The effect of magnetic field geometry on filamentary plasma structures in TJ-K

S. Garland[1], G. Fuchert[2], M. Ramisch[1], T. Hirth[3]

[1] *IGVP, Universität Stuttgart, 70569 Stuttgart, Germany*

[2]*Max Planck Institute for Plasma Physics, 17491 Greifswald, Germany*

[3]*Karlsruhe Institute for Technology, 76131 Karlsruhe, Germany*

Introduction

Turbulent transport is the dominant transport mechanism in many magnetic confinement fusion plasmas. Various instabilities can be responsible for the development of plasma turbulence, however the most important instabilities at the plasma edge are the drift wave instability and the interchange instability. Whilst the mechanisms giving rise to these instabilities are different, in a strong magnetic field the resulting dominant structures of the density fluctuations have one important similarity, namely that their parallel wavenumber is much smaller than their perpendicular wavenumber. Due to their filamentary form, magnetic shear can have a deformative effect on these turbulent structures. For this contribution, the effect of magnetic shear on two types of turbulent structure has been studied: firstly blobs [1], which occur in the scrape-off layer (SOL) and whose dynamics are determined by interchange drive; and drift waves, which occur predominantly in the high pressure gradient region of the confined plasma. It will be demonstrated that blob filaments do not experience a strong effect of the magnetic shear, whereas in the case of drift waves an effect is clearly visible.

Experimental setup

Experiments were carried out at the stellarator TJ-K [2]. Ions are typically cold at $T_\mathrm{i} \leq 1\,\mathrm{eV}$ whilst $T_\mathrm{e} \leq 20\,\mathrm{eV}$ and $n_\mathrm{e} \approx 1 \times 10^{17}\,\mathrm{m}^{-3}$. These parameteres allow Langmuir probe measurements not only in the SOL region, but also in the confined plasma volume. For this contribution, three different probe diagnostics were used. In order to investigate the 3D structure of blob filaments, simultaneous measurements with a 2D-scanning probe (capable of point measurements in a poloidal cross section) and a 64-probe matrix were obtained. The probe matrix (see e.g. [3]) consists of an 8×8 grid of probes spaced equally apart by 1 cm. In the case of the drift wave investigations, a poloidal array of 64 probes (see e.g. [4]), positioned equidistantly along a flux surface was used in conjunction with the 2D-scanning probe. The poloidal array is located at an outer port of TJ-K, and is therefore called the Outer Port Array (OPA). The probes on the OPA are located on a flux surface approximately 1.5 cm inside the last closed flux surface (LCFS).

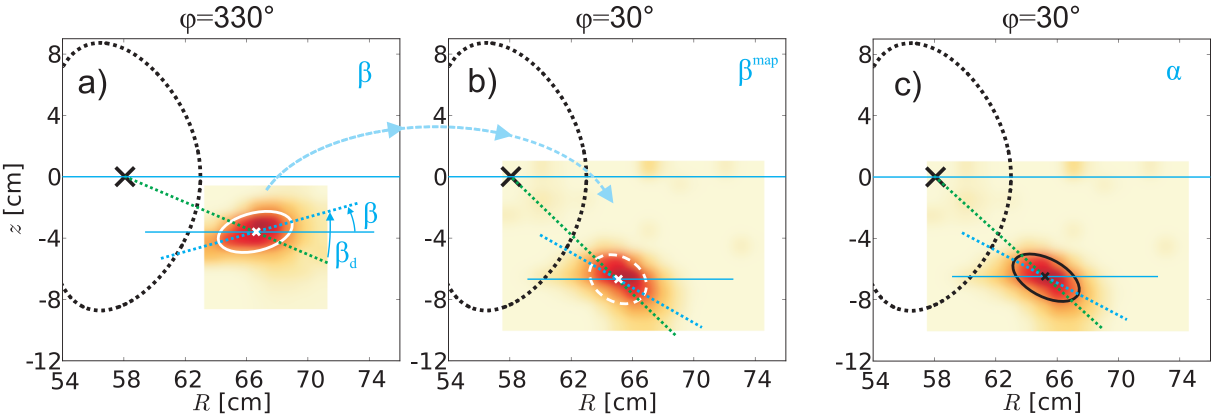

Figure 1: *Conditionally averaged* $I_{\mathrm{i,sat}}$ *normalised by* $\sigma_{I_{\mathrm{i,sat}}}$ *fluctuations at toroidal angles* $\phi = 330^\circ$ *and* 30° *(plots a and c). Ellipses are fitted to the blob structures in plots a and c (white and black ellipse respectively). Plot b shows again the conditionally averaged data from plot a but with the ellipse fitted to the mapped blob structure (dashed white).*

The magnetic field geometry in TJ-K can be slightly varied changing the ratio of the magnetic fields produced by the main helical winding and a pair of vertical field coils, r_{vh}. For the blob experiments, it was advantageous to increase r_{vh} from the standard $r_{\mathrm{vh}} = 57\%$ to $r_{\mathrm{vh}} = 63\%$ which increases the physical SOL width on the outboard side.

