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Features of electrostatic structures in Reversed Field Pinch edge region

M. Spolaore[1], V. Antoni[1,2], H. Bergsåker[2], R. Cavazzana[1], J. Drake[2],

E. Martines[1], G. Regnoli[1,2], G. Serianni[1], E. Spada[1], N. Vianello[1]

[1]Consorzio RFX, Associazione EURATOM-ENEA sulla Fusione, corso Stati Uniti 4, 35127 Padova, Italy; [2]Istituto Nazionale di Fisica della Materia, Unita' di Padova, Italy
[2]Alfvén Laboratory, Royal Institute of Technology, Association EURATOM/VR 10044 Stockholm, Sweden

A major subject in physics of magnetically confined plasmas for thermonuclear fusion research concerns the mechanisms which drive energy and particle confinement. It is recognised that in these plasmas fluctuations play a major role in determining the so called 'anomalous' transport [1]. 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 the RFP configuration it has been found that these bursts, although representing a small fraction of the signal, carry up to 50% of the particle flux losses [5].

A detailed statistical study of electrostatic fluctuations, performed in the edge region of the RFP experiments RFX [6] and Extrap-T2R [7], has shown that fluctuation bursts have an intermittent character. Furthermore these events tend to cluster during the relaxation processes typical in RFPs, highlighting a strong non linear coupling between internally resonant MHD modes and electrostatic fluctuations at the edge. It has been found that intermittent events correspond to coherent structures, with vortex–like velocity patterns, and a dominant rotation direction determined by the mean E×B drift velocity shear, in agreement with the behaviour in ordinary fluids [8].

Aim of this paper is to extend the investigation of these coherent structures comparing density and potential structures and plasmas with different mean velocity shear, in RFX [9] and Extrap-T2R [10], two RFP devices with aspect ratios R/a=2m/0.5m and R/a=1.2m/0.183m respectively. The data refer to low plasma current, respectively 300 kA and 80 kA, to allow the insertion of Langmuir probes arrays. The average electron density in RFX was about 2 $10^{19}m^{-3}$ and 5 $10^{19}m^{-3}$ respectively for hydrogen and helium discharges, and about 1 $10^{19}m^{-3}$ in Extrap-T2R for hydrogen discharges. Measurements of electrostatic quantities, floating potential, V_f, plasma density, n, and electron temperature, T_e, have been performed with 1 MHz sampling rate in RFX and 3 MHz in EXTRAP-T2R and the maximum bandwidth was 400 kHz in both experiments due to electronic conditioning of signals. It has been observed that the T_e fluctuations do not affect the main features of structures so that, in this contest, we assume that fluctuations of V_f and I_s, ion saturation current, are representative respectively of plasma potential and density fluctuations. The statistical analysis was performed taking into account the most significant time scales for the electrostatic particle flux, which is maximum at about 10 µs (RFX) and 5 µs (Extrap-T2R).

The spatial features of electrostatic structures have been obtained by using the conditional averaging technique applied to time window including intermittent events. Positive and negative events have been separately averaged. Figure 1 shows an example of this analysis applied to Extrap-T2R data, where two radial probe arrays have been used to measure simultaneously V_f and I_s, on six radial positions spanning a radial extension of 15 mm. The conditional average has been applied on positive events detected on I_s, and for a time window of 40 µs, suitable for investigating events with time scale of 5 µs. The spatial feature in a signal A is obtained as an ensemble average of $a=(A-\langle A\rangle)/\sigma$, where σ is the root mean square of signal in the time window. In figure 1, where $A=I_s$ (top) and $A=V_f$ (bottom), the 2-D plots *a(r,t)* (left) and the time behaviour (right) at the radial position where the events have been detected are shown. It can be observed that both V_f and I_s structures have a radial extent of a few cm and, from the time width of the average structures a toroidal extent of few tens of cm, can be deduced [11]. Structures detected in V_f and I_s are well correlated, and a similar result is found using events in V_f signal as reference intermittent events, instead of those in I_s.

