ELMs and Pedestal Characteristics

Peeling-Ballooning Stability, ELM modification, and NSTX/DIII-D Comparison Expts

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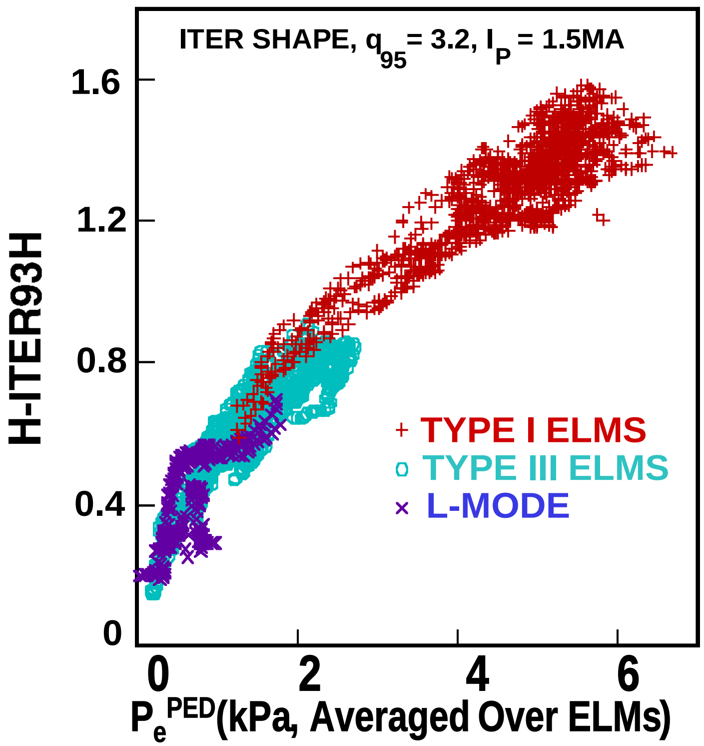
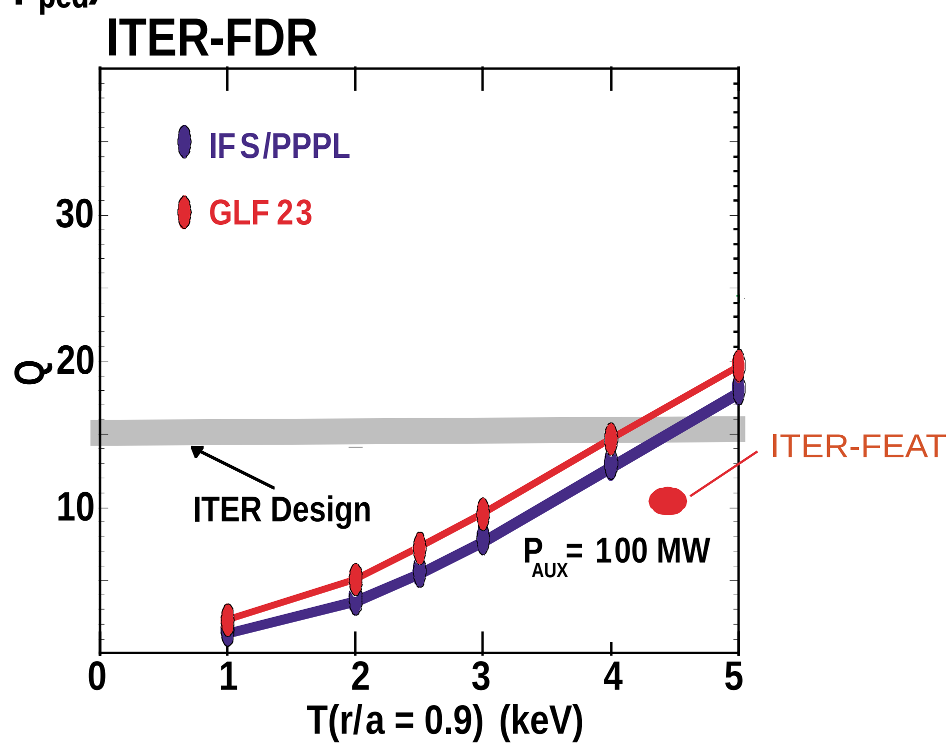
General Atomics, San Diego, CA, USA

