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Coherent structures in the simple magnetised Thorello plasma

C. Riccardi[1], H.E. Roman[1], R. Barni[1], M. Fontanesi[1]

[1] *Dipartimento di Fisica Occhialini, Universita' degli Studi di Milano-Bicocca,*
p.za della Scienza, 3 I-20216 Milano, Italy

The study of turbulence in magnetized plasmas is of great importance due to its link to the practical problem of increasing the quality of plasma confinement. Indeed it is established that anomalous particle transport plays a major role in reducing the confinement in fusion devices [1] and more generally in magnetized plasmas. In the past years a consensus is arising on the role that burst-like structures plays in transport. Such kind of objects has been analysed with different techniques in several different devices, including tokamak SOLs [1-2], stellarators and reverse field pinches [3], simple magnetized tori [4] and linear Q-machine [5]. Here we report on an experimental study of coherent structures in the turbulent regime of the simple magnetized toroidal device Thorello. There a low temperature, high density steady turbulent plasma state can be produced and mantained in a hydrogen low pressure discharge [6]. Turbulence has been studied by means of multiple pin electrostatic probes. A conditional sampling analysis has been performed to detect the spatiotemporal evolution of structures in a poloidal section of the device. The Thorello device produces a hot cathode discharge in a magnetized torus, with a peculiar non-axisymmetric potential well. The plasma is produced in a steady turbulent state with a high level of electrostatic fluctuations (with rms up to 50% of their mean value, shear in the radial electric field and other interesting features [8]). Typical parameters of this very low β plasma are T_e~1-4 eV, T_i~0.3 eV, n_+~5 $\cdot 10^{11}$ cm^{-3} at center and decreasing by two order of magnitude in the edge. The Debye length as well as the ion Larmour radius are small everywhere. The electrostatic fluctuations of density and plasma potential are obtained by means of a Langmuir probe array, made up of four tungsten wires. The scanning probe system, developed to study a 3D portion of the plasma, has been used to characterize an area 9x8 cm^2 of the poloidal section in a grid with 323 positions. In order to apply the conditional sampling technique we also put a reference single pin probe at a fixed position in the poloidal section, toroidally apart by 3 cm. Conditional sampling has been performed on the floating potential and ion saturation current time series, requiring that a particular condition is met in the simultaneously acquired reference probe time series (such an event triggers the selection of a fixed time window out of the scanning probe time series [4]). A hundred time windows, about 100 μs long, have been acquired and averaged for each position. In addition, mean plasma parameters have been extracted from averaged Langmuir characteristics, obtained by summing one hundred probe current curves measured slowly sweeping the probe potential (100 V in 0.1 s [7]). Reported experiments refers to steady discharge conditions, when the filament current, the toroidal magnetic field, the hydrogen pressure and the cathode bias with respect to the grounded ring limiter are fixed (I_f =116 A, B=0.1 T, P=2$\cdot$ 10^{-4} mbar, V_c=-80 V). The discharge current stays almost stationary for a few hours, I_d=0.82±0.02 A. Maps of the mean poloidal section profiles of the ion density, electron temperature and plasma potential are shown in fig.1.

