The Center for Extended Magnetohydrodynamic Modeling

(Global Stability of Magnetic Fusion Devices)

S. Jardin—lead PI

June 6, 2008

10:00-10:15am

a SciDAC activity…
Partners with:
TOPS
ITAPS
APDEC
SWIM
CPES

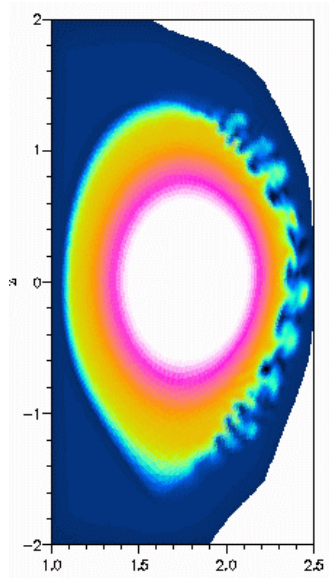
GA: V. Izzo
LANL: A. Glasser
MIT: L. Sugiyama, J. Ramos
NYU: H. Strauss
PPPL: J. Breslau, M. Chance, J. Chen, S. Hudson, W. Park, R. Samtaney
TechX: S. Kruger, S. Ovtchinnikov
U. Colorado: S. Parker
U. Wisconsin: C. Sovinec , D. Schnack
Utah State: J.-Y. Ji, E. Held

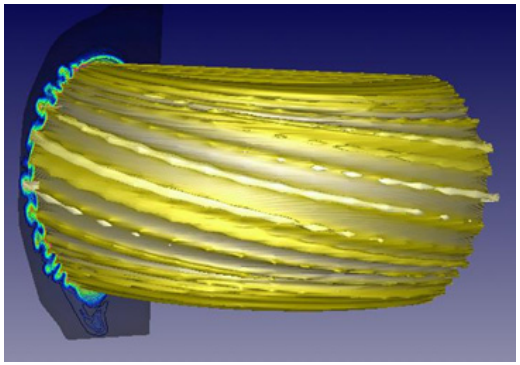
Outline

- Applications
  - ELMs
  - Sawtooth
  - Disruptions
  - 3D Pellet Injection simulations
  - RF stabilization of NTM
  - 2F Equilibrium with flow
  - RMP and Error Field Studies
  - 2F Reconnection with Guide Field
- M3D Code Optimization
- A SciDAC Success Story
  - M3D-C^1 Joint Code Development CEMM/ITAPS/TOPS
- Other CEMM items of interest

Nonlinear MHD ELM simulations show 3 stages of evolution

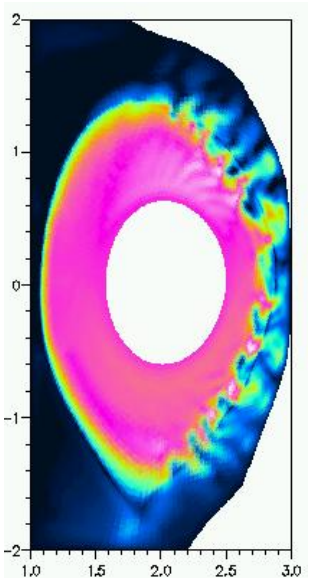
t=77 τ_A
Fast ballooning

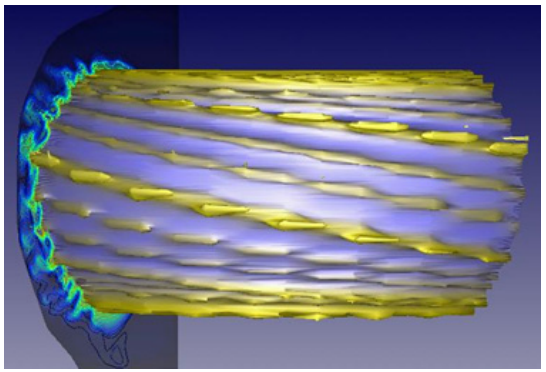




Ballooning perturbation follows magnetic field lines

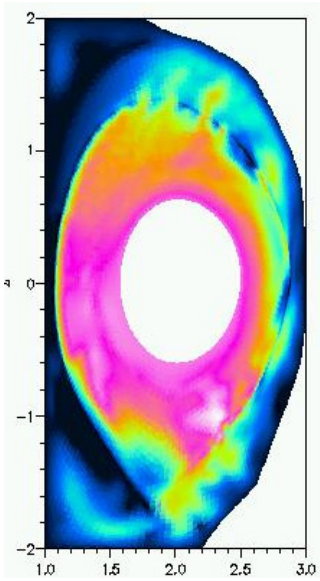
t=99 τ_A
Mixing/dispersal

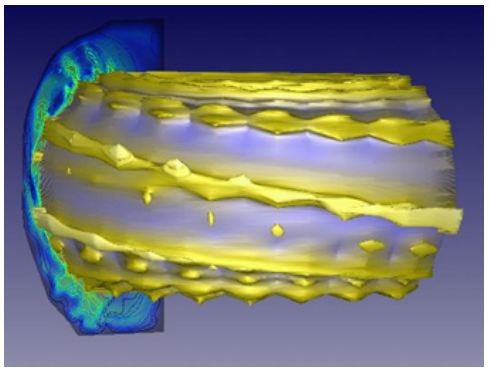




Plasma hits wall. Pert strong on certain field lines.

t=492 τ_A
Long-time Healing



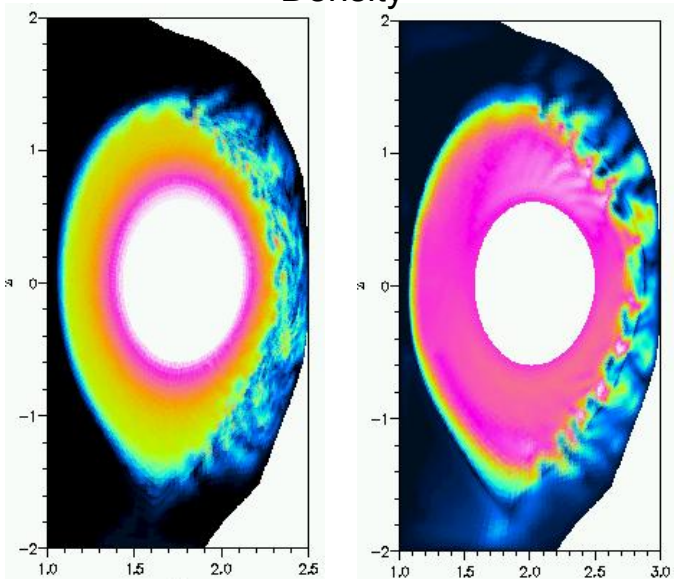


Healing to near original configuration

Sugiyama

Two-fluid Non-linear ELM Simulations

Density



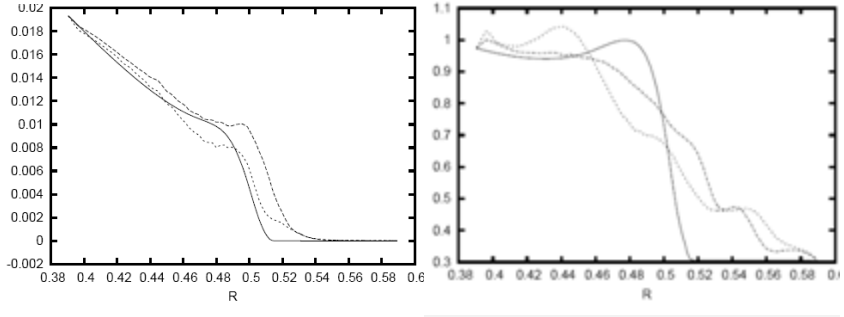
2F: t=90 τ_A MHD: t=99 τ_A

- Two-fluid has weaker linear growth rate, due to ion diamagnetic rotation

- Nonlinear two-fluid ballooning mixes faster in vacuum region, reducing the edge pressure gradient that drives MHD instability

