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Electrostatic and magnetic structures in the edge region of RFX-mod experiment

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The understanding of transport mechanisms in the edge region of magnetic confined plasmas is a key subject in order to gain insight on the realization of an efficient fusion reactor. The investigations on fusion devoted experiments agreed on the so called anomalous feature of the transport [1], where the turbulence plays a key role.

Analogous features have been observed in the edge turbulence of different devices and in particular bursts on electrostatic fluctuations have been observed in the edge region of several fusion experiments including tokamaks [2,3] stellarators [4] and reversed field pinches (RFP) [5]. In different experiment a coherent part has been detected in the edge fluctuations that has been associated to presence in the edge region of coherent structures with eddy features or blobs of density [6]. It is believed that these structures play a major role in driving the transport in the edge region. In particular in the RFP configuration it has been found that strong bursts, although representing a small fraction of the signal, carry up to 50% of the particle flux losses [7].

Measurements of electrostatic and magnetic fluctuations have been performed in the edge region of the recently upgraded RFX-mod reversed field pinch experiment (R/a=2m/0.459m) [8], which features a substantial improvement of the magnetic boundary provided by a sophisticated and effective system for feedback control of the radial magnetic field at the edge.

Turbulence features in the edge region have been investigated by using a new and original probe system, dubbed U-probe. The system is constituted by two blocks toroidally spaced by about 90 mm, each of them equipped with a matrix 5 (toroidally) times 8 (radially) of Langmuir pins and a radial array of seven 3-axial magnetic probes. The diagnostics peculiarity allowed a detailed analysis of the fluctuations both on electrostatic and magnetic quantities with a radial resolution of 6 mm, the high sampling rate (5 MHz) and the relative bandwidth allowed a high time resolution as well. Concerning electrostatic parameters the measurement technique of 5-pin triple

balanced Langmuir probe provided simultaneously local measurements of radial profiles of floating potential V_f, ion saturation current, I_s,and electron temperature T_e. Furthermore in the same location the three components of magnetic field fluctuations, B_r, B_θ and B_t, have been measured and the preliminary results are reported in this paper. The probe has been inserted in different radial position in order to investigate the edge region up to r/a~0.9, spanning a radial region of 36 mm at each shot. Due to probe insertion the plasma current has been limited to 300-350 kA with an average plasma density of about 2 $10^{19}m^{-3}$.

By using the statistical techniques described in [9] the occurrence of intermittent burst have been identified in the fluctuation time series. The spatial shape of electrostatic and magnetic structures have been investigated in the cross field plane (r, phi) by applying a conditional average technique on a time window including the intermittent events. The conditional average has been applied by averaging separately the positive and negative events on the reference signal.

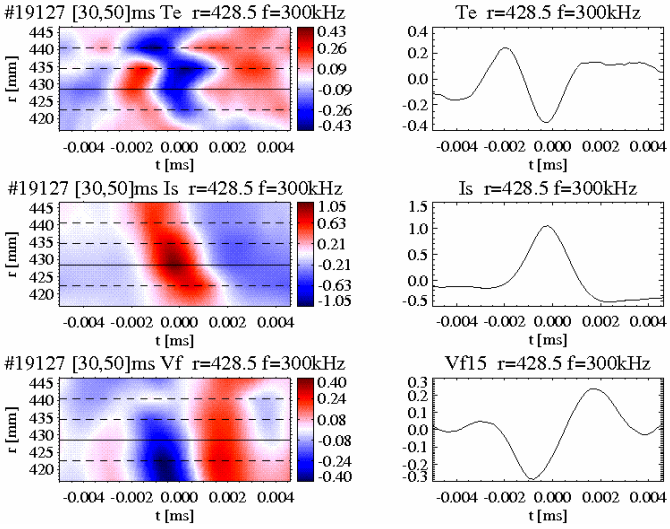

Fig. 1 Conditional average with trigger on positive events detected on I_s fluctuations at r=428.5 mm. From top to bottom panels: $(T_e(r,t)-\langle T_e(r,t)\rangle)/\sigma$ (left); $(T_e(t)-\langle T_e(t)\rangle)/\sigma$ at r=428.5 mm (right); analogous quantities for I_s and V_f.

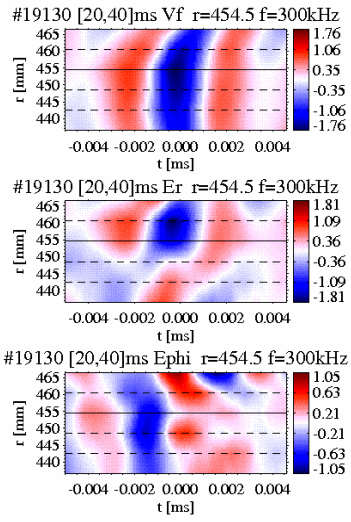

Fig. 2 Conditional average triggered on negative burst in V_f and performed on the same time windows on $E_r(r,t)$ and E_{phi} (r,t)

In fig. 1 an example of this kind of analysis is shown: as reference events positive burst at a time scale of τ=3.3μs on I_s signal at r= 428.5 mm have been chosen. The conditional average has been applied on the corresponding time windows $\Delta\tau=3\tau$ both to the reference signal and to the adjacent I_s measurements as well as to the radial arrays of V_f and T_e signals measured in the same location, for each plot the average fluctuation normalized to the standard deviation is shown. It

can be observed that the I_s events are associated to a radially extended structure (middle panel) of about 3 cm. By assuming that the structure travelling at the local E×B velocity (~20 km/s see ref. [10]) could pass the probe without major modifications, also a finite toroidal width of about 6 cm can be deduced. A spatial structure of V_f is also correlated to the I_s one and exhibit a dipolar feature, however also cases with a single pole on V_f are found. A typical phase-shift of $\pi/2$ characherizes V_f and I_s structures as already found [11]. Furthermore these structures are also correlated with a spatial structure of T_e (top panel), which in the most of cases exhibit a "colder" region corresponding to the I_s blob.

