

Investigations of the magnetic field dependence of blob velocity and size with Li-BES at ASDEX Upgrade

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Introduction

At the edge of fusion plasmas, intermittently expelled density filaments, so called blobs [1, 2], are propagating through the scrape-off layer (SOL), which determines perpendicular transport, and can lead to a degradation of plasma facing components. Since this degradation is critical for the first wall in future fusion devices, an understanding of the generation and the propagation of blobs is needed.

In toroidal plasmas, blobs are thought to be solitary density perturbations appearing together with an electric dipole from poloidal charge separation as a result of magnetic field inhomogeneities. Depending on the plasma regime, the dipole can radially accelerate the blob via the $E \times B$ drift to a greater or lesser extent, and a relation between the size of a blob a and its radial velocity v_r can be derived. A compact expression for a multi-regime scaling which takes into account three different effects (sheath-dissipation, inertia and divergence of ion polarization current) was derived by Theiler *et al.* [3]:

$$v_{r,\text{theo}} = \frac{\sqrt{\frac{2a}{R}} c_s}{1 + \frac{1}{\rho_s^2 L} \sqrt{\frac{R}{2}} a^{5/2}} \frac{\delta n}{n}. \quad (1)$$

Here, R is the major plasma radius, L the parallel connection length, $c_s = \sqrt{T_e/m_i}$ the sound velocity, $\rho_s = \sqrt{m_i T_e}/(eB)$ the drift scale with electron temperature T_e , magnetic field strength B and ion mass m_i . $\frac{\delta n}{n}$ is the density fluctuation level.

In order to test the ρ_s dependence of Eq. 1, dedicated discharges with different magnetic fields strengths from $B = 1.4$ to 3.2 T have been performed at ASDEX Upgrade in order to get a large variation in $v_{r,\text{theo}}$. The edge electron density was kept constant at $n = 1.3 \cdot 10^{19} \text{ m}^{-3}$ in only ohmically heated L-mode plasmas. The Lithium beam emission spectroscopy (Li-BES) system at ASDEX Upgrade is able to directly measure $\delta n/n$, a and v_r in the SOL. Therefore, it is an ideal diagnostic for the evaluation of the blob velocity scaling of Eq. 1 in a high temperature fusion device.

Sensitivity of the Li-BES system

The Li-BES system at ASDEX Upgrade measures the emission of the Li_{2p-2s} optical transition, and is routinely used to determine electron density profiles in the edge plasma [4, 5]. A recent upgrade of the system (new optical head, faster data acquisition system, new and more lines of sight) allows for the determination of emission profiles at 26 radially displaced channels with a temporal resolution of $5 \mu s$. Typically, the ten outermost channels cover the whole SOL, and the arrangement of the observation volumes (radial width ~ 5 mm, radial distance between the volumes ~ 6 mm) allows for the measurement of blob structures with a radial wavelength $k_r < 12.5 \text{ cm}^{-1}$.

A blob in the SOL is a localized plasma density perturbation which excites the penetrating beam neutrals (acceleration voltage ~ 40 keV) into the Li_{2p} state by collisions. Due to a finite lifetime of the Li_{2p} state of about 27 ns, the Li_{2p-2s} photons are not emitted immediately after the collisions but some time later while the fast neutrals have already penetrated deeper into the plasma. Therefore, a "smearing" of the line emission takes place and the radial width of the blob appears to be larger in the emission profile than it actually is.

This effect can be numerically evaluated taking into account the beam neutrals velocity, the background density profile of the plasma and the collisional-radiative model which is routinely used for the density profile evaluation [5]. As an example, Fig. 1a shows the effect of an artificial density blob in the SOL on the emission profile. Obviously, the blob's emission response width defined as the half width of the half maximum (HWHM) in the emission profile appears much wider than the actual size a (HWHM of the density perturbation). In a systematic study, the relation between the emission response width and the actual density blob size a was determined numerically in order to allow for a translation of the measured emission response width into the parameter of interest a (Fig. 1b). This relation depends on the radial position of the blob and was therefore evaluated for $r = 4$ cm corresponding to $\rho_{pol} = 1.044$ in the considered experiments.

