Data-driven discovery approach to tackle turbulence in fusion plasma

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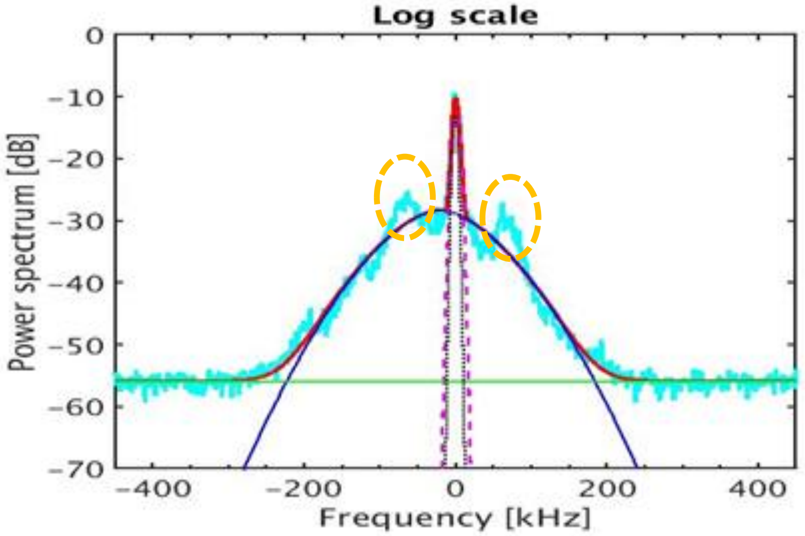
Introduction

Fixed frequency reflectometry is widely used to probe density fluctuations and turbulence in fusion plasma. Several components have been identified in the Frequency spectrum :

V. Vershkov 04
A. Krämer-Flecken 15
Y. Sun 19



Spectrum decomposition from ToreSupra #40806 using Y. Sun's method

Low frequency components
Broad-band turbulence
Noise
Quasi-coherent modes

The Broad-band and the low frequency components are present in every plasma conditions, but the quasi-coherent (QC-mode) are not. It is known that :

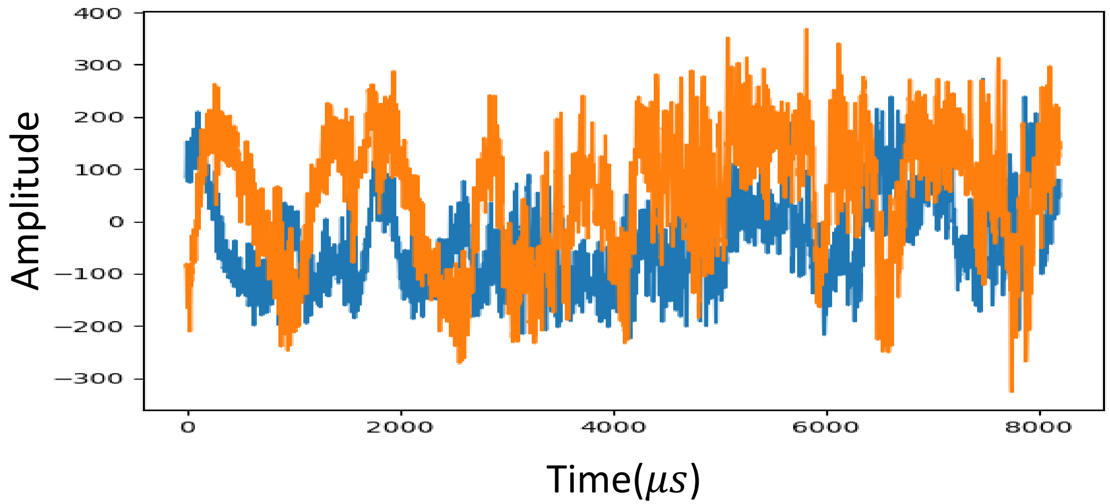
- The QC-modes bandwidth (10-50 kHz) is intermediate between the narrow coherent modes (few kHz) and the broad-band fluctuations (>100 kHz)
- Quasi coherent (QC) modes are attributed to Trapped Electron Modes instabilities (H. Arnichand 15).

But how to identify them?
Study dynamics of QC modes → Frequency-time representation + A.I. techniques

