Innovative Confinement Concepts (ICC)

PPPL Theory Department Review

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Presented by

S. C. Jardin

FESAC 5 Year goals: *Make preliminary determination of the attractiveness of the Spherical Torus, Reversed-Field Pinch, Stellarator. Resolve key issues for a broad spectrum of configurations.*

PPPL theory has an active program in ICC

- α Intense activity during the time of the S-1 spheromak (early to mid 1980s)

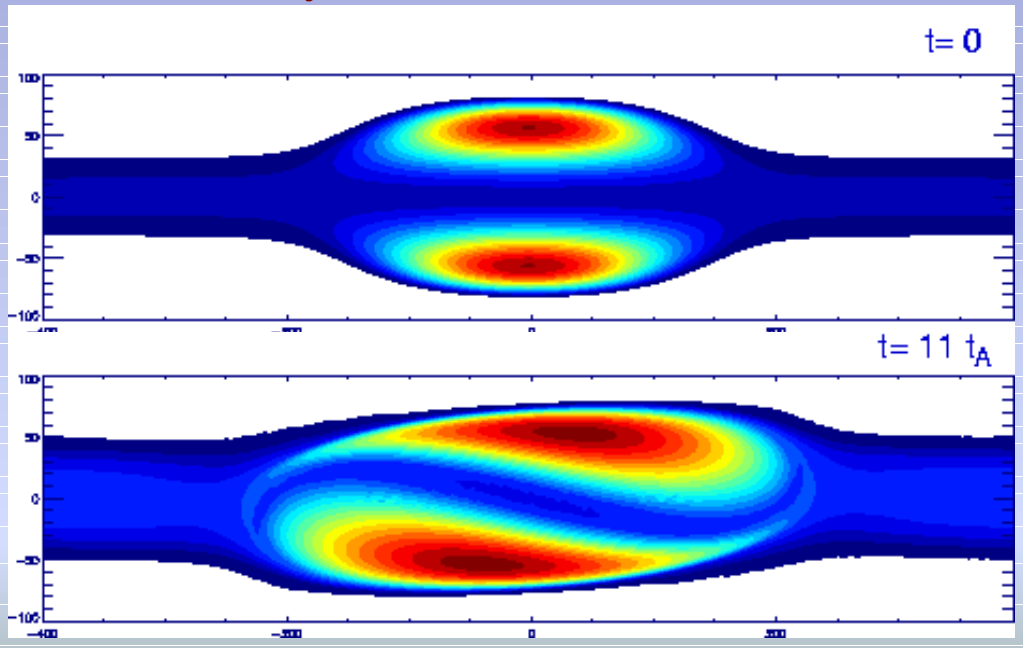
Present activity is primarily in the following areas:

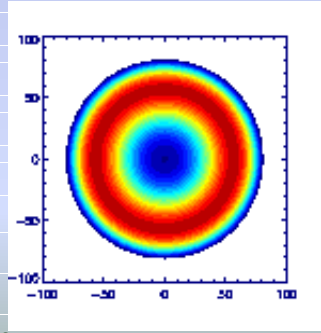
- Stellarators
- Spherical torus
- Inertial Fusion
- Feedback Stabilized Tokamaks
- Stability of Field Reversed Configuration
- Merging Spheromaks
- Liquid Lithium walled tokamaks
- 2D Modeling of MHD thrusters

Stability of the Field Reversed Configuration

- theoretically – in MHD description, all configurations unstable to tilt mode
- experimentally – these are made and they persist for 100's of Alfven times

⇒ we are in the 3rd year of a 3 year ICC theory contract aimed at resolving this. FRC theory consortium members include U. Washington and G.A.





