*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-5.027 (2005)*

High-speed turbulence imaging and wavelet-based analysis in TJ-II edge plasmas.

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Introduction

Transport in fusion devices is a phenomenon with high degree of complexity. Localized layers where $E \times B$ shear stabilization mechanisms are likely playing a role, have extensively been proved to have a beneficial impact in confinement. A reduction in turbulence amplitude is expected and measured [6]. However few attempts have been made to study the effects of such layer on the morphology of turbulent structures [8]. Two-dimensional images of edge plasma turbulence have been obtained by high-speed imaging in the visible range in the edge of tokamak devices [9], [7]. This paper reports a a 2-D visualization of transport in the plasma edge of TJ-II stellarator. We introduce an wavelet-based image analysis method to localize and characterize blob-like structures. The impact of shear flow on turbulent structures is investigated by means of this method.

Experimental description

A Princeton Scientific Instruments intensified camera with CCD sensor (PSI-5) was used with H_α filter, achieving recording ratios up to 250.000 frames per second. The storage capacity is 300 frames with 64 by 64 pixels resolution, thus giving 1.2ms total recording time at maximum speed with an image every 4μs.

The view plane is in a near-poloidal cross-section with optimized B-field perpendicularity. The dimension of the frame is 11cm$\times$11cm.

Neutral recycling at the poloidal limiter is used to light up the outer plasma region ($\rho \sim 0.8$-1). Bright, long-living structures are frequently seen with a spatial extent of few centimeters. Those structures show predominant poloidal movements with typical speeds of 10^3 - 10^4 ms^{-1} in agreement with the expected $\mathbf{E} \times \mathbf{B}$ drift rotation direction. Moreover, projection of the magnetic field lines on the image frame, reveals little or no velocity component in the field line direction (see fig.1). The light cloud extent along field lines was measured and is in the range of few centimeters ($\sim$10cm). It should be noticed that, with this light cloud thikness, long parallel

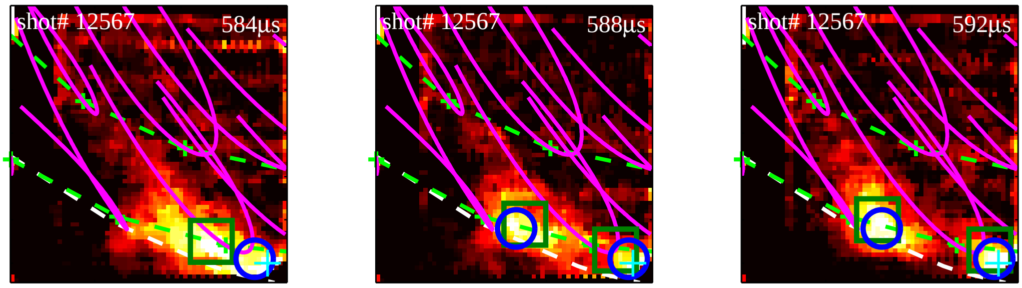


Figure 1: Blob transit over three frames. Dashed white line is the limiter ridge, dashed green lines are magnetic surfaces ($\rho = 0.9$, $\rho = 0.7$). Magnetic field lines projected on the view plane are drawn as magenta continuous lines. Detected large scale blobs are labeled with squares, circles are used for medium blobs and pluses for small ones.

strucutres can have a parrallel velocity component not visible from the camera position.

Interpretation of the measured light is not direct. Intensity depends on neutral density (slowly varying for the turbulence space and time scales) and electron density and temperature [9].

Image processing with 2-D directional continuous wavelets: description

Image analysis techniques were implemented for characterising blob geometry (aspect ratio, orientation...) in TJ-II different velocity shear regimes. The method has a detection-recognition scheme based on isotropic (detection) and anisotropic (recognition) 2D wavelets [1]. Three different scales were considered in the analysis (3cm, 1.5cm and 0.75cm).

In the detection stage, convolution with 2D Mexican Hat wavelet extracts image features of a given scale a. Weak structures are removed after thresholding. Threshold becomes more severe for smaller scales which are more affected by noise. Local maxima $\vec{b}_k$ stand as blob positions.

In a second stage angular convolution with a corrected Morlet wavelet ($k = 3, \varepsilon = 1$) gives the *angular response curve* of the k-th blob detected $W_i^{(k)} = W^{(k)}(\theta_i) = \langle \psi^{Morlet}_{a_k,\vec{b}_k,\theta_i} | Image \rangle$. From this curve, an orientation angle $\theta^{(k)}$ can be inferred. The similarity of the Morlet wavelet with the second order derivative operator allows aspect ratio to be estimated as $AR^{(k)} = \sqrt{\frac{W^{(k)}(\theta)}{W^{(k)}(\theta+\pi/2)}}$.

