Extended MHD Simulation of Neoclassical Tearing Modes in Tokamaks [1]

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Thesis

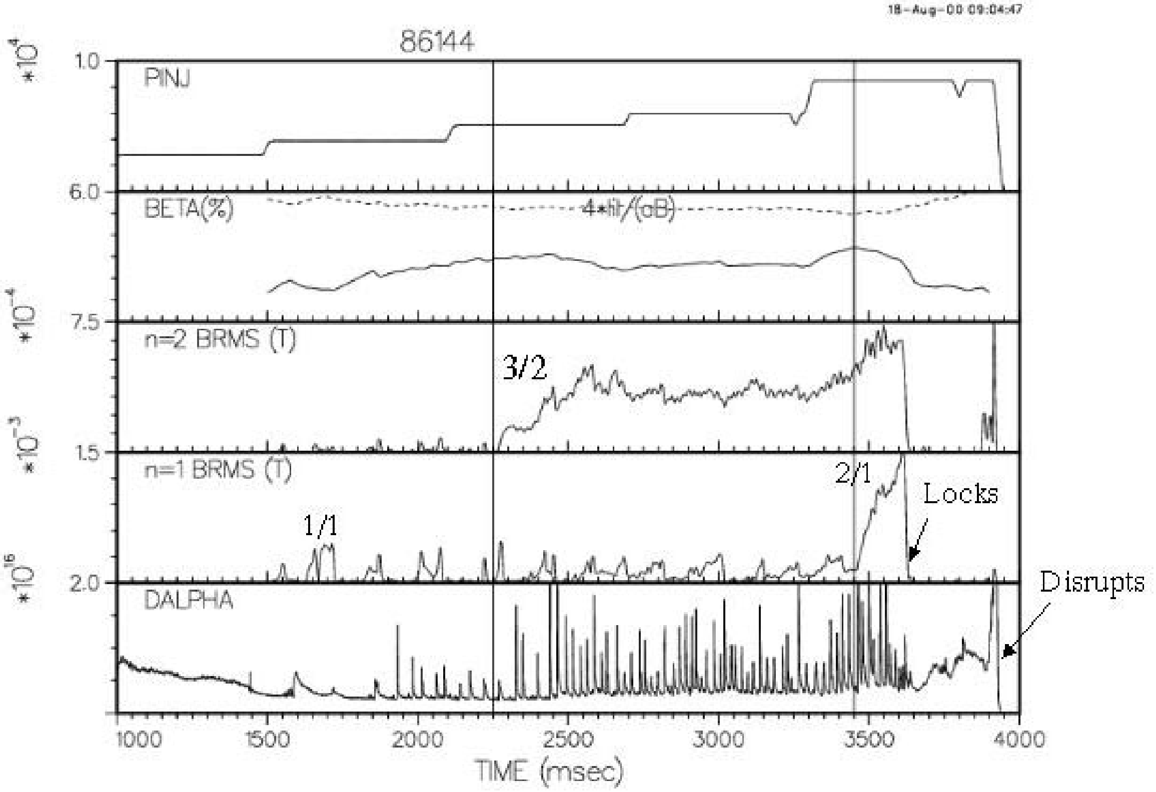
- **Neoclassical tearing mode simulations of D3D Shot 86144 are underway but the results remain inconclusive.**

Outline

- **Secondary Island Formation from internal kink.**
- **Nonlinear island evolution equation.**
- **Nonlinear threshold for neoclassical tearing modes.**

