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Fast characterization of plasma states in W7-X with permutation entropy

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Overview

Today: introduce *permutation entropy* (PE)[1] and report on application case

PE: measure for complexity of time series from information theory. In practice, a single number.

Benefit of PE: **fast** and **robust** method (sorting algorithms) for the detection of plasma state changes: potential → in-situ monitoring of plasma parameters.

Main result: PE detected changes in the plasma state unraveled in large-scale data mining in ECE and soft-X ray data.

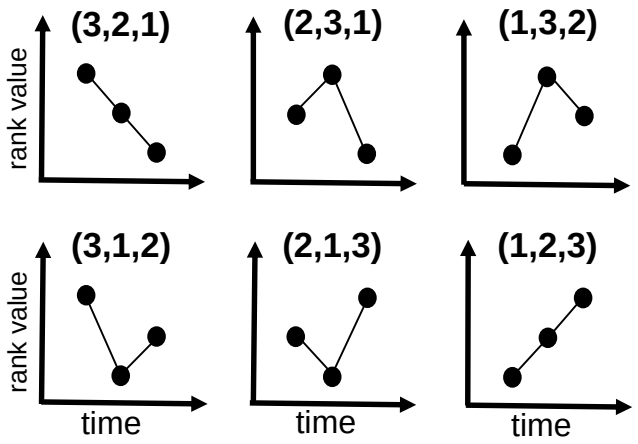
[1] C. Bandt, B. Pompe, Phys. Rev. Lett. 88, (2002) 174102

Quantifying disorder with permutation entropy

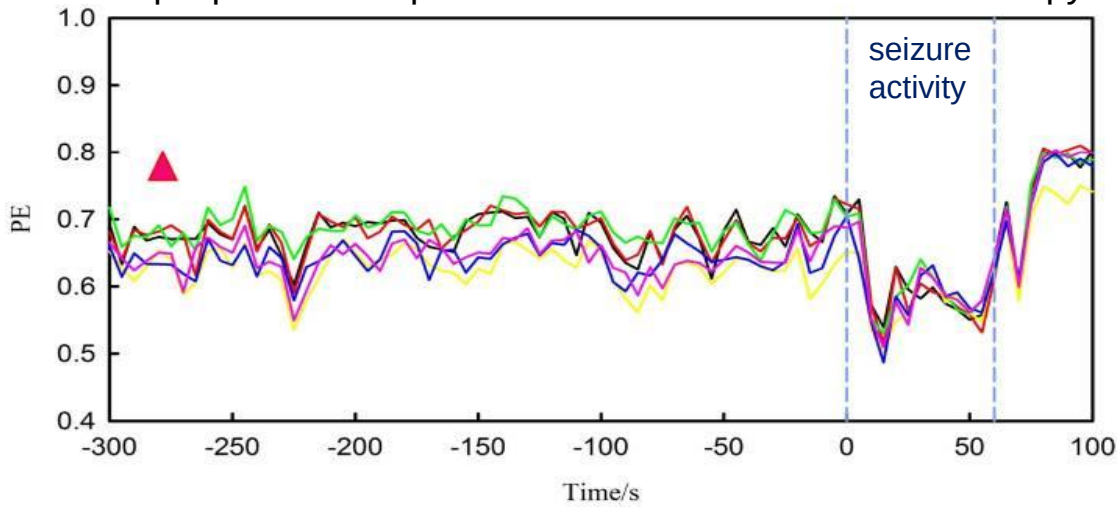
How is PE defined and calculated?

Basis: Shannon Entropy: $H(X) = -\Sigma_x p_x \log(p_x)$ → PE: permutation probabilities (p_x) of m-th order

Example: PE of order $m = 3$



Epileptic seizure prediction based on Permutation Entropy [1]