NSTX Research Forum, Princeton NJ, November 2001

Pedestal & ELMs Key to Plasma Performance

- Both experiment and theory predict a strong dependence of core confinement, and therefore Q on the pedestal height (T_{ped}, p_{ped})

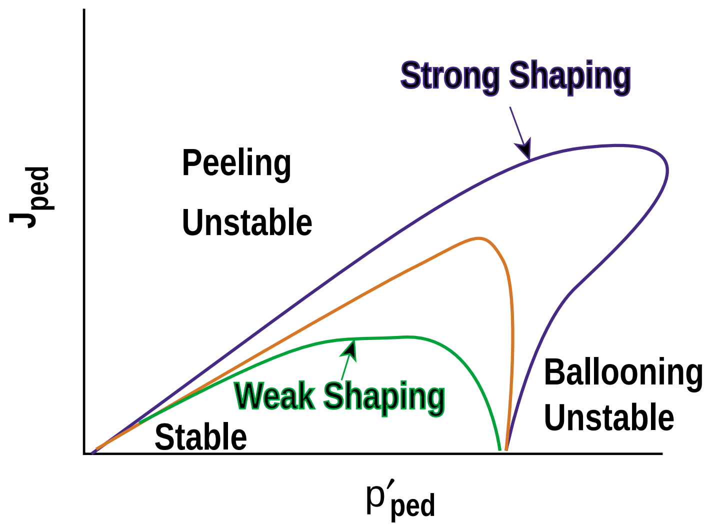


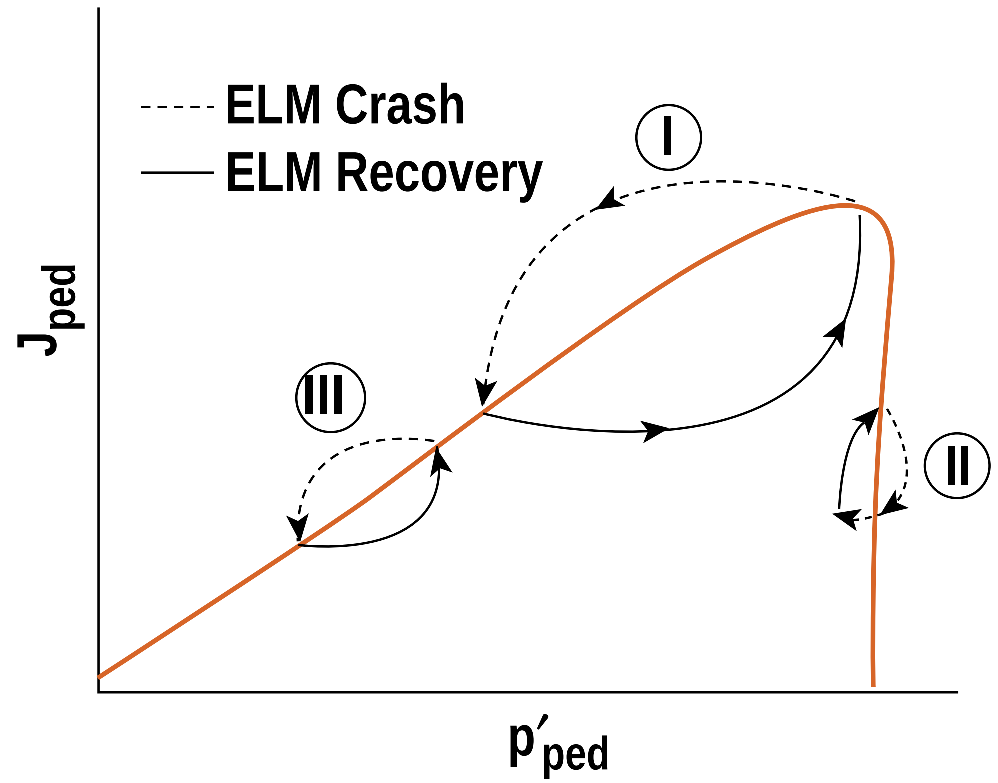


- ELM characteristics strongly impact divertor heat load constraints (large Type I ELMs may not be tolerable in Next Step)

➡ Scaling of ELMs and Pedestal with aspect ratio key issue for low-A Fusion Devices

Model of ELMs and Pedestal Constraints





- ELMs triggered by intermediate-*n* peeling-ballooning modes, ELM size correlates to depth of most unstable mode and to location in parameter space
- Pressure rises up on transport time scale between ELMs, current rises to steady state value more slowly
- Predict changeover in ELM behavior when $J_{ped}<J_{peel} \Rightarrow$ strong density and shape dependence

