No ELM, Small ELM and Large ELM Strawman Scenarios

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ARIES Team Meeting

Bethesda, Md

July 29 - 30 2010

Both ELM-free and Small ELM Regimes May be Available for a Reactor

- **ELM-free Scenarios:**
  - Enhanced D-alpha (EDA) Mode:
    - Observed in C-Mod
  - Quasi-H (QH) Mode:
    - Observed in DIII-D
  - Resonant Magnetic Perturbation (RMP) Discharges:
    - Observed in DIII-D with non-axisymmetric coils
  - Li Conditioned Discharges:
    - Observed in NSTX
- **Small ELM scenarios:**
  - Shaping:
    - Large squareness
  - Type II (“grassy”) ELMs:
    - Mostly seen in JT-60
  - Type III ELMs

ELM-free Regimes Offer the Most Promise But are Presently Restricted to Fairly Narrow Operational Ranges

- **EDA:**
  - Apparently requires controlled increased recycling
  - Observed only with ICRH
  - D_α actually increases but confinement improves and high pedestal gradients obtained
  - Restricted to intermediate δ and q_{95}:
    - $0.3 < \delta < 0.55$ and $3.5 < q_{95} < 4$
  - Associated with continuous modes
  - Only observed reliably so far in C-Mod
    - Similar mode observed on JET
- **QH:**
  - Mostly lower to moderate performance discharges
    - Pedestal usually lower than conventional ELMing H-mode
  - Associated with continuous modes
  - Extended recently to co-rotation in DIII-D and to JT-60U

ELM-free Regimes Offer the Most Promise But are Presently Restricted to Fairly Narrow Operational Ranges

- **RMP:**
  - Mostly lower to moderate performance
    - Pedestal usually lower than conventional ELMing H-mode
  - Physics responsible is unknown
  - Heat transport and particle transport ‘uncoupled’
- **Li Conditioning:**
  - Range from ELMing to infrequent ELMs to ELM-free discharges
    - Depends on level of Li conditioning
  - Fully ELM-free apparently requires massive amounts of Li
  - Physics responsible is unknown:
    - Change in the density profile from Li is thought to be the first step to ELM suppression

Small ELM Regimes Offer Promise But are Also Apparently Restricted to Narrow Operational Ranges

- **Shaping:**
  - Strong outboard squareness makes higher n more unstable
    - ⇒ Smaller more frequent ELMs:
- **Type II:**
  - Observed in JT-60 and occasionally in DIII-D
  - New "Type V" regime in NSTX has many similarities
  - Generally strong shaping ($\kappa > 1.8$, $\delta > 0.3$) and low current
  - Not reliably reproducible
  - Mostly lower to moderate performance
    - Pedestal usually lower than conventional ELMing H-mode
- **Type III:**
  - Occur only at low $T_e \sim 1/n_e$ near H-mode threshold
  - Generally associated with reduced confinement
  - Precursor usually observed: more coherent than for Type I
  - Pressure threshold can be near Type I values since $T_e \sim 1/n_e$
  - Thought to be due to resistive instability
  - ELM frequency decreases with increased heating

Essential Physics For ELM Onset is MHD Instability Driven by Steep Edge Gradients

- **Basic ELM issue:**
  - Steep localized edge (pedestal) pressure gradient is both cause and consequence of improved confinement in H-mode
  - Local pressure gradient drives local bootstrap current density through neoclassical effects
  - Both pressure gradient p’ and current density j drive MHD instability
  - Instability observed as a precursor to ELM event
    - Typically low to intermediate n: $2 < n < 30$
    - Limits final edge pressure gradient and width
- **ELM type is determined by different physics associated with varying:**
  - Specific mixture of p’and j drive
  - Pedestal width and height

EPED1.6 Model Predicts Maximum Edge Pedestal Height and Width Due to Type I ELM Onset