Signal processing approach

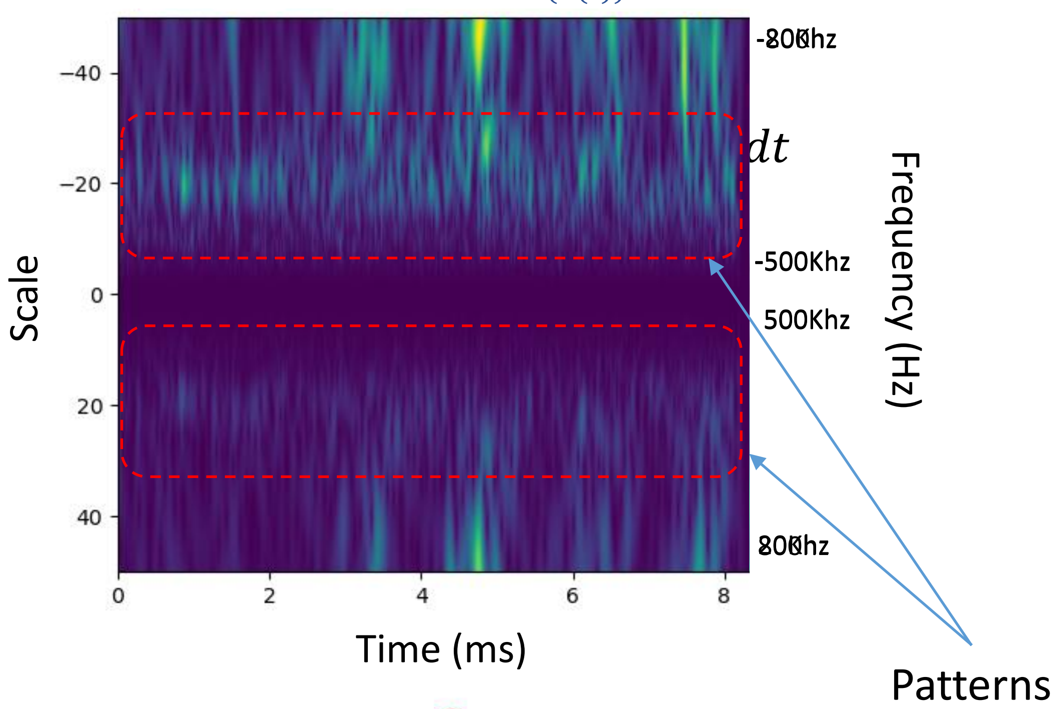
(frequency-time representation)

Complex signal S(t) at $f = cte$:



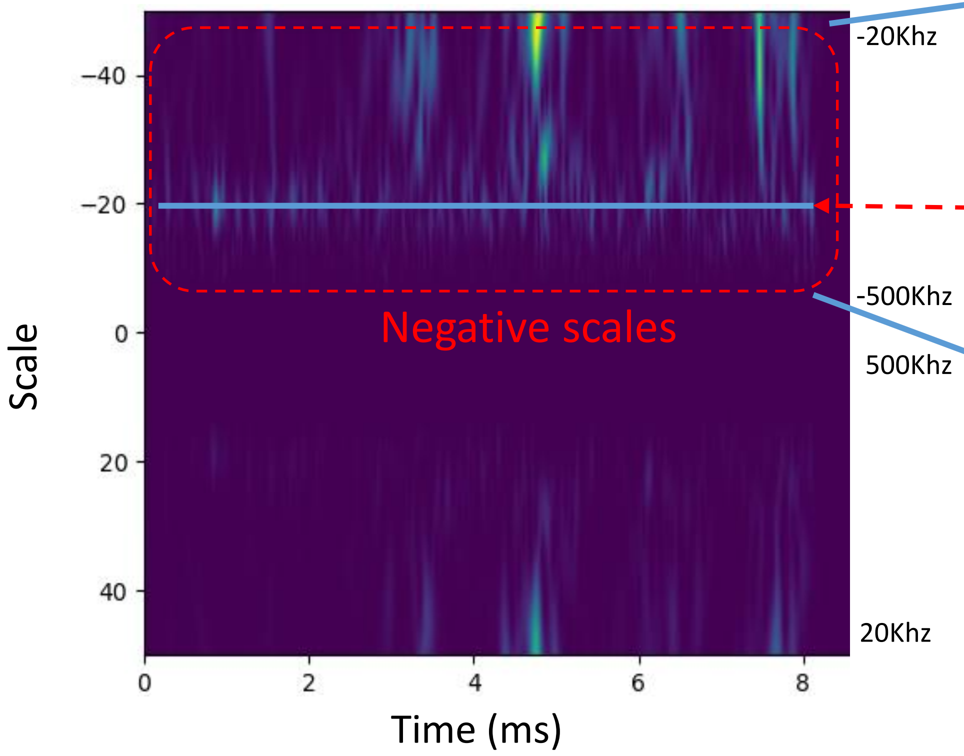
$$S(t) = A(t)cos(\varphi(t)) + A(t)sin(\varphi(t))i$$

Continuous wavelet transform :