Sugiyama

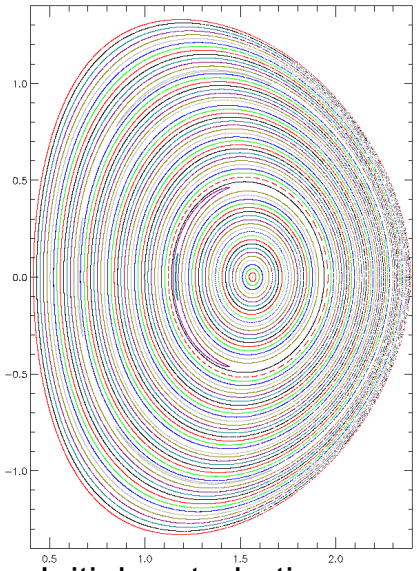
Temperature Density



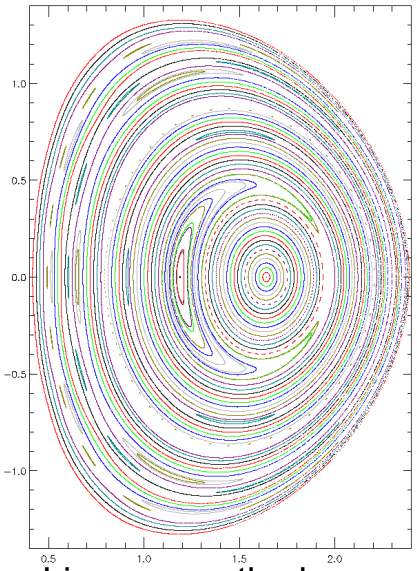
Strauss

- Density and temperature profiles at same times
- Density profile is seen to change more than temperature as a result of ELM crash.
- Now beginning modeling of RMPs
  - Initial results show that when strong rotation is included, RMP has much more effect on density profile than on temperature

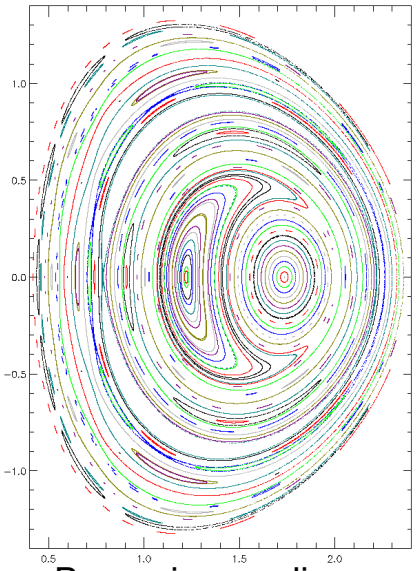
Sawtooth study defined and published results from new analytic equilibrium



