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LOCAL MULTIFRACTAL CHARACTERISTICS OF CONFINED FUSION PLASMA AND NEUTRAL FLUID TURBULENCE

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Abstract. Intermittency in the scrape-off layer (SOL) region of magnetically confined fusion plasma and velocity intermittency of neutral fluid are compared from the aspect of local multifractal properties.

1. INTRODUCTION

Velocity field statistics are an essential tool and the major source of information in neutral fluid turbulence. The influence of the external magnetic field on turbulent flow of an compressible plasma fluid leads to much more complicated behavior which modifies turbulent motions. In particular we are interested in the local multifractal properties of intermittency phenomenon, and in the case of confined plasma we study intermittency in the scrape-off layer (SOL) of fusion plasma devices. Comparison analysis includes L- and dithering H-mode of the MAST; Mega- Ampere Spherical Tokamak (UK, Culham). The quantity of interest in the case of neutral fluid turbulence is one-component fluid velocity while for a plasma case it is the ion saturation current fluctuations of reciprocating Langmuir probe.

1.1. Experimental conditions

The plasma intermittency datasets analyzed here consist of measurements of the ion saturation current (ISAT) performed by the moveable Langmuir probe located at the outboard mid plane on MAST device (Dudson et al. 2005). Sampling rate was 1 MHz and during the discharge the distance from the plasma edge to the probe changed slowly. Probe distance from the plasma edge was 4.4 -5.7cm. The data for neutral fluid were obtained by a hot-wire measurement in the central region of an air into air round free jet. Detailed account of the experimental setup is given in Renner et al. (2001). In our analysis we have used one data set of the local velocity measured at a sampling frequency of 8 kHz (corresponds to spatial resolution of 0.28 mm). The Reynolds microscale number was $Re_\lambda = 190$; implying $Re = 3.6 \times 10^4$. The integral length scale is 6.7 cm while the Kolmogorov scale is 0.3mm.

2. LOCAL TURBULENCE PROPERTIES

Nonstationary turbulent fluctuations usually exhibit approximate stationarity in the appropriately chosen segments within which spectral densities, exhibit approximate power law scaling. Estimation of the power law behavior of spectral densities from the measured plasma edge fluctuations is based upon appropriate segmentation of the data. Detailed presentation of the method is in SØlna and Papanicolaou (2002), Rajković et al. (2007). The motivation for a such a procedure is first to estimate the local temporal variations in the correlation properties of the fluctuations and to evaluate the variation of the absolute level of these correlations. The second is the propagation of microwaves in plasma for the purpose of Doppler reflectometry used for estimating plasma rotation profiles. Multifractal behavior may be modeled locally in time (space), by self-similar (monofractal) fractional Brownian motion (fBm) within the appropriately chosen segments. Fractional Brownian motion represents the simplest local power law process which is nonstationary with stationary increments. The variance of the stationary increments is quantified by the structure function given by

$$E\left\{(B_H(t+\Delta t) - B_H(t))^2\right\} = \sigma^2 \left|\Delta t\right|^{2H}, \quad H \in [0,1]. \qquad (1)$$

The Hurst exponent H determines the correlation distance for the increments of the process and the quantity 2 quantifies the absolute level of correlations. Ordinary Bm, a monofractal process, is characterized by H = 1/2. Fractional Brownian motion is self-similar since $B_H(t) = a^H B_H(t/a)$, where the equal sign implies equality in distribution. Increasing the exponent i.e., H > 1/2 corresponds to positive correlations (persistence) and long memory, while the case of H < 1/2 corresponds to negative correlations (anti-persistence). Power law processes are usually observed through a filter that cuts off very low frequencies so a power law may be associated with fBm

$$P_{B_H} \propto \sigma^2 \left|\omega\right|^{-(2H+1)}. \qquad (2)$$

In the Kolmogorov case H = 1/3 over some range of frequencies (inertial range). Eq. (1) may be used only in the restricted temporal domain in which turbulent signal is self-similar. The main steps in estimation of local turbulence properties are the following: *1*) Partitioning of data into equal segments of approximate stationarity. A filtering procedure is devised to remove dependence of the estimated parameters on segmentation (Rajković et al. 2007). *2*) Wavelet decomposition of the data and evaluation of the scale spectra within each segment. *3*) Determination of the inertial range of the scale spectra and evaluation of the power law parameters based on the fBm model.