Modern Tokamak Discharges Have Rich Magnetic Behavior

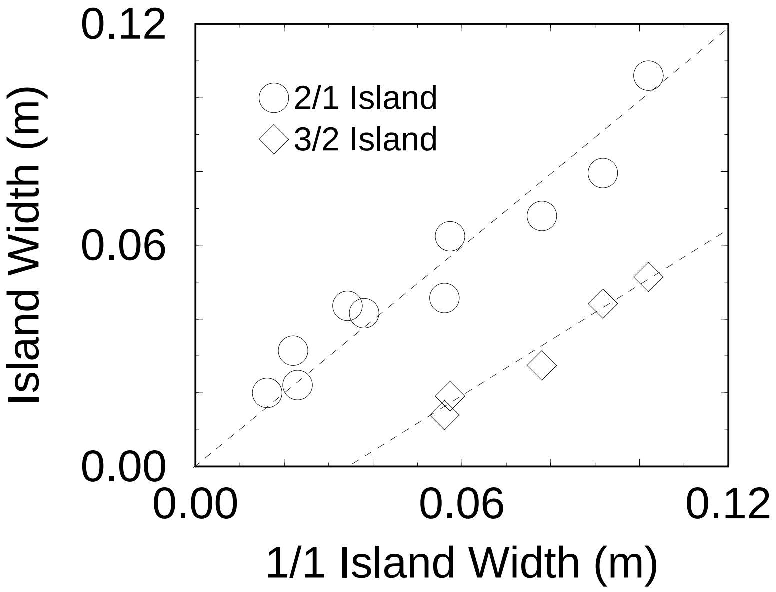
NIMROD

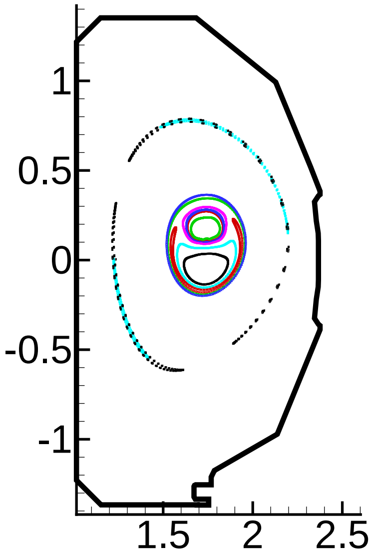


Courtesy of R. LaHaye, General Atomics

Resistive MHD predicts secondary island generation.

- **Island widths estimated from Poincare plots.**
- **Island widths are too small to explain observed 3/2.**
- $\boldsymbol{S = 10^4}$ **and** $\boldsymbol{P_m = 10}$**.**
- **At** $\boldsymbol{S = 10^7}$ **and** $\boldsymbol{P_m = 10^3\ W_{2/1} = 0.03(m),\ W_{3/2} = 0}$ **.**





NIMROD Simulations are based on poloidal flow damping closure form.

- The suggested form for $\vec{\nabla} \cdot \Pi_\alpha$ is

$$\vec{\nabla} \cdot \Pi_\alpha = \rho_\alpha \mu_\alpha \left\langle B^2 \right\rangle \frac{\vec{V}_\alpha \cdot \vec{e}_\Theta}{\left(\vec{B} \cdot \vec{e}_\Theta\right)^2} \vec{e}_\Theta,$$

  μ_α is the viscous damping frequency for each species α,
  Depends on the collisionality regime.
  $\vec{e}_\Theta = \mathcal{J} \vec{\nabla} \zeta \times \vec{\nabla} \psi$ and ζ is the axisymmetric toroidal angle,
  ψ is the poloidal flux,
  $\mathcal{J}$ is the Jacobian of the coordinate system.

- The form can be shown to be dissipative.
- Linear layer analysis yields bootstrap current, flow damping, and neoclassical enhancement of the polarization current.
- Additional approximations can be made:

  Diamagnetic approximation expresses electron flow as pressure gradient.
  Hole approximation uses analytic pressure profile about island.

Nonlinear Rutherford island evolution equation predicts a stability boundary.

$$\frac{k_0}{\eta^*}\frac{dW}{dt} = \Delta^* + \frac{W}{W^2+W_d^2}\left(D_{nc} + \frac{D_R}{\alpha_s - H}\right) + \ldots$$

where W is the full-width of the island.

D_{nc} is the measure of neoclassical tearing mode stability.

$D_R = E + F + H^2$ is the resistive interchange parameter.

α_S and α_R are the small and large Mercier index.

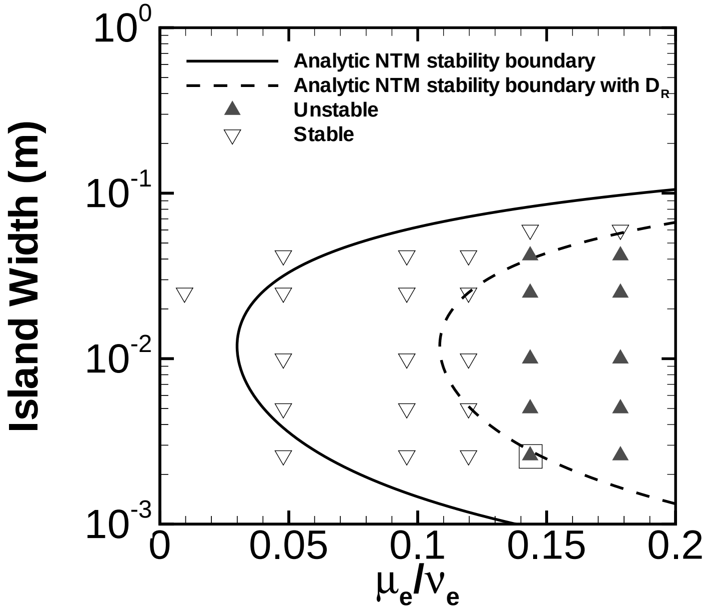
η^* is the resistive diffusion coefficient in flux space.

$\Delta^* = \Delta^{'}|W/2|^{-2\alpha_l}\sqrt{-4D_i}$.