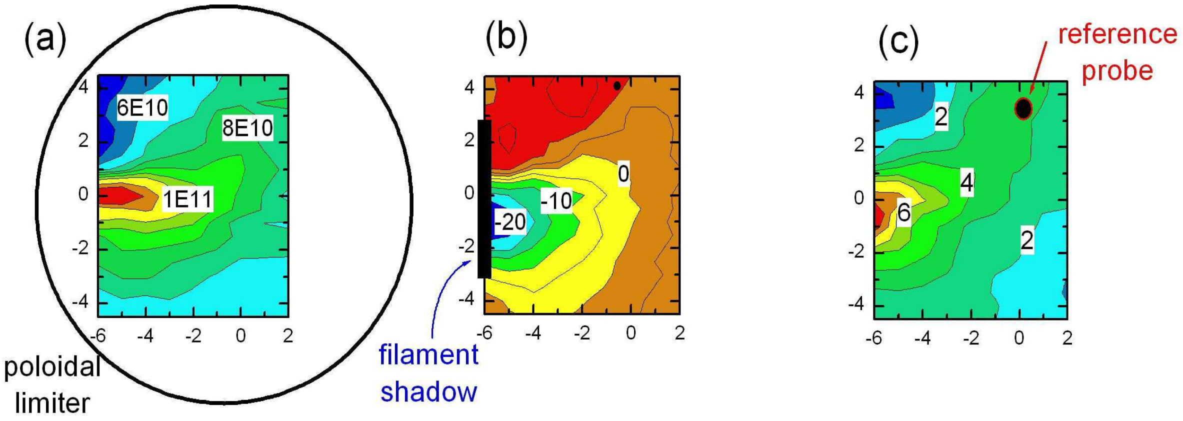

Fig. 1 - Mean ion density (a), plasma potential (b) and electron temperature (c) in the poloidal cross-section. The location of the filament, of the reference probe and of the poloidal limiter are also displayed.

The potential well is centered on the filament and appears to be partially asymmetric and elongated. The reference probe position was chosen at the edge of the well. The corresponding ExB velocity is always subsonic and reaches 10 km/s on the upper edge. We observe also that such velocities are substantially larger than any other drift or Bohm diffusion rate. Potential profile asymmetry implies that the plasma rotation cannot be uniform and a velocity shear develops around the edge of the potential well. Ion density peaks at the filament and a dense plasma fills the potential well (n_+~1-2$\cdot 10^{11}$cm^{-3}). However a diffuse plasma is present also in the whole poloidal cross-section of the device (n_+~3-6$\cdot 10^{10}$cm^{-3}). Electron temperature is about 3-5 eV in the potential well, while outside the plasma is colder, with T_e~1-2 eV. Besides conditional sampling analysis, the acquired time series were used to make some statistical characterization of the turbulent regime. A substantial intermittency was observed (Skewness, S=-0.64±0.05; Kurtosis, K=0.48±0.24). Power spectra are generally broad, showing several peaks, usually below 50 kHz and a power-law high frequency tail, with exponents ranging between -2 and -4.5. No single peak appears to dominate. The autocorrelation function of the reference probe potential shows a central peak surrounded by an alternating series of minima and maxima of decreasing amplitude. The peak periodicity is about 35 μs, while their amplitude decreases like a power-law with an exponent of -1.3±0.1, indicating some long-range correlations between subsequent bursts. Because of the negative skewness, we chose to report here about negative potential structures, selected with a threshold of $-2.75\cdot\sigma$ for trigger. A mean of 83±16 events have been found and averaged during scan and the results are displayed in fig.2. The structure in the a.c. floating potential looks like a dipole vertically oriented. It appears from the inside in the upper part, just across the edge of the mean potential well. It propagates radially outwards mainly along this edge in about 15 μs. Superimposed to the mean d.c. potential, it appears as a small displacement and flattening of the potential well. The dipole extends itself radially for 2-3 cm, while it is long about 5-6 cm in vertical direction. As for the ion saturation current the structure appears as a broad positive blob (that is corresponding to an increased plasma density), moving radially outwards and detaching from the main plasma column, with extension comparable to the size of the scanned region, with sizes of 2-3 cm in both directions. Time evolution seems compatible with the overall ExB velocity (blob pictures imply a mean speed of 3.3 km/s). Lifetime of the reported structures appears smaller than in other similar devices [4]. This could be adscribed to the potential well asymmetry leading to shape distortion and to an accelerated loss of coherence. However the conditional sampling procedure do not allow to draw definite conclusions about that due to smearing induced by the averaging method.

