Electromagnetic filaments and edge modifications induced by electrode biasing in the RFX-mod tokamak

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H-mode in magnetic plasma confinement devices is characterized by the creation of an edge transport barrier and a reduction in the turbulence levels [1]. Such reduction is usually associated with a massive shear in plasma flow, which impacts on turbulence structures at the edge and scrap-off-layer (SOL). Blobs or filaments are coherent structures that appear at the edge and SOL of magnetic plasma confinement devices. They are usually identified as a density structure, aligned to the magnetic field and with a potential dipole (with a vorticity associated) transverse to the ExB driven motion and electromagnetic feature [2]. On the other hand, the Edge-Localized Modes (ELM's) are also filament structures; they appear at the plasma edge during the H-mode and are related to a quasi-periodic relaxation of the transport barrier [3]. Nevertheless, they hold many characteristics of the turbulent blobs, which bringing an interesting parallel between them. The aim of this work is study blobs at edge and SOL in the RFX-mod operating as tokamak in L and H-mode [4], free ELMs and ELMs phase.

This experiment was carried out in the RFX-mod [5], operating as tokamak, with plasma current ≈ 50 kA, central line density average $\approx 2 \times 10^{18}$ m^3 and magnetic field on axis up to 0.55 T. An insertable Langmuir probe with two towers spaced 88 mm poloidally was used in this work. This probe, called U probe, has 40 tips (5x8 array) in each tower, with 5 pins align poloidally and spaced 3 mm and 8 tips align radially and spaced 6 mm. Moreover, seven magnetic 3-axial coils 6 mm radially spaced are installed in each tower, allowing thus the simultaneous measure of the three components of the local magnetic field. The probe was inserted at the low field side equatorial plane. All probe data were acquired with a sampling frequency of 2 MHz. H-mode is induced in the RFX-mod operating as tokamak through an electrode biased inserted at plasma edge from the bottom, producing a negative voltage up to -400 V with respect to the wall (ground potential). The voltage signal on the electrode is a square pulse with 400 ms duration. The global view can be seen in the Fig.1. The average
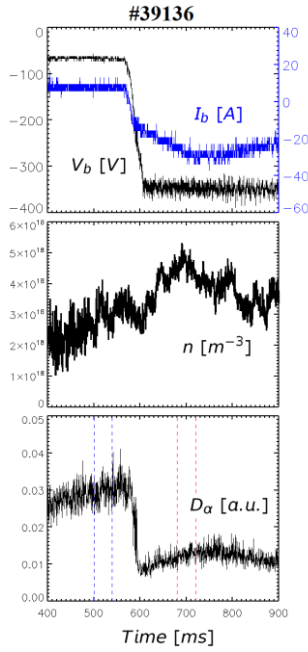
Fig.1 Bias voltage (V_b) and bias current (I_b), average central line density (n) and D_α line. LH transition.

electron and ion temperature, respectively. The biasing increases the shear layer, which quench the fluctuations by turbulence decorrelation and generates a transport barrier [1].

central line density (n) increases during negative biasing, while the D_α line decreases [6]. These are signatures of the improvement on the plasma confinement: since less particles scape from the confinement (the recycle rate decreases), the core density increases.

The biasing also provokes a change in the edge and SOL. Fig. 2 shows the profiles of floating potential and ion saturation current in time, after and during biasing. A huge change can be noticed: the floating potential profile get steeper during biasing, with lower values inside plasma and almost no change in the SOL. In the same way, the ion saturation current increases inside the plasma and decreases in the SOL, causing a rise in electron density gradient, since $I_{sat} \propto n(T_e + T_i)^{1/2}$, T_e and T_i are the
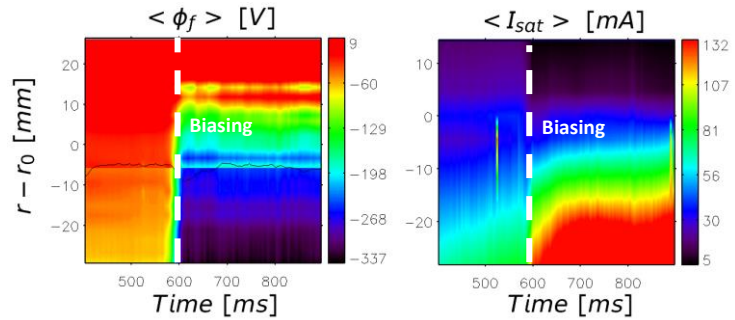

