On the statistics of ELM filaments measured by fast low field side wall Langmuir probes on TCV

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Introduction

Previous studies [1, 2, 3] suggests that during the ELM, filaments will grow in the pedestal region and travel across the separatrix into the scrape-off layer carrying particles and heat with them. Complex filamentary or fine scale ELM structure has been observed and characterized in the scrape-off layer of the DIII-D [1], ASDEX and JET tokamaks [2]. In this contribution we report on the statistical properties of fine structures found in the ELM driven ion fluxes registered at the low field side main chamber walls of the TCV tokamak.

Measurement setup

Experiments were carried out in both ohmic heated H-mode plasmas with type III ELMs and third harmonic electron cyclotron resonance (X3) heated H-mode discharges with large ELMs. Otherwise these discharges were standard single null lower (SNL) configurations with $I_p = 420$ kA, $\bar{n}_e = 6-7 \cdot 10^{19} m^{-3}$ for ohmic discharges and $I_p = -350$ kA, $\bar{n}_e = 4-5 \cdot 10^{19} m^{-3}$ for X3 heated shots. The principal diagnostic tool was the array of 19 single tip Langmuir probes displaced by 11 mm and embedded in the graphite made first wall tiles of the TCV vessel. These probes have been located at outer midplane of $z = +25cm$ equilibrium configuration, in three groups slightly displaced toroidally as it is seen in Fig. 1. Ion saturation current signals have been acquired at 125 kHz and 200 kHz rates for type-III and large ELMs respectively.

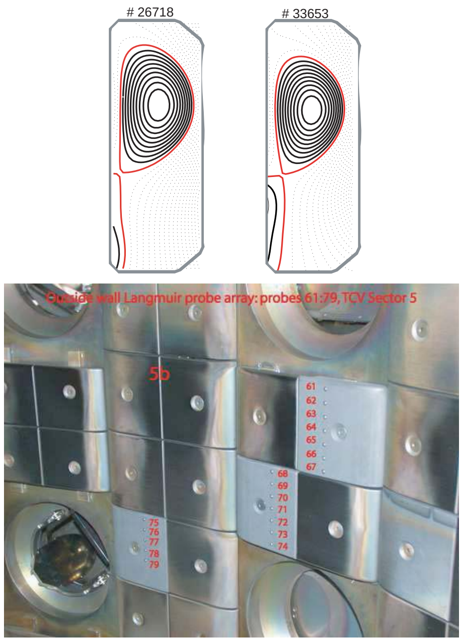

Figure 1: Tile embaded Langmuir probes at the LFS wall of the TCV.

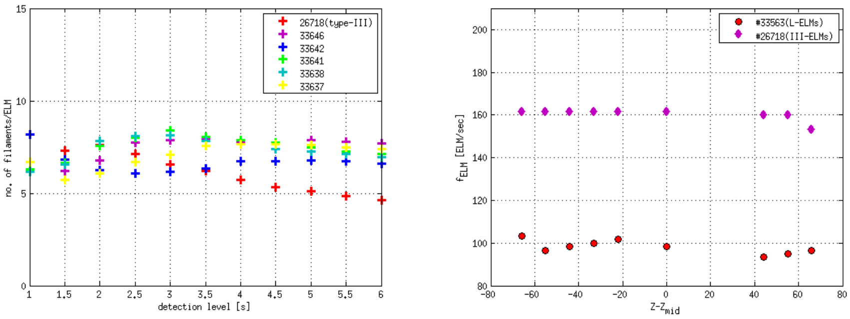

Figure 3: (left) average number of ELM substructures detected, as a function of the detection level for both type-III ELMs (# 26718) and for large ELMs (the others). (right) ELM frequency it is shown as a function of the distance in z-direction from the midplane.

