Extraction of coherent structures out of Tore Supra density signals using wavelets

Romain Nguyen van yen[a], Marie Farge[a], Kai Schneider[b], Nicolas Fedorczak[c], Pascale Monier-Garbet[c], Jamie Gunn[c]

(a) LMD, ENS Paris (b) D2R2, Université de Provence (c) DRFC, CEA Cadarache

Goals

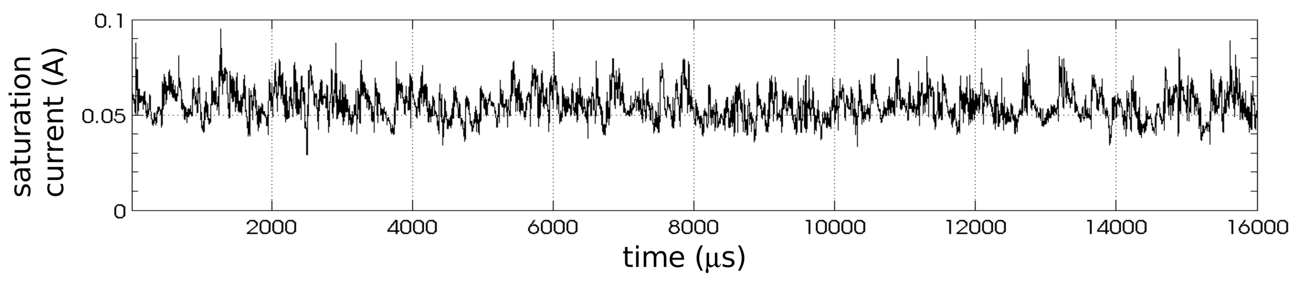
Coherent structures known as *blobs* have been described in the Scrape-Off Layer (SOL) of many tokamaks. The goals of this experimental study are :

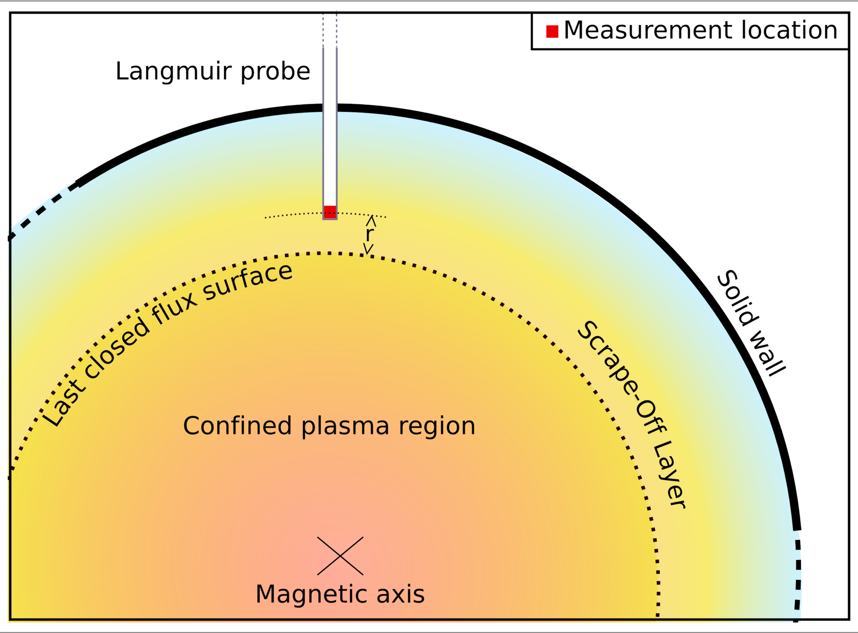
- to characterize the coherent structures, in particular because of plasma-wall interaction issues,
- to relate their properties to those of the **edge turbulence** that creates them.

Experimental measurements

CADARACHE

The ion saturation current was measured in Tore Supra by a Langmuir probe at one location in the SOL, which is a region of unconfined plasma near the edge of the tokamak torus (picture on the right). This current is proportional to the **local ion density**. The signal is sampled at 1MHz. Here, we focus on one probe position (35mm from the Last Closed Flux Surface) during 16ms (below).





A wavelet method to extract coherent structures

There is no commonly accepted definition of coherent structures.

Therefore, we rely only on the minimal hypothesis :

Coherent structures are not noise.
Extracting coherent structures thus becomes a **denoising** problem.

We work on a translation invariant complex-valued **wavelet representation**[1] of the signal. By **nonlinear thresholding** of the wavelet coefficients, we split the intensity signal in two parts :

$$I = I_C + I_I$$

coherent part (I_C): Reconstructed from the wavelet coefficients with large modulus

incoherent part (I_I): Reconstructed from the wavelet coefficients with small modulus

To select the threshold[2], we have to make hypotheses on the noise. Here, we have considered a stationary Gaussian noise. We check a posteriori that the incoherent part is indeed Gaussian (see below).

