Blob properties in L- and H-mode plasmas of ASDEX Upgrade

G. Fuchert[1], G. Birkenmeier[2], D. Carralero[2], T. Lunt[2], P. Manz[4], H. W. Müller[2], B. Nold[3], M. Ramisch[3], V. Rohde[2], U. Stroth[2,4] and the ASDEX Upgrade team

[1] *IJL, Université de Lorraine, CNRS (UMR 7198), BP 70239, Vandoeuvre-lès-Nancy, France*

[2] *Max-Planck-Institut für Plasmaphysik, Garching, Germany*

[3] *Institut für Grenzflächenverfahrenstechnik und Plasmatechnologie, Universität Stuttgart, Stuttgart, Germany*

[4] *Physik-Department E28, Technische Universität München, Garching, Germany*

Introduction

In the scrape-off layer (SOL), filamentary structures called *blobs* contribute substantially to the turbulent transport. This leads to wall deterioration and, hence, increased impurity fluxes in the edge. The transport caused by blobs depends on the generation rate, cross-field size and velocity of the filaments. Most blob models assess the size and velocity by regarding the blob as a field-aligned filament, which is polarized poloidally by magnetic curvature, causing radial $\mathbf{E} \times \mathbf{B}$ drifts. Depending on the plasma conditions, different effects dominantly reduce this polarisation and, thus, different regimes of the model are obtained (see [1] and references therein). Just recently, the effects of a finite ion temperature were included into a blob model [2]. For the sheath limited regime, where the blob polarization is balanced by parallel currents across the sheath only, this model predicts the highest growth rate for a blob size δ_* of

$$\delta_* = \rho_\mathrm{s} \left(8(1+\tau_\mathrm{i})\right)^{1/5} \cdot \left(\frac{l_\parallel^2}{\rho_\mathrm{s} R}\right)^{1/5} . \tag{1}$$

Here, $\tau_\mathrm{i} = T_\mathrm{i}/T_\mathrm{e}$ is the ratio of the ion and electron temperature, $l_\parallel$ the parallel length of the filament, $\rho_\mathrm{s} = \sqrt{m_\mathrm{i} T_\mathrm{e}}/eB$ the drift scale and R the major radius. Since δ_* is the blob size at the largest growth rate, individual blobs can have different sizes δ_b. However, it can be expected that the value of δ_* influences the distribution of δ_b observed in the experiment. The corresponding velocity for the same regime is given by

$$v_{r,\mathrm{b}} = (1+\tau_\mathrm{i}) c_\mathrm{s} \left(\frac{\rho_\mathrm{s}}{\delta_\mathrm{b}}\right)^2 \frac{l_\parallel}{R} . \tag{2}$$

Concerning the blob generation rate, there is no quantitative prediction from blob theory yet.

In the following, the results of gas-puff imaging experiments at ASDEX Upgrade are compared to these predictions with special focus on differences in L- and H-mode discharges.

Experimental setup

The experiments presented were all performed on ASDEX Upgrade in the magnetic lower single null configuration with a line averaged edge density n_e was about $2 \cdot 10^{19}/m^3$. Each discharge consisted of a purely Ohmically heated L-mode phase before additional 3 MW of ECR heating triggered the L-H transition and a stable H-mode was sustained.

The blob properties were studied using a fast camera. The field-of-view covers a region of approximately $5 \times 5\,cm^2$ (resolution about 1 mm/pixel) on the low field side below the midplane. The frame rate is 120 kfps (kilo frames per second). To increase the emitted light intensity locally, deuterium gas was puffed into the imaged region (gas-puff imaging, GPI). The maximum intensity is observed close to $\rho_{pol} \approx 1.065$, which is in the limiter shadow of the heat shield for the L-mode phases, but not for the inter-ELM H-mode phases. The influence of this circumstance on the blob dynamics has to be studied in the future. The blob properties were determined from the image data using an object recognition algorithm. Due to the lack of T_e-profiles from probe measurements for the analyzed discharges, T_e had to be assumed in the far-SOL for a comparison with the analytical scalings. Thomson data and an outward shift in the emission intensity suggest a slight increase in T_e in the H-mode phases. This is uncommon for ASDEX Upgrade, but has been observed before [3]. Hence, it is assumed that $T_{e,L} = 15 \pm 5\,eV$ and $T_{e,H} = 20 \pm 5\,eV$. These values have to be checked in future experiments.

