First 2D measurements of the edge turbulence with fast camera in a RFP device

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The study and the characterization of the turbulence of the edge plasma, its interaction with edge flow and gradients and its impact on the plasma wall interaction (PWI) is crucial to improve the plasma performance and mitigate the PWI [1,2]. In the reversed field pinch RFX-mod device, the plasma edge is diagnosed with different diagnostics, spectroscopic, electrostatic and magnetic [3]. Recently, a Phantom V710 fast camera has been installed [4], in order to obtain a 2D image of the turbulence and study the behaviour of the edge blobs. This is the first time a fast camera for turbulence studies has been used in a RFP. In RFX-mod it is coupled with the gas puff imaging diagnostic (GPI) [5]: the two systems view the same plasma region and use the same puffed gas. If compared with tokamaks, RFPs have smaller access portholes, and a magnetic configuration with more twisted magnetic lines, resulting in a more difficult coupling between plasma and field of view. In RFX-mod the camera views the toroidal-poloidal plane: since the edge magnetic field is mainly poloidal, the plane observed is not the usual perpendicular one. An example of an image obtained is shown in figure 1. The figure shows the torodal-poloidal plane imaged by the camera, with the magnetic field lines represented as dashed lines. The region viewed in this exposure of 2.1 μs is 48mm x 6mm (toroidal x poloidal) using the configuration 256 x 32 pixels, which allows a frame rate of 390 kHz.

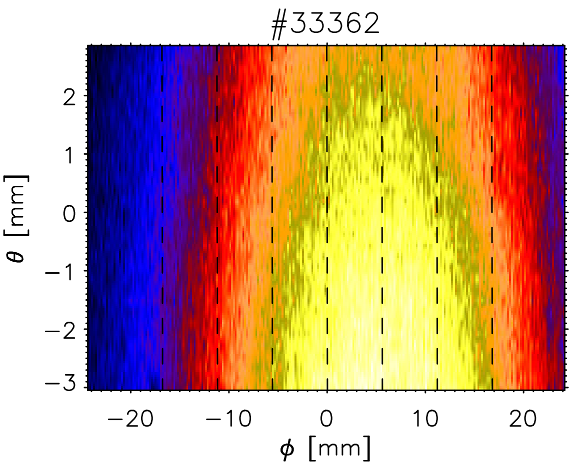

Fig1. *Single frame in the poloidal-toroidal plane, taken with a time exposure of 2.1μs. The almost vertical dashed lines represent the magnetic filed lines, which are almost poloidal. The yellow structure is a blob.*

We acquire data for 80 ms of the discharge, limited by the required data storage of 500 MB per discharge. As clearly shown in figure 1, the camera allows the first direct 2D visualization of the blobs in a RFP device. The yellow poloidally elongated structure is a blob moving in the toroidal direction: as expected, it is aligned with the magnetic field. The typical time behaviour of one pixel signal is shown in figure 2. In a He discharge, neutral He is puffed at t_p=0.085s (red arrow): for t<t_p the camera views the background HeI emission; the increase of the signal from t=t_p indicates that the measurement is local. In the lower panel the rms of the raw signal *rms(I)* for the same pixel is reported.

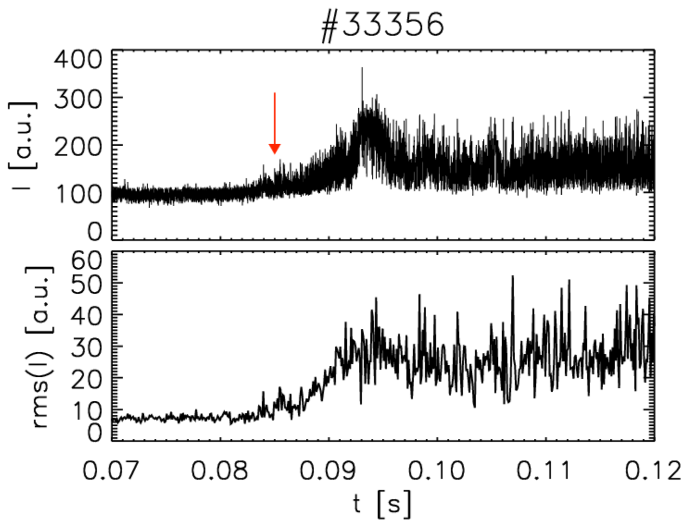

Fig1. *Example of the signal of one pixel as a function of the time (upper panel). The lower panel is the time evolution of the rms of the signal. The arrow indicates the time t_p of the He puffing.*

When He is puffed *rms(I)* increases, therefore the puffing ensures a better signal-to-noise ratio which allows the analysis of the turbulent fluctuations. Without the local puff, the signal and the fluctuation level are too low, preventing a reliable characterization of the high frequency fluctuations. The power spectra of the time signal of one camera pixel is reported in figure 3, and compared with the GPI one, which uses photomultipliers as light detectors. The two spectra show similar features, although the camera covers a smaller part of the frequency range, being limited to sampling rate of 390 kHz compared with 10 MHz of the photomultipliers. For frequency larger than 20 kHz the two spectral shapes are identical, and show a power-law decay, an indication of the energy exchange processes occurring in the inertial scales. This is the spectral region where the turbulence develops. Since the two power spectra are similar, and since the cross correlation between the GPI signal and the camera is about 1 (not shown here), we can conclude that the two diagnostics view the same features. Thus it is possible to complete the 1D information obtained with the GPI [6] with the 2D measurements now available.

