New Developments in M3D-C1

by
Nate Ferraro

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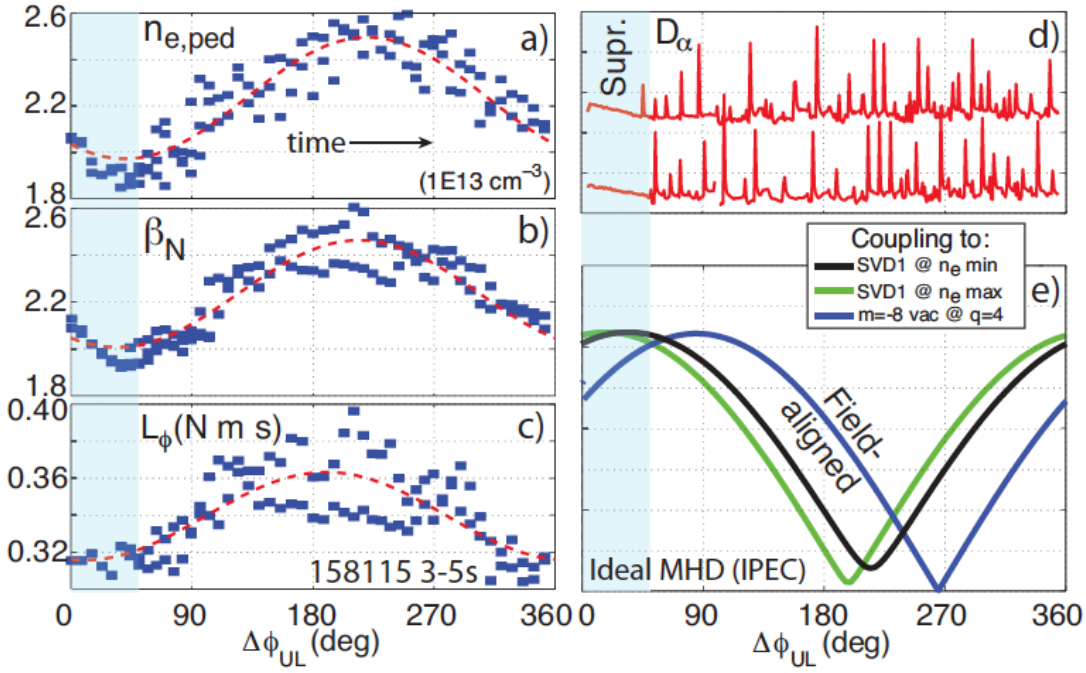
What's New in ELM Suppression Modeling

ELM Suppression Modeling is A Continuing Opportunity for MHD Codes

- **Recent RMP ELM Suppression experiments have yielded significant new data, clarifying physics of ELM suppression**
- **Clear evidence that transition to ELM suppression is accompanied by nonlinear emergence of new 3D magnetic equilibrium**
  - Seems to involve penetration / locking
- **Extended MHD codes are best (uniquely?) positioned to model this**
- **Path to predictive modeling may involve coupling to neoclassical or other transport model**

n = 2 ELM Suppression Experiments Show Correlation Between ELM Suppression, Transport

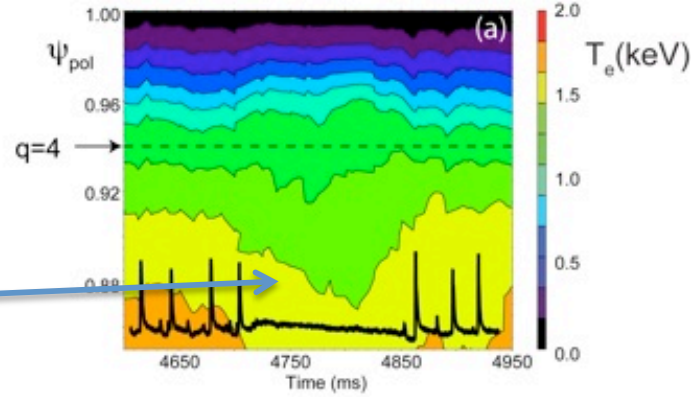
- Relative phase of upper, lower I-coils is smoothly varied
- Transport is maximized near 0° (even parity)
- ELM suppression is also achieved near 0°

