Analysis of divertor island properties at Wendelstein 7-X using Alkali Beam Emission Spectroscopy

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Introduction: Alkali Beam Emission Spectroscopy (A-BES) [1-2] of W7-X is a diagnostic system capable of the analysis of the edge density profiles and related radial transport processes. The time resolution of the diagnostic is in the order of 50 μs with a spatial resolution of approximately 0.5cm. Its observation line is on the symmetry plane, horizontally crossing the O-point of a divertor island at the bean-shaped plane for standard configuration. The density profiles obtained from the diagnostic are most accurate in this island region, which makes it suitable for the evaluation of divertor island properties. In this study a few overall features obtained with the diagnostic related to the island structure in the Wendelstein 7-X standard configuration are summarized.

Fit-function: The density profiles from the experimental data have been reconstructed with SPADE, a linearized density reconstruction method [3]. This data often indicate a flattening of the electron density profiles at the location of the divertor island for the standard configuration. To separate the contribution of the divertor island parameters, a function in the following form was fitted to the density profiles:

$$n_e(R) = \frac{A}{2}\left[tanh\left(\frac{R-R_p}{S}\right)+1\right] + \alpha\frac{1}{\sqrt{2\pi}}e^{-(R-R_m)^2/2\sigma^2}\left[1+erf\left(\beta\frac{R-R_m}{\sqrt{2}\sigma}\right)\right]. \qquad (1)$$

Here, n_e is the electron density and R is the major radius. The first term, the tangent hyperbolic function corresponds to the effect of the main plasma and is defined by the following parameters: A – height, R_p – center position, *1/S* – steepness. The second term is a skewed Gaussian distribution used to model the contribution of the magnetic island and is defined by the following parameters: α– line-integrated density, R_m – center position, σ – variance, β – skewness. The latter is expected to be caused by the strongly varying connection length. The skewness has been introduced to allow asymmetry in the density contribution of the magnetic island. An example for the fitted function is shown in Figure 1.

To validate, whether the location of the skewed Gaussian function matches the island location, the Poincare plot of the magnetic field is shown on Figure 2. The lower plot of Figure 1 contains three

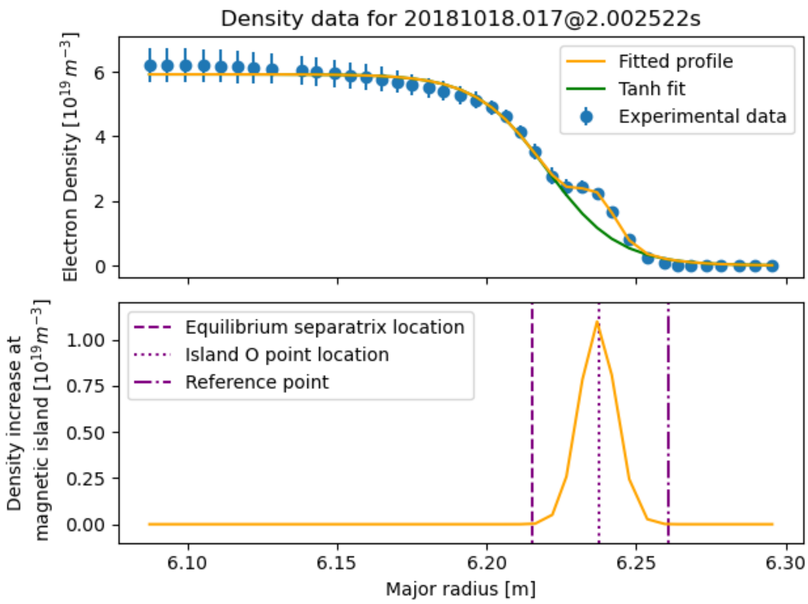

Figure 1: An example for the fitted function to experimental density results. Upper plot: The experimental data (blue curve) , the contribution of the tanh function (green curve) and the whole fit-function (orange plot). Lower plot: The assumed contribution of the magnetic island to the density profile with a number of reference lines to Figure 2.

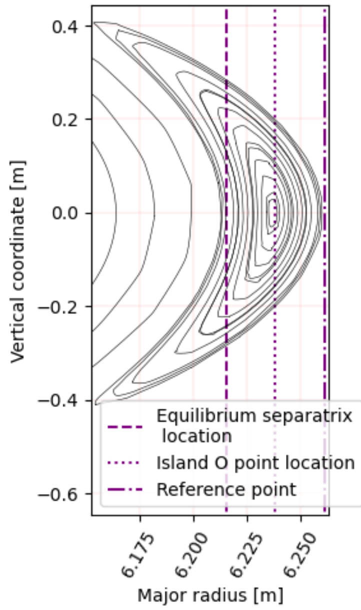

Figure 2: The Poincare plot of the magnetic field for experiment 20181018.017 at the toroidal cross section of the A-BES diagnostic. The magnified section of the plot with the reference lines of Figure 1 is plotted as well.

reference lines. These two align sufficiently well to conclude that the presumed contribution of the magnetic island on the density profiles is indeed localized at the magnetic island divertor.

