Nonlinear Simulations of ELMs with NIMROD

D.P. Brennan

Massachussetts Institute of Technology

Cambridge, MA

S.E. Kruger
Tech-X Corp, Boulder, CO
A. Pankin, D.D. Schnack
SAIC, San Diego, CA
P.B. Snyder
General Atomics, San Diego, CA

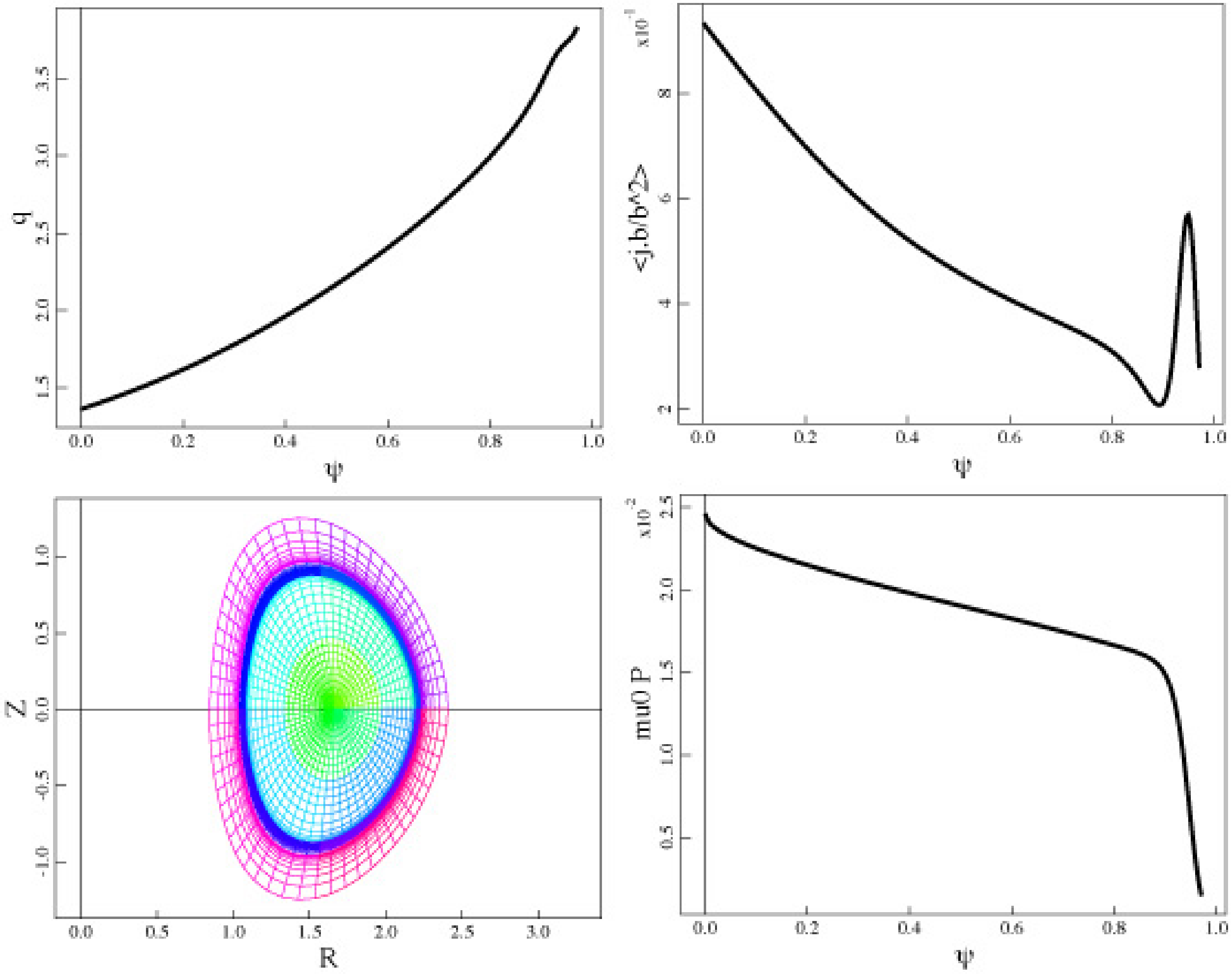
Goals for Nonlinear

Extended MHD Simulations of ELMs

- **Energy loss and mode saturation mechanisms of ELMs**
- **Influence of resistivity and inertia / viscosity on the nonlinear mode evolution**
- **Studying the nonlinear mode coupling and how energy is transported in (R, Z) and n**
- **Anisotropic thermal transport coefficients with realistic heat loss treatment**
- **How toroidal rotation effects mode structures and evolution (QH mode)**
- **Two fluid and FLR effects**

