§31. Multifractal Characterization of L- and H-mode Plasma Edge Turbulence

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Measurements of the edge plasma turbulence obtained by the reciprocating Langmuir probe are analyzed and tested for self-similarity, long-range dependence and multifractality. We provide evidence for the multifractal character present in both L- and dithering H-mode data and also provide support for the local self-similarity in the case of L-mode. Further, we claim that neither L-mode nor H-mode data seem to exhibit self-similarity in the global sense. Moreover, we use several fractal and multifractal measures in addition to some non-standard statistical techniques in order to characterize the L and H-mode fluctuations. Widely used methods [1] of characterization of plasma turbulence time series include probability distribution function (PDF), autocorrelation function (ACF) and power spectrum (PS), while recently several papers address the topic of possible long-range dependence in the edge turbulence of toroidal magnetic confinement devices. Upon getting a Hurst exponent in the range $0.5 < H < 1$, the authors often make conclusions concerning the global self-similar properties, particularly in relationship with the Self-organized criticality (SOC) models [1-2]. Still, self-similarity is a strong statistical property and the process $X = \{X(t), t \in R\}$ is self-similar with parameter $H > 0$ (the so called H-ss process) if $X(0) = 0$ and $X(at) = a^H X(t)$. We show that the datasets from two different confinement regimes in MAST (Mega Amp Spherical Tokamak, UKAEA, Culham are locally self- similar (i.e. self-similar for sufficiently small time scales). We also show that the L-mode data, in agreement with the previous analysis [1], exhibit long range property in the sense that the spectral density $S(\omega)$ satisfies the following relationship $S(\omega) \sim C_f \mid \omega|^{-\alpha}$, as $\omega \to 0$, $(0 < \alpha < 1, C_f \neq 0)$. Again, consistently with [1], the particular H-mode does not show long range dependence property. However, we also give evidence that the processes under study in two datasets do not seem to be globally self-similar.

With the use of the wavelet analysis, we indicate that both the L- and H-mode regimes seem multifractal so that no single parameter (so called Hölder exponents) might be necessary to characterize the data [3-4], corresponding to various confinement conditions. Diagrams presented in Fig. 1, clearly illustrate that the confinement regimes under study are multifractal processes, and hence cannot be characterized by a single Hölder (Hurst) exponent. Specifically, none of the Linear multiscale diagrams have approximately constant h_q for positive q (a sign of global scaling). A Hölder exponent between 0 and 1 indicates that the signal is continuous but not differentiable at the considered point, and the lower the exponent the more irregular the signal is. Hence, all modes are characterized by continuous but not differentiable signals. The meaning of the above mentioned analysis is as follows. Local exponents h are evaluated through the modulus of the maxima values of the wavelet transform at each point in the time series. Then, the scaling partition function $Z_q(a)$ is defined as the sum of the q-th powers of the local maxima of the modulus of the wavelet transform coefficients at scale a. For small scales, the following relationship is expected $Z_q(a) \sim a^{\tau(q)}$. For certain values of q, the exponents $\tau(q)$ have familiar meanings. In particular $\tau(2)$ is related to the scaling exponent of power spectra, $S(f) \sim 1/f^{\beta}$, as $\beta = 2 - \tau(2)$. For positive q, $Z_q(a)$ reflects the scaling of the large fluctuations and strong singularities, while for negative q, $Z_q(a)$ reflects the scaling of the small fluctuations and weak singularities [4]. Hence, the scaling exponent $\tau(q)$ may reveal much about the underling dynamics.

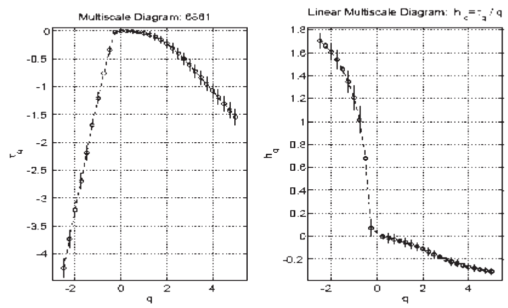

Fig. 1 Multiscale and Linear multiscale diagram for 6861 L- mode. No flatness, due to lack of global self-similarity.

Monofractal signals display linear $\tau(q)$ spectrum, $\tau(q) = qH - 1$, where H is the global Hurst exponent. For multifractal signals $\tau(q)$ is a nonlinear function $\tau(q) = qh(q) - D(h)$, where $h(q) \equiv d\tau(q)/dq$ is not constant, D(h) is the fractal dimension $D(h) = qh - \tau(q)$. In order to distinguish between low and high confinement regimes we turn to the different multifractal properties such as regularization dimension, local Hölder exponents, various multifractal spectra etc. A typical example is pointwise Hölder exponents, measuring the scaling behavior at infinite resolution. The Large Deviation Spectrum; coarse grained Holder exponents measuring scaling at finite resolution, points to discernible differences between the confinement regimes. Based on our results, it seems that two studied signals are the product of small-scale stochastic plasma turbulence, without large-scale events; consistent with Dudson et al [1]. Finally, we present a method based on the wavelet analysis which may characterize the long-range property, simultaneously with the intermittent property. In addition, it quantifies the degree of intermittency, enabling an efficient way of discerning between different intermittency regimes.

References

1) B. D. Dudson et al. PPCF 47 (2005) 901.
2) B. Ph. van Milligan, et al., Phys. Plasma, 5 (1998) 3632
3) A. Komori et al., Phys. Rev. Lett. 73 (1994) 660
4) M. Rajkovic, M.M. Skoric, NIFS Report No 833 (2006)