Results: Altogether 15 experiments in the standard configuration were analyzed with the fit-function. These experiments were selected because high-quality A-BES data were available for them. The time evolution of the fit-function parameters was analyzed, and an example for this result is shown in Figure 3.

The parameters of the fit-function were well-defined for the tangent hyperbolic function, e.g. their time evolution during experiment 20181018.027 from NBI injections was clear within their uncertainty limits. Nevertheless, for the divertor island contribution, only the time evolution of α could be inferred from the data. The uncertainty of all other parameters was too large. Therefore, in the following only this property of the island divertor is analyzed in more details.

For all analyzed experiments, the relative density of the magnetic island, α/A, is plotted against the line-integrated density [4], steepness, -1/S, and R_p on Figure 4. The dependence of α/A on A is not shown as an artificial negative correlation can occur between the two due to the method used for the density reconstruction of A-BES data. No overall correlation between α/A and the line-integrated density or R_p has been observed. Nevertheless, the upper plot of Figure 4 indicates a positive correlation between the steepness of the tangent hyperbolic function and α/A for every experiment

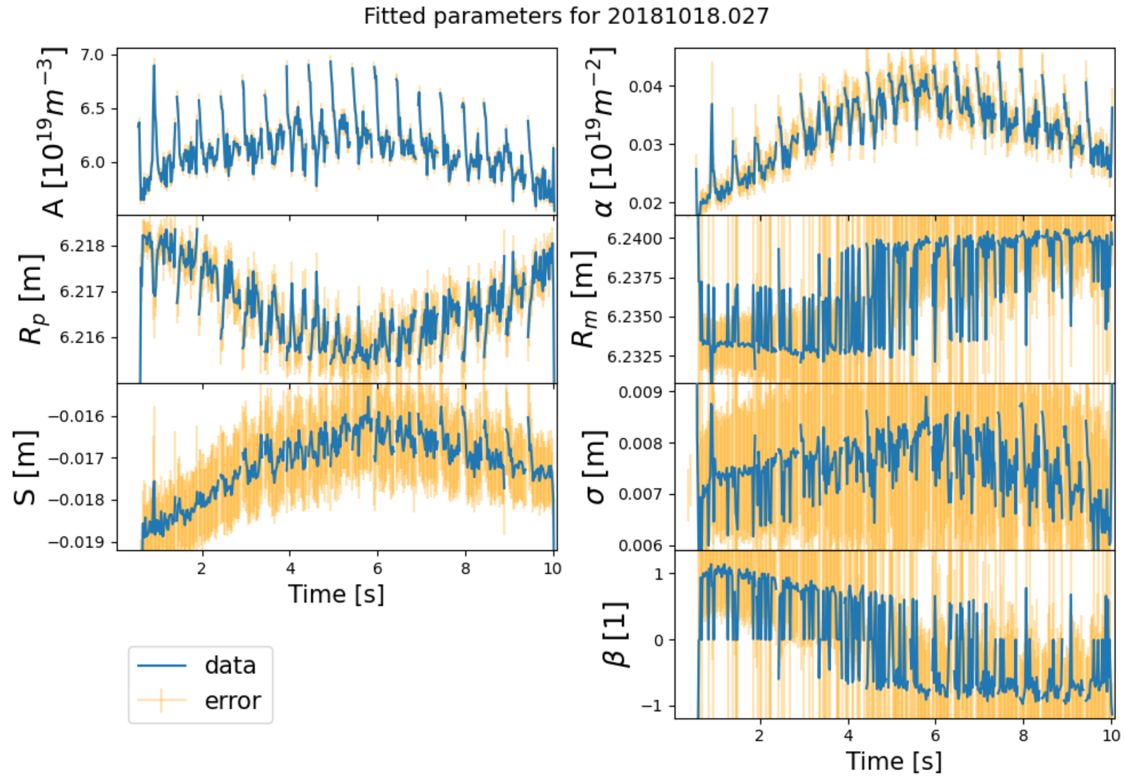

Figure 3: An illustration for the time evolution of the fit-function parameters, using the data from experiment 20181018.027. The left-hand side corresponds to the parameters of the tangent hyperbolic function, while the right-hand side to the parameters of the presumed island contribution. The data is plotted in blue, while the error bars in orange.

with sufficiently accurate data. The positive correlation between the relative island density and steepness indicates that a considerable amount of fueling of the island occurs from the plasma core. Moreover, it also indicates that this fueling scales with $\partial n_e/\partial R$. A further notable point when considering possible transport processes explaining the results is the often-observed density-peaking of the island at its O-point, as shown in Figure 5. This indicates that the density profiles cannot be simply explained by diffusive transport alone, as that process cannot lead to profile peaking.

Summary: The experimental data from the Alkali Beam Emission Spectroscopy has been utilized for the general analysis of divertor island density profiles using a fit-function. It has been found that the data is mainly suitable for the analysis of the line-integrated contribution of the island to the profiles. Via analyzing the data for several experiments, an overall positive correlation between the core plasma steepness and the relative density of the divertor island has been observed.

