# Statistical analysis of SOL fluctuations on COMPASS tokamak as measured by the Li-BES diagnostic

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## Introduction

In this paper the capabilities of the COMPASS Li-BES (Li-Beam Emission Spectroscopy) system are demonstrated in SOL (Scrape-Off Layer) density fluctuation studies. Li-Bes is a diagnostic technique based on injecting a neutral Li beam into the plasma, where it emits a light of characteristic wavelength due to collisional excitation and spontaneous decay.[1] The effect of atomic physics on this measurement is examined using a collisional-radiative model. Simple numerical simulations based on stochastic models of the SOL filaments (blobs) [2] have been performed to study the effect of atomic physics on them. The results are compared to experimental data and theoretical expectations [3]. The problem of the so called "hole" emergence is also been addressed as a result of atomic physics effects. Finally the statistics of experimental BES signals are investigated and explained in the context of theoretical models [3].

## Numerical calculation of plasma-beam interaction

A MATLAB code developed at COMPASS to solve the rate equations:

$$\frac{\mathrm{d}}{\mathrm{d}z}N_i(z) = \sum_{j=1}^{5} \left[n_\mathrm{e}(z)a_{ij}T_\mathrm{e}(z) + b_{ij}\right] N_j(z) \tag{1}$$

where $N_i$ is the occupation density of the $i^{\text{th}}$ excitation level, $z$ is the coordinate along the beam, $a_{ij}$ are the transition rate coefficients, $b_{ij}$ are the Einstein coefficients of spontaneous emission, $n_\mathrm{e}$ and $T_\mathrm{e}$ are the electron density and temperature.

## Effects of Atomic Physics

The measured light emission response due to small local perturbations of the density profile depends on the details of the plasma-beam interaction. The light response can be characterized by the following quantities: **1.** smearing, **2.** offset of maximum and **3.** anti-correlation beyond the top of the light profile. To study them, Gaussian perturbations were applied to artificial density profiles which are constructed of a tanh function that smoothly transitions to a linear rise to match experimentally measured profiles (Fig. 1). The amplitude of the response, its radial offset and smearing seem to scale linearly by the size of the perturbation. It was found that the offset of its maximum is below the spatial resolution of the measurement which is 1 cm on COMPASS (Fig. 2). These effects were also examined on various density profile shapes to investigate how they behave in different plasma scenarios (Fig. 3). Shape was controlled by the

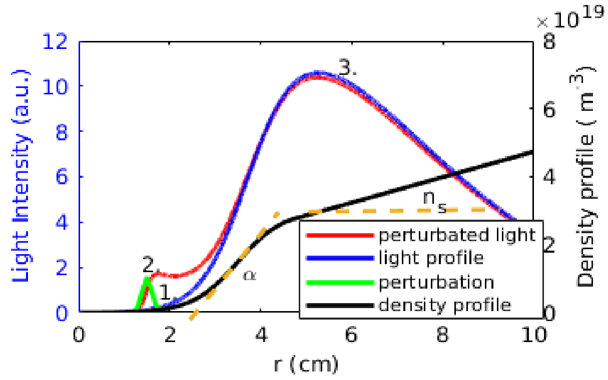


Figure 1: Light emission response to local density profile perturbation.

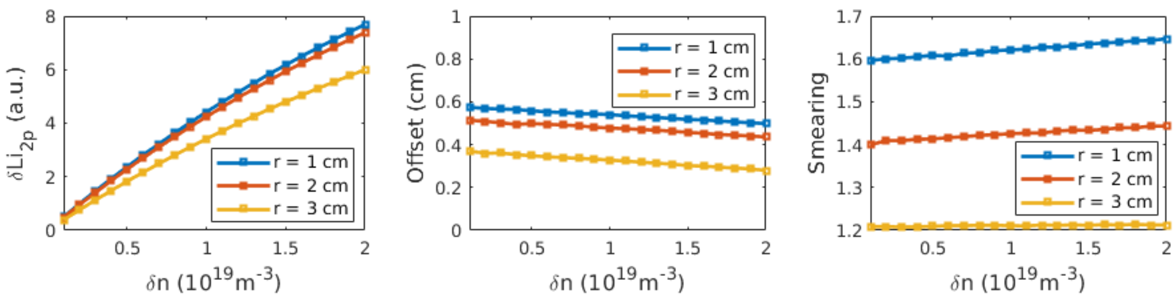


Figure 2: Perturbation response at various radial positions in the SOL

angle of the tanh at its infelxion ($\alpha$) and its saturation value ($n_s$). By this exercise it can be concluded that the magnitude of these effects is mostly governed by the density of the plasma the beam travels through. It means that a higher density, a less steep rise of the pedestal or be-