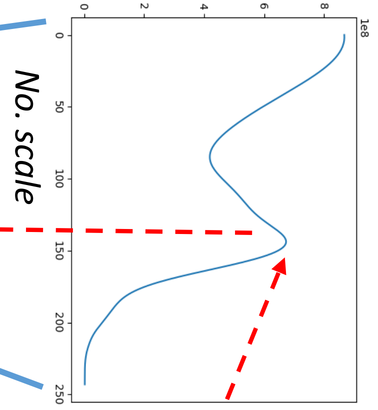


Correlation and Energy threshold

Energy density : $|W_{morlet}|^2$

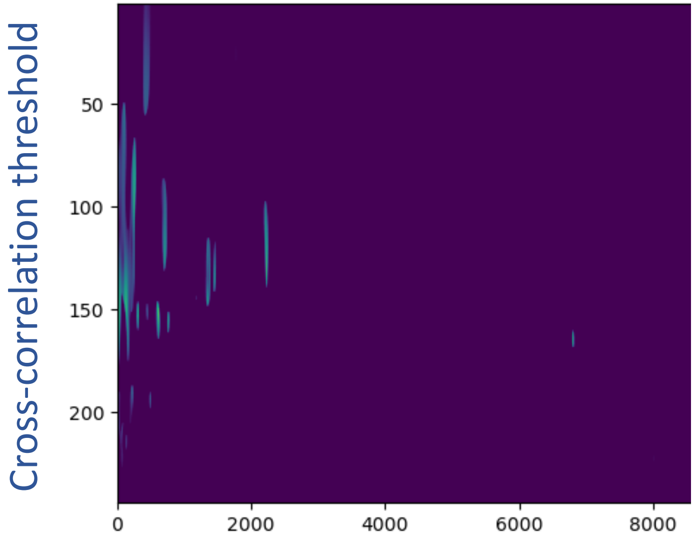


Energy density

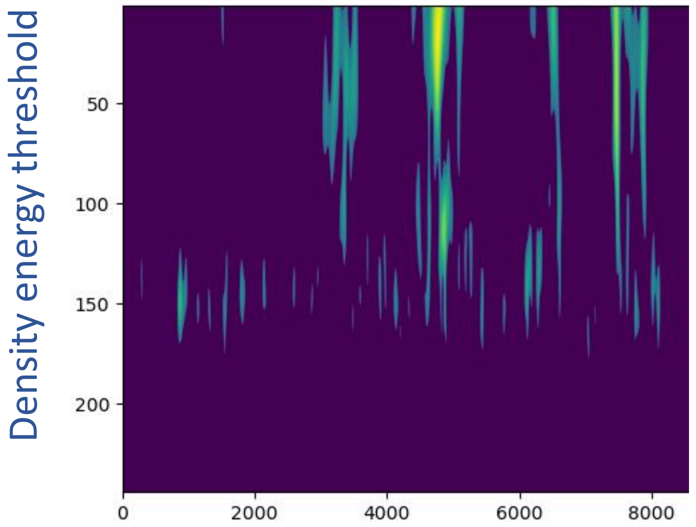


High density energy

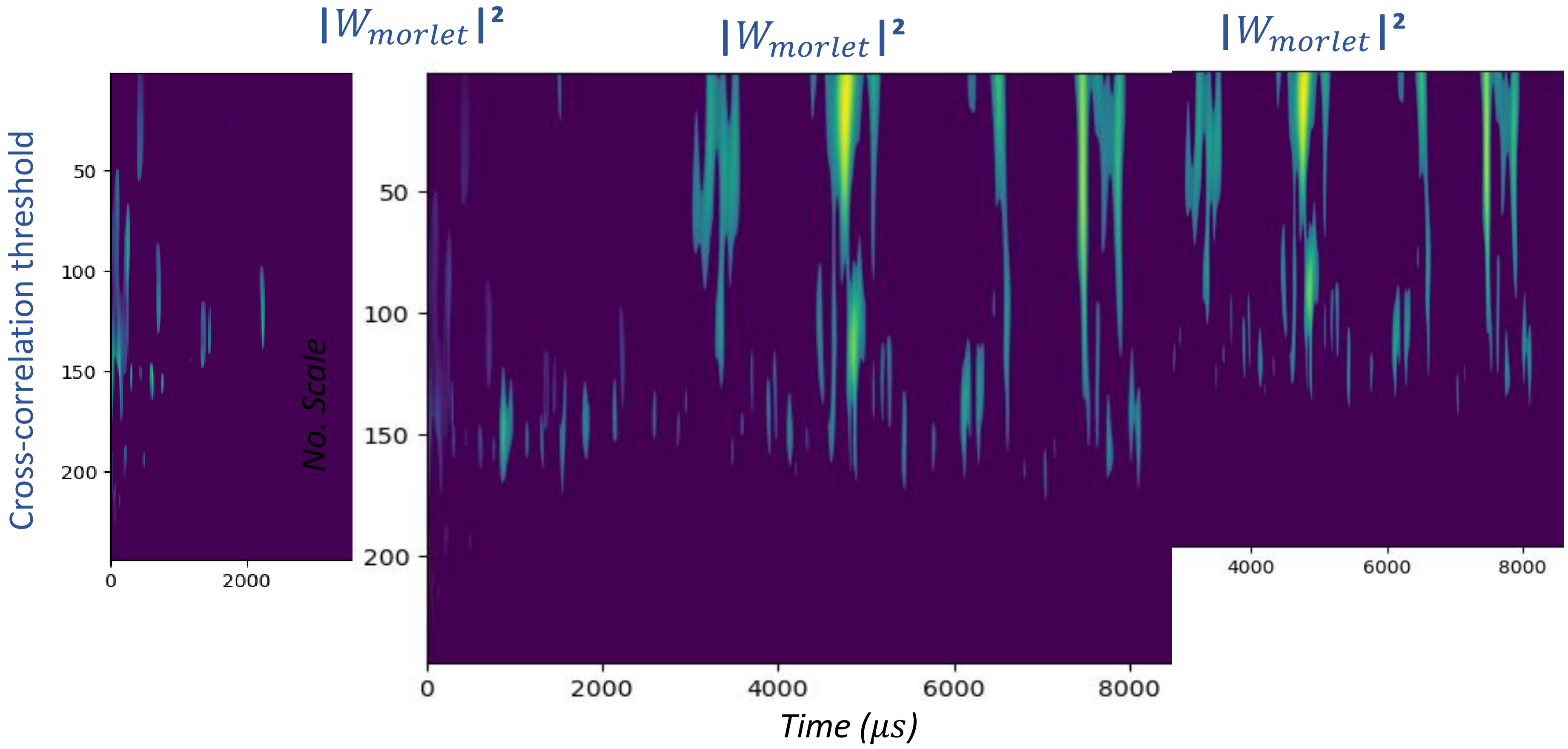