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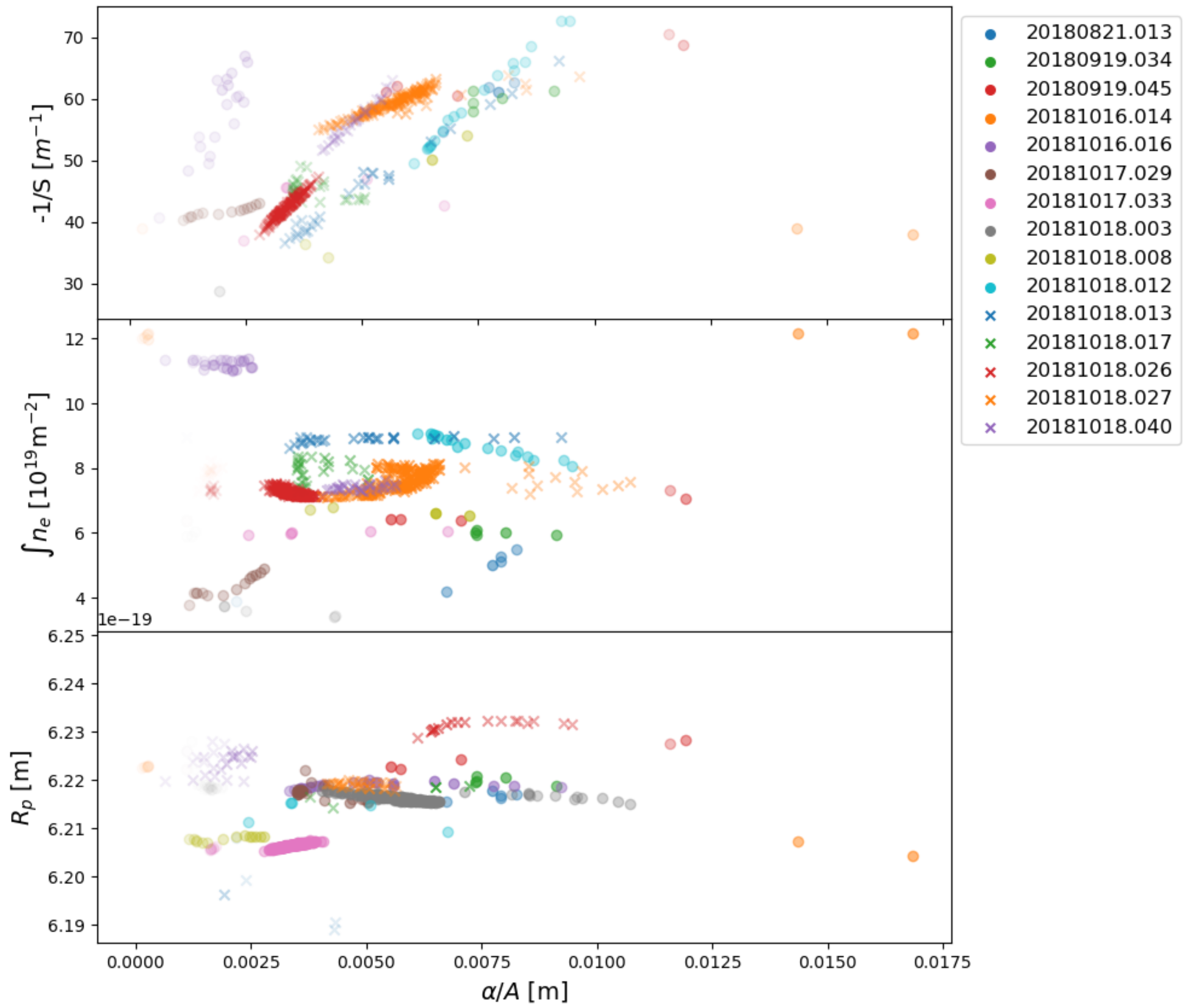

Figure 4: The dependence of the relative island density on plasma core parameters. The opacity of a point on the plot is increased as the uncertainty of the related parameters is increased.

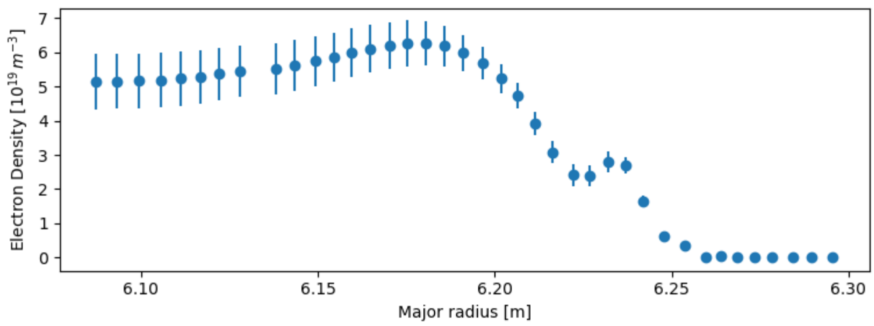

Figure 5: Illustration for the island density peaking, using experiment 20181018.027

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