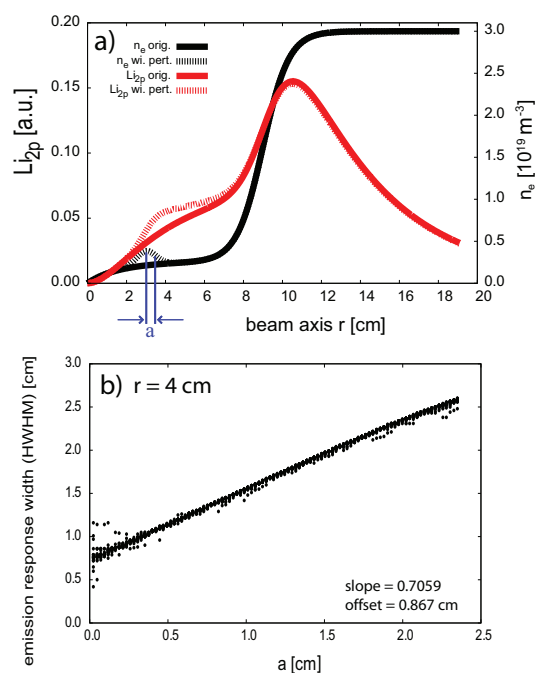


Figure 1: *Effect of a density blob on the emission profile (a). Relation between blob width a and the corresponding response in the emission profile (b).*

Size and Velocity Scaling of Blobs

In order to evaluate the size a and the velocity v_r of the blobs, a conditional averaging procedure [6] (threshold: 2.5 standard deviations) has been applied to 400 ms of mean free and low-pass filtered ($f < 20$ kHz) Li-BES raw data of 10 different discharges.

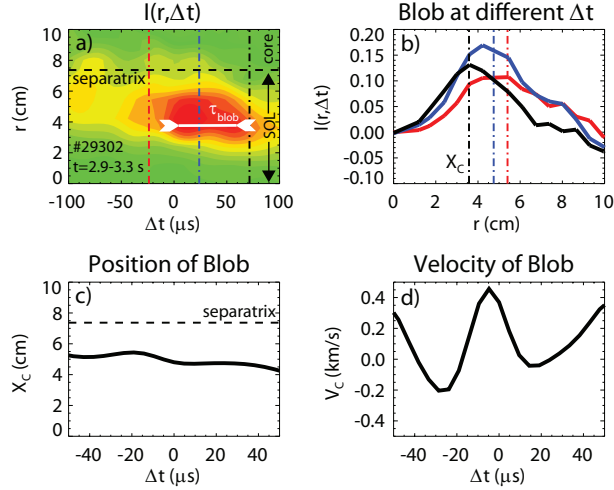


Figure 2: (a) Spatio-temporal picture $I(r, \Delta t)$ of averaged blob. (b) $I(r, \Delta t)$ at three selected time points. Center-of-mass coordinate X_C (c) and velocity V_C (d) of blob.

aged time window.

While the emission response width is determined as the HWHM from the measured blob intensity $I(r, \Delta t)$ and translated into blob size a by means of Fig. 1, the fluctuation amplitude $\delta n/n$ is determined directly from the autocorrelation function of the raw signal $\delta I/I$ as described in Ref. [7]. The error bars (1σ) for all quantities are from statistical deviations of different sub-series within the same discharge.

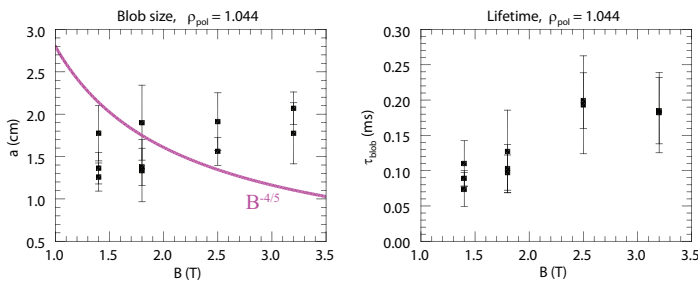


Figure 3: Measured blob size a (left) and lifetimes τ_{blob} (right) depending on magnetic field B .