2.1. Local features of MAST edge turbulence

For the MAST data size of segments ranged from 256 μs to ~ 2 ms. The lower limit of the segment size is governed by the maximum temporal extent of the inertial range. Based on our fBm wavelet model temporal variations of the local Hurst exponent and the variance for the case of L- and dithering H-mode MAST are presented in Figs. 1 and 2, respectively. Both parameters show random fluctuations with local Hurst exponent fluctuations closer to the Kolmogorov's value of 1/3 in the L-mode, so that from that aspect of multifractality of L-mode turbulence is similar to the neutral fluid turbulence. In the case of dithering H-mode, Fig. 2, the average Hurst exponent value is lower than in the L-mode case however it exhibits distinct random variability from a minimum value of H = 0.1. Both cases are typical of multifractal processes which show fast, random fluctuations of the regularity parameter H. For the case of neutral fluid turbulence, Fig. 3, Hurst parameter varies in the vicinity of the Kolmogorov value of 1/3. A brief comparison of Figs. 1, 2, shows that fractal quantities exhibit purely stochastic variation for the case of MAST L-mode and in the case of neutral fluid turbulence although the difference in these fluctuations may be easily recognized.

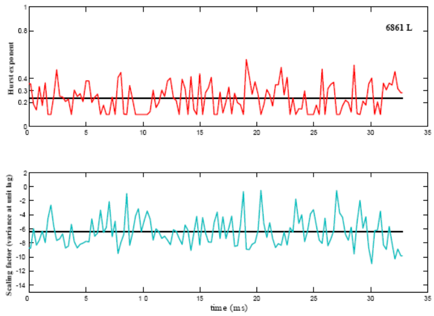

Figure 1: Parameters of the fBm model, Hurst exponent and the variance at unit lag, for the L-mode of MAST. The smoothed vales are represented by solid lines. The Hurst exponent fluctuates around the smoothed value H=0.23.

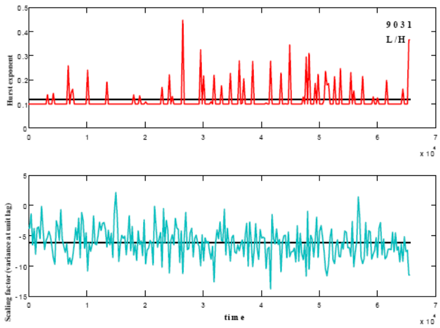

Figure 2: Parameters of the fBm model, Hurst exponent and the variance at unit lag for the dithering H-mode in MAST. Note considerably lower value of the Hurst exponent than in the case of L-mode.

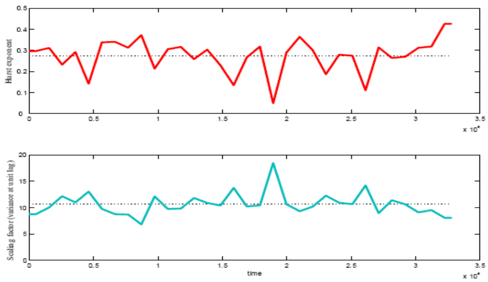

Figure 3: Parameters of the fBm model, Hurst exponent and the variance at unit lag, for neutral fluid turbulence. The smoothed value of the Hurst parameter is close to the Kolmogorov value H=1/3.

In conclusion, local features of turbulence exhibit unique variability with multfractal behavior both for the magnetically confined plasma and neutral fluid turbulence. The latter has very well defined inertial range which is well captured in the wavelet scale spectra irrespective of the segmentation of the turbulent signal.

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References

Abry, P., Flandrin, P., Taqqu, M. S. and Weitch, D.: 2000, Chapter 2 in Self Sim- ilar Network Tra¢c and Performance Evaluation, Editors K. Park and W. Willinger, Wiley-Interscience, New York.

Dudson, B. D., Dendy, R. O., Kirk, A., Meyer, H. and Councel, G. F.: 2005, *Plasma Phys. Control Fusion*, **47**, 885-901.

Papanicolaou, G., Washburn, D. and SØlna, K.: 1998, *Proc. of SPIE*, **3381**, 256.

Rajković, M., Skorić, M., SØlna K. and Antar, G.: 2007, *Nucl. Fusion*, **47**, 1-13.

Renner, C., Peinke, J. and Friedrich, R.: 2001, *J. Fluid. Mech.*, **433**, 383-409.

SØlna, K. and Papanicolaou, G.: 2002, Wavelet Based Estimation of Local Kolmogorov Turbulence in Theory and Applications of Long-range Dependence, Editors P. Doukhan, G. Oppenmeim and M. S. Taqqu, Birkhäuser Boston, pp 473-506.