SCRAPE-OFF LAYER INTERMITTENCY IN THE CASTOR TOKAMAK

M.V.A.P. Heller, Z.A. Brasilio, I.L. Caldas, J. Stöckel[1] and J. Petržílka[2]

Institute of Physics, University of São Paulo,
C. P. 66318, 05315-970 São Paulo, SP, Brazil

[1]*Institute of Plasma Physics, Prague, Czech Republic*

[2]*Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic*

Abstract

We applied conditional and wavelet analyses to identify coherent structures in the non-Gaussian intermittent electrostatic fluctuations in the scrape-off layer at CASTOR tokamak.

1. Introduction

Turbulent electrostatic fluctuations are measured systematically with poloidal arrays of Langmuir probes in CASTOR tokamak. The Probability Density Functions (PDF) of the observed turbulence deviates from the Gaussian behavior [1]. These features show the existence of intermittency with formation and destruction of coherent structures. Here, we applied the following statistical techniques to obtain information about intermittency, coherent structures, and their nonlinear interactions at the scrape-off layer of this tokamak.

- **Conditional averaging technique** [2] follows the statistical evolution of selected conditions in the measured fluctuations. If a strongly coherent component exists in the fluctuation, this component should exhibit correlation lengths and lifetimes significantly larger than most of the fluctuation levels examined.

- **Wavelet technique** resolves short-lived events, pulses, and intermittency. Definitions of cross-spectrum and cross-coherence with wavelets are analogous to the usual definitions of Fourier analysis. The coherence spectrum provides the correlation evolution between two time series at a particular frequency band [3].

- **Bicoherence technique** detects phase coupling between short lived wavelets rather than between modes as Fourier bicoherence [4-6].

2. Results and Discussion

Here we analyze data measured by two arrays (ten tips spaced poloidally by 5 mm) of Langmuir probes, which are spaced toroidally by 10.5 mm. The first array measures the ion saturation current (I_{sat}) and the second one measures the floating potential (φ) [1]. The plasma current is kept at I_p= 6 kA (q(a) ≈15). Signals were digitized with the rate 3.25 μs/sample.

Gaussian signals have skewness S=0 and kurtosis K=3. In our data the I_{sat} fluctuations deviate from the Gaussian distribution significantly. Fig. 1 shows the PDF for φ

(S=0.04±0.02, K=3.07±0.04), and I_{sat} (S=0.66±0.02, K=3.40±0.04). Similar results are obtained with all probes suggesting intermittency with long-scale length coherent structures.

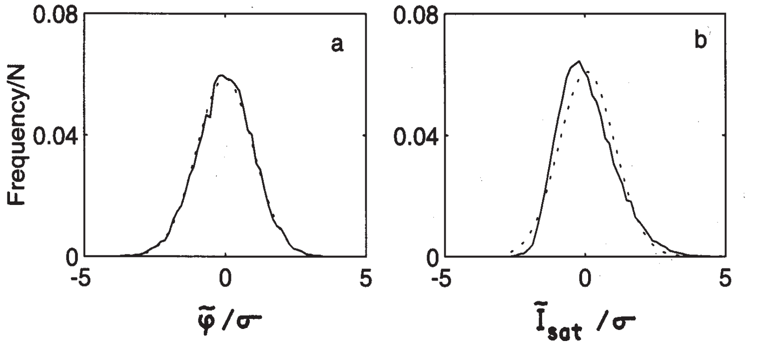

Fig. 1. PDF functions for $\tilde{\varphi}$, (a) and $\tilde{I}_{sat}$ fluctuations (b), as a function of fluctuation amplitude normalized to the respective standard deviation (dashed curves represent Gaussians).

Coherent structures are detected by means of conditional averaging of the fluctuation amplitudes. The conditional average, $\varphi_{cond}(r+\delta_r, \tau)$ is approximated by a power series representation around the condition, Φ_c , applied to the signal at the reference point r, and time t; $\varphi_{cond}= (r+\delta_r, \tau)=\Sigma_{i=1}\, \alpha_i(\delta_r , \tau)\, [\Phi_c]^i$; where the coefficients α_i depend only on the separation, δr, and the time delay, τ, between the signal at the reference probe and the signal of the other probes [2]. Fig. 2 shows the conditional averages at r=9.0 cm for I_{sat} fluctuations.

