COHERENT STRUCTURES IN THE EDGE REGION OF THE CASTOR TOKAMAK

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Coherent structures are localized and long-lived structures which form in a turbulent medium due to nonlinear interactions [1]. Their existence in fluid turbulence formed in the boundary layer near solid walls is well known, as is their role in determining the frictional drag exerted on the wall. Several authors have pointed out the existence of coherent structures in the electrostatic turbulence measured in the Scrape Off Layer of tokamak plasmas [2,3]. Such findings are in agreement with the predictions of drift wave turbulence simulations, which also show the formation of coherent structures [4].

In this paper we report a clear experimental evidence of the existence of coherent structures in the edge plasma of the Castor tokamak (R = 40 cm, a = 8.5 cm, B_T = 1 T, I_T = 8-18 kA). The experiments have been performed inserting in the edge plasma a 2D array of electric probes located on the poloidal plane. The array consists of 64 (8 by 8) graphite pins housed in a stainless steel housing covered by an insulating coating of BC. The array is inserted from above, so that the 8 columns of probes extend in the radial direction, as shown in fig. 1. For the present experiments only the innermost 6 rows of probes were sampled, for a total of 48 probes. The array was inserted at several radial positions, and in some cases part of it fell inside the last closed flux surface (LCFS). The LCFS is defined by a downward shift of the plasma column and a poloidal limiter, and in the discharges under consideration was located, in the upper part of the machine, at r = 65÷70 mm. The effect of the array, which acts itself as a local limiter when protruded inside the LCFS, is discussed below. The horizontal distance between adjacent probes is 6 mm and the vertical distance is 4.5 mm, so that the area covered by the active pins is a rectangular region of 42 by 22.5 mm. The pins have been used to measure the floating potential V_f at a sampling frequency of 1 MHz. A moving average with a window of 201 samples is subtracted from the signals prior to the analysis. This treatment corresponds to a high-pass filtering which isolates the fluctuations discarding the slow equilibrium evolution.

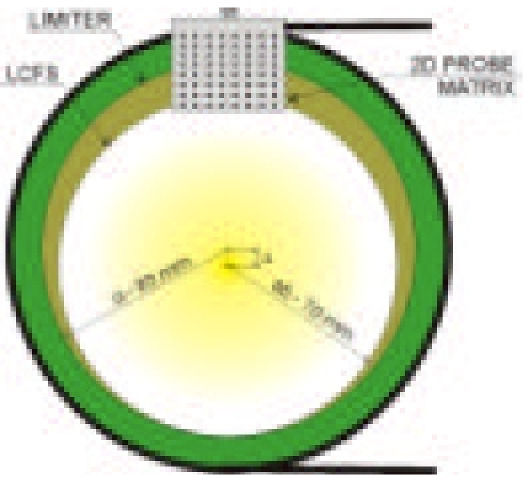

Fig. 1: Schematic of the 2D array of probes in the Castor poloidal section.

The visual inspection of the V_f patterns recorded by the probes and of their time evolution shows the presence of potential “blobs” (structures) which flow in the poloidal direction according to the **E**×**B** rotation of the plasma. The cross-correlation function $C(\tau,\theta)$ has been computed for each row of probes (i.e. for each value of the radial coordinate). The result is shown in fig. 2. The cross correlation function displays an inclined pattern which indicates a poloidal propagation. The propagation velocity is consistent with the **E**×**B** velocity evaluated from the avreage V_f profile. Furthermore, the velocity is different in the different frames of fig. 2, which correspond to different rows of the matrix and therefore to different radial positions. This is the signature of the presence of a velocity shear. The slopes of the patterns in fig. 2 suggest a poloidal propagation speed ranging from 2 km/s at r = 87.5 mm to 8 km/s at r = 69.5 mm. The patterns shown in fig. 2 give also information concerning the radial correlation length of the turbulence, which turns out to be less than 5 mm in the most external positions and up to 2 cm in the most internal ones.

The motivation for the search of coherent structures comes from the observation that the floating potential patterns seen by the array seem to repeat themselves in a quasi-periodic fashion. An example of this behaviour is shown in fig. 3, where the measurements made by one column of probes (the most upstream one) are plotted as a function of time and radial position. The red corresponds to negative voltage and the blue to positive one, with peak values at ±27 V. The presence of a quasi-periodicity is apparent from the figure. This has motivated further analysis, carried out under the assumption that the periodic behaviour is due to long-living structures convected poloidally by the plasma, with a lifetime much longer than the poloidal revolution period.

