Plasma edge properties in different magnetic topologies in the RFX-mod device

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In nuclear fusion devices confinement properties are strongly affected by the physics and the transport in the edge region [1], due mainly to the presence of turbulence and coherent structures moving within the plasma [2]. Despite differences in the magnetic configuration (reversed field pinch, tokamak, stellerator), turbulence arises in a region where strong gradients of temperature and density are present, acting as sources of free energy for turbulence development. Besides turbulence and gradients, in Reversed Field Pinch (RFP) experiments the peculiar decreasing profile of the safety factor q from the core to the wall and the presence of the reversal surface in the edge where $q=0$, create a complex magnetic topology at the edge. At the reversal surface, few centimetres from the first wall, all the $m=0$ magnetic modes resonate, and a chain of almost poloidally symmetric islands are formed; these islands are modulated by the beating of $m=1$ modes [3]. In the RFX-mod RFP experiment ($R=2$ m, $a = 0.46$ m) the edge region is well diagnosed, and it is possible to measure the radial profiles of electron density (n_e), temperature (T_e), pressure (P_e), the fluctuations due to turbulence and the magnetic modes. In particular it is possible to study the mutual interactions between these phenomena and their role in the plasma confinement. The main diagnostic used here to measure the profiles is the thermal helium beam [4]: it measures the three emission lines of the HeI injected into the plasma edge: $\lambda_1=667.8$ nm,

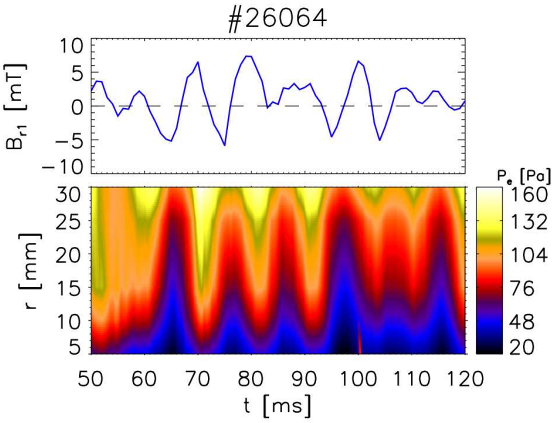

Fig1: *time evolution of the radial component of $m=1$ modes (top) and of the electron pressure profile in the far edge ($r=0$ is the first wall).*

λ_2=*728.1 nm*, and λ_3=*706.5 nm*. The intensity ratio between λ_1 and λ_2 is proportional to the local n_e, and the ratio between λ_2 and λ_3 is proportional to the local T_e.

In *Fig.1* the correlation between the magnetic field and the plasma edge is clarified, by showing how the radial component due to the *m=1* modes (B_{r1}) modifies the electron pressure profile measured between *5* and *30 mm* from the first wall. $P_e(r)$ has cyclical periodical oscillations well correlated with the oscillations in B_{r1}: when B_{r1} assumes positive values (outward), plasma pressure increases and the gradient becomes steeper. A similar interaction is observed also for both T_e and n_e. This behaviour confirms the relation between magnetic topology and electron temperature profile modification as described in [5].

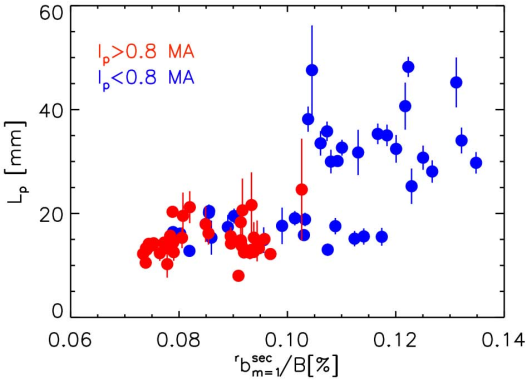

Fig2: *Characteristic pressure scale length at the far edge as a function of the normalised amplitude of the secondary modes for two different plasma currents (red and blue points).*

A deeper insight in the relation between the magnetic topology of the edge and the gradients is given by *Fig.2*, where the characteristic radial pressure length L_p is compared with the amplitude of the radial component of the secondary modes ${}^{r}b^{\sec}_{m=1}$ normalised to the total magnetic field at the edge, for two different plasma currents. The amplitude of the secondary modes is evaluated as ${}^{r}b^{\sec}_{m=1} = (\sum_{n=-8}^{-15} ({}^{r}b_{m=1,n})^2)^{1/2}$, when excluding the *m=1, n=-7* that is the dominant one. The relation between the magnetic boundary and L_p is evident: on decreasing the magnetic fluctuations, i.e. with an improved magnetic boundary, the pressure profile becomes steeper. It has to be noted that at higher level of magnetic fluctuations the plasma exists in a so-called multiple helicity state, where a stochastic core is present; on the other hand for lower level of secondary modes a more ordered topology is found (Quasi Single Helicity) with better plasma confinement [6]. So an improvement in the plasma core is linked with an improvement also in the edge. Since the edge gradients can be one of the possible drives for the generation and evolution of the edge turbulence, it is interesting to study the existence of a link (if any) between L_p