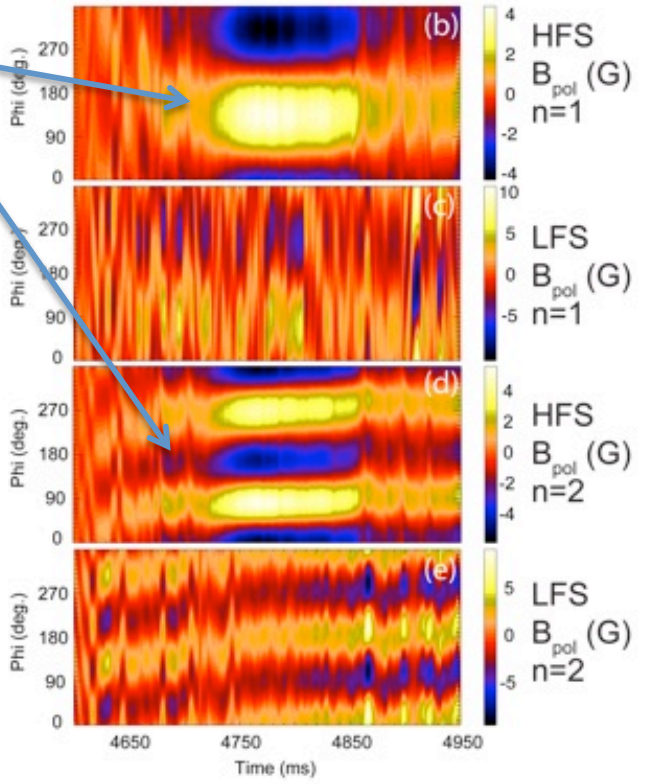


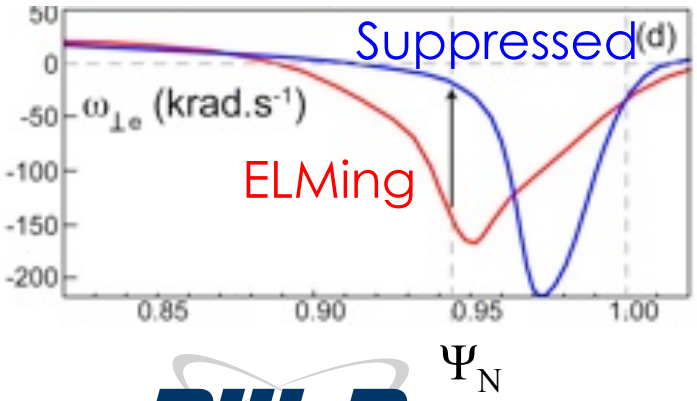
- IPEC SVD1 coupling is maximized near 0°
- Vacuum Island Overlap Width is maximized closer to 90°
- IPEC, MARS, and M3D-C1 (Lyons) show varying support for finding that ELM suppression is correlated to kink response

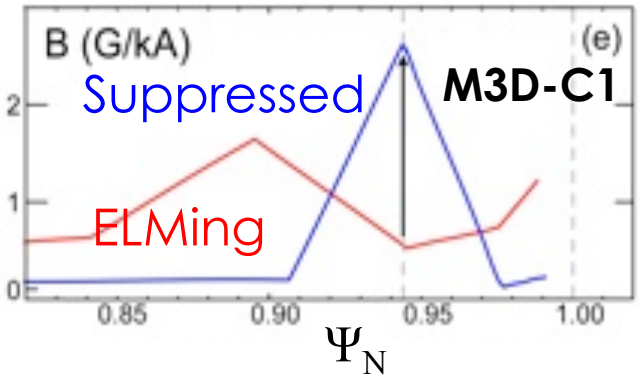
Clear Magnetic Signatures Are Found Upon Entering / Leaving ELM Suppression

- **Plasma enters and exits ELM suppression as *n* = 2 poloidal spectrum is changed**
- **Flattening of T_e seen at pedestal top**
- **Strong *n* = 1 and *n* = 2 signal seen on HFS**
- **Looks a lot like island penetration…**
  - M3D-C1 finds strong resonant field (tearing) drive at top of pedestal when suppressed









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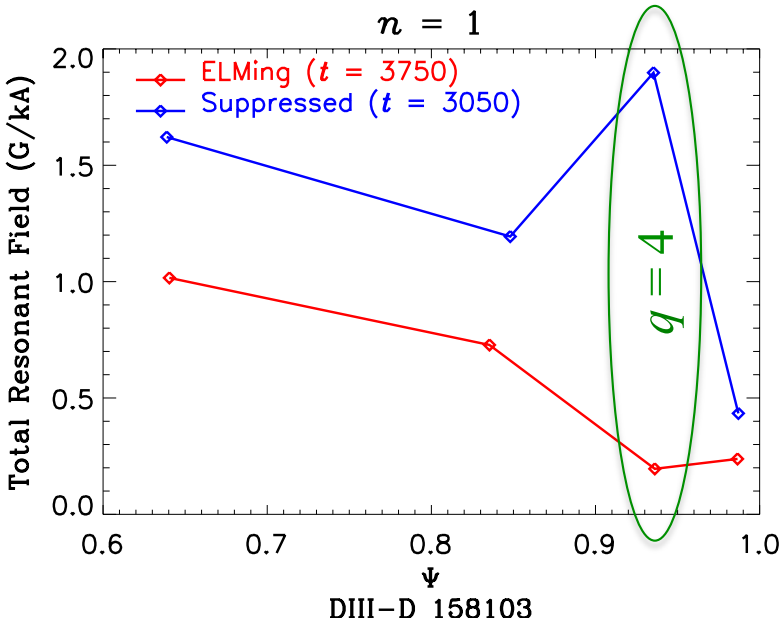
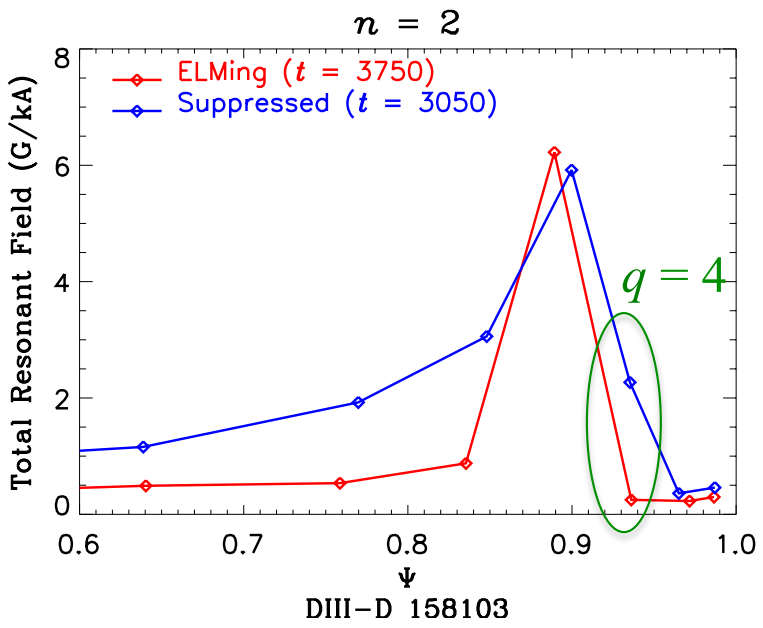
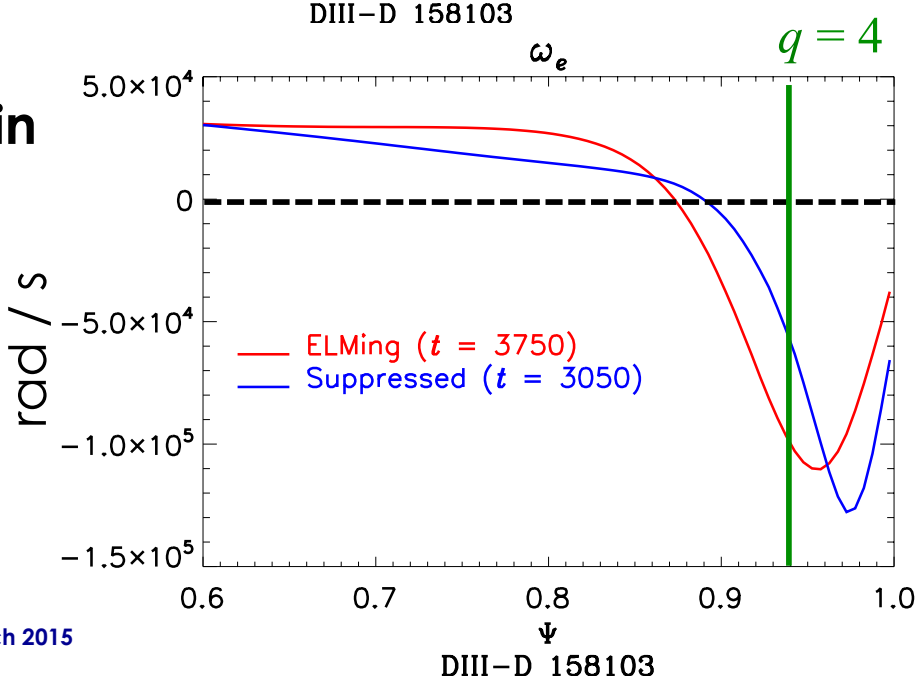
R. Nazikian

