Interaction between turbulence and electron profiles in the RFX-mod helical plasma edge

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The control and mitigation of the plasma wall interaction is and will be a key issue for fusion experiments, in particular for ITER. The studies regarding non-axysimmetric magnetic perturbation and magnetic field ergodization of the boundary region of the plasma are trying to face this issue. In fact, the edge ergodization in TEXTOR, DIII-D and Tore Supra using the ergodic divertor, results in ELM mitigation, reduction of the plasma wall interaction and modification of the electrostatic turbulence behaviour [1]. On this topic RFX-mod can give an important contribution, in particular studying the physics of the interaction between magnetic field and magnetic islands with the plasma. In fact during high plasma operations RFX-mod is characterised by the spontaneous formation of a helical core due to the presence of the dominant (m,n) = (1,-7) mode, that induces a small helical ripple also at the edge. This ripple is sufficient to modulate all the kinetic properties of the plasma boundary [2,3], giving to it a space-time modulation that follows the one of the magnetic field, with a (1,-7) pattern. In this way RFX-mod magnetic boundary resembles the one that can be obtained with the ergodic divertor. This behaviour is clearly highlighted in figure 1. On the left it is shown the plasma displacement Δ (= deformation of the equilibrium magnetic flux function) due to the dominant magnetic mode as a function of time and toroidal angle, compared with the

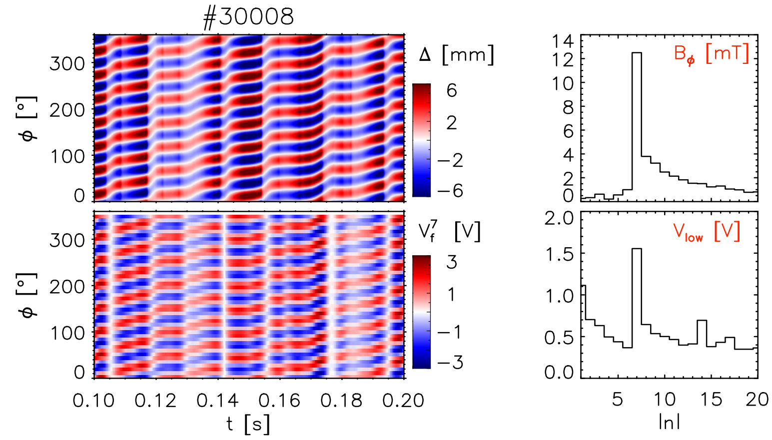

Fig1. *Left: magnetic shift (top) and floating potential (bottom) as a function of time and toroidal angle. Right: toroidal spectra of magnetic field (top) and floating potential (bottom).*

pattern of the |n|=7 component of the floating potential (V_f^7) as measured with toroidally distributed electrostatic probes [4]. The |n|=7 component of the floating potential reflects the same behaviour of the magnetic displacement, demonstrating that RFX-mod edge plasma has a |n|=7 modulation. In the same figure, on the right, the toroidal spectra of the magnetic field (top) and of low-pass filtered V_f (bottom) are compared: the largest mode for the two quantities is the |n|=7. The floating potential spectrum is less "clean" respect to the one of the magnetic fluctuation, with larger values of the amplitude of the secondary modes (|n|≠7). This happens because the system does not allow to disentangle m=0 and m=1 components and moreover because V_f is more sensitive to local plasma wall interaction that could introduce higher n harmonics in the spectrum. In order to characterise this helical modulation of the plasma edge, diagnostics at different poloidal and toroidal angles have to be used; so it is useful to introduce an appropriate helical angle $u = m\theta - n\phi + \Phi$, where θ and ϕ are the poloidal and toroidal position of the diagnostics, and Φ the phase of the dominant mode. Since the modulation is due mostly to the (1,-7) mode, m = 1 and n = -7 is used for the calculation of u. This helical angle describes the magnetic topology of the edge: the O-point of the (1,-7) island is located at $u=\pi/2$, the X-point at $u=-\pi/2$. The relation between u and the magnetic field is explained in figure 2(a). In black there is the magnetic displacement Δ: it is maximum at $u \approx 0$, in between the O and X-points of the (1,-7) island. Instead the radial magnetic field (blue) has a space shift of $\pi/2$ respect to Δ, maximum at the O-point. In panel (b) it is

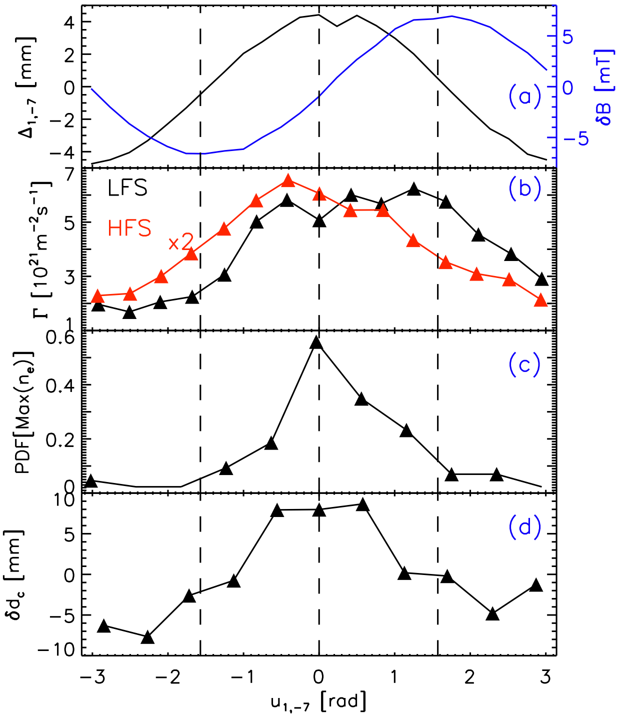

Fig2. *(a): magnetic shift Δ in black and radial magnetic field δB in blue; (b): H_α influxes at low (black) and high (red) field side; (c): PDF of the maxima of the edge electron density; (d): fluctuation of the radial position of the density layer with $n_e \approx 1 x 10^{19}$ m^{-3} measured with reflectometer. Every graph is an average over different discharges.*

