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Soft x-ray emissivity characterization in RFX-mod

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Abstract

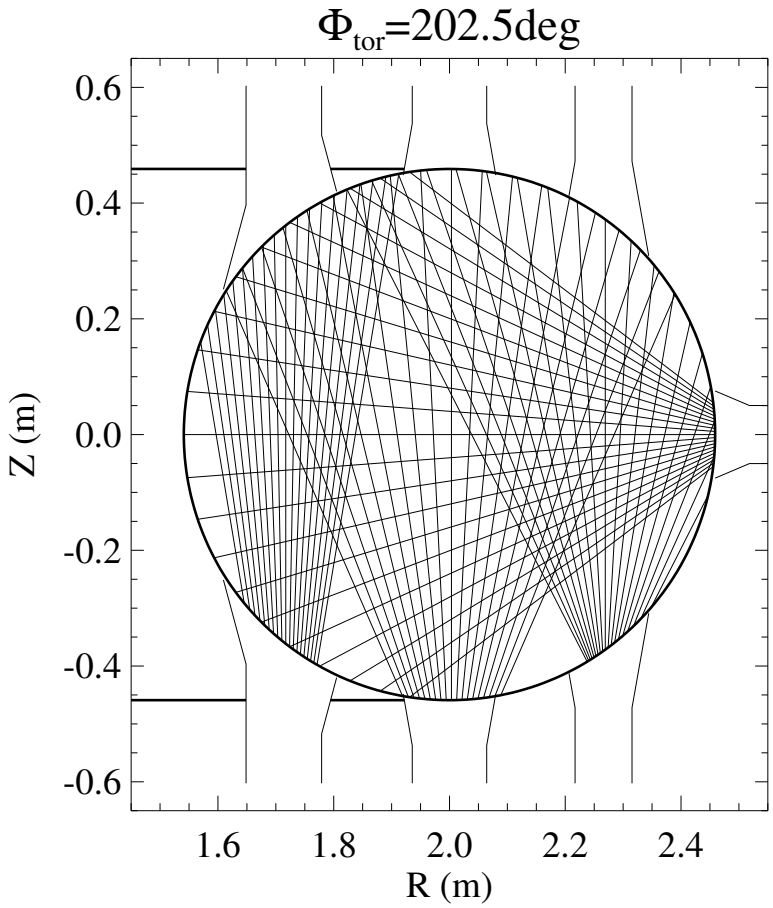
A characterization of the soft x-ray (SXR) plasma emissivity in the RFX- mod reversed field pinch (RFP) device is illustrated.

- The **high spatial resolution SXR tomographic diagnostic** [Franz_2001] installed in RFX-mod [Rostagni_1995, Sonato_2003] allows for analyzing the plasma reconstructed emissivity in different scenarios : Standard, Virtual Shell (VS) [Paccagnella_2006] and OPCD [Bolzonella_2001] operations have been considered.

- The regimes explored are those of the Multiple Helicity (**MH**) and Quasi Single Helicity (**QSH**) states. In the latter case, asymmetric brightness profiles are indicators of the arising of a hotter localized structure emerging from the plasma core, and corresponding to the presence of a dominant (m=1,n) mode in the magnetic spectra.

- The profiles measured with the tomography have been also compared with those obtained with the new SXR multichord diagnostic [Bonomo_2006] for the estimation of the **electron temperature profiles** over the low-field side RFX-mod chamber.

SXR tomography



Geometrical layout
[Franz_2001]

Main features:

- the continuum of the soft x-ray (SXR) radiation is detected by Silicon photodiodes through 25μm-thick Beryllium filters
- 78 lines of sight (for a spatial resolution of several cm) permit to detect localized asymmetries emerging in the plasma core, associated to MHD phenomena
- the high temporal accuracy (up to hundreds of kHz) allows for following in time the MHD plasma dynamics

Tomographic reconstructed emissivities are obtained from the truncated series of the analytical solutions based on the Cormack-Bessel algorithms [Franz_2001].

Electron Temperature from SXR

- The **ratio *R*** of two SXR brightnesses measured by two detectors looking at the same plasma region through two different Beryllium filter thicknesses, Be_1 and Be_2, is a **strong function of the highest temperature (T_e)** along the line of sight considered [Donaldson_1978, Kiraly_1987].

- **Energy range free from line radiation.** If the plasma follows a Maxwellian distribution function, the Bremsstrahlung formula is a good approximation of the SXR plasma emissivity.

- In RFX-mod, **Oxygen radiation lines** [Carraro_2000] can affect the measurements. The *choice of 37μm as the thinnest Be foils for the multifoil spectrometer and the multichord diagnostic prevents from absorbing radiation not due to Bremsstrahlung emission*.

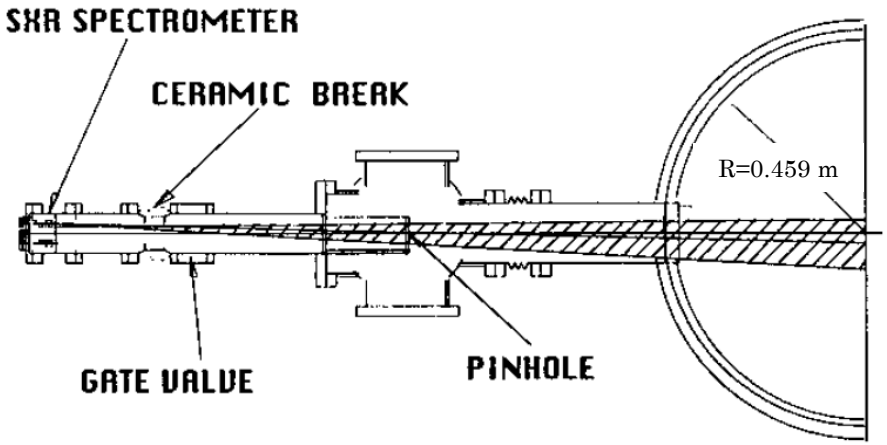
T_e estimation is based on the filter absorption technique, also referred to as the "**double-filter**" method [Martin_1996].

Te estimation from SXR in RFX-mod

SXR on-axis multifoil spectrometer

[Murari_1999]

- **4 diodes** observing the plasma through 4 beryllium filters of different thicknesses along the **equatorial plane**
- dynamic T_e evaluations up to a tenths-kHz band-width can be performed, confirming the potentialities of the technique to follow fast phenomena.

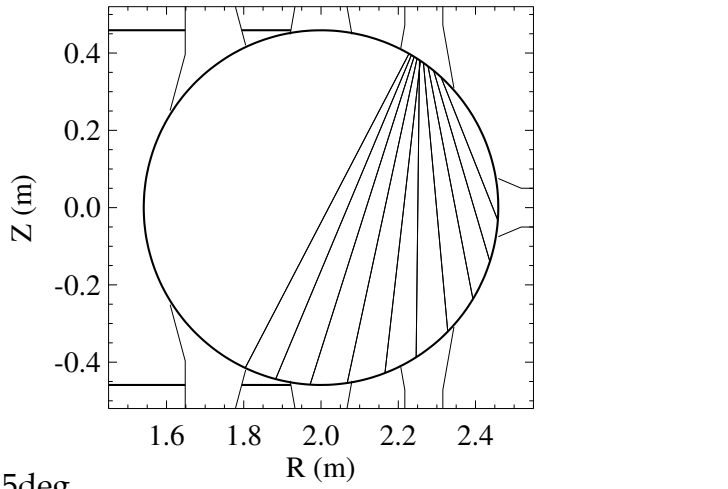


Φ_{tor}=7.5deg

SXR multichord diagnostic

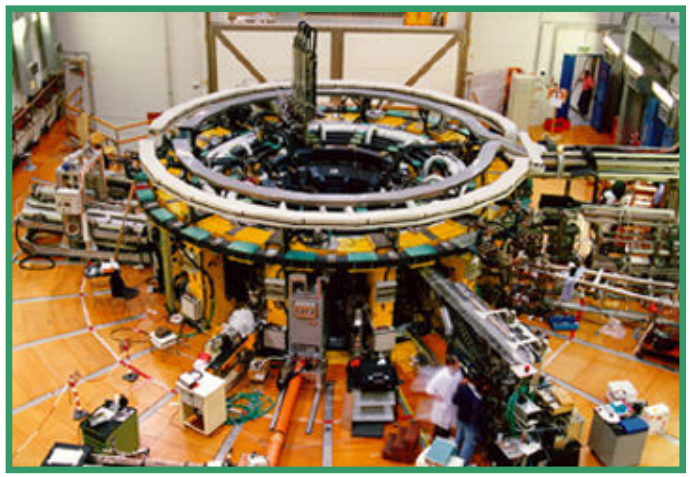
[Bonomo_2006]

