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

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Introduction

A number of studies [1, 2, 3, 4] suggest that during an ELM event, 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 [2] , ASDEX and JET tokamaks [3]. 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 are performed 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. Both discharge types are standard single null lower (SNL) configurations with $I_p = 420$ kA, $\overline{n}_e = 6-7\cdot 10^{19} m^{-3}$ for ohmic discharges and $I_p = -350$ kA, $\overline{n}_e = 4-5\cdot 10^{19} m^{-3}$ for X3 heated shots (see Fig. 1). The principal diagnostic tool is a poloidal array of 19 single tip, domed graphite Langmuir probes displaced by 11 mm and embedded in three of the TCV low field side wall protection tiles. As shown in Fig. 1 these three tiles are distributed about the plasma midplane and slightly displaced toroidally (at a vertical height of $z \approx 25cm$). Ion saturation current signals have been acquired at 125 kHz and 200 kHz for type-III and large ELMs respectively.

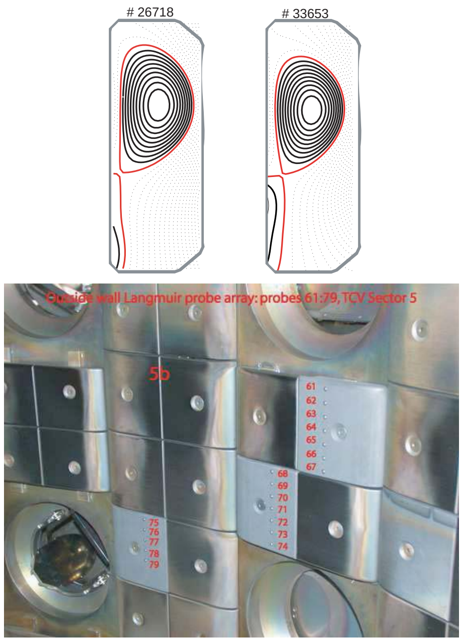

Figure 1: Tile embedded Langmuir probes on the TCV LFS wall.

Threshold based event detection

The ion particle flux intercepted by the wall probes displays an extremely rich fine structure at every ELM, the intensity of which depends sensitively on the poloidal location of the probe with respect to the point of closest approach to the midplane plasma. The aim of this short contribution is to address the question of whether this substructure can be characterised by the same turbulent character as that seen in the inter-ELM or L-mode background plasma. The latter has been extensively characterised in studies on TCV using a midplane reciprocating probe [5]. If not, then one implication would be that the substructure is a chain of events constituting a single ELM and corresponding to multiple release of events in the pedestal or near SOL region. The first step in such a statistical investigation is to establish an event detection technique by which to isolate the structures. This is performed simply by defining a threshold level, fixed here at $2.5 \cdot \sigma$, where σ is the standard deviation of the whole j_{sat} signal. By assigning a binary value to all events above and below this threshold, a new time record (a "mask") is obtained. Using this mask, it is trivial to derive a series of important parameters such as ELM frequency, number of substructures per ELM etc. An example of the application of this process is shown in Fig. 2).

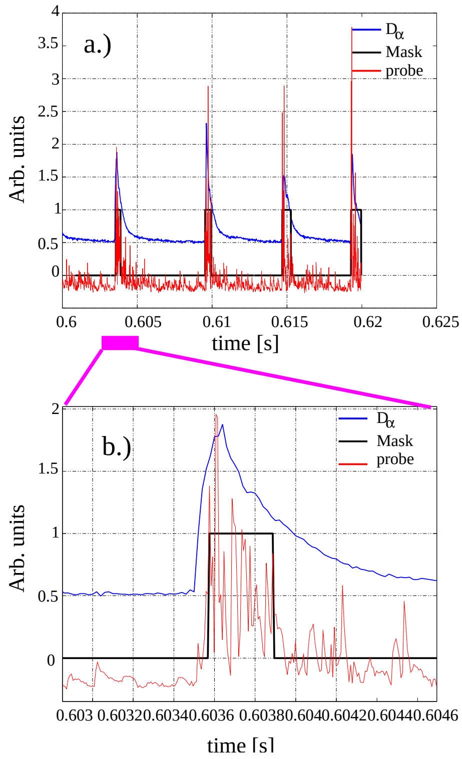

Figure 2: (a): I_{sat} raw signal measured at the midplane (red) and the D_α signal (blue). The masks resuled from $2.5x$ rms detection level are shown in black. (b): enlarged view.

For both Type III and large ELMs, Fig. 3 shows the number of detected filaments per ELM as a function of the threshold level. When one takes the largest substructures only, i.e. a high threshold level, the number of substructures is less for type-III ELMs (the difference is about 40 %). Since the duration of the large ELMs is five times the duration of the type-III, the 40 % in the number of substructures can only be explained by assuming a lower arrival rate for large ELMs.

