Spatiotemporal variations of blob properties in ASDEX Upgrade

G. Fuchert[1,2], G. Birkenmeier[1,3], D. Carralero[1], P. Manz[1,3], U. Stroth[1,3],
E. Wolfrum[1], and the ASDEX Upgrade team
[1] *Max-Planck-Institut für Plasmaphysik, Boltzmannstraße 2, 85748 Garching, Germany*
[2] *Max-Planck-Institut für Plasmaphysik, Wendelsteinstraße 1, 14791 Greifswald, Germany*
[3] *Physik-Department E28, Technische Universität München, James-Franck-Str. 1, 85748 Garching, Germany*

Introduction

Turbulence generated plasma filaments of increased pressure ("blobs") contribute significantly to the SOL turbulence in tokamaks and stellarators. Hence, it is necessary to understand the blob dynamics and identify robust scaling parameters, which might allow the development of means to control the blob-induced transport. There are analytical scaling laws, which describe the properties and dynamics of the blobs. Despite their simplicity and the assumptions made during their derivation, these scaling laws help to identify the parameters mainly determining blob properties like perpendicular size and radial velocity.

According to theory, the collisionality in the SOL should be one such parameter. If the collisionality is sufficiently high, parallel currents along the filament, which in the standard picture counteract the blob polarization, are strongly reduced and the filament *detaches* from the plasma facing components. Experiments show that the blob dynamics changes indeed if a threshold *effective collisionality* $\Lambda = \nu_{ei} L_{\parallel} / (\Omega_e \rho_s) \approx 1$ (see Ref. [1]) is surpassed. However, due to strong radial variations in density, temperature and connection length, Λ is not constant across the SOL. Hence, depending on the radial profile of Λ, regions of different blob regimes should be observed simultaneously at different spatial locations. Furthermore, in order to be a useful control parameter, blob properties have to respond also to temporal variations of Λ. The ASDEX Upgrade experiments presented in this contribution, including measurements with Langmuir probes and gas-puff imaging, show both described effects: Following the variations in the Λ profile induced by density ramps, significant changes in the blob properties are observed in space and time.

Theoretical background

The radial motion of blobs is explained by a poloidal charge separation within the filament due to magnetic curvature effects. This charge separation leads to an electrical field and, in turn, to a radial outward motion of the filament. This process can be described analytically, yielding scaling laws for the cross-field size and radial velocity of the filaments. The blob dynamics is governed by mechanisms that balance further charge separation and, hence, heavily depend on the parallel boundary conditions. In SOL plasmas with low resistivity, currents parallel to the filament can short-circuit the oppositely charged regions of the blob at the wall. For a large parallel resistivity the parallel current is suppressed and the charge accumulation has to be balanced by perpendicular processes like the ion polarization current. An electrostatic two-region model compares the parallel and perpendicular dynamics by the aforementioned *effective collisionality parameter* Λ. Parallel currents play a decisive role if $\Lambda \lesssim 1$ (often referred to as the *sheath limited regime*. The bi-normal cross-field size δ_b (diameter) and radial velocity $v_{\mathrm{b},r}$ can then be written as [2]

$$\delta_b = 2\rho_{\mathrm{s}} \left(\frac{l_{\|}^2}{\rho_{\mathrm{s}} R} \right)^{1/5} , \quad v_{\mathrm{b},r} = 2c_{\mathrm{s}} \frac{\tilde{n}}{n} \left(\frac{\rho_{\mathrm{s}}}{\delta_{\mathrm{b}}/2} \right)^2 \frac{l_{\|}}{R} , \tag{1}$$

where ρ_{s} is the drift scale, c_{s} is the sound speed, $l_{\|}$ the parallel connection length, R the major radius, and $\tilde{n}/n$ the relative fluctuation amplitude (ASDEX Upgrade: $\tilde{n}/n \approx 0.3$ inside and 0.5 outside of the divertor). It has been shown in ASDEX Upgrade that this scaling describes filaments in the SOL for $\Lambda < 1$ at very different radial locations [3, 4] if ion temperature effects are taken into account [5]. For $\Lambda > 1$ a disconnection of the filaments is clearly documented for ASDEX Upgrade [6], leading to filament properties that disagree with predictions by Eq. (1). While there is experimental evidence [4] that the radial velocity scales with the square root of the blobs size, as it is predicted for the *resistive ballooning regime* (described in Ref. [1]).