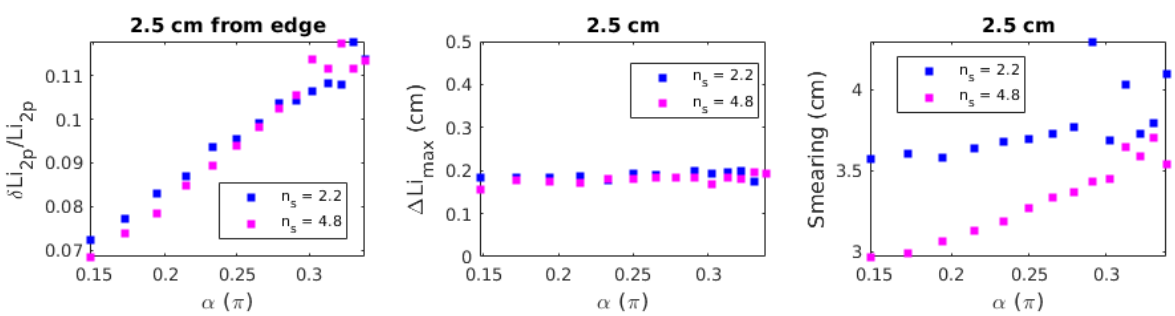


Figure 3: Perturbation response on various density profile shapes in the SOL (different colors for different saturation value of the tanh)

ing further in the plasma mitigate these effects. This can be explained by beam loss caused by ionization before the perturbation and increased collision induced deexcitation after.

## Simulation of intermittent fluctuations

Particle and heat transport in the SOL is dominated by the radial motion of filaments commonly referred to as "blobs". To simulate blob behavior in the SOL a MATLAB code was developed based on the model described in [2], [3]. Its postulates are **1.** blobs come as a sequence of bursts, **2.** with waiting time that follows an exponential distribution, **3.** their amplitude is also exponentially distributed, **4.** they have a double exponential waveform. It concludes that a signal based on these premises in high intermittency limit **1.** has a PDF of Gamma distribution (scale parameter: blob amplitude, shape parameter: duration/waiting time) and **2.** has a quadratic relationship between its skewness and kurtosis (Fig. 4).

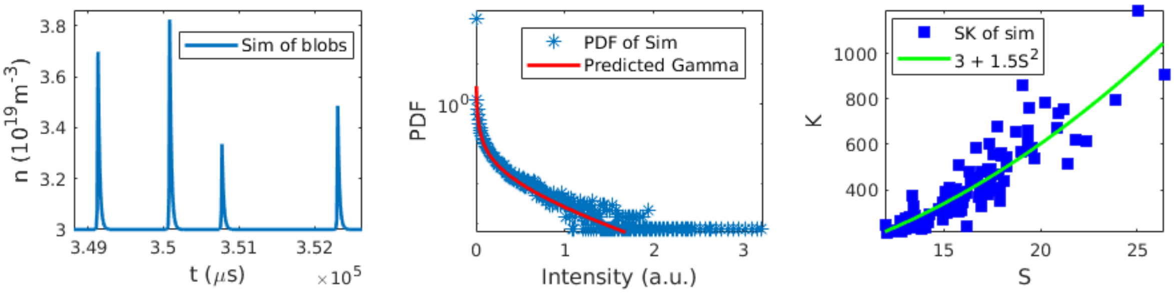


Figure 4: Simulated blobs and their statistics

The code can simulate a 2d measurement where blobs are generated according to the model. They are propagated radially outward with a velocity that is linearly dependent on blob amplitude (with a Gaussian scatter [3]) placed on a density profile. Atomic physics than can be applied to create synthetic diagnostics. For increased realism, white noise can be added to account for the electronic noise present in the measurement. By applying atomic physics to the simulation it was seen that the statistics of the blobs does not change significantly. The main difference is that they appear wider and less sharp due to smearing. It was found however that "holes" appear as artifacts on channels after the maximum of the light profile. Their appearance

