UNDERSTANDING REACTOR RELEVANT TOKAMAK PEDESTALS

UK Atomic Energy Authority

C J Ham[1], A Bokshi[2], D Brunetti[1], G Bustos Ramirez[3], B Chapman[1], J W Connor[1], D Dickinson[4], A R Field[1], L Frassinetti[5], A Gillgren[9], J P Graves[3], T Kiviniemi[6], S Leerink[6], B McMillan[7], S Newton[1], S Pamela[1], C M Roach[1], S Saarelma[1], J Simpson[1], S F Smith[1], E R Solano[8], P Strand[9], A Virtanen[6] and the JET Contributors*

[1]UKAEA-CCFE, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK. [2]Institute for Plasma Research, Gandhinagar, India; [3]EPFL, Swiss Plasma Center, CH-1015 Lausanne, Switzerland;
[4]York Plasma Institute, University of York, Heslington, York YO10 5DD, UK; [5]Division of Fusion Plasma Physics, KTH, Stockholm SE; [6]Aalto University, FI-00076 Aalto, Finland;
[7]University of Warwick, Coventry CV4 7AL, UK; [8]Laboratorio Nacional de Fusión, CIEMAT, Madrid, Spain; [9]Chalmers University of Technology, SE-412 96 Gothenburg, Sweden;
*See author list of E. Joffrin et al., Nucl. Fusion 59 112021 (2019)

Abstract

It is important to understand reactor relevant pedestals so that we can design tokamak fusion power plants and confidently predict their performance.

This collaboration investigated the following areas:

- Pedestal prediction
- Poloidal density variation
- Small ELM regimes – type II/Grassy ELMs and type III ELMs
- QH mode (Quiescent H-mode)

Improved Pedestal Prediction

Seek to test ideas for improving the Europed model [Saarelma].

JET pedestals can have different density and temperature widths so Europed has now been upgraded to allow different density and temperature widths.

We test an idea to remove the pedestal density as a model input by using a gyrokinetic calculation.

We assume the heat source at the top of the pedestal is equal to the heat crossing the separatrix.

The work flow is as follows:

1) Use Europed to calculate a set of pairs of density and temperature profiles around the predicted pressure profile (Figure 1).

2) Use a gyrokinetics based calculation to calculate the heat flux associated with each pair of profiles.

3) The pedestal prediction is then the density and temperature pair that reproduce the experimental heat flux.

Unfortunately, when we tested this method the gyrokinetic runs did not significantly differ from each other. Indeed, η_e is similar for the three sets of profiles.

We need to re-examine how we could use physics-based calculations to reduce the inputs to Europed.