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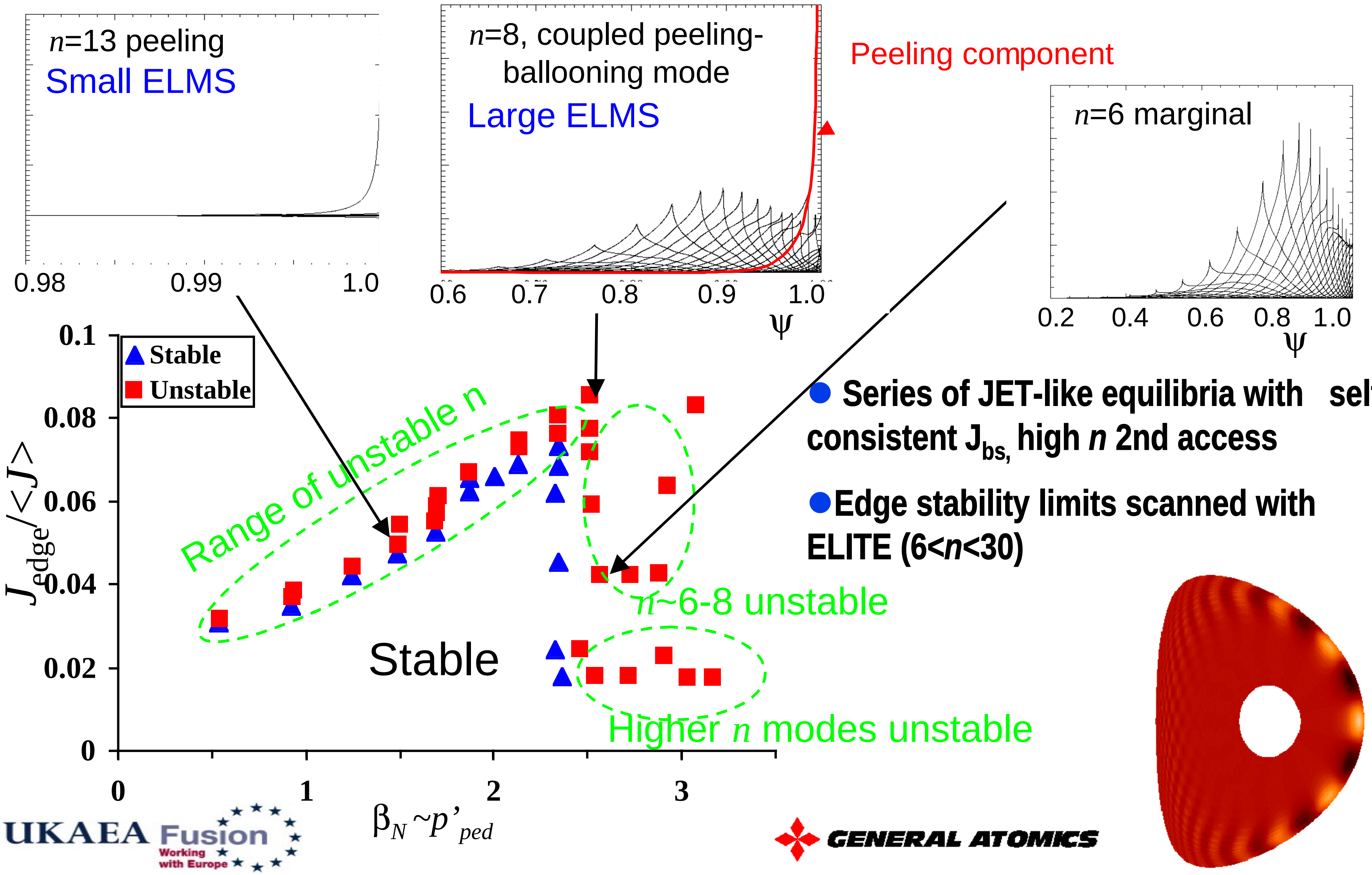
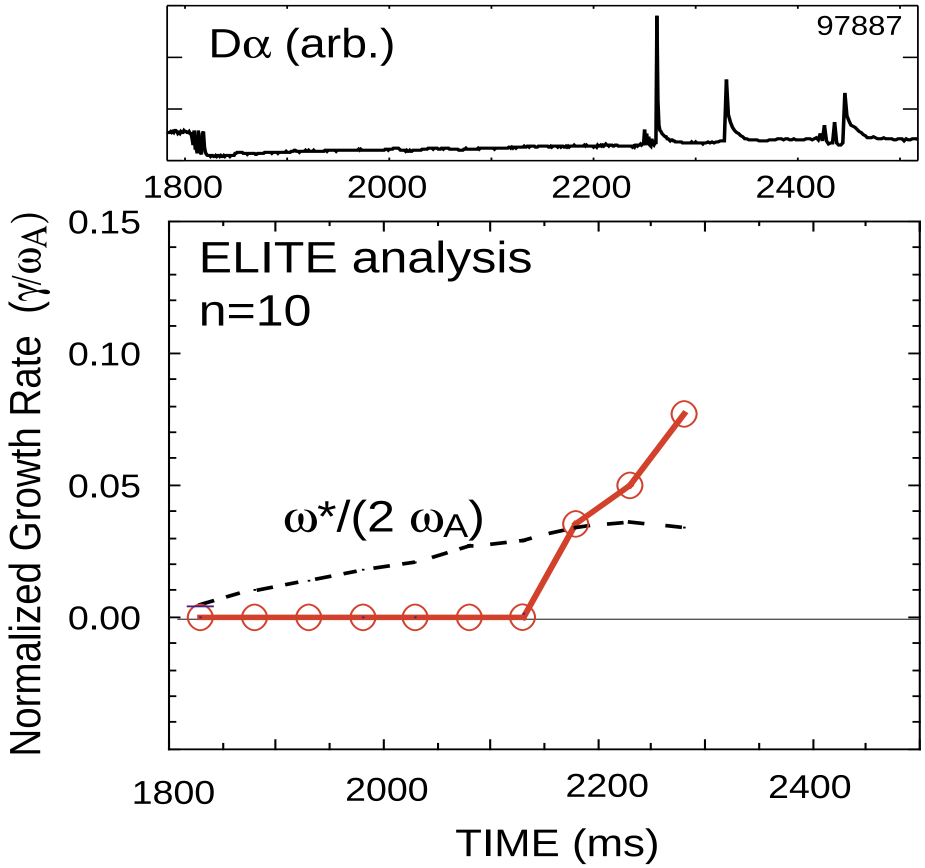
