Source impact on density peaking in JET experiments

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Introduction

Despite a vast body of knowledge that has already been accumulated on particle transport at both theoretical and experimental level, a simple method for estimating the source impact on density peaking has been lacking. In [1] a parameter for calculating the source strength (S_{str}, the S parameter), the source ratio of the total density peaking was applied for ASDEX Upgrade. The formula is derived from particle continuity equation and approximations introduced in [1] enable easy calculation of the source contribution with the knowledge of density, temperature and heat source profiles.

In this study the formula was applied to a pre-existing database of JET pulses. As comparison two previously studied 3-point identity scans by T. Tala et al. [2, 3, 4] are used.

Formula

Starting from the particle continuity equation, assuming steady state, separating the particle flux to diffusion (D) and convection (v) and multiplying the equation with minor radius / gradient length ($a/Ln = a\nabla n/n$), the right side of the equation (1) separates to turbulence (left) and source (right) contributions

$$\frac{a}{Ln} = -\frac{a\,v}{D} + \frac{a\,\Gamma}{Area\;n\;D} \tag{1}$$

The source strength, the S-parameter (S) is the ratio of source contribution over total density peaking. Furthermore, replacing the particle flux $\Gamma = P_{NBI}/E_{NBI}$ the equation becomes:

$$S = \frac{P_{NBI}}{E_{NBI}} \frac{Ln}{Area\;n\;D} \tag{2}$$

and using approximations [1] $Ln/Area \sim a^2/V$, and $D \sim \chi$:

$$S \approx C \frac{P_{NBI}}{E_{NBI}\;n} \frac{a^2}{V\chi_{eff}} \tag{3}$$

where P_{NBI}/E_{NBI} is the particle flux in s^{-1}, the Neutral Beam Injection (NBI) power divided by the beam ions injection energy, n is the plasma density in m^3, V is the plasma volume, a is

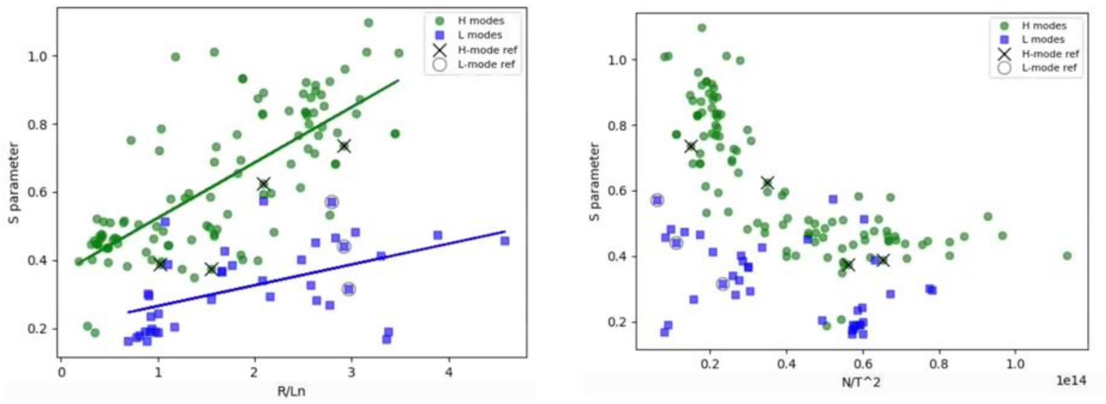

Figure 1: *S parameter vs* R/L_n*, equation* (3)

the plasma minor radius and χ_{eff} is the effective core heat transport diffusivity in m^2/s. The coefficient C is a fitted parameter value from an ASDEX Upgrade experiment, which may need to be changed for these JET pulses.

Database and reference pulses

This research was done using a pre-existing database of 165 JET steady state intervals in both H- and L-mode, mainly with NBI heating. Same pulse can be in the database more than once with a different steady state period. JET processed data was time averaged over steady state interval, and density and temperature gradients were calculated from quadratic curve fit between $\rho_{tor} = 0.3 - 0.7$, and density and temperature values at mid-radius (ρ_{tor} = 0.5) were calculated from the fitted curves. χ_{eff} was calculated at $\rho_{tor} = 0.5 - 0.7$.

Two previously studied three-point identity scans by Tala et al. [2, 3, 4] are used for comparison. The results indicate that in the parameter range studied in H-mode the source contribution is 50-60% and in L-mode 10-20%. No dependence on collisionality was found in the parameter range studied.

Results with formula with approximations

First, the formula was applied in the same format as in [1] with the same constant C. This is equation (**??**), and it can be easily calculated when one has the information on pulse density, temperature and heat sources profiles. The results appear in reasonable range.

