*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-2.155 (2006)*

Multiscale analysis of the edge plasma turbulence in TEXTOR : some preliminary results using the reciprocating probe.

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Understanding turbulence properties in plasmas is a key issue to understand anomalous transport. It is well known that the turbulence signals in fusion devices can depart from pure self-similarity, as reported in recent papers [1, 2, 3]. In order to gain further insight into the multiscale properties of the plasma turbulence, in this work, we used two different methods to analyze the fluctuation data recorded at the boundary of the TEXTOR tokamak before and during the 3/1 mode Dynamic Ergodic Divertor (DED) operation [4, 5]. First we computed the probability distribution function (PDF) of fluctuations at different temporal scales transformed via wavelet analysis then we looked at the multifractal spectrum by calculating the Hölder exponent.

The experimental data were taken in ohmic discharges on TEXTOR with typical parameters of $R/a \cong 1.75/0.48m, I_p = 250\,kA, B_T = 1.9\,T$, and line averaged density $\langle n_e \rangle = (1.5 - 2.0) \times 10^{19}\,m^{-3}$ [5]. The 3/1 DED was operated by applying a DC DED current of 2.5 kA in the stationary phase of the ohmic shot. The fluctuation data, digitized at 500 kHz, were measured by a fast reciprocating Langmuir probe plunged twice into the plasma during one discharge: one plunge before and the other during the DED phase, from the outer midplane of the machine. In this study, we mainly analyzed the multifractality of the ion saturation current (I_{sat}), which is assumed to be proportional to the density, and then compared its features before and during the DED phases.

With DED, a strong enhancement of intermittent behaviour is observed in the I_{sat} signals detected in the scrape-off layer (SOL), as illustrated in Fig. 1(a), where the raw data of I_{sat} displays a lot of large positive bursts.

This increase of the intermittency and thus non-Gaussianity from the ohmic to the DED phase can be further confirmed by the quantitative computation of the skewness ($S = \langle \Delta^3 \rangle / \langle \Delta^2 \rangle^{3/2}$) and kurtosis ($K = \langle \Delta^4 \rangle / \langle \Delta^2 \rangle^2$) of the signal, where $\Delta = I_{sat} - \langle I_{sat} \rangle$, and the brackets $\langle \cdot \rangle$ design the average. The radial dependence of S and K before (in black) and during (in red) the DED are plotted in Figs. 1(b) and (c), respectively. From the figures, it is clearly seen that with DED both S and K are largely enhanced in the SOL and deviate much from the Gaussian value, for which $S = 0$ and $K = 3$. We therefore mainly concentrated our analysis on the data detected in this region to compare the different multiscale properties of $\mathrm{I_{sat}}$ before and during the DED.

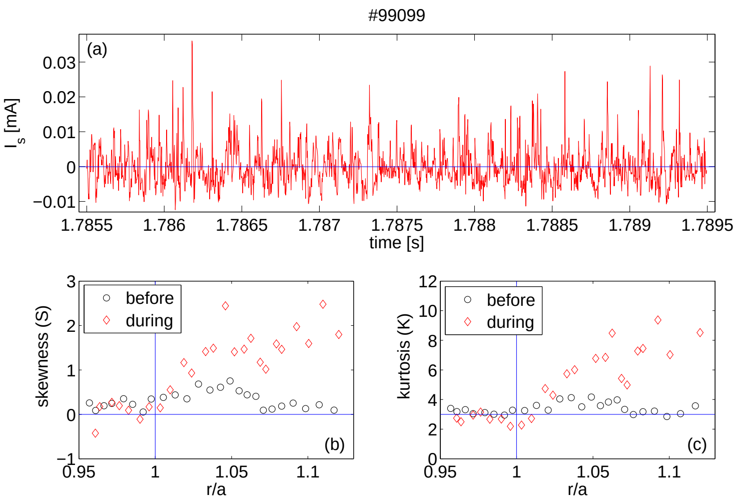

Figure 1: *(a) Time trace of I_{sat} detected by a Langmuir probe during the DED phase at $r \approx 50$ cm. Shown in (b) and (c) are the radial profiles of skewness and kurtosis of I_{sat} measured before (in black) and during (in red) the DED.*