It has been found that a comparable size characterizes HeI emission structures observed by a Gas Puff Imaging diagnostics resolved at 10 MHz [12] and I_s fluctuations structures measured by langmuir probes. It is worth noting that the velocity of the structure measured by the GPI system is consistent with the average E×B velocity measured by the probes, and in particular the time lag between the structures observed by the two diagnostics is consistent with the hypothesis of a density structure travelling at the average E×B velocity between their two toroidal location. This experimental results provides a lower limit estimate of the lifetime of the structure of about 35μs, supporting the "frozen turbulence" hypothesis [13] assumed for the spatio-temporal transform of the fluctuations measured by the probes.

By using the radially and toroidally spaced V_f simultaneously measured, it is possible to calculate the radial profiles respectively of the radial, $E_r(r,t)$ and toroidal, $E_{phi}(r,t)$ electric fields and then to provide an estimate of the radial profile of the vector E×B flow, $\mathbf{v}_{E\times B}(r,t)$, in the cross field plane. Specifically the flow $\mathbf{v}_{E\times B}=(v_r,v_{phi})$, has been estimated as follows: $v_r=-E_{phi}/ B_\theta \sim \nabla_{phi}V_f/ B_\theta$ and $v_{phi}=E_r/ B_\theta \sim -\nabla_r V_f/ B_\theta$, remembering that in the edge region of an RFP $B\sim B_\theta$. By using the same statistical technique described above, the conditional average have been applied also to the calculated time series of $E_r(r,t)$ and $E_{phi}(r,t)$ and the results are shown in fig. 2. It can be noticed that to the V_f structure are associated radially extended structures with comparable sizes also on $E_r(r,t)$ and $E_{phi}(r,t)$. The time phase shift of about $\pi/2$ between the radial and toroidal local average electric fields along all the radial extension of the respective structures is consistent with a local vortex-like $v_{E\times B}$ pattern associated to the floating potential structure.

In order to verify if the above described electrostatic structures exhibit electromagnetic features, the conditional average technique has been applied also to the measured fluctuation of toroidal

and radial magnetic field, extending the investigation reported in [14]. An example is shown in fig.3 where the positive burst on I_s have been used as trigger events; it can be deduced that also radially extended structures, comparable or larger are associated to the electrostatic ones. Furthermore a time phase-shift is observed between B_r and B_t, which decreases going towards inner radial positions.

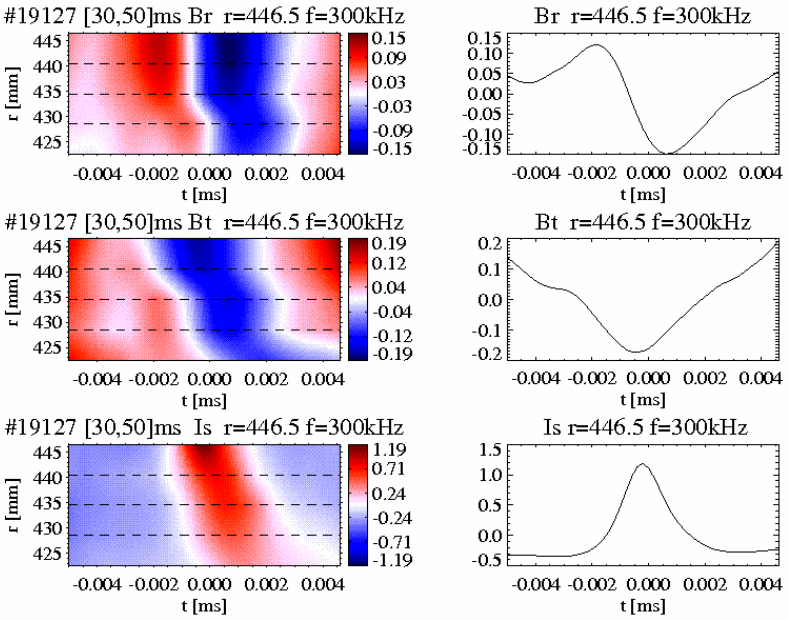

Fig. 3 Conditional average with trigger on positive events detected on I_s fluctuations at r=446.5 mm. From top to bottom panels: $(B_r(r,t)-< B_r (r,t)>)/\sigma$ (left); $(B_r (t)-< B_r (t)>)/\sigma$ at r=446.5 mm (right); analogous quantities for B_t and I_s.

Further investigation is needed to better understand the electromagnetic features of coherent structures in the edge region of RFX-mod.

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