- **10 pairs of chords** covering the low-field side of RFX-mod plasma allow for detecting the SXR emissivity with high spatial accuracy
- the **several kHz bandwidth** electronic system permits to follow in time the evolution of plasma dynamics



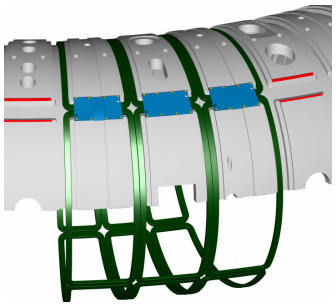
Φ_{tor}=262.5deg

RFX-mod: experimental scenarios



[Sonato_2003, Paccagnella_2006]

Virtual Shell (VS) operation



48 × 4 saddle coils allow for an active control over the magnetic boundary

Standard (Std) operation

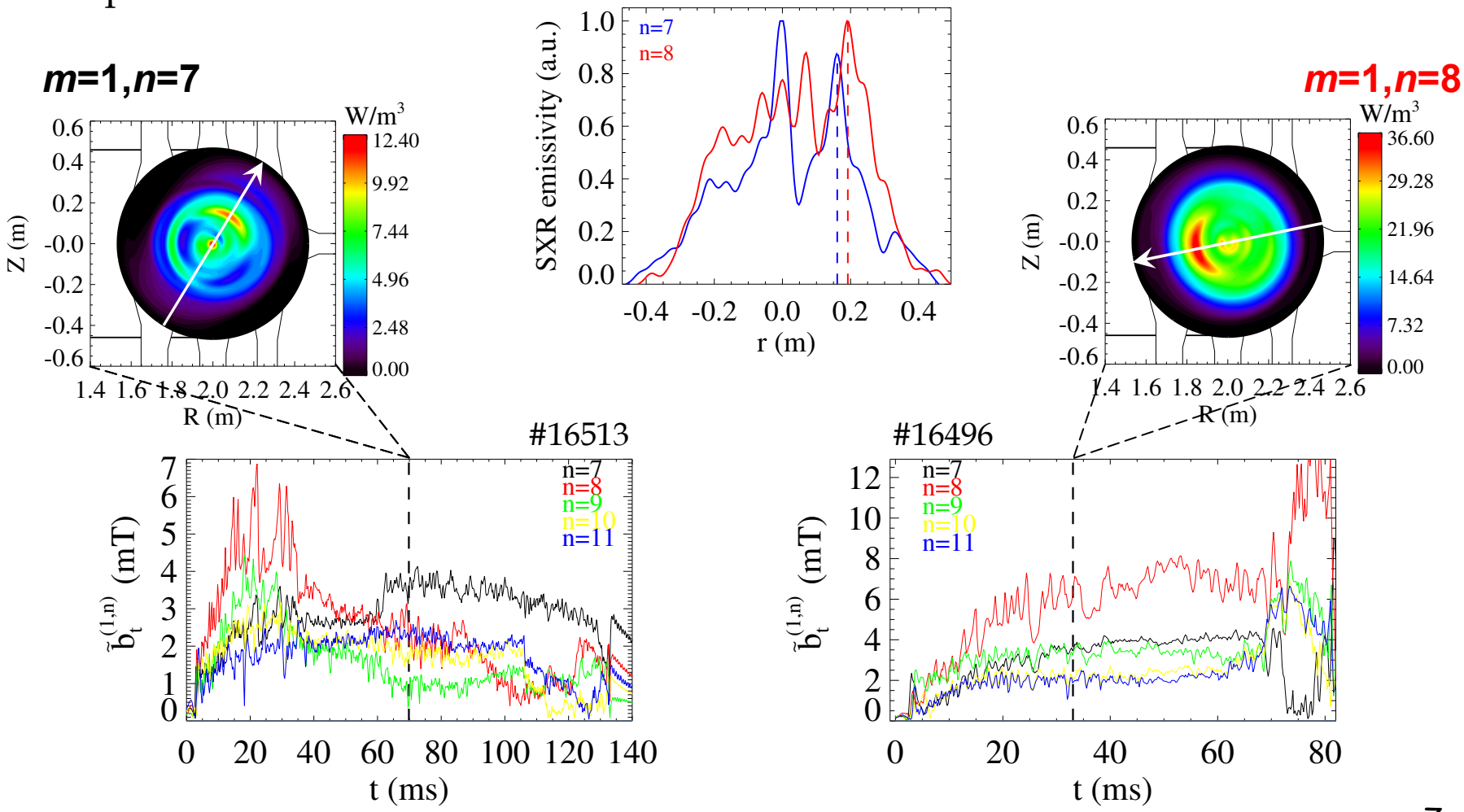
No saddle coils mode control, except for the plasma equilibrium

Selective VS (SVS):
a selected tearing mode is not controlled and allowed to naturally evolve

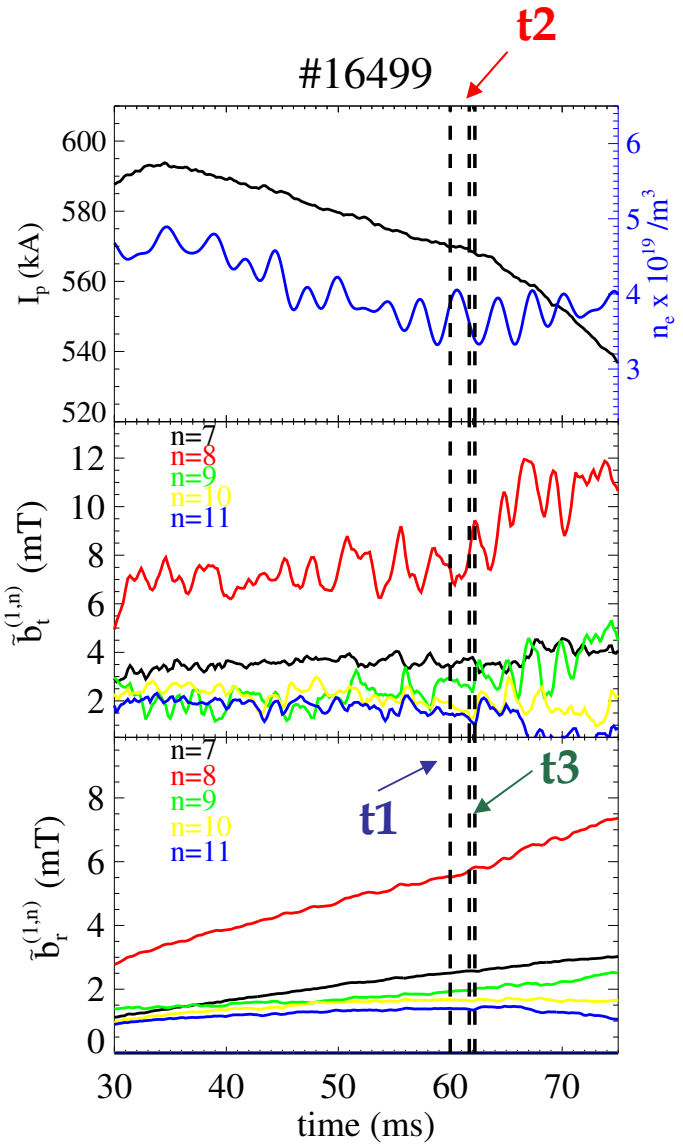
Feedback VS (VSf):
the amplitude of a selected tearing mode is externally controlled

