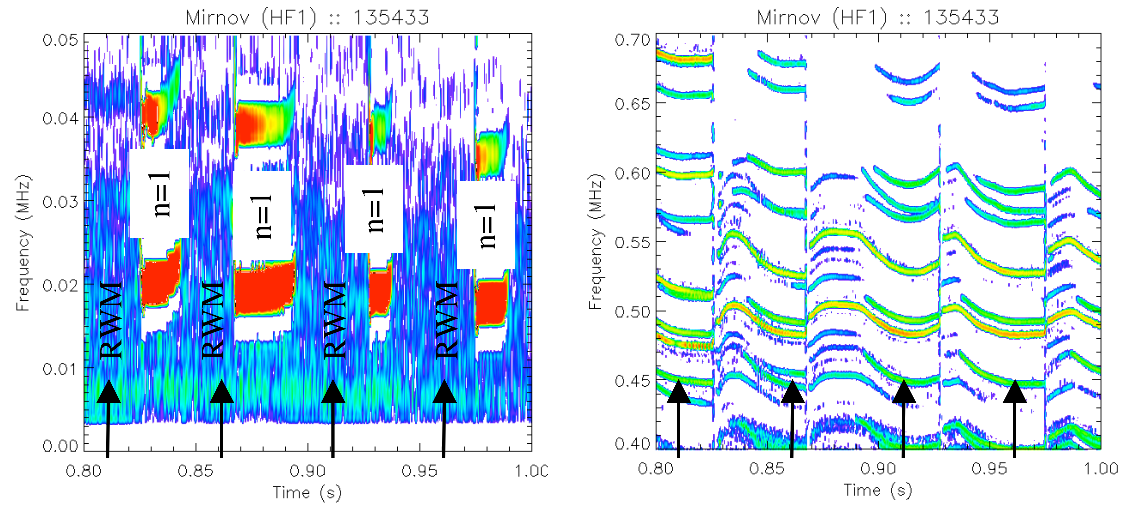
~20 Hz RWM

Line-integrated ME-SXR signals



High-frequency signals from Mirnov coils

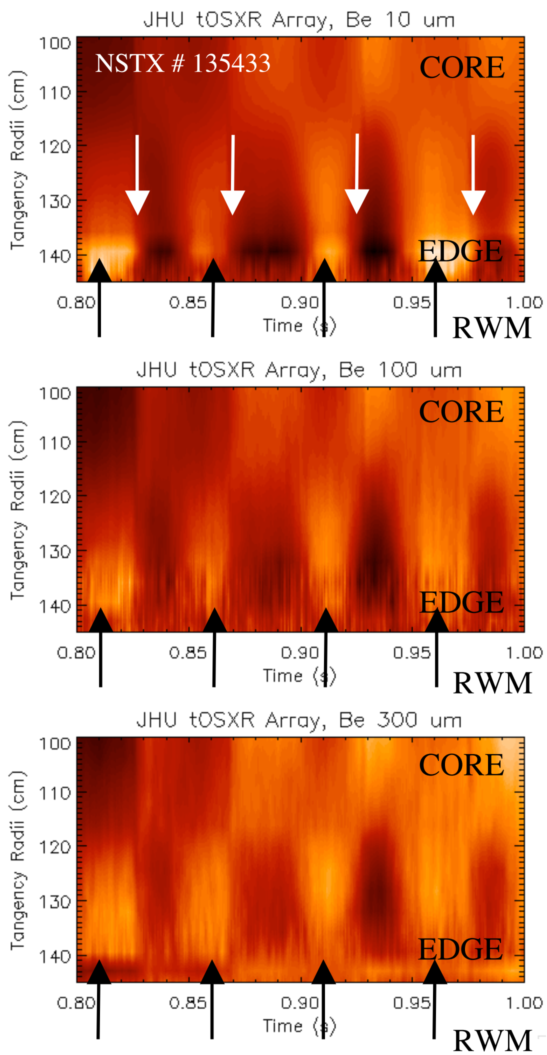