The influence of magnetic shear on blobs

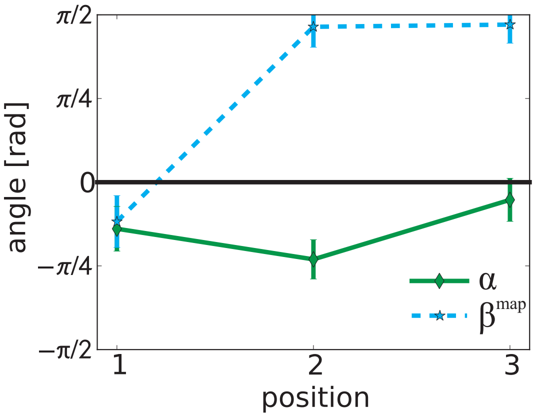

Figure 2: *The angles* α *and* β^{map} *as a function of 64-probe matrix position in the SOL.*

Simultaneous measurements using the 64-probe array and the 2D-scanning probe enabled the determination of the 3D structure of blob filaments as they propagated through the SOL of TJ-K. Measurements were conditionally averaged using a common reference probe resulting in the average blob cross-sections simultaneously at two toroidal positions. The trigger condition required that fluctuations in the ion saturation current signal, $\tilde{I}_{\mathrm{i,sat}}$, rise from below to above $2\sigma_{I_{\mathrm{i,sat}}}$ within one time step ($1\,\mu$s). By positioning the probe matrix at different locations in the SOL, the 3D form of blobs could be investigated along their typical trajectories (see [5]). In order to achieve this, the probe matrix was placed at three locations in the SOL, centred on $(R,z) = (67.2\,\mathrm{cm}, -4.6\,\mathrm{cm})$, $(71.2\,\mathrm{cm}, -1.6\,\mathrm{cm})$ and $(71.2\,\mathrm{cm}, 0.9\,\mathrm{cm})$, and the same analysis was carried out at each location. These locations are referred to henceforth as positions 1, 2 and 3 respectively. Figure 1 shows the conditionally averaged $I_{\mathrm{i,sat}}$ fluctuations measured by the probe array and the 2D-scanning probe. Blob tilt (to be distinguished from blob pitch) was quantified by fitting ellipses to the resulting blob cross sections, as well as to the blob coordinates mapped along the magnetic field lines by $\Delta\phi = 60^\circ$, from $\phi = 330^\circ$ to $\phi = 30^\circ$. Two angles, α and β^{map}, can then be defined, where α is the angle between the horizontal ($z = 0$) and the major axis of the ellipse fitted to the data at $\phi = 30^\circ$, and β^{map} is the angle between the horizontal and the major axis of the ellipse fitted to the blob mapped into the $\phi = 30^\circ$ plane. By comparing these two angles at the 3 probe array positions, the tilt of the blob to the magnetic field can be determined along its trajectory. Figure 2 shows α and β^{map} as a function of position in the SOL. As can be seen from the figure, at the first position, close to the LCFS, the blob filament is contained within a local flux tube. However, as the filament propagates through the SOL to positions 2 and 3, the two angles deviate significantly, indicating a tilt of the structure relative to the magnetic field. Further, it was shown in [6] that blob filaments remain approximately rigid as they propagate through the SOL, and do not experience the deformative effect of magnetic shear. The reason for this is unclear, and is the subject of ongoing work.

The influence of magnetic shear on drift waves

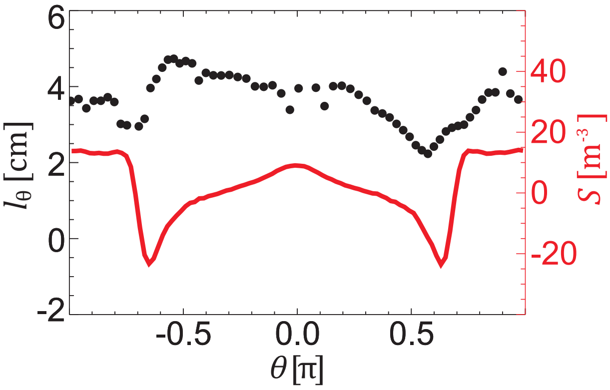

Figure 3: *The poloidal correlation length, l_θ as a function of poloidal angle θ. The local magnetic shear, S, is plotted in red.*