Fig.2 Radial average profiles in time (1 ms average), before and during biasing; floating potential (Φ_f) and ion saturation current (I_{sat}) (#39136). The r_0 is the radial position of the last closed flux surface and r is the probe position. Dashed line indicates biasing start.
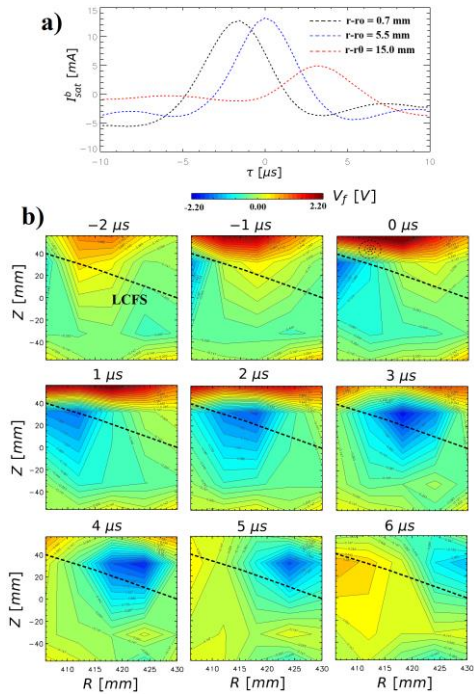
Blobs were identified from the ion saturation current signals. The intermittent behaviour skews its probability density function (PDF) to positive branch in SOL. In this work, blobs were considered as the events that are higher than 3σ (standard deviation of the ion saturation current PDF), that is, those ones that start to deviate from a Gaussian distribution. The considered fluctuations are in the range of 2-500 kHz. Through conditional average, blob is defined in a 10 µs time slice, by the average over all the events found by the threshold criterion; in the reference signal (auto conditional average) and in the neighbouring signals (cross conditional average). An example during L-mode can be seen in the Fig.3 (analysis done in 40 ms time window indicated by the blue dotted line in the Fig.1). The blob defined from one of the I_{sat} travels from the edge, closed to the LCFS, into SOL with a velocity of about 3 km/s. The radial turbulent particle flux was obtained considering:

Fig.3 Conditional average L-mode; a) ion saturation current; b) Floating potential 2-D map. Blob tracking; event defined from I_{sat} (dotted circle in the 0 μs frame).

$\tilde{\Gamma}_r = \langle \tilde{n}_e\, \tilde{v}_r \rangle \propto \langle \tilde{I}_s\, \tilde{E}_\theta \tilde{T}_e^{-\frac{1}{2}} \rangle / B_\phi$, where B_ϕ is the toroidal magnetic field and T_e is the electron temperature, got in this experiment from the triple probe configuration. The poloidal component of the electric field is approximately obtained from the difference of two floating potential spaced d_θ poloidally: $E_\theta \approx (\phi_{1f} - \phi_{2f})/d_\theta$. The electron density is approximately: $n_e \approx I_{sat}/\sqrt{e^2 A^2 T_e/m_i}$, where e is electron charge, A is the probe surface, m_i is the ion mass. Besides, the vorticity is $\vec{\omega} = \vec{\nabla} \times \vec{v}$, where $\vec{v}$ is the local flow and its longitudinal component is roughly: $\omega_\parallel = \frac{1}{B_\phi} \nabla_\perp^2 \phi_f$.