highlighted how the helical deformation gives to the plasma-wall interaction the same spatial pattern. Using the helical angle u, the H_α influxes (Γ) measured at low ($\theta = 0$, in black) and at high ($\theta = \pi$, in red) field side of the machine collapse into a unique curve. The region with largest influx is located at $u \approx 0$, where the positive shift produces a stronger interaction with the graphite wall, at both sides of the machine. Due to the Shafranov shift, Γ is at least two times larger at $\theta = 0$ than at $\theta = \pi$. In the same regions of large influxes, the thermal helium beam (THB) diagnostic [5] measures an increase of electron density (fig.2(c)). It measures in a fixed toroidal position ($\phi = 322°$, $\theta = 0°$) the time evolution of n_e and T_e, at $r/a \approx 0.98$. The two quantities oscillate in time, and n_e increases in correspondence of the maximum of the magnetic displacement Δ, where typically T_e decreases. Evaluating the distribution of the edge n_e maxima as a function of the helical angle u, these maxima are located at $u \approx 0$ (see fig.2(c)). Similar information can be obtained by the reflectormeter, which measures the position d_c of the density layer with electron density of about $1\text{x}10^{19}\text{m}^{-3}$ [6], in a toroidal position ($\phi = 352°$, $\theta = 0°$) different from the THB one. In panel (d) of fig.2 $\delta d_c = d_c - \langle d_c \rangle$ is reported (<> indicates time average): positive value means that the density layer of $1\text{x}10^{19}\text{m}^{-3}$ moves toward the first wall, in agreement with the THB measurements. Thus at $u \approx 0$, i.e. where the magnetic shift is positive, the local plasma wall interaction increases and the cold particles from the wall accumulate. Instead at $u = \pm\pi$ both the edge density and H_α influxes decrease. So also the plasma wall interaction and the edge electron density and temperature are modulated with the same helical pattern of the magnetic topology.

Moreover this helical magnetic deformation which induces a helical pattern to the kinetic properties of the plasma edge interacts with the high frequency fluctuations, which are due to the presence of turbulence and blobs. To detect the turbulent fluctuations, the HeI light emission is measured with the Gas Puff Imaging (GPI) [7] at different radial positions; moreover, with in-vessel pick up coils also the fluctuations of the radial magnetic field are measured. To study the high frequency activity on these signals, the power spectrum is evaluated as a function of the time during the plasma discharge. Then, the percentage of the power contained in the higher frequencies ($f > 100$ kHz) is measured ($P^>$), and its dependence with the helical angle u is studied. Since in RFX-mod

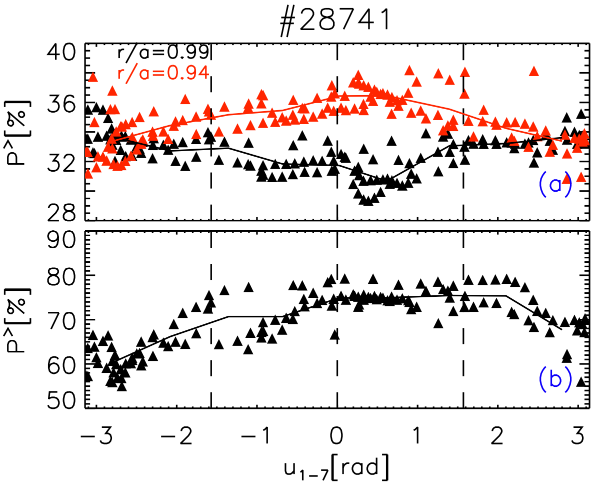

***Fig3.** Percentage of the power of the fluctuations with frequency f > 100 kHz for the GPI emissivity signal at two radial positions (a) and for the radial magnetic field (b)*

the frequency range of the edge turbulence is f > 100 kHz, $P^>$ can be used as an estimator of the turbulent activity. The measure of $P^>$ for two radial positions of the HeI fluctuations (r/a = 0.99 and 0.94) is shown in figure 3 (a) as a function of the helical angle u. In the same graph (b) $P^>$ is shown for the radial magnetic field fluctuations too. The behaviour of the high frequency fluctuations of the GPI depends on the radial position: for the outermost measurement $P^>$ has its maximum at $u \approx \pm\pi$, i.e. where Δ is negative, and it coincides with the low pressure gradient region, as already described in [3]. Instead at r/a = 0.94 this maximum is at u=0, with a similar behaviour detected also for the radial magnetic field fluctuations (fig.3(b)). It has to be underlined that in the He I fluctuations the frequencies larger than 100 kHz account for about 30% of the signal, instead in the magnetic fluctuations they account for more than 70%.

All the analyses here reported, show how the m=1, |n|=7 helical deformation affect the kinetic properties of the plasma edge: the presence of the islands gives to the floating potential, plasma wall interaction, electron density profile and edge turbulence a spatial modulation with the same periodicity.

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