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Fast electrons and intermittent events in the RFP device TPE-1RM20

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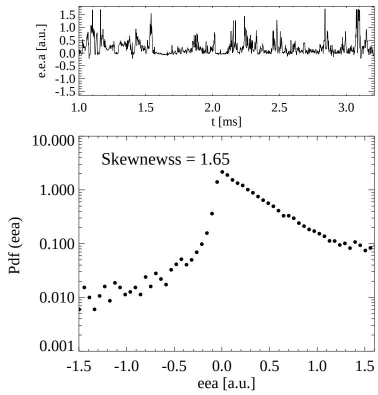
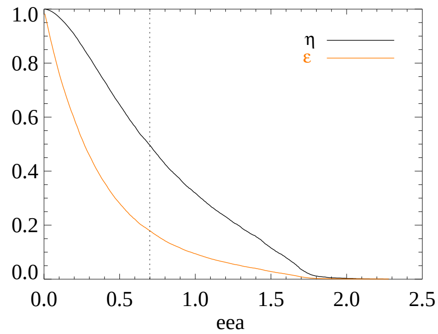
A major challenge for the progress of magnetically confined plasmas for thermonuclear fusion is understanding the mechanisms for energy and particle transport. It is generally recognised that in these plasmas fluctuations play a major role in the so called *anomalous transport* [1]. In recent years growing attention has been devoted to bursty behaviour of electrostatic fluctuations and transport: indeed this feature has been observed in all magnetic configurations including tokamaks [2], stellarators [3] and Reversed Field Pinches (RFPs) [4]. In the RFP configuration it has been found that these bursts, although representing a small fraction of the signal, can account for up to 50% of the particle losses [4]. In the same magnetic configuration it has been found that these bursts, which exhibit an intermittent character belonging to the non-gaussian tails of the Probability Distribution Function (PDF) of the signal increments [4], tend to concentrate during relaxation processes occurring during RFP sustainment, suggesting a strong non-linear coupling between internally resonating MHD modes and electrostatic fluctuations at the edge [4, 5]. Besides electrostatic signals, also electron current, as collected from Electron Energy Analyzer (EEA), exhibits a bursty behaviour where higher currents are observed in correspondence to superthermal electrons (fig 1(a) upper panel) [6]. In this contribution, statistical analysis is applied to EEA current in order to investigate the common electromagnetic origin of these bursts.

Data have been collected in the edge region of TPE-1RM20 RFP device. The probe consists of an Electron Energy Analyser, four tungsten pins (2.5mm toroidally and 1.5mm radially separated) and two magnetic coils (measuring B_r and B_ϕ fields), housed in a boron nitride case having 25mm×25mm cross section [6]. Experimental campaign have been performed with the probe inserted 15 mm inside the plasma ($r/a = 0.92$). To minimise the damage of the probe experiments have been conducted at low plasma current (~ 80 kA). The first experimental observation regards the statistical properties of the EEA current. Indeed the PDF of this signal exhibits a pronounced non-gaussian tails at higher electron energy as shown in the lower panel of figure 1(a). The importance of the tail of the PDF in determining the total electron current may be evaluated, accordingly to the method proposed in [4], considering the fraction events $\varepsilon(J)$ and the fraction of current $\eta(J)$ beyond a given threshold. These two parameters are defined as $\eta(J) = \frac{\int_J^{+\infty} J' p(J')\, dJ'}{\int_0^{+\infty} J' p(J')\, dJ'}$ and $\varepsilon(J) = \frac{\int_J^{+\infty} p(J')\, dJ'}{\int_0^{+\infty} p(J')\, dJ'}$, where $p(J)$ is the Probability density function of EEA current shown in figure 1(a). For a threshold calculated according to the method proposed in [7] almost 50% of electron current is found to be carried by less than 20% of current events as shown in figure 1(b). Using the *Local Intermittency*



(a) Top: EEA signal. Bottom PDF of EEA signal



(b) η and ε as a function of positive EEA signal

Figure 1: EEA signal statistical properties

Measure technique [8] we are able to identify the temporal occurrence of intermittent events on EEA, indicated as vertical dotted lines in figure 2 (a). It results that they tend to appear not homogeneously distributed in time, but as clusters of events. This behavior is compared with the reversal parameter $F = \frac{B_\phi}{\langle B_\phi \rangle}$, which oscillates because of the cyclical process of magnetic diffusion and flux generation which takes place in the RFP plasma core. By focusing on one of these clusters around 3.3 ms, indicated by a colour bar on the figure, an intense fluctuation on the parameter F is observed, and the RFP equilibrium in the $F-\Theta$ plane, where $\Theta = \frac{B_\theta(a)}{\langle B_\phi \rangle}$ is the pinch parameter, follows a closed trajectory during this oscillation, as observed in figure 2 (c). In the same figure with red dots the occurrence of intermittent events is shown: the events are