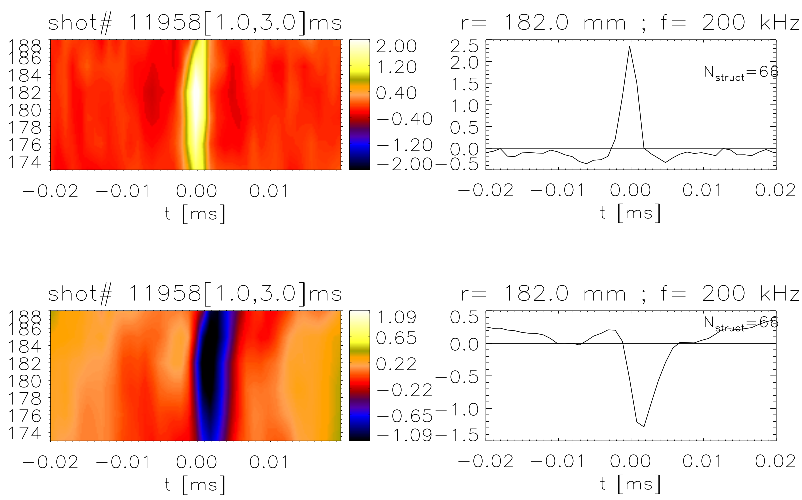

Fig 1 Conditional average on Is peaks. Top: (Is(r,t)-<Is(r,t)>)/σ (left); (Is(t)-<Is(t)>)/σ at r=182 mm (right); bottom: analogous quantities for Vf.

It has been observed that the same phase shift, of about π/2, characterizes the relationship between I_s and V_f structures in all cases. As it is known that vortices in sheared plasmas tend to evolve from dipolar to monopolar ones [12,13], this result may suggest that these structures are non symmetrical dipolar vortices undergoing the effect of the velocity shear.

In figure 2 (bottom) the distribution along the radial direction of the relative fraction of positive events, N_p, over negative events, N_n, is shown and for comparison the corresponding average E×B drift profile is also shown (top). These quantities are shown for three experimental conditions. In the region r/a<1, the ratio N_p/N_n is lower than 1, where the $v_{E\times B}$ shear is negative, and swaps to values higher than 1, where the shear is positive. In particular in He case in a wide region at low shear results N_p/N_n~1, confirming that in absence of shear no selection is provided. It is worth noting that in the region r/a>1 different mechanisms, due to the interaction between vortices and the wall become important.

The radial distribution of the total number of detected structures per millisecond is also shown in the same figure (bottom). No clear correlation between the number of structures and the shear is observed and this is consistent with the effect of a relatively weak E×B shear, which can select the rotation direction of vortex–like structures, but which is not strong enough to destroy them.