Simple Equilibrium Chosen for Study

- **Limiter Case**
- **Pedestal Edge**
- ***Low* Edge Current**
- **Flat Core Profiles**
    - **Stable in Core**
    - **Unstable at Edge**
- **Moderate Edge q**



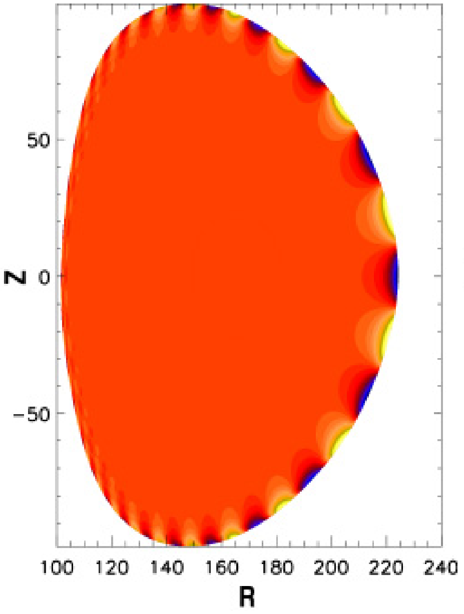
NIMROD Shows Agreement with ELITE Mode Structure

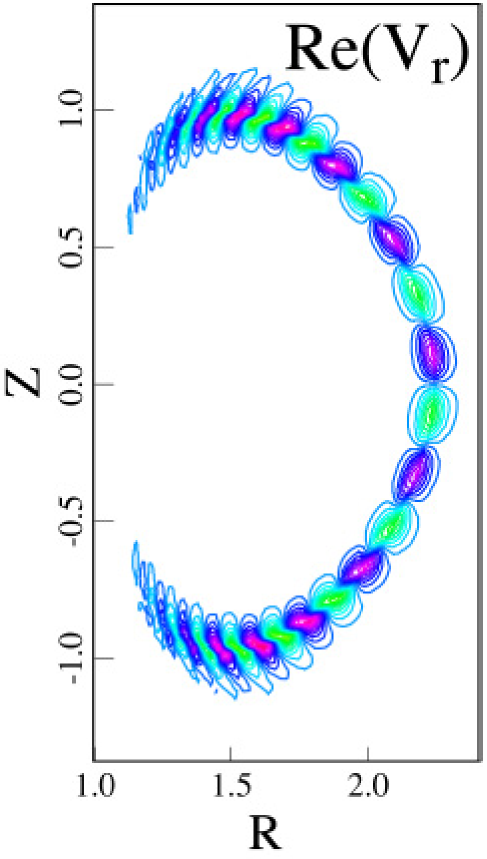
- **ELITE Figure does not include vacuum perturbation**

Poloidal and radial distribution of the mode is in rough agreement

Peeling Component not Captured?

