Bursty fluctuation events in magnetically confined plasmas:
avalanche-like SOC processes or MHD turbulence?

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Magnetic and electrostatic fluctuations in RFX exhibit bursty behavior as commonly observed in other fusion experiments. A detailed investigation of the statistical properties of these fluctuations has revealed that their Probability Distribution Function (PDF) is not self-similar at the different scales [1,2], developing non-gaussian tails at the smaller scales. This property allow bursts in RFX to be named 'intermittent events' according to the definition of intermittency as departure from pure self similarity [3]. Owing to the relationship between magnetic and electrostatic turbulence and anomalous particle and energy fluxes, the statistical properties of the fluctuations of the primary quantities (namely magnetic fields, density, temperature and plasma potential) and derived fluxes, are expected to be related to the fundamental processes underlying the anomalous transport. In order to identify this processes the statistical properties of the particle flux have been compared with the predictions of Self Organized Criticality (SOC) models. These models have been proposed to describe the transport processes in plasmas for thermonuclear fusion research, owing to some properties [4] like density and temperature profile resilience and power law decay in fluctuation spectra. Among the different SOC models discussed in literature, [see [5] for a review, the running sand pile model developed by Hwa and Kardar [6],appears particularly suitable to better mimic a magnetically confined plasma continuously powered and refueled with particles. So that in this contribution the comparison will be made with this model.

The experimental data have been collected in the edge region of the Reversed Field Pinch (RFP) experiment RFX (R = 2 m, a = 0.46 m) operated at low plasma current (300-400 kA) and with electron density ~ 3.5×10^{19} m^{-3}. The electrostatic fluctuations have been measured by a set of Langmuir probes described elsewhere [7] and the data have been sampled at 1 MHz.

The instantaneous radial particle flux induced by the electrostatic turbulence Γ_{es} has been evaluated from two-point measurements as $\Gamma_{es}=\langle En\rangle/B_\Theta$ where B_Θ is the mean magnetic field (which is mainly poloidal at the edge) and E and n are the electric field and density signals. In this case temperature fluctuations have been neglected, so that E and n have been approximated by ion saturation current and floating potential signals . It has been found that the particle flux is mostly concentrated in the range 30-250 kHz [7] which corresponds to time scales approximately in the range 4 - 30 µs. The power spectrum of particle flux, as previously observed for the primary quantities (i.e. plasma density and potential), decays with a power law behavior, as shown in fig.1, in the frequency range relevant for transport processes.

The Probability Distribution Function (PDF) of the particle flux has been found asymmetric with a longer positive tail which corresponds to outward directed fluxes [8]. To discriminate between bursts and fluctuating background a threshold in the particle flux has been obtained by a recursive method described in [9]. By applying this methods the bursts have been selected and it has been found that these intermittent events carry more than 50% of the outward particle flux due to electrostatic turbulence [8]. The Waiting Time Distribution (WTD) defined as PDF of the times between subsequent events, has been derived and it is shown in fig.2. The WTD shows a power law decay with an exponential ~ -1.8. It is worth mentioning that a similar decay was observed in density fluctuations [10]. As previously noticed [8,10], this behavior is inconsistent with predictions of all SOC models but the continuos finite drive model proposed by Hwa and Kardar [6] which allows avalanches to interact among themselves.

The analysis of the PDF of particle flux fluctuation at different time scales has been carried out by wavelet decomposition of the signals. In Fig. 3 an example of normalized PDF's for two different time scales τ= 4 and 36 is shown. It appears that at the smaller scale the PDF develops non-gaussian tails as observed for primary quantities [1,2]. In order to compare this behavior with SOC models, the same wavelet analysis has been applied to the PDF of the dissipated energy fluctuations in the running sand pile model at high input rate, i.e. in the regime where the PDF of laminar times has a power law decay consistent with experimental data.

In Fig. 4 the PDFs at ten different time scales (in the range 30-400 time steps) are shown : the PDFs appear self-similar and with a shape close to a gaussian distribution. This result is not consistent with the intermittent character of the experimental fluctuations and with the PDF shape at the smaller scales. Therefore statistical properties of experimental fluctuation appear inconsistent with those predicted by SOC models including the sole SOC model in which the WTD statistics was consistent with the experimental results.