$|W_{morlet}|^2$



Kernel density estimation

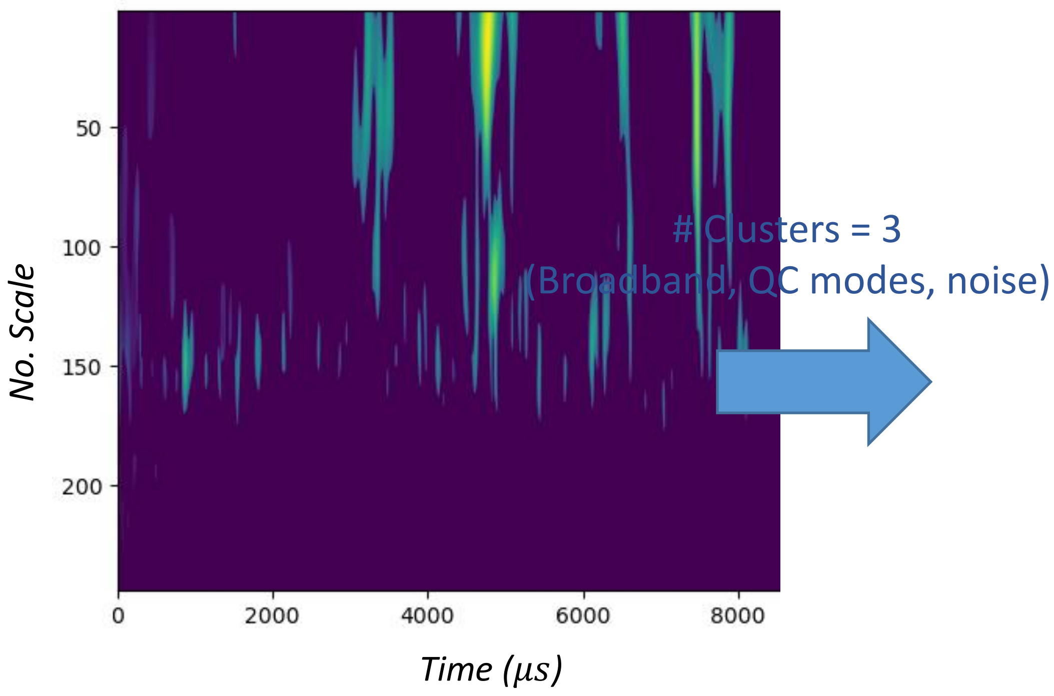


Union of patterns

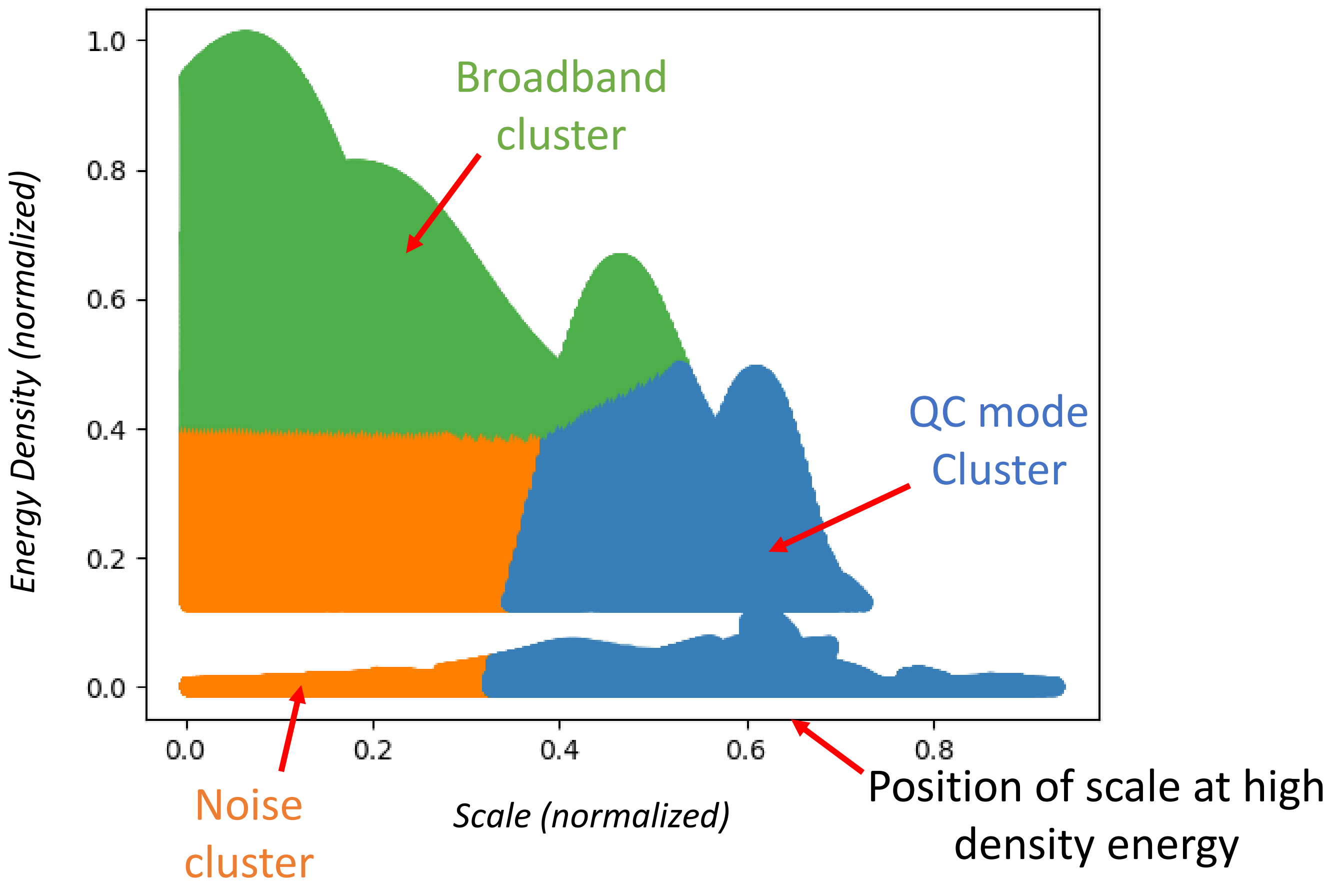


QC modes ares expected to be found in this whole pattern but how to extract them?

Machine learning approach
(Scale-Energy representation)