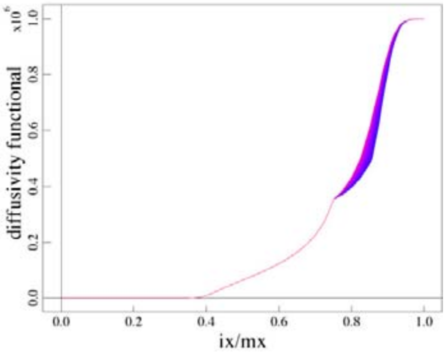
n=7 shown

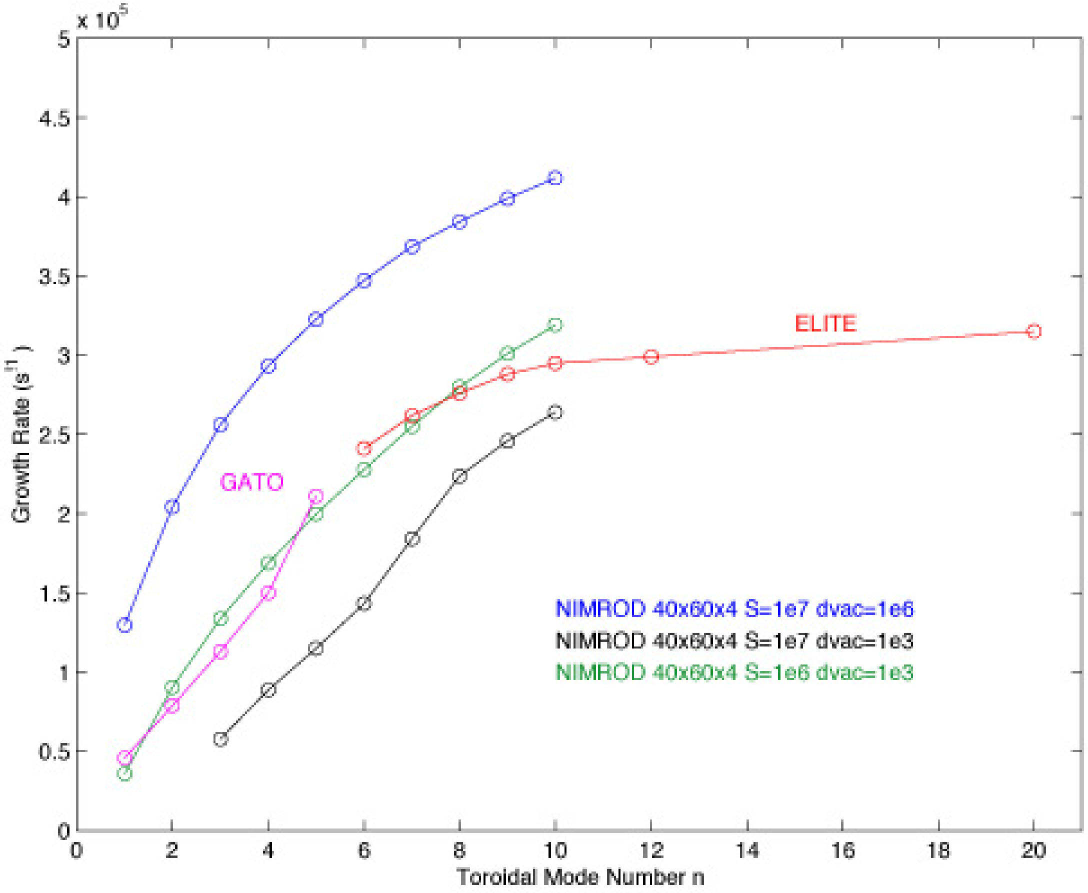




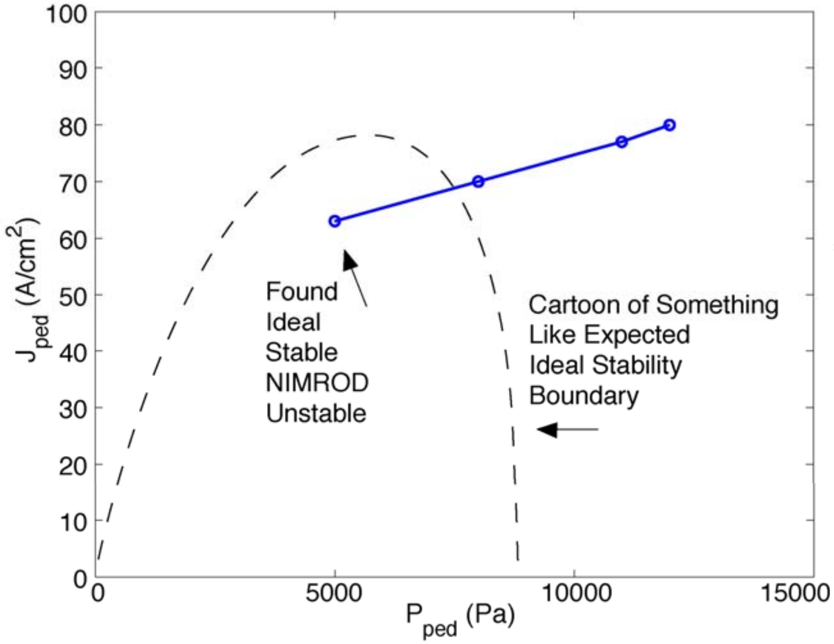
Growth Rates From Ideal Codes Bracketed by NIMROD depending on resistivity in edge region