Threshold based event detection

Using fast Langmuir probes at the wall, temporal fine structure of the ELMs can be observed. Raw signals show clear substructures or fluctuations during the ELM events (see Fig. 2). The question we would like to address is whether the observed ELM substructures are caused by the individual filaments, originating from the pedestal region and propagating into the scrape-off layer until reaching the outer midplane wall, or they could be explained as an enhancement of the 'normal' scrape-off layer turbulence by the propagating hot and dense plasma front caused by an ELM event. In order to investigate this question it is needed the use of an event detection based statistical analysis. First a threshold level has to be defined at e.g. 2.5 times the standard deviation of the whole I_{sat} signal, then at all the time points where the signal sits above this level we put ones and where the signal is below this level we put zeros. This way a new time record called a mask it is obtained. Using these masks we can easily get parameters such as the ELM frequency, the number of substructures per ELM etc (see Fig. 3).

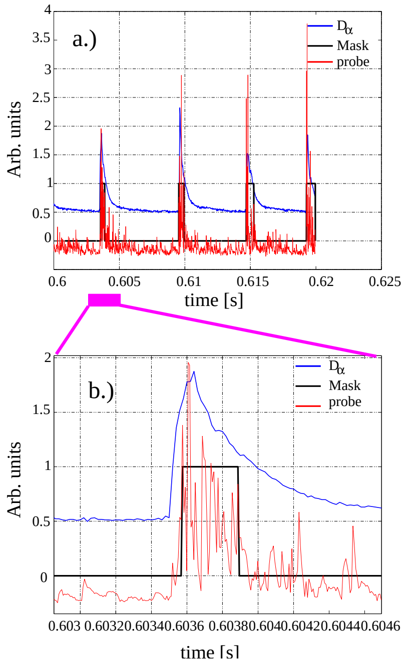

Figure 2: Masks.

From the plots of Fig. 3 it is clear when we take just the largest substructures, taking higher threshold level, the number of substructures is smaller for type-III ELMs. This could be caused by the larger RMS amplitudes of substructures in large ELMs. As the difference of the number of detected substructures during the two different types of ELMs can be as large as 40 % and at the same time the difference in the duration of ELM events is about 500 % (for type-III is $\sim$ 1ms and for large ELMs is about 5ms), we can conclude that the arrival of substructures at the wall for type-III ELMs should be more frequent as for large ELMs.

Comparison of ELM and inter-ELM fluctuations

In order to statistically characterize the nature of ELM substructures one may treats those as fluctuations on the top of a mean value defined by an envelope of the raw signal. This can be done using an appropriate digital filter such as the Savitzky-Golay filter. Figure 4 gives an example of the smoothing process comparing the result of a simple moving average and the Savitzky-Golay filter. From the amplitude changes of the fluctuating signal in Fig. 4, one can identify three time periods: the ELM part with large fluctuations and a very rich fine structures, the so called 'trailing wake' with still enhanced fluctuation activity and finally the inter-ELM period behaving as 'normal' SOL turbulence. The main aim of this contribution is to compaire different statistical properties of these characteristic time periods of the ELM event.

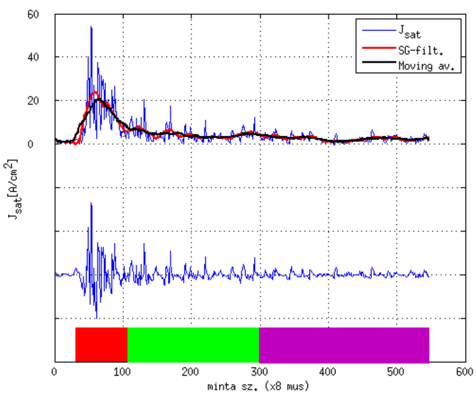

Figure 4: Substraction of the ELM envelope using Savitzky-Golay filtration and deviding.

Comparing different statistical processes we have to compaire:

- amplitude distributions (rescaled PDFs)
- relevant time scales of fluctuations (autopower spectra, autocorrelation function, conditional average)
- relevant spatial scales of fluctuations (spatial cross-correlation functions)

In many cases when we have different random time records, taking just the first two moments of their PDFs we can get very different values. In this case it is usfull to rescale the original amplitude distribution function. Let us suppose that we have a random process represented by a time series $x(t)$, the amplitude distribution function is $PDF_0(x)$.