- **Combines physics models for the controlling instabilities:**
  - Height and width controlled by steepness and width:
    - Pedestal steepness largely set by MHD stability from low to intermediate n modes
    - Pedestal width largely set by Kinetic ballooning mode onset
  - But division is not ‘orthogonal’:
    - MHD stability also sets partly the pedestal width

Essential Physics of ELM-free and Small ELM Regimes Needs to be Understood

- **Required conditions need to be determined more precisely for each regime:**
  - Present operational range of conditions is relatively narrow
  - Depend on at least:
    - Profiles n_e, n_i, T_e, T_i
    - Rotation
    - Recycling
    - Pumping
  - How many of the current operational restrictions can be extended ?
- **Essential physics needs to be understood for each regime:**
  - Is it p', j, shape, transport that determines whether ELM is small or stabilized or continuous mode:
    - Answer appears to be different for each regime

Propose to Study Possibility of Self-consistently Including Options for ELM-free and Small ELM Scenarios in ARIES

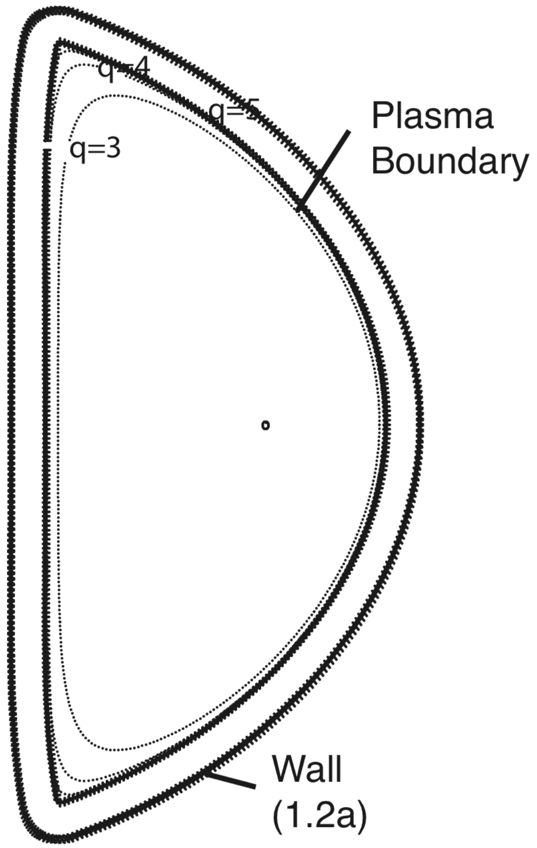
- **Take representative discharges for each regime in the respective machines and determine essential physics:**
  - Discharges from DIII-D, C-Mod, NSTX
  - Determine essential profiles and other characteristics
  - Utilize GATO to study n = 1 - 5, and ELITE for n > 3 modes
  - Characterize dependence of ELM type and size
- **Scale configurations to ARIES:**
  - Use profiles in ARIES configuration:
    - Density and temperature profiles from respective discharges with ARIES q profile
  - Adjust configuration as necessary:
    - Adjust q profile from bootstrap current self consistency
    - Modify shape as needed
    - Include other characteristics (eg. rotation)
- **Study low to intermediate n stability:**
  - Utilize GATO and ELITE to characterize dependence of ELM type and size