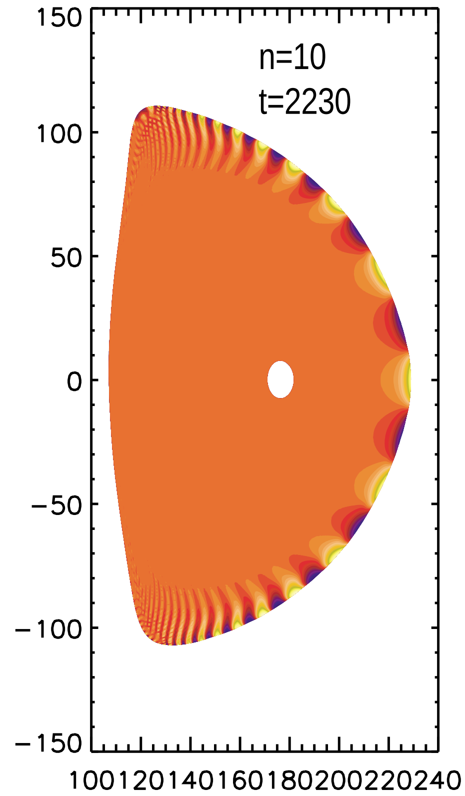
Pedestal Constraints and Mode Structures Quantitatively Predicted



