Abstract

RWM stabilization by plasma rotation in NSTX is impeded by the presence of a time-dependent non-axisymmetric component to the toroidal field [1]. Confinement is improved by active correction of this error field; its exact cause is still under investigation. A numerical study of the effects of the error field on magnetic island formation was conducted with ideal linear codes [2], providing estimates of the island widths based on the amplitudes of the singular current sheets that result from the perturbation. We extend these results by conducting nonlinear, non-ideal studies of these effects using the M3D code [3]. The nonlinear correction to the linear response to a pure m=2, n=1 perturbation is shown.

[1] J.E. Menard, *et al*., submitted to *Nucl. Fus*., 2007.
[2] J.K. Park, poster presented at Sherwood Fusion Theory Conference, Annapolis, MD, April 2007.
[3] W. Park, et al., *Phys. Plasmas* **6**, 1796 (1999).

Overview

- RWM stabilization by plasma rotation in NSTX is impeded by moving, nonaxisymmetric TF error.

- Active error correction improves confinement.

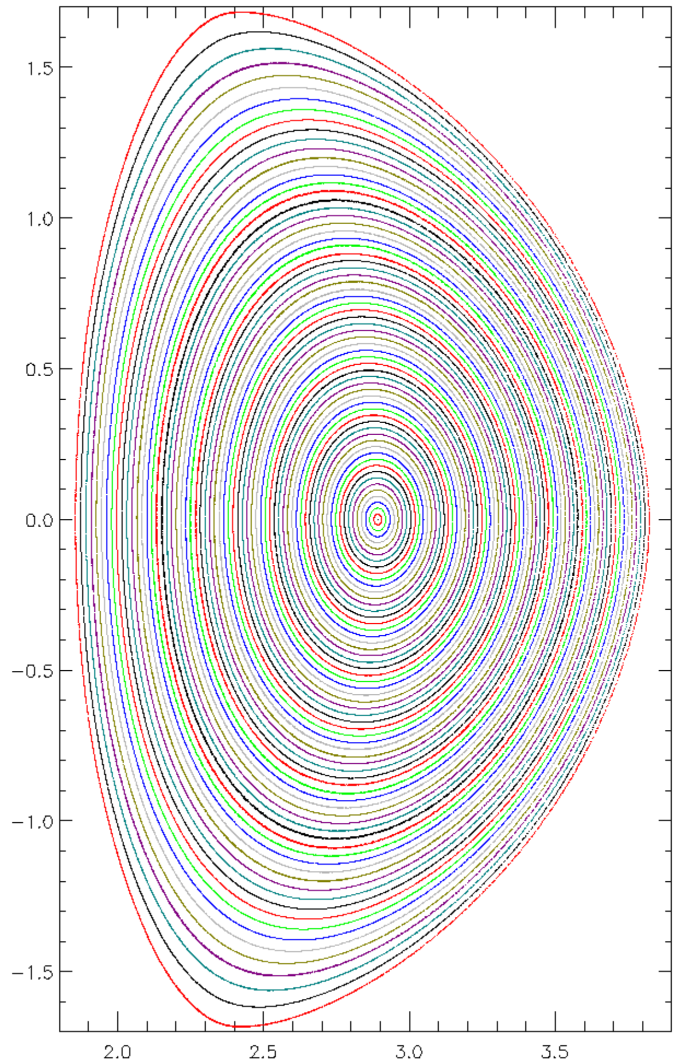
- J.K. Park has computed ideal, linear plasma response (singular current layers) to pure m,n perturbations in sample equilibria.

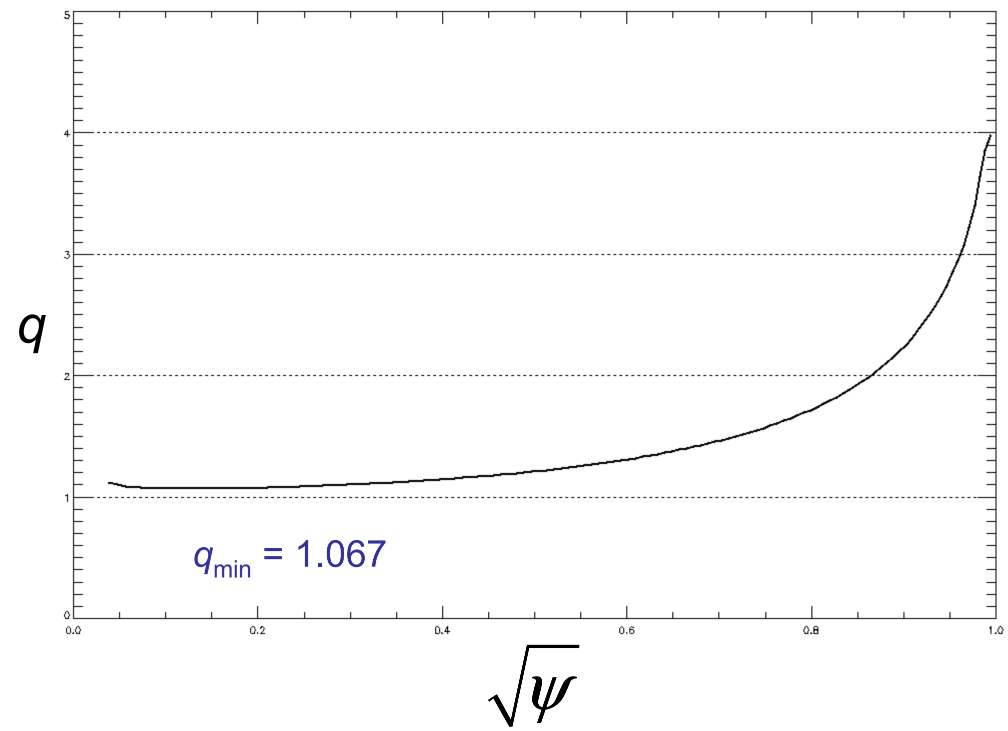
- For benchmarking and extension to non-ideal, nonlinear MHD, useful to compare with M3D.

Initial study

- Begin with a DIII-D equilibrium.
- Add an m=2, n=1 perturbation of specified amplitude to initial poloidal flux on plasma boundary.
- Measure plasma displacements, singular currents with linear code; infer island widths.
- Evolve M3D nonlinearly until saturation of n=1 islands; compare widths.

DIII-D Equilibrium





Resistive MHD Equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}_i) = 0$$

$$\rho\left[\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right] = -\nabla \mathbf{p} + \mathbf{J}\times\mathbf{B} + \mu\nabla^2\mathbf{v}$$

$$\mathbf{E} + \mathbf{v}\times\mathbf{B} = \eta\mathbf{J}$$

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla\times\mathbf{E}$$

$$\mathbf{J} = \nabla\times\mathbf{B}$$

$$\frac{\partial p}{\partial t} + \mathbf{v}\cdot\nabla p = -\gamma p \nabla\cdot\mathbf{v} + \nabla\cdot n\chi_\perp \nabla\left(\frac{p}{\rho}\right)$$

Artificial sound wave model for $\chi_{\parallel}$:

$$\frac{\partial T}{\partial t} = s\frac{\mathbf{B}\cdot\nabla u}{\rho}$$

$$\frac{\partial u}{\partial t} = s\mathbf{B}\cdot\nabla T + \nu\nabla^2 u$$

M3D variables:

$$\mathbf{B} = \nabla\psi\times\nabla\phi + \frac{1}{R}\nabla_\perp F + \left(R_0 + \tilde{I}\right)\nabla\phi$$

$$\mathbf{V} = \frac{R^2}{R_0}\nabla U\times\nabla\phi + \nabla_\perp\chi + V_\phi\hat{\phi}$$

Initial Perturbation

- Add instantaneous helical perturbation to poloidal flux function ψ on boundary of the form

$$\tilde{\psi}_{boundary}(\theta,\varphi) = \tilde{\psi}_0 \cos(\varphi - 2\theta)$$

where φ is the toroidal angle, θ is the geometric poloidal angle defined by

$$\tan(\theta) = \frac{z}{R - R_0}$$

(normalized major radius R_0=2.89), and the equilibrium flux is ψ= 0 on the boundary and ψ= -0.506 on the magnetic axis.

- To generate 2,1 islands large enough to resolve numerically, choose

$$\tilde{\psi}_0 = 7.5\times 10^{-3} \qquad \left(\frac{\tilde{\psi}_0}{|\psi_0|} = 1.48\times 10^{-2}\right)$$

- Do not perturb initial boundary current density.

Initial State

- Begin by solving the Poisson equation

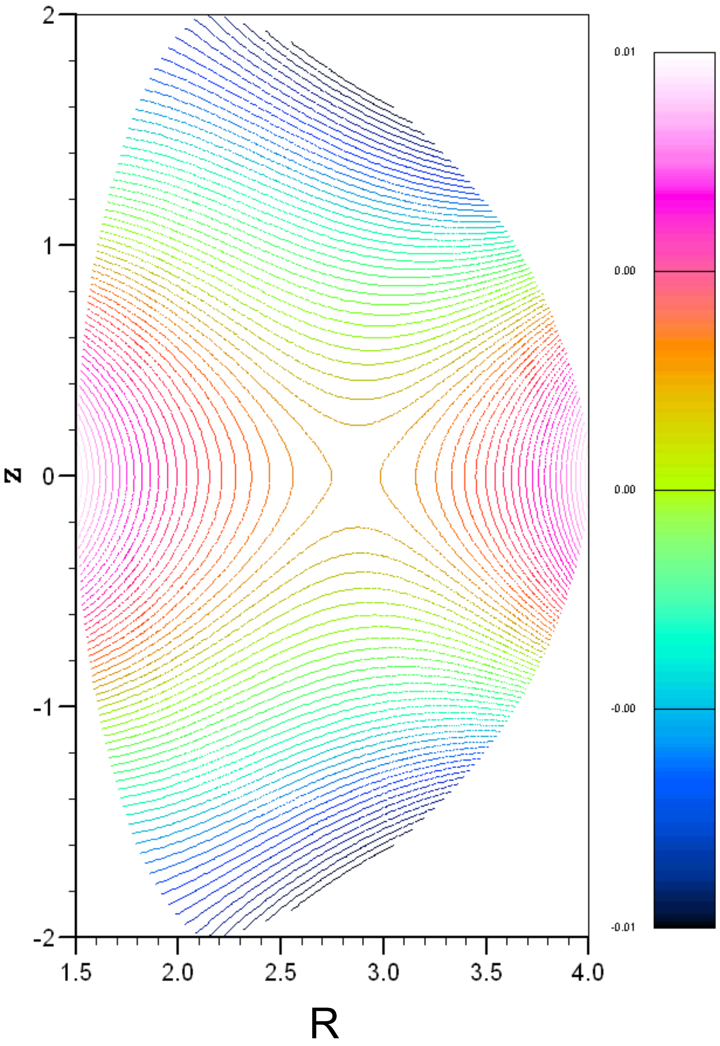
$$\frac{\partial^2 \psi}{\partial R^2} - \frac{1}{R}\frac{\partial \psi}{\partial R} + \frac{\partial^2 \psi}{\partial z^2} = -RJ_\phi$$

for ψ subject to the perturbed boundary condition, where J_ϕ is the unperturbed equilibrium toroidal current density.

- Because the initial current remains unperturbed, the resulting state represents the superposition of the equilibrium field (including external and plasma currents) and the error field, without the plasma reponse.

- Time-evolving from this state with various choices of resistivity η will show the effect of the plasma response on the islands.

