ELECTROSTATIC TURBULENCE INTERMITTENCY DRIVEN BY MHD RELAXATION PHENOMENA IN A RFP PLASMA

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It is generally accepted that electrostatic turbulence and the related anomalous transport play a major role in reducing the confinement in fusion devices [1,2]. The origin of electrostatic turbulence is currently not clear, although in some Reversed Field Pinch (RFP) experiments a possible non-linear coupling between low-frequency MHD activity and high frequency electrostatic fluctuations has been suggested [3]

Recently new insight on the physics of electrostatic fluctuations has been gained from the analysis of the statistical properties of the signal.

A detailed study of the floating potential [4] and magnetic fluctuations [5] at the edge of the RFX device has shown that these fluctuations show intermittency. In order to avoid possible confusion between bursty fluctuations and intermittency, according to Frisch[6], we define intermittency as a departure from pure self-similarity characterized by a change of Probability Distribution Function (PDF) of normalized fluctuations as the time scale is varied.
If we introduce a scaling law for generic fluctuations $\delta\Phi(\tau) \sim \tau^h$ (where $\delta\Phi(\tau) = \Phi(t+\tau)-\Phi(t)$ is the typical fluctuation of the signal Φ at the scale τ) a scale variation $\tau \rightarrow \lambda\tau$ leads to a scaling law of the fluctuations as $\delta\Phi(\lambda\tau) = \lambda^h\, \delta\Phi(\tau)$ which in fully developed turbulence is interpreted as an equality in distributions. In a pure self-similar case the scaling exponent h is unique and the standard variables $\delta\Phi(\tau)/\sigma_\tau$ (where σ_τ is the standard deviations of $\delta\Phi(\tau)$) must collapse to a unique PDF. Intermittent effects are responsible for an increasing of the tails of PDF at smaller scales deviating from a gaussian distribution.

A clear example of this behavior is reported in figure 1 where the PDF of fluctuations at two different time scales of floating potential signal at the edge of RFX are shown. It clearly appears that the PDF changes from a gaussian shape to a more leptokurtic one with the increasing of the tails of PDF. This means that at smaller time scales intense fluctuations occur more frequently than in a simple normal distribution.

The phenomenon identified in RFX has been observed also in many experimental investigations of turbulence in fluid flows and magnetohydrodynamic MHD flows and in numerical simulations [6]. Recently the presence of intermittency has been claimed also in tokamak electrostatic turbulence [7] by studying multifractal properties of fluctuations.

This paper aims at establishing the relationship between intermittent events, which appear to be an important feature of electrostatic turbulence and responsible of the departure from pure self-similarity of the fluctuations, and relaxation phenomena driven by large-scale tearing modes originating in the core of an RFP plasma.

The results come from the RFX experiment, a large RFP device with major radius R=2m and minor radius a=0.457 m. The present measurements were performed in low-current (300-400 kA) hydrogen plasma, using electrostatic probes inserted into the plasma. The measuring head was equipped with 7 probes at the same toroidal and poloidal position but 8 mm radially spaced. The probes measured floating potential ϕ_f.

A quasi periodic behavior of floating potential signal is found at the frequency of a few kHz. These oscillations are well correlated with an oscillation of the reversal parameter $F = B_\phi(a)/\langle B_\phi \rangle$. The F oscillations are related to the "sawtooth activity" which is a typical evidence of the cyclical diffusion-relaxation process which sustains an RFP plasma equilibrium. An example of the correlation between F and ϕ_f is reported in figure 2 a), where the mean-subtracted oscillations (normalized to their standard deviation) of the two signals are plotted on the same graph. The floating potential signal has been low-pass filtered at 5 kHz while the F parameter is sampled at 10 kHz. The graph clearly shows that in corrispondence to the local maxima of the reversal parameter, the floating potential has a local minima. This behaviour may be induced by the modification of the global velocity profile during relaxation events and the consequent modification of the radial electric field through the force balance equation. Other possible explanations are related to the presence of fast electrons which escape from the core during dynamo events although it has to be mentioned that the probe orientation was such as to avoid measurements from facing the electron drift side.

In fluid dynamics the deviation of PDF from gaussianity can be characterized through the generation of ``structures'' at all scales [8]. To identify the occurrence of strong fluctuations responsible of PDF tail increasing we apply a method introduced by Farge [8] and developed by Onorato *et al.* [9]. This method requires the application of a Continuous Wavelet Transform (CWT) to the signal ψ_0 : $C(t,\tau) = \frac{1}{\sqrt{\tau}} \int \psi_0(s) W\left(\frac{s-t}{\tau}\right) ds$. Through the wavelet coefficients

$C(t,\tau)$, which are a measure of the typical fluctuation of the signal $\delta\psi_o(\tau)$, we introduced a unambiguous caractherization of the local activity of the signal at time t and scale τ by defining the *local intermittency measure* (LIM) $l(t,\tau) = C(t,\tau)^2/\langle C(t,t)^2\rangle$ where $\langle \bullet \rangle$ indicates time average. An intermittent event is characterized by a large value of $l(t,\tau)$.