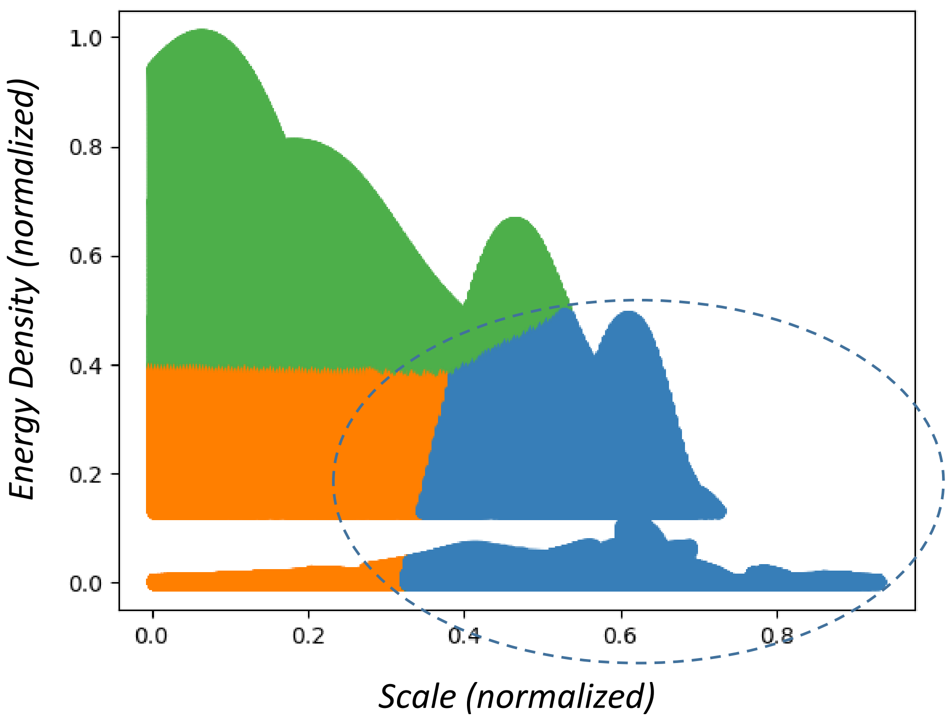


Clustering by MiniBatchKMeans

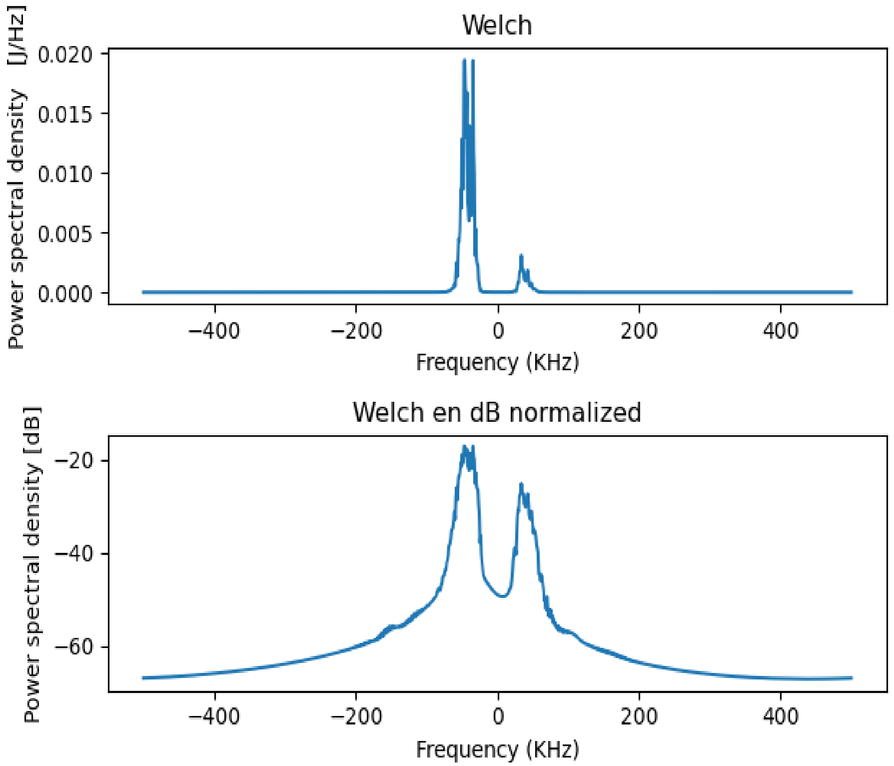


L. Salazar et al. 4th FDPVA meeting 03/12/21