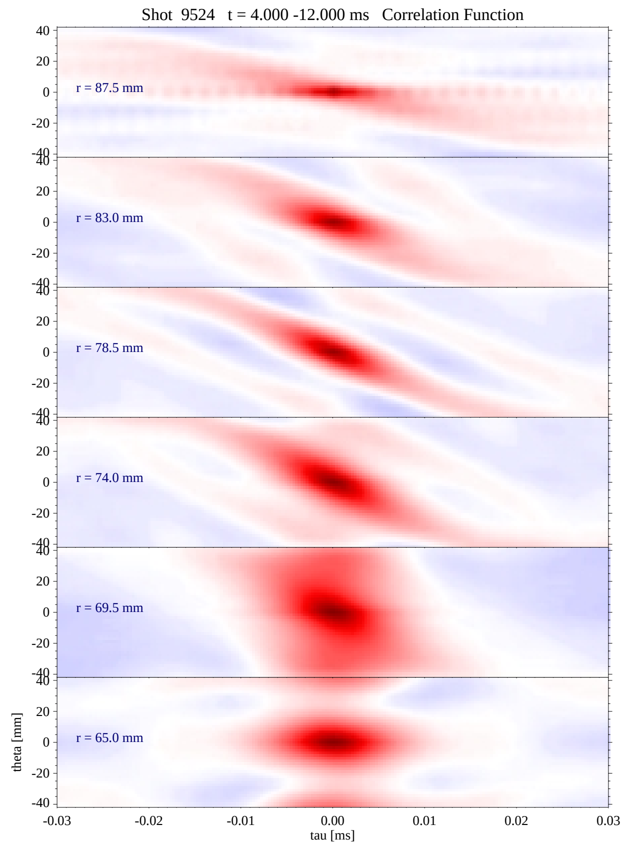

Fig. 2: Cross-correlation function $C(\tau,\theta)$ at several radial positions.

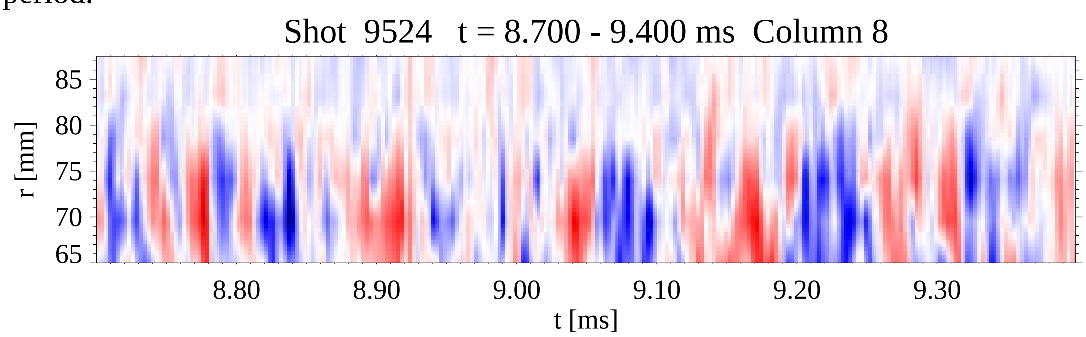

Fig. 3: Signals from upstream column of probes.

A further proof of the presence of periodicity is given by the autocorrelation function. Since the structures in fig. 3 appear to be rather elongated in the radial direction, the autocorrelation function has been computed on the average of the signals of the three most inserted probes of the upstream column. This treatment enhances the effect of the elongated structures. The result is shown in fig. 4. An oscillating behaviour is clearly seen on the function, well above the significance level shown by two horizontal dotted lines. The oscillation is convolved with a decay, which has been found to have the shape of a power law. Indeed, the dashed curve in