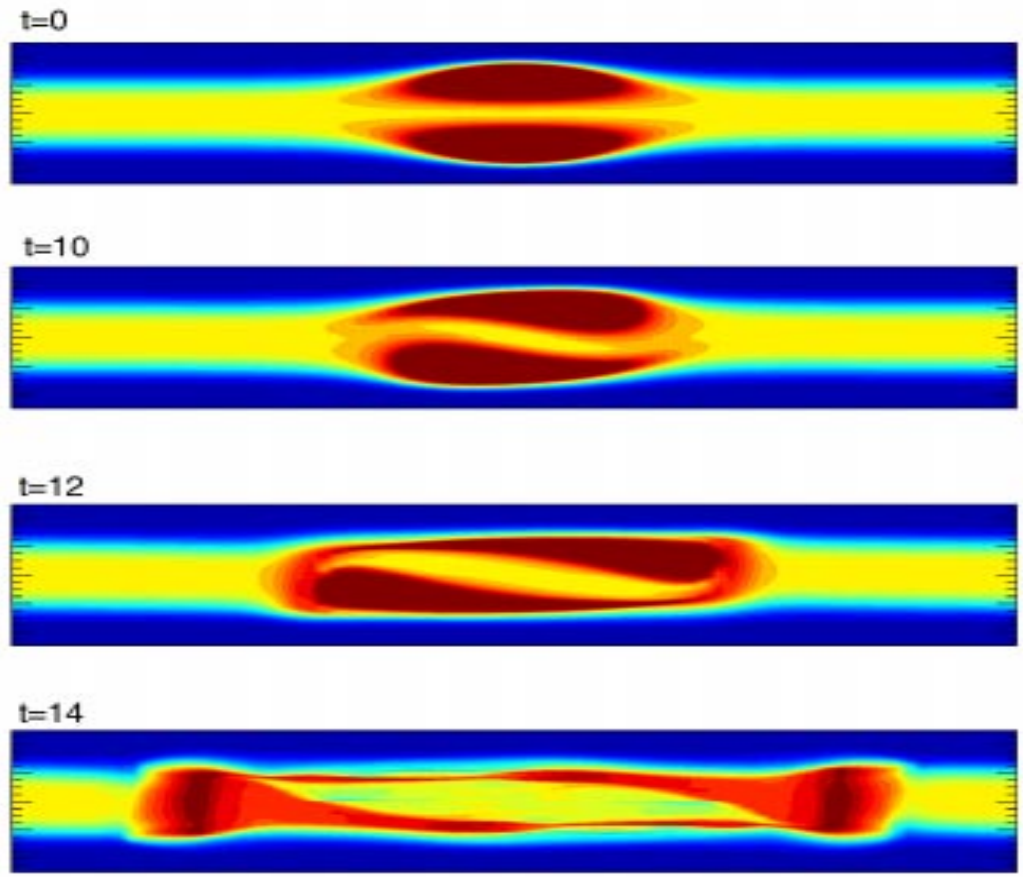
E. Belova et al, "Numerical study of tilt stability of prolate FRC", submitted to PoP, 2000

3D resistive MHD simulations have been performed with a wide range of profiles

- including rigid and sheared rotation

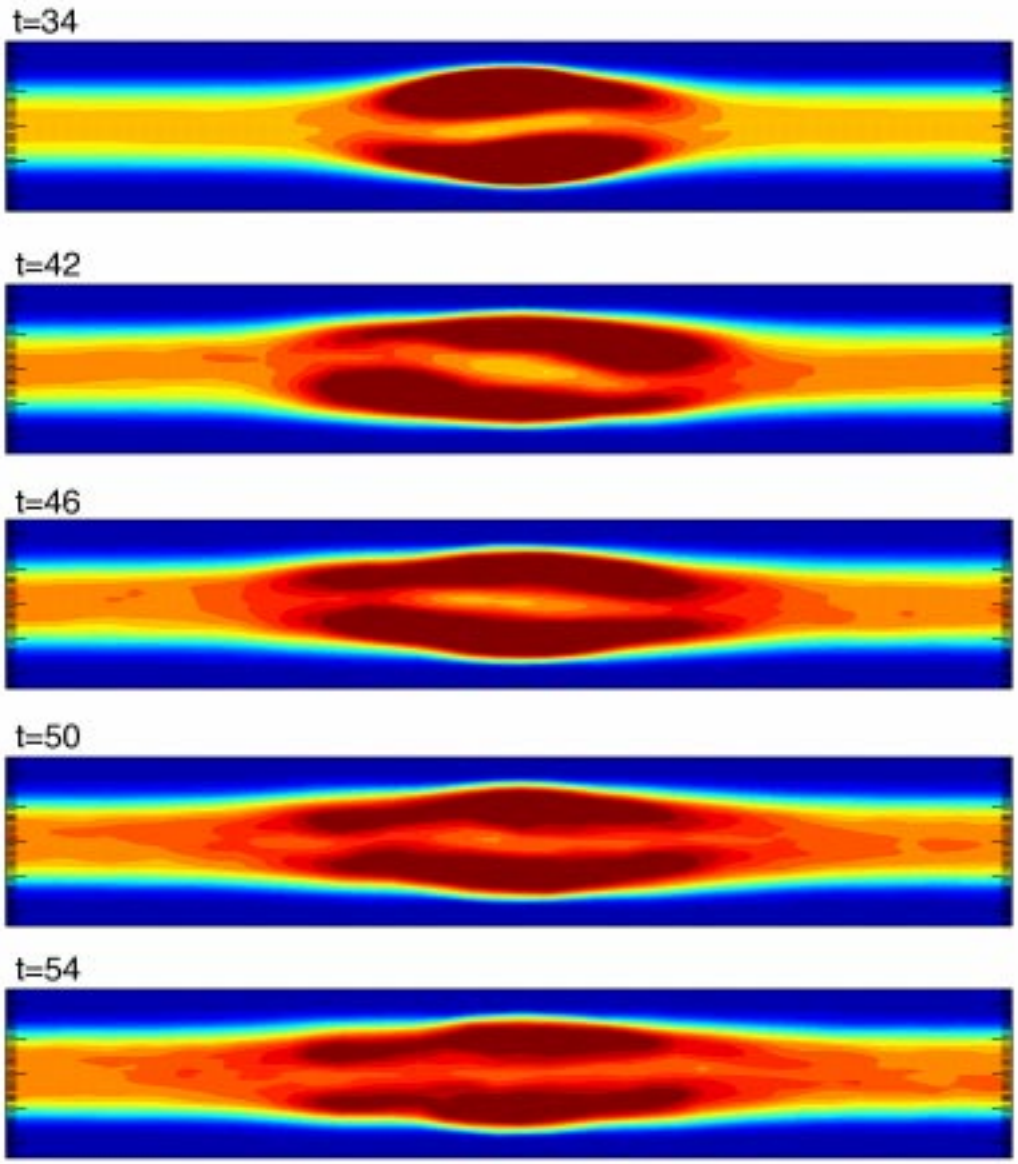
- we have established contact with previous work and substantially extended it