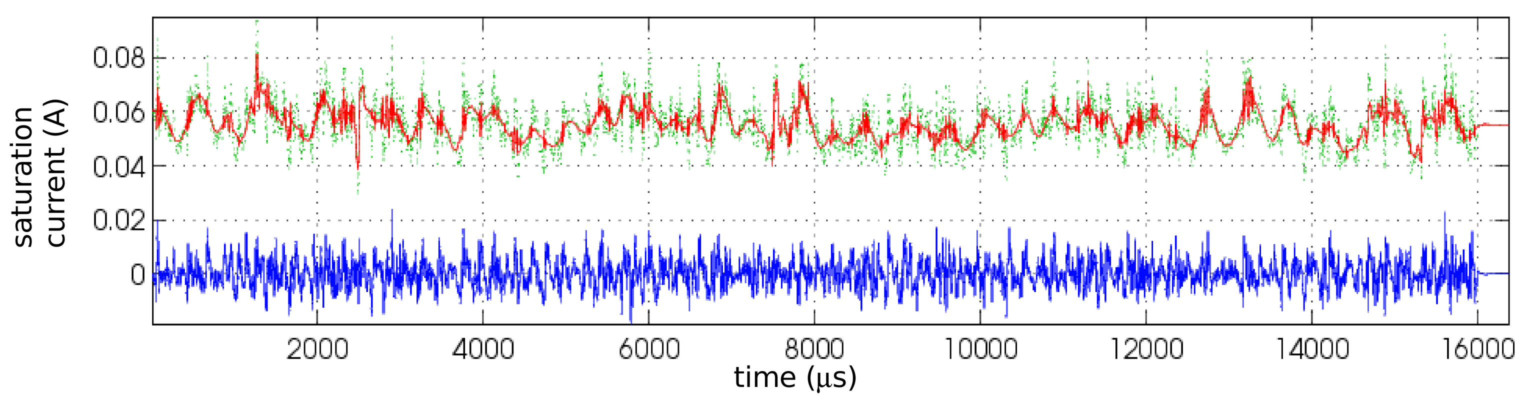
Note on the CVS method :

The approach presented here has been initially proposed[3] and studied under the name CVS (Coherent Vortex Simulation) in the context of computational fluid dynamics. During a high Reynolds number simulation, we want to keep track only of the degrees of freedom attached to the coherent structures, while the incoherent part is modeled as a noise and discarded. Therefore we are interested in the **compression rate**, that is, the percentage of wavelet coefficients that are retained in the coherent part.

[1] N. Kingsbury, *ACHA* **10** 234-253 (2001)
[2] A. Azzalini et al, *ACHA*, **18** 177-185 (2004)
[3] N. Kevlahan et al., *PoF* **11** 2187-2201 (1999)

Extraction results

The coherent part corresponds to only **3.1 %** of the wavelet coefficients. It displays remarkable temporally localized bursts. High frequency oscillations occur during most of the bursts.



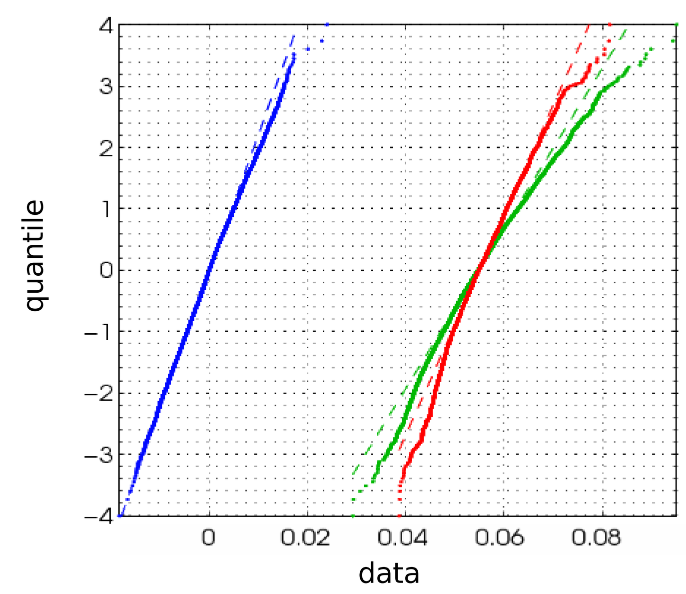
The incoherent part corresponds to **96.9 %** of the wavelet coefficients. It oscillates around zero and appears stationary. Comparison with other probe positions shows that its variance decreases like an inverse power of the distance to the confined plasma.