A reference channel corresponding to a radial position of $\rho_{pol} \approx 1.044$ (mid-SOL) in normalized poloidal flux coordinates was chosen.

The result is an averaged spatio-temporal data set of the Li_{2p-2s} emission $I(r, \Delta t)$ shown in Fig. 2a. Evaluating the center-of-mass velocity $V_c = dX_c/dt$ with the center-of-mass radial coordinate (dashed vertical line in Fig. 2b)

$$X_c = \frac{1}{Q} \int r I(r, \Delta t) dr \quad \text{with} \quad (2)$$

$$Q = \int I(r, \Delta t) dr \quad (3)$$

during the evolution of the blob (Fig. 2b), it is possible to determine the blob trajectory (Fig. 2c) and radial velocity (Fig. 2d) for the averaged

As shown in Fig. 3 (left), the blob size a scales slightly positively with B . A blobs size scaling $a \sim \rho_s^{4/5} \sim 1/B^{4/5}$ [2] (solid line in Fig. 3, left), which is often used for normalization is rather incompatible with our data.

The lifetime τ_{blob} of the blobs (Fig. 3, right), defined as the FWHM of $I(r, \Delta t)$ at the reference channel around $\Delta t = 0$ more than

doubles with increasing magnetic field which is almost beyond the error bars. This could be an effect of decreased perpendicular drifts v_{\perp} at high magnetic fields which are in general $v_{\perp} \sim 1/B$, and lead to an increased detection time in front of our channel [7].

In Fig. 4, the maximum blob velocity $v_{r,\max}$ is plotted against the blob size a (squares) determined at the time point of achieving the maximum velocity. The measured velocities are between $v_{r,\max} = 0.3$ and 0.75 km/s and tend to smaller values for larger blob sizes a .

As a first approximation which will be revised in future investigations, we assume a connection length of $L = 15$ m and an electron temperature of $T_e = 20$ eV for the calculation of a theoretical velocity $v_{r,\text{theo}}$ according to Eq. 1 (Fig. 4, circles). The quantities a , B , $R = 2.155$ m and $\delta n/n \approx \delta I/I$ were taken from the experiment. The theoretical velocities underestimate the measurements. However, the order of magnitude is the same as for the measurements, and the trend of decreasing velocities with increasing blob size can be seen in both data sets.

While the multi-regime formula Eq. 1 gives comparable values to the measurement, a scaling for the inertial regime proposed by Garcia *et al.* [8] overestimates the measured velocities by a factor of 10. Thus, the measured blob velocities in the considered density range are rather dominated by sheath-dissipation than by inertial effects.

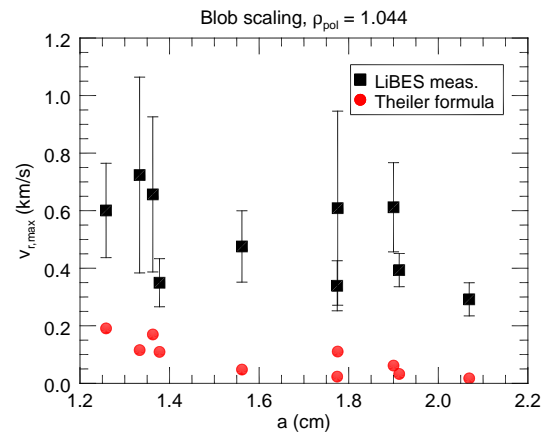


Figure 4: Measured maximum blob velocity depending on the blob size (squares). The calculated velocities acc. to Eq. 1 show the same trend (circles).

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