# Characterization of the scrape-off layer and pedestal conditions at JET using density profile measurements by reflectometry

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## Introduction

The edge electron density at the midplane is a very important interface parameter between core (associated with fusion performance) and divertor plasma (able to control power exhaust). The separatrix density is also essential to assess the pedestal stability and has been observed to be related with the plasma energy confinement, with a significant impact on the Edge Localized Mode (ELM) dynamics. Previous studies indicate that divertor conditions and the separatrix density are correlated influencing even the core plasma confinement (e.g. [1]). Mechanisms such as confinement degradation with gas fuelling, the role of neutrals and the importance of the separatrix density are however not fully understood.

Measurements of the midplane density with high temporal and spatial resolution are therefore instrumental. A reflectometry diagnostic is available at JET that provides density measurements with the required temporal and spatial resolution [2]. A large dataset of measurements is available that enables to estimate physics relevant parameters characterizing the density profile such as pedestal density, pedestal width, separatrix density and scrape-off layer (SOL) width.

In this work, a set of different density profile models are presented as possibilities to expand to the SOL the commonly used modified hyperbolic tangent (mtanh) function. Different SOL models were compared, ranging from simple linear slopes to polynomials and exponentials. A database was established with discharges selected to offer a wide variation of global parameters such as plasma confinement or discharge conditions as impurity seeding, fuelling rate and divertor configuration.

## Methodology

The JET reflectometry diagnostic has been designed to measure density profiles from the far SOL to the core plasma with high spatial resolution, allowing for studies relating the different plasma regions. To condense the profile information into physics relevant quantities, the density profiles are fitted to a model in order to extract profile parameters such as pedestal density, pedestal width and SOL width.

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As an illustration, figure 1 shows an experimental density profile together with the fit resulting from three of the models tested: a modified 'mtanh' ('mtanhexp', orange) that replaces the flat SOL with an exponential decay, $n_{SOL}(R) = b \cdot \exp\left[\frac{(R_0+d)-R}{L_{SOL}}\right]$, where $b$ is the pedestal bottom, $R_0$ the center of the steep region, $d$ the pedestal half-width and $L_{SOL}$ the SOL width. It is often found that the exponential term is still dominant in the steep gradient region resulting in unrealistic low pedestal widths. Therefore, a two-step method was implemented where first the region around the pedestal is fitted with a 'mtanh' and then the region $R > R_0 + d$ is fitted with an exponential to obtain the SOL width ('mtanh+exp', red). Similarly, a two-line method was also tested, where lines to the pedestal top and steep gradient regions are fitted simultaneously and then in a second step an exponential is fitted to the SOL ('twoline+exp', blue).

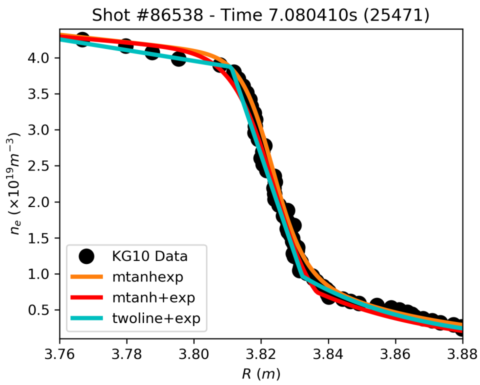


Figure 1: Experimental density profile together with the fit resulting from some of the models used. Lines are slightly shifted.

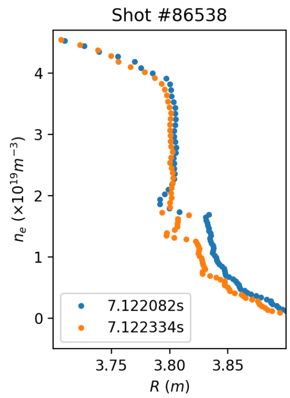


Figure 2: Examples of "broken" density profiles.

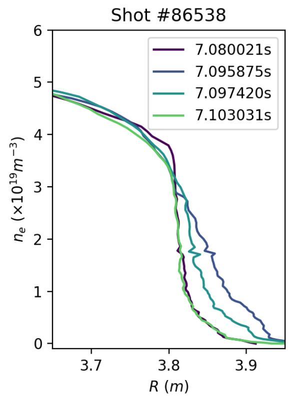


Figure 3: Density profile evolution along an ELM cycle.

Although the different methods have their own advantages and disadvantages and the best option may depend of the plasma conditions (e.g. during an ELM), it is generally observed that both two-step methods produce more reliable results. In addition, SOL density profiles are typically well characterized by an exponential fit as expected from a simple SOL model.

Before the fitting process, profiles have to be validated as not all profiles are realistic. A known issue with the JET reflectometry system is the reduced power for probing frequencies around 75 GHz (near the top of the V-band and the bottom of the W-band) that sometimes leads to problems in the profile reconstruction (as illustrated in figure 2) that often results in "broken" profiles. To prevent these issues from affecting the final results, profiles are pre-validated using simple heuristics, e.g. large distance between points in the steep region, negative gradients.

**Profile evolution along the ELM cycle**

The JET reflectometer provides profiles with a maximum repetition rate of one profile every 15 $\mu$s, being therefore able to track fast events such as ELMs. Figure 3 presents an example of density profile evolution along an ELM crash. The collapse of the density pedestal can be seen, characterized by the increase of the pedestal and SOL widths, followed by the recovery of the edge plasma where both widths are again reduced but without a build-up of the pedestal density.