Two-fluid response Shows Increased n=1 and n=2 Tearing Drive at Pedestal Top in ELM-Suppressed Phase





- **M3D-C1 finds a significant change in the tearing drive at the top of the pedestal between ELMing and Suppressed state**
- **This change is consistent with reduction in ω_e at $q = 4$**



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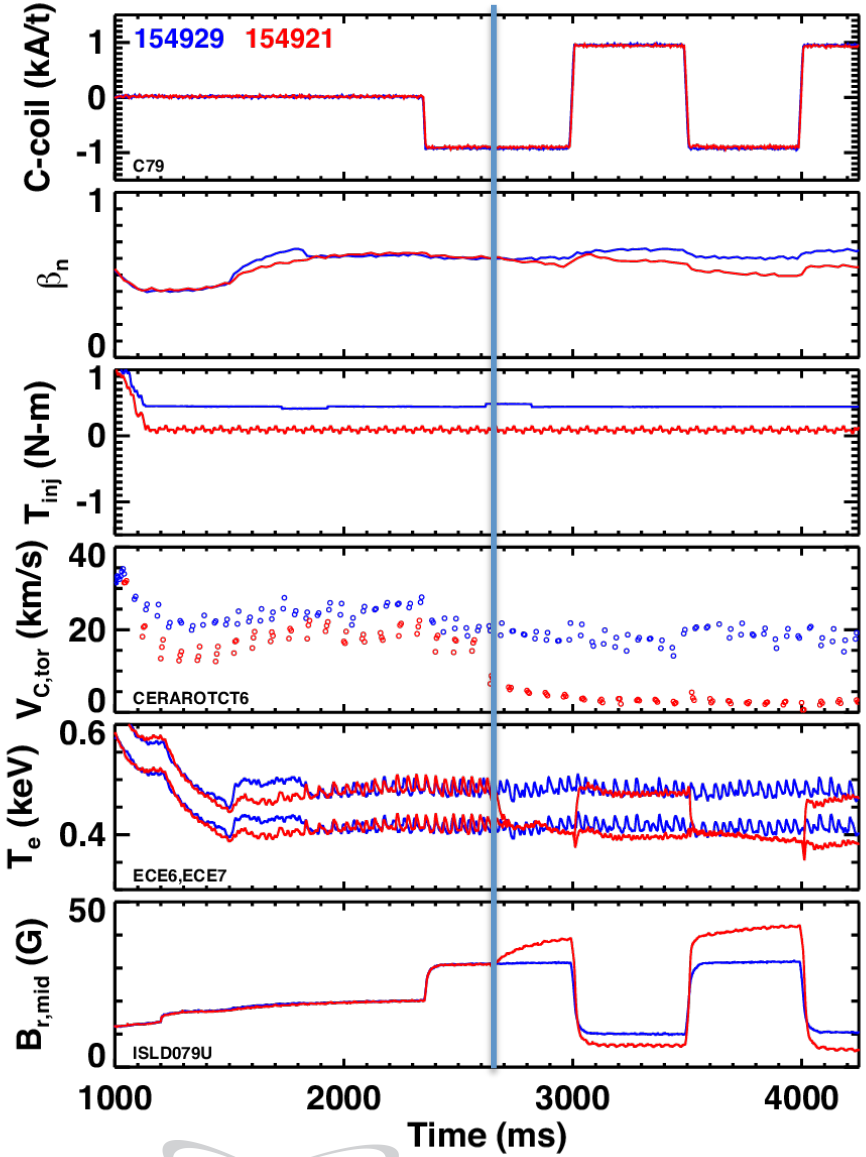
Predictive Modeling of ELM Suppression Modeling May Require Predictive Model of Locking Thresholds