In the physical picture discussed above, a blob would react on changes in the SOL plasma on characteristic time scales τ_{c} between $v_e/l_{\|}$ (parallel electron dynamics, v_e is the thermal electron speed) and $c_{\mathrm{s}}/l_{\|}$ (parallel ion dynamics and sheath effects). Together with the radial velocity of the filament this gives an estimate of the radial length scales $\lambda_{\mathrm{c}} \approx v_r \tau_{\mathrm{c}}$ on which these changes should be observed. Close to the separatrix ($T_e = 50\,\mathrm{eV}$, $v_r = 1\,\mathrm{km/s}$, $l_{\|} = 50\,\mathrm{m}$) it is found that $2\,\mathrm{cm} \leq \lambda_{\mathrm{c}} \leq 2\,\mathrm{m}$, which is large compared to the blob size and extent of the SOL. However, further outwards ($T_e = 10\,\mathrm{eV}$, $v_r = 0.1\,\mathrm{km/s}$, $l_{\|} = 10\,\mathrm{m}$) the situation is different with $3\,\mathrm{mm} \leq \lambda_{\mathrm{c}} \leq 5\,\mathrm{cm}$. Hence, if blobs are generated in a high density discharge at $\Lambda > 1$, it can be expected that they "reattach" to the walls as Λ drops below 1 in the SOL.

Experiments and results

In the typical tokamak SOL, the electron temperature drops very quickly to a rather constant level, while the density decays much slower. Furthermore, while radially leaving the divertor towards the walls, the parallel connection lengths gets shorter. Since $\Lambda \propto n_e l_{\|}/T_e^2$ [7], outside of the strong temperature gradient region Λ decays quickly for a radially outward propagating blob and, as discussed above, blobs in high-density regimes should “reattach” to the walls as they propagate radially outwards.

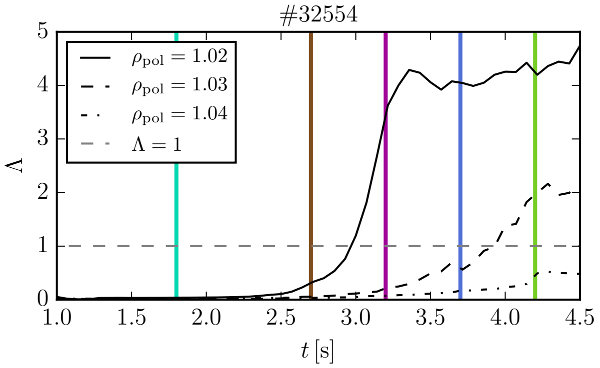

Figure 1: *Temporal evolution of the effective collisionality Λ at different radial locations in #32554. The vertical lines indicate probe plunges.*

Figure 1 shows the temporal evolution of Λ in the divertor region (using temperatures and densities in the divertor as well as the shortest connection length to the divertor targets) for the ASDEX Upgrade discharge #32554 at three different radial locations $\rho_{\mathrm{pol}} = [1.02, 1.03, 1.04]$. By increasing the gas fueling, Λ increases and as expected at all times it is $\Lambda(1.02) > \Lambda(1.03) > \Lambda(1.04)$.

Using a reciprocating multip-pin probe, the blob properties are monitored during 5 probe plunges ($t_{\mathrm{stroke}} = [1.75,\ 2.65,\ 3.15,\ 3.6,\ 4.15\,\mathrm{s}]$), remaining for about 150 ms at the innermost positions $\rho_{\mathrm{pol}} \approx 1.02$ (#32553) and $\rho_{\mathrm{pol}} \approx 1.04$ (#32554). After the last plunge the blob properties are measured outside of the divertor region, where $\Lambda < 1$ the entire time, ($\rho_{\mathrm{pol}} \approx 1.08$) by gas-puff imaging (GPI) ($t = 4.65\,\mathrm{s}$).