Results

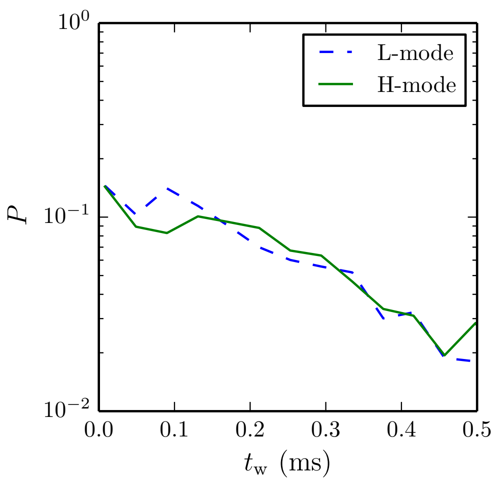

Figure 1: *Comparison of waiting-time distributions observed in an L-mode phase and inter-ELM H-mode phases of #28769.*

In Ref. [5] it was observed that blob generation at ASDEX Upgrade takes place approximately 1 cm outside of the nominal separatrix position. Here, the blobs are not detected in this region, but after propagating into the field of view of the camera, where the gas-puff provides sufficient light intensities to detect turbulent structures in the SOL. Since there is no indication that blobs appear spontaneously in the far SOL, the detection rate can be used as a proxi of the generation rate.

Blobs are detected in the image data by an amplitude threshold of one standard deviation and an area threshold of 20 pixels to prevent spurious blob detection due to noise. To determine the detection rate, a square of 10×10 pixels around the center of the image is defined and only events with a center of mass position (of the intensity fluctuations) inside this region are considered in the following. The detection time t_i of an individual structure i is defined as the time when the blob enters the detection region. Structure labeling prevents multiple counting of the same structure. As a result, the detection rate and waiting-time distribution (WTD) are obtained (with the waiting time $t_w = t_i - t_{i-1}$).

The resulting WTDs for an L-mode phase and inter-ELM H-mode phases are compared in Fig. 1. The corresponding detection rates are 3320 blobs/s for the L-mode phase and 4416 blobs/s for the inter-ELM H-mode phases (with comparable rates for other discharges). The shape of the WTDs and the detection rates compare well for both phases, which indicates that the blob generation mechanism does not change fundamentally. The slight increase in the detection rate observed in the inter-ELM H-mode phases does not necessarily indicate a larger generation rate: Due to a slightly larger average blob size (see below) more blobs exceed the area threshold introduced above.

The poloidal blob size is deduced from image data in L- and inter-ELM H-mode phases and averaged for all events detected in the region between the radial positions $R = 2.175$ and $2.180\,\mathrm{m}$ and the vertical positions $z = -0.15$ and $-0.145\,\mathrm{m}$ (around $\rho_{pol} = 1.07$). The average sizes obtained that way are about 7 mm in all analyzed phases and discharges. A comparison with the prediction according to Eq. (1) (assuming $T_i = 3T_e$ according to Ref. [4]) is shown in Fig. 2. It can be seen that δ_b is increased in the inter-ELM H-mode phases. However, the change of $10-20\,\%$ is small. The absolute values are in good agreement with the prediction.