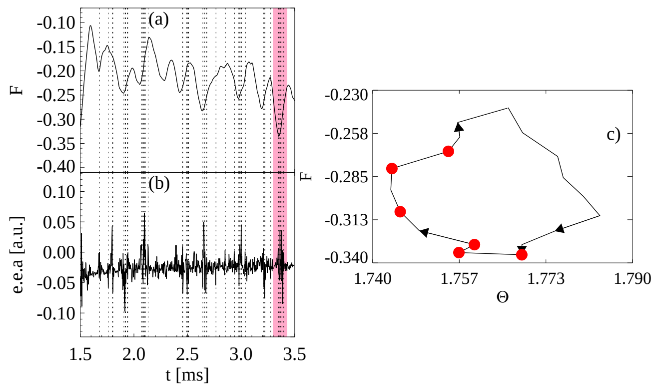


Figure 2: Temporal evolution of EEA current (a) and of reversal parameter F (b). With vertical dotted lines the occurrence of intermittent events on EEA at $\tau = 5\mu$s is indicated. (c) $F - \Theta$ trajectory of plasma equilibrium in the time interval indicated. The red dots shows the occurrence of intermittent events.

found mainly during the recovering phase of the F oscillations, suggesting a relationship with magnetic energy release during relaxation processes. Therefore a strong relation between current events and MHD low-frequency oscillation appears in analogy to what has been observed on floating potential in RFX and Extrap-T2R [9, 5]. As burst on V_f has been related to plasma spatial structures, a similar analysis has been performed on bursts of electron current. In particular we have performed a conditional average on floating potential, EEA current and toroidal and radial magnetic fields signals, taking the occurrence of EEA intermittent structures at time scale $\tau = 5\,\mu$s as reference event (see figure 3). The analysis shows that in correspondence to current density peaked structures a minimum of the floating potential occurs, very similar to what observed in RFX and Extrap-T2R [10, 5] performing intermittency analysis on floating potential. In the case of floating potential, intermittent structures have been identified as vortex-like structures with a preferred vorticity strongly influenced by local $\mathbf{E} \times \mathbf{B}$ shear [10]. Therefore this analysis suggests that these structures have also an associated electron current. As far as it concerns magnetic fluctuations a clear pattern may be recognised in both toroidal and radial component. These fluctuations are $\pi/2$ phase-shifted, with a maximum of B_r located approximately where B_ϕ changes sign. This behaviour is consistent with a poloidal current filaments which is moving in one of the measured direction (toroidal or poloidal). To verify this hypothesis we focused on the toroidal propagation of the radial component of magnetic field structure, using another coil spaced 13 mm toroidally away (see fig. 3 (d)). A propagation of the structures may be

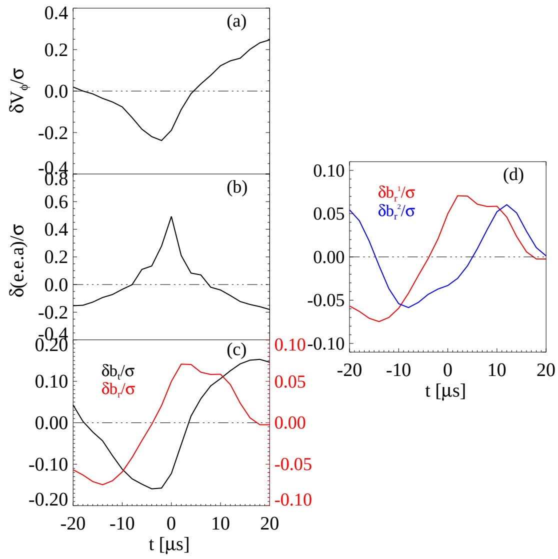


Figure 3: Conditional average on normalised signals using EEA intermittent event as reference event. From top to bottom (a) floating potential, (b) EEA current, (c) toroidal and radial (red line) magnetic field. Panel (d) shows two different radial magnetic field conditional average at two different toroidal position

deduced with a time delay between the maxima of approximately 10 μs corresponding to a toroidal velocity of about 1 km/s close to the lower toroidal drift velocity expected near the reversal surface. In conclusion we have found that electron current collected by an EEA analyser has a bursty behaviour, and that the bursts can account for almost 50% of the total current. We have observed that bursts of electron current are associated to events belonging to non-gaussian tail of the PDF and that they tend to cluster in time during magnetic relaxation events. We have also shown that average electron current structures can be identified and associated to vortex-like structures of the velocity field, so that they have the typical features of current filaments propagating in the toroidal direction.

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