- Series of JET-like equilibria with self-consistent $J_{bs,}$ high *n* 2nd access
- Edge stability limits scanned with ELITE (6<*n*<30)

Intermediate *n* Peeling-Ballooning Modes are a Solid Candidate for ELMs: Case Study in DIII-D





- DIII-D shot analyzed using experimental reconstruction of equilibria
- *n*=10 growth rate attains significant value just before ELM observed

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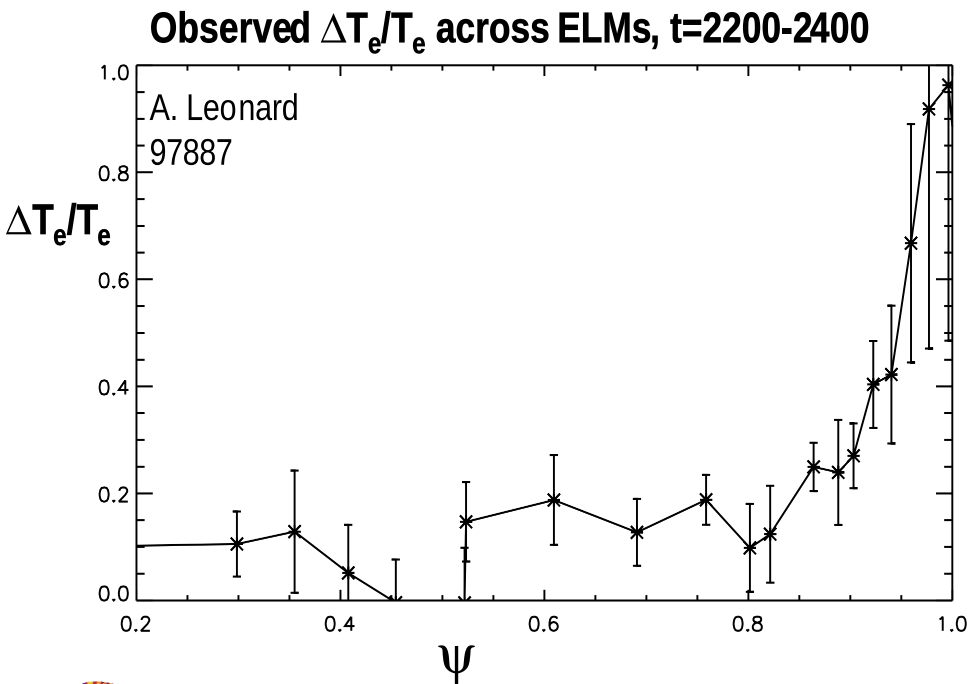
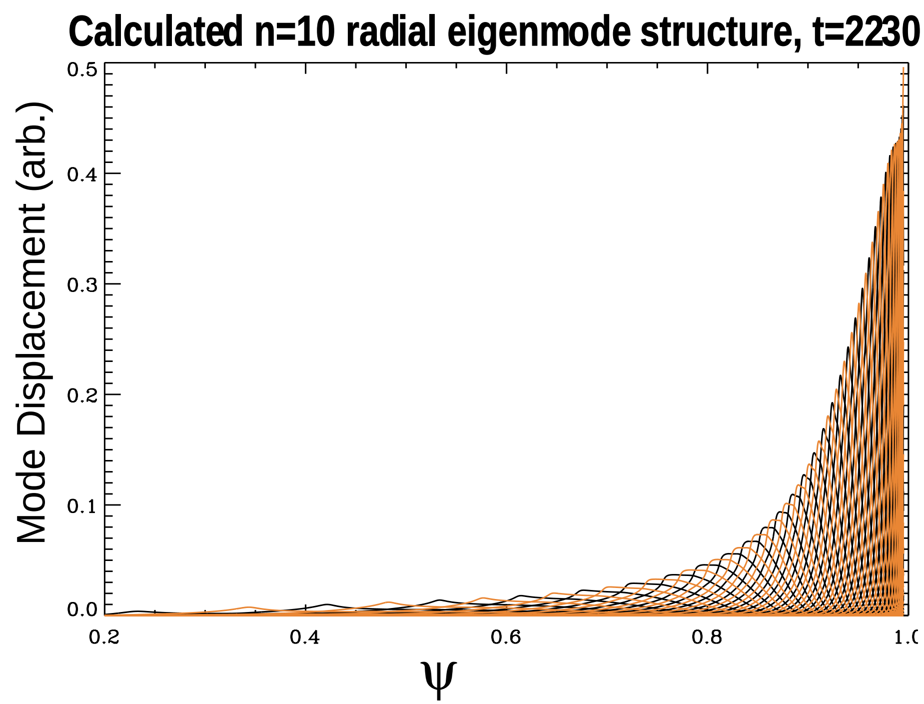
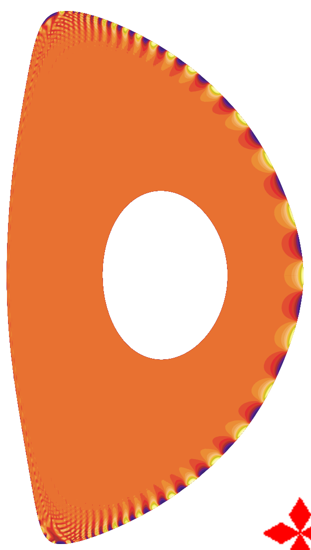
Calculated Mode Structure Consistent with Observed ELM Depth