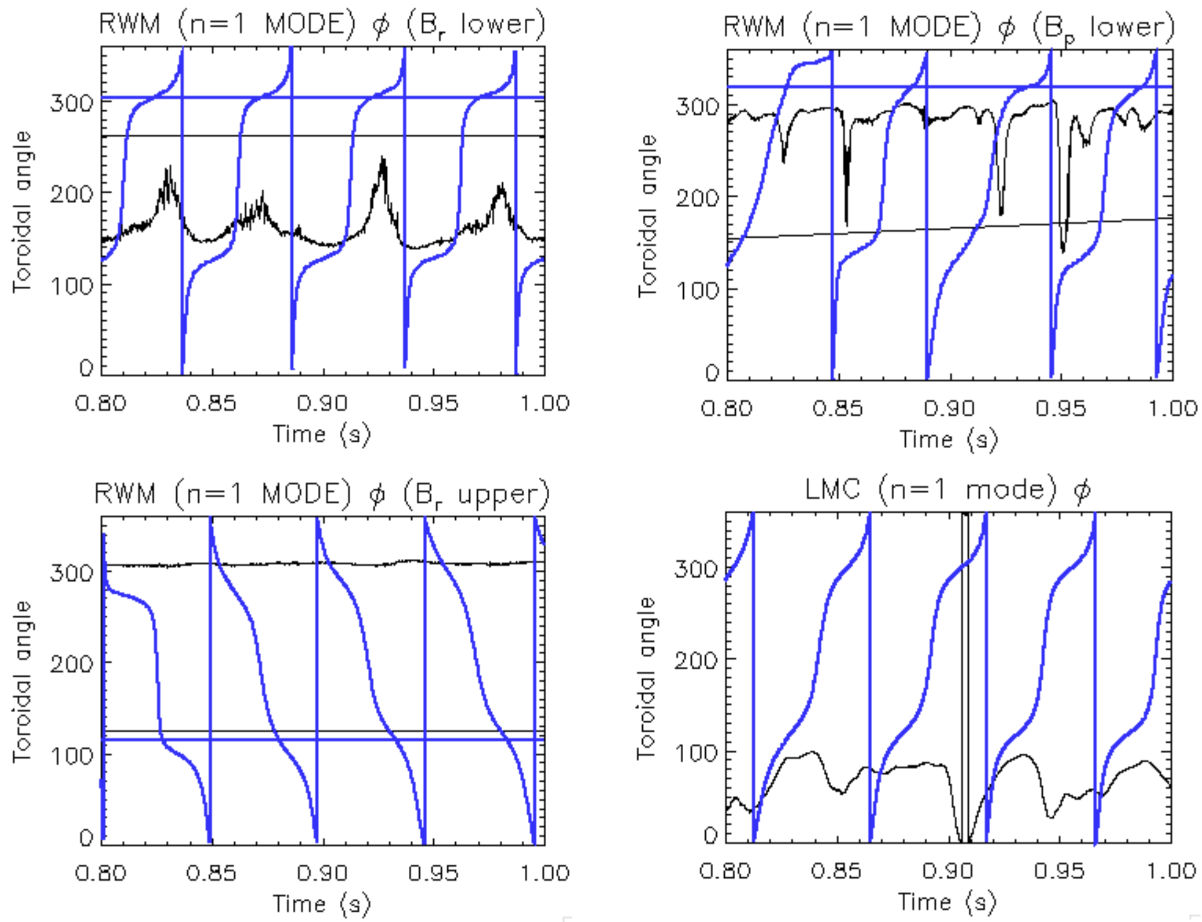
- RWM not affected by fast MHD?
- *n=4-7* CAE's frequency modulation due to n_e and/or V_ϕ fluctuations from *n=1* mode.