and the spatial dimension of the edge structures. Coherent structures (blobs) are detected in the edges of all fusion devices [2,7], and their average perpendicular dimension L_b can be estimated as: $L_b = v_\perp \tau_a$, where $v_\perp$ is the perpendicular velocity of the edge fluctuations, and τ_a, is their autocorrelation time. The autocorrelation time can be interpreted as the time needed by the average blob to cross the field of view of the diagnostic, thus multiplying by the velocity it is possible to estimate its perpendicular width. The signals used for this analysis are the fluctuations of the neutral HeI collected in the edge using the Gas Puff Imaging diagnostic [8]; this signal is mainly proportional to the local electron density. *Fig3* shows the relation between L_b and L_p: every cross is an average during the flat top phase of the discharge, and the green line is the linear fit of the data. The x-axis is divided into 4 intervals and the average value of the characteristic pressure length and L_b have been calculated and reported in the plot (red full triangles).

The average perpendicular dimension of the turbulent structures increases linearly with L_p, suggesting that there is a mutual interaction between the pressure gradient and the edge turbulence. Two interpretations can be given of this evidence: (a) the pressure gradient is a source of free energy for the turbulence, L_p is the injection scale, the average coherent structures are born with a dimension L_b linked with L_p and then they break into smaller ones; (b) the coherent structures interact directly with the gradients determining their scale length. More detailed analyses have to be done in order to distinguish between (a) and (b).

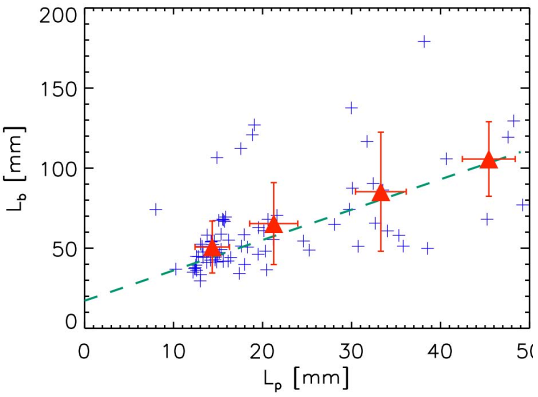

Fig3: *perpendicular dimension of edge structures L_b as a function of the pressure scale length L_p.*

With the conditional average technique applied to the signals of the thermal helium beam it is possible to measure the two dimensional electrostatic parameters of the coherent structures (also at high plasma current, up to the maximum achievable by RFX-mod, *2 MA*, when insertable probes cannot be used), as reported in *figure 4*. The plane shown is the radial-toroidal plane (time can be converted in toroidal angle by considering the toroidal velocity of propagation of the fluctuations), which is the plane perpendicular to the magnetic field at the edge. The bursts are positive blobs of density and pressure, with a more complicated pattern in temperature. The radial extension of the average structure is comparable with the radial range covered by the diagnostic; it appears also slightly stretched in the toroidal direction, probably due to the presence of the radially sheared toroidal flow that characterises the edge region. These results of the conditional average are similar to what has been observed with Langmuir probes for low current discharges ($I_p = 350 \div 450$ *kA*) [9].

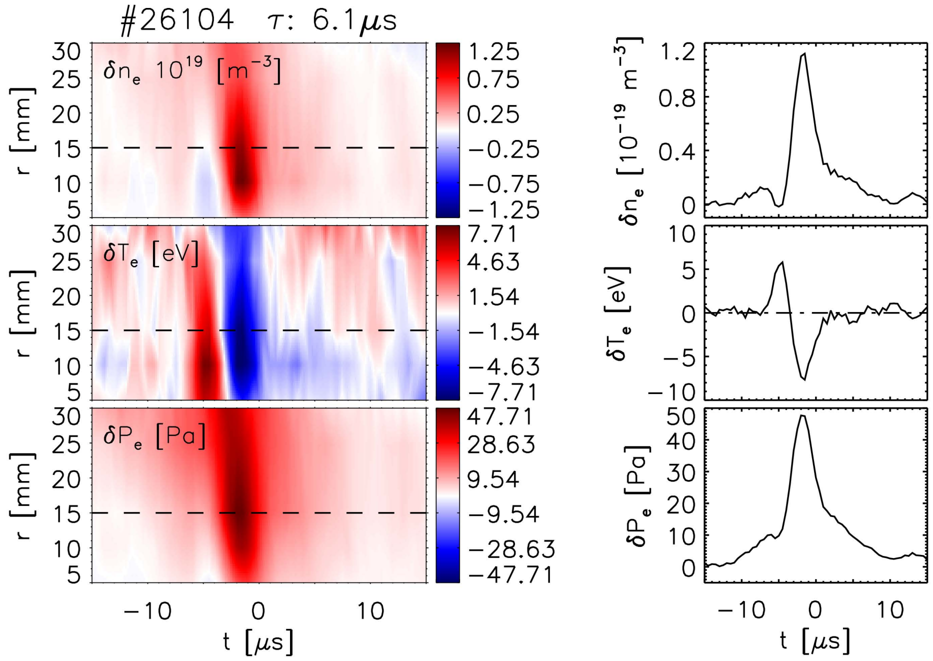

Fig4: *edge structure of electron density, temperature and pressure obtained with the conditional average technique. At right, conditional average structure for r = 15mm*

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