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A first comparison between probes, fast imaging, and reflectometry synchronous measurements of edge turbulence in Tore Supra

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It is now widely admitted that a significant part of the particle and energy transport in the Scrape-Off Layer (SOL) is due to intermittent phenomena, corresponding to the propagation of structures known as filaments or blobs [1-4]. Studying the origin and dynamics of these structures is a key issue for understanding transport in the SOL and acting on it. In order to characterize turbulence over different temporal and spatial scales, synchronous measurements involving a poloidal rake probe, Doppler backscattering [5], fast sweeping reflectometry, and a fast camera were recently performed in the Tore Supra tokamak. We present first analyses of data obtained during this experimental campaign. Here, we focus on estimating the poloidal propagation velocity of plasma fluctuations by cross-checking simultaneous measurements obtained with a fast camera and Doppler backscattering in the edge plasma (r/a~0.6), and simultaneous probe and Doppler backscattering measurements in the region located across the Last Closed Flux Surface (r/a~1).

In order to observe fluctuations at frequencies of the order of a few kHz, a Photron SA1.1 camera was installed on Tore Supra. Such a camera is sensitive to visible light only, therefore detached plasmas characterized by a high radiative fraction were chosen for observation. In this contribution, we focus on the analysis of shot #TS42967, for which movies were recorded at a frame rate of 40 kHz, with a shutter time of 20 µs. Fig. 1 represents a single raw frame. A radiative layer is seen at a radius r/a~0.6, i.e. well in the closed field line region. In the inner part of this layer, toroidally elongated filaments can barely be distinguished, whereas in its outer part irregular structures are visible. These are blobs, i.e. coherent structures propagating radially. In order to obtain the velocity fields from the movies, Turbulence Image Velocimetry (TIV) is used. This technique, derived from Particle Image Velocimetry [6], consists in looking at the displacement which minimizes the squared difference between sub-windows in consecutive frames. The minimum quadratic distance (MQD) method is employed, since it has been proven to have a better accuracy than cross-correlation calculation when images have a non uniformly distributed illumination intensity [6]. On this movie, 40*40 pixels sub-windows with a 75% overlap where used.

A simple pre-processing consisting in removing the background obtained by averaging 300 frames is used in order to highlight fluctuations before computing TIV. TIV makes it possible to derive a velocity field from any given pair of frames. However, spurious vectors originating either from experimental noise or from the method itself usually appear. Since these vectors are almost randomly distributed in space and in time, a simple procedure, which consists for each sub-window in keeping only the most probable velocity in a given time interval, is applied. This procedure permits highlighting large poloidal plasma flows, but its drawback is that information on intermittent radial propagation is lost. For that reason, we focus in this contribution on the comparison between camera and Doppler backscattering measurements of the poloidal velocity of the fluctuations.

Figure 2 represents a typical velocity field obtained by looking at the most probable velocities among 100 pairs of frames. To guide the eye, the velocity field is superimposed on an image of the fluctuations denoised using a 2D Kingsbury wavelet [7]. Although a few spurious vectors appear in the SOL, rotation of the radiative layer is well captured. In order to limit the effects of complex geometry and light integration in the line of sight, which are responsible of an artificial velocity shift, we restrict our study to a rectangular area crossing the radiative layer in the equatorial plane. Figure 3 shows the probability distribution of the poloidal velocities in this region, computed over 3000 pairs of frames. The most probable poloidal velocity is found to be ~800m/s, in agreement with Doppler backscattering measurements (Fig. 4), but a non negligible probability of velocities is found in the opposite direction. This may be partly related to the chosen grid size and overlap, leading to a stroboscopic effect at the considered frame rate. In order to improve the robustness of the method, an analysis taking into account more TIV parameters, like auto-adaptative grid size, will be carried out soon, and possible benefits of a systematic wavelet denoising will be investigated. A major improvement to come soon will be brought by the reconstruction of the data in a poloidal cross-section of the tokamak, based on inversion methods.

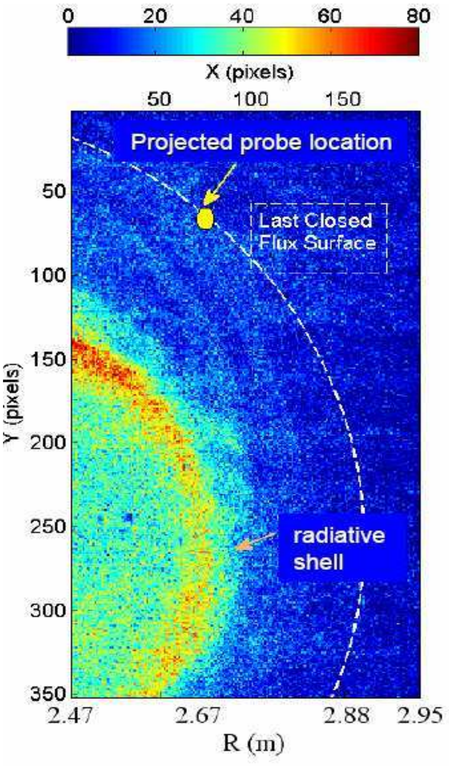

Fig.1: Raw camera image showing the location of the radiative layer, the Last Closed Flux Surface and the location of the magnetic connection with the rake probe.