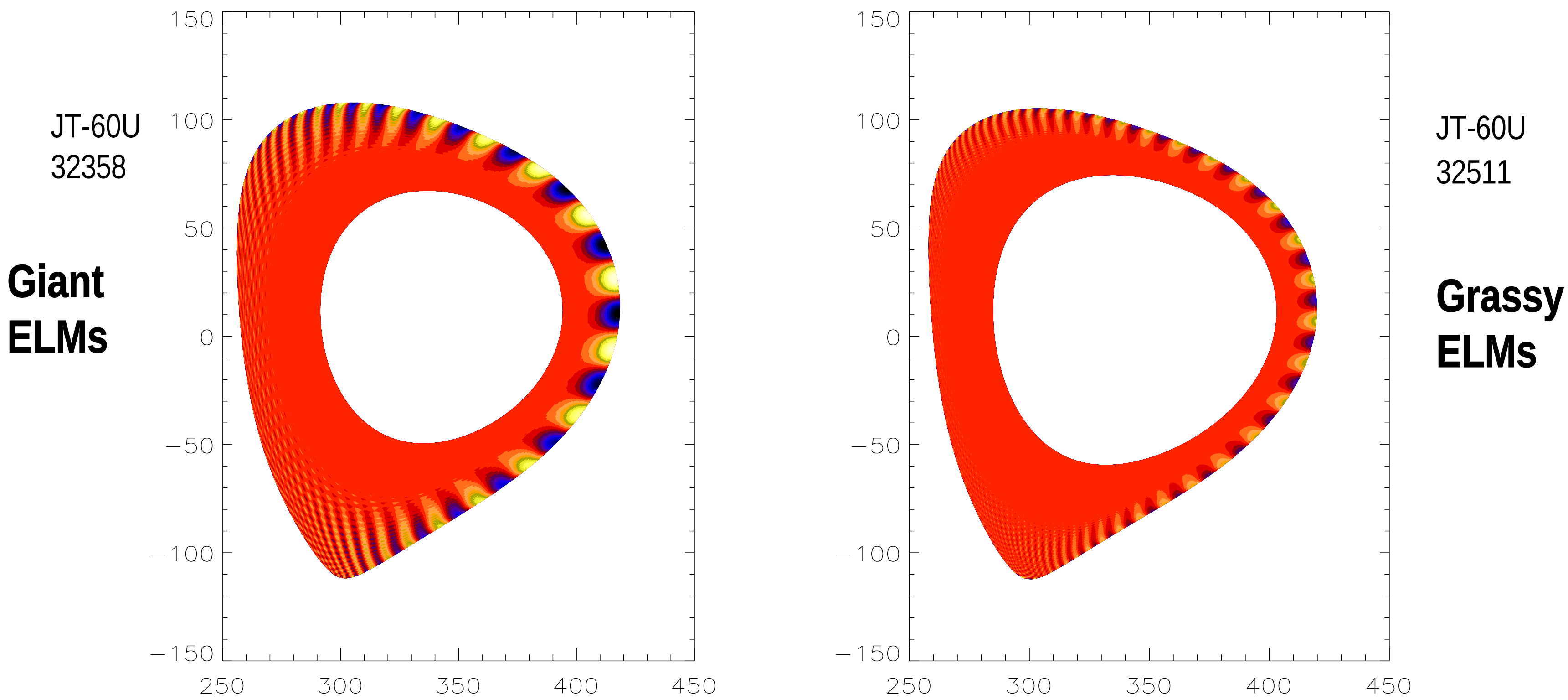


- Pedestal extends from $\psi \sim .95-1$, both observed depth and calculated mode extend well inside the pedestal

- Further support for predicted mode structure provided by divertor balance experiment (T. Petrie et al): ELM signals absent on high field side for double null

Stability model explains features of JT-60U,C-Mod ELMs

- Mode structure calculated with the ELITE code using JT-60U, C-Mod equilibria
- JT-60U: Narrow modes predicted when small ELMs observed, wide modes for giant ELMs
- Type II ELMs -> narrow mode structure + low steady state J_{bs}? [Saarelma, Snyder, Lao]



Study on C-Mod finds wide, unstable peeling-ballooning modes just before ELMs observed. EDA and ELM-free cases marginally stable [Mossessian et al]

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Issues

- **Aspect Ratio**
  - Impact on bootstrap current, peeling stability and ballooning 2nd stability
  - Coupling to core modes
  - Impact of high q, local pitch of field lines
- **General Pedestal Physics**
  - Pedestal Width: stability, transport, neutrals, ion orbit effects?
  - Stability constraints on pressure gradients, and nature of most unstable modes
  - Importance of non-ideal effects
  - ELM types
  - Scaling of confinement and pedestal with shape, density etc
  - Energy and density loss resulting from ELMs

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Equilibrium and Full Spectrum Stability Tools