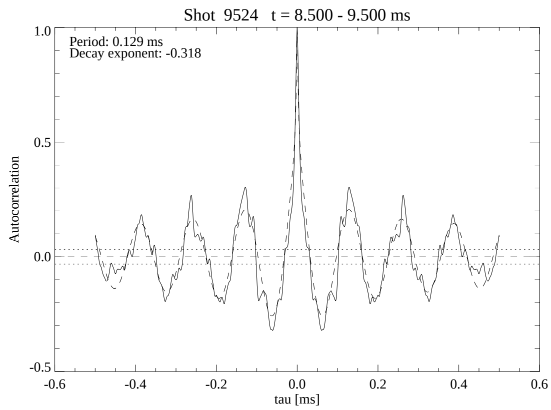

Fig. 4: Autocorrelation function computed on the average of the three most inserted probes in the upstream column.

fig. 4 is the result of a fit with a function of the kind $f(\tau) = (\tau/\tau_0)^{\alpha}\cos(\omega\tau)$. The curve fits well the data with an oscillation frequency $\omega/2\pi$ = 7.7 kHz and a decay exponent α = -0.32. It is worth noting that an exponentially decaying curve does not give a good fit. The power-law decay is in agreement with previous findings of long range correlations in the turbulence measurements in the edge of fusion devices [5]. The rotation frequency corresponds to a poloidal velocity of 3.4 km/s, compatible with the **E**×**B** velocity. This confirms the hypothesis that some turbulent structures are convected poloidally, living long enough to execute several poloidal revolutions.

The long life of the structures suggests that, to a first approximation, the turbulence can be considered as frozen during one poloidal revolution. Based on this idea, the data shown in fig. 3, taken within two subsequent revolution periods, have been mapped onto the poloidal plane, assuming a constant rotation velocity. The result, shown in fig. 5, further confirms our working hypothesis. In fact, the two resulting patterns share many similarities, supporting the idea of frozen turbulence convected by the plasma rotation.

Turning now to the issue of whether the turbulent structures under study deserve the name of “coherent structures”, it is worth noting that some disagreement exists in the literature about the definition of coherent structure. One popular definition in the field of fluid turbulence is to call coherent those eddies which have a lifetime longer than the eddy turnover time, defined as $\tau \sim l/v$, where l is the characteristic size of the eddy and v is the characteristic velocity. In our case, since the structures under study can be characterised as potential blobs, they will give rise to an eddy-like plasma motion around them, due to the fluctuating **E**×**B** velocity. It is thus

