Effect of magnetic field geometry on blob structure and dynamics in TJ-K

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Introduction

A detailed understanding of scrape-off layer (SOL) turbulence is of high importance to the design of future fusion reactors. Density fluctuations in the SOL of most magnetic confinement devices exhibit positive skewness, which is generally associated with relatively dense and hot mesoscale structures elongated along the magnetic field lines, otherwise known as blobs [1]. These structures transport particles and heat through the SOL to the reactor first wall, potentially resulting in high heat loads on plasma facing components. Knowledge of the dynamics and structure of blobs is therefore crucial. For this contribution, investigations have been carried out into the effect of magnetic field curvature and shear on poloidal blob velocity and blob 3D structure respectively.

Experimental setup

Experiments were conducted in the small-sized torsatron TJ-K [2], which has a major radius of $0.6\,\mathrm{m}$ and a minor plasma radius of $0.1\,\mathrm{m}$. Electron densities are of the order of $10^{17}\,\mathrm{m}^{-3}$ whilst electron temperatures are typically around $10\,\mathrm{eV}$ and those of ions $1\,\mathrm{eV}$, allowing Langmuir probe access to the entire plasma volume. Measurements can therefore be taken with the necessary spatio-temporal resolution to study plasma turbulence in detail.

A range of Langmuir probe diagnostics are available for use at TJ-K, with a data acquisition frequency of up to $1\,\mathrm{MHz}$. For the present contribution two main probe diagnostics were used: a 2D scanning probe unit, capable of sampling fluctuations within a poloidal cross section; a probe matrix comprising an equally spaced square 8x8 probe grid covering $49\,\mathrm{cm}^2$. In typical TJ-K discharges, fluctuations in ion saturation current, $\tilde{I}_{i,sat}$, can be assumed proportional to those of density due to the lack of temperature fluctuations [3].

In order to create a controlled environment for blob studies, a pair of poloidal limiters were installed at the toroidal angles $\phi = 150^\circ$ and 270°, giving an enlarged SOL as well as an extended region of approximately uniform magnetic field line connection length.

Geodesic curvature drive

Blob propagation is generally thought to be driven by charge separating drifts, e.g. curvature drifts, which polarise blob filaments perpendicular to the magnetic field. The subsequent transverse electric field results in the ExB advection of the blob through the SOL [5, 4]. Due to

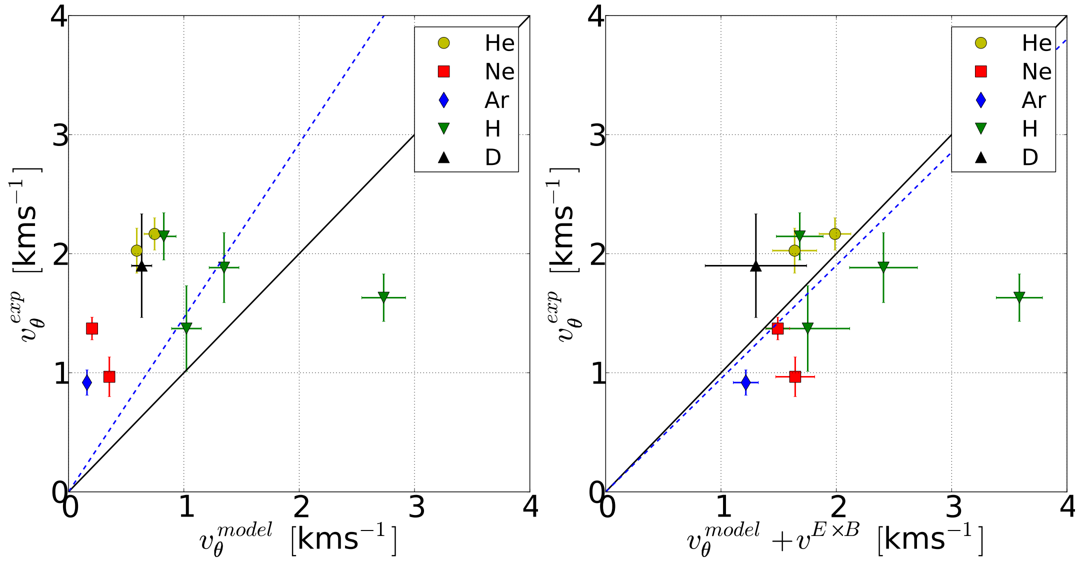

Figure 1: *Experimental poloidal blob velocities compared to predictions from the analytical model with (right) and without (left) the addition of background ExB flow speeds.*

diagnostic limitations in many magnetic confinement devices, the study of blob velocity in the perpendicular direction has mostly been limited to the radial component, thought to be driven by normal curvature. It is predicted, however, that non-zero geodesic curvature gives rise to a poloidal velocity component.

An analytical model [4, 5] has previously been found to compare well to experimental radial blob velocities in TJ-K in the so-called inertial regime [6]. In this regime the radial blob velocity is related to the blob size δ_b, the field line curvature $1/R$, and the blob-background density ratio $\hat{n} = (n_{blob} - n_0)/n_0$, via $v_r = \sqrt{2\delta_b/R}c_s\hat{n}$ [6, 7], where c_s is the speed of sound. Within the same approximation, the model can be used to express blob velocity, $\mathbf{v}_b$, in terms of the field line curvature vector for an arbitrary coordinate system,

$$\mathbf{v}_b = -2c_s^2\gamma^{-1}\hat{n}\boldsymbol{\kappa} \tag{1}$$

where $\gamma = \sqrt{2/(R\delta_b)}c_s$, and $\boldsymbol{\kappa}$ is the curvature vector. Thus, the radial and poloidal velocity components can be expressed approximately in terms of the normal and geodesic curvature,

$$\begin{aligned} v_{r,b} &= -2c_s^2\gamma^{-1}\hat{n}\kappa_n \\ v_{\theta,b} &= -2c_s^2\gamma^{-1}\hat{n}\kappa_g \end{aligned} \tag{2}$$