Extraction of QC mode

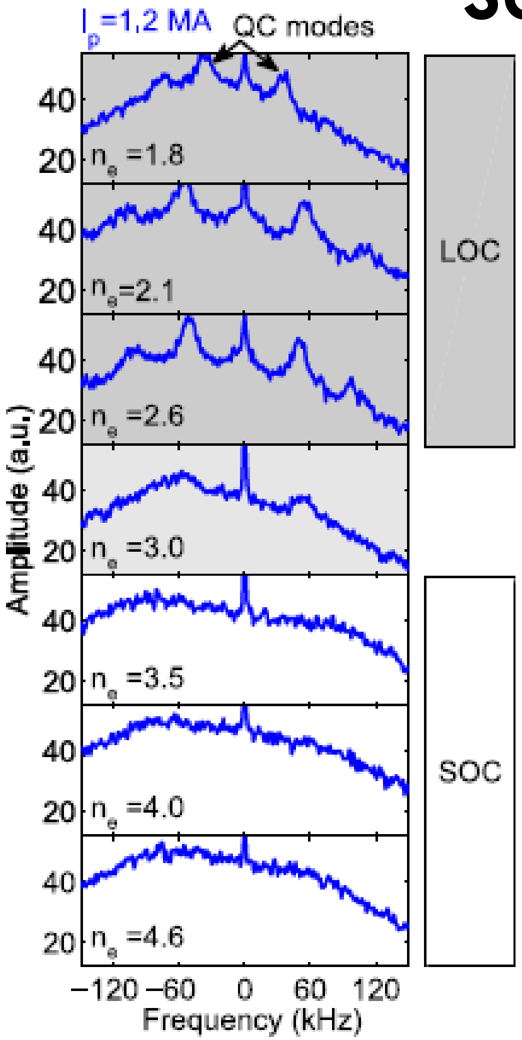


Inverse CWT

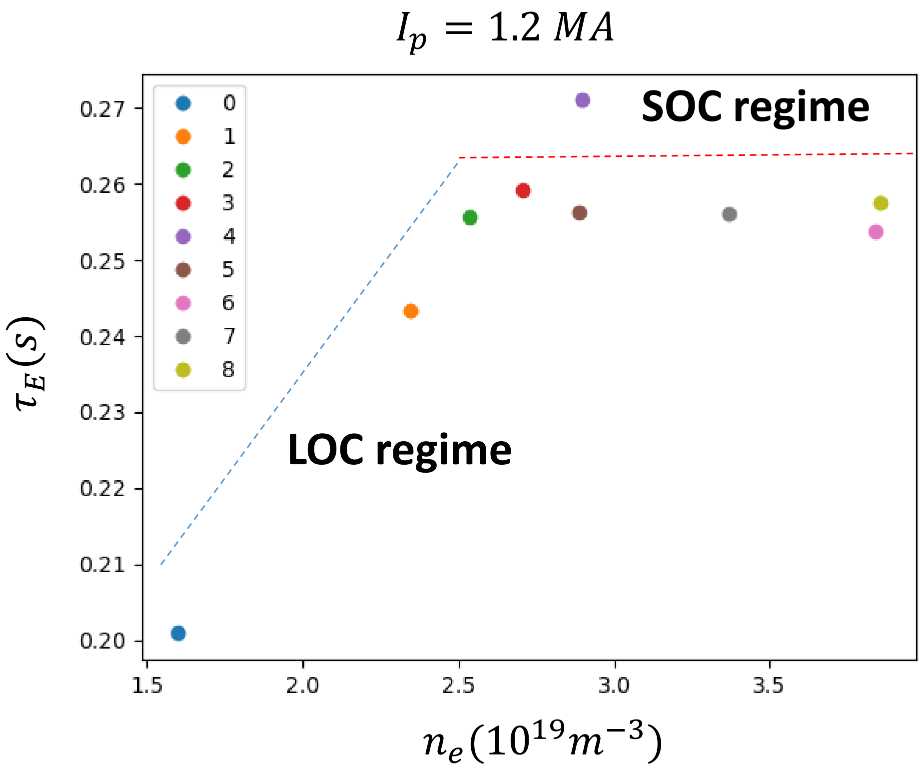


Let's apply it to a Regime change!