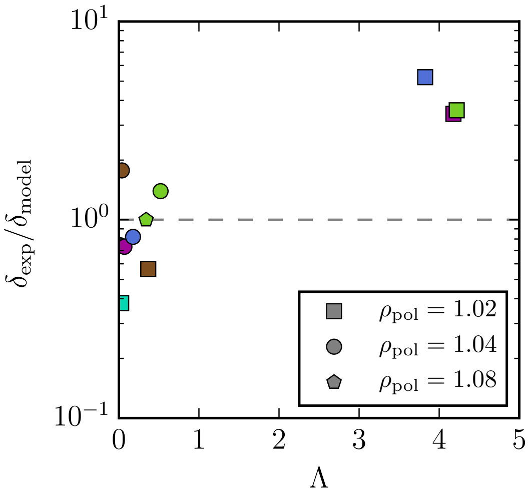

Figure 2: *Ratio of the experimental and predicted blob sizes as a function of the effective collisonality Λ. The color represents the time (Fig. 1) and the symbol shape the radial location of the measurement.*

Figures 2 and 3 show the ratios of the experimental values for blob size δ_b and radial velocity v_r and the values predicted by the scaling laws given in Eq. (1) (valid when parallel currents play a role). The symbol colors correspond to the probe plunges indicated in Fig. 1 and are, hence, an indicator of the time evolution, while the symbol shape represents the radial location of the measurement. It can be seen that at earlier times $\Lambda < 1$ everywhere. The sizes are well predicted around $\rho_{\mathrm{pol}} \approx 1.04$ and underestimated around $\rho_{\mathrm{pol}} \approx 1.02$. The velocities are in agreement with the prediction apart from one data point. Since the first two plunges should be more or less equivalent, this seems to be an outlier. As time advances, Λ exceeds 1 around $\rho_{\mathrm{pol}} \approx 1.02$ and the blob properties deviate from the prediction. Further outside, no such change in the blob properties can be observed. Outside of the divertor region ($\rho_{\mathrm{pol}} \approx 1.08$), both velocity and size are in agreement with the prediction. This implies that parallel currents along the filaments that were suppressed around $\rho_{\mathrm{pol}} \approx 1.02$ arise while the filament propagates outwards and Λ decreases.

Summary and conclusions

Prior experiments in ASDEX Upgrade documented a change in the characteristic blob properties in high-density discharges around $\Lambda = 1$. This is in agreement with analytical blob models predicting a change in the relevant blob regime around this threshold value in the effective collisionality. If this explanation is correct, this would imply that a) different blob regimes would co-exist in the SOL of ASDEX Upgrade and b) blobs generated in high-Λ regions would "reattach" to the walls while they propagate radially outwards. The presented experiments show that these effects are indeed observed in ASDEX Upgrade. While these results represent further evidence that the present blob theory is able to describe several features of turbulent structures in the SOL of fusion experiments, they are also of practical importance for the heat and particle deposition on the walls. The latter is the case since a change in the blob dynamics by reattachment determines if and where the blobs will end up in the divertor region or will reach the first wall. Furthermore these experiments show that it would in principle be possible to influence the blob dynamics by varying Λ in the SOL (e. g. by the parallel connection length).

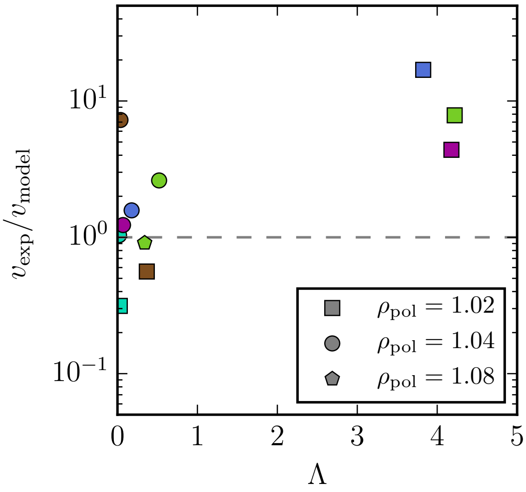

Figure 3: *Same representation as in Fig. 2 but for the radial velocity.*

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