The results indicate different source contribution for H-mode and L-mode pulses and increase in source contribution to density peaking with increase in density peaking. There is also a correlation with collisionality, stronger in H-mode but non-negligible also in L-mode, which was not found in the reference pulses [2]. Comparing to the reference pulses the H-mode shots could not be scaled with a single scalar. To investigate scaling of the results to JET we looked at the

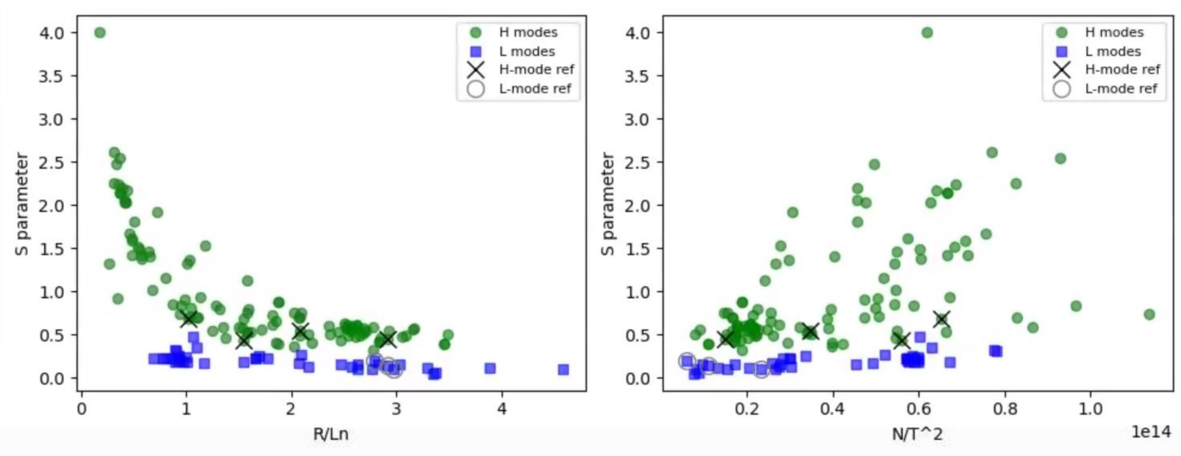

Figure 2: *S parameter vs* R/L_n*, equation* (2) *(left) and vs* R/L_{Te} *(right)*

original formula without the approximations.

Impact of approximation $Ln/A \sim a^2/V$

Undoing of the approximation $Ln/A \sim a^2/V$ changes the trend of the S pameter in this database. In the database the minor radius a, plasma volume V and plasma area A are fairly constant, and only the gradient lenght Ln varies between the pulses.

When this approximation is not used, the results in figure 2 (on the left) indicate a negative correlation between gradient length and source contribution to density peaking in H-modes and a fairly constant contribution in L-modes. Correlation between source contribution and collisionality decreases. High values of source contribution are on fairly flat profiles, which might indicate, as suggested by the math of the formula, that without the source contribution the profile would be hollow.

Approximation $D \sim \chi$ and constant C, very preliminary

The database was scaled to the reference pulses using $D \sim \chi_{eff}$ and constant C (figure 2). Different constant C was required for L-modes (=2.1) and H-modes (=3.5), differing also from the one for ASDEX Upgrade and not producing excellent match particularly for the H-mode pulses. This may indicate that the relationship between D and χ_{eff} is not constant across the database. The validity of these approximations will be further investigated with simulations; this work is currently ongoing.

Discussion

The source contribution to density peaking is expected to vary depending on the main turbulence type, since particle diffusion D is affected by the main turbulence type, and the source parameter formula (eq. (2)), as derived from the particle continuity equation, includes D.

In [5] ion and electron diffusion in different turbulent domains is investigated. It is shown that ratio D_i/χ_{eff} and ratio D_i/D_e varies depending on the main turbulent regime. Furthermore, the D that should be used in the formula of the S parameter is the smaller of the two, D_i and D_e, since it is the one determining the relaxation time of the core density profile. However, within the approximate R/L_{Te} range of these pulses, according to [5] in GA standard case D_i/χ_{eff} and D_i/D_e vary only moderately. Approximation with a constant C may be sufficiently accurate for this JET database, although it would not be applicable for extrapolation. We hope to increase our understanding with simulations on whether more than a constant is required for scaling the results of this database, and if so, how to reflect this in the formula with an easy to calculate approximation.

Next steps

Simulations with JETTO (v111120) with TGLF (SAT1) are used with predictive density and temperature and interpretative current and toroidal momentum.

Successful profile matches have been reached so far mainly for L-mode reference shots. In H-mode pulses so far the density profile is overestimated in several cases, and in some cases also the temperature profile is not successfully repeated by the simulation. An example of overestimation of density profile is in figure 3. Investigation on simulation settings to overcome the issue are ongoing.

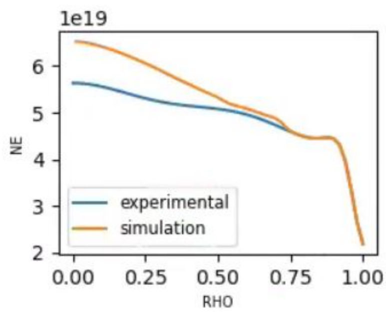

Figure 3: *Density profile of pulse 87425, experimental profile (blue) and simulation results(orange)*

References

[1] E. Fable, et al. Nuclear Fusion, 59(7):076042, Jun 2019.
[2] T. Tala, et al. Nuclear Fusion, 59(12):126030, Oct 2019.
[3] F Eriksson, et al. Plasma Physics and Controlled Fusion, 61 (11):115004, Sep 2019.
[4] E. Fransson, et al. Nuclear Fusion, 61(1):016015, Nov 2020.
[5] C. Bourdelle et al. Nuclear Fusion, 58(2018):076028.

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