Previous measurements have shown that the poloidal correlation length, l_θ, of drift wave turbulence is reduced by approximately a factor of 2 in the region of high local magnetic shear, S [4]. This quantity is shown in figure 3 for data obtained with the current experimental setup, and exhibits a similar trend to that previously observed in [4]. The precise effect that magnetic shear has in reducing the poloidal correlation length, however, was not clear. Was it due to a reduction in typical size of drift wave structures, due to an increase in ellipticity, or due to an average tilting of elliptical structures? These questions can be addressed using conditionally averaged two dimensional measurements taken with the scanning probe and using a poloidal array of 16 reference probes, separated by 120° in the toroidal angle. The 16 reference probes correspond to every fourth probe taken from the OPA, starting from the midplane. These 16 equally spaced reference probes allow conditionally averaged drift wave structures to be investigated as a function of poloidal angle, and thus a comparison to the poloidal variation of magnetic field properties to be made. The same trigger condition was used as described in the previous secion. The conditionally averaged data was analysed in a time window of 100 μs around the trigger condition, resulting typically in several hundred drift wave structures per conditional average time series.

The simplest quantity to calculate from the resulting conditionally averaged data is the typical drift wave length scale associated with its cross-sectional area, $A^{1/2}$. The bounding contour of a drift wave structure was taken to be at the e-folding length $\tilde{n}_{\text{bound}} = \tilde{n}_{\text{max}}/e$, where $\tilde{n}_{\text{max}}$ is the local maximum of a detected drift wave structure. The dependence of $A^{1/2}$ on θ is shown for a helium discharge in figure 4. Comparing figures 3 and 4, strong resemblances between the two data sets are evident insofar as $A^{1/2}$, determined from the conditionally averaged data, is reduced in the region where l_θ is reduced, at approximately $\theta = \pm\pi/2$, where the local magnetic shear is strongly negative. This suggests that the decrease in poloidal correlation length is due to a decrease in cross-sectional area of drift waves in regions of high local magnetic shear. This result is in line with the expected damping of drift waves by high local magnetic shear [7].

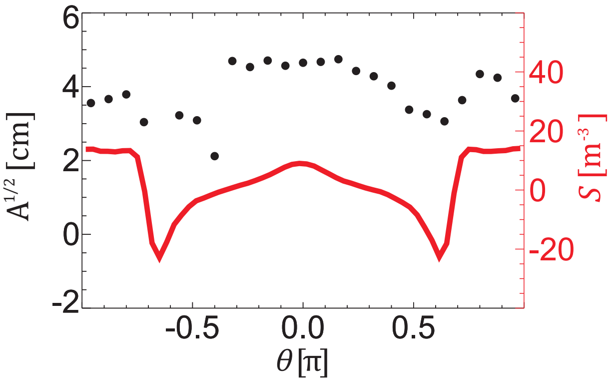

Figure 4: *The typical drift wave length scale determined from the conditionally averaged drift wave area, A, as a function of poloidal angle θ. The local magnetic shear, S is plotted in red.*

Further investigations into the ellipticity, ε, of ellipses fitted to conditionally averaged drift wave cross-sections, along with their tilt, α, to the flux surface, have been carried out. The drift wave ellipticity was determined using $\varepsilon = (a-b)/a$, where a is the major radius and b is the minor radius. Drift waves showed a weak tendency towards higher ellipticity in the high local magnetic shear regions, and the tilt angle α suggests that the ellipses are oriented more perpendicularly to the flux surfaces at $\theta = +\pi/2$, however this is not the case at $\theta = -\pi/2$, suggesting that the tilt is not clearly influenced by the local magnetic shear.

References

[1] D. A. D’Ippolito et al., Phys. Plasmas **18**, 060501 (2011)
[2] U. Stroth et al., Phys. Plasmas **11**, 2558 (2004)
[3] M. Ramisch et al., Phys. Plasmas **12**, 032504 (2005)
[4] G. Birkenmeier et al., Plasma Phys. Contr. Fusion **55**, 015003 (2012)
[5] G. Fuchert et al., Plasma Phys. Contr. Fusion **55**, 125002 (2013)
[6] S. Garland et al., Plasma Phys. Contr. Fusion **58**, 044012 (2016)
[7] A. Kendl et al., Phys. Rev. Lett. **90**, 035006 (2003)