In conclusion, a wavelet decomposition of particle flux fluctuations in the edge region of RFX has revealed that fluctuations are not self similar in character and that the PDFs have non-gaussian tails in a range of time scales where most of the transport is concentrated. Moreover the laminar times between bursts exhibit a power law decay. These two properties are in contrast with statistical properties of avalanches in a wide class of SOC models including the running sand pile model, which allows avalanche interaction. Therefore we conclude that the statistical analysis performed on the particle flux rules out avalanche-like processes in a RFP configuration. On the other hand recent work on RFX [11] has shown that the intermittent events in the electrostatic turbulence are related to Magneto Hydrodynamic (MHD) relaxation processes. In particular it has been found that the intermittent events in the floating potential are associated to spatial 'coherent' structures reminiscent of structures observed in Tokamaks [12,13]. These findings suggest that the nature of these intermittent events, which appear rather important in the particle losses economy since they carry more than 50 % of the particle flux, is related to non linear phenomena occurring in the plasma turbulence which cannot be described as avalanche-like processes.

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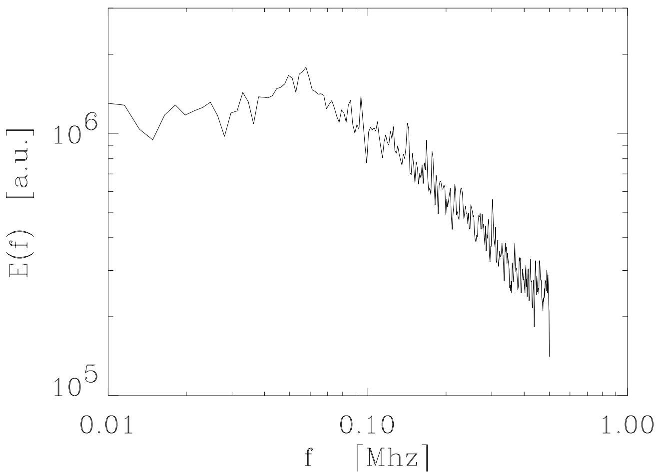

Fig.1 Power spectrum of particle flux fluctuations.

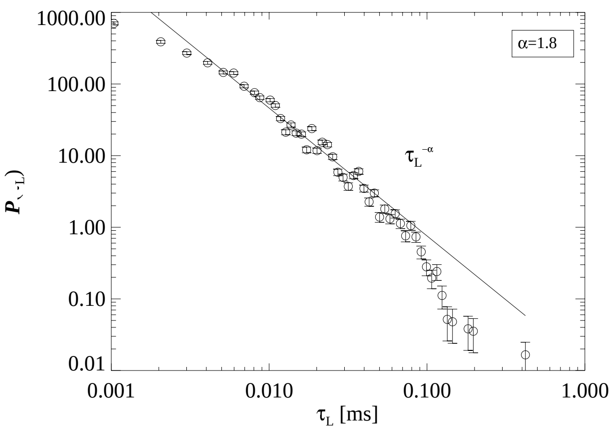

Fig.2 Waiting Time Distribution of Particle flux bursts.