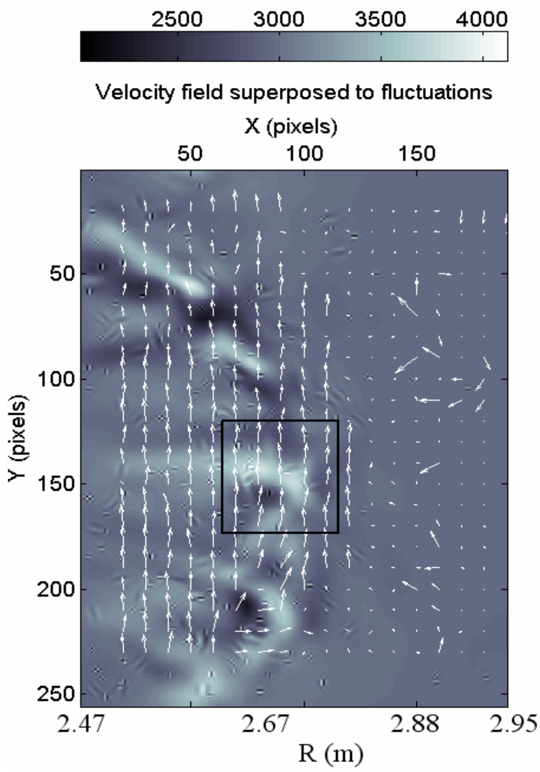

Fig. 2: Velocity field obtained with the TIV method for 100 frames, superimposed on fluctuations obtained with nonlinear wavelet filtering at a single frame. Black square indicates the region considered in Fig. 3.

In order to investigate the SOL, two reciprocating probes are located at the top of the machine (cf. Fig. 1). One is equipped with a Retarding Field Analyser and the other one, dedicated to turbulence studies, consists in a poloidal rake of 6 thin pines spaced every 3 mm (and 2 collectors on the rake sides). The saturation currents (probe biasing -200V) are sampled at 1 MHz during the full reciprocation to the LCFS. High correlations exhibited by intermittent fluctuations in the poloidal direction are interpreted as the consequence of blobs propagation. To detail the velocity variation according to the structure size, a continuous temporal wavelet correlation analysis is performed: given two signals recorded at different poloidal locations, the phase between the coefficients at each scale and time is compiled. In attached phase, a clear tendency exists between the scale and the time averaged cross phase, read as a dispersion relation that returns a phase velocity depending on the time scale (not figured here). However, different histograms are obtained for a detached plasma as for shot#TS42967. The phase distribution is more random, which can be understood as no net poloïdal flow. As it can be seen in Fig. 4, this result is in good agreement with Doppler backscattering measurements.

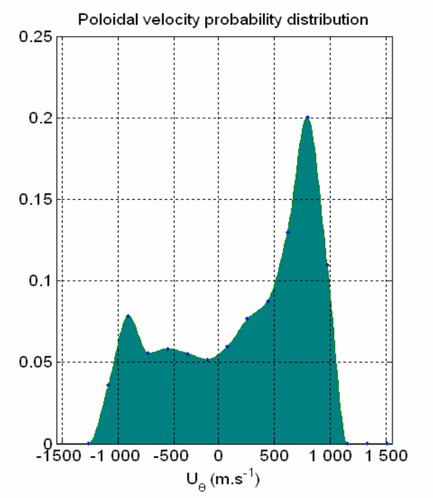

Fig. 3: Probability distribution of poloidal velocity in the radiative layer, computed on 3000 pairs of frames.

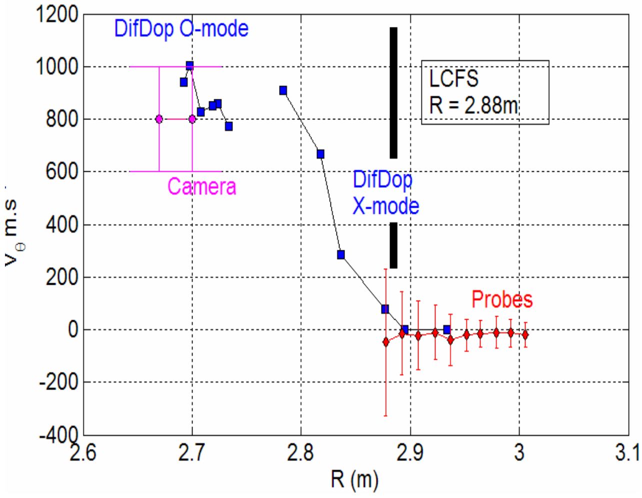

Fig. 4: Radial profiles of poloidal propagation velocity as obtained from Doppler backscattering, Camera and probe measurements.

Next steps will be guided by the aim of better understanding the relation between the poloidal and radial transports in the edge and in the SOL. In addition to inversion method for image reconstruction and to improvement of the TIV method, important results regarding phenomena in the radial direction are expected to come from comparisons with fast sweeping reflectometry measurements.

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