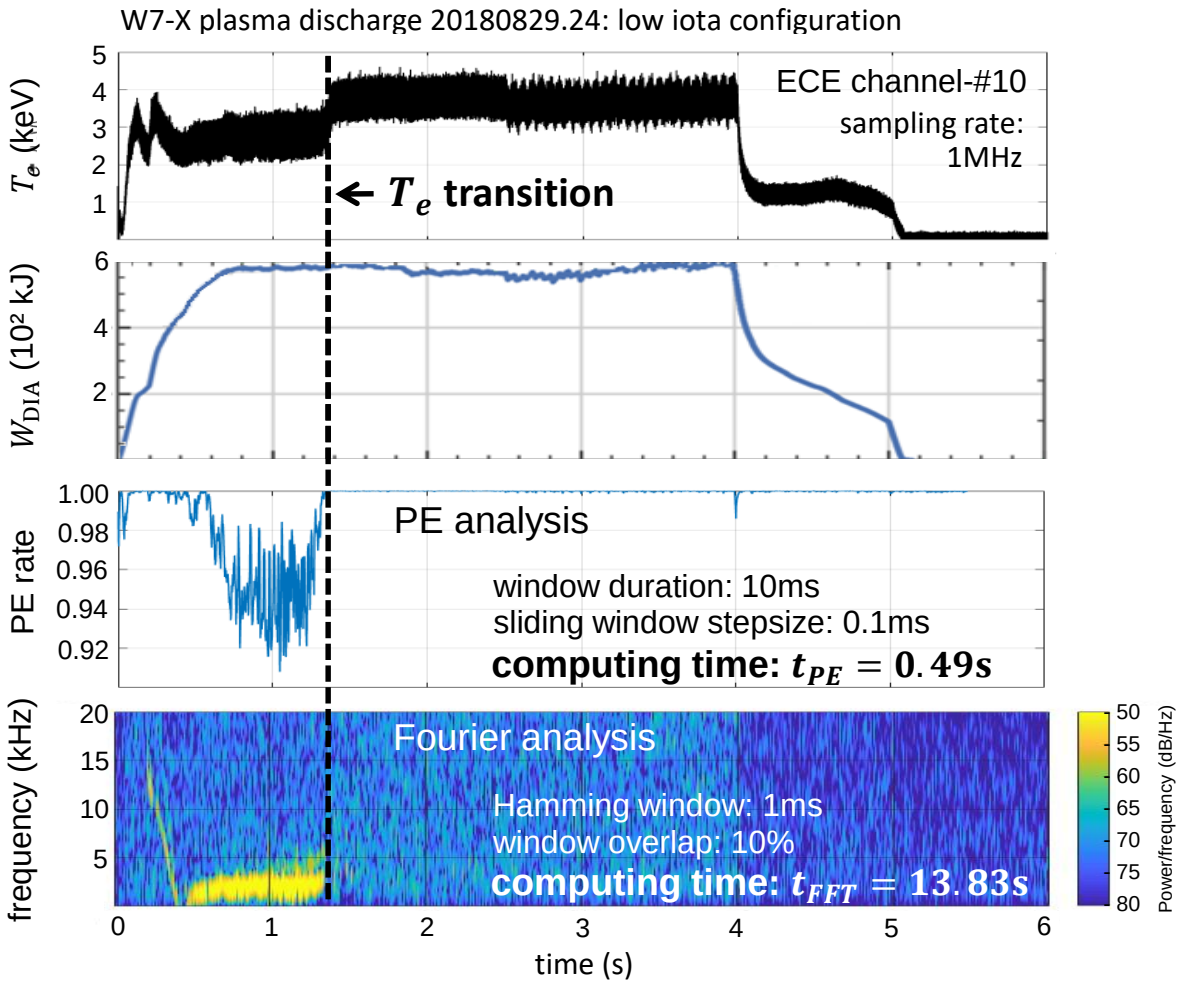


- ✓ **Fast**: based on sorting algorithms
- ✓ **Robust**: ordinal method (invariance for order preserving mappings)

PE: tool to detect irregularities based on Shannon Entropy that describes degree of randomness (disorder)