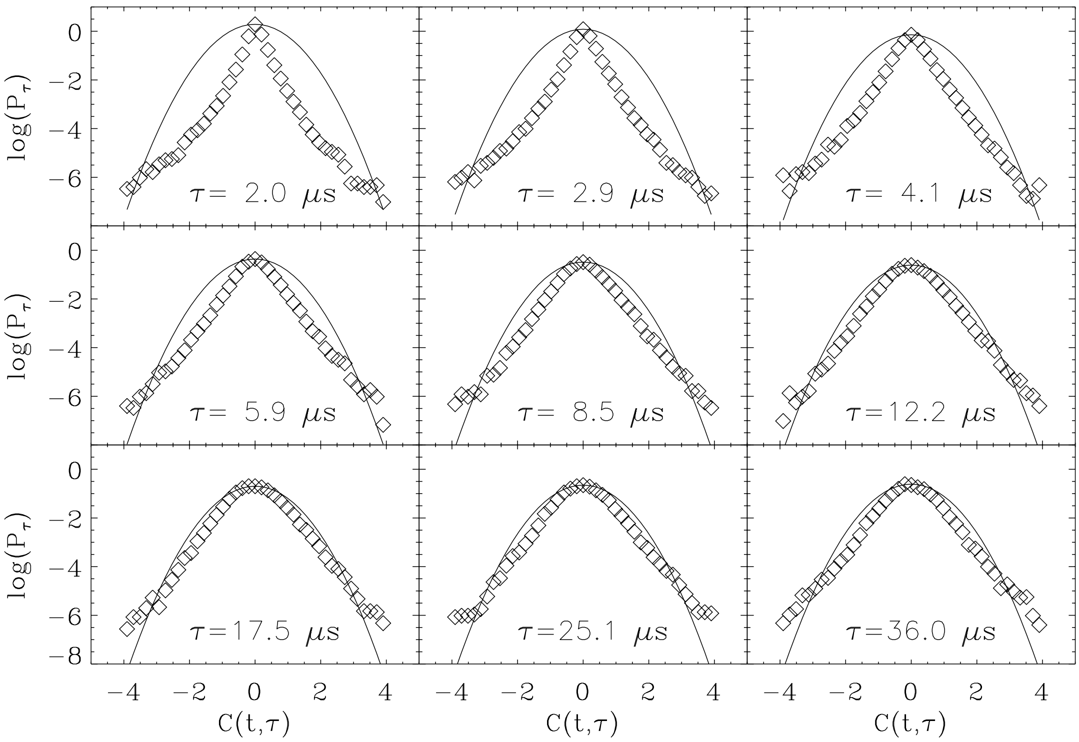

Fig.3 Normalized PDF's of particle flux fluctuations at different time scales τ. A gaussian PDF is superimposed

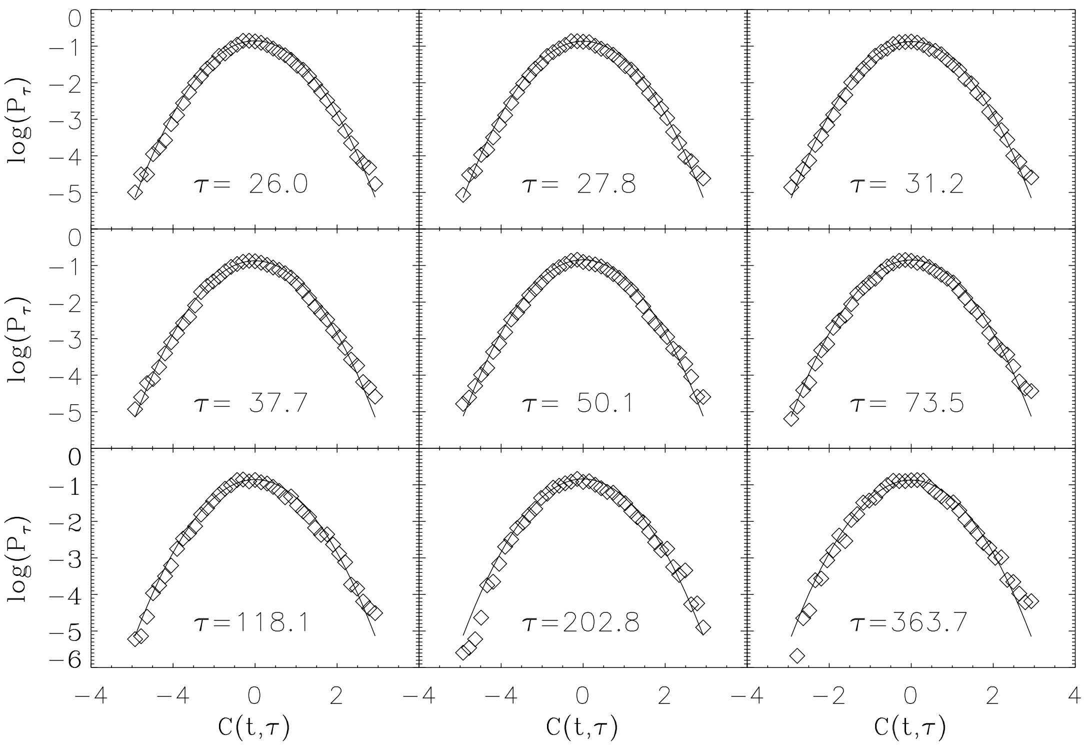

Fig.4 PDFs at different time scales (in the range 30-400 time steps) for SOC model.