Comparison of ELM and inter-ELM fluctuations

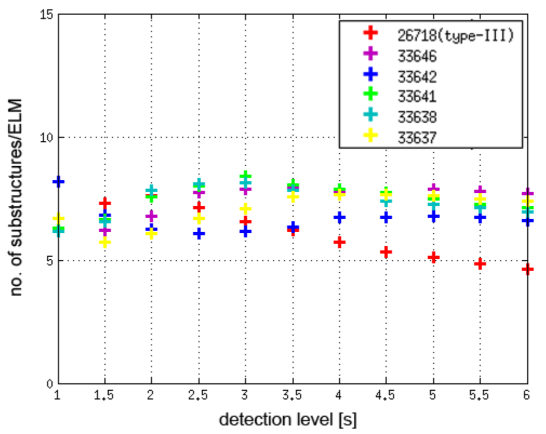

Figure 3: Average number of ELM substructures detected, as a function of the detection level for both type-III ELMs (# 26718) and for large ELMs (the others).

Results in this section are presented for type-III ELMs, but the same calculations and comparisons were performed for large ELMs and exactly the same features have been found. In order to statistically characterize the nature of ELM substructures they must be treated as fluctuations on 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 illustrates this smoothing process in comparison with the result of a simple moving average. From the amplitude changes of the fluctuating signal in Fig. 4, three time periods can be identified: the ELM part with large fluctuations and a very rich fine structures, the so called 'trailing wake' during which the fluctuations are still enhanced over background and finally the inter-ELM period behaving as 'normal' SOL turbulence.

The statistical properties of the J_{sat} time series in the different phases of the ELM are compared for a single probe near the outboard midplane in terms of amplitude distribution (rescaled PDF) and the relevant timescales of the fluctuations (autopower spectra, autocorrelation function).

A rescaled PDF can be used to compare amplitude distributions across the different ELM phases. This is defined here as:

$$PDF_r(x - \langle x \rangle) = \sigma \cdot PDF_0,$$

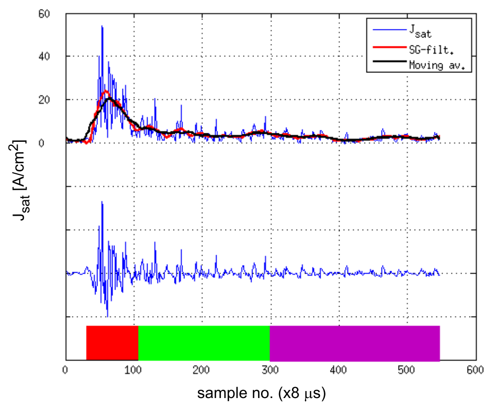

Figure 4: Subtraction of the ELM envelope using Savitzky-Golay filtering.

where

$$\langle x \rangle = \frac{1}{n}\sum_{i=1}^{n} x(t_i), \quad \text{and} \quad \sigma^2 = \langle (x - \langle x \rangle)^2 \rangle .$$

The PDFs from the various ELM phases shown in Fig. 5a show clearly that the amplitude distribution of fluctuations is invariant across the three phases. The inter-ELM turbulence has

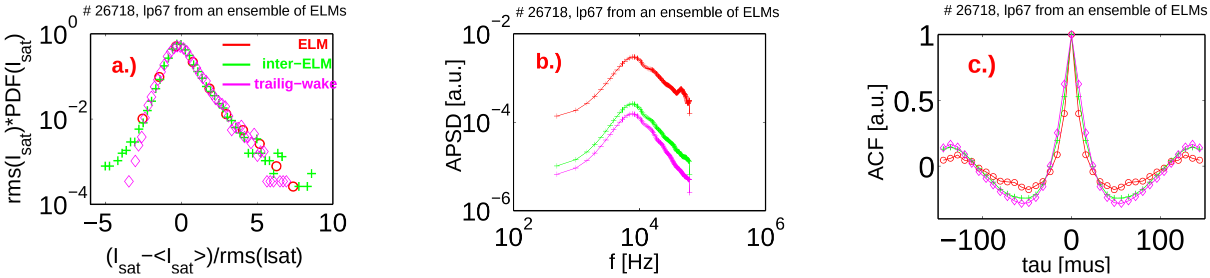

Figure 5: Statistical characterisation and comparison of fluctuations of different ELM phases (see Fig 4).

the same statistical character as the substructure during the ELM itself.

Figure 5b compiles the Fourier spectra of the same ELM ensemble as for Fig. 5a for the 3 phases during the ELM. Although the power stored in the different frequency components decreases for the larger amplitude events (substructure) to the smaller turbulence in the wake and inter-ELM phases, the overall shape of the autopower spectra remain the same. In Fig. 5c, the autocorrelation functions (ACF) again suggest statistical similarity of the timescales of the fluctuations in each phase of the ELM, indicating typical timescales of 10-30μs.

Conclusions

The analysis presented here demonstrates that the structure seen inside ELM bursts arriving at the low field side walls of TCV is statistically indistinguishable from that found in the inter-ELM phases. Separate studies, (not discussed here) also show that the turbulent character is very similar to that seen in L-mode turbulence at the wall radius. The substructure found in individual ELM filaments at the wall is therefore the same in character as the ubiquitous "blobby" transport in the ELM-free or L-mode far SOL.

References

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