- Configuration always becomes unstable and destroys in ~ 10 τ_A



Fully kinetic-ion simulation shows much different behavior

- Simulation starts out with linear growing instability with reduced growth rate
- However, instability saturates nonlinearly!
- Saturated state persists with field reversal for >100 Alfven times
- Shows remarkable agreement with experimental data in n=0 and n=1 diagnostic signatures
- Tuszewski called special attention to this at ICC 2000



Why does instability saturate in FRC for kinetic description ?

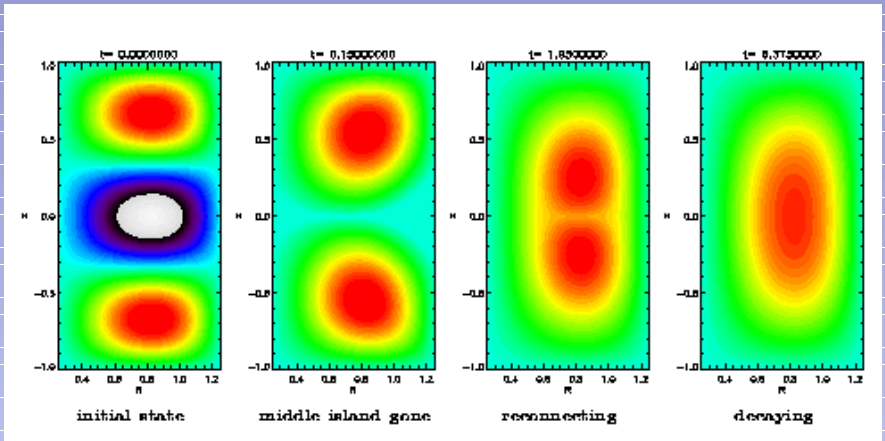
- We have verified that instability saturates only when ion Larmor radius is comparable to the device radius:
  - **ρ_L / R ~ 2 => saturates**
  - **ρ_L / R ~ 8 => does not saturate**

- During nonlinear development:
  - elongation increases
  - distribution function deviates from Maxwellian
  - particles satisfying resonant condition $\omega - n\Omega = \pm\Omega_\beta$ are especially affected

Future Directions:

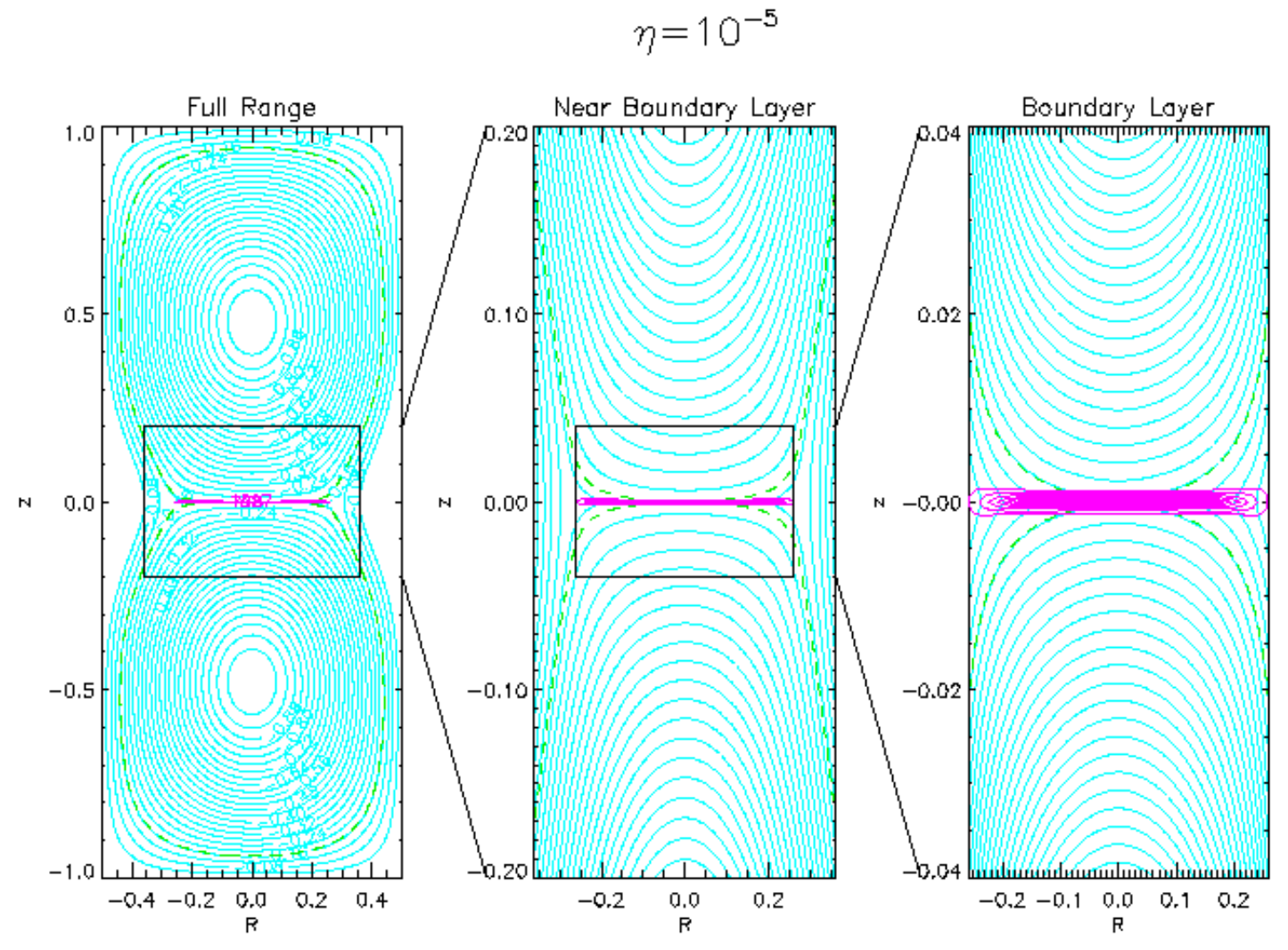
- We have applied for a follow-on contract to apply this to an experimental design
- Neutral beam or Ion-beam injection may be able to maintain reversal
- Discussions and possible collaboration with Cornell Ion Beam group

2D Magnetic Reconnection in Merging Spheromaks



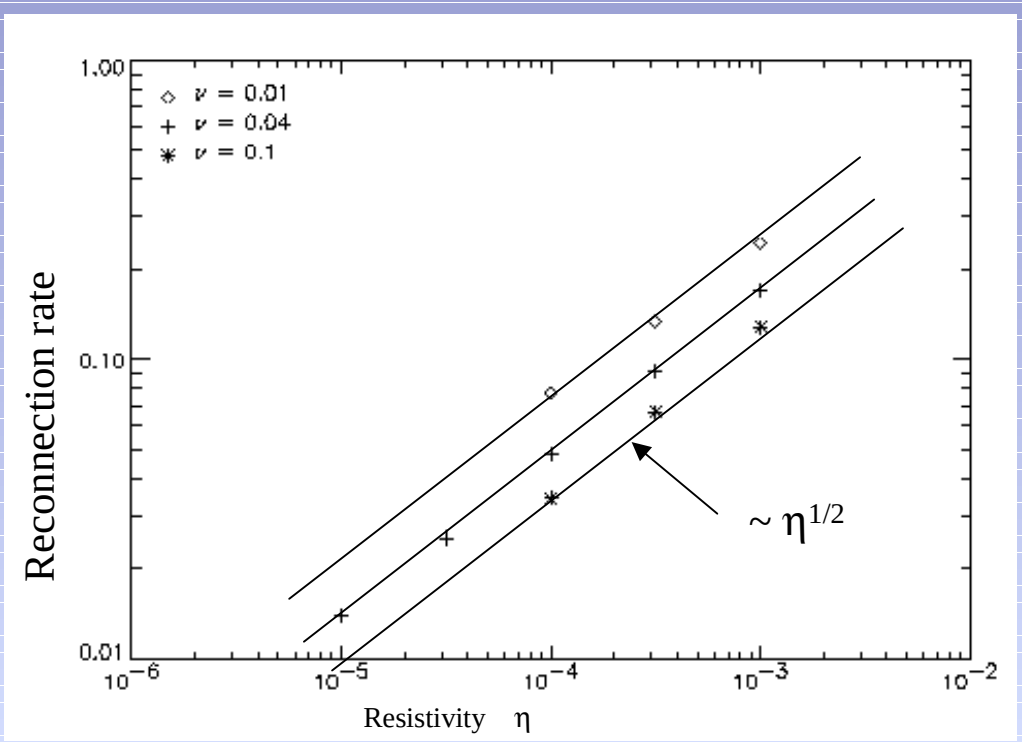
- 2 co-helicity spheromak configurations initially separated by central high-resistivity spheromak
- As central structure decays, the 2 spheromaks merge
- Provides a simple configuration for understanding magnetic reconnection…similar to MRX experiment
- Could provide design basis for merging spheromak formation of FRC experiment (SPRINT)