The profile evolution along a few type I ELMs has been studied in a discharge period with fast sweep rate. Figure 4 shows the evolution of the plasma parameters derived for the two-step mtanh fit including an exponential fit for the SOL, together with the beryllium emission. Validated profiles are shown in black although all profiles have been fitted (indicated in grey). As illustrated, non-valid profiles lead to a large scatter in the parameters derived from the fit. As expected, the ELM crash is associated with a fast decrease of the pedestal height density and an increase of the pedestal and SOL widths. The SOL and pedestal widths recover in a shorter time scale (2-3 ms) than the pedestal height density ($\gtrsim$ 15 ms) that may still be evolving when the next ELM occurs. The time scales for ELM crash and recovery will be compared for a wide variety of plasma conditions in future work.

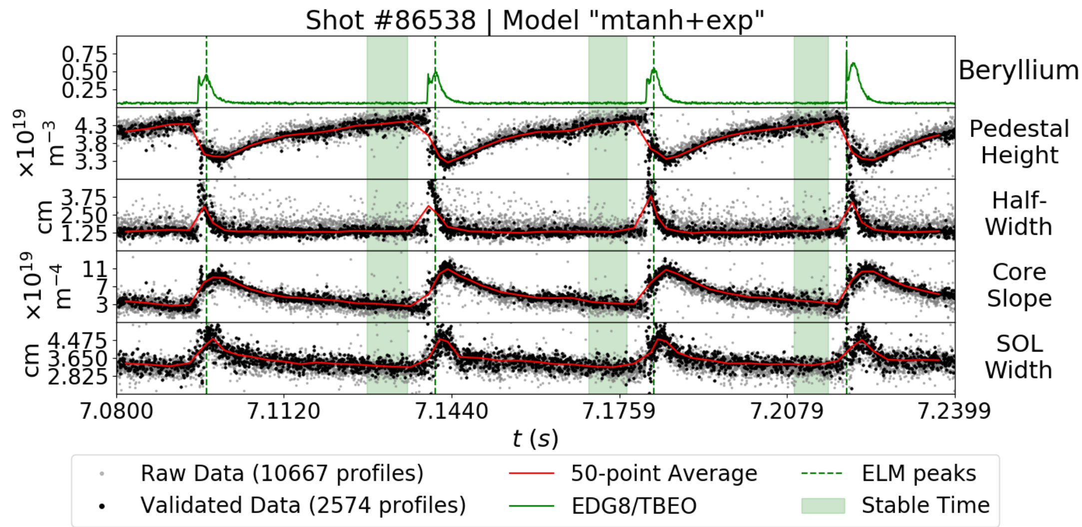


Figure 4: Evolution of fitted parameters during the ELM cycle. Shaded regions indicate the periods used to estimate the average quantities in the discharge.

## Correlations between plasma parameters

A database was established with discharges selected to offer a wide variation of global parameters such as plasma confinement or discharge conditions as impurity seeding, fuelling rate and divertor configuration. The plasma parameters characterizing the density profile were averaged during roughly stationary periods just before the ELM crash (as indicated in figure 4 by the shaded green areas) and correlated with selected discharge parameters. Two examples of our initial results are presented in figure 5. As shown before [3], the pedestal width presents a small increase with gas rate, similarly to our observations. Taking advantage of the quality of the SOL measurements by reflectometry we can also conclude that the SOL width also increases with the gas rate. In a second example, the pedestal height in density is shown for different divertor configurations. As observed before[3] the pedestal density decreases as the outer strike-point is moved from tile 5 (horizontal target) through tile 6 (corner, strike-point close to the pumping duct) to tile 7 (vertical target).

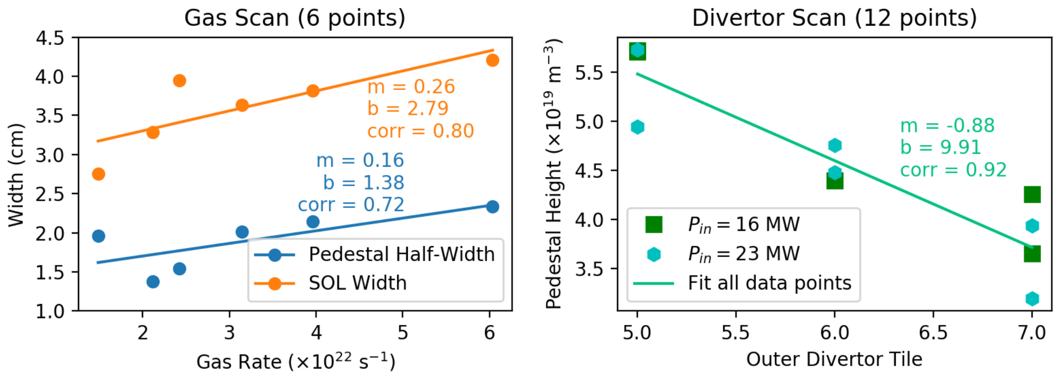


Figure 5: Examples of correlations between parameters fitted from density profiles with selected discharge parameters. Left, dependence of the pedestal and SOL density width on the gas rate at 2.5 MA, 2.4 T, input power from 16 to 18 MW at low triangularity in corner configuration; right, impact of the divertor configuration on the pedestal height density at 2.5 MA, 2.7 T, two steps of input power (16 MW and 23 MW) at low triangularity and with a gas rate $[2-2.2]\times10^{22}e/s$.

## Conclusion

This work presents our initial results on the characterization of the density profiles measured by reflectometry at JET. A code has been developed that validates the density profiles and then fits different models for the pedestal and SOL profiles. Encouraging results were obtained that allow the determination of the time scales for ELM crash and recovery based on the evolution of parameters such as pedestal and SOL width and separatrix density. By calculating the average parameters characterizing the density profile, initial results on the their correlations with selected discharge parameters are presented showing a good agreement with previous observations for the pedestal quantities and providing new information for the SOL region.

The current database will be expanded to include not only more data from previous campaigns, taking advantage of the extensive dataset of density profiles measurements available, but also data from the present experimental campaigns.

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