First, we analyzed the self-similar features of the fluctuation data at various scales using the wavelet transform [6] $C(s,\tau) = \frac{1}{\sqrt{s}}\int_{-\infty}^{+\infty} \mathrm{I_{sat}}(t)\,\overline{\Psi\left(\frac{t-\tau}{s}\right)}\,dt$, where $\Psi(t) = \frac{d^8}{dt^8}\exp\left(-t^2/2\right)$, the 8-th derivative of the Gaussian, is chosen for its good time-scale localization and its blindness to polynomial trends up to degree 8. This allows us to obtain the decomposition of the signal at the scale s as a function of the time delay τ. Thus, we can establish the PDF of the signal, $\Pi_s(\tau)$, at different time scales. For each radial position, the data analyzed are taken from a time window of 2200 points ($\sim$4.4ms) measured by the fast probe.

After looking at the $\Pi_s(\tau)$ at different s, ranged roughly from 4 to 120 μs, it is generally found that in the ohmic discharge before DED the PDFs are quite similar at all scales and very close to Gaussian, suggesting a scale-invariance or self-similarity of the turbulent data. However, during the DED the PDFs deviate from Gaussianity at fine time scales (normally $< 40\mu s$) while at large scale they remain rather Gaus-

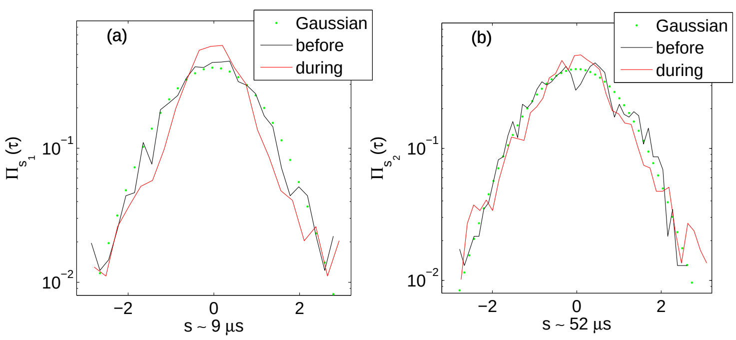

Figure 2: *Semi-log plot of the PDFs of the signal measured in the SOL (r/a =1.1) for two different scales, normalized at mean 0, and variance 1. (a) $s_1 = 9\mu s$ and (b) $s_2 = 52\mu s$ before (in black) and during (in red) the DED. The dotted points indicate the best Gaussian fit.*

sian. The $\mathrm{I_{sat}}$ signal therefore has lost its self-similarity. As an example, the typical $\Pi_s(\tau)$ at two scales ($s_1 = 9\mu s$ and $s_2 = 52\mu s$) are shown in Fig. 2 for the $\mathrm{I_{sat}}$ measured in the SOL before (in black) and during (in red) the DED. These results indicate that the departure of self-similarity is indeed attributed to the small scale non-Gaussian behaviour due to intermittent bursts occurring at short time intervals in the turbulence phenomena, as seen in Fig. 1(a).

By calculating S and K from the $\Pi_s(\tau)$, we obtain the skewness and kurtosis at each scale, s. In Fig 3, the skewness and kurtosis are drawn as a function of the scale. To have a good illustration, the S and K values are averaged over all radii in the SOL. Several features can be seen: (i) before DED (black curves), both S and K are close to the Gaussian ($S = 0$ and $K = 3$); (ii) with DED (red curves), the S and K are much higher than before, especially at small s, confirming that self-similarity is broken at small scale; (iii) in the curves of S before DED and K before/during the DED phases, a sharp change appears in the values of S and K at time scale around $40\mu s$. On the left side, from the smallest scales until $\sim 40\mu s$, the skewness and kurtosis are rather high while on the right side their values are much lower. This implies that a critical scale around $40\mu s$ plays an important role in determining the multiscale behaviour of the present turbulence data. This scale, indeed, is compatible with the lifetime of intermittent bursts, as reported in [7]. This again verifies the importance of intermittency for the deviation of Gaussianity of the data.