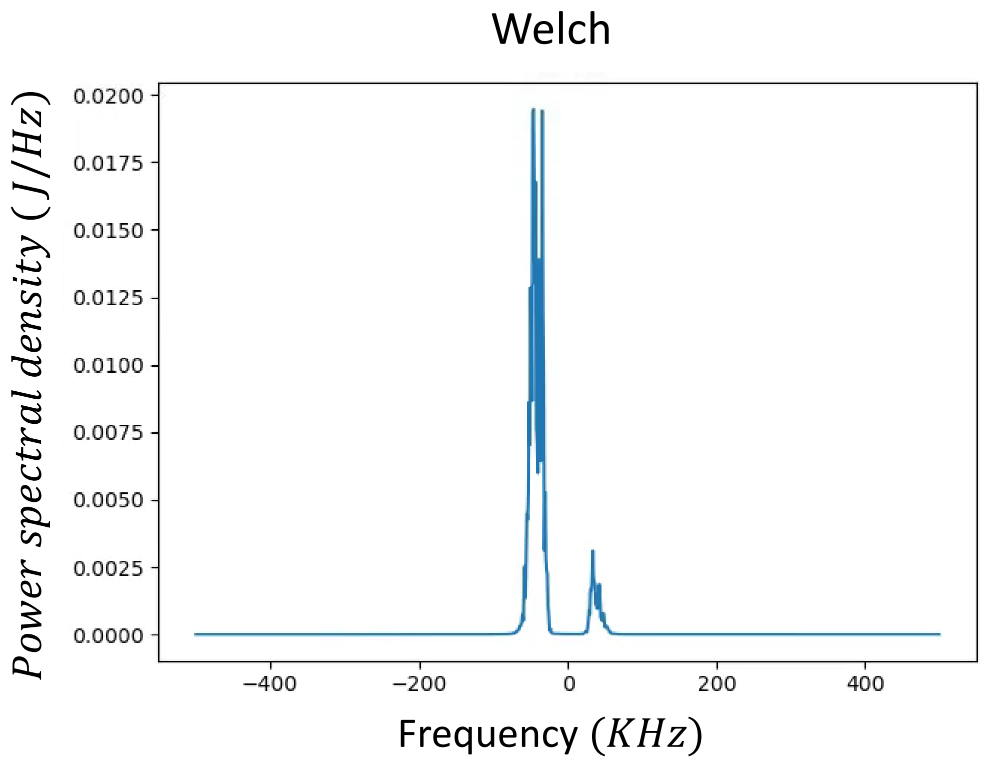
Linear Ohmic Confinement - Saturated Ohmic Confinement transition



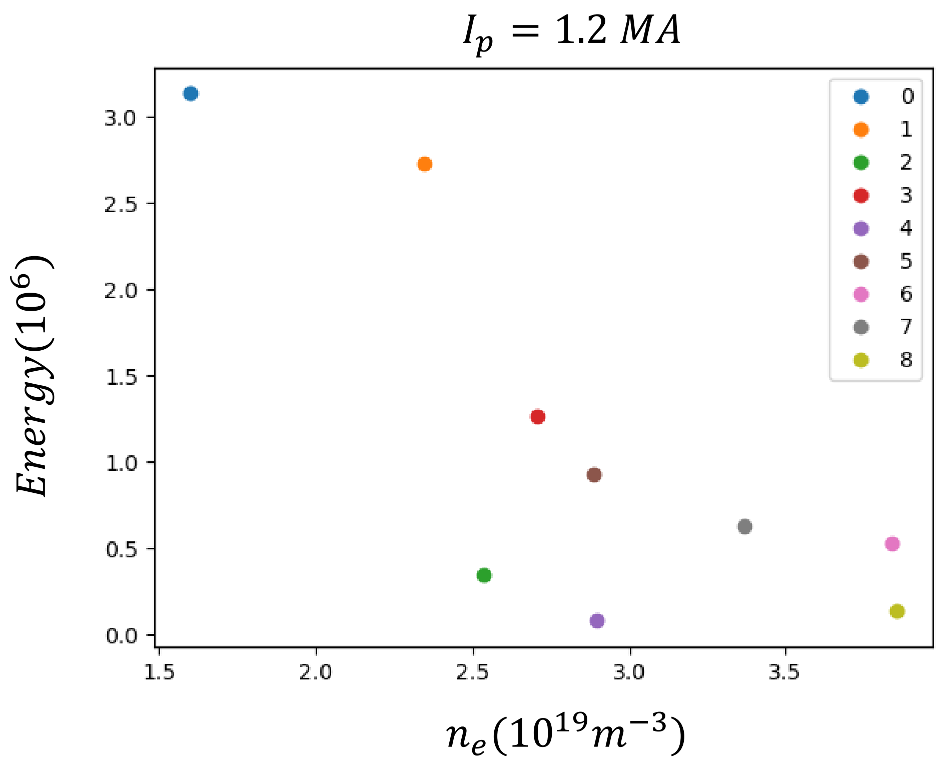
Tore Supra reflectometry spectra during a LOC-SOC transition from H. Arnichand 15



Spectrum evolution



Spectrum evolution of QC modes



Energy vs n_e

CONCLUSION

- From a single antenna a first attempt of extraction of QC-mode has been achieved.

- The energy of the QC-mode component decreases from LOC to SOC regime.

PERSPECTIVES

- Correlation reflectometry offers a way to experimentally identify the QC-mode. Apply the method to TEXTOR correlation reflectometry and make a comparison.