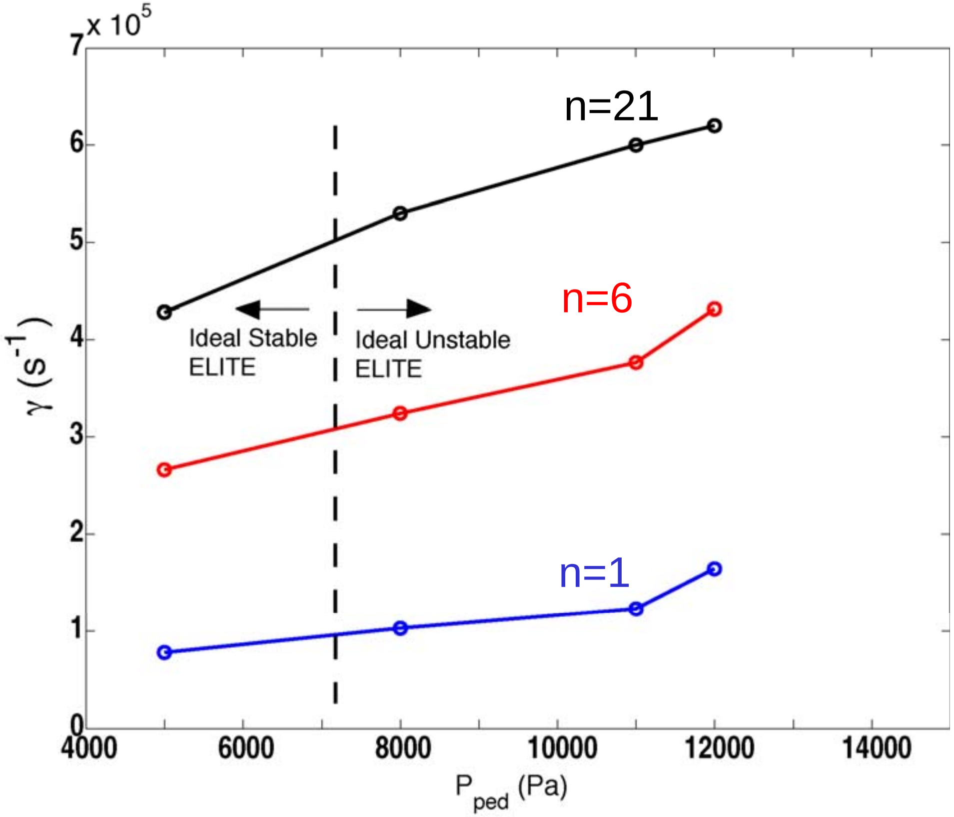
NIMROD growth rates depend on local resistivity, and therefore dvac which sets the vacuum resistivity ratio to core, and slightly affects resistivity at edge.





Growth rates decrease with pedestal height but remain unstable in the ideal stable regime





- More work is needed to find the stability boundary: Experiment resides near and crosses stability boundary.
- Is it necessary or even wise to map out J,P space?
- Destabilizing effects of resistivity are not countered with stabilizing effects found in experiment.