Good correlation between kinetics and magnetics

~20 Hz RWM
Line-integrated ME-SXR signals



Toroidal phase measured by the RWM $B_{r,p}$ and LM coils

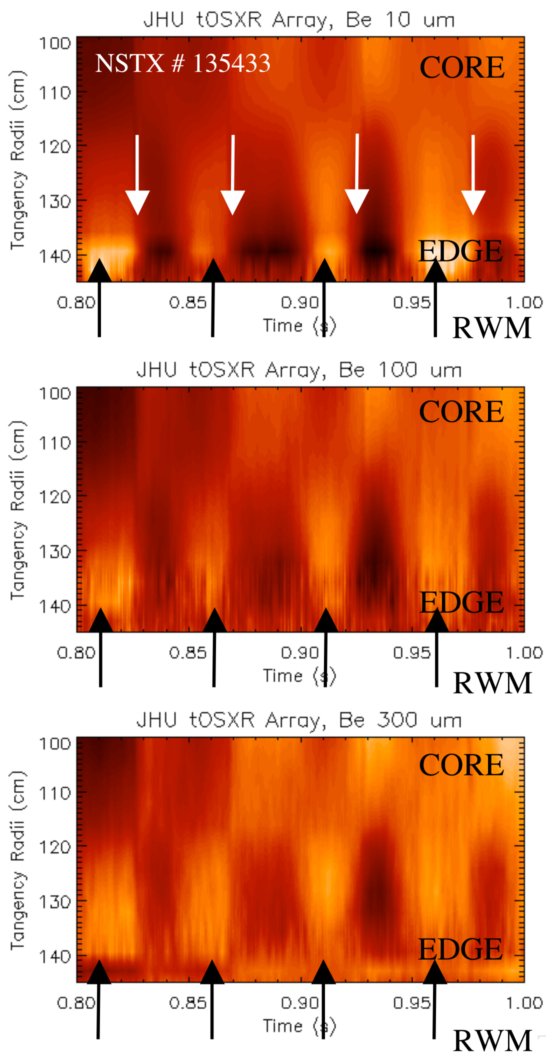


The ~20 Hz n=1 mode is stable and rotating toroidaly

A suite of diagnostics also show *n=1* component

~20 Hz RWM

Line-integrated ME-SXR signals

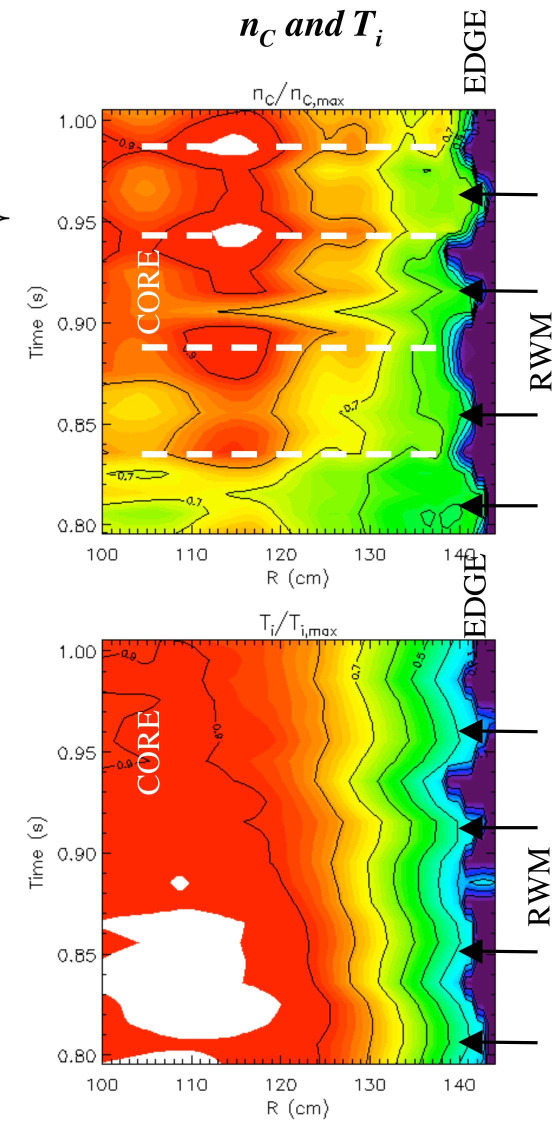


- *n_C and T_i at the edge are correlated.*
- *n_C at the edge and core appear to have an offset.*

- *V_ϕ (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.*

CHERS

n_C and T_i



Summary

1. *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.*

2. *High β_N~5-6 plasmas exhibit low frequency activity in magnetic and kinetic diagnostics.*

3. *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.*

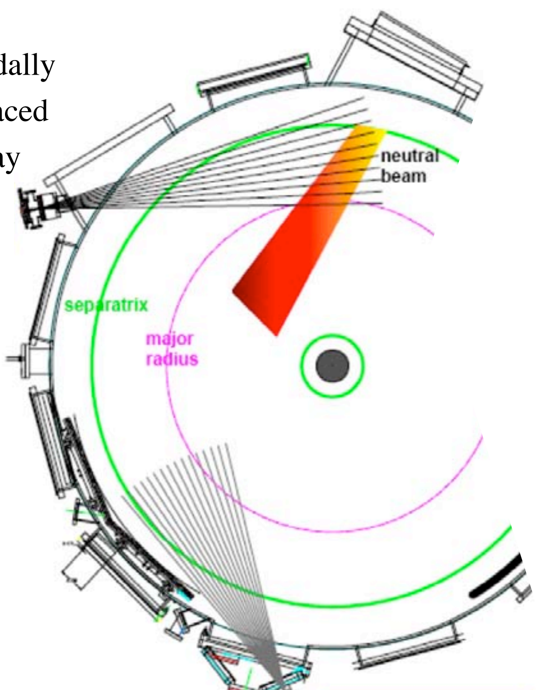
1. *New research targets:*

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

New capability for mode detection and control using toroidally displaced arrays

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

Toroidally displaced array



ME-TOSXR

a) Continuous coverage with high resolution (~1.5 cm) at the edge.

b) Development of tools for RWM diagnostic and control.

c) Accurate n=1 identification.

e) Possible multi-mode RWM components.

Future work

a) Obtain edge SXR emissivity profiles with enhanced (1-2 cm) resolution for MHD and transport studies.

a) Second toroidally displaced array will be very important for MHD mode identification and to resolve impact of equilibrium and $n=1, 3$ fields on the plasma.

b) SXR-based fast temperature measurements at the edge and core including bolometer and transport constraints.

d) These results indicate that the ME-SXR technique has very good potential for non-magnetic control of fusion plasmas.