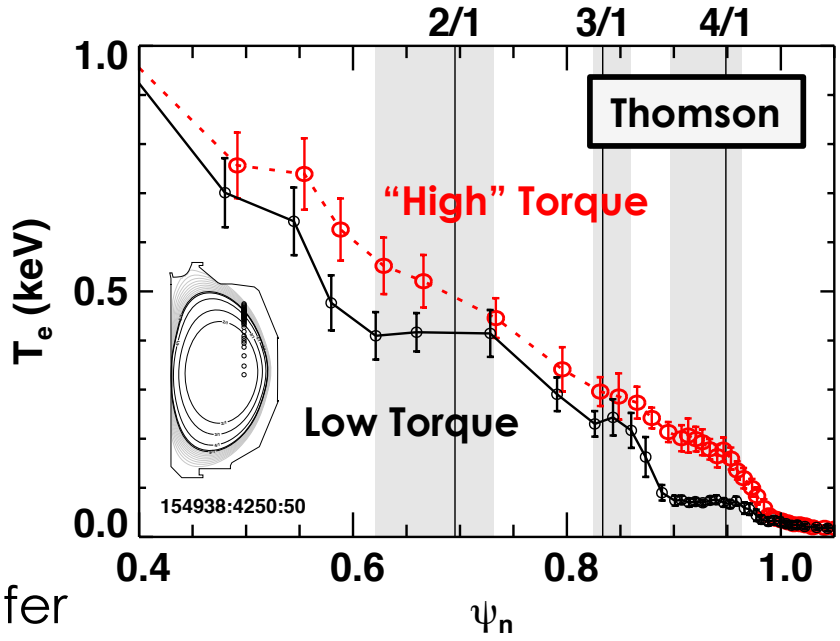
- **Experiments show nonlinear bifurcation**
  - Multiple n's involved; quick transition to new 3D equilibrium
  - Orlov experiment with missing coils strongly suggests that multiple spectral modes play role in suppression (see Orlov poster)
  - Hysteresis has not been clearly documented
- **Linear modeling shows enhanced tearing drive in the suppressed state**
  - Consistent with bifurcation being a locking bifurcation
- **So to model ELM suppression we need:**
  - To be able to model penetration / locking
  - Possibly: to model transport changes due to 3D fields
    - Effect on bootstrap current, particle transport