Begin with Base Line ARIES L-mode and H-mode Cases From 2000 Study

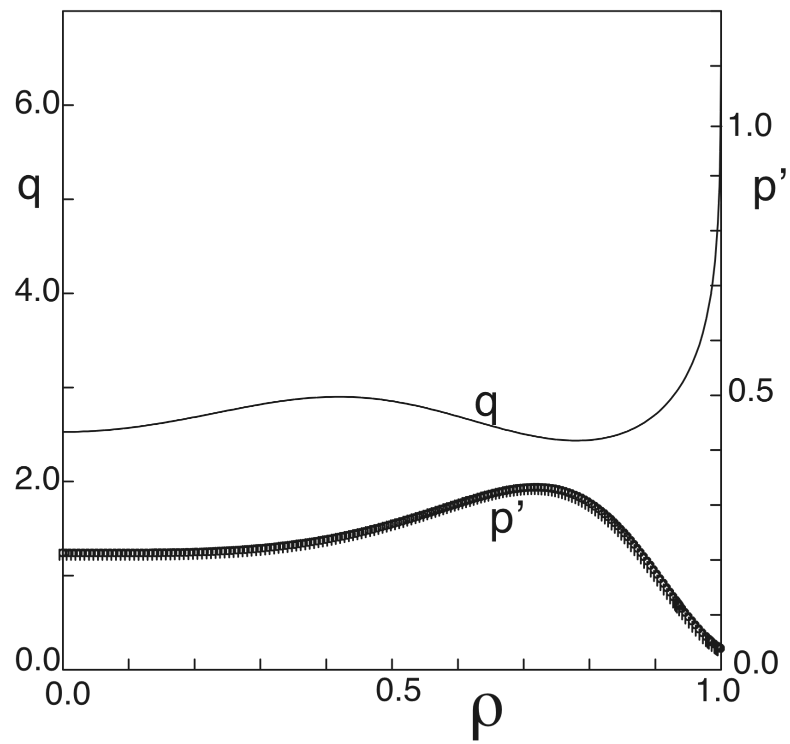
- **Base equilibria unstable to n = 2,3,4,… edge modes:**
  - Provides a baseline in terms of mode width:
    - Mode width ~ pedestal width
  - Stability calculations underway:
    - Grossly unstable with no wall
    - Each n = 1,2, and 3 stable for conformal wall at 1.2a
    - Need to establish correct wall configuration
- **Compare with:**
  - ITER demo steady state DIII-D discharge #131198:
    - Relatively high β and high pedestal
  - DIII-D high performance H-mode discharge #87099:
    - Elevated q > 1.5 with higher β_N:
    - Calculations for this case have been done and published:
      - ⇒ Results are not very encouraging

