Studies of the Pedestal Structure in JET with the ITER-like Wall

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Acknowledgements

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Outline

- Pedestal width scaling
- Pedestal evolution during the ELM cycle
- First results on isotope effects
Width & gradient independent of $\rho^*$

- No sizeable dependence of $\Delta_{pe}(\psi)$ and $\alpha_{exp}$ on $\rho^*$
- Consistent with JET-C/DIII-D and JT-60U

[Frassineti, PPCF 2016]

[Beurskens, PoP 2011]  [Urano, NF 2008]
Pedestal width broadens with beta poloidal

- $\Delta_{pe}(\psi)$ broadens consistently with $\sqrt{\beta_{pol,PED}}$ dependence at low $D_2$ gas injection rates

Power scans at low and high $\delta$
1.4MA/1.7T
Low $D_2$ gas rate $\sim 3 \times 10^{21}$ e/s

$0.076 \times (\beta_{pol,PED})^{0.5}$

[Maggi, NF 2015]
Pedestal width broadens with gas rate

- $\Delta p_e (\psi)$ broadens with increasing $D_2$ gas rate at constant $\beta_{pol,PED}$

Power and gas scans 1.4MA/1.7T

$\Gamma = 3 \times 10^{21}$ e/s
$\Gamma = 8 \times 10^{21}$ e/s
$\Gamma = 18 \times 10^{21}$ e/s

$\Gamma = 3 \times 10^{21}$ e/s

[Leeland, NF 2015]
[Maggi, NF 2015]
$\Delta_{pe}(\psi)$ broadens with $\nu^*$ at constant $\beta_{pol,PED}$

Dimensionless $\nu^*$ scan at low $\delta$

$\Delta_{pe}(\psi) \sim (\beta_{pol,PED})^{0.5} (\nu^*_{PED})^{0.26}$

[Frassinetti, NF 2016]
Normalized $\Delta_{pe}$ broadens at constant $\nu^*$

- $\Delta_{pe} (\psi)/\sqrt{\beta_{pol,PED}}$ broadens with increasing $D_2$ gas rate at constant $\nu^*_{e,PED}$ → possible role of atomic physics

Power and gas scans 1.4MA/1.7T

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Outline

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- First results on isotope effects
**EPED model assumption**

- **P-B constraint**
- **KBM constraint**

**[Snyder, NF 2011]**

- Pedestal pressure gradient grows unconstrained \( (a) \)
- KBM boundary is reached (proxy: \( \Delta_p \sim \sqrt{\beta_{pol,_PED}} \) \( (b) \))
- \( p_{PED} \) can only increase further via widening of \( \Delta_p \) at fixed \( \nabla p \) \( (b) \)
- P-B boundary is reached \( \Rightarrow \) type I ELM is triggered \( (c) \)
Profile analysis during the ELM cycle

- $T_e,_{PED}$ and $n_e,_{PED}$ typically **not** at same radial location

- $p_e,_{PED}$ and $\Delta p_e$ from $mtanh$ fit to experimental HRTS pressure data
Low gas injection: P-B constraint satisfied

The pre-ELM edge stability (Helena/ELITE) is consistent with the ELMs being triggered by P-B modes, both at low and high $\beta_N$.

Power scans at low and high $\delta$
1.4MA/1.7T
Low $D_2$ gas rate $\sim 3 \times 10^{21}$ e/s

[Challis, NF 2015]
[Maggi, NF 2015]
[Saarelma, PoP 2015]
\( p_{e,\text{PED}} \) evolution at low gas injection

- **Low** \( \beta_N \): \( p_{e,\text{PED}} \) increases due to steepening of \( \nabla p_e \) at \( \sim \) constant width
  \( \rightarrow \) not consistent with KBM constraint \( \rightarrow \) not consistent with EPED

- **High** \( \beta_N \): \( \nabla p_e \) increases, then saturates & \( \Delta p_e \) narrows then widens
  \( \rightarrow \) consistent with KBM constraint \( \rightarrow \) consistent with EPED
Power scans at high D$_2$ gas injection

- P-B constraint satisfied at low $\beta_N$
- P-B constraint not satisfied at higher $\beta_N$: missing physics for the ELM trigger?

[Maggi, NF 2015]
$p_{e,PED}$ evolution at high gas injection

- **Low $\beta_N$:** width narrows & gradient steepens, then $\Delta p$ broadens & $\nabla p$ reduces $\rightarrow$ qualitatively consistent with KBM constraint + P-B constraint satisfied $\rightarrow$ consistent with EPED

- **High $\beta_N$:** $\Delta p_{e} \sim$ constant and $\nabla p_{e}$ first increases, then $\sim$ saturates $\rightarrow$ qualitatively consistent with KBM constraint + P-B constraint not satisfied $\rightarrow$ not consistent with EPED
Temperature gradient saturates at high gas rate

- $\nabla T_e$ initially increases, then clamps half way of ELM cycle
- $\rightarrow$ suggestive of instabilities limiting growth of $T_{e,ped}$: MTMs?

See e.g exploratory GK study by [Hatch, NF 2016]
Increasing neutral gas (ν*) reduces $j_{BS}$

- Avoiding saturation of $\nabla T_e$ during the ELM cycle is crucial to maximizing pedestal performance.
• Pedestal width scaling

• Pedestal evolution during the ELM cycle

• First results on isotope effects
Isotope effect of type I / type III ELM threshold

- Power threshold for type I ELMs ~ doubles from D to H
Isotope effect of energy confinement

- Lower energy confinement in H than in D

Preliminary, assuming $T_i = T_e$

Power scans at same gas injection rate

$W_{th} [MJ]$ vs $P_{loss} [MW]$

1.4MA/1.7T, low $\delta$

Deuterium

Hydrogen

L-modes

Low Gas Injection: $\Gamma \sim 3-4 \times 10^{21}$ e/s
Edge $T_e - n_e$ diagram

- Weak fuelling efficiency in D type I ELMy H-modes
- $p_{e,\text{PED}}$ decreases in D as gas rate $\uparrow$ and power $\downarrow$
Hydrogen type III ELMy pedestals

- Lower density in H than in D

\[ \Gamma = 3-4 \times 10^{21} \text{ e/s} \]
\[ \Gamma = 8 \times 10^{21} \text{ e/s} \]
\[ \Gamma = 16 \times 10^{21} \text{ e/s} \]
• Lower density and stronger fuelling efficiency in H than in D
• Hydrogen type I ELMMy pedestals evolve at similar $p_{e,\text{PED}}$
Conclusions

- Pedestal width is independent of $\rho^*$, widens with $\sqrt{\beta_{\text{pol, PED}}}$ at low gas injection and with $v^*/\text{gas rate}$ at constant $\beta_{\text{pol, PED}}$
- Inter-ELM pedestal evolution depends on discharge conditions & not always consistent with EPED paradigm
- Avoiding saturation of $\nabla T_e$ as pedestal re-builds between ELMs is crucial for maximizing pedestal performance
- Edge GK analyses and experimental identification of nature of pedestal turbulence in JET-ILW are needed
- Strong isotope effect in energy and particle confinement