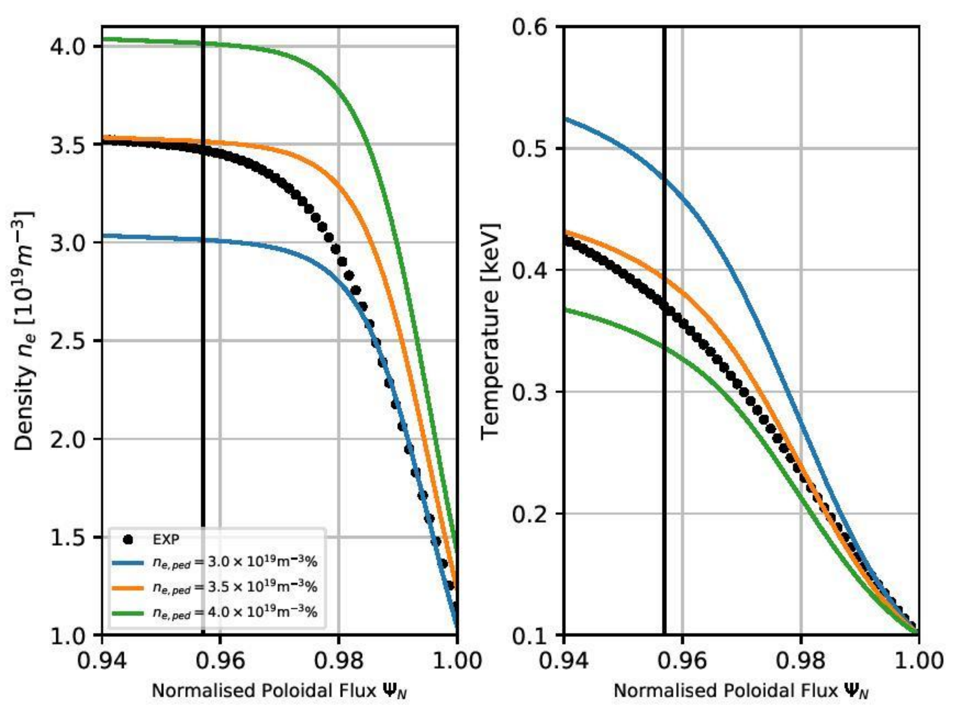

Figure 1: Density (left) and electron temperature (right) as a function of normalised flux in the pedestal region for JET-ILW pulse \#84793. An mtanh fit to raw HRTS data is shown in black. Blue, orange, and green traces show Europed pedestal predictions using 3.0×10^{19} m^{-3}, 3.5×10^{19} m^{-3}, and 4.0×10^{19} m^{-3} respectively. Vertical black line denotes the location of the temperature pedestal top for the widest pedestal prediction.

Poloidal Density Variation

We have calculated the effect on the bootstrap current of a poloidal variation in the density using both analytical and numerical (using the code ELMFIRE [Heikkinen]) approaches.

It was found that the bootstrap could be altered by poloidal density variation. Figure 2 shows results from ELMFIRE with a particle source at four different locations

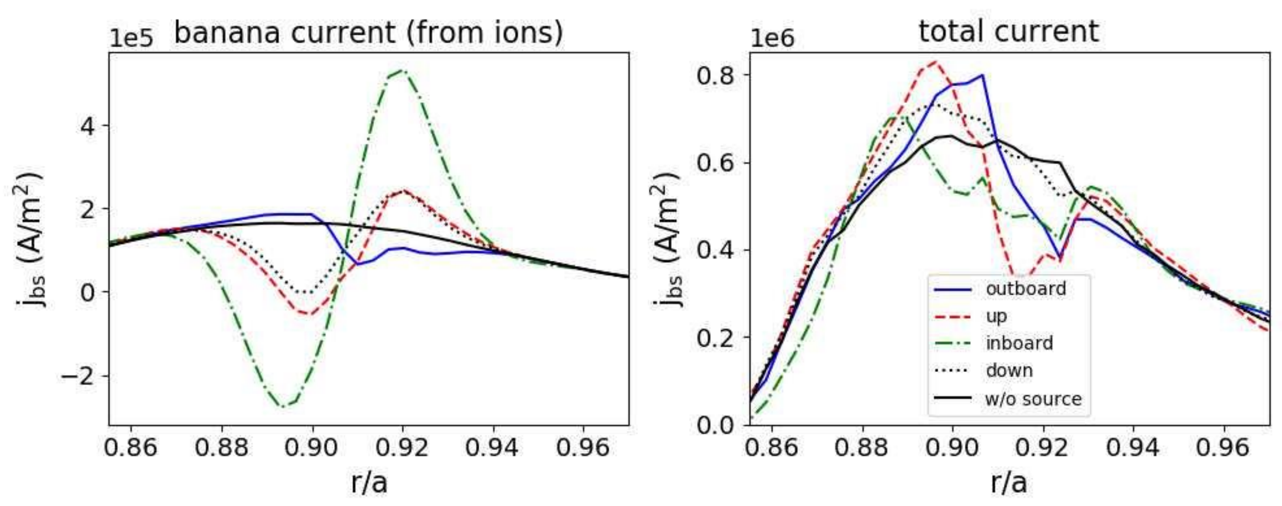

Figure 2: Scan of a) banana current and b) total bootstrap current as a function of radius for thermal particle source located at four different poloidal angles.

Type III ELMs

Extended the theory of resistive ballooning modes, by including plasma shaping effects and equilibrium poloidal ExB flows within the drift-MHD model.

Simple dispersion relation derived by employing the ballooning framework.

Elongation alters the magnetic well and both layer resistivity and plasma inertia contributions.

Additional branches of the dispersion relation appear due to the ExB frequency shift, acting similarly to the ion FLR corrections.

QH-mode

Nonlinear equilibrium modelling has produced saturated MHD states that may explain the QH-mode. There are two different mechanisms that produce these states; a current driven mode and a pressure driven mode [Kleiner].

We compare the linear ballooning stability of these two states.

The current driven mode in its saturated state changes the 2D Grad-Shafranov equilibrium to a 3D equilibrium that is more unstable to ballooning modes than the original equilibrium. This may indicate that KBMs are more unstable in this 3D equilibrium. These KBMs may produce the density transport required to avoid ELMs.

The pressure driven mode doesn't change the ballooning stability significantly.

This analysis would suggest the QH-mode is related to the current driven mode but there is more to this picture than this one element.

