Influence of plasma edge dynamics on blob properties

G. Fuchert[1]*, B. Bätz[1], G. Birkenmeier[1,2], M. Ramisch[1], U. Stroth[1,2]

[1] Institut für Plasmaforschung, University of Stuttgart, 70569 Stuttgart, Germany

[2] Max-Planck-Institut für Plasmaphysik, EURATOM Association, 85748 Garching, Germany

Abstract

Density structures elongated along the magnetic field lines, so-called blobs, are able to contribute significantly to the scrape-off layer (SOL) transport in magnetically confined fusion plasmas. Thus, understanding of generation and dynamics of blobs is needed to predict the particle and energy flux to the walls of a future fusion reactor. Although the understanding of blobs has improved a lot over the recent years [1, 2], the details about both, blob generation and evolution remain still unknown. In this paper, studies of blob properties at the stellarator TJ-K are presented. The generation rate, blob size, and velocity have been studied with Langmuir probes and a fast camera. Special emphasis is put on the influence of the edge turbulence.

Experimental setup

The presented measurements were performed at the stellarator TJ-K [3, 4] in hydrogen, helium, neon and argon discharges with a low (67 mT) and high (300 mT) magnetic field in order to vary the plasma parameters over a broad range. All discharges were heated with microwaves at 2.45 GHz and 8 GHz for the low-field and high-field shots, respectively. All presented discharges were limited by two poloidal limiters, which were introduced to get a larger SOL with homogeneous connection lengths. The high-speed camera is a Photron SA-5 with a frame rate up to 750 kfps (kilo frames per second).

Birth rate of blobs

Conditional average analyses of probe measurements showed that blobs are generated by turbulent drift-wave structures in the confinement region of TJ-K [5]. Thus, there should be a connection between the occurrence of high-amplitude drift-wave structures in the confinement region and blobs in the SOL. This connection can be shown by a waiting-time analysis, where the waiting time is defined as the time between two subsequent amplitude maxima of drift waves in the confined plasma or blobs in the SOL in a small observation region of the camera images. Fig. 1 shows the waiting time distributions (WTD) for a low-field hydrogen discharge.

*fuchert@ipf.uni-stuttgart.de

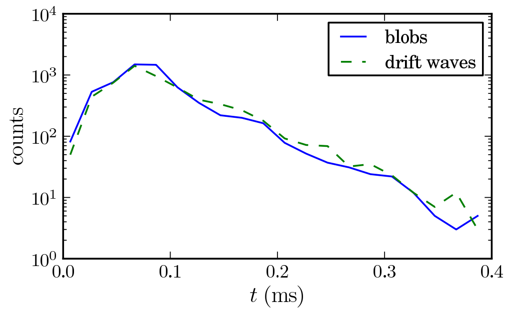

Figure 1: Comparative waiting time distribution for blobs and drift waves.

For a random process, one would expect an exponential decay of the WTD. However, there is a peak at $\approx 90\,\mu$s for both, drift waves and blobs. This feature varies scarcely for shots with comparable plasma parameters. Also the total number of detected events is very similar. The generation rate for blobs with intensity amplitudes larger than $1\,\sigma$ is about 10400/s, while drift-wave structures are detected with a rate of about 9600/s, which lies in the typical frequency range of the drift-wave turbulence in TJ-K.

Blob-size scaling

Since the blobs in TJ-K are observed to detach from turbulent drift-wave structures extending over the last closed flux surface (LCFS), a connection between the sizes of drift waves and blobs perpendicular to the magnetic field can be expected. For drift waves, this has already been investigated in TJ-K [6] and, summarized very briefly, a scaling with ρ_s^α has been found, where $\rho_s = \sqrt{T_e m_i}/eB$ and $\alpha \approx 0.5$. This study has been done, however, in the standard setup of TJ-K without poloidal limiters, such that turbulent structure sizes are not as subject to system limitations as in the present case. Hence, the result of size scaling might differ and is, therefore, measured together with that of blobs in the SOL. The structure size is measured by conditionally averaging the 2D probe data and fitting an ellipse to the observed density structures in the confinement region and SOL. For the fit, all points are considered where the density is larger than 1/e of the structure's density maximum. Since this method yields exactly one averaged blob size for every shot, it contains no information about the spread of the blob size. Thus, the fast camera is used to detect single blob events and measure the blob size for comparison together with the blob size spread. ρ_s is varied by using different gases and magnetic field strengths. The results of the blob size measurements are shown in fig. 2. The scaling factors are $\alpha_{\text{cam}} = 0.19 \pm 0.03$ and $\alpha_{\text{probe}} = 0.26 \pm 0.20$ for the blobs and $\alpha_{\text{cam}} = 0.23 \pm 0.04$ and

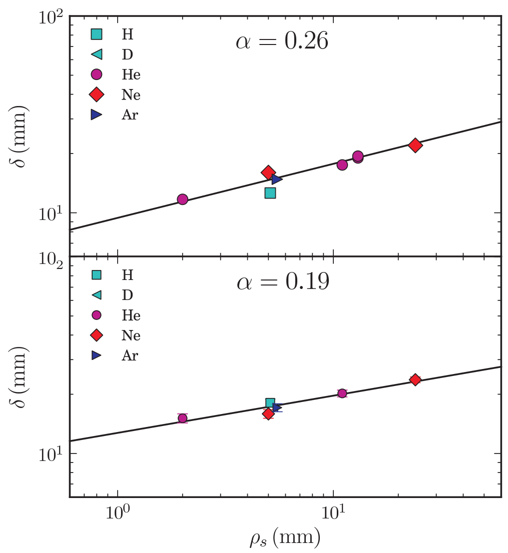

Figure 2: ρ_s-scaling of the blob size from probes (top) and fast camera (bottom). The error bars for the camera measurement are in the range of the symbol size.