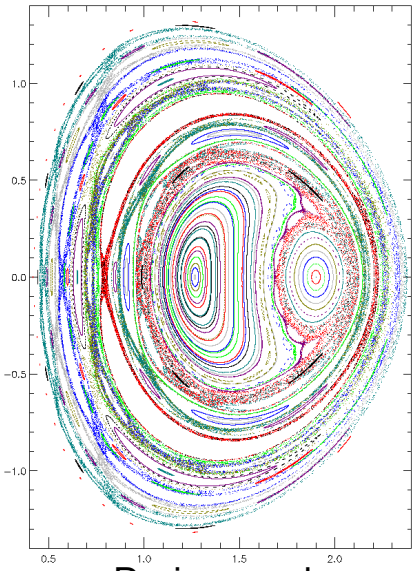
Initial perturbation



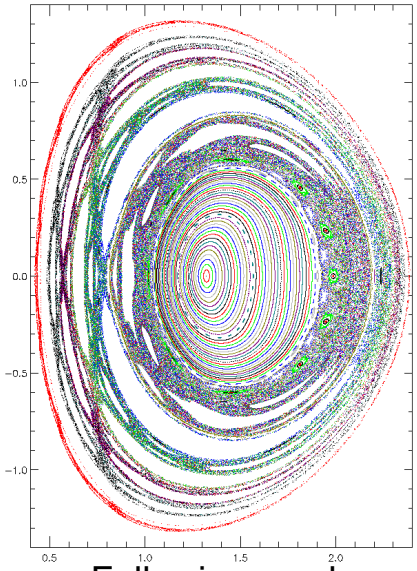
Linear growth phase



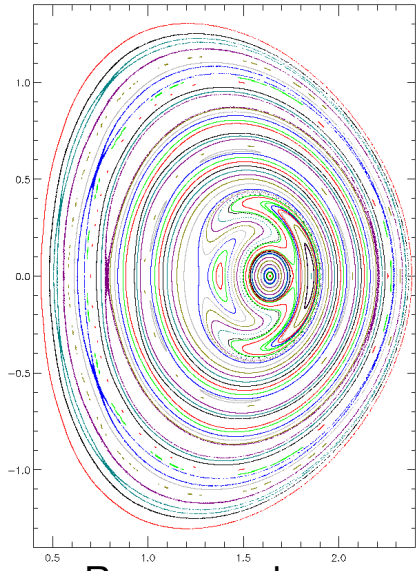
Becoming nonlinear



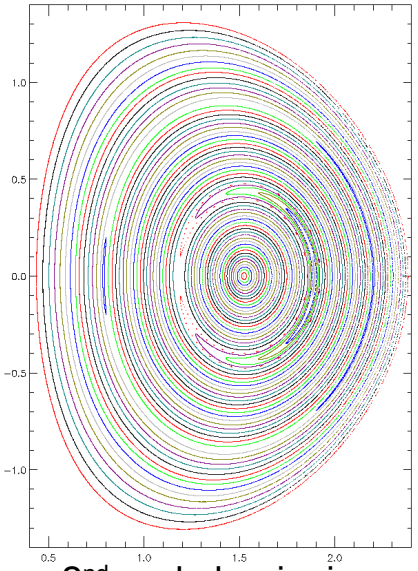
During crash



Following crash



Recovery phase



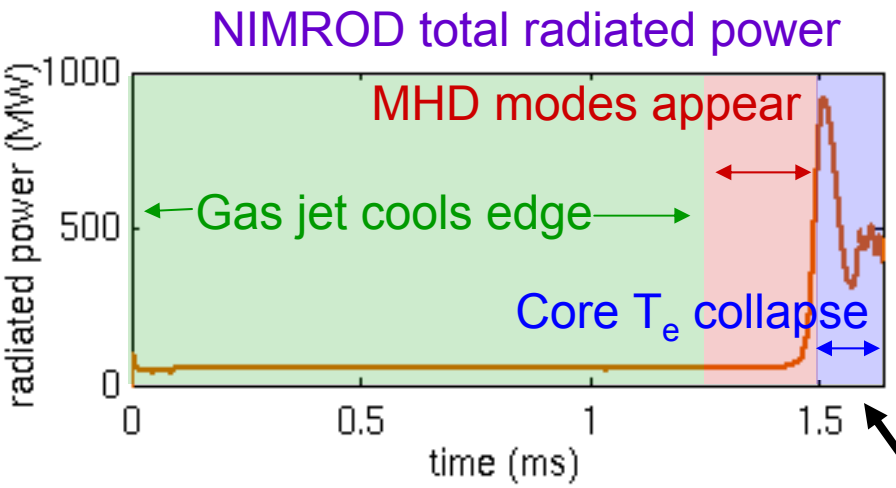
2nd cycle beginning

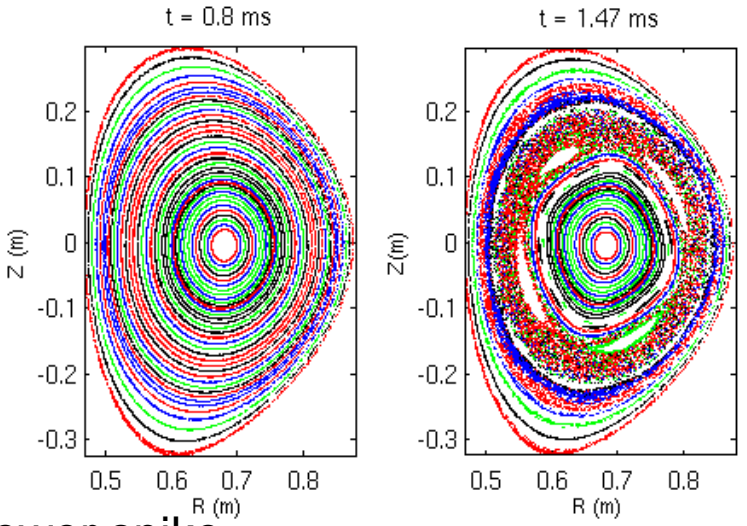
Now extending to:

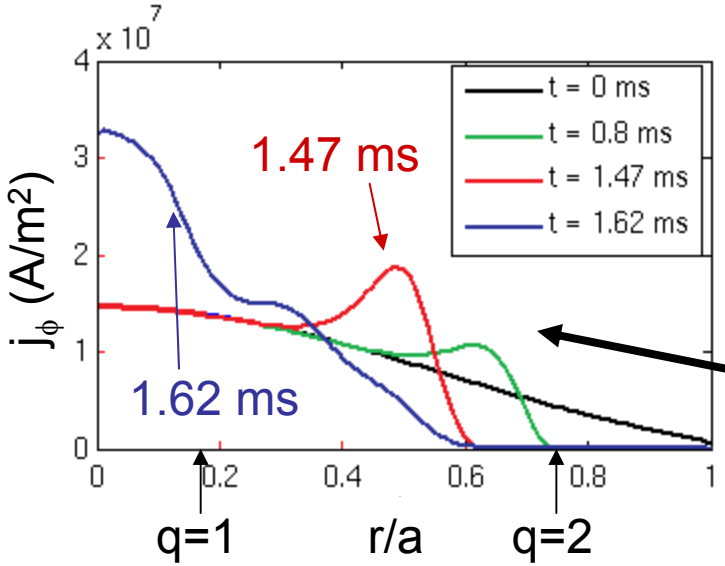
- Two fluid
- Higher S
- Energetic particles
- RF

Breslau

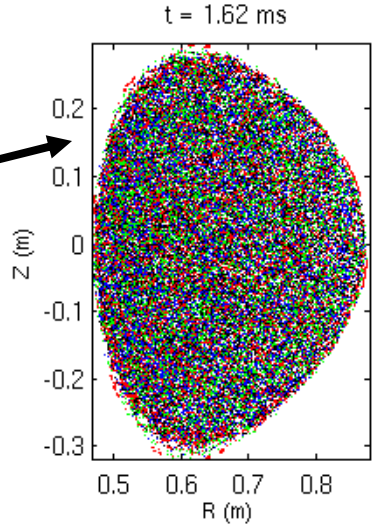
NIMROD simulations of disruption mitigation by massive gas injection (MGI)







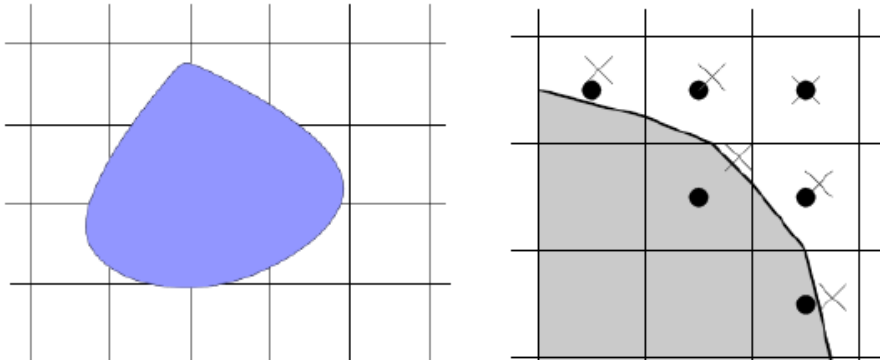
- Radiated power spike accompanies plasma thermal quench
- MHD modes destroy flux surfaces
- Current density is redistributed into the core prior to current quench