The local parallel current density is obtained from the magnetic field signals, by the Ampère's law: $j_\parallel = 1/\mu_0\,(\partial_r b_\theta - \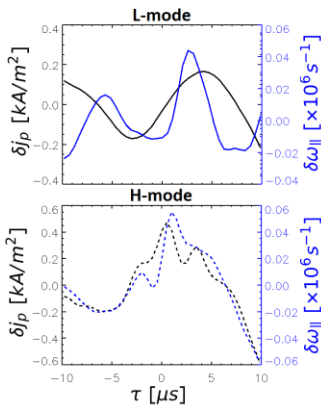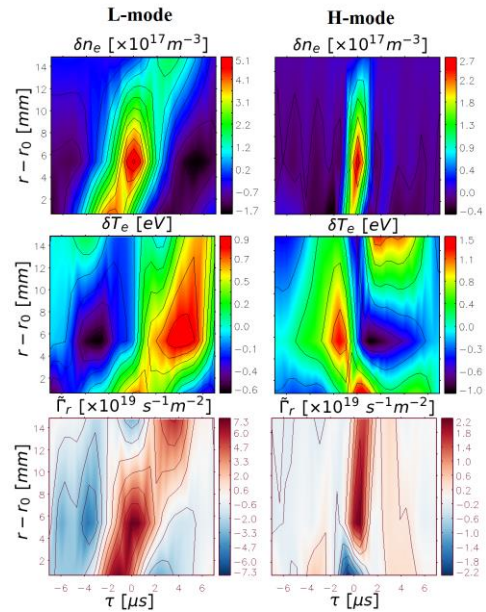partial_\theta b_r)$. A comparison between blobs in L and H-mode is presented in the Fig. 4. It is shown a time slice of the electron density, electron temperature and turbulent particle flux from the conditional average (I_{sat} as reference). Outward blob propagation in the L-mode plots can be observed,

Fig.5 Current density and vorticity; L and H mode.

Fig.4 Conditional average, L and H mode. From the top to the bottom: electron density (n_e), electron temperature (T_e) and turbulent particle flux ($\tilde{\Gamma}_r$).

consistent with the graph shown in the Fig. 3. On the other hand, in H-mode the blobs detected have lower density, but higher temperature. The turbulent particle flux is also lower than in L-mode, in agreement with the blob supress or trap by the shear layer [7]. Fig. 5 shows current density and vorticity associated with the ion saturation current burst in L and H
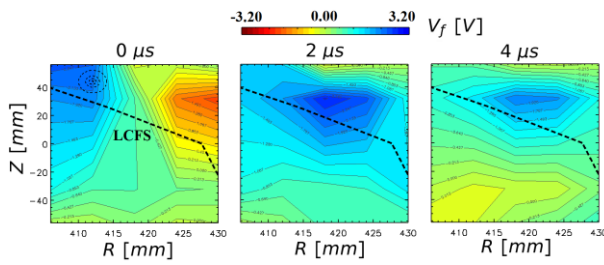
Fig.6 Floating potential 2-D map during H-mode.

mode, exhibiting blob electromagnetic feature. It seems from density in H-mode (Fig. 4) that the structure does not propagate, it is only spreads radially; or it propagates with a much higher velocity than L-mode. However, there is still some transport activity. In the 2-D floating potential map Fig. 6, such behaviour is better pronounced. The structure comes from the vicinity of the LCFS and propagates until certain position in SOL, where it stopes and then fades way. That position is a high shear position, as can be seen in the Fig.2. Thus the blobs are either trapped or torn apart by the shear. Only those ones that survive this effect will escape from the confinement, which makes a non-zero turbulent particle flux. A situation where the structures escape from the confinement, even with a strong shear layer setup, is during ELMs. They are related to the relaxation of the transport barrier, the filaments created in the deep edge in this case propagates to the far SOL.

ELM's structures are detected during biasing in the RFX-mod operating as tokamak [4]. Its fast radial propagation can be seen in the Fig. 7. They come from edge, where fluctuation is lower in comparison to the average background, to SOL, where they are comparable.
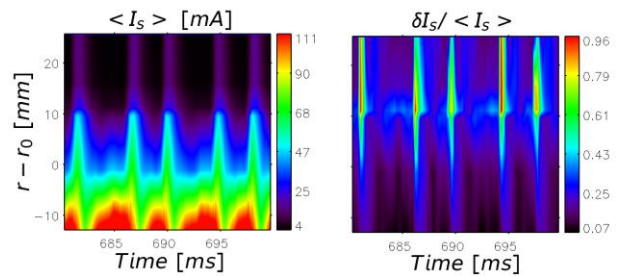

Fig.7 Average ion saturation current and relative fluctuation during ELM's events in the RFX-mod (#39121).

Summarizing, blob feature and propagation in L and H mode were addressed in this paper. It was seen that blobs detected at vicinity of the LCFS propagates outward in L-mode to the SOL, whereas they are trapped in the H-mode. ELMs structures though, propagate until the far SOL.

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