J. Breslau



- Variable resolution grid allows resolution of disparate space scales.
- note: cyan: flux purple: current

Standard Sweet-Parker scalings obtained for classical resistivity, single-fluid MHD



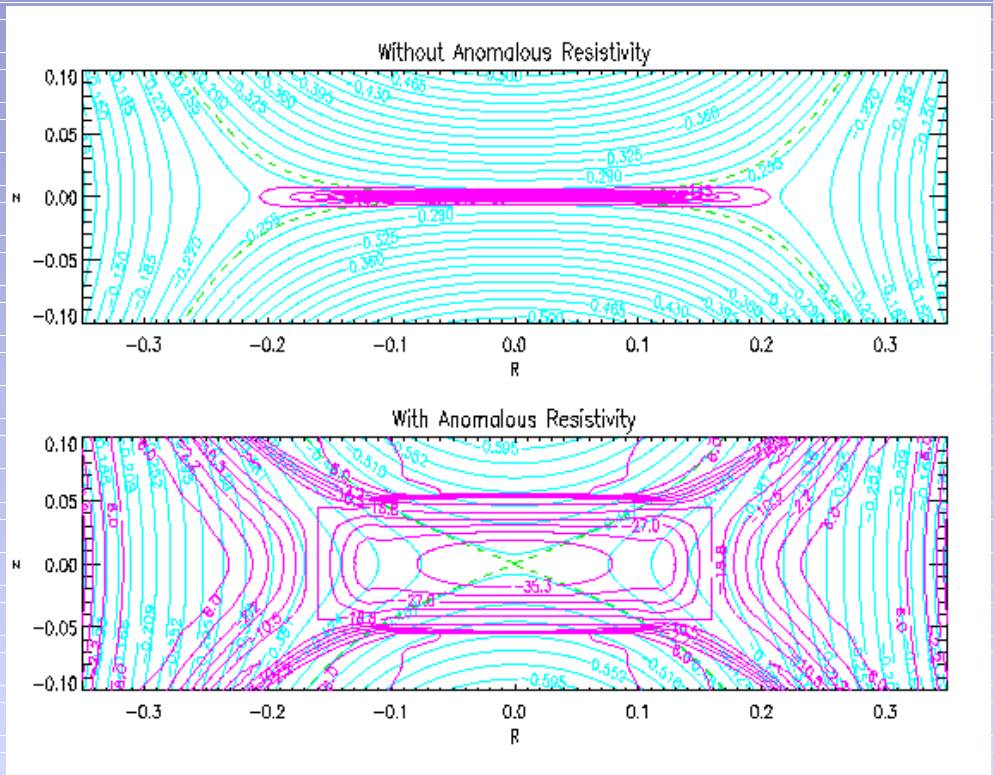
However, it is found that magnetic reconnection rate can increase dramatically ($\times$ 20 or more) due to either of 2 effects:

I. Anomalous resistivity

resistivity is anomalous only in the high current density regions (where kinetic theory predicts instability)

η_{ANOM} only when $(v_d/v_{ti}) > 1$

Reconnection region broadens and reconnection becomes more Petschek-like with greatly increased mass outflow



However, it is found that magnetic reconnection rate can increase dramatically ($\times$ 20 or more) due to either of 2 effects:

II. If the Hall-term is included in the generalized Ohm's law

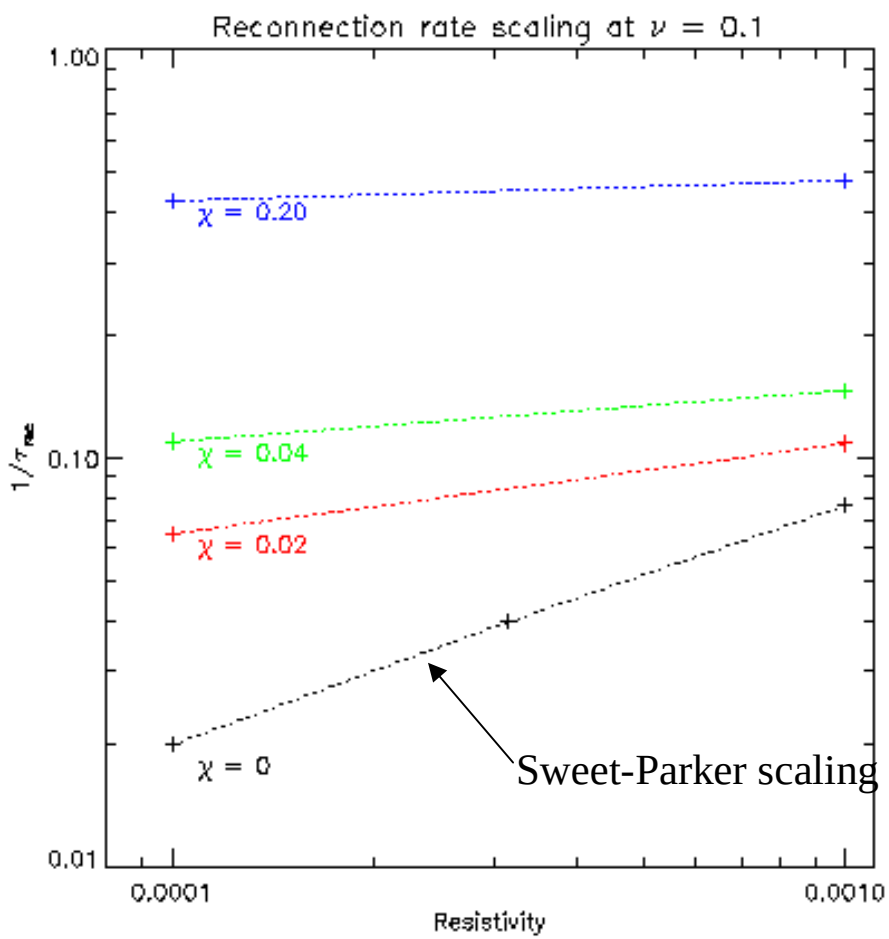
ie: $\eta J \rightarrow \eta J + (J \times B - \nabla p)/ne$

$= \eta J + \chi (J \times B - \nabla p)$

here $\chi = 1 / \Omega \tau_A$

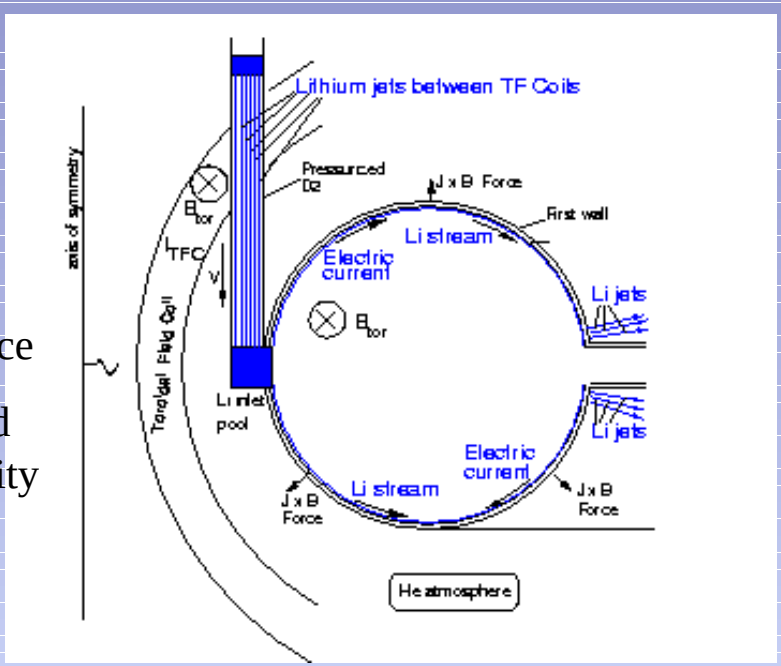
Future Directions:

1. Benchmark with M3D
2. Extend to 3D
3. Reproduce with fully kinetic ions



Theory of the Liquid Lithium wall tokamak

- electric current in lithium keeps lithium against wall and propels it across field
- preliminary stability analysis of lithium itself indicates good stability properties
- builds on TFTR experience of great increase in confinement for Lithium surface
- temperature and current profile predicted to be very broad…good for internal stability
- lithium itself provides stability against external kink mode



Future Directions:

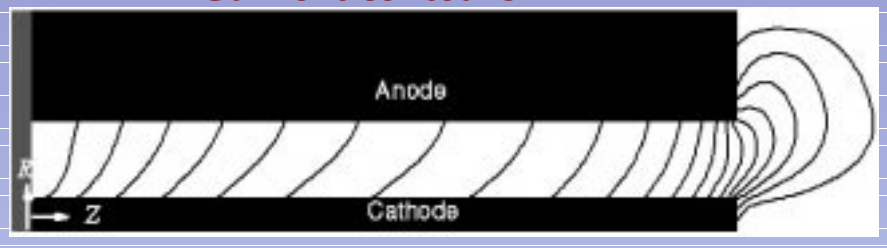
- CDX-U experiments this starting this FY
- Contracts with ALPS/APEX on reactor implications
- Possible new experimental proposal