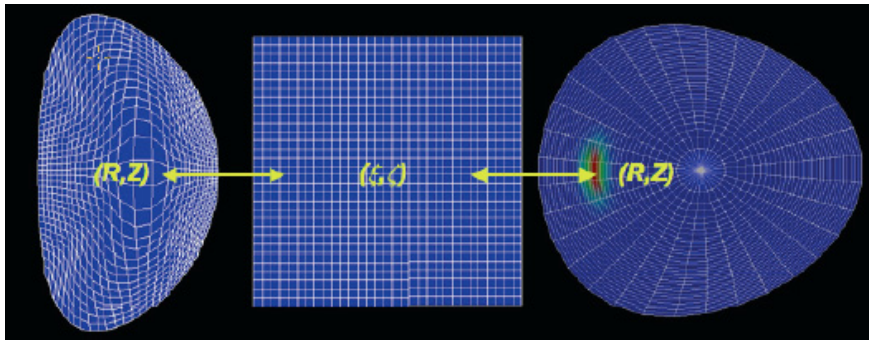
Izzo

3D AMR Studies of Pellet Injection

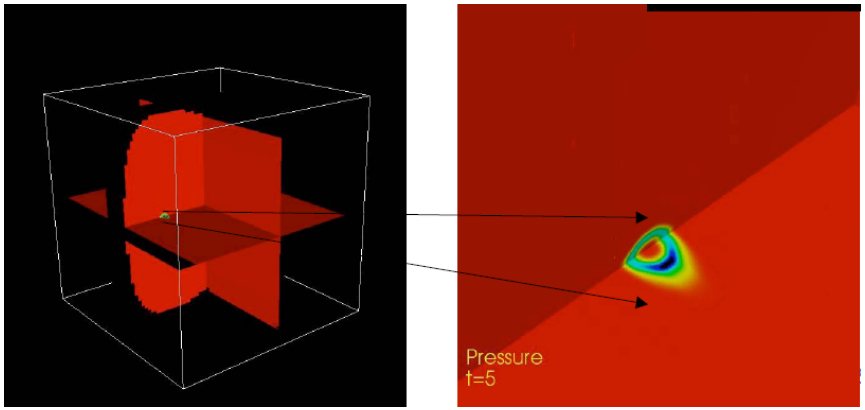
Adopted Level-set approach to calculate computational boundary



Found to be more compatible with AMR than mapped grids



AMR allows modeling of near-pellet features

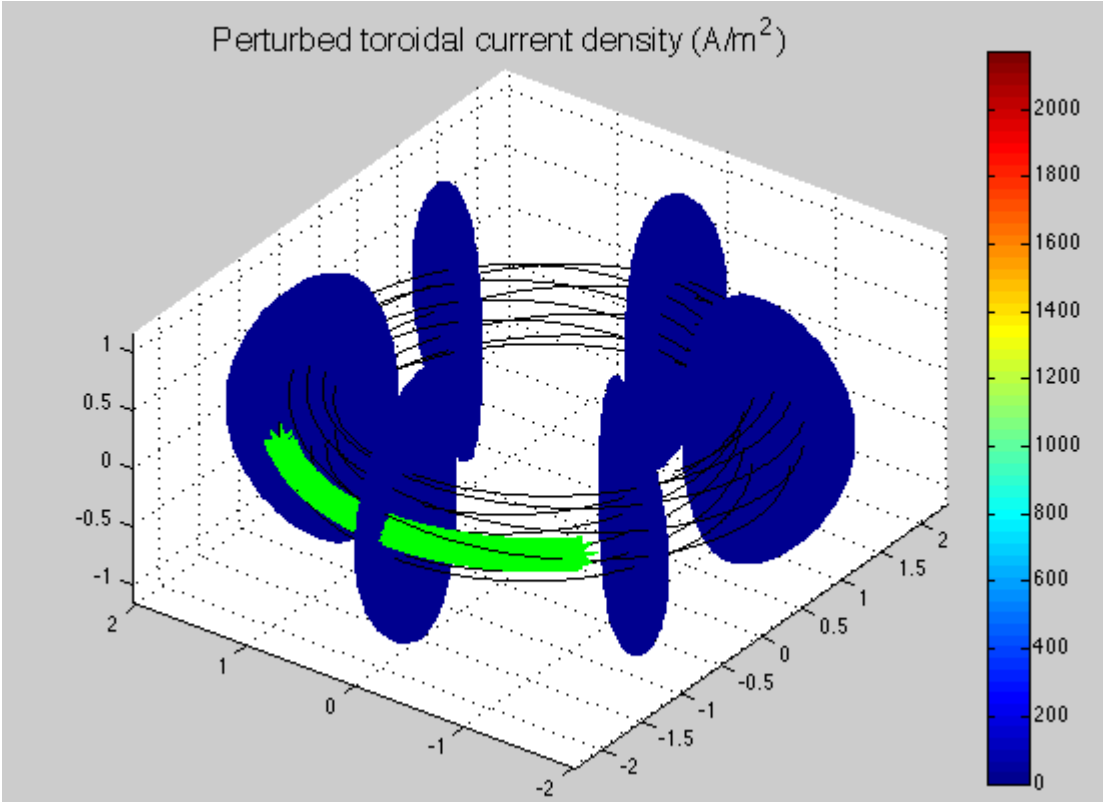


Electron Heat flux by Parks semi-analytic model

$$-\nabla \cdot q_e = \frac{q_\infty n}{\tau_\infty}\left[g(u_+) + g(u_-)\right]$$

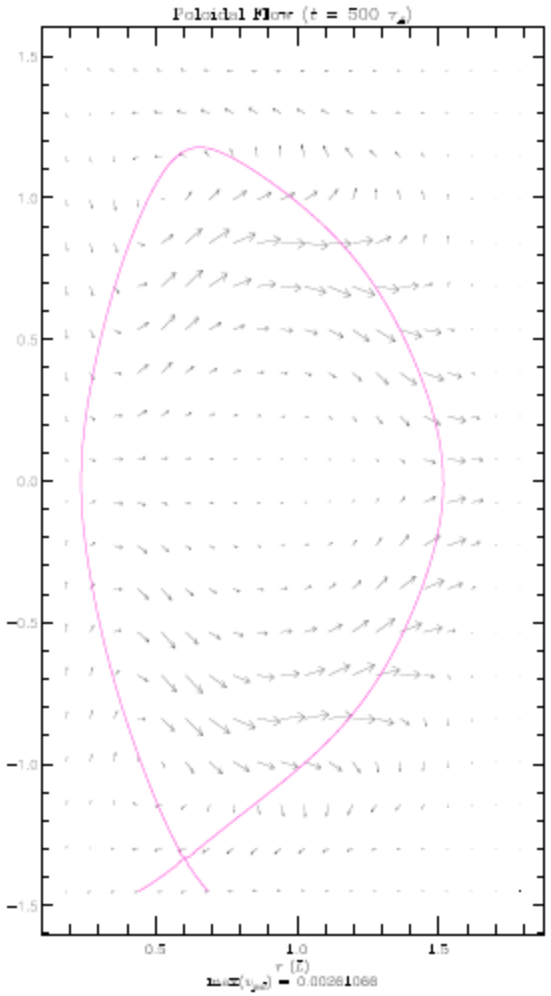
Samtaney

Work has begun on the coupling of RF to NIMROD to model ECH stabilization of NTM (with SWIM)