[1] Y. Yang, et al., Front. Comput. Neurosci. 12, (2018) 55

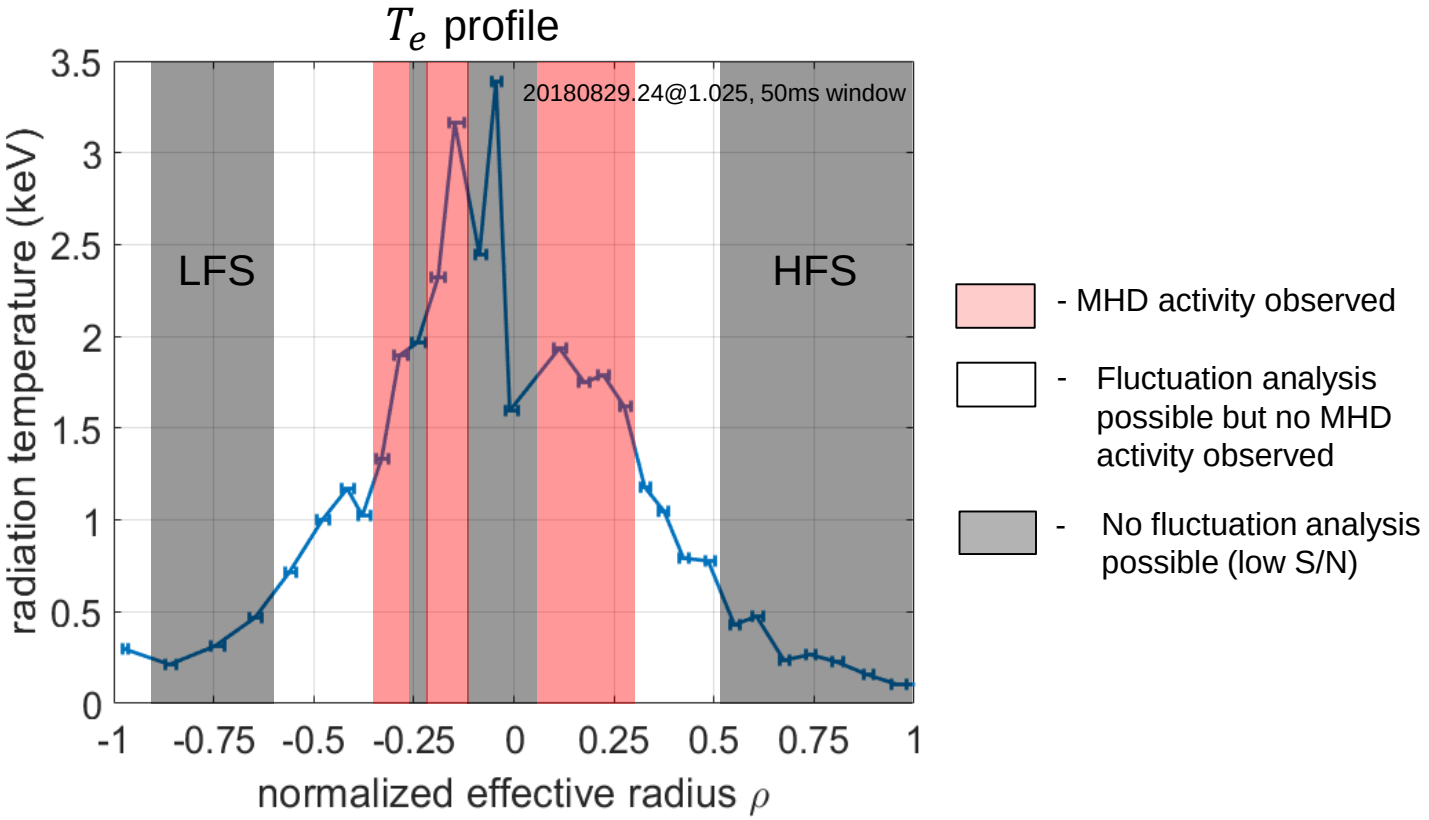
Plasma state characterization through permutation entropy



PE detects transient mode activity (seemingly linked to plasma state change – see T_e)

Localization of spontaneous T_e increase and mode activity

Do all ECE channels measure a T_e increase?