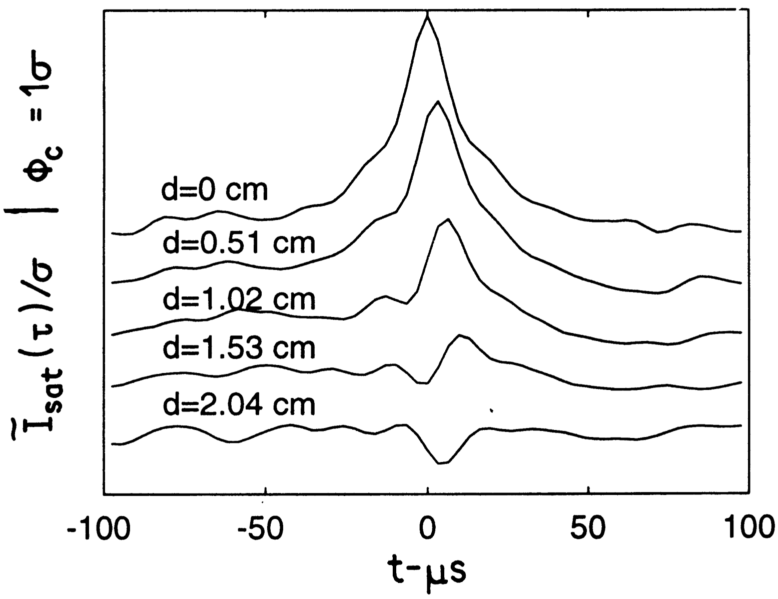

Fig. 2. Conditional average for Φ_c=1σ, at different poloidal separations, d, for $\tilde{I}_{sat}$ fluctuations

The same aspect is obtained for φ fluctuations. Cross-correlation functions for φ fluctuations are in good approximation to conditional average. However, this is not so for the I_{sat} fluctuations. The conditional correlation length, L_d, and lifetime, L_t, can be obtained by fitting the decay of the peak of the conditional average to an exponential function. Figs. 3 show L_d and L_t for conditions Φ_c ranging from -2.0σ to 3.0σ for φ and for I_{sat} fluctuations. The changes in correlation lengths and lifetimes for different conditions for φ fluctuations are less than 7%. For I_{sat} the variation in L_d for different conditions is ≈8%, while the variation in L_t is ≈32%. Moreover, we observed a pronounced asymmetry between positive and negative conditions. Larger correlation lengths and lifetime occur at larger conditions. This result seems consistent with the hypothesis that coherent structures, at larger amplitudes, would have long lifetimes compared with structures with a smaller condition.