What's New in Mode Locking Modeling

DIII-D Has Plethora of Mode-Locking Data

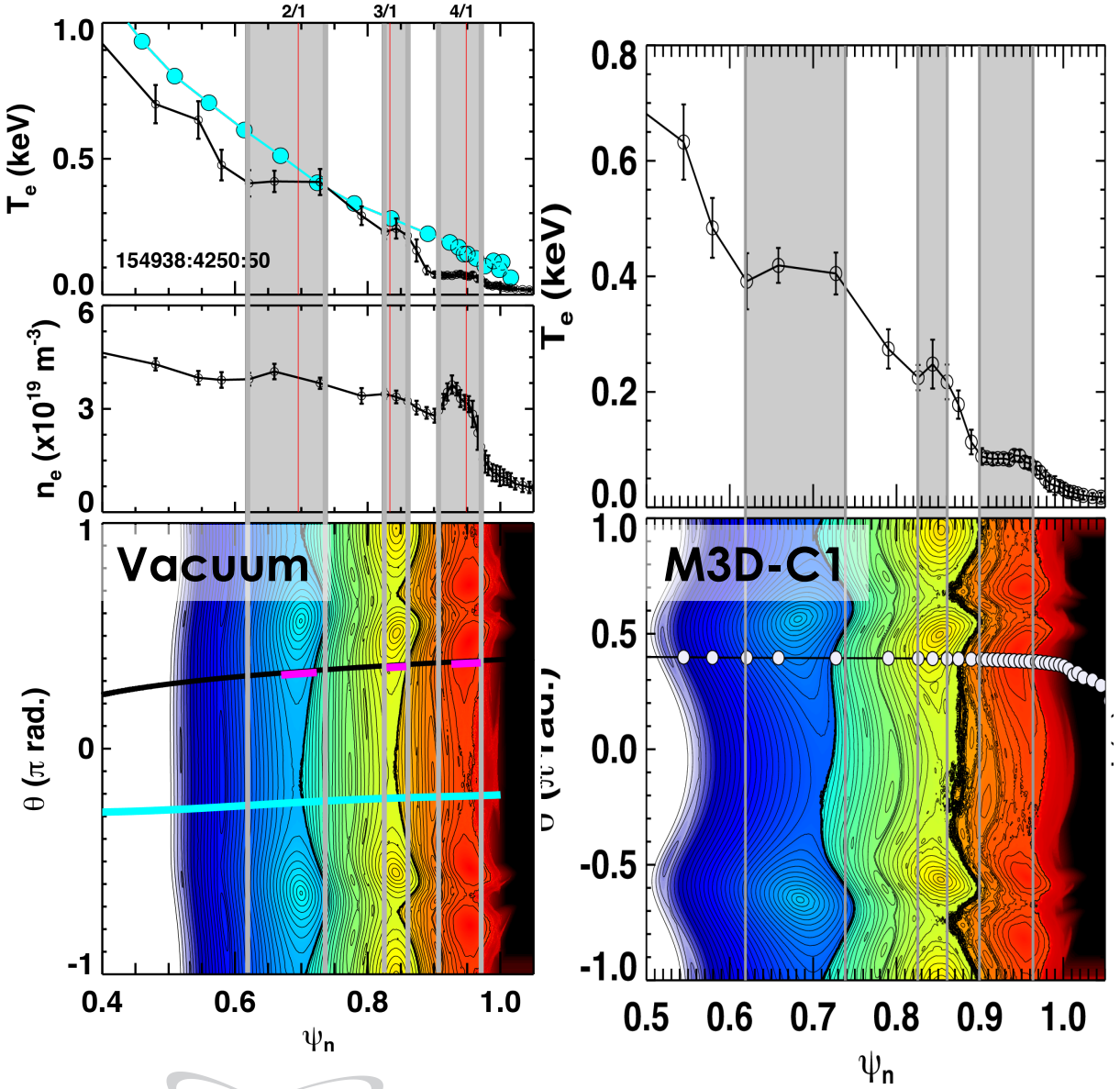


- **Locking was explored using limited discharge**
  - n=1 phase flips
  - Several shots with various NBI torque
- **Rotation drops, then mode starts growing**



M. Shafer

Linear M3D-C1 Modeling Captures Island Enhancement, But Not Locking



- **Islands are measured to be larger than the vacuum prediction**
- **Linear, two-fluid modeling also finds island enhancement**
  - Probably fortuitous; linear model probably not accurate for saturated islands

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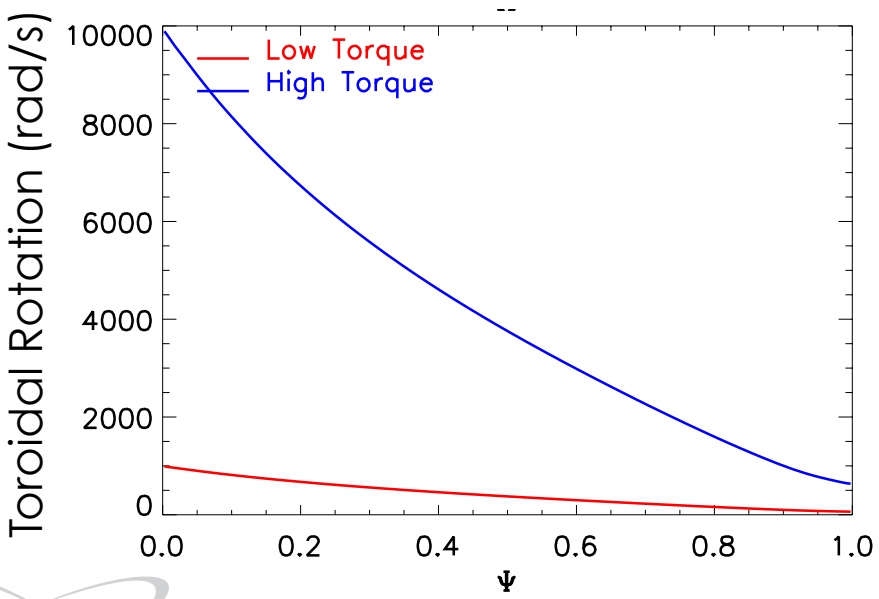
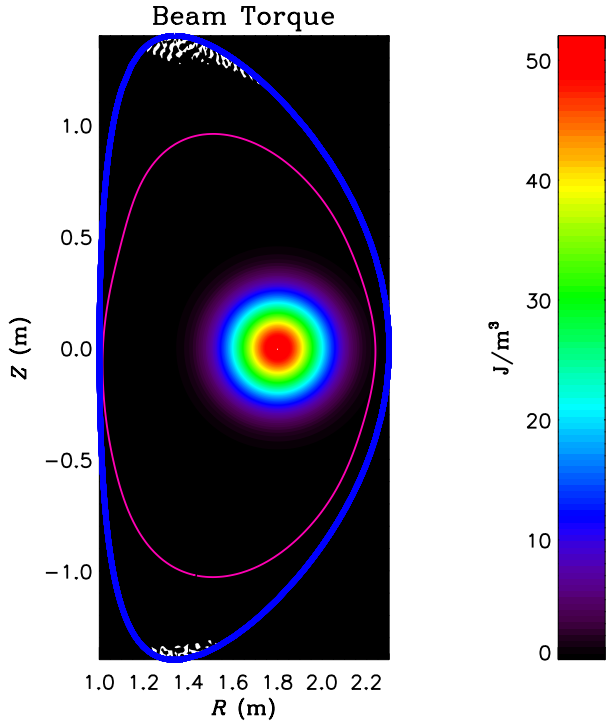
Nonlinear Modeling of Locking Experiment Underway

- **Two nonlinear calculations for this case have been run with M3D-C1**
  - 1 Nm NBI Torque vs. 10 Nm NBI Torque
  - Torque source is included; rotation allowed to evolve
  - Initial toroidal rotation is axisymmetric steady-state solution
- **Simulations are initialized with vacuum fields throughout**
  - Initial conditions in "penetrated" but not "locked" state