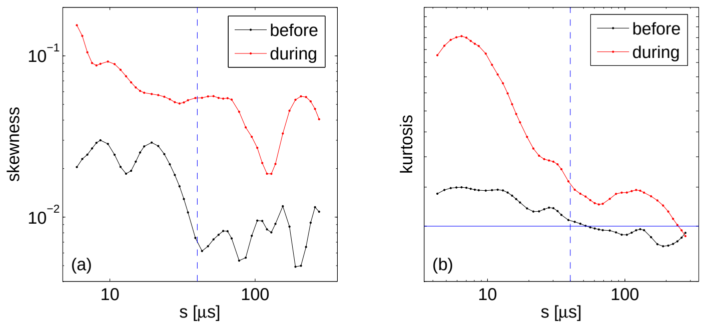

Figure 3: *Log-log plot of (a) skewness and (b) kurtosis as a function of the scale. The S and K values in the plots are averaged over all radii in the SOL. The dashed lines mark the time scales around* $40\mu s$.

The multifractal behaviour of plasma turbulence can be further illustrated by analyzing the Hölder exponent, computed for small scales, on the basis of the wavelet method [2]. The Hölder exponent at time t is defined as $h(t) = \lim_{s\to 0} \sup\left(\log|\mathrm{I_{sat}}(t+s) - \mathrm{I_{sat}}(t)|/\log|s|\right)$. The multifractal spectrum can also be understood as the PDF of the Hölder exponent, i. e., the wider the spectrum, the less self-similar the signal. This information is extracted by fitting a parabola $d(h) = ah^2 + bh + c$ to the spectrum. We then calculated the coefficient $W_d = -1/a$, where W_d is a measure of the width of the spectrum.

The radial profiles of W_d before (in black) and during (in red) the DED are plotted in Fig. 4(a), which again shows that the multifractality is enhanced during the DED period as W_d is increased, in particular, in the far SOL (r/a>1.08).

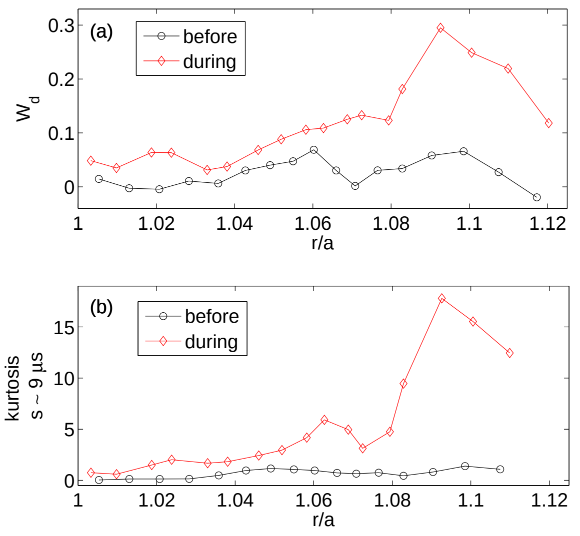

Figure 4: *The radial profiles of (a)* W_d *and (b) small scale kurtosis (*$s = 9\mu s$*) calculated from the PDF of* $\Pi_s(\tau)$ *before (in black) and during (in red) the DED.*

For comparison, we also plotted in Fig. 4 (b) the radial profiles of the small scale kurtosis ($s = 9\mu s$) calculated from the PDF $\Pi_s(\tau)$ before (in black) and during (in red) the DED. The results are very similar.

In conclusion, in this work, we carried out the multiscale analysis of I_{sat} before and during 3/1 mode operation of the DED on TEXTOR. The analysis of the PDFs at different scales using a wavelet transform, together with the calculation of the multifractal spectrum of the Hölder exponents have confirmed that the source of the non-Gaussianity of the data is mainly due to intermittency, present at small scale and is consistent with previous observations [1, 2, 3]. A transition scale of about $40\mu s$ has been suggested, separating small scales with non-Gaussian and large scales with Gaussian distributions. This analysis further confirmed the enhancement of the intermittent character of the I_{sat} during the 3/1 DED operation.

The authors thank Drs. M. Lehnen and R. Jaspers for help and discussions. The first author would also like to thank Dr. B. Lashermes for fruitful discussion about the multifractal tools.

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