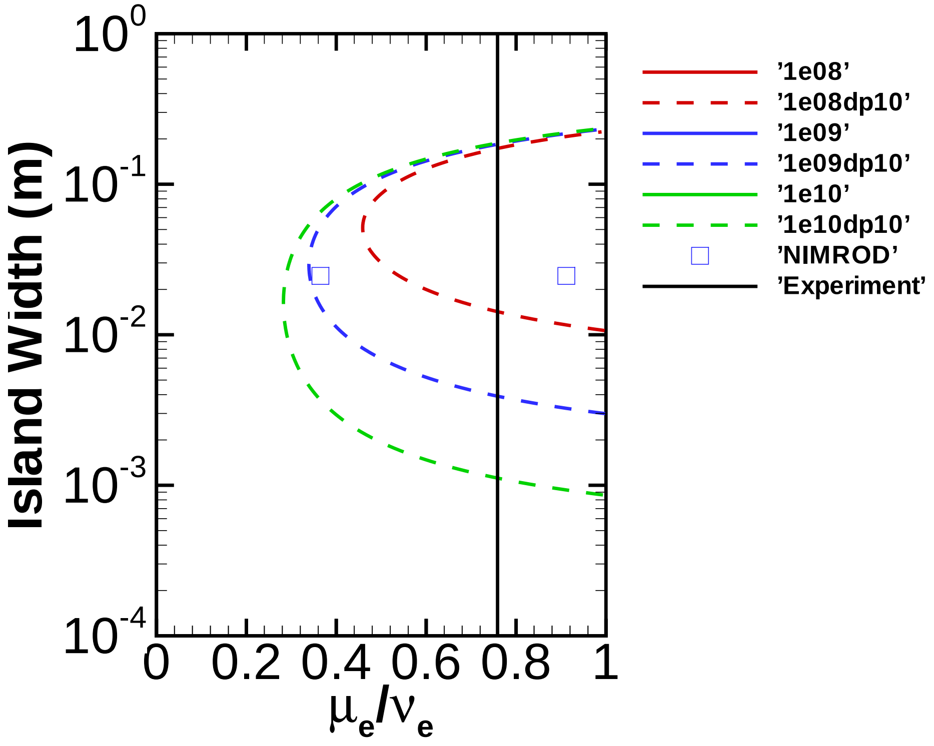
- May be additional effects such as FLR, NEPC.
- $\Delta^{'}$ is typically stabilizing.
- D_{nc} is typically destabilizing.
- D_R is typically stabilizing and the anisotropic thermal diffusion may take a different form.

Neoclassical Tearing Mode Stability Boundary agrees with analytics.

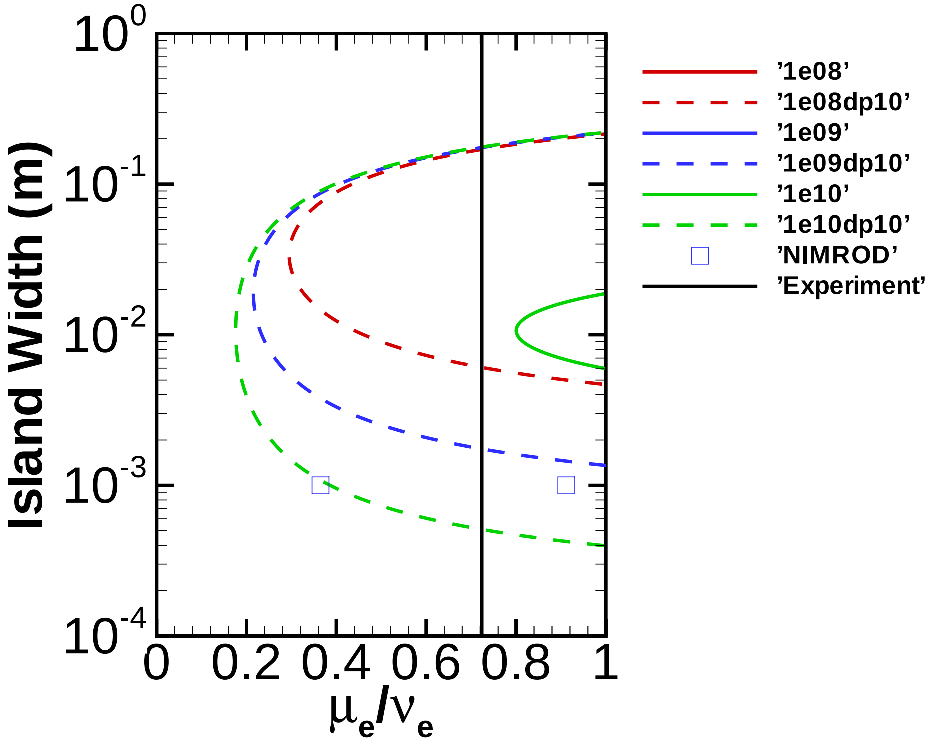
- Here, μ_e/ν_e parameterizes the bootstrap current, $D_{nc} \propto \mu_e/\nu_e/(1+\mu_e/\nu_e)$.
- Stability boundary requires inclusion of D_R.
- Discrepancy exists at samll μ_e/ν_e.



The 2/1 NTM tearing mode should be stable.



The 3/2 NTM tearing mode should be unstable.



Conclusions

- **An effective form of the neoclassical-viscous stress tensor has been implemented and tested.**
- **Analyic theory predicts the experimental observation of 2/1 NTM stability and 3/2 tearing instability.**
- **NTM simulations of 86144 are proceeding.**