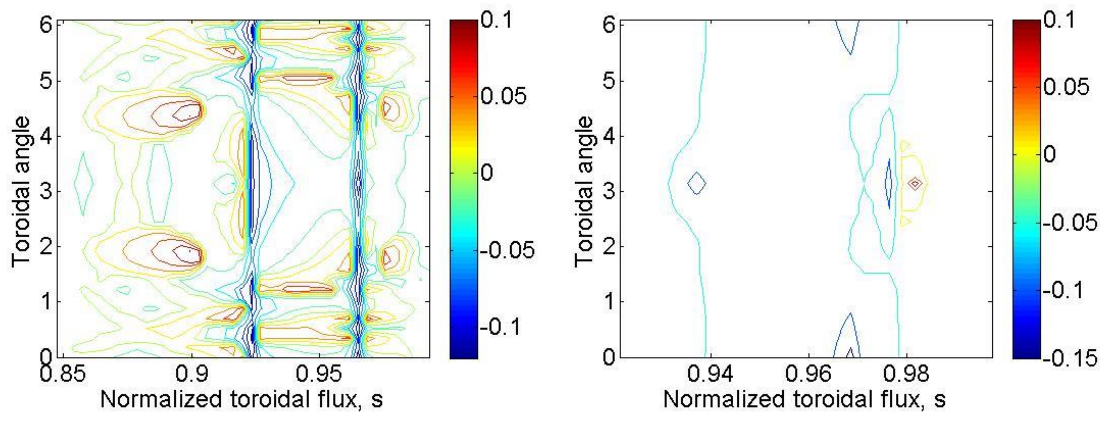

Figure 3: Contours of the ideal ballooning mode growth rate for (left) the current drive mode and (right) the 'exfernal' or pressure driven mode.

Neural Networks for Pedestals

Empirical pedestal model based on neural networks

Trained on H-mode (Type-I ELM) plasmas from JET

Predicts both temperature and density (electrons) from global parameters

- Global β_N, I_p, B_T, Minor radius, κ, NBI power, Total power, δ_{up}, δ_{low}, plasma volume, q_{95}, Z_{eff}

Integrated in the European Transport Solver (ETS)

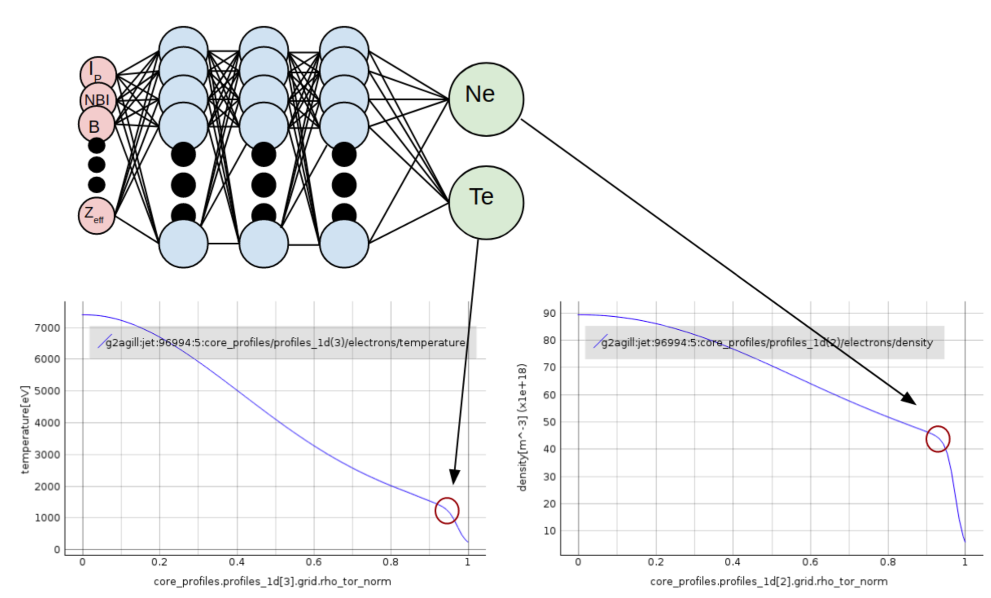

Figure 4: Illustration of how the neural network makes pedestal predictions from global parameters, and how the result is integrated in the European Transport Solver (ETS) to set new boundary conditions for the core transport models. Here, the profiles are taken from shot #96994 at JET

Summary

There is still much to understand before we can predict the height and width of suitable reactor relevant pedestals i.e., which have no/small ELMs

We have taken first steps towards understanding some of the key issues i.e., improved physics understanding of the pedestal structure, the effect of poloidal variation, and improving physics understanding of small/no ELM regimes.

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