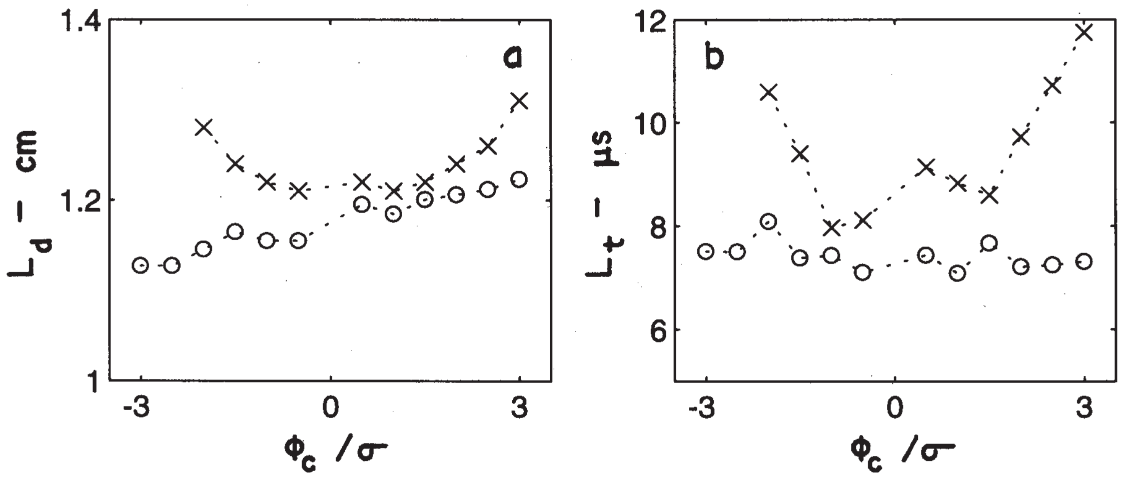

Fig. 3. Exponential decay coefficients in space and time L_d and L_t, (a), (b), for different conditions Φ_c. Floating potential (o), and ion saturation current (x).

Wavelet power spectra of φ and I_{sat} show intermittency at low frequencies. Fig. 4 shows the temporally resolved coherence between two poloidally separated probes for φ, (a), and I_{sat} (b). Noise level is ≈ 0.15 for low frequency components. The coherence is highly intermittent for both kind of fluctuations lifetimes compared with structures with a smaller condition.

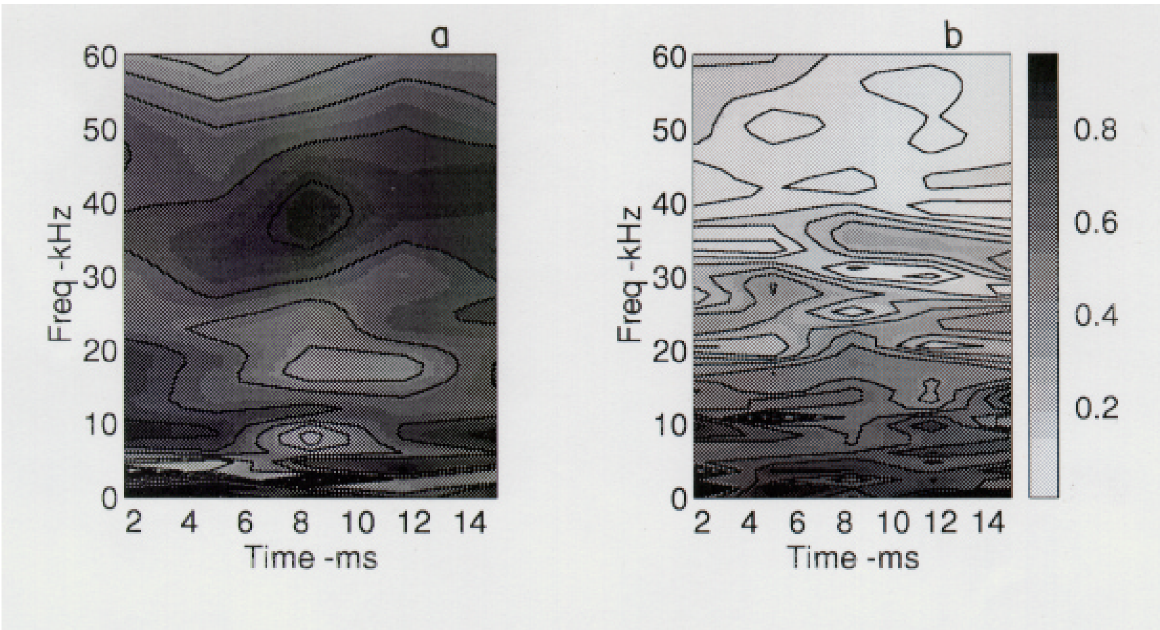

Fig. 4. Time-resolved wavelet coherence-versus-time of φ, (a) and I_{sat} fluctuations (b).