Std operation: QSH regimes

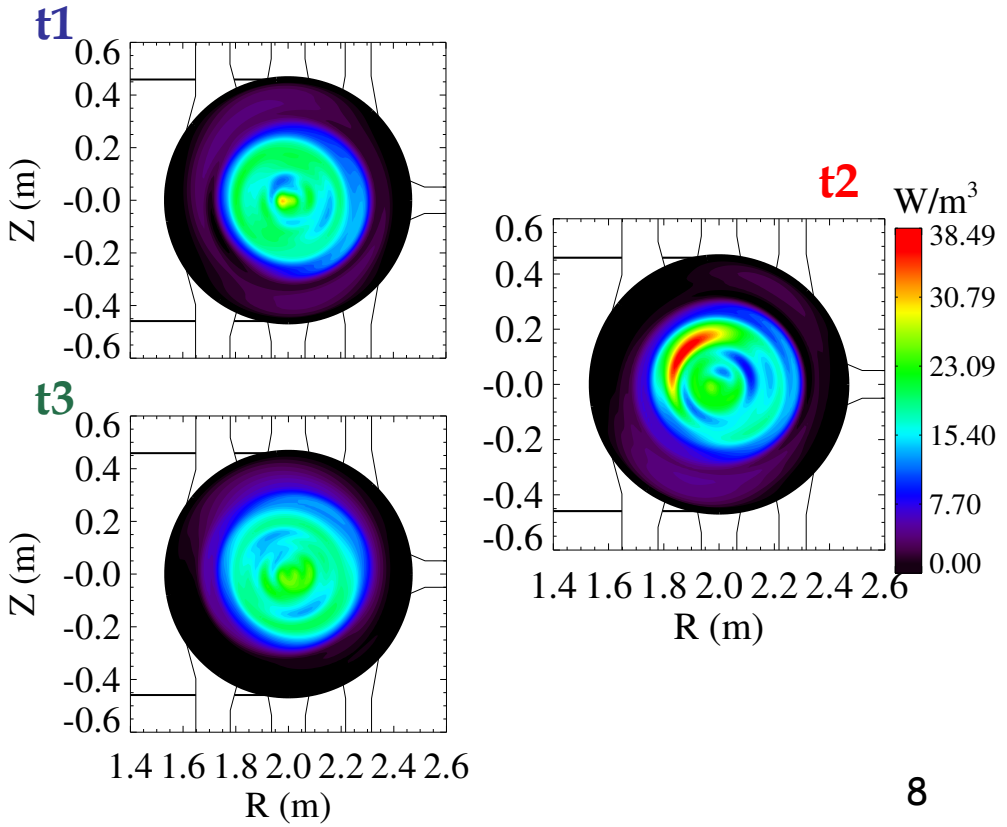
- SXR reconstructed emissivities identify localized *m*=1 structures at different *n*, naturally emerging in the plasma core at the correspondent resonant radial position



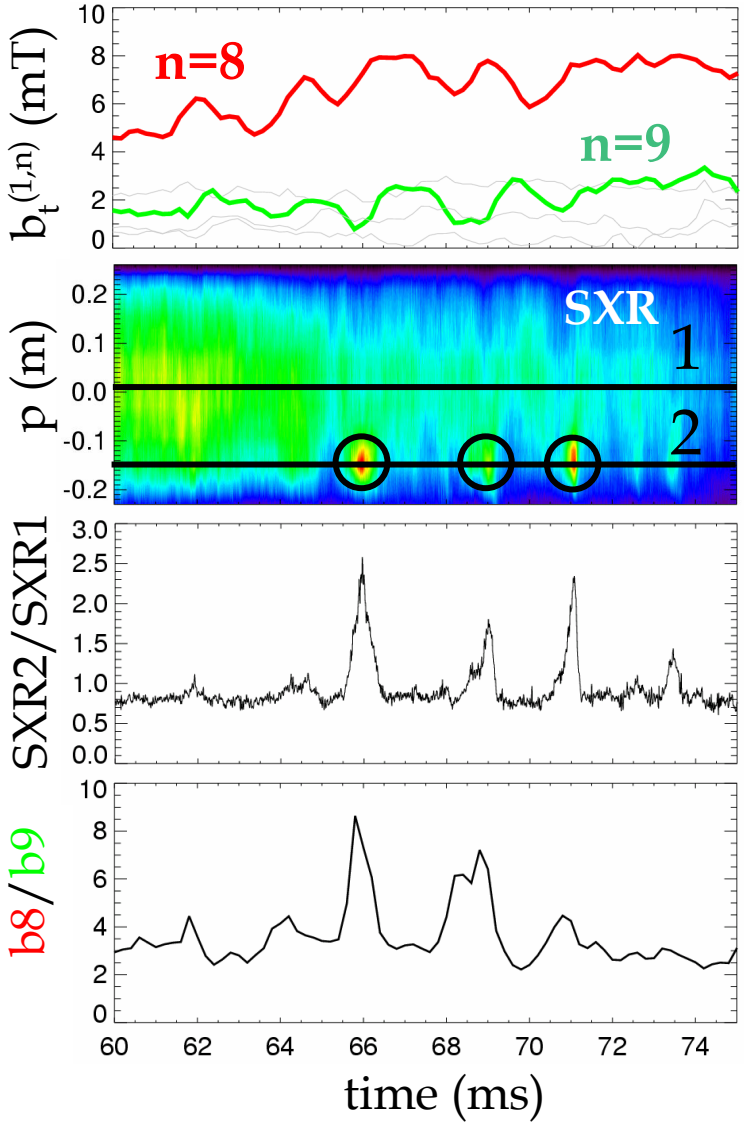
Std operation: island intermittency /1

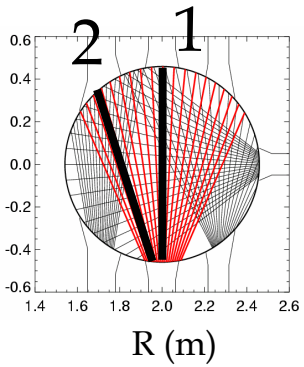


- The SXR tomographic accurate spatial resolution and the high temporal accuracy allow for detecting structure intermittency: the island presence is linked to the behavior of the amplitude of both the dominant (1,*n*) magnetic mode and the secondary ones



Std operation: island intermittency /2





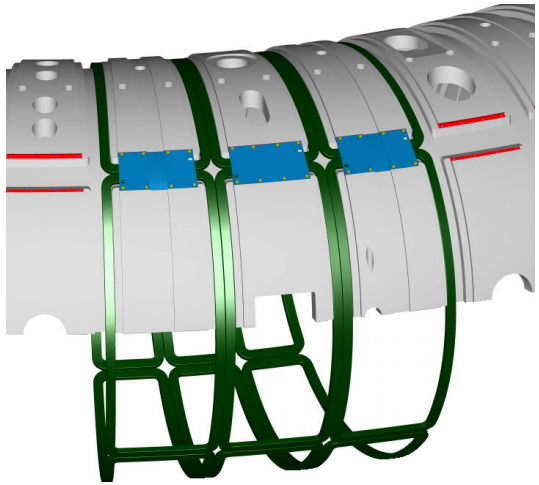
Geometric layout of the SXR tomographic system

A soft x-ray island corresponding to the m=1, n=8 appears in the plasma core when the **secondary mode** amplitude is sufficiently low.

As the secondary island grows, it overlaps with the dominant one, and magnetic chaos is thus produced.

VS operations

RFX-mod is equipped with
48×4 saddle coils.



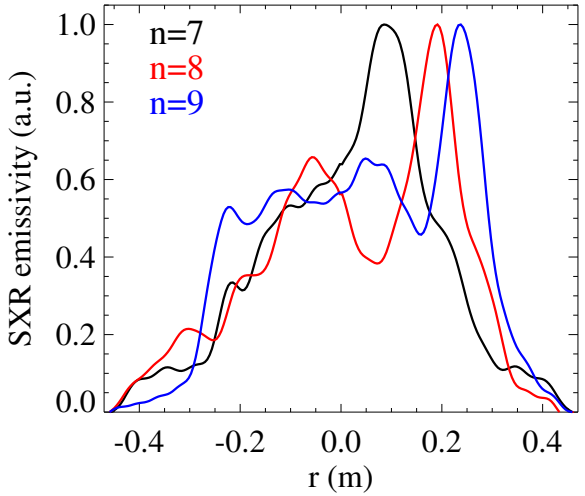
The system flexibility allows to specify different feedback laws for the various helicities [Marrelli_eps2006]:

- In "natural" evolution experiments, a selected tearing mode is not controlled and the mode reproducibly grows to a high amplitude
- In feedback controlled experiments, the amplitude of one or several selected tearing modes is increased and SXR structures can be observed, similarly to what happens in natural transitions to QSH states

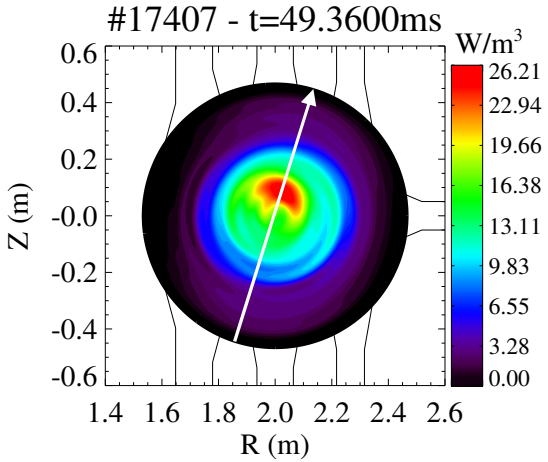
SVS: QSH in "natural" evolution

The uncontrolled mode growth occurs simultaneously with a decrease of the secondary modes, similarly to spontaneous transitions to QSH in Std:

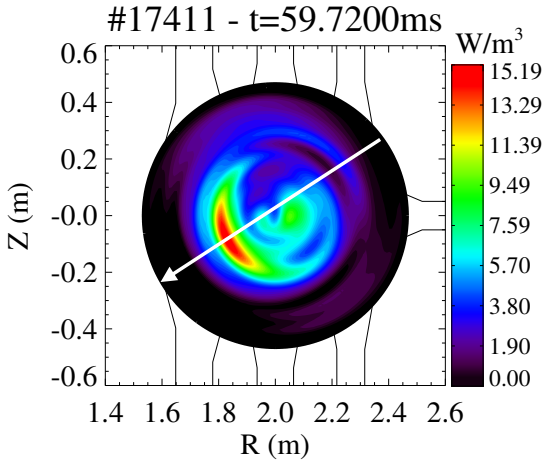
- SXR structures appear in the plasma column, at radial and poloidal locations consistent with magnetic islands O-points



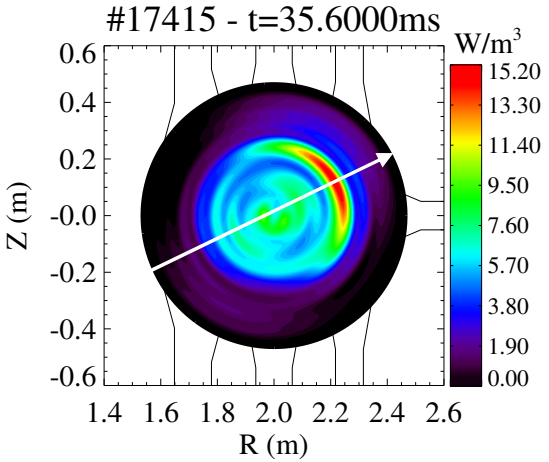
n=7



n=8



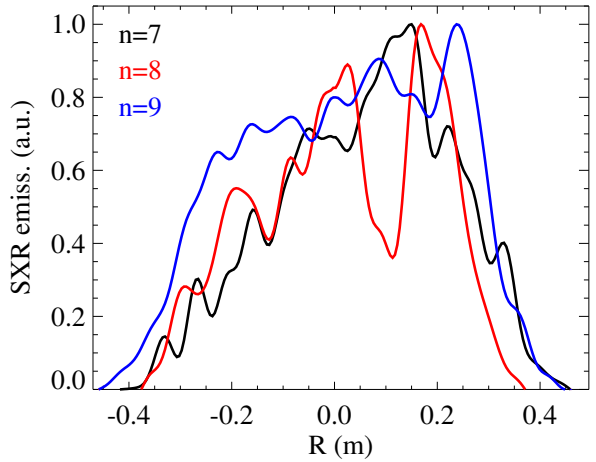
n=9



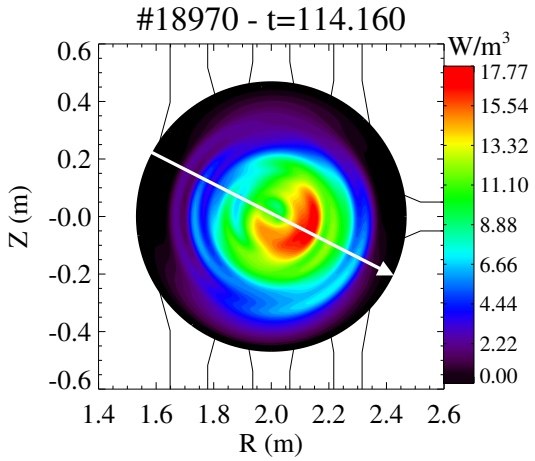
VSf: QSH induction

A non zero reference value for the amplitude of the radial component of a selected helicity can be prescribed:

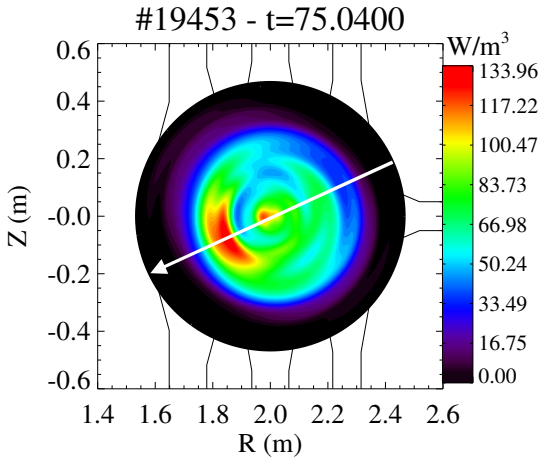
- SXR reconstructed emissivities reveal the presence of localized *m*=1 islands in correspondence of the dominant magnetic mode externally inducted



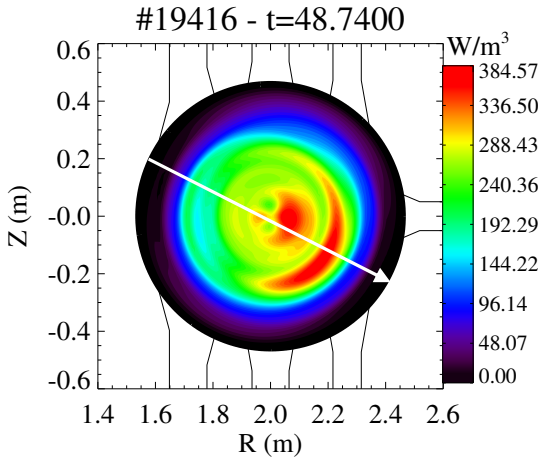
n=7



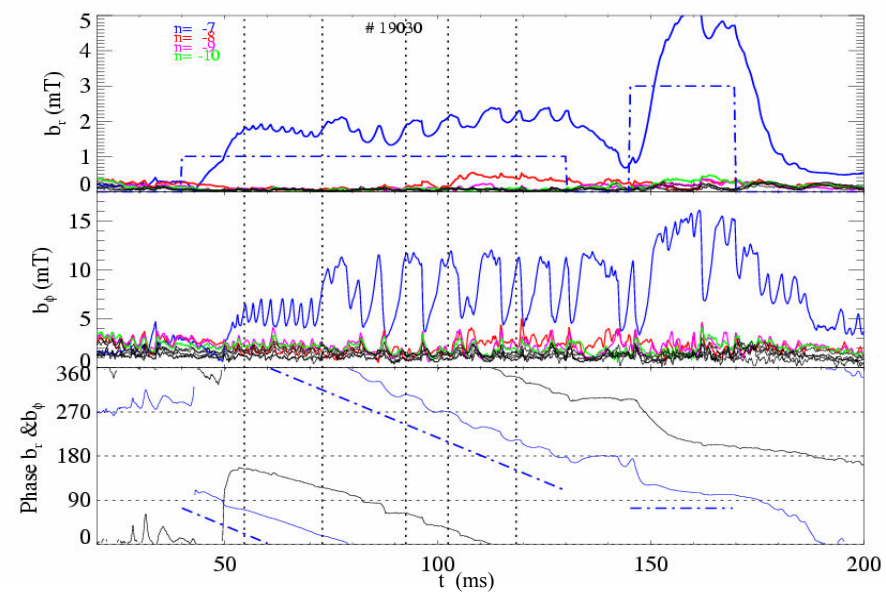
n=8



n=9

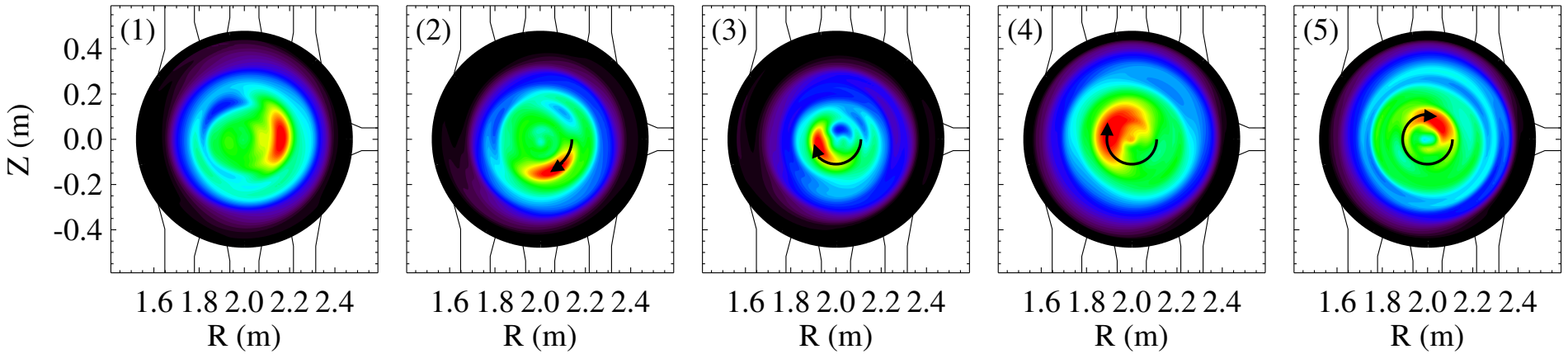


VSf: magnetic mode rotation /1

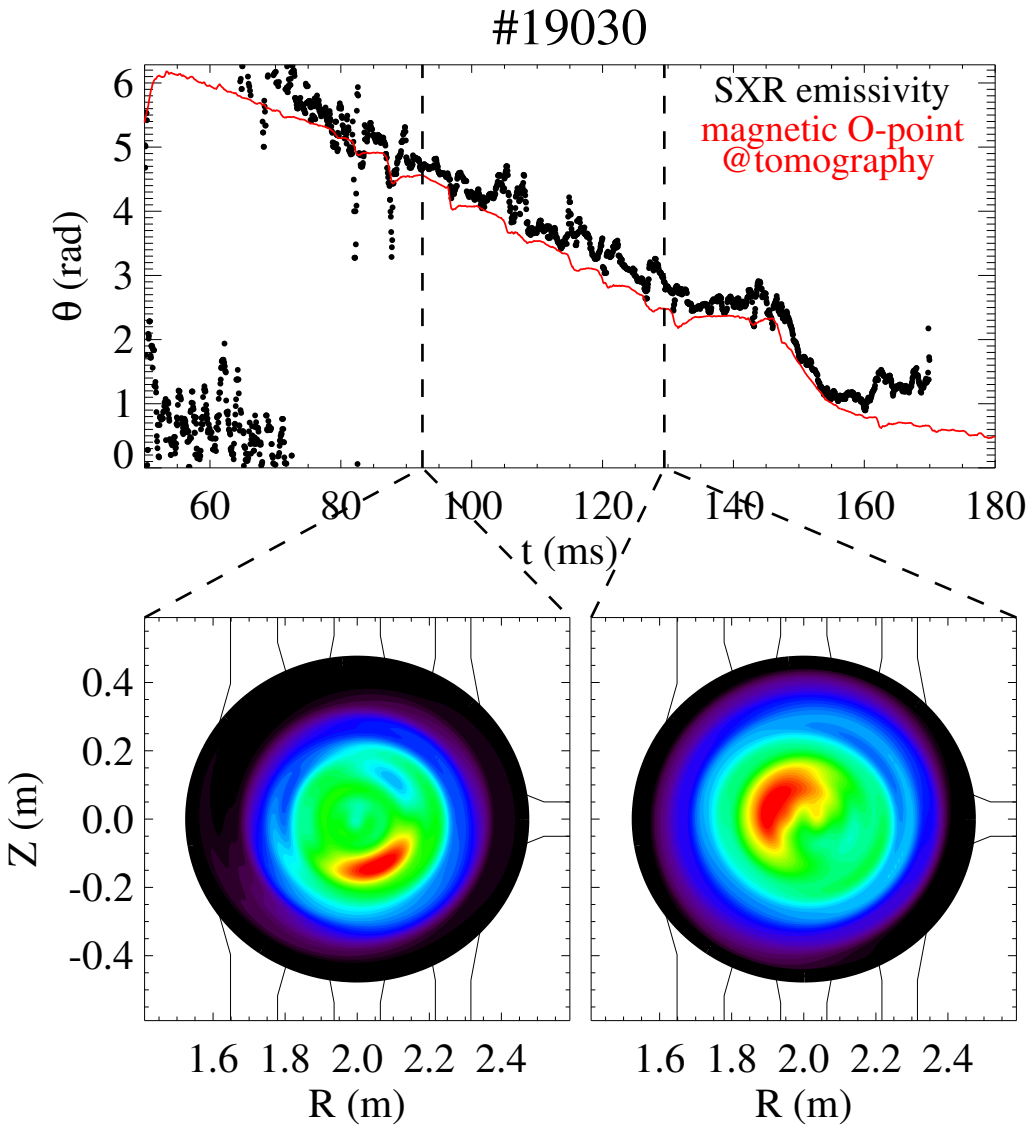


The magnetic mode phase can externally be varied in time…

... and the plasma dominant magnetic mode follows the reference phase, as shown by the SXR island poloidal rotation at the tomography section

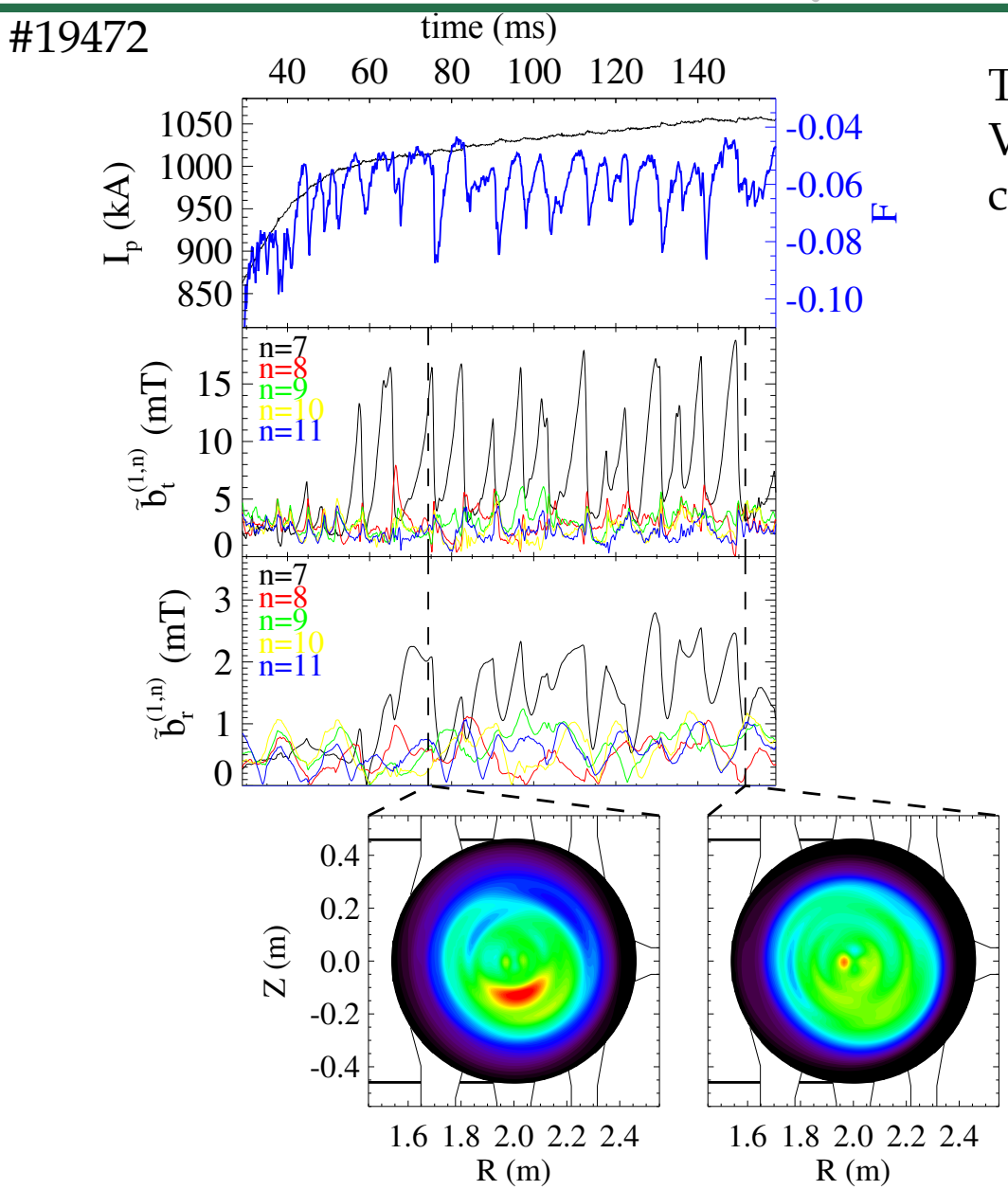


VSf: magnetic mode rotation /2



… and the reconstructed SXR emissivity center of mass follows in time the position of the magnetic mode O-point for the whole external mode rotation

VSf: intermittency…



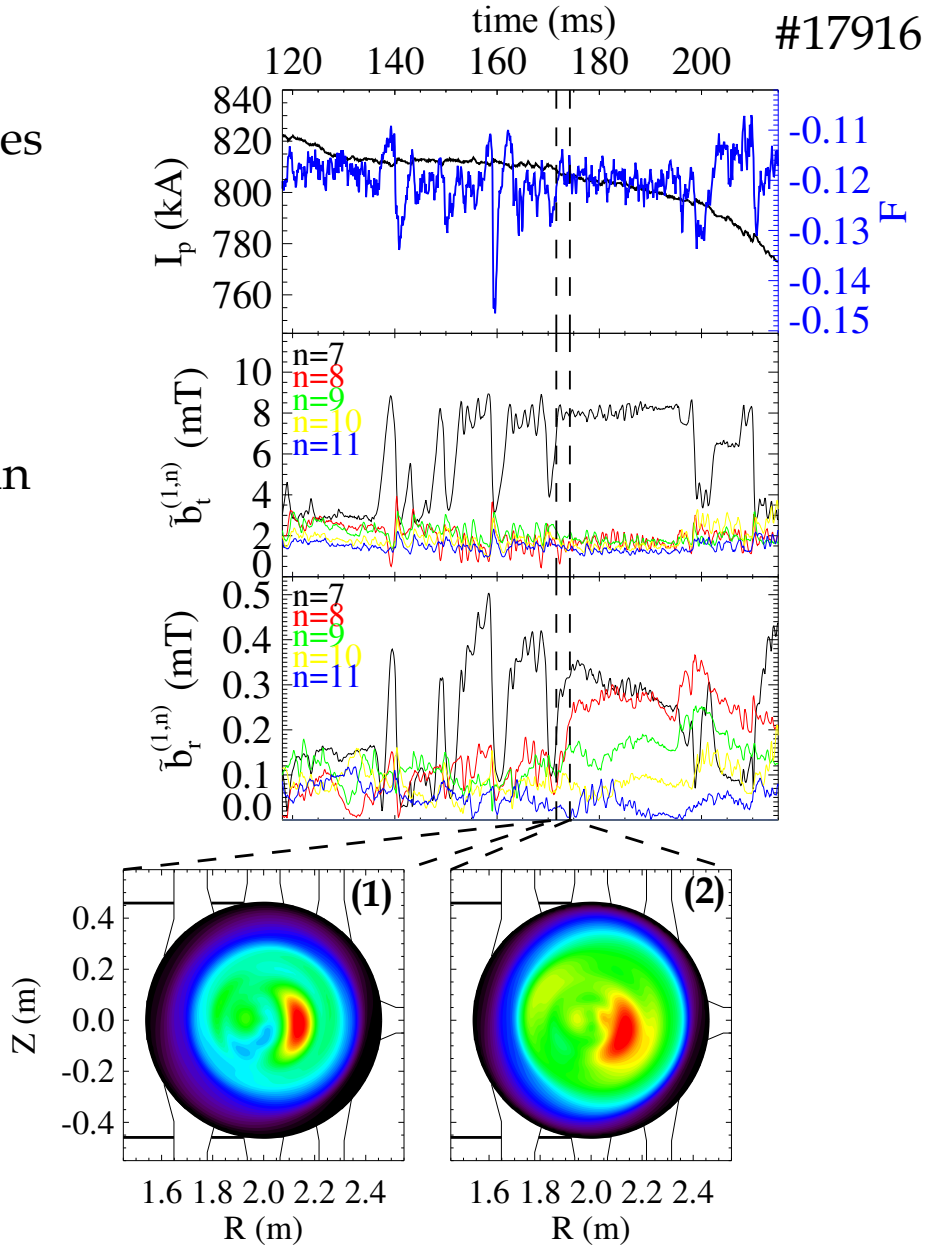
Transitions to QSH regimes in VSf operations can be characterized by intermittency:

- the dominant magnetic mode is mainly the innermost resonant (n=7) as typically shown in the RFP MST device
- in the QSH state, a more emissive SXR structure appears in the plasma column
- in between two consecutive QSH regimes, the SXR emissive profile assumes a symmetric shape, centered in the magnetic axis as in the typical MH regimes.

… and "quasi-stationary" QSH

However, sometimes, QSH regimes in VSf operations have a "quasi-stationary" behavior:

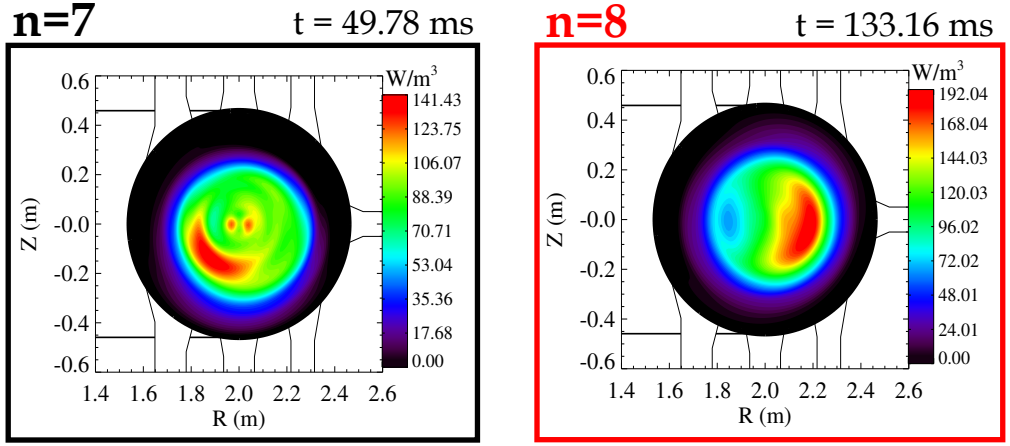
- the dominant magnetic mode remains high for longer time
- the SXR structure (1) emerging in the plasma core is not intermittent, but is evident throughout the entire QSH regime (2)

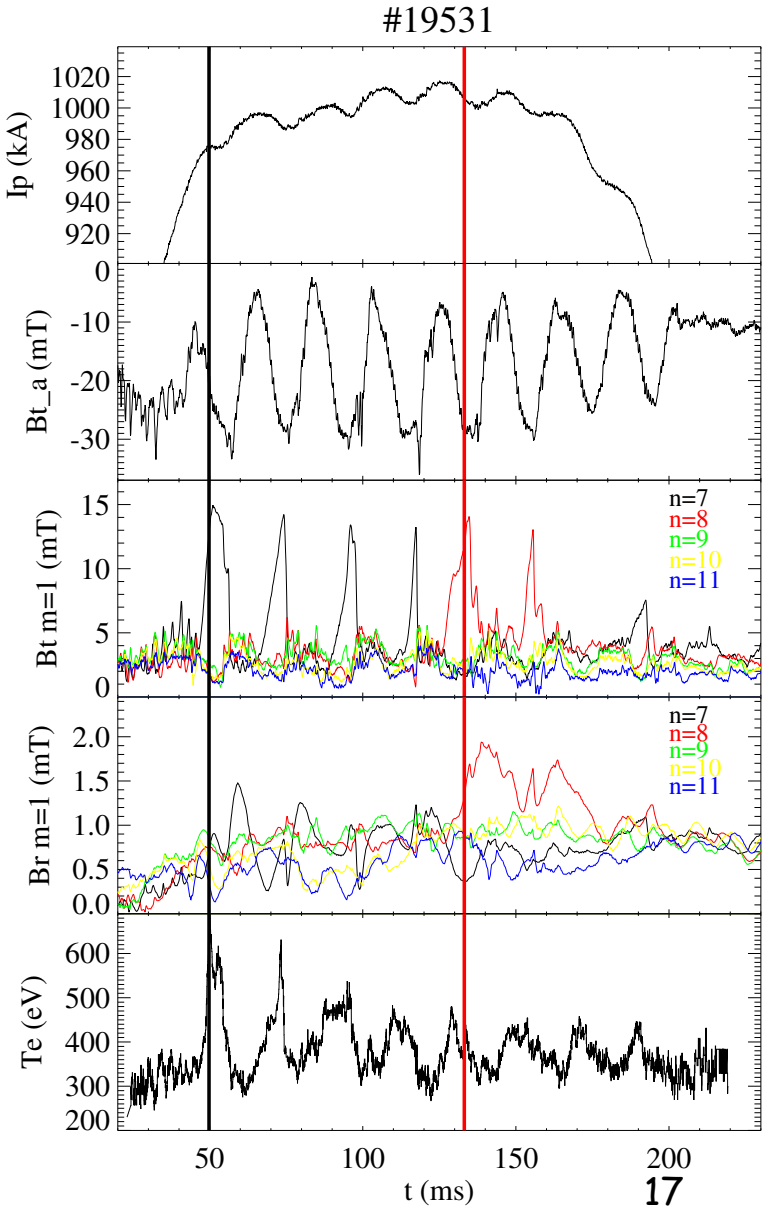


OPCD in VS scenarios

OPCD cycles are characterized by:

- transition to QSH regimes with different dominant n mode (n=7 or n=8), leading to a SXR more emissive structure emerging in the plasma core
- outstanding T_e oscillations in the center of the plasma column, as detected by the on-axis multifoil spectrometer, in phase with the $B_t(a)$ oscillations





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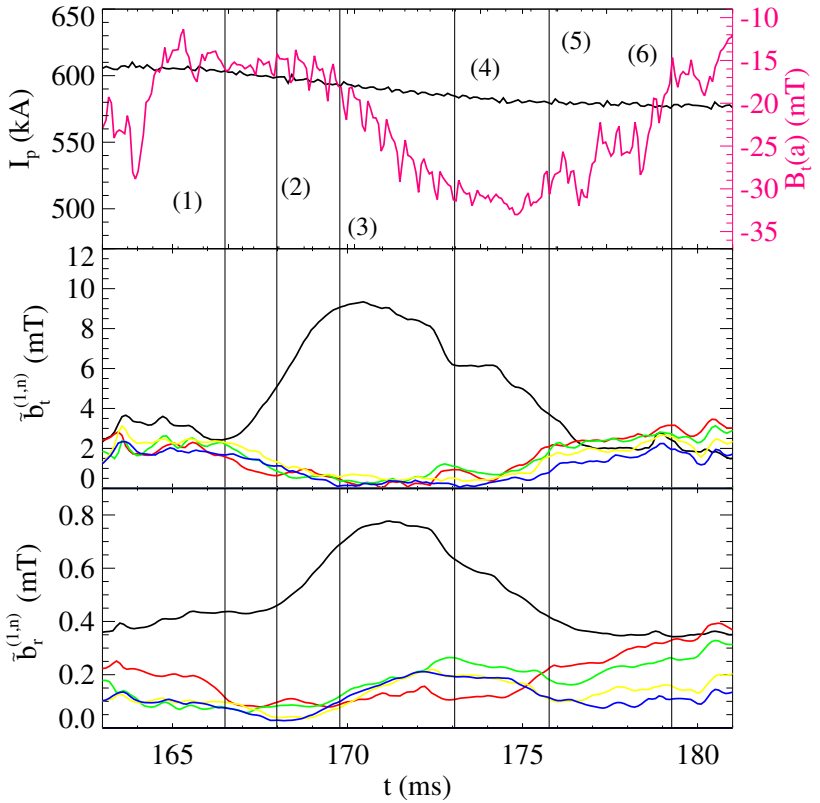
OPCD & SXR structures



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- In correspondence of a OPCD cycle, a more emissive SXR structure often appears in the plasma core, in correspondence of the magnetic island O-point

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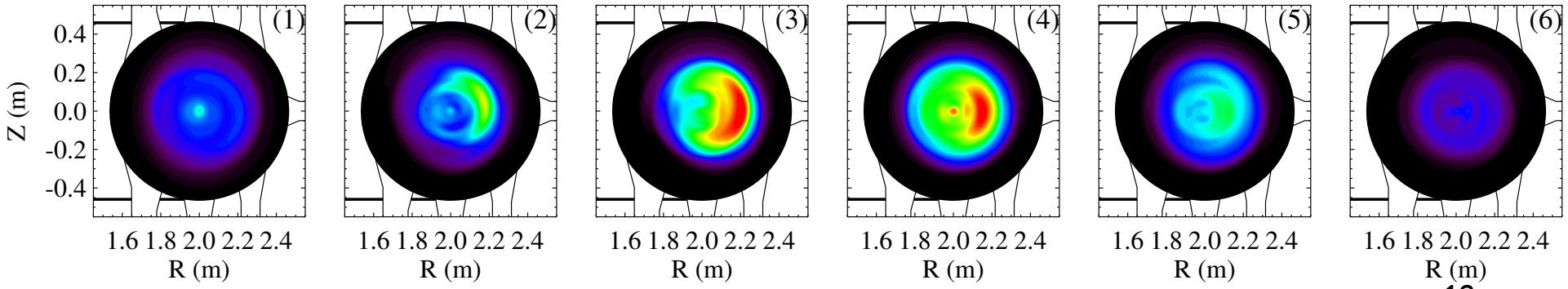
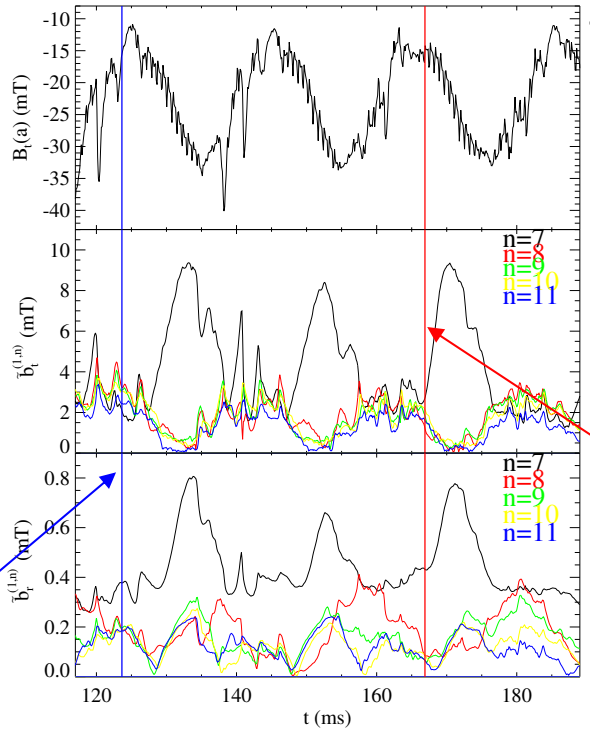
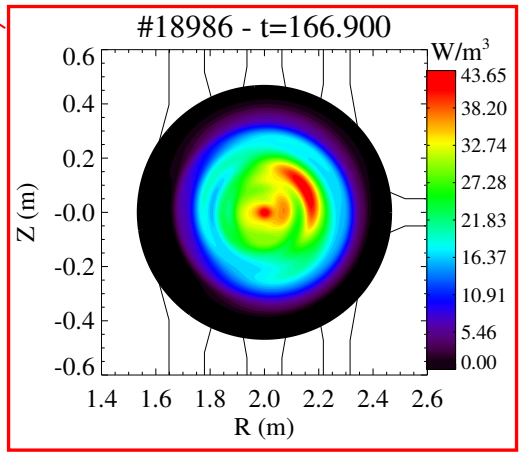


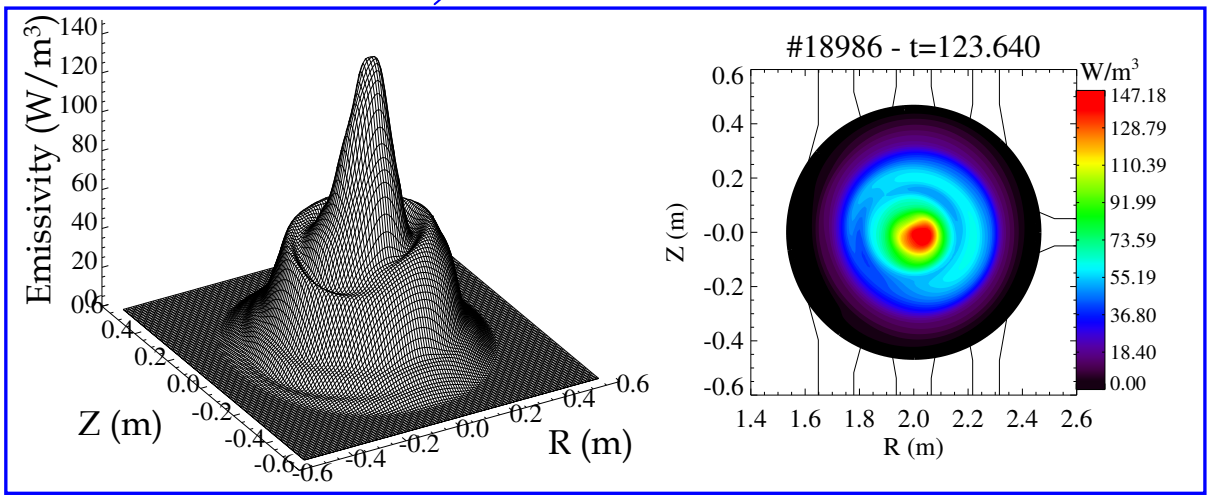
OPCD and the anti-dynamo

- In the OPCD anti-dynamo, SXR structures often disappear (MH regime), while the reconstructed SXR emissivity shows a symmetric profile, which could be even quite picked…



… but sometimes, in a correspondence to a residual dominant $b_r^{(1,n)}$ component, a residual asymmetry remains





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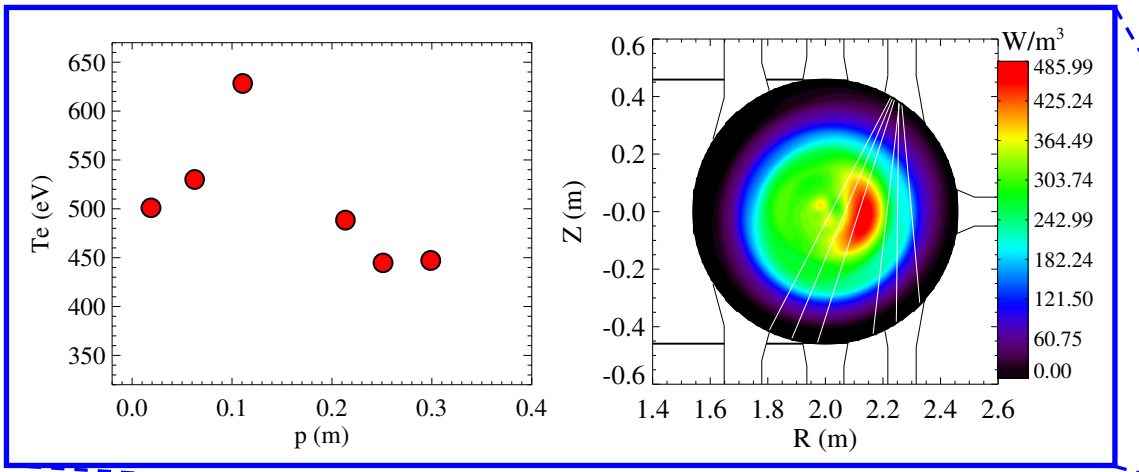
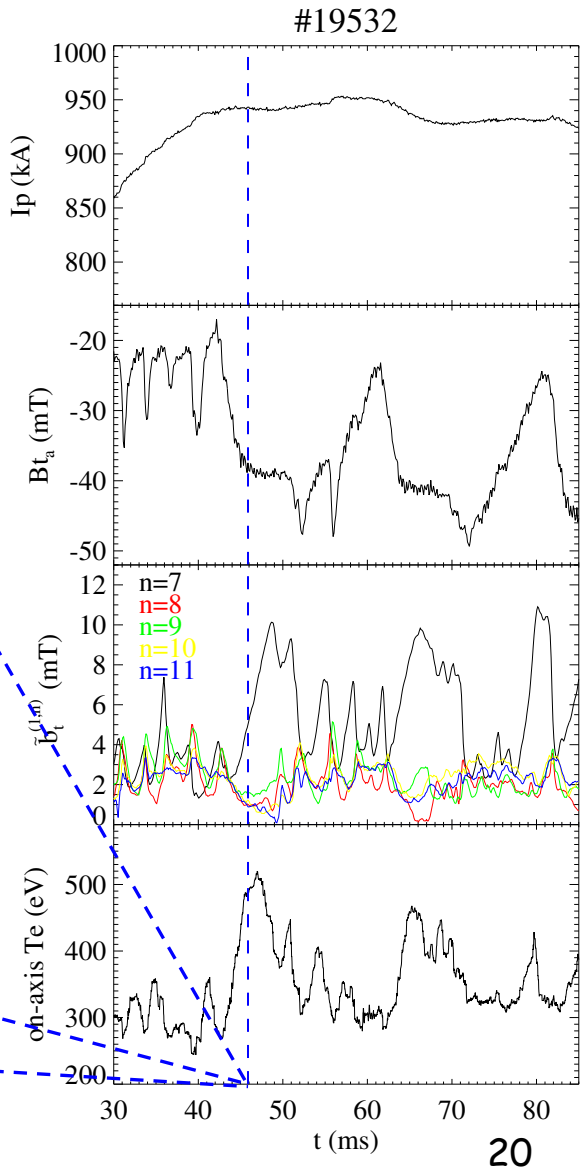
OPCD & Te : hotter SXR islands

During the dynamo phase, a localized improvement of T_e is detected by the on-axis multifoil spectrometer:

- the T_e oscillations are associated to the SXR structure emerging in the plasma core, hotter than the plasma nearby, as it is confirmed by T_e radial profiles





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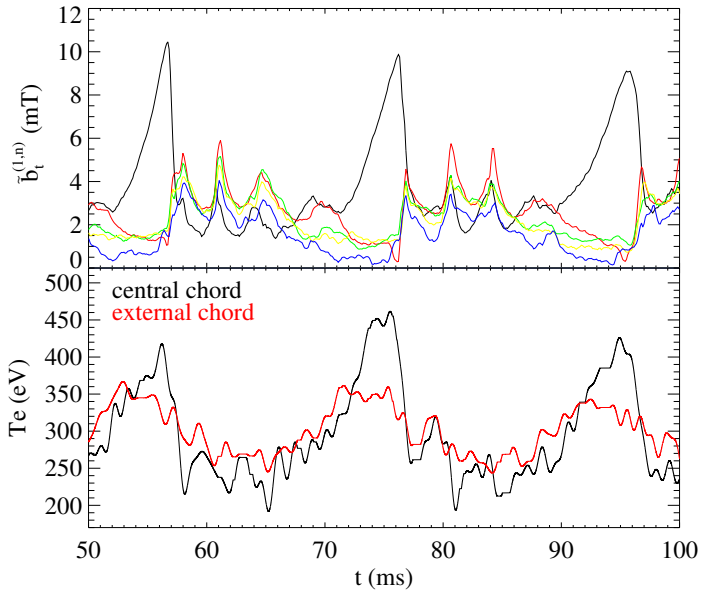
OPCD & Te: global improvement

Global T_e improvement:

- T_e oscillations in the external chords of the multichord diagnostic (not intersecting the structure associated to m=1,n=7 magnetic mode) indicate a global T_e increase in the plasma column during PPCD



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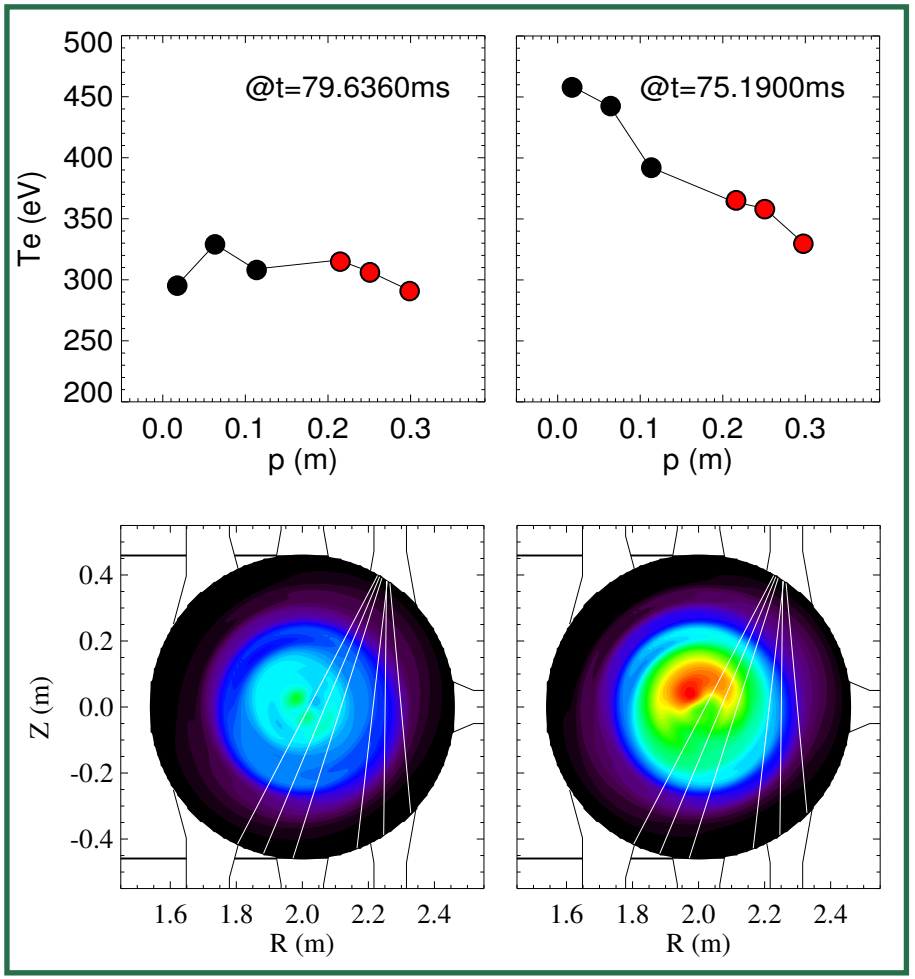

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