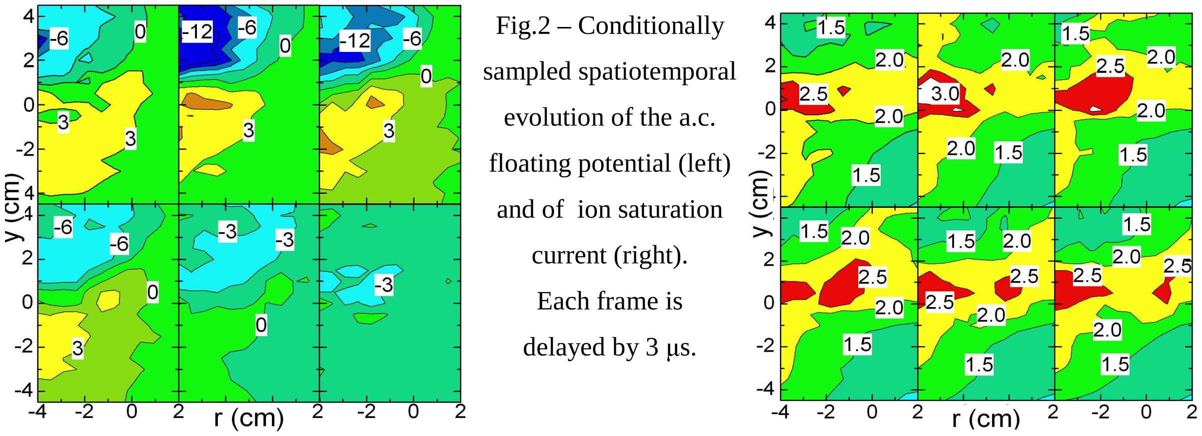

Fig.2 – Conditionally sampled spatiotemporal evolution of the a.c. floating potential (left) and of ion saturation current (right). Each frame is delayed by 3 μs.

An independent way to study the structure coherence and motion is based on the measurement of the cross-correlation between the whole time series of the moving and the reference probe. The shape of the cross-correlation between the two floating potential time series looks similar to that of the autocorrelation function, with an oscillating damped time dependence. The amplitude of the main peak reflects the degree of time coherence in the correlation while the position of the main peak reflects the delay time in the correlation between the two spatially separated positions, which are displayed in fig.3. Cross-correlation is high in the upper part and the delay time increases almost linearly with the radial separation, as expected if the correlation signal is caused by an extended structure which is moving radially at an almost constant velocity. Cross-correlation of the ion saturation current with the floating potential in the reference probe shows a negative main peak with smaller amplitude, while the delay time displays the same pattern. Fig.4 shows the contour plots of the cross-correlation measured along a horizontal line. A clear radial motion of the correlation is displayed by the results, with an almost constant velocity of about 5.5 km/s, comparable to that inferred in the conditional sampling analysis. In conclusions, results show the presence of spatially small density fluctuations propagating mainly under the overall ExB drift, associated to a local modification of the electric field. The evolution is a net ExB drift inducing transport of plasma blobs across the magnetic field towards the limiter which could contribute to the anomalous transport, as pointed out in theoretical models and simulations [8]. Our results support the view that outwards convection of plasma blobs is a general feature of magnetised plasma turbulence. However the detailed phenomenology does depend on the particular experimental conditions, casting some doubts on the kind of universality recently claimed [9]. Several statistical characteristics of plasma turbulence, known since a long time, appear to be linked to such burst phenomenology, as the intermittent character of plasma fluctuations.

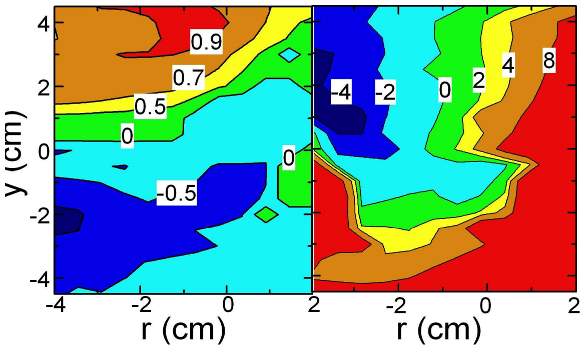

Fig.3 – Peak amplitude (left) and time delay (right) of the cross-correlation.

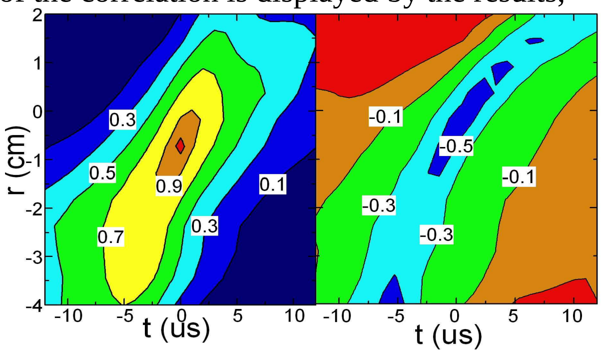

Fig. 4 – Cross-correlation for the floating potential (left) or for ion saturation current (right) measured along a line.

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