Suppression of large edge localized modes with a stochastic magnetic boundary in high confinement DIII-D plasmas

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Structure, stability and ELM dynamics of the H-mode pedestal in DIII-D

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Fenstermacher EX2-5Rb
DIII-D has made substantial progress on developing pedestal solutions for ITER

**ELM Suppression (EX/2-5Ra)**

- Type-I ELMs are suppressed with resonant magnetic perturbations
  - no confinement degradation
  - good suppression for $\Delta t \sim 9\tau_E$ (some isolated ELMs remain)
- A new type of dynamical state replaces Type-I ELMs
  - transport dominated by small, high frequency fluctuations
  - divertor surface temperature spikes reduced by at least a factor of 5

**Pedestal Structure, Stability and Dynamics (EX/2-5Rb)**

- Structures resembling Peeling-Ballooning modes observed in CIII
- Neutral penetration physics dominates in setting $n_e$ pedestal width
- Measured edge currents agree with NCLASS code

*See posters Wednesday morning*
ELM control is a high priority ITER issue

- $T_{e}^{\text{ped}} \geq \sim 4 \text{ keV for } Q \geq 10 \text{ in ITER}$

- Normalized ELM energy ($\Delta W_{ELM}/W_{\text{ped}}$) increases with $T_{e}^{\text{ped}}$

- In ITER $\Delta W_{ELM}/W_{\text{ped}} > 20\%$
  - exceeds carbon ablation limit by a factor of 2-4
The DIII-D I-coil provides a flexible system for n=3 ELM control experiments.
ELMs are suppressed without degrading confinement

- Several isolated ELM-like events remain
- ELMs return after I-coil pulse turns off
Dynamical state of pedestal changes globally

- Suppression seen on:
  - all $D_\alpha$ arrays (outer midplane, upper and lower divertor, inner wall)
  - particle flux and heat flux to the primary (lower) divertor

- ELM transport is replaced by an increase in the edge magnetic field and density fluctuations
  - modulated by a 130 Hz coherent oscillation
Stored energy drops are smaller and slower with the I-coil reducing the impulses by > 3X

\[ \langle \Delta W_{\text{ELM}} \rangle = 14.1 \text{ kJ} \]

\[ \langle \Delta W_{\text{osc}} \rangle = 5.5 \text{ kJ} \]
High frequency transport replaces ELM transport
- bursty, intermittent and less impulsive
Peaks in the divertor surface temperature due to ELMs are reduced by at least a factor of 5 with the I-coil.
Good ELM suppression is obtained in LSN, high triangularity and ITER scenario 2 shapes.

Evans EX2-5Ra

- High Triangularity: $\delta=0.76$
- ITER scenario 2: $\delta=0.60$
- Lower Single Null: $\delta=0.37$
Physics that controls pedestal structure, stability and ELM dynamics is critical to understanding ELM suppression

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Measured edge current in H-mode large compared with L-mode; agrees with NCLASS calculation

- Large $J_{H\text{-mode}} = 1.5$ MA/m$^2$ measured in H-mode compared with negligible $J_{L\text{-mode}}$ in L-mode
- Magnitude of $J_{H\text{-mode}}$ agrees with calculation of $J_{\text{NCLASS}} = J_{BS} + J_{PS}$ from NCLASS code
- Effect of edge current on stability important to understand ELM onset and ELM suppression
DIII-D/JET pedestal similarity experiments show importance of neutral penetration

- Matched shapes and \((\beta, \nu^*, \rho^*, q)\) at top of pedestal
- Neutral penetration physics dominates in setting the density width
  - Mahdavi-Wagner model reproduces differences in DIII-D vs JET profiles
- Plasma physics dominates in setting the transport barrier
  - \(T_e\) width \(\propto a\)
Structure of linear P-B ELM instability seen in CIII image data during ELM

- Most unstable modes from ELITE linear P-B instability calculation are $16 \leq n \leq 24$

- CIII emission structure during ELM suggests $n \sim 17$
Summary and conclusions

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