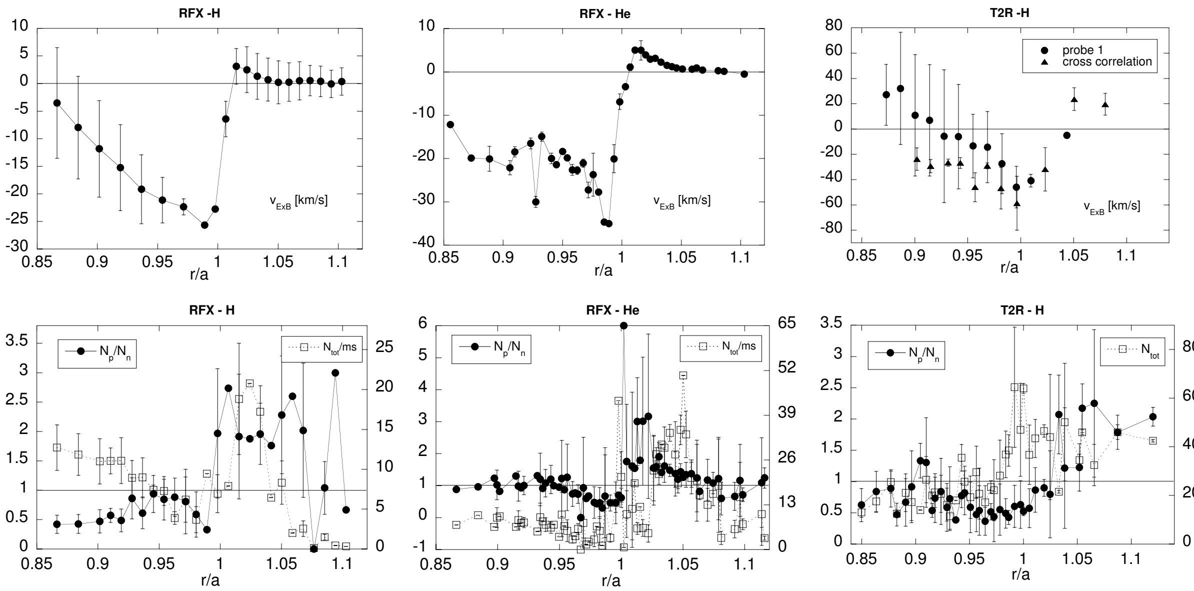

Fig. 2 Top: radial profiles of vE×B; bottom: positive over negative events ratio and total number of intemittent events per ms vs r/a

From a theoretical point of view the dipolar structures, consisting of two counter rotating vortex, are the natural, finite amplitude solution in a non sheared plasma, and an important role played by this kind of structures in driving anomalous transport is predicted by theory [12,13,14]. An investigation on the possible presence of dipolar structures and their radial distribution has then been performed on the discharges that we are studying and the preliminary results are shown in the figure 3. As a working hypothesis we assume that, where positive and negative events are detected as intermittent events, they are coupled as much as possible as dipolar structures. Therefore the total number of the so called monopolar structures, N_{mono}, and dipolar structures, N_{dip}, can be estimated as: $N_{mono} = \left|N_n - N_p\right|$ and $N_{dip} = \left(\left(N_p + N_n\right) - N_{mono}\right)/2$.

Figure 3 shows the relative fractions of monopolar and dipolar structures vs the normalized radius, for the same three cases examined in figure 2. It can be observed that, as expected, the radial distribution of the dipolar structure fraction is not uniform and in particular it is higher where the E×B drift shear is relatively low.

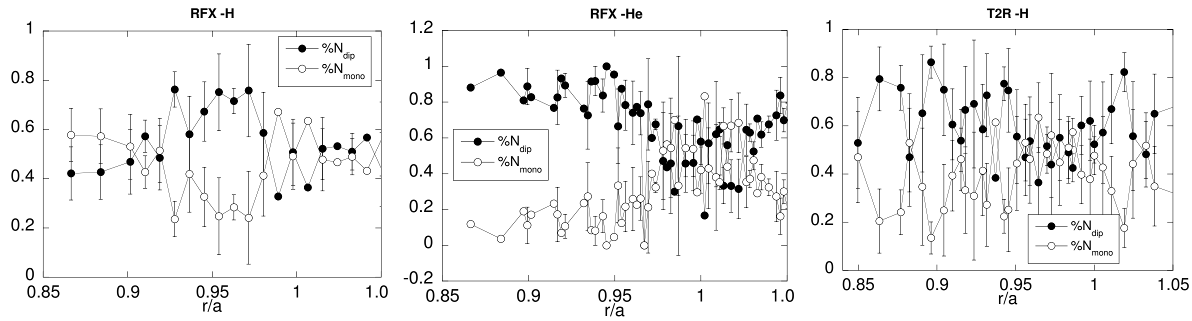

Fig. 3 Relative fraction of monopolar and dipolar structures vs r/a

In conclusion it is confirmed that the E×B drift shear, observed in the edge of RFP experiments provide a selection effect on the rotation direction of the structures while it does not seem to affect their number. The presence of dipolar structures has been assumed and their estimated radial distribution results higher in the regions where the flow shear is lower, as predicted by theory. Work is in progress to set up an improved tool for a better identification of dipolar vortex structures and for gaining insight on their role in providing anomalous transport.

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