- **EFIT, TANHFIT, TOQ, ONETWO and Corsica for equilibrium reconstruction & manipulation**
- **GATO for low-n stability, BALOO for infinite-n**
- **ELITE is a 2D eigenvalue code, based on ideal MHD (amenable to extensions):**
  - Highly efficient new code, calculates MHD growth rates and mode structures for 5<~n<~60
  - Benchmarked against GATO and MISHKA
  - Allows scans of real equilibria over wide pedestal parameter space
  - Study coupled peeling/ballooning modes and quantitative constraints on edge gradients and pedestal height
- **BOUT (LLNL) for nonlinear dynamics, non-ideal effects, X-point geometry**
  - Kink term recently added
- **GYRO for future gyrokinetic analysis, including non-local geometry**

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Research Plan

Long term collaborative effort:

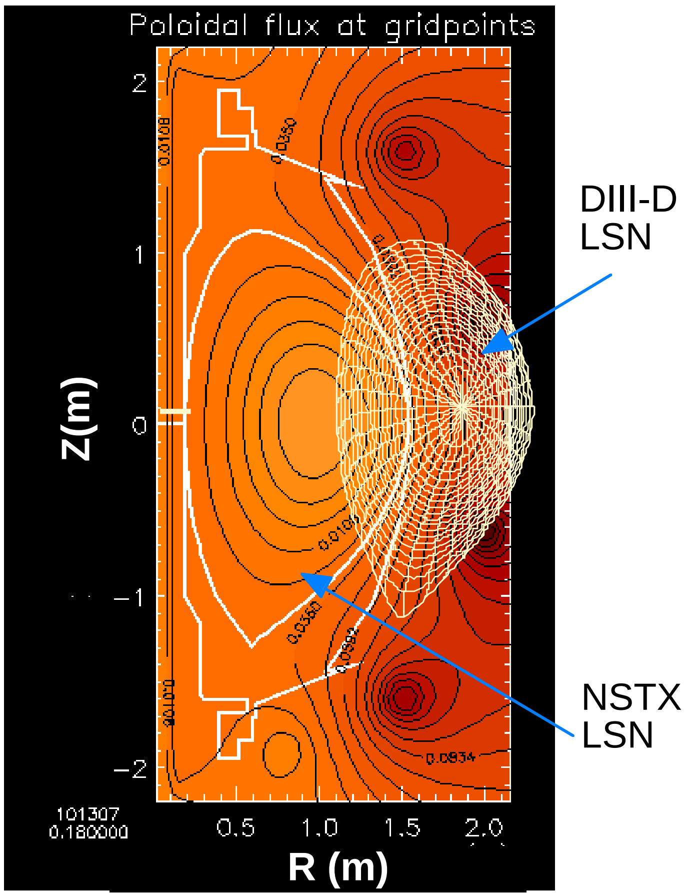
<u>1st year</u>

- **Analysis and Modeling**
  - Predict pedestal stability constraints and ELM types
- **Participate in any necessary H-Mode development**
- **Detailed comparison with models probably limited by Thomson pedestal resolution**

<u>2nd-3rd year</u>

- **Improved diagnostics anticipated: 10-15 pedestal Thomson locations?**
- **Peeling-Ballooning Stability Expts, motivated by modeling**
- **Pedestal Modification Expts**
  - Vary shape, density, impurity concentration at edge

Research Plan: NSTX/DIII-D Pedestal Comparison



Paoletti, Sabbagh (Columbia)

- **DIII-D/C-Mod pedestal similarity expt successfully carried out, continuing in 2002. JET/DIII-D comparison also planned for 2002**
- **Have done stability analysis comparisons on DIII-D, JT-60U, C-Mod, JET and planned collaboration with ASDEX-U. Very useful to add NSTX.**
- **Similar NSTX/DIII-D cross sections (and low field capability of DIII-D) allow for good similarity expts, varying only aspect ratio**

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