To extract the blobs from the camera data, the central pixel is taken as reference signal. Then the strong fluctuations (with characteristic frequency larger than 20 kHz) which cause the deviation of the PDF from the Gaussian one are considered as edge structures. If we look at the complete 2D images at the time instant when a structure is detected in the single pixel, a clear 2D blob is visible, as the one shown in fig.1. This result confirms that the edge fluctuations in the edge of RFX-mod are due to blobs. Once a blob is detected, its toroidal correlation length λ_ϕ is measured, together with its propagation velocity in the toroidal direction v_ϕ. The result of this analysis made for 5 similar plasma discharges is reported in figure 4. The toroidal correlation length, which is one of the two perpendicular lengths of the blob, varies from 30 to 70 mm. Most of them have a negative toroidal velocity, i.e. in counter-I_p direction. Since the edge flow is mainly $\mathbf{E}_r x \mathbf{B}_\theta$ flow [3], negative velocity corresponds to inward (from the wall to the plasma) radial electric field. The typical value reflects the one obtained with the GPI and Langmuir probes [3]. There are also a small fraction of structures that move in the opposite direction (positive toroidal velocity), which may suggest a local inversion of radial electric field. Figure 4 does not show any clear trend between the dimension and the velocity of the blobs. However, structures with positive toroidal velocity have smaller λ_ϕ respect the ones with negative velocity, highlighting the influence of the radial electric field in the plasma edge [7].

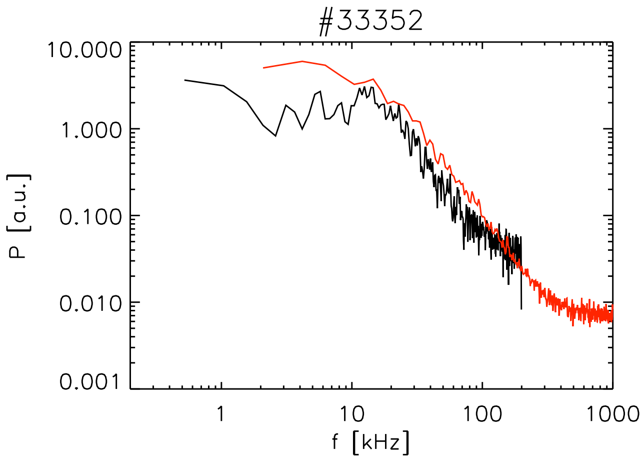

Fig3. *Power spectra of the camera signal (black curve) and of the photomultiplier detector (red curve).*

It is not possible to obtain an estimate of the parallel (poloidal) correlation length of the blobs, since the camera views only 6 mm in that direction. So in this paper we have shown the first application of a fast camera to an RFP device, in order to measure the edge turbulence. We pointed out the difficulty of using such diagnostic in a RFP: due to limitations in access portholes and to the geometric configuration of the edge magnetic field lines we did not measure the turbulence in the perpendicular plane. We also point out a difficulty operating at plasma current larger than 1 MA due to magnetic field interference with the camera.

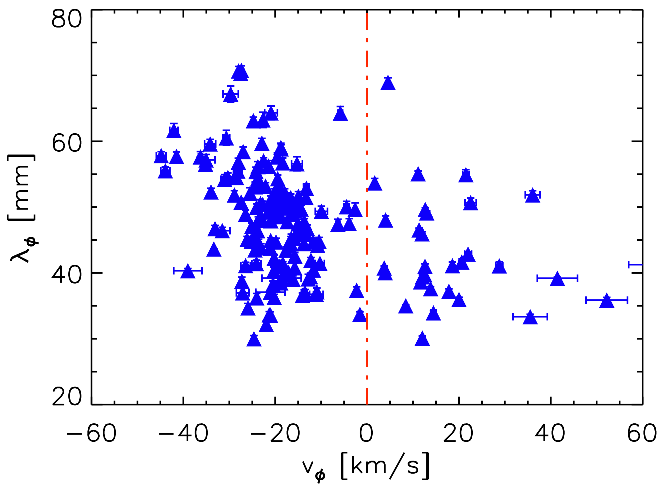

Fig4. *Toroidal correlation length λ_ϕ Vs toroidal velocity v_ϕ of the edge blobs. Each point represents one single blob. The error bars are the standard deviation of the measurement.*

However it was possible to give a first characterization of the 2D structure of the RFP edge turbulence. Blobs appear as structures elongated in the poloidal direction, with a toroidal dimension of about 50-60 mm, and a toroidal velocity of about -20 km/s. It was shown that the strong fluctuations present in the time signal on single pixels are related to the presence of 2D emissivity structures. The high correlation found between the GPI photomultipliers (which observes the same plasma region) and the phantom camera means that the two diagnostics observe the same phenomena.

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