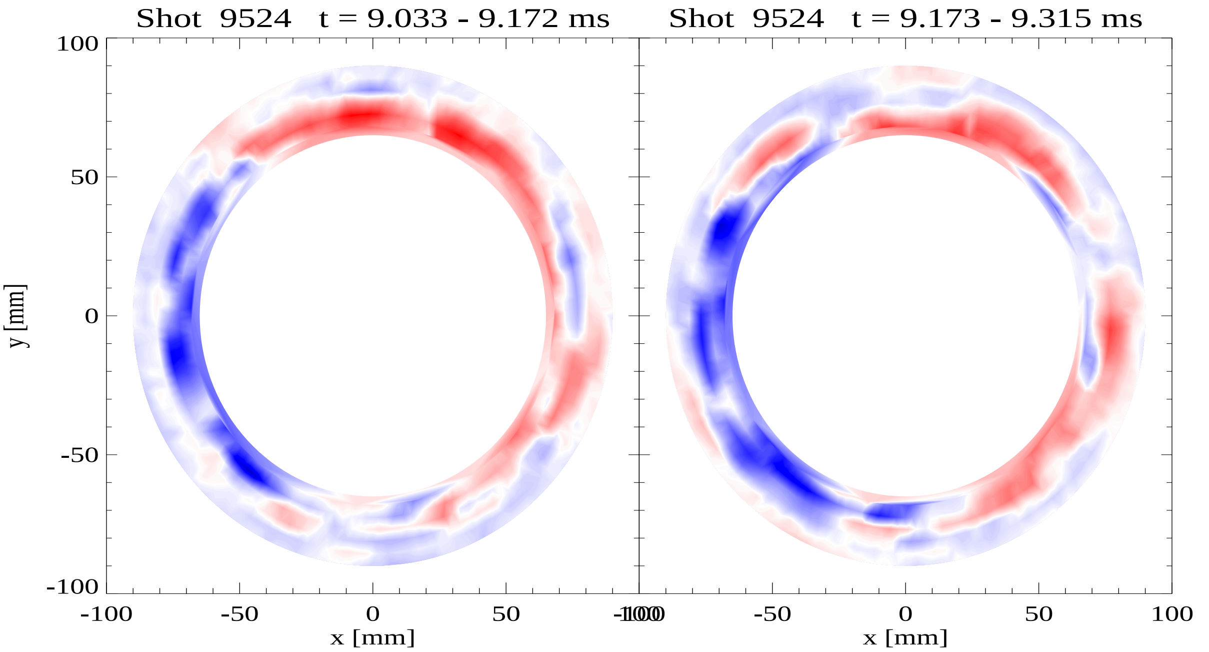

Fig.5: Measurements of the upstream column of probes mapped onto the poloidal plane for two subsequent poloidal revolutions of the plasma, under the assumption of frozen turbulence.

possible to define a characteristic speed as v ~ E/B ~ ϕ/lB, where ϕ is the height (or depth) of the potential structure. We thus have a turnover time $\tau \sim l^2B/\phi$. Being l ~ 5 cm and ϕ ~ 30 V, the resulting time is τ ~ 80 μs. This is much shorter than the structure lifetime, which is several times the revolution period T ~ 150 μs. It is therefore possible to conclude that in the edge of the Castor tokamak there are coherent structures in the electrostatic turbulence.

As mentioned in the introduction, the 2D array is rather large and acts as a local limiter when protruded inside the LCFS. This might lead to the impression that the coherent structures are confined to the Scrape Off Layer (SOL), since this is the only region which can be seen by the probes. Although this is partially true, it is very interesting to observe that a different behaviour is observed by those probes which, in the unperturbed case, would fall inside the LCFS, and those which would fall in the unperturbed SOL. An example of this is shown in fig. 6, which is the same as fig. 3, but for a different discharge in which the array was protruded more. A very clear distinction can be seen between the regions inside and outside r = 67 mm. This position can be considered, given the spatial resolution of the probe array, as coincident with the unperturbed LCFS. Generally speaking, a positive structure at r > 67 mm is associated with a negative one at r < 67 mm, and viceversa. This is not always true, though, since some structures are found to elongate over most of the radial span covered by the array. It is worth noting that a behaviour of the autocorrelation function similar to that shown in fig. 4 is found also by considering an average of all the probes of the most inserted row for the case of fig. 6. This indicates that also the structures at r < 67 mm can be ragarded as coherent.

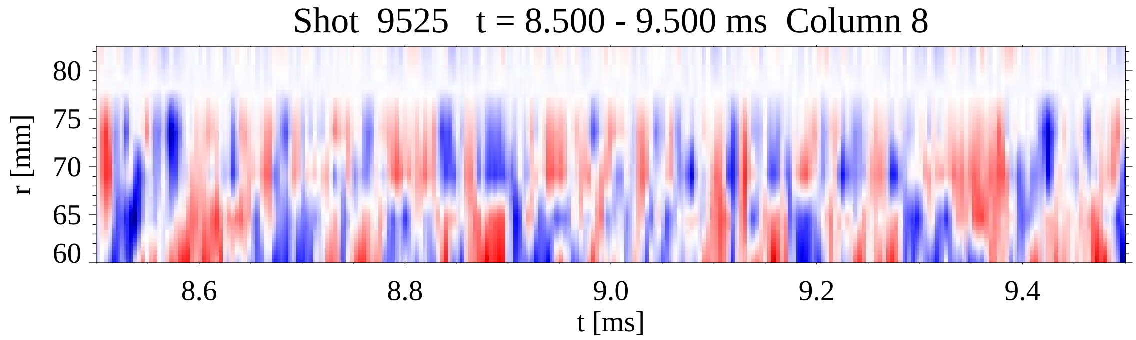

Fig. 6: Signals from the upstream column of probes, at deeper insertion than in fig.3.

In conclusion, it has been shown that the electrostatic turbulence in the edge of the Castor tokamak features long-living coherent structures. These structures are found in the SOL created by the machine limiter, and also in the confined plasma. In this second case it is not possible to rule out a perturbing effect due to the probe array. However, the clearly distinct features of the structures within and outside the unperturbed LCFS indicate that this perturbing effect is not enough to completely disrupt the distinction between SOL and confined plasma, so that some of the features of this second region are certainly retained even in the presence of the array.

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