Dimensionless pedestal identity plasmas on Alcator C-Mod and JET

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* see appendix of M L Watkins et al, Fusion Energy (Proc 21st Int Conf Chengdu, 2006) IAEA

Outline

- Motivation
- Identity scheme and plasma regimes
- Analysis of pedestal widths and sources
- Conclusions
When is (density) pedestal width related to edge sources?

- $\Delta n_e^{\text{ped}}$ decreasing with $n_e^{\text{ped}}$
  
  consistent with neutral-particle penetration model on DIII-D, MAST.

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When is (density) pedestal width related to edge sources?

- $\Delta n_{\text{ped}}$ decreasing with $n_{\text{ped}}$ consistent with neutral-particle penetration model on DIII-D, MAST.

- Not seen in AUG, C-Mod.

- Recall if $\nabla p_{\text{ped}}$ is stability limited $\Rightarrow \Delta p_{\text{ped}}$ can influence $\Delta T_{\text{ped}}$ too.

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Clarify role of sources by pedestal dimensionless identity tests

- Matching $\rho_*^{\text{ped}}$, $v_*^{\text{ped}}$, $\beta^{\text{ped}}$ in tokamaks [1], [2] in principle keeps edge plasma transport the same, so other influences are emphasized, notably sources (also $f_{\text{Gw}d}$, $P_{\text{in}}/P_{\text{thresh}}$, ...).

\[
\begin{align*}
\nu_* & \propto \frac{Z_{\text{eff}}}{e} \frac{q_95}{e^{5/2}} \frac{n_e}{T_e^{2/3}} \\
\beta & \propto \frac{n_e T_e}{B_0^2} \\
\rho_* & \propto \frac{\sqrt{T_e}}{a B_0} \\
q_95 & \propto \frac{a B_0}{I_p} \\

C-\text{Mod} \quad & JET \\
n_e^{\text{ped}} (10^{19} \text{ m}^{-3}) \quad 20 \quad 1.2 \\
T_e^{\text{ped}} (\text{eV}) \quad 550 \quad 270 \\
B_0 (\text{T}) \quad 7.9 \quad 1.4 \\
I_p (\text{MA}) \quad 1.3 \quad 0.91 \\
P (\text{MW}) \quad 3.7 \quad 1.3 \\

Parameters to realise pedestal identity for size ratio $a_{\text{JET}}/a_{\text{C-Mod}} \approx 4.1$
\end{align*}
\]
C-Mod SND equilibrium accurately reproduced on JET

- Field, current, medium shape (from EFIT) well matched – but global $\beta_N$ higher on JET.
ELM-free H-mode on C-Mod, stationary near-ELM-free state on JET

- Global quantities typically less well matched in best pedestal counterparts – implying different H-mode regimes?

- JET state very steady without significant ELMs – though radiation persistently high.
Pedestal profiles interpolated with modified tanh function

\[ f(R) = b + \frac{h}{2} \left[ \tanh \left( \frac{R_0 - R}{d} \right) + 1 \right] + m \left[ R_0 - R - R \right] H \left( R_0 - R - R \right), \]

where \( H(x) = \begin{cases} 0, & x < 0 \Rightarrow R > R_0 - d \\ 1, & x \geq 0 \Rightarrow R \leq R_0 - d \end{cases} \),

height \( b + h \), width \( 2d \), position \( R_0 \), inner linear slope \( -m \).

- For C-Mod, 3 neighbouring time-slices averaged in steadiest parts of H-mode phases.

- For JET, instrument resolution also modelled by convolution with top-hat function 1.5 cm wide – however, effect not typically significant.

- Profiles averaged in 0.5 s window of new High-Resolution Thomson Scattering system – see poster GP8.00089 A Alfier, R Pasqualotto et al.
C-Mod pedestal heights spanned exhibit smaller change in widths

- Range in C-Mod pedestal pressures has smaller variation of widths with $\Delta T_{\text{ped}} \approx \Delta n_{\text{ped}}$. 
JET power scan matches C-Mod at upper end of density range, scaled density pedestal systematically wider on JET

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- Pedestal identity conditions achieved where JET $P_{\text{RF}}$ scan crosses upper end of data but scaled $\Delta n_{\text{ped}}$ consistently wider than C-Mod.
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- Range in C-Mod pedestal pressures has smaller variation of widths with $\Delta T_{ped} \approx \Delta n_{ped}$.
- Pedestal identity conditions achieved where JET $P_{RF}$ scan crosses upper end of data but scaled $\Delta n_{ped}$ consistently wider than C-Mod.
Best matching pair show steeper pedestal for C-Mod case

- Superimposing C-Mod, scaled JET profiles in normalised-flux space checks relative positions and widths by inspection.

- For matching heights, pedestal is steeper in C-Mod plasma.
Kinetic modelling of ionisation sources within C-Mod/JET pedestals

- Penetration of ionisation sources into pedestals modelled with 1-D kinetic code KN1D, using ionisation / Penning gauges respectively for boundary conditions ($p_{D2}^{\text{C-Mod}} \sim 100 \times p_{D2}^{\text{JET}}$).
EDGE2D-NIMBUS for JET matched upstream and at target

- upstream divertor outboard target

- 2-D modelling fitted well to HRTS upstream and outboard target probes in divertor.
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- Penetration of ionisation sources into pedestals modelled with 1-D kinetic code KN1D.

- JET results supported by independent calculation with 2-D EDGE2D-NIMBUS (M-C) code.
Kinetic modelling of ionisation sources within C-Mod/JET pedestals suggests decay-lengths in proportion to their widths

- Penetration of ionisation sources into pedestals modelled with 1-D kinetic code KN1D.
- JET results supported by independent calculation with 2-D EDGE2D-NIMBUS (M-C) code.
- Decay-lengths of ionisation sources are in almost exact proportion to pedestal thicknesses.
Normalised KN1D results suggest slightly deeper sources on JET

- Normalising KN1D sources / radial co-ordinates shows marginally deeper penetration on JET.
- Does this contribute to its broader density pedestal?
Conclusions

- Non-dimensional identity at the pedestal top has been achieved in H-modes at high field (7.9 T) on C-Mod and low field (1.4 T) on JET, encompassing a factor $\approx 4$ in absolute size.

- Despite some global plasma differences, pedestal profiles are similar – but not identical. In particular, density pedestal width is proportionally somewhat wider on JET.

- 1-D (2-D) kinetic modelling of edge sources indicates neutral particles may penetrate deeper into the JET pedestal, perhaps contributing to its broadening.

- Results are therefore consistent with an intermediate condition where both plasma transport and edge sources influence pedestal formation.

- A next question would clearly be how this interplay evolves for lower $v_{\ast e}^{\text{ped}}$, higher $\beta^{\text{ped}}$.

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