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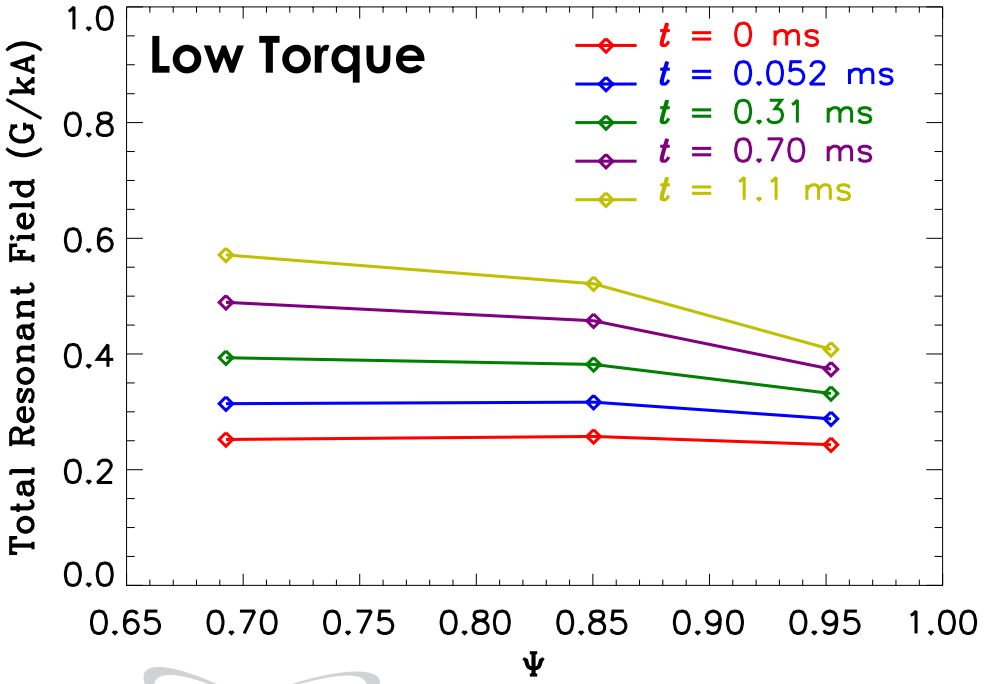
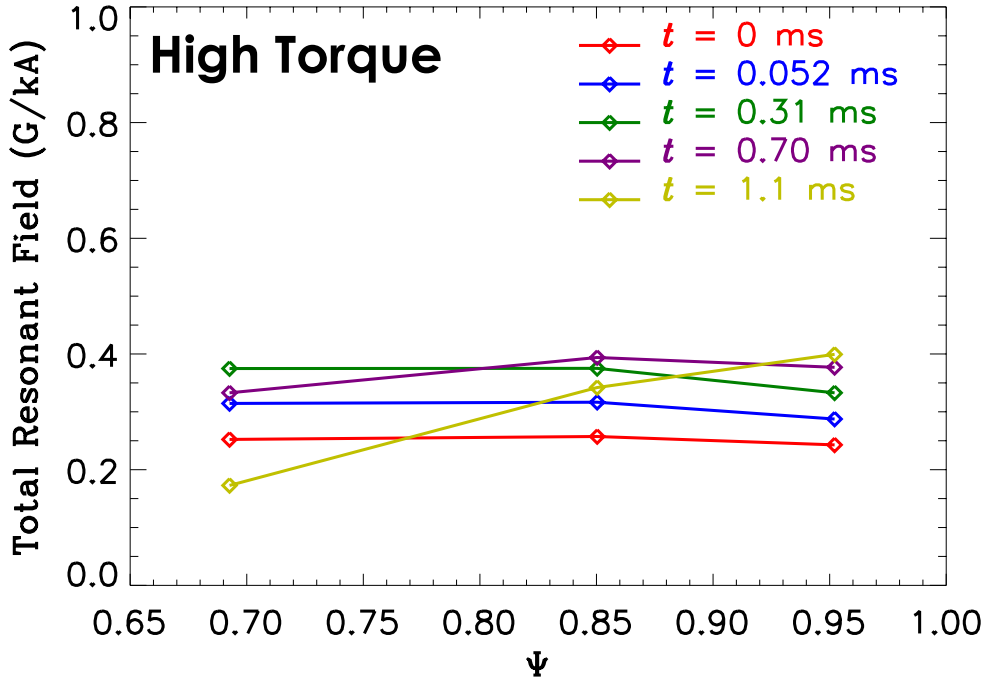
Simulations Not Yet Complete, But 10 Nm Case Seems To Be Showing Transition to Screened State

- Islands in low-torque case continue to grow steadily
- 2/1 and 3/1 islands in high-torque case initially grow, but then transition to screened state after ~1 ms