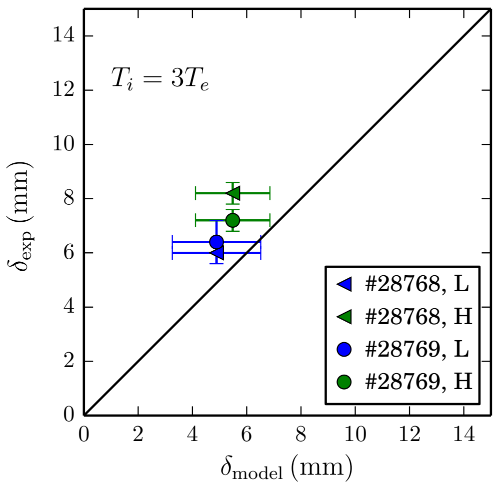

Figure 2: *Comparison of the average blob size δ_{exp} with the prediction δ_{model} from a warm ion model.*

The radial blob velocity is determined by using the object recognition method and tracking the individual blobs over several images. For a quantitative comparison with Eq. (2) the radial velocities are averaged in the same region as the blob sizes above. The results are shown in Fig. 3, again assuming $\tau_i = 3$. Although the velocity scaling predicts velocities of the right order of magnitude, the predicted values are too high. Due to the strong T_e dependence of Eq. (2) and the fact that T_e had to be assumed for the analyzed discharges, the error bars of the theoretical prediction are large. Future experiments will investigate this discrepancy in more detail. For the moment it remains unclear why the size prediction shows a remarkable agreement with the experimental observations, while the radial velocity is smaller than predicted.

Summary and conclusion

The blob detection rate, size δ_b, and radial velocity were determined in Ohmic L- and inter ELM H-mode plasmas of ASDEX Upgrade. Although the edge plasma parameters change drastically from L to H-mode, surprisingly only small changes in the blob properties were observed.

The blobs in H-mode are larger in size and have a smaller radial outward velocity. Both changes are, however, not as striking as to indicate a dramatic change in the blob dynamics between L- and H-mode. The same is true for the detection rate and waiting-time distribution. The detection rate is slightly increased in H-mode. This may be explained by the larger blob size in that phase, which leads to a larger number of events exceeding the area threshold or an increase in the generation rate. These results indicate that the turbulent dynamics just around the separatrix, which is likely responsible for blob generation, is probably unaffected by the striking changes in the edge parameters comparing L- and H-mode plasmas.

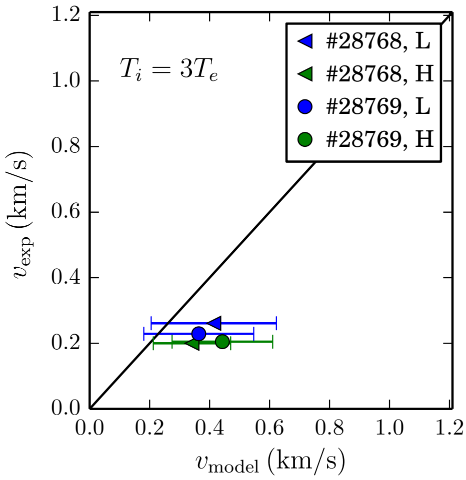

Figure 3: *Comparison of averaged radial velocities (v_{exp}) with a warm ion model.*

The experimentally observed values for δ_b and $v_{r,b}$ were compared to a novel blob model including warm-ion effects [2]. First results are promising, but a larger data base is needed with special focus on reliable temperature profiles in the far-SOL.

References

[1] D. A. D'Ippolito, J. R. Myra and S. J. Zweben, Phys. Plasmas **18**, 60501 (2011)

[2] P. Manz *et al*, Phys. Plasmas **20**, 102307 (2013)

[3] J. Neuhauser *e*t al, Plasma Phys. Control. Fusion **44**, 855 (2002)

[4] M. Kočan, F. P. Gennrich, A. Kendl, H. W. Müller and the ASDEX Upgrade Team, Plasma Phys. Control. Fusion **54**, 085009 (2012)

[5] B. Nold *et al*, Plasma Phys. Control. Fusion **52**, 065005 (2010)

[6] D. Carralero *et al*, submitted to Nucl. Fusion

This project has received funding from the Euratom research and training programme 2014-2018