Base Line ARIES H-mode Case From 2000 Study

- **ARIES H-mode cross section:**

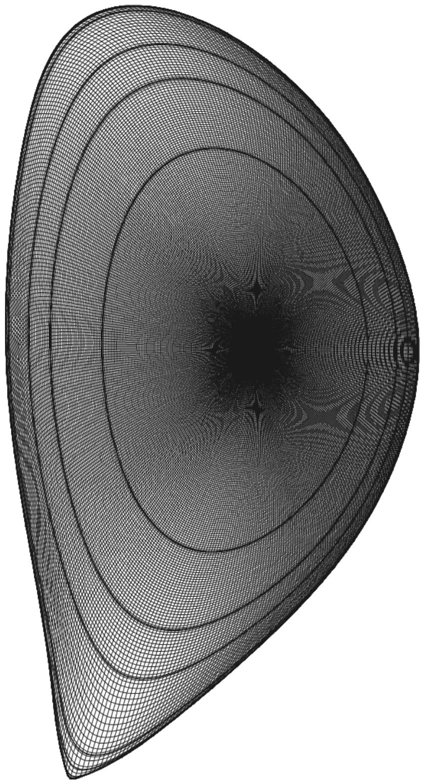


- **q profile:**

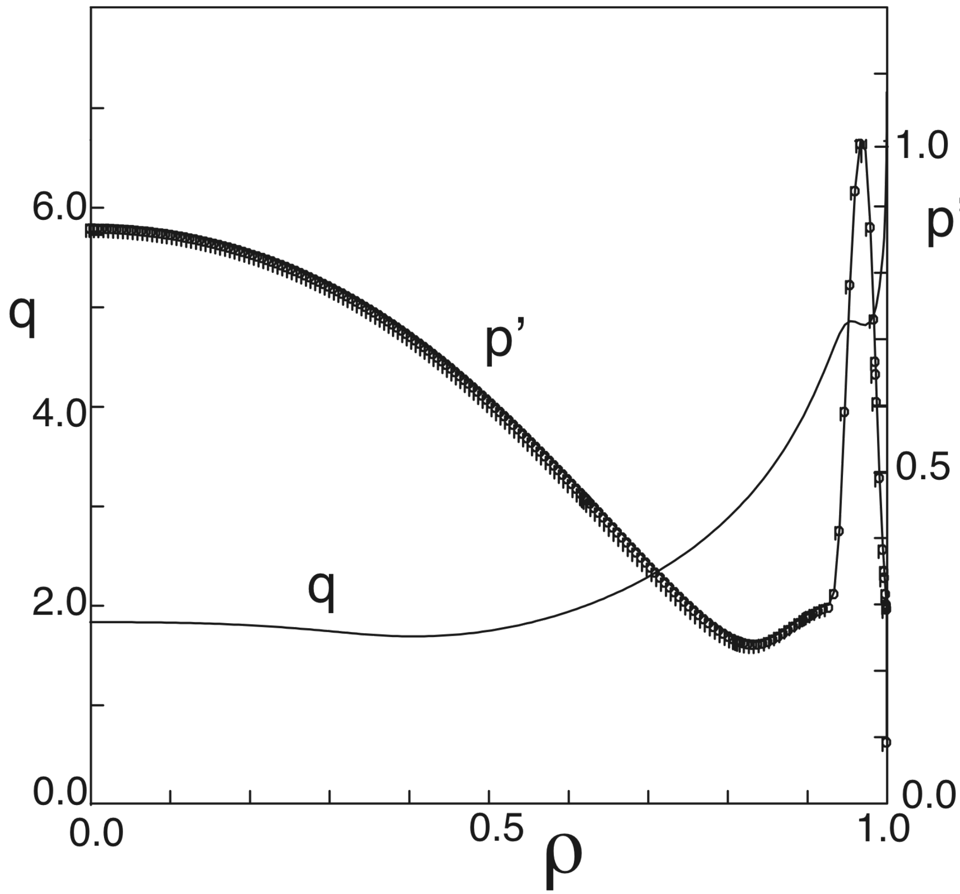


DIII-D ITER Demonstration Steady State Discharge Discharge #131198 (t=3550) Equilibrium

- DIII-D Steady State H-mode cross section:



- q profile:



ELM-free regimes for ARIES Taken From Existing Experimental Equilibria:

- **EDA: Need to get equilibrium from C-mod**
- **QH: Use DIII-D 131922:**
  - ELM-free
  - Very high pedestal
- **RMP: Use DIII-D 129750:**
  - RMP discharge with ELMs fully suppressed
- **Li Conditioning: Use NSTX:**
  - 129015: Type 1 ELMing H-mode:
    - No lithium
  - 129030: Type 1 ELMing H-mode:
    - Much lithium
    - ELM-free following an initial low frequency ELMing phase
  - 129031: ELM-free:
    - Much lithium
    - ELM-free following an initial ELMing phase
  - 129038 - Completely ELM-free:
    - Massive lithium

Need to Obtain Good Relatively High Performance Discharge Equilibria for Small ELM Regimes

- **Shaping:**
  - From DIII-D high squareness experiments
- **Type II:**
  - From DIII-D experiments:
    - Difficult to reproduce
  - Consider NSTX 'Type V' ELM regime
- **Type III:**
  - From DIII-D:
    - Difficult to find high performance discharges

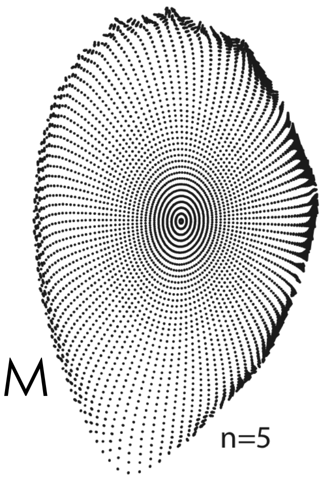
Issues: How to Scale the Discharges to ARIES