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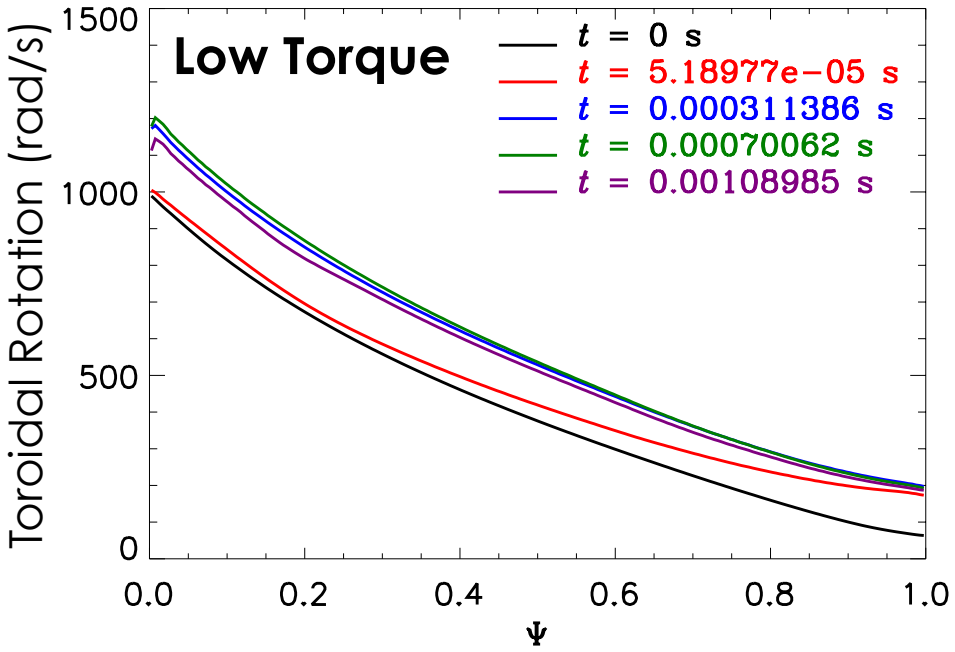
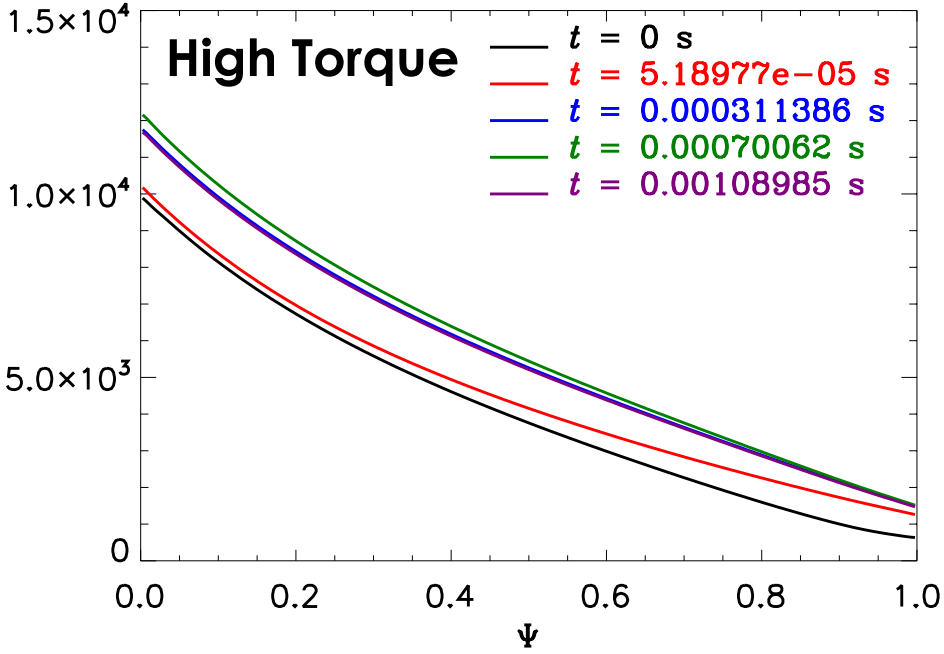
Both Cases Show Small Transient Spin-Up; Not a"Bifurcation"





- **Potential Issues:**
  1. Showing true locking probably requires model where coils are inside domain to allow torque transfer
  2. n=1 locking exhibits significant hysteresis. Maybe we should start from "screened" state to see locking. Two ways:
     - Start RMP at 0 amplitude and ramp during simulation
     - Start from ideal MHD solution

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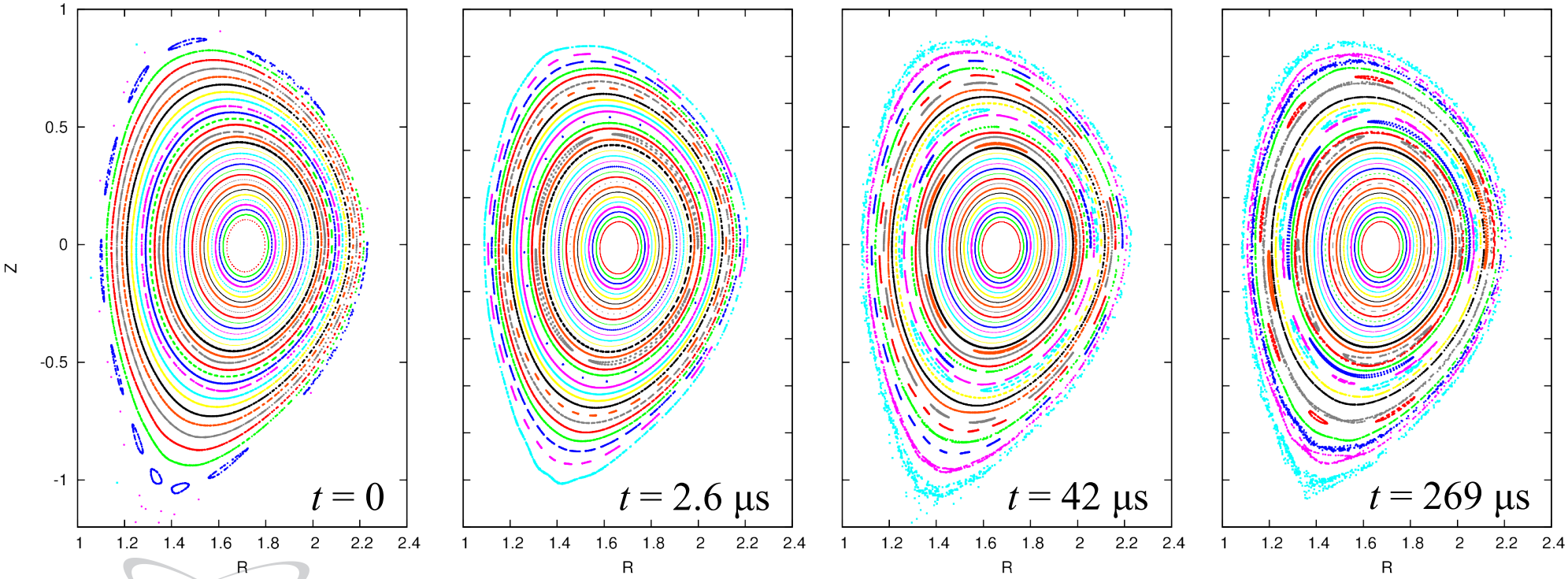
M3D-C1 Can Now Use VMEC Equilibrium as Initial Condition