The method divides the sets of wavelet coefficients into two orthogonal subsets $\{C(t,\tau)\} = \{C_e(t,\tau)\} \oplus \{C_g(t,\tau)\}$ the former related to intermittent events and the latter related to the gaussian background. The definition of the two sets is made through an iterative process which assures that the flatness $F(\tau) = \langle C_g(t,\tau)^4\rangle / \langle C_g(t,\tau)^2\rangle^2$ calculated on the coefficients belonging to the gaussian background is equal to 3.

The method allows to identify in time the occurrence of intermittent events. In figure 2 b) we report the floating potential at r/a = 0.92 and with vertical dotted line we indicate the time occurrence of intermittent events at a time scale corresponding to a frequency of f = 100 kHz. It may be observed that the events mainly concentrate on floating potential minima, i.e. during relaxation events. We may argue the existence of a non-linear relationship between low-frequency magnetic turbulence and the generation of high-frequency intermittent events. This may happen also through a modification of global magnetic environment or through the modification of velocity profile.

The analysis method allows the study of the typical shape of intermittent event by choosing a suitable time window of the signal around it. To apply an average procedure on different structures for each time window we renormalized the signal by subtracting the mean value and dividing by the standard deviation. In figure 3 we report the average shape of 50 events. It has the shape of a clear potential well. By assuming a typical plasma velocity of 10 km/s and applying Taylor hypothesis of equivalence between time and space, the toroidal extension of the structure is ~ 20 cm. By applying the same assumption the structure can be associated with a toroidal electric field structure or equivalently to a corresponding $\mathbf{E}\times\mathbf{B}$ radial velocity. The behavior of radial electric field at the same instant is presently under investigation.

To summarize it has been established that the large scale MHD dynamo relaxation, which rules magnetic behavior of an RFP plasma, has a clear relation with intermittency in the edge small-scale electrostatic turbulence. Important consequence regards the particle tranport in the edge, which in an RFP is induced by electrostatic fluctuations [1]. The importance of these structures on particle transport is presently under investigation. It has to be mentioned that, the laminar times of these intermittent events (i.e. the time interval between two successive structures) are distributed according to a power law static [10]. According to Antoni *et al*. [11] this behavior in the absence of self-similarity of PDFs is sufficient to establish the inconsistency of RFP electrostatic fluctuations with Self Organized Criticality (SOC) models.

References

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Figures

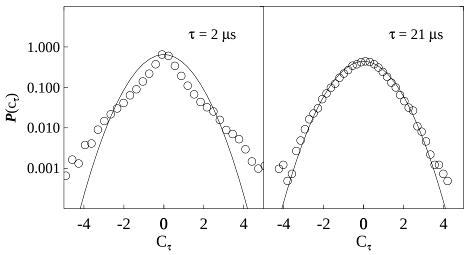

Fig 1: PDFs of the floating potential fluctuations at two time scales. A change of shape from a gaussian to heavy tails can be seen as the scale is decreased

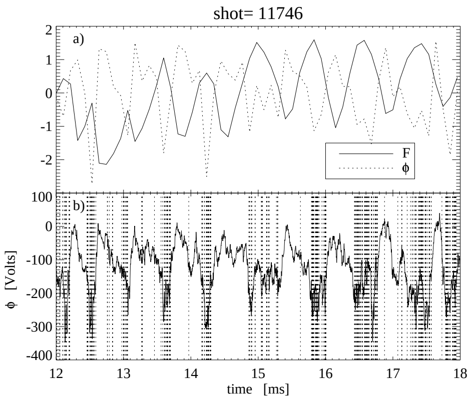

Fig 2 a) Overplotting of the *F* oscillations (solid line) and low-frequency oscillations of ϕ_f (dotted line) b) Floating potential signal. With vertical dotted lines the time occurrence of intermittent events at scale τ=10μs are indicated

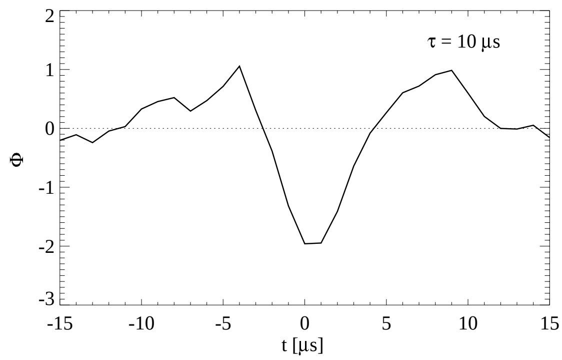

Fig 3: Mean shape of intermittent event of floating potential signal ($\Phi = (\phi - <\phi>)/\sigma_\phi$) at scale τ = 10 μs.