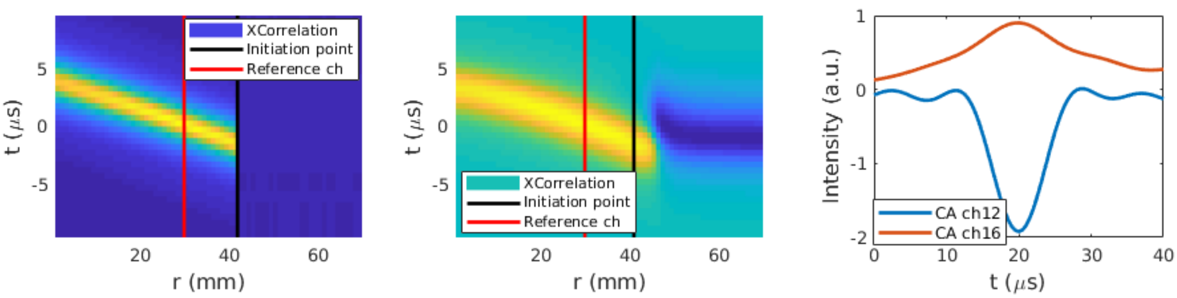


Figure 5: Smearing and hole appearance on correlation plot of simulation and CA of experimental data

corresponds with blobs on outer channels therefore the most likely explanation is that they are caused by beam loss on the blobs. This was seen in experimental data as well using Conditional Averaging (Fig. 5).

## Experimental verification of the statistical model

Using Conditional Averaging (CA) on COMPASS Li-BES signals it was found that blob statistics are in good agreement with expectations (Fig. 6).

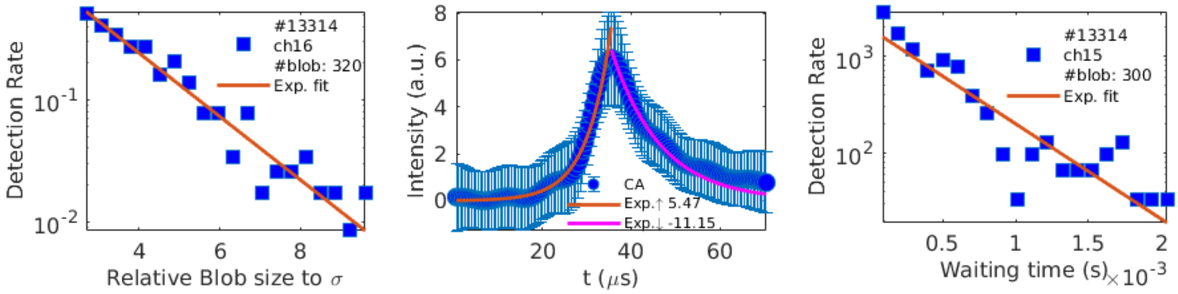


Figure 6: Blob statistics from Conditional Averaging of Li-BES Signal

The PDF of the signal on the other hand seems to differ from what the model predicts. By adjusting the parameters and adding white noise however the PDF can be recreated by simulation and curve fitting (convolving the Gamma distribution of the blobs with the Normal distribution of the noise) as seen on Fig. 7. The parameters are the duration of blobs which can be measured by CA and the waiting time that can be acquired from the shape parameter of the Gamma distribution fitted to the tail of the PDF. The results suggest that the signal is dominated by frequent (even overlapping) events of various size instead of large but rare ones.

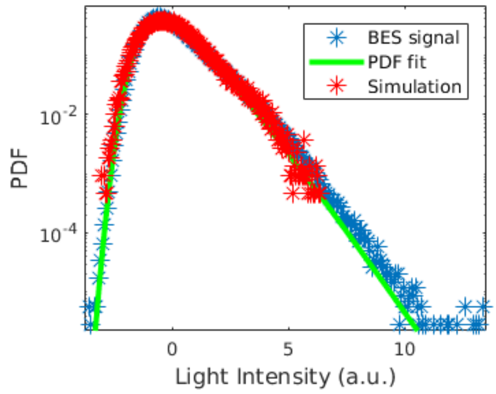


Figure 7: PDF of BES signal approximated with simulation and curve fitting

## Conclusions

The capabilities of the COMPASS Li-BES system are demonstrated in the study of SOL density fluctuations. Using synthetic diagnostics it is shown that atomic physics has no detrimental effect on the measurement of blob statistics, however it does create "holes" as artifacts after the maximum of the light profile. SOL BES signal statistics are explained and reproduced in the context of existing models by expecting low intermittency between events.

## References


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