Scaling of the H-Mode Pedestal and ELM Characteristics on the JET and DIII-D Tokamaks

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An understanding of H-mode pedestal structure is important for predicting tokamak performance

- $P_{\text{FUSION}} \propto \beta_{\text{ped}}^2$
- $Q = P_{\text{FUSION}} / P_{\text{AUX}} \propto \beta_{\text{ped}}^2$

- Edge pressure gradient limit is well understood
- ETB width physics remains uncertain
Pedestal structure based on Thomson scattering measurements of electron profiles

- Data accumulated from a certain fraction of the Type I inter-ELM period for many ELMs
- Average profile over ELM irregularities
- Separatrix sweeps increase profile coverage
- JET data requires large correction for instrumental averaging.

Profiles must be deconvolved on JET due to spatial averaging.

Inst. Kernel
• Determine whether scaling with pedestal plasma physics dimensionless parameters is applicable to pedestal structure
  – If true, ETB width $\propto a$ with all dimensionless parameters matched
  – Other possibilities: neutral physics (some theories suggest a role for neutrals in the ETB width) 3D fields, ...

• Determine scaling of pedestal structure with normalized gyro radius $\rho_* = \rho/a$.
  – Vary $\rho_*$ keeping $\beta$, $u_*$, $q$, $T_e/T_i$, $M$, plasma shape fixed
  – $\rho_{*\text{ITER}} < \rho_{*\text{JET}} < \rho_{*\text{DIII-D}}$ and some theories predict an unfavorable scaling of ETB width

• Determine scaling of ELM size (energy loss) with $\rho_*$
ρ$_{\text{PED}}$ scans carried out in H-mode discharges with high and low triangularity shapes

$R_{\text{JET}} = 2.95\text{m}, a_{\text{JET}} = 0.95\text{m};$
$R_{\text{DIII-D}} = 1.67\text{m}, a_{\text{DIII-D}} = 0.54\text{m}$

Global stored energy tied to pedestal stored energy

Shapes normalized to major radius, R

$W_{\text{ped}}/W_{\text{TOT}} \sim 30\%-40\%$
Good match of DIII-D / JET at dimensionless match point but some variation of other parameters with $\rho^\text{PED}_*$

$\beta$ Match at identity point $\implies$ ETB Width $\propto a$
assuming stability is governed by plasma physics

Values at pedestal top
Previously published results on $\rho_*$ scaling of edge transport barrier width MAY BE INCORRECT

- The effect of instrumental averaging for the JET TS data was significantly underestimated.

- Inconsistencies in the ETB width data have not been resolved.
  - Near limits of the capabilities of the present TS systems on both DIII-D and JET.

- Only pedestal height results reported here
Comparison of $\rho^{*}_{\text{PED}}$ pressure results with empirical scalings may reveal $\rho^{*}$ dependency of pedestal structure

$$p_{\text{CORDEY-MHD}} = 0.83 \rho^{0.27}_{\text{ped}} \nu^{0.08}_{\text{ped}} m^{0.2} F^{2.29}_{q} \epsilon^{-2.56} \kappa^{2.48} (Rl^{2})/(1.5V)$$

- Ballooning mode scaling for $p'$ and $\rho$ scaling for width.
- Derived from fitting to the ITPA H-mode database.
- Residual $\rho^{*-0.8}$ suggests $P \propto \rho^{*-0.5}$
Comparison of Pedestal Pressure with EPED1 Model also suggests an inverse $\rho_*$ dependence

- Fits overall data better than semi-empirical models
- Suggest residual $\rho_*^{-0.7}$, mostly a separation between JET and DIII-D

$\chi^2/\nu=14.1$
Lincor=0.90

Correlation Lengths of Long Wavelength Density Fluctuations Do Not Vary Significantly with $\rho_*$

- Beam Emission Spectroscopy (BES) measures $k_\perp\rho_i<1$ fluctuations across the edge pedestal
- Radial and poloidal correlation lengths are unchanged with $\rho_*$, i.e., turbulent transport scale size is unchanged
- Fluctuation amplitude increases with $\rho_*$
ELM energy losses increase strongly with $\rho_*$ on DIII-D

- ELM losses increase strongly with $\rho_*$ on DIII-D
  - Increase is most pronounced in conductive channel, $n \Delta T$, but convective channel $T \Delta n$, also increases.

- Losses match at identity point but trend with $\rho_*$ reverses in JET with losses increase weakly at smaller values of $\rho_*$
Large ELM energy loss at high \( \rho_* \) is outside of usual scaling and correlated with ELM depth and duration.

- Losses match at identity point \( \rho_* = 0.4\% \)
- ELM loss at high \( \rho_* \) on DIII-D exceed value expected from Loarte empirical \( \nu_* \) scaling
- Large ELM losses at high \( \rho_* \) on DIII-D are correlated with increased ELM depth (ne profile change) and duration
Large ELM Losses In DIII-D at High $\rho_*$ Might Result from Proximity to Low-Density H-mode Threshold Power

- $P/P_{\text{LH}}$ unknown in low density $P_{\text{LH}}$ regime.
- ELMs usually large near H-mode threshold.

DIII-D/JET Joint Experiments Were Performed to Address Pedestal Structure and ELM Scaling with Machine Size

- Normalized pedestal pressure, $\beta$, is independent of machine size with all dimensionless parameters matched
  - Consistent with dimensionless scaling of pedestal structure
- Comparison with models suggests inverse $\rho^*$ pressure dependence for pedestal pressure
- Lack of turbulence correlation length change with $\rho^*$ suggests no dependence of pedestal structure on $\rho^*$
- (Fractional) ELM energy loss increases at large $\rho^*$ and exceeds usual $\nu^*$ scaling
  - $\rho^*$ may not be controlling parameter: more work needed on ELM scaling
- Improvements planned for JET and DIII-D TS systems should allow more certainty in directly scaling the ETB width.