Zakharov

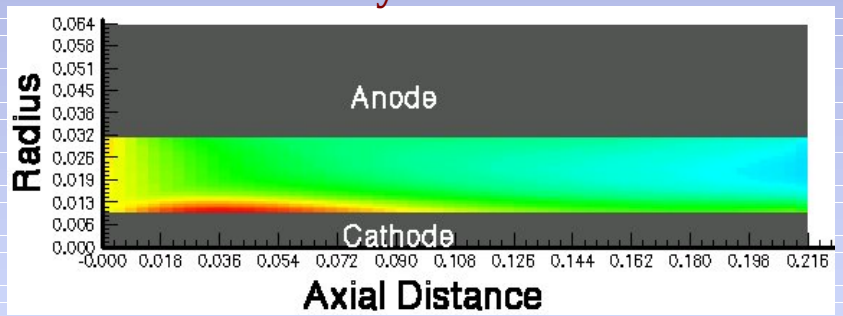
MHD Hall-Thruster Simulations

- We are collaborating with Prof. Choueiri in the PU Mech. & Aerospace Engr. Dept on developing 2D MHD models of his NASA funded Thruster experiments
- Lots of similarity between this and the CHI modeling for NSTX
- This is expected to lead to a much large modeling contract with NASA

Current contours



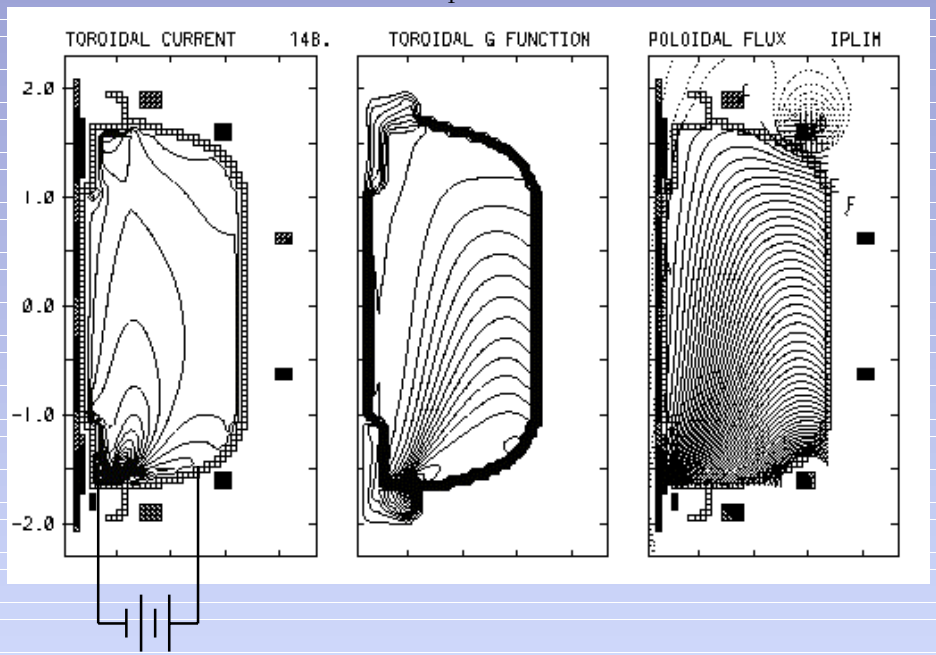
density contours



K. Sankaran

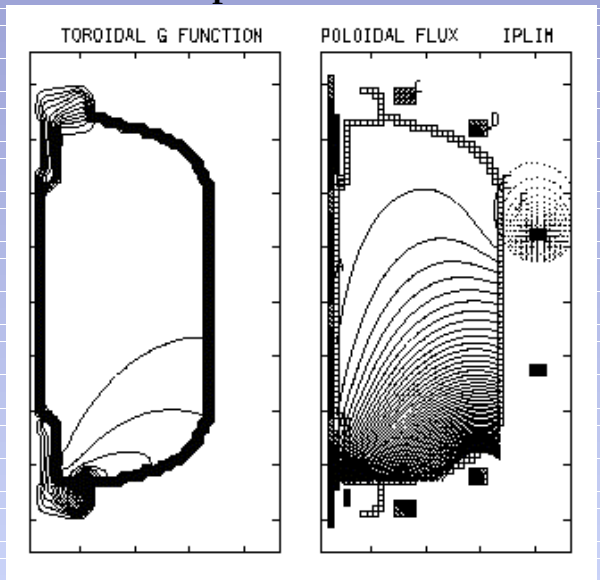
NSTX Shot 102080 CHI Experiment

RB_T

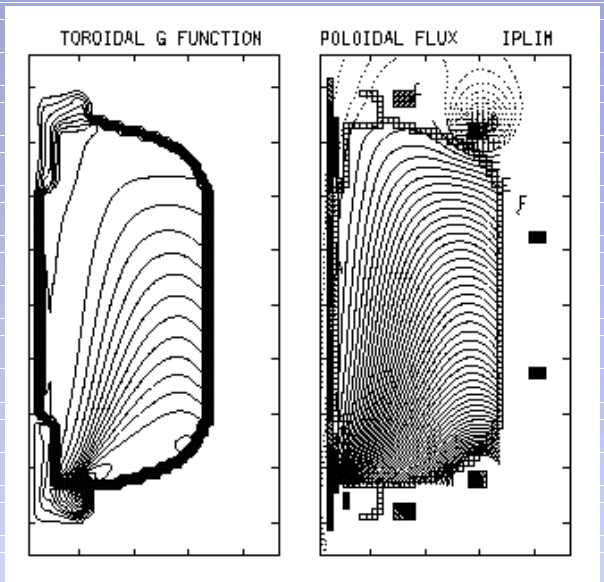


NSTX Shot 102080 CHI Experiment

I_P = 20 kA

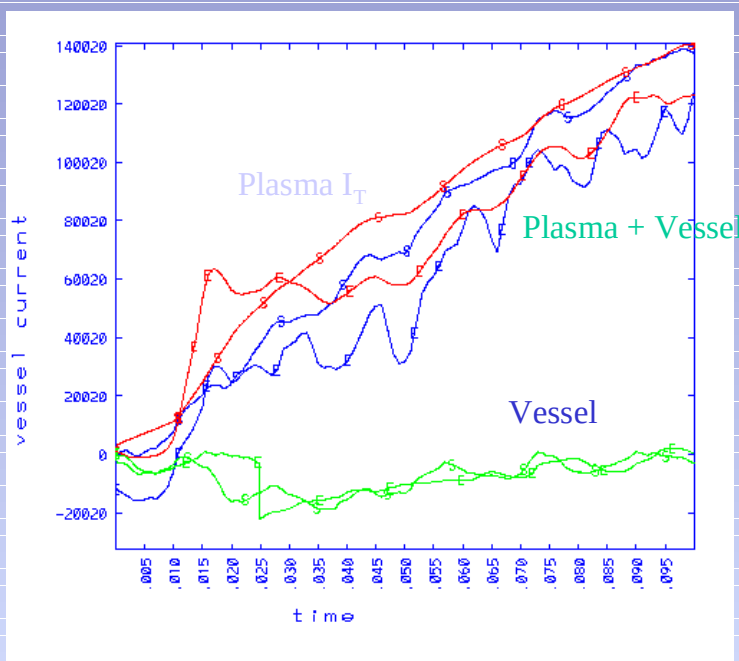