- **M3D-C1 reads VMEC equilibria from (R, φ, Z) grid of (B_R, B_φ, B_Z, p) data**
  - Same format as probe_g files from TRIP3D for fields from 3D coils
  - Easily extensible
  - Requires vacuum fields from VMEC (DIAGNO)



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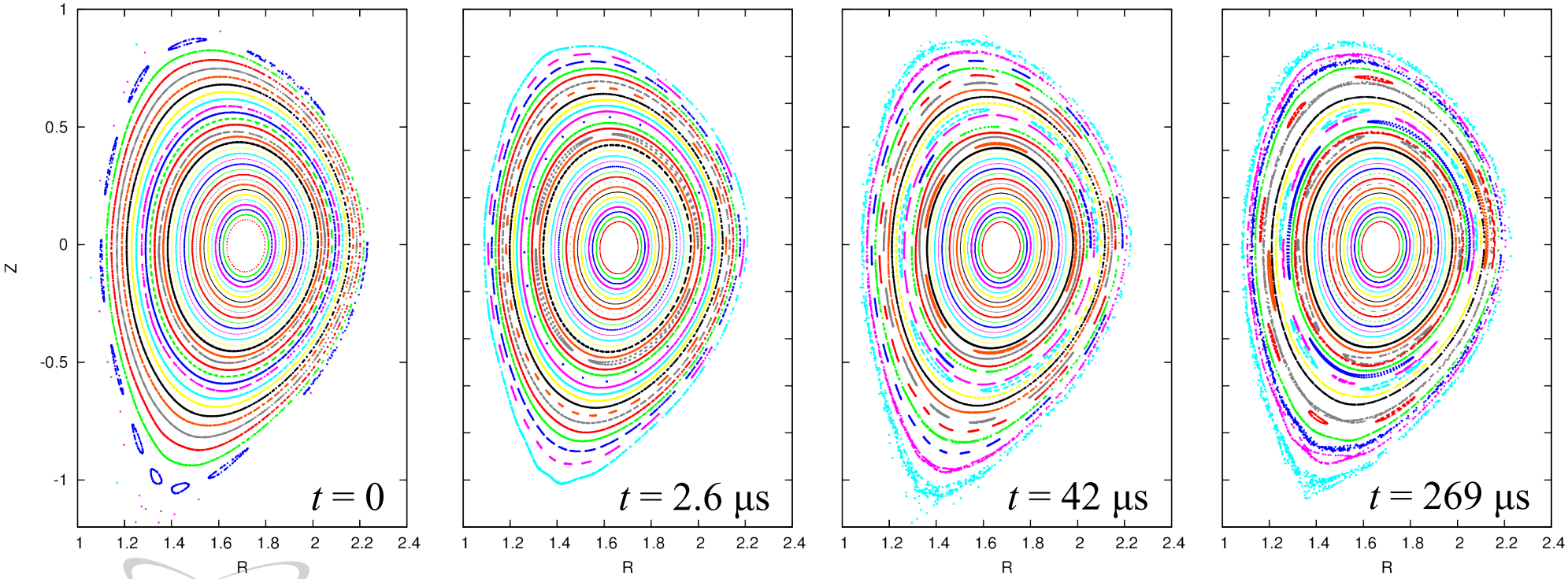
M3D-C1 Can Now Use VMEC Equilibrium as Initial Condition

- **RMP case (DIII-D 148712) simulated with M3D-C1 from VMEC equilibrium**
  - Torque / rotation not included (no screening is expected)

- **Simulation starting from VMEC equilibrium shows various stages:**
  - Quick (~μs) return to force balance (elimination of interpolation errors)
  - Slow (~ms) evolution of islands



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Summary

- **New experimental results highlight the importance of nonlinear transition to new 3D equilibrium in ELM suppression**
  - Extended MHD codes are best positioned to address this
- **Two-fluid linear modeling shows hints of possible locking transition**
  - ELM suppressed state show stronger tearing response due to change in rotation profile
  - Nonlinear models are required to investigate locking thresholds and dynamics
  - Transition may also depend on transport changes – need transport models in 3D geometry
- **Initial nonlinear M3D-C1 modeling of locking experiment seems to be showing transition, but not bifurcation – still lots to be done!**

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