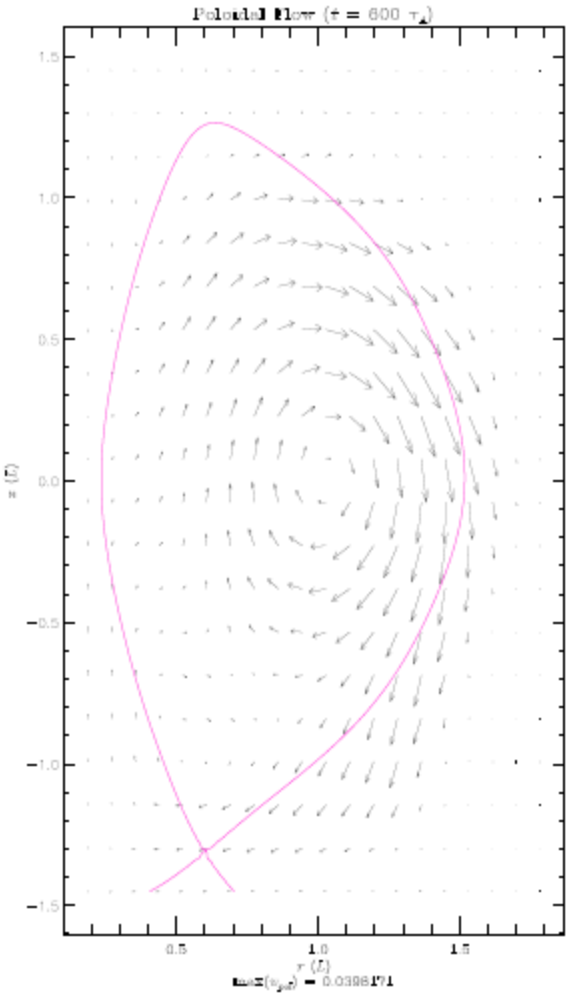


Jenkins

2F equilibrium obtained by solving 2D 2F equations to steady state in toroidal geometry



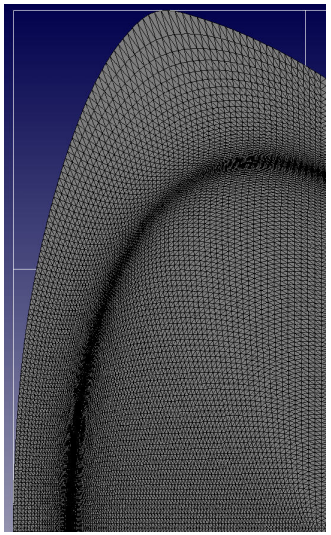
Without gyroviscosity



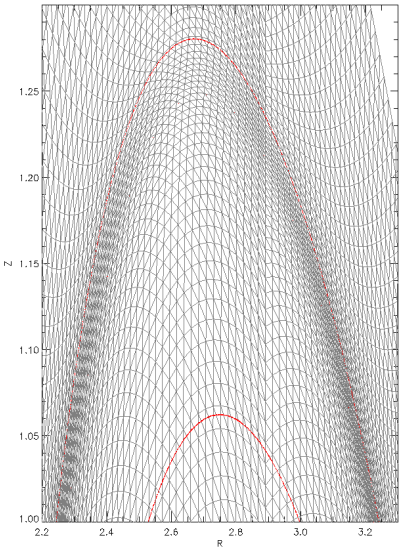
With gyroviscosity

Ferraro

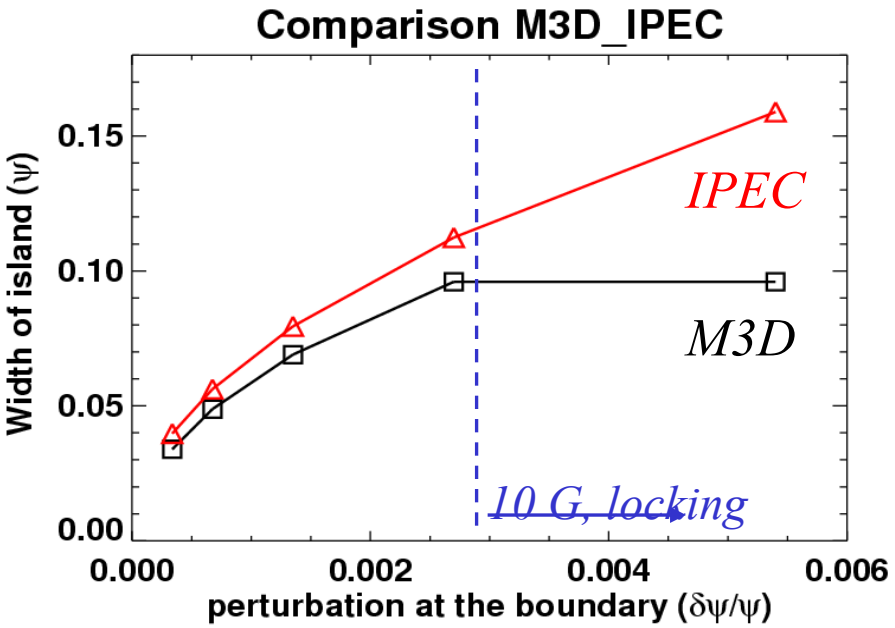
Error field study shows good agreement with theory

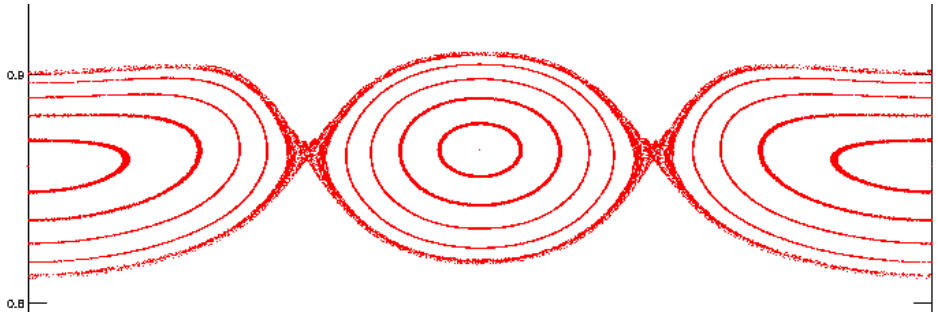


Packed mesh



Mesh closeup

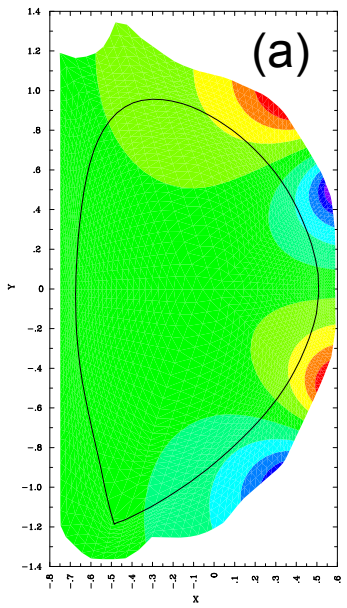




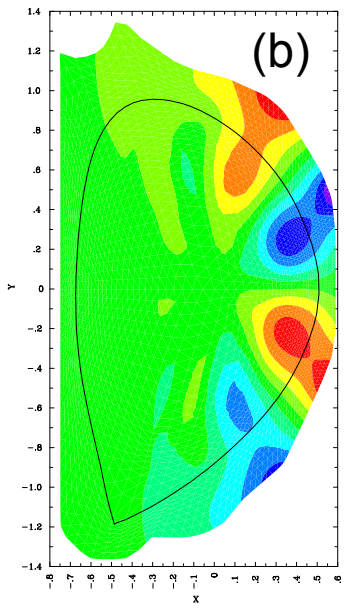
Now being extended to:

- dynamic studies
- dependence on S, 2F effects
- effects of flow
- experimental comparisons

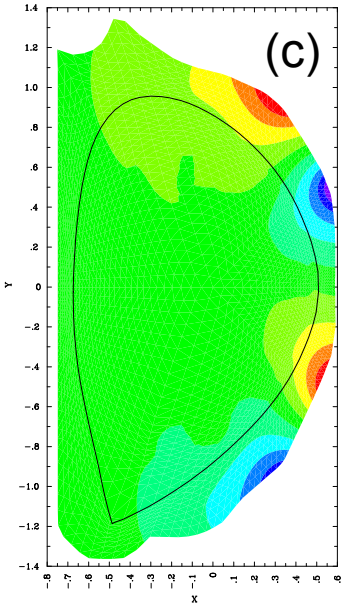
Preliminary RMP studies show importance of plasma rotation



Vacuum RMP



No Rotation

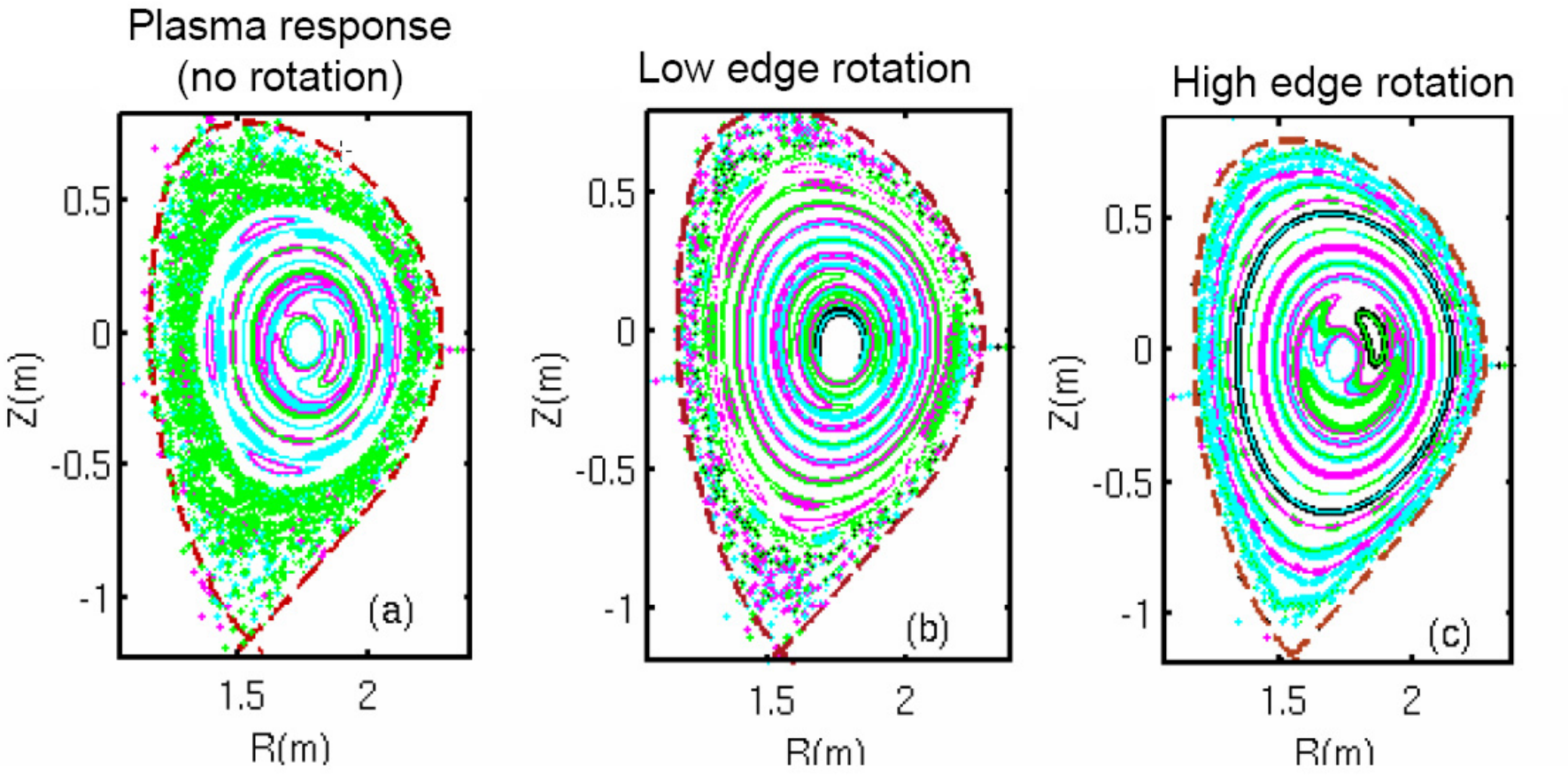


With Rotation

Shown is the n=3 component of the poloidal flux. The RMP appears to couple to a resistive mode. Magnetic perturbations exceed the vacuum RMP. Rotation suppresses the mode as well as screening the RMP. Comparisons made at t=53 (Alfven times)