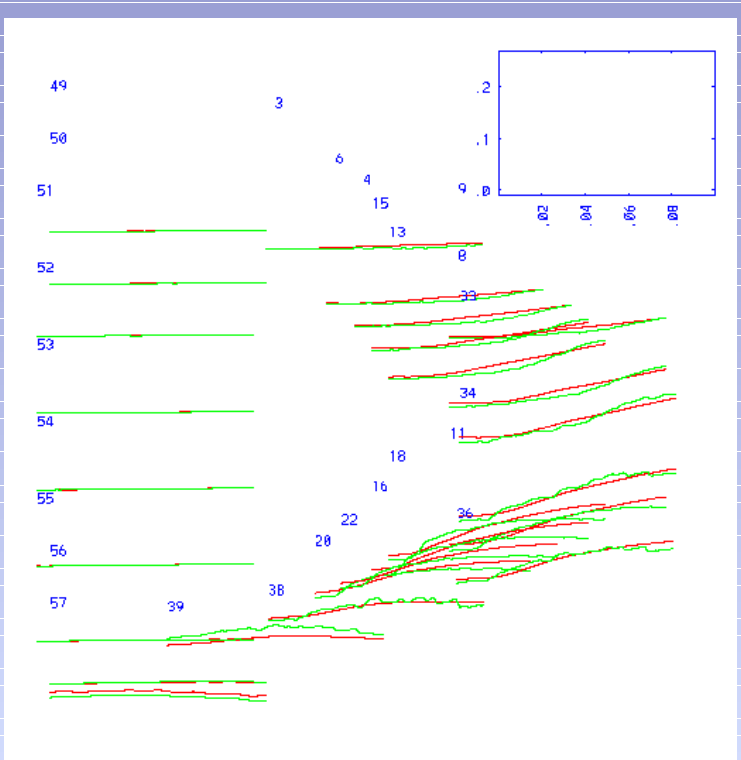
I_P = 120 kA



Flux surfaces are greatly modified by the CHI currents, but TSC doesn't predict any closed field lines

NSTX Shot 102080 CHI Experiment





TSC currents and fluxes agree well with experimental data

Summary

- PPPL theory has been involved in the ICC area for > 20 years
- Lots of excitement in a number of different concept areas
  - Stellarators
  - Spherical torus
  - Inertial Fusion
  - Feedback Stabilized Tokamaks
  - Stability of Field Reversed Configuration
  - Merging Spheromaks
  - Liquid Lithium walled tokamaks
  - 2D Modeling of MHD thrusters
- Strong driver for progress in plasma science