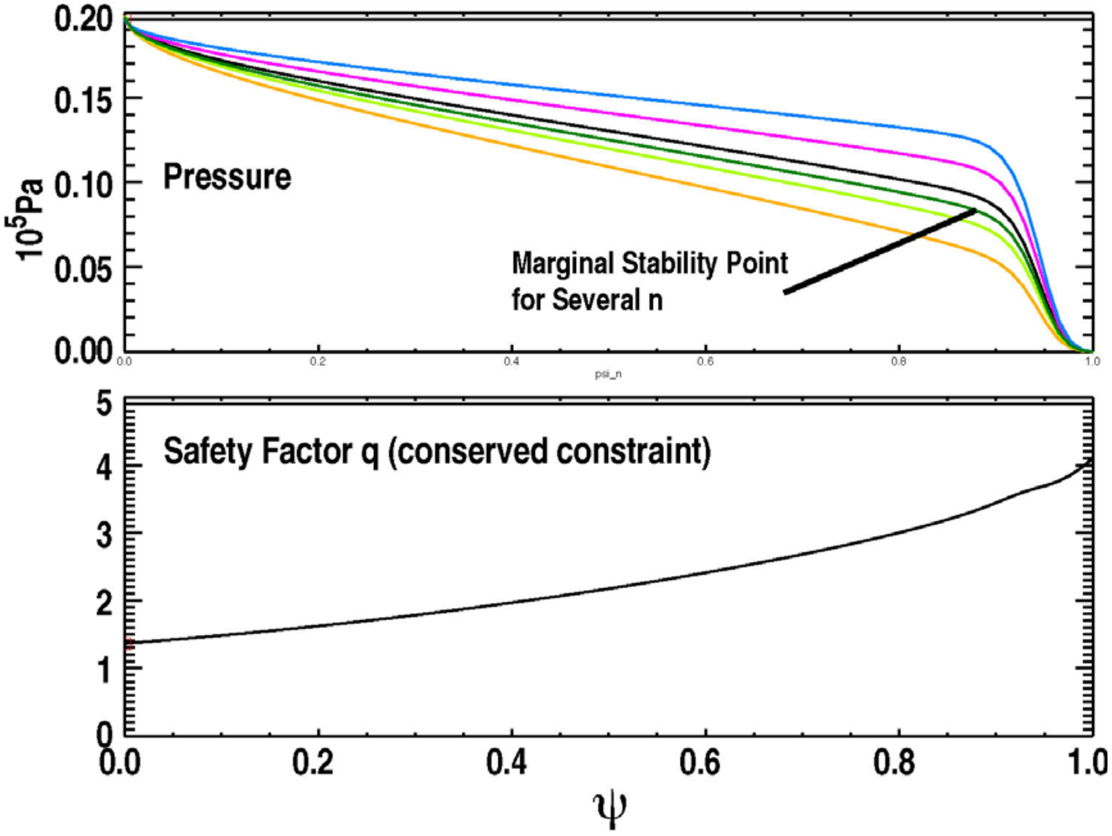
To Study This Problem and Relate to Experiment

Explore the Stability Boundary in s,α Space

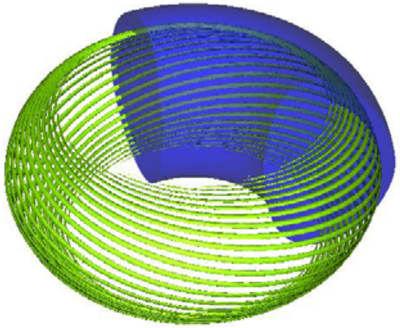
Pedestal height is varied while conserving the core pressure and q, for an α scan.

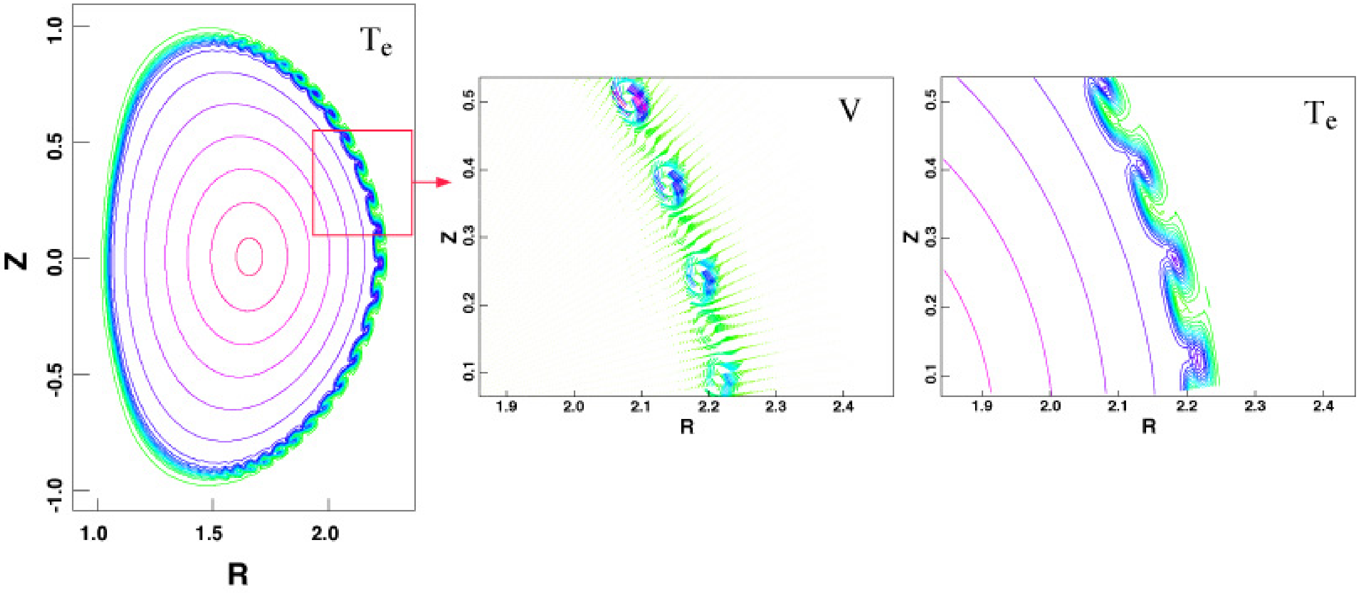
It is hoped that marginally unstable modes will saturate nonlinearly at a small size.