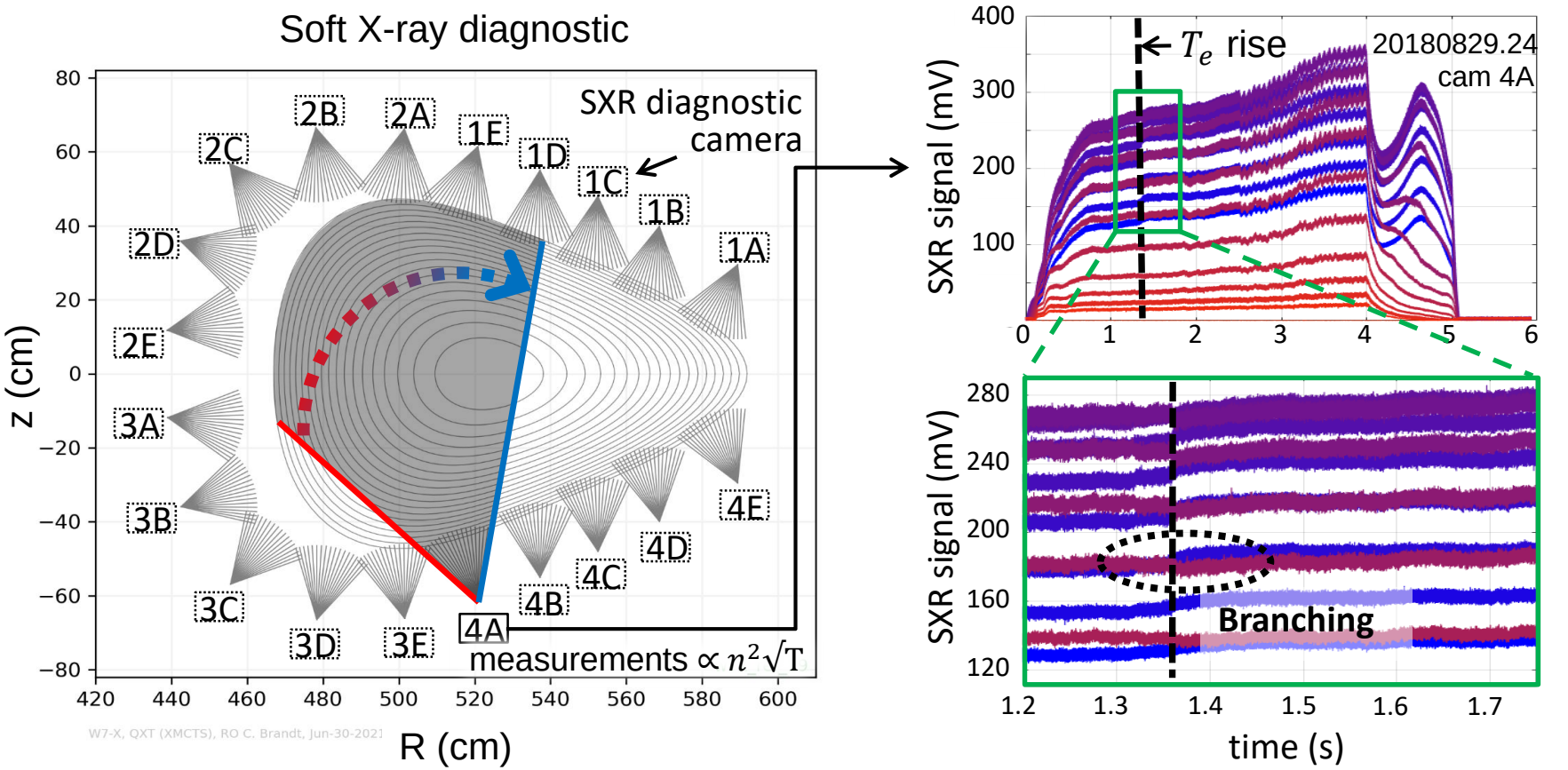


PE/spectral analysis: identify channels with low response for fluctuations ('blind' channels)