Image processing with 2-D directional continuous wavelets: results

An edged shear-layer naturally occurs in TJ-II plasmas above a threshold density ($\sim 0.6 \times 10^{19}\mathrm{m}^{-3}$), as reported by Langmuir probes and HIBP diagnostics [2], [4]. Recent experiments have shown that the threshold density depends on magnetic topology (iota, ripple) [4]. The controllable occurrence of this shear-layer allows us to study its impact on turbulent structures. Several image sequences for shots with and without shear-layer were analysed. Blob parameters statistics are shown in table 1. First and second columns are shot number and line averaged elec-

Shot#	n_e (10^{19}m^{-3})	blobs (a=1)	Scale Ratio*	%Elongated	$\hat{\theta}$	σ_θ
12361	1.10	204	0.15	30	46	30
12367	0.76	202	0.07	22	50	29
12369	0.84	188	0.16	30	44	31
12370	1.10	144	0.06	35	42	29
12372	1.20	179	0.21	30	45	29
12378	0.81	171	0.10	23	36	34
12365	0.39	184	0.01	27	127	46
12371	0.43	176	0.03	25	39	42
12373	0.49	212	0.05	26	34	43
12375	0.50	187	0.16	18	38	40
12386	0.47	160	0.06	20	61	32
12387	0.51	136	0.27	19	15	33

* number of medium-scale blobs over large-scale blobs

Table 1: Blob statistics of analysed shots

tron density respectively. Third column is the number of large scale blobs (i.e. ~3cm) detected. Scale ratio is the relative activity of medium scale over large scale blobs.

For a blob to be considered orientable its aspect ratio must exceed a chosen value. The percent of blobs exceeding that value is the percentage of elongated blobs (fifth column). Finally, $\hat{\theta}$ and σ_θ stands as the mean angle and standard deviation of the angular distribution of elongated blobs.

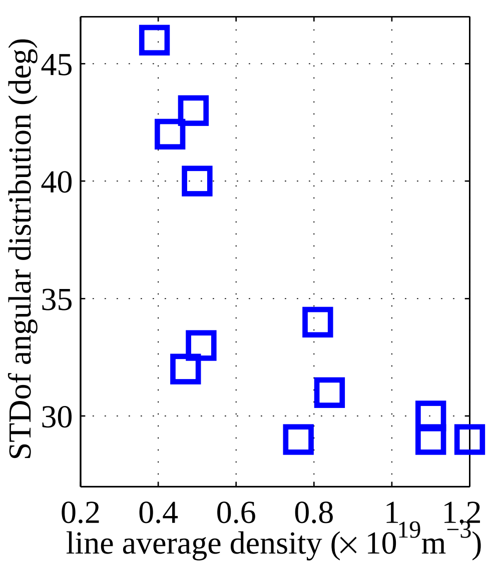
In order to avoid edge effects in determining blob characteristic parameters, only frame-centered blobs were included in the statistics.

Figure 2 shows standard deviation, mean angle and percentage of elongated blobs vs. density for the shots in table 1.

Conclusions

Preliminary results show a reduction in the angular dispersion of blobs as the shear layer is established in the boundary, as well as a slight though sensible shift of the aspect ratio histogram toward higher values (fig.2). These results are consistent with the picture of the shear layer stressing blobs as well as ordering them.

Neither significant changes in turbulence intensity (as the number of blobs detected) nor a clear reduction in turbulence scale could be detected within the experimental uncertainties. It



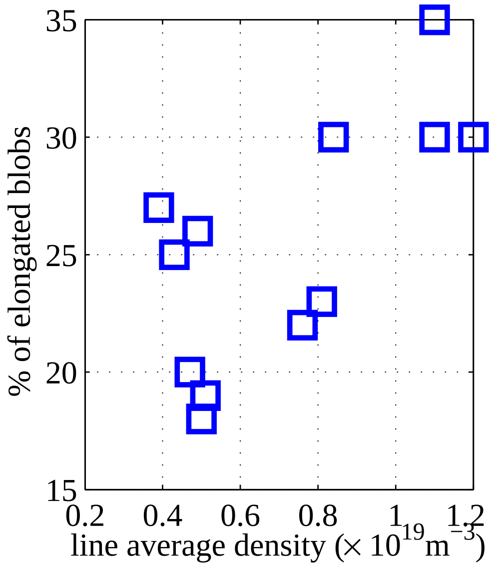


Figure 2: Density dependence of the standard deviation of blobs angular distribution (left) and population of elongated blobs (right)

should be noted that spontaneous edge sheared flow and fluctuations are near marginal stability, thus no strong reduction in turbulence scale can be expected. However, probe measurements show that when sheared flow are developed the level of fluctuations slightly decreases [4].

Further studies are in progress to characterise the structure of turbulence during edge biasing improved confinement regimes [3]. The analysis presented here includes only positive structures (i.e. light fluctuations above the time averaged value). Negative structures and its connection with positive ones (i.e. bipolarity of fluctuations) are also of interest to gain experimental insight into plasma turbulence [5].

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