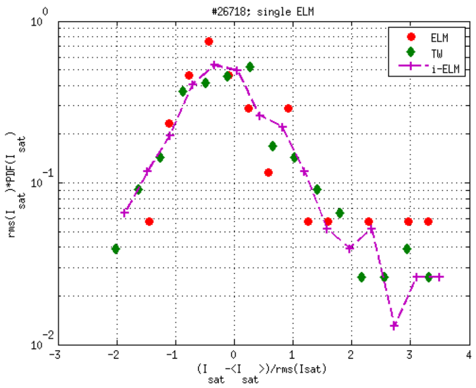

Figure 5: Rescaled PDFs.

The rescaled PDF is defined as: $PDF_r(x- < x >) = \sigma \cdot PDF_0$, where $< x >= \frac{1}{n}\sum_{i=1}^{n} x(t_i)$ the mean value, and $\sigma^2 =< (x- < x >)^2 >$ the variance. Figure 5 shows in terms of rescaled PDFs the amplitude distributions of fluctuating part of ion saturation current at the midplane for different stages of ELM event evolution. In all cases the PDFs look very similar suggesting that the statistical process behind does not differ for the inter-ELM fluctuations and the fluctuations in the ELM. For comparison of the time scales we have many possibilities, Fig. 6 shows two of them.

Fourier spectrum of the fluctuations for an ensamble of about 40 ELMs can be seen in the top plot of Fig. 6, the power stored by the different frequency components decrease starting from the the large amplitude part (in red) to the low amplitude, inter-ELM part (in black). Another possibilities is shown in the bottom plot of the Fig. 6, called conditional average where, besides giving the relevant time scale $(10-20\mu s)$ of fluctuating structures, also gives the temporal shape of the 'blob'-like events. These temporal features also suggest the statistical sameness (identity) of fluctuations seen in different periods of the ELM evolution at the TCV wall.

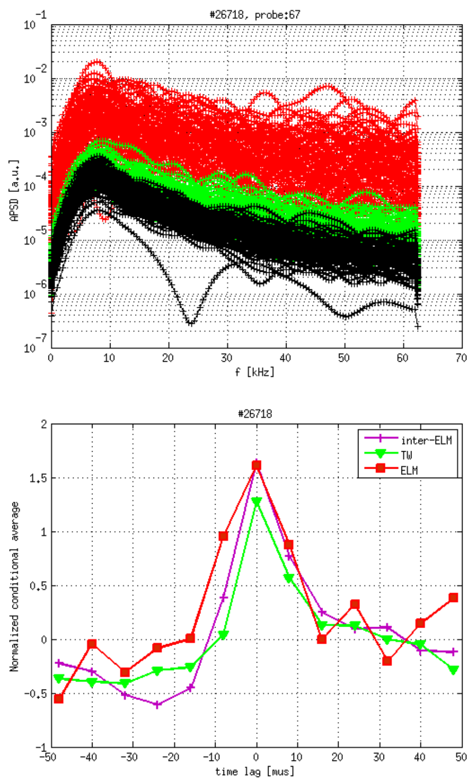

Figure 6: Statistical characterization of fluctuations of different ELM phases (see Fig 4).

Conclusions

The statistical analysis presented above has been performed for large ELMs as well. The result (not presented in this short contribution) shows the same similarity of fluctuations belonging to different time periods. All of these results show that the fluctuations inside the ELMs (ELM substructures) follow the same statistics as the inter-ELM turbulent structures (blobs). This strongly suggest that the fine structure of an ELM mesured at a given spatial position at the tokamak wall originates from the enahncement of the background SOL turbulence rather than from the so called ELM filaments originating from the pedestal region.

References

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