Mode activity localized at: $-0.35 < \rho < 0.3$

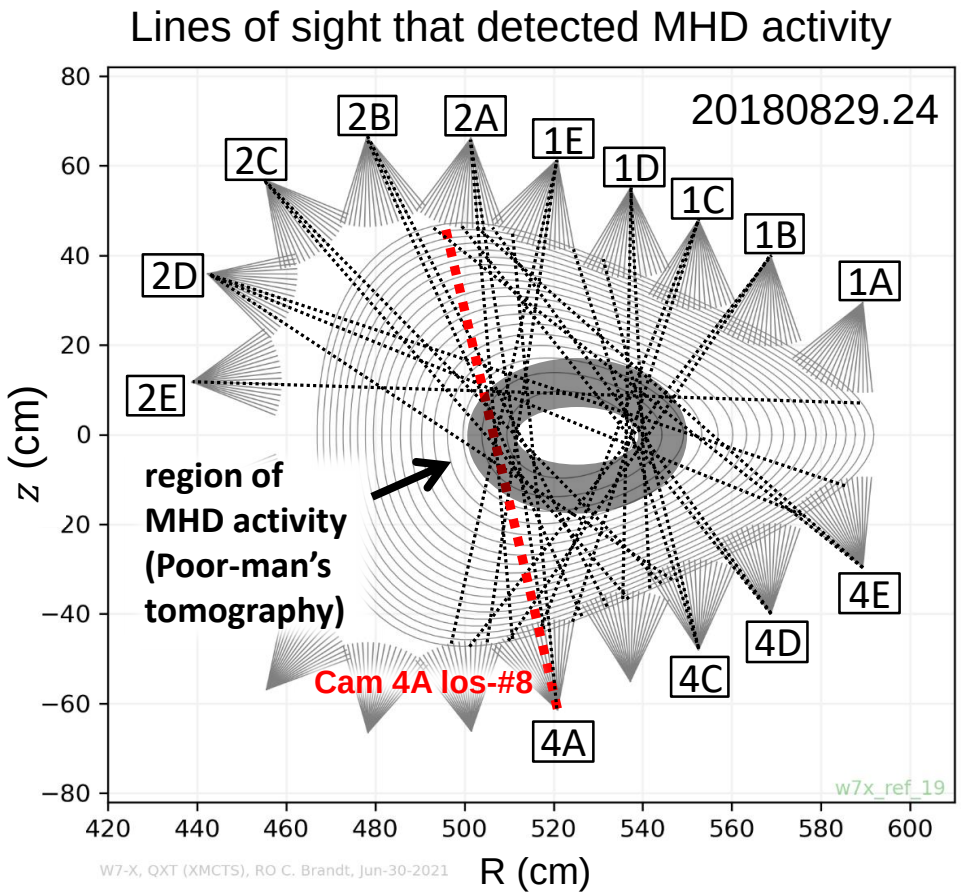
SXR data and behavior w.r.t. T_e

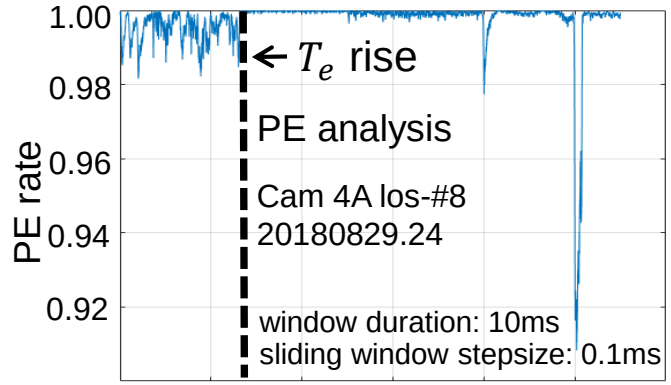
Can spontaneous T_e increase and mode activity be detected from SXR data through PE?

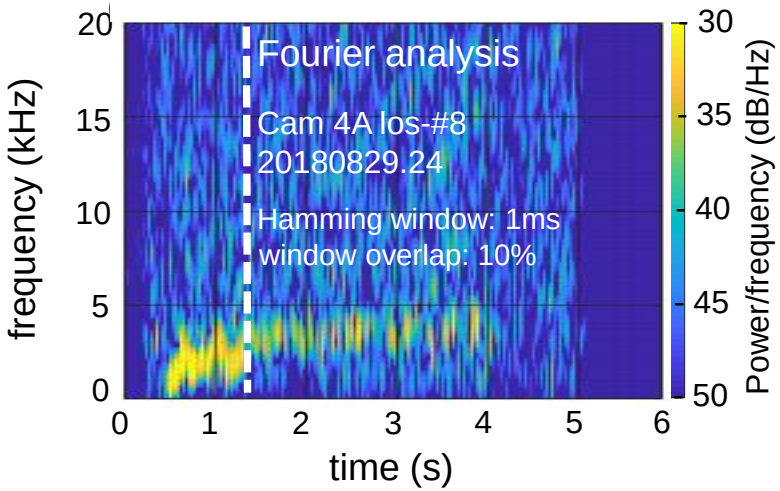


SXR data fluctuates when T_e suddendly rises → indication for plasma state change detection
Local characteristics: both increasing and decreasing emissivity time series found.