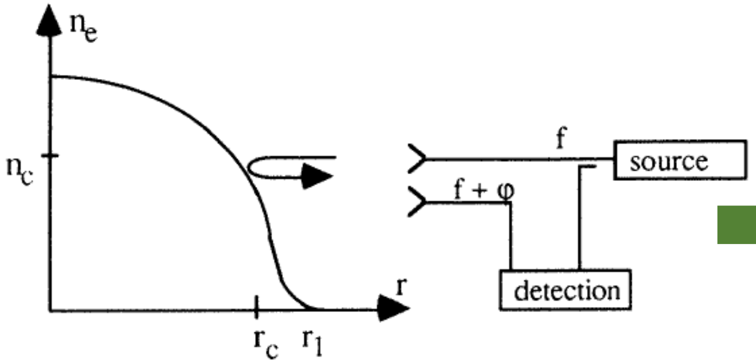
- Dynamic and energy exchange among other clusters.

- Perform statistical analysis of Tore Supra and WEST reflectometry database.

Backup

Reflectometry

Radar-like **diagnostic** sensitive to density fluctuations δn_e

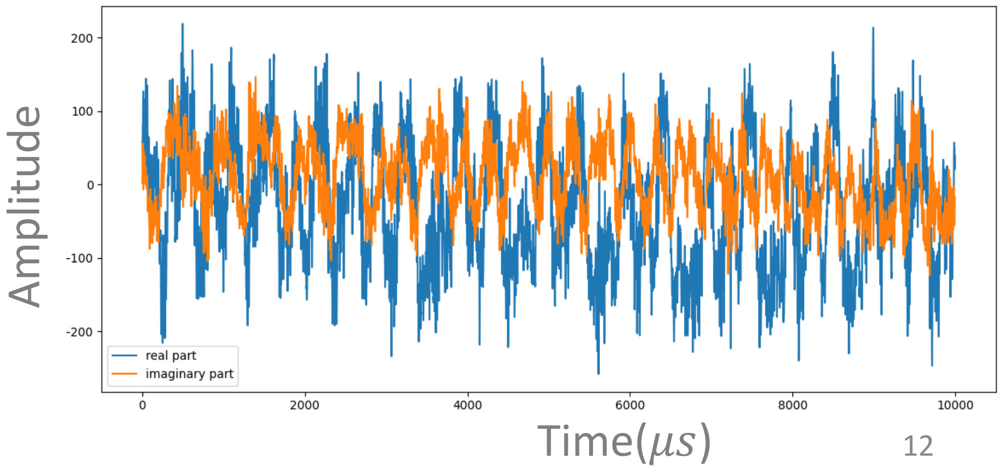


r_c : Position de la couche de coupure
r_1 : Position du bord de plasma
n_c : Densité plasma à la couche de coupure

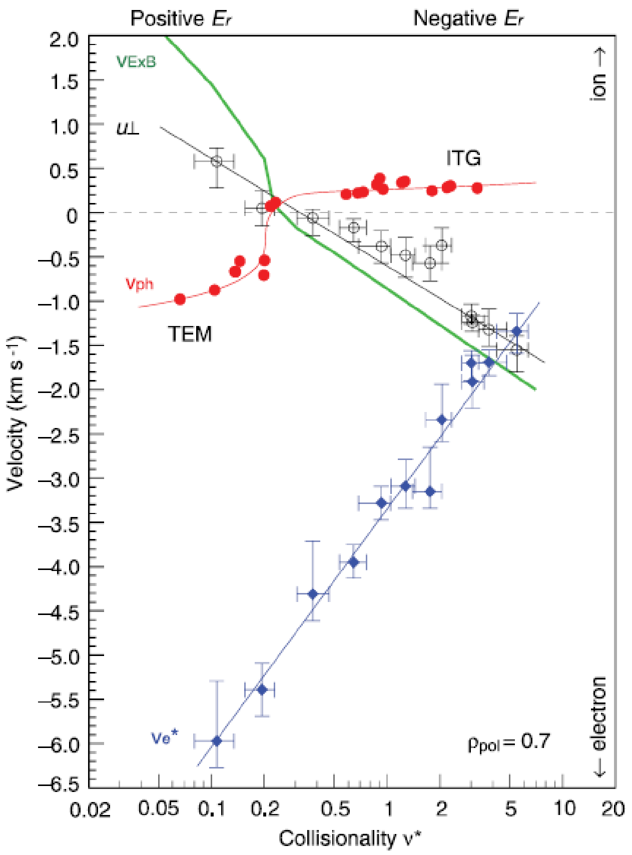
- Profile reconstruction
- **Fluctuation measurement**

Extract the raw complex signal S(t) at $f = cte$:

$$S(t) = A(t)cos(\varphi(t)) + A(t)sin(\varphi(t))i$$



LOC-SOC transition



Computed turbulence phase velocity(red dots) as function of collisionality from Conway G.D. et al 06

- Gyro-kinetic simulations suggests that the effects of sub-dominant TEMs are important in the LOC regime while ITG mode turbulence dominates with SOC.
- For a better understanding of LOC-SOC phenomenology, it is crucial to consider sub-dominant modes, as well as the interplay between TEM and ITG mode turbulence in a multi-scale approach.