Strauss

NIMROD Study also shows that plasma rotation strongly suppresses effects of RMP

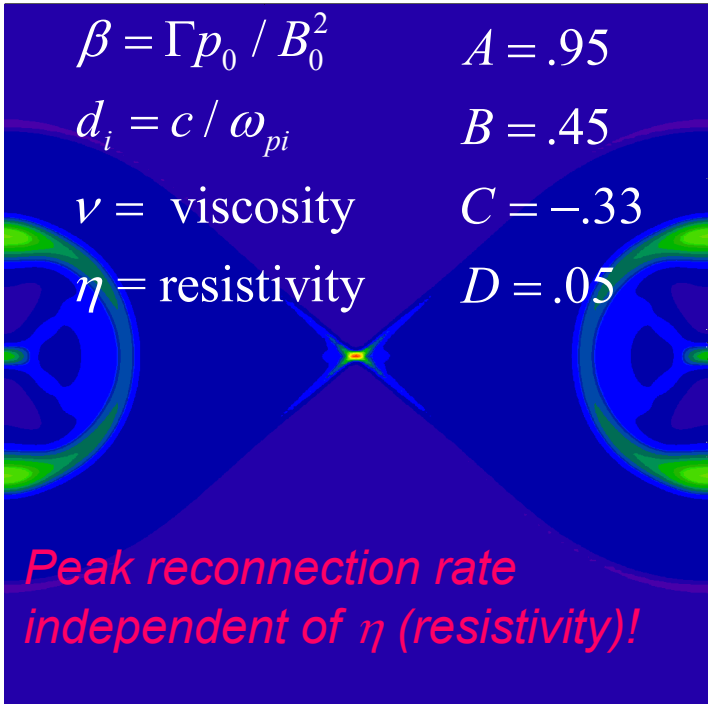


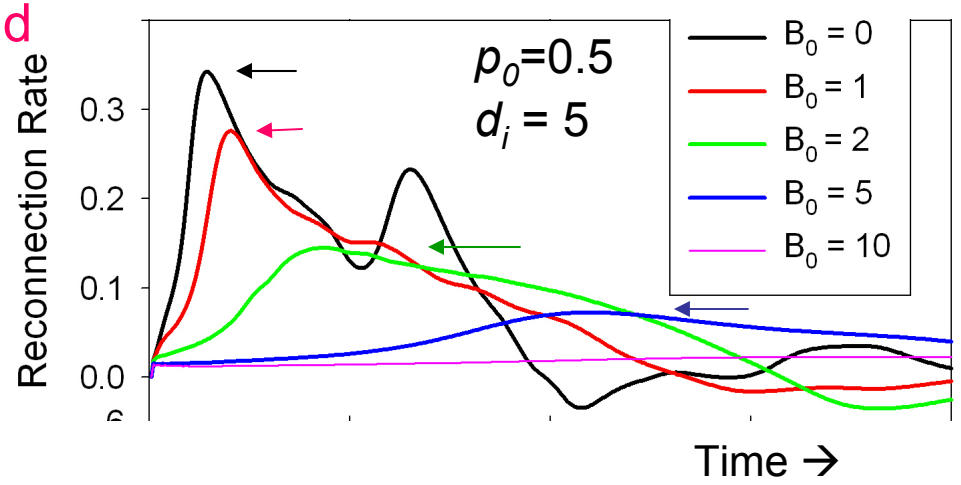
Izzo

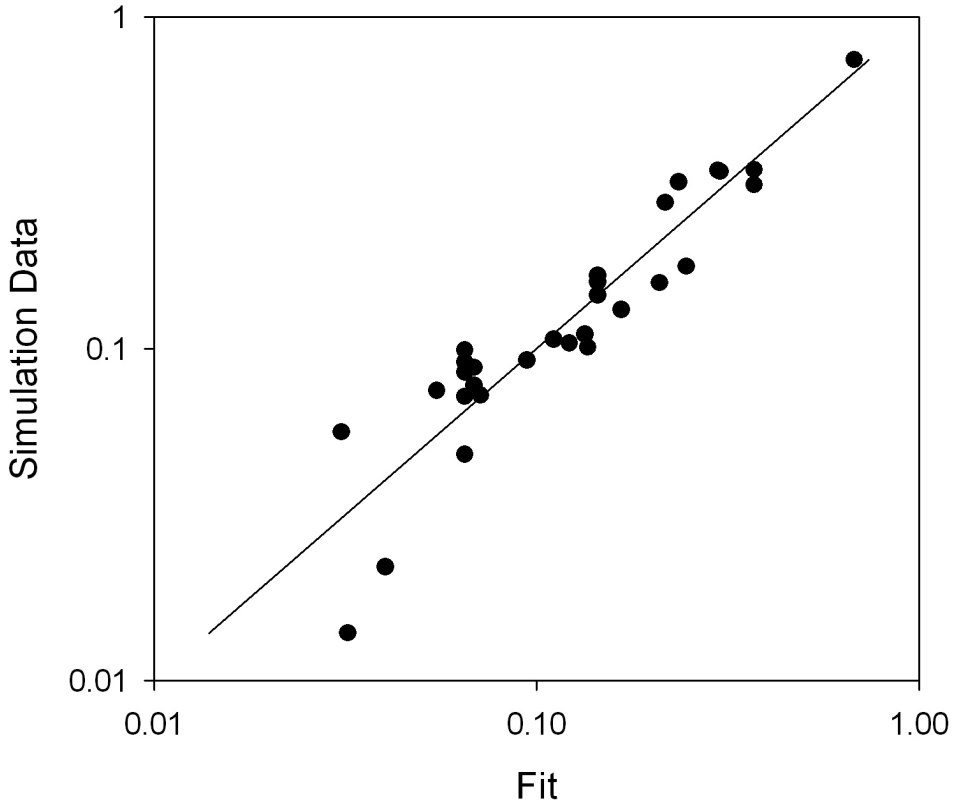
2F GEM reconnection with Guide Field

We performed a regression analysis to find the dependence of the peak reconnection rate.

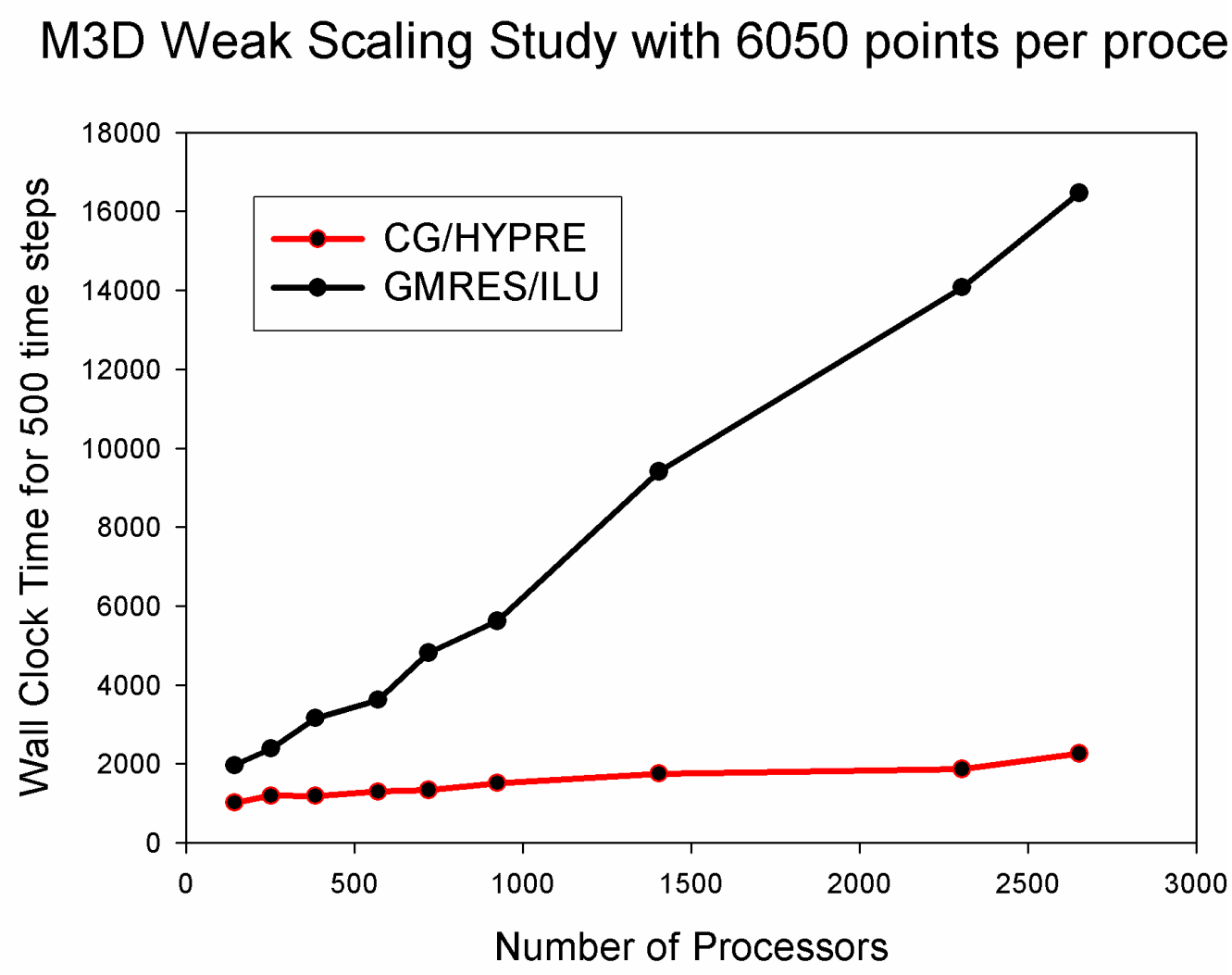
$$\dot{\psi}_{MAX} = C\left[\frac{\beta}{1+\beta}\right]^{A} d_i^{B} \nu^{C} \eta^{D}$$