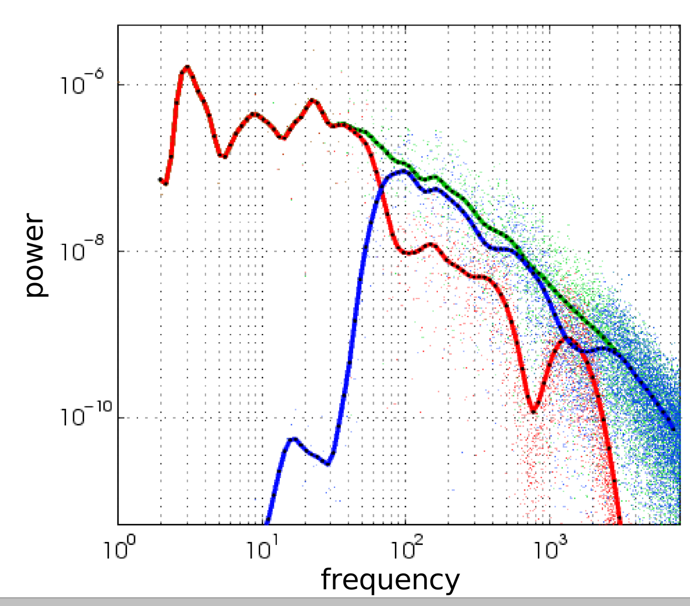
The incoherent part has the statistical properties of a **correlated Gaussian noise**

- The **skewness** of the incoherent part is greatly reduced compared to the one of the total signal. However the **flatness** remains near 3 which indicates Gaussianity.

	Total signal	Incoherent	Coherent
Skewness	0.41	0.16	0.35
Flatness	3.2	3.2	3.1

- The **Gaussian probability paper plot** of the incoherent part is close to a straight line, which demonstrates at least marginal Gaussianity (top right).
- The **spectrum** of the incoherent part closely follows the one of the total signal with a ν^{-2} decay at high frequencies. However, one can see that the coherent part contains small contributions at high frequencies up to about 70 kHz. Bottom right : the wavelet scalograms of the total, coherent and incoherent parts are shown in full line. They correspond to smoothed versions of the Fourier spectra (shown in dots).
- In the future, we would also like to quantify the **stationarity** of the incoherent part.

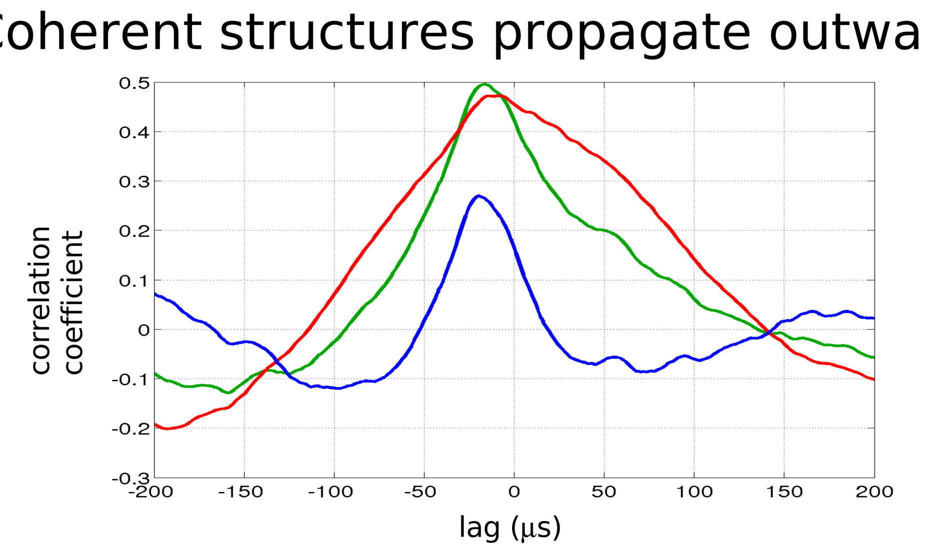




We have applied the same method to the **radial drift velocity**.

An estimate of the radial drift velocity close to the probe is estimated by subtracting two neighboring measurements of the floating potential. Because these measurements are recorded simultaneously with the saturation current, we can calculate a cross correlation function (below).

Coherent structures propagate outwards



The peak in the correlation function between the coherent parts of the density and of the radial drift velocity (above in red) demonstrates that the coherent structures propagate outwards. The correlation between the incoherent parts is much less pronounced.

Conclusion and perspectives

Our method has allowed us to extract coherent structures propagating outwards. We conjecture that they are closely related to the *blobs* that have been previously described. Our method was based on the hypothesis of a Gaussian correlated incoherent part, and we have checked it *a posteriori*.

In the future we will use these results to estimate what fraction of the radial particle flux is carried by the coherent structures, depending on the plasma parameters. Note that the procedure was applied entirely in the time domain, without requiring any kind of Taylor hypothesis. However, processing images recorded by a fast camera would certainly provide new insights, in particular concerning propagation.

Thanks to Pr. Kingsbury for his complex wavelet transform software and expertise. This work has been carried out under financial support by the CEA-Euratom agency.
Contact for this poster : R. Nguyen van yen, rnguyen@lmd.ens.fr