Blob velocity components were determined experimentally by calculating blob centre of mass (CoM) displacements from 2D conditionally averaged probe data, obtained on a 1 cm discretised grid with a fixed reference probe. The blob detection trigger condition applied to the reference

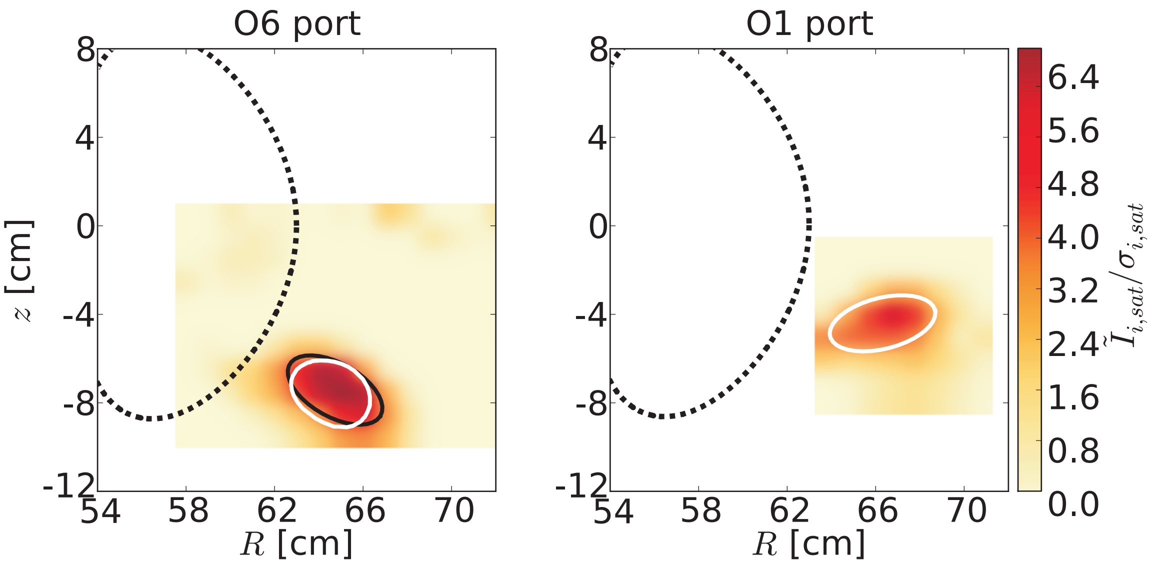

Figure 2: *The conditional average of* $I_{i,sat}$ *fluctuations normalised by* $\sigma_{I_{i,isat}}$ *at two toroidal positions, O6 (left) and O1 (right), separated by* 60°. *In the left hand plot, the white ellipse is fitted to the cross section of the blob structure, and in the right hand plot the black ellipse is fitted to the struture whilst the white shape corresponds to the field line traced ellipse.*

signal was $2\sigma_{I_{i,isat}}$. CoM coordinates were also used to extract local parameters for input into the analytical model. In order to vary the parameter space, the gases H, D, He, Ne and Ar were used at field strengths ranging between approximately 60 and 85 mT.

The left hand plot of figure 1 shows the experimental poloidal velocity components compared to the predictions of the analytical model in the inertial regime, as per equation 1. The linear fit of the data, given by the blue dashed line, indicates a substantial deviation of the experimental data from the prediction of the analytical model.

Radial plasma potential gradients in the SOL of TJ-K lead to background ExB flow which may also affect the poloidal blob propagation. In order to determine the background flow, emissive probes were used to directly measure plasma potential profiles for each shot, whilst the magnetic field components were determined using a field line tracing code. As can be seen from the right hand graph of figure 1, the poloidal velocity components compare well to the model when the background ExB flow speed is also accounted for. This result is consistent with the geodesic curvature drive of poloidal blob propagation.

The 3D structure of blobs

Due to fast parallel transport, blobs are generally assumed to be field-aligned structures. A consequence of this is that they are influenced by magnetic field shear, becoming deformed in regions of high shear (e.g. [8]).

The three dimensional structure of blobs has been investigated using $\tilde{I}_{i,sat}$ measurements in two different poloidal cross sections, separated by 60°. At one toroidal position (port O1, $\phi = 30^\circ$) fluctuations were measured using the 8x8 probe matrix, whilst at the other (port O6, $\phi = 330^\circ$), the 2D scanning probe was used to take simultaneous measurements. An additional fixed probe was installed in order to conditionally average all fluctuations with a common reference signal, and the same trigger condition of $2\sigma_{I_{i,isat}}$ was used.

Blob structures occuring in the conditionally averaged probe matrix data were fitted with ellipses, the coordinates of which were then followed using a field line tracing code along the vacuum magnetic field lines to the poloidal plane containing the 2D scanning probe ($\mathrm{O1} \longmapsto \mathrm{O6}$). Figure 2 shows the conditionally averaged fluctuations at the two different toroidal positions, for time $t = 0\,\mu$s in the conditional average time series. The data was taken during a He discharge at $B \approx 70\,$mT.

It can be seen from the figure that the traced ellipse (white), deformed through field line tracing by magnetic shear, is roughly aligned with ellipse fitted to the blob structure at O6 (black). This indicates that blob structure is influenced strongly by magnetic shear. Future work will investigate this effect further by extending the region of study into higher shear regions.

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