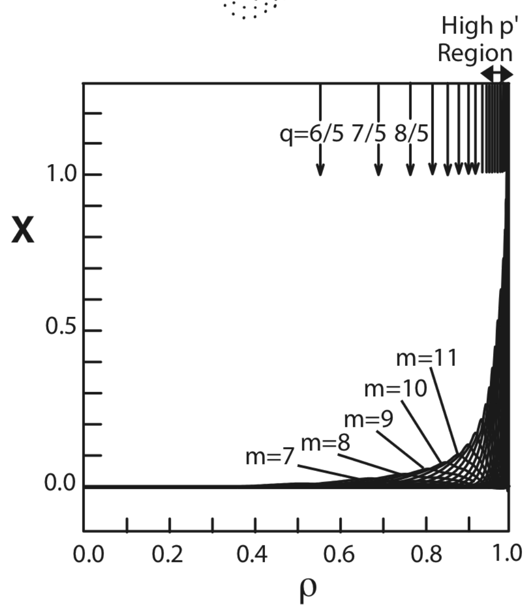
- **ARIES β_N ~ 5 but all these discharges have much lower β_N:**
  - High β_N will make the modes much larger with same pedestal:
    - How does pedestal width and height really scale if these operating modes are reproduced in an ARIES scale reactor?
    - Experimentally ELM losses are proportional to energy contained in the pedestal
- **ARIES has high internal q with flat low shear profile:**
  - How does this affect coupling of edge pedestal stability to core:
    - Likely to increase mode width
- **What is role of nearby wall:**
  - Coupling to wall will be quite different at high β_N with high bootstrap fraction:
    - Modes are generally much more global

DIII-D Advanced Tokamak Discharge #87009 Has Wide Pedestal and Correspondingly Broad Edge Instability

DIII-D discharge #92001: $\beta_N < 2$
Standard H-mode

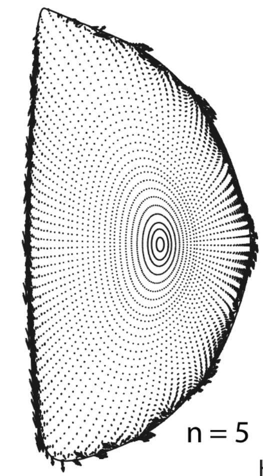
Standard Type I ELM

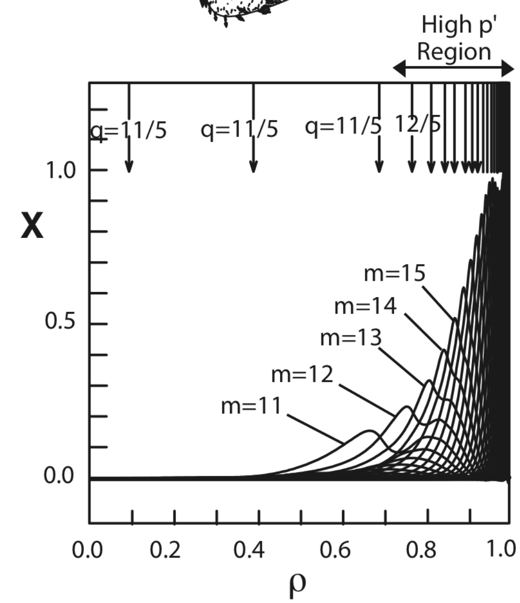




DIII-D discharge #87099: $\beta_N \sim 2.5$
Advanced Tokamak H-mode

X-Event (Giant ELM)





Issues: What is the Crucial Physics

- **What is role of rotation:**
  - Important at least for QH
- **What is role of density profile:**
  - Important at least for Li Conditioning
  - Pumping appears to generally important:
    - ⇒ Is it density or recycling ?
- **What is role of nonaxisymmetry in RMP:**
  - Is an ergodic edge important?
  - Is it the effect on the T, n, J_{bs} profiles that is important?