A comparative analysis of nonlinear evolution with high and low shear alone would be interesting, even without saturation.



Nonlinear Simulations of Edge Localized Modes are Pioneering a New Understanding of ELM Evolution





The coupled modes form complex structures in flow velocity and Temperature, among other fields.

Areas of high temperature are seen flowing out, in agreement with previous analyses.

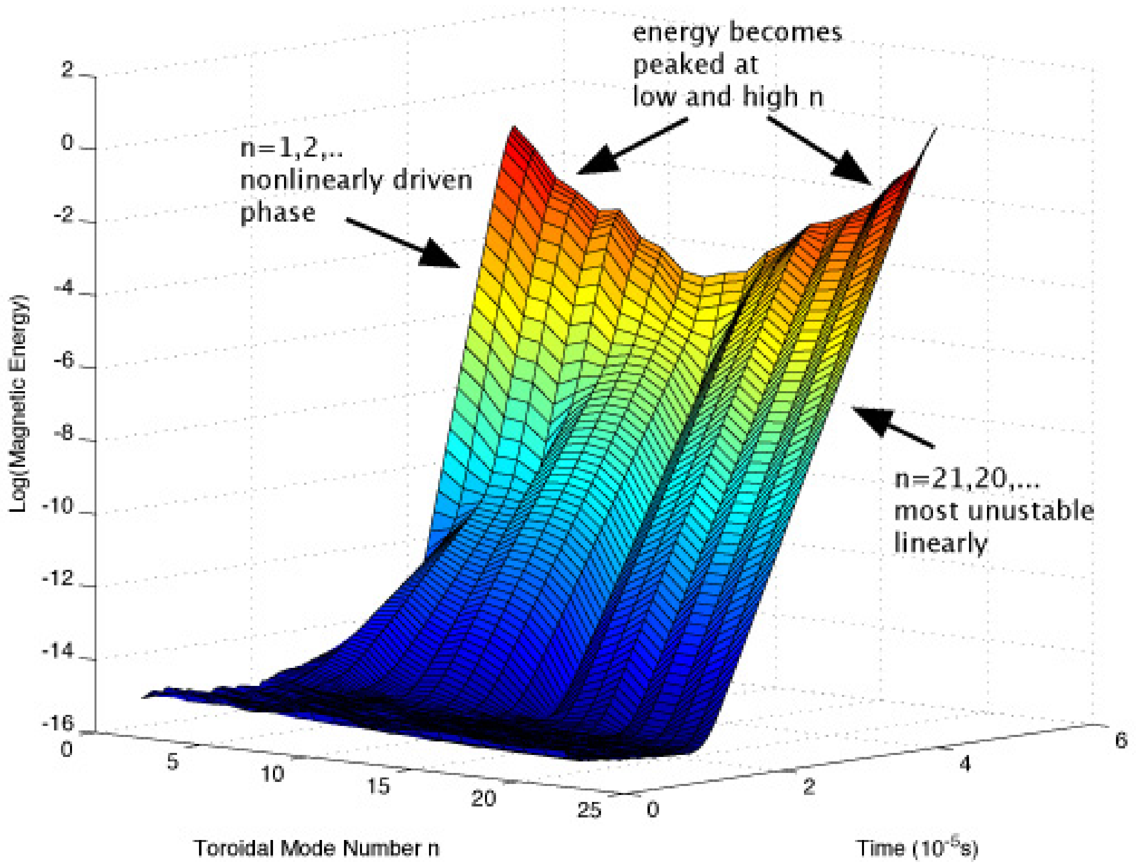
Nonlinear heat loss mechanisms of ELMs are not well understood.

Coupling to low n modes ubiquitously drives large low n modes in the early nonlinear phase

Energy distribution peaked at low and high mode numbers.