$\alpha_{\text{probe}} = 0.21 \pm 0.20$ for the drift waves (not shown in fig. 2). The relatively large difference between the scaling factors for the blob scaling can be understood by the limitations of the camera measurement due to integration along the line of sight. Blobs and drift waves show a comparable size scaling. Even though blobs and drift waves have different dynamical properties, the size scaling is surprisingly comparable, which hints to larger drift waves generating larger blobs.

Velocity scaling of blobs

The dynamics of blobs can be described by a 2D model [1, 7] with blobs as filaments with $k_{\parallel} = 0$, which are polarized by, e. g., magnetic curvature effects. This polarization leads to poloidal electric fields and, hence, radial $\mathbf{E} \times \mathbf{B}$ drifts. A quantitative estimate for this outward propagation including effects of the ion polarization current, parallel currents in the blob, and ion neutral collisions has been given in [8]:

$$v_{\text{blob}} = \frac{\sqrt{\frac{2\delta_b}{R}}c_s}{1 + \frac{1}{\rho_s^2 l_{\parallel}}\sqrt{\frac{R}{2}}\delta_b^{5/2} + \frac{v_{\text{in}}\sqrt{R\delta_b}}{\sqrt{2}c_s}} \frac{\delta n}{n}, \tag{1}$$

with the blob size δ_b, major radius R, sound velocity c_s, neutral ion collision frequency v_{in}, density n, $\delta n = n_{\text{blob}} - n_0$, and $l_{\parallel}$ the length of the blob (distance between the two limiter plates). The blob velocity can be determined from the conditionally averaged 2D probe measurements by fitting an ellipse to the blob and tracking the center of the ellipse. ρ_s and c_s were determined by measuring electron temperature profiles for every discharge. The neutral collision term in (1) is negligible for plasma parameters in TJ-K, as long as the cross section is smaller than $10^{-14}\,\text{cm}^2$, which should well be the case. Fig. 3 shows a good overall agreement with the measured blob velocities. However, the measured velocity in hydrogen discharges is significantly smaller than the prediction. Effects due to the stellarator geometry should influence all discharges comparably. Thus, it is more likely that the model describes the various gases differently well. As a matter of fact, the cross phase between density and potential $\alpha^{\Phi,n}$, which can be estimated from the probe data [9], is significantly smaller for hydrogen than for the other gases. The blob model, however, describes blobs as in-

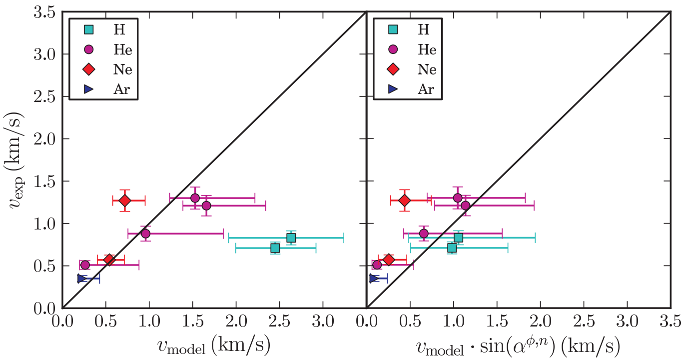

Figure 3: Comparison of measured blob velocities with (1) (left) and the same with an empirical correction, describing the effect of $\alpha^{\Phi,n} < \pi/2$ (right).

terchange driven objects with a cross phase of $\pi/2$. Any deviation from this should reduce the effectiveness of the interchange drive and, therefore, the velocity of the blobs. Thus, an empirical correction factor of $\sin\left(\alpha^{\Phi,n}\right)$ is multiplied to (1). It can be seen from the right diagram in fig. 3 that the relatively large deviation for hydrogen could be explained by the reduction of the interchange drive by the measured cross phase smaller than $\pi/2$.

Conclusion

In the presented experiments it could be demonstrated that the properties of the edge turbulence influence the properties of blobs in the SOL. A waiting time analysis showed that the occurrence of blobs and drift waves is closely coupled, while a comparative ρ_s scaling of the structure size revealed a connection between large drift waves and large blobs. Both findings could be explained by the generation mechanism for blobs in TJ-K, where density maxima of turbulent drift-wave structures partly extend over the LCFS due to turbulent $\mathbf{E} \times \mathbf{B}$ drifts, followed by the detachment of the SOL structure from the generating drift wave.

Finally, the outward velocity of the blobs has been measured and compared to the prediction in [8]. Despite of the fact that this model does not include the stellarator geometry, a remarkable agreement with the prediction has been found. However, the blobs observed in TJ-K are no perfect interchange objects, as can be seen from the cross phase between density and potential, which has been found to be smaller than $\pi/2$. This results in a reduced blob velocity, compared to the prediction. Furthermore, it is interesting to note that the overall applicability of the blob model for TJ-K implies that the characteristic size of drift-wave structures indirectly influences the outward velocity of blob filaments in the SOL, due to the blob size dependence of (1) and the influence of the drift-wave turbulence on the blob size.

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