Since the wavelet scale lengths can be interpreted as inverse frequencies, the wavelet-bispectrum can be interpreted as the amount of coupling between wavelets of frequencies such that $f=f_1+f_2$. The squared wavelet-bicoherence $[b^w(f_1,f_2)]^2$ is the normalized squared bispectrum with values between 0 and 1. The summed wavelet-bicoherence is defined as $[b^w(f)]^2=\Sigma[b^w(f_1,f_2)]^2$. Wavelet-bicoherences are calculated on a frequency grid with 256 points from 0 to 307.7 kHz and selecting five data sections of ≈3.3 ms. Figs. 5 show the summed wavelet-bicoherence for I_{sat} at two intervals of the discharge (0-3.3ms and

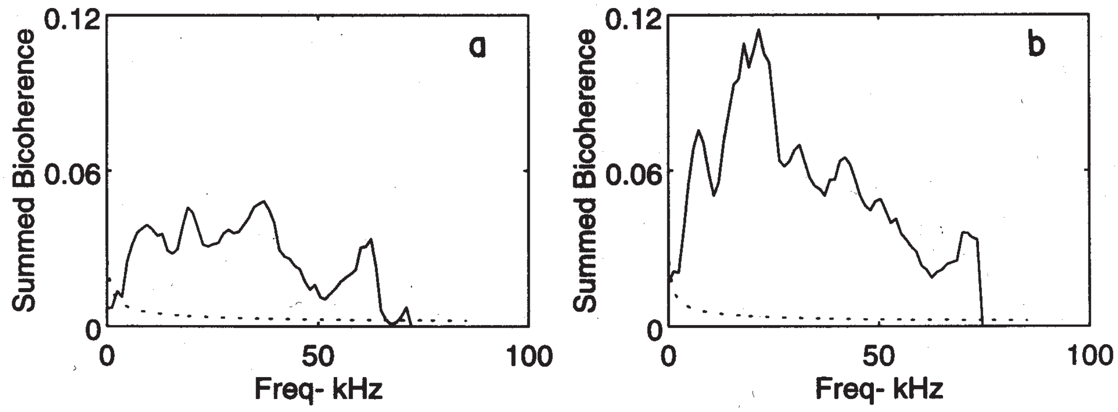

Fig. 5. Summed wavelet-bicoherence for I_{sat} fluctuations at two time intervals from 0-3.3 ms (a) and 13.2 -16.5 ms (b). Noise level is indicated by the dashed lines.

13.2-16.5ms). The summed wavelet-bicoherence shows that the maxima are mainly due to sum frequencies in the range of 10-30 kHz. Although, turbulent structures are not constant in time, the interval from 13.2-16.5 ms shows a rather strong bicoherence. Two peaks at ≈ 10 and 20 kHz indicate a structure that is not clearly present at the interval 0-3.3 ms and even in the other intervals. Further results about turbulent particle flux and wavelet bispectral analysis will be reported later in a full-length article.

This work supports the efficacy of wavelet analysis in analyzing nonstationary plasma fluctuations and demonstrates a better detection of turbulence nonlinearity that could be compared with numerical models of chaos and turbulence.

Acknowledgements

Grants of FAPESP, CNPq and the Academy of Sciences of the Czech Republic N^0 G-IA 1043701.

References

[1] J. Stöckel et al.: *Proceed. of the 1996 Inter. Conf. on Plasma Physics*, **I**, 322 (1996); *Proceed. of 24th European Phys. Soc. Conf. on Controlled Fusion and Plasma Physics* (Berchtesgaden, Germany) (1997).

[2] A.V. Filippas, R.D. Bengtson, G.X. Li, M. Meier, Ch.P. Ritz, E.J. Powers: Phys. Plasmas **2**, 839 (1995).

[3] S. Santoso, E.J. Powers, R.D. Bengtson, and A. Ouroua: Rev. Sci. Instrum. **68**, 898 (1997).

[4] Ch.P. Ritz, E.J. Powers and R.D. Bengston: Phys. Fluids **B1**, 153 (1989).

[5] R.M. Castro, M.V.A.P. Heller, I.L. Caldas, Z.A. Brasilio, R.P. da Silva, and I.C. Nascimento: Phys. Plasmas **3**, 971 (1996); Phys. Plasmas **4**, 329 (1997).

[6] B. Ph. van Milligen, C. Hidalgo, E. Sánchez, M.A. Pedrosa, R. Balbín, I. García-Cortés, and G.R. Tynan: Rev. Sci. Instrum. **68**, 967 (1997).