Low n modes initially have lower linear growth rate compared to higher n.

Assuming equipartition of energy as initial condition, the higher n modes grow linearly to large amplitude and their beating nonlinearly drives the lower n modes to large amplitude. Intermediate n=5-10 modes are robustly linearly unstable but are not strongly driven in the early nonlinear phase.



energy becomes peaked at low and high n

n=1,2,.. nonlinearly driven phase

n=21,20,... most unustable linearly

Without hyperviscosity high n initially dominant, causes low n coupling and low n shelf in growth rates

- Movie starts in the nonlinear phase.

- The **high** n become largest **first** and nonlinearly drive a **low** n **shelf** in growth rates.

- Intermediate n are eventually driven with the largest growth rate as low n become large amplitude.

QuickTime™ and a
decompressor
are needed to see this picture.

With hyperviscosity low n initially dominant, causes high n coupling and high n shelves in growth rates

- Movie starts in the nonlinear phase.

- **low** n become largest **first** and nonlinearly drives a **high** n

- Growth rates plateau at different levels for different range of n’s

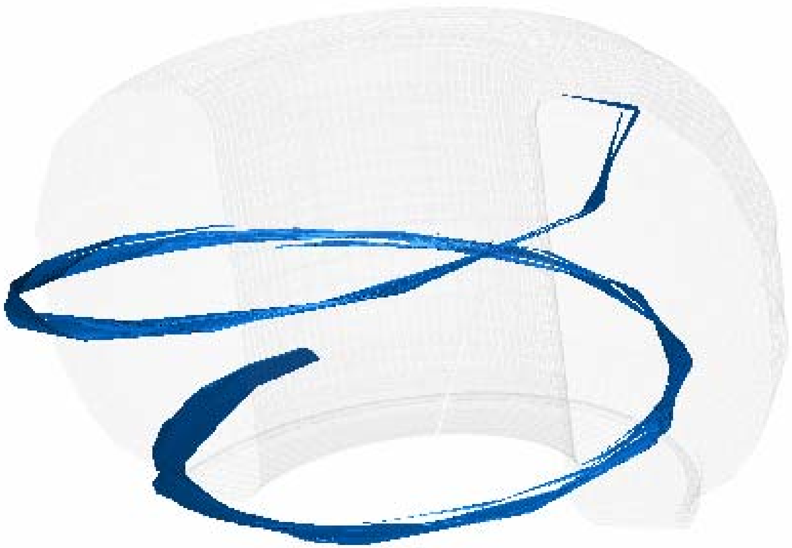
QuickTime™ and a
decompressor
are needed to see this picture.

Basic Agreement with BOUT Simulations and Experiment is Sought in Structure of Nonlinear Mode

A single “finger” of high density propagates out into the vacuum region in a DIII-D simulation of an ELM using BOUT.

Either a single finger or a multi filament structure is observed depending on initial conditions, single n or multiple n unstable (see Snyder’s invited).

It is thought that the basic structure of the ELM should agree between NIMROD and BOUT.



DATA Courtesy of X.Q. Xu (LLNL) and P.B. Snyder (GA)

Summary of Current Status

- ELITE, GATO and NIMROD show similar results
- Growth rates for ideal codes may only match NIMROD in extreme limit of sharp edge diffusivity transition
- Stability boundary in s,α space is being explored and both compared to linear results from ELITE and GATO
- Preliminary nonlinear results show outward propagation of high temp regions
- Coupling to drive large low n modes is expected to be ubiquitous in early nonlinear evolution (will we see a “finger”?)
- Hyperviscosity has been applied to stabilize the highest n and retain toroidal resolution, mimicking two fluid effects

Near Future Directions

- Complete benchmarking with ELITE and GATO, sharper edge transition
- Simulate evolution late into nonlinear phase, possibly to saturation
  - Look for signs of the formation of a “finger”, compare with BOUT
  - Study saturation with marginally unstable equilibria
- Include equilibrium toroidal rotation, compare with ELITE
- Increase toroidal resolution to 44 modes with hyperviscosity effecting n>35.
- Include x-point

Far Future Directions

- Nonlinear energy cascade (R, Z and n), depth, energy loss
- Resistive wall boundary conditions and deposition to the wall
- Direct comparison of code against experimental diagnostics using equilibrium reconstructions from DIII-D
- Full two-fluid modeling