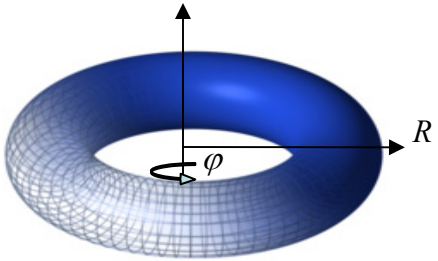
M3D Scaling dramatically improved with availability of HYPRE via PETSc



Chen

Joint Development of M3D-C^1: A SciDAC Success Story

CEMM: Equations and Algorithm



$$\mathbf{A} = R^2\nabla\varphi\times\nabla f + \psi\nabla\varphi - F_0\ln R\hat{Z}$$

$$\mathbf{V} = R^2\nabla U\times\nabla\varphi + \omega R^2\nabla\varphi + R^{-2}\nabla_\perp\chi$$

$$\left\{\rho-\theta^2(\delta t)^2 L\right\}\mathbf{V}^{n+1} = \left\{\rho-\theta^2(\delta t)^2 L\right\}\mathbf{V}^{n} + \delta t\left\{-\nabla p+\frac{1}{\mu_0}(\nabla\times\mathbf{B})\times\mathbf{B}\right\}^{n+1/2}$$

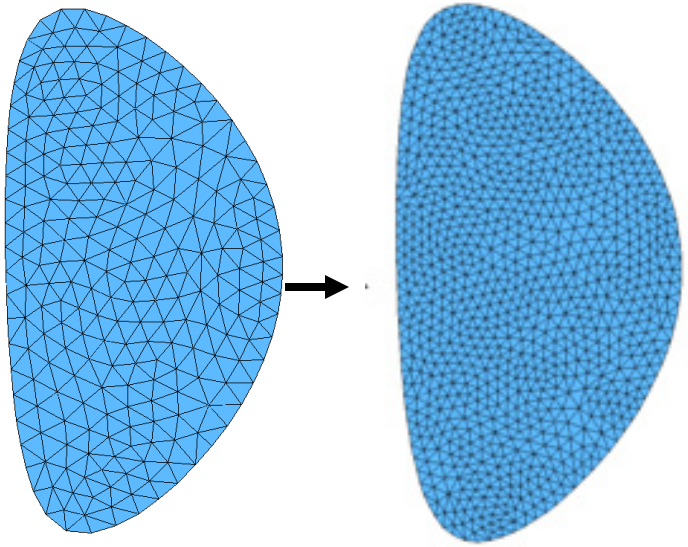
$$L\{\mathbf{V}\} = \frac{1}{\mu_0}\left\{\nabla\times\left[\nabla\times(\mathbf{V}\times\mathbf{B})\right]\right\}\times\mathbf{B} + \frac{1}{\mu_0}(\nabla\times\mathbf{B})\times\left[\nabla\times(\mathbf{V}\times\mathbf{B})\right] + \nabla(\mathbf{V}\bullet\nabla p+\gamma p\nabla\bullet\mathbf{V})$$

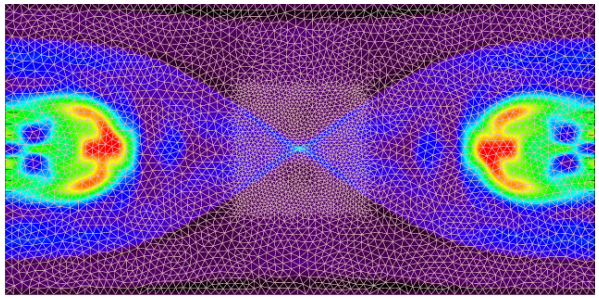
$$\iint d^2R\,\nabla_\perp\nu_i\times\nabla\varphi\bullet R^2 L\{\mathbf{V}\}$$

$$\iint d^2R\,\nu_i R^2\nabla\varphi\bullet L\{\mathbf{V}\}$$

$$\iint d^2R\,\nabla_\perp\nu_i\bullet R^{-2} L\{\mathbf{V}\}$$

ITAPS: Adaptive Meshing and Interface Routines





TOPS: Linear Equation Solvers

$$\begin{bmatrix} X & & & X & & & \\ & X & & & & X & \\ & & X & & X & & \\ & X & & X & & & \\ & & & & X & & \\ & & X & & & X & \\ & & & & & & X \\ & & & & & & X \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \\ \\ \\ \\ x_N \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ \\ \\ \\ \\ b_N \end{bmatrix}$$

PETSc

SuperLU_dist

Other

- Well attended CEMM meetings at APS and Sherwood
- CEMM co-sponsoring a meeting in Aug08 on RMP at GA
- Made a CEMM presentation at ITPA meeting in Jan08
- Progress in NIMROD parallel heat conduction (MFEM)
- Progress in RWM studies of ITER…benchmark with MARS
- CEMM IAEA paper on two-fluid effects accepted
  - Linear 2F tearing and comparison to extended theory
  - Non-linear 2F reconnection with guide field
  - 2F tokamak equilibrium stationary on all time scales
  - 2F effects on sawtooth and heat conduction in chaotic magnetic fields
- Active involvement with SWIM and CPES