2-D localization of T_e increase and MHD activity



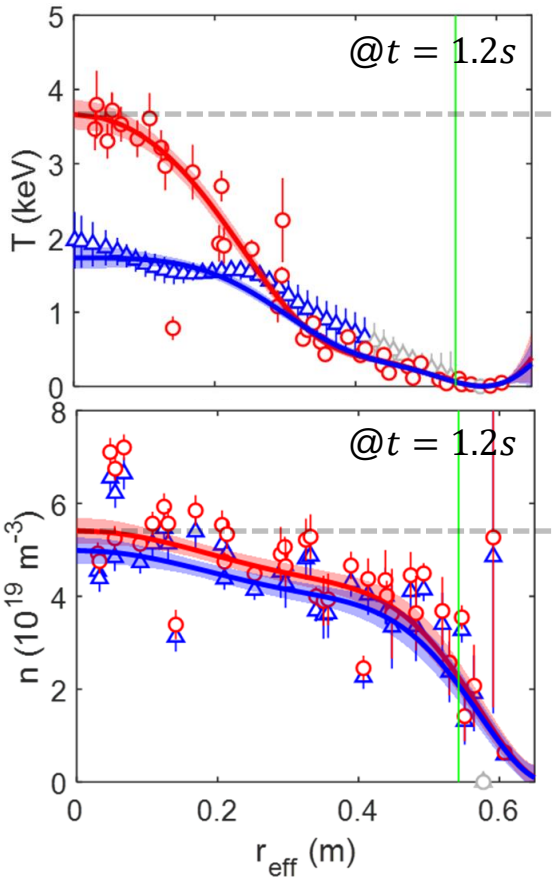




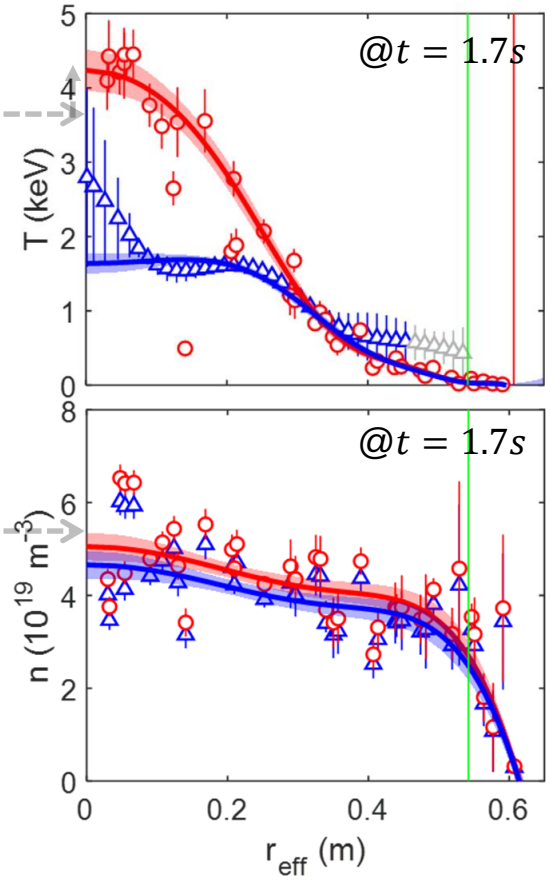
Spectrogram: two ‚mode activities' one ~ 3 kHz (all times), one ~2 kHz (up to transition)
PE analysis: clear detection of transition

Plasma state characterization through permutation entropy

Before T_e transition ($\mathrm{PE_{ECE}} = 0.94$)



After T_e transition ($\mathrm{PE_{ECE}} = 0.99$)



Decay in PE goes along with previously unrevealed change in plasma profiles

Summary

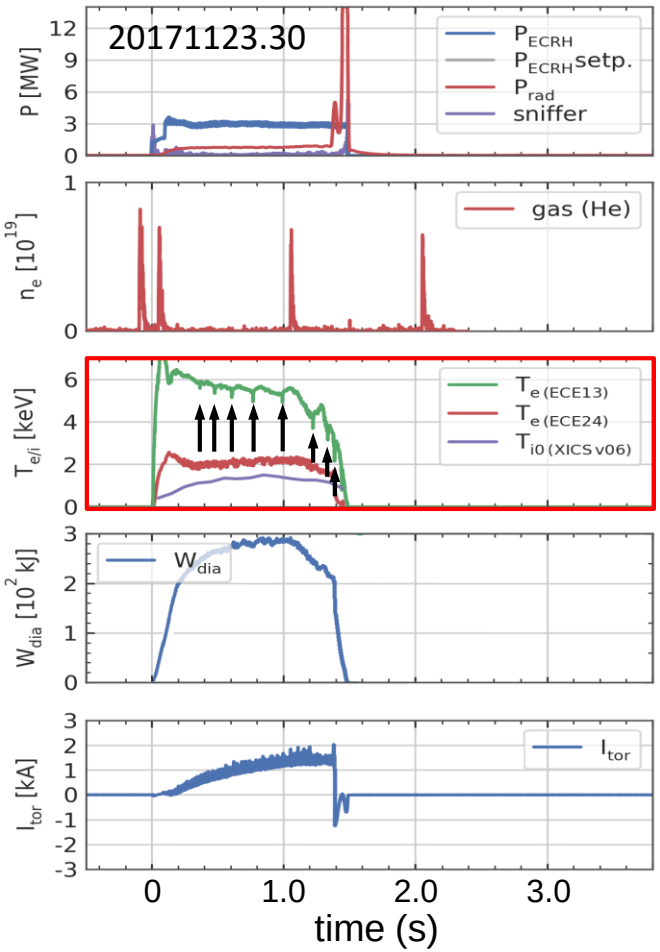
- PE analysis is a method for calculating complexity in time series
- Use case: detection of spatio-temporal bifurcation of T_e data
- Fast and robust detection of previously unrecognized mode activity seemingly linked to plasma state changes: potential applicability in machine learning to analyze bulk data
- Transport investigations underway

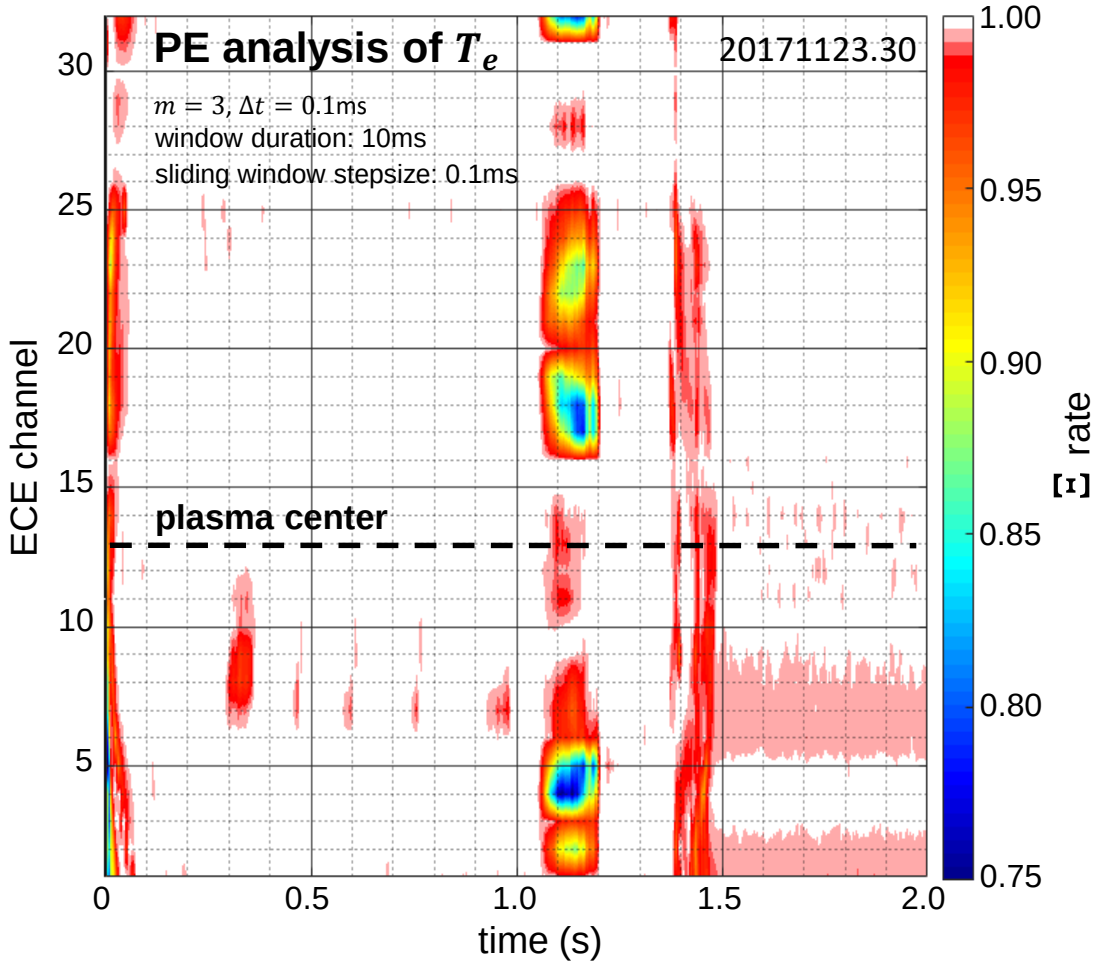
→ **PE is a suitable tool to detect plasma state changes and novelty detection in plasma data**

Appendix

Additional use case: detecting precursors of plasma termination events

High-iota plasma with ECCD driven MHD activity: strong "event" led to plasma termination

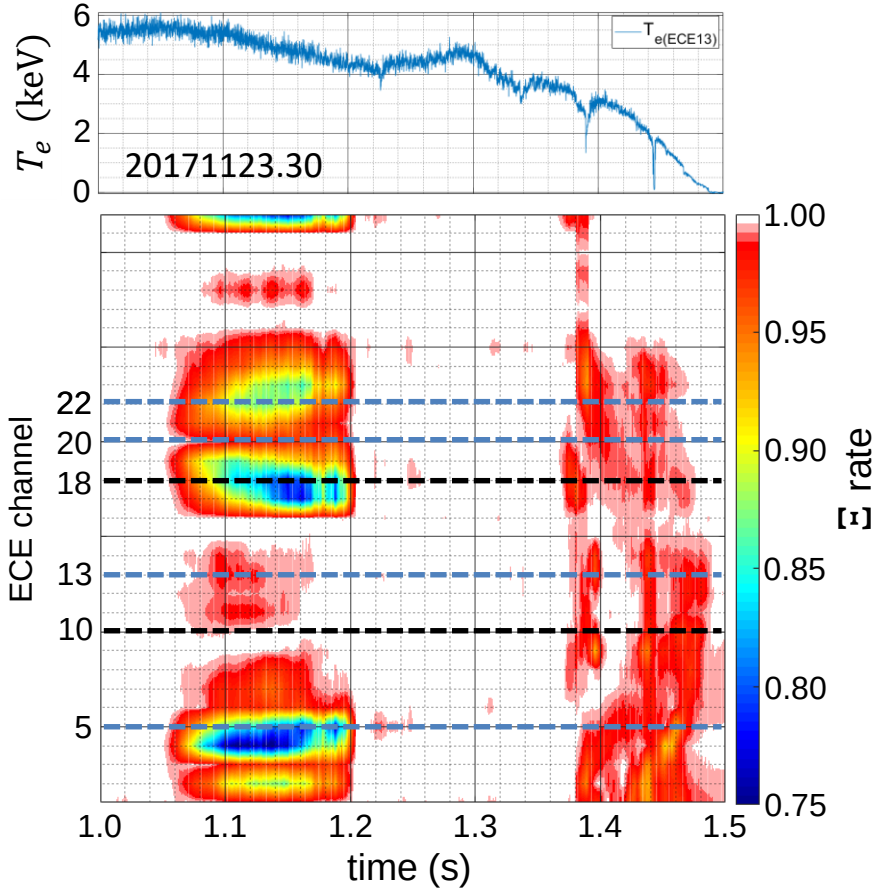


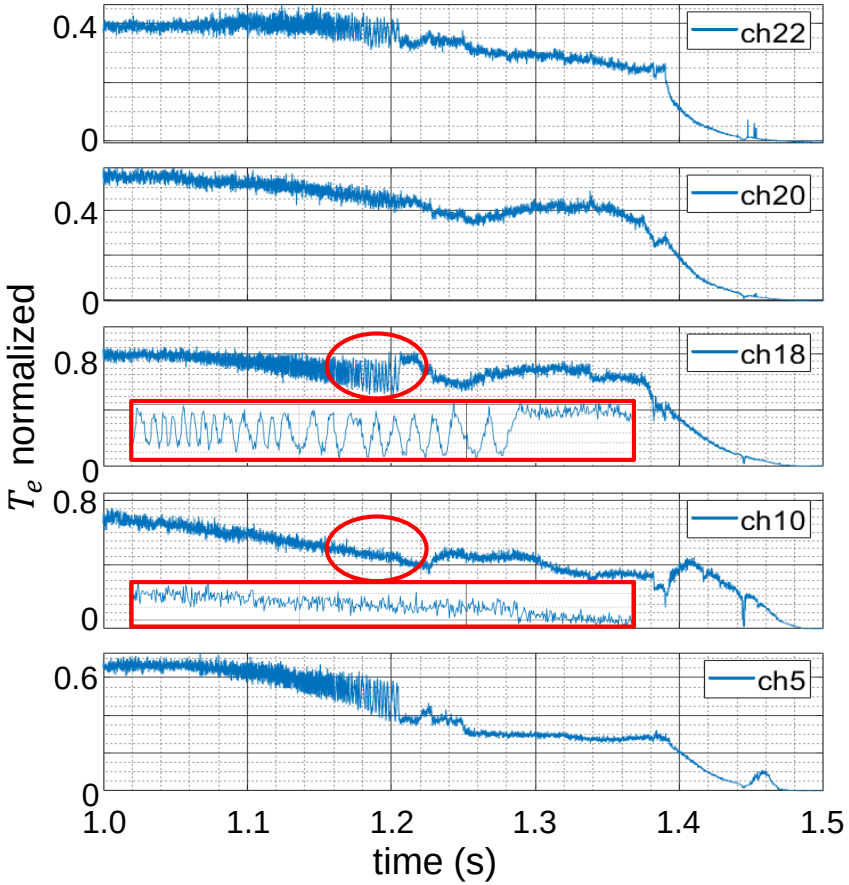


PE analysis detects structures apparently linked to plasma termination (see W_{dia})

Additional use case: detecting precursors of plasma termination events

What is PE detecting?





Down-chirp (2 kHz → 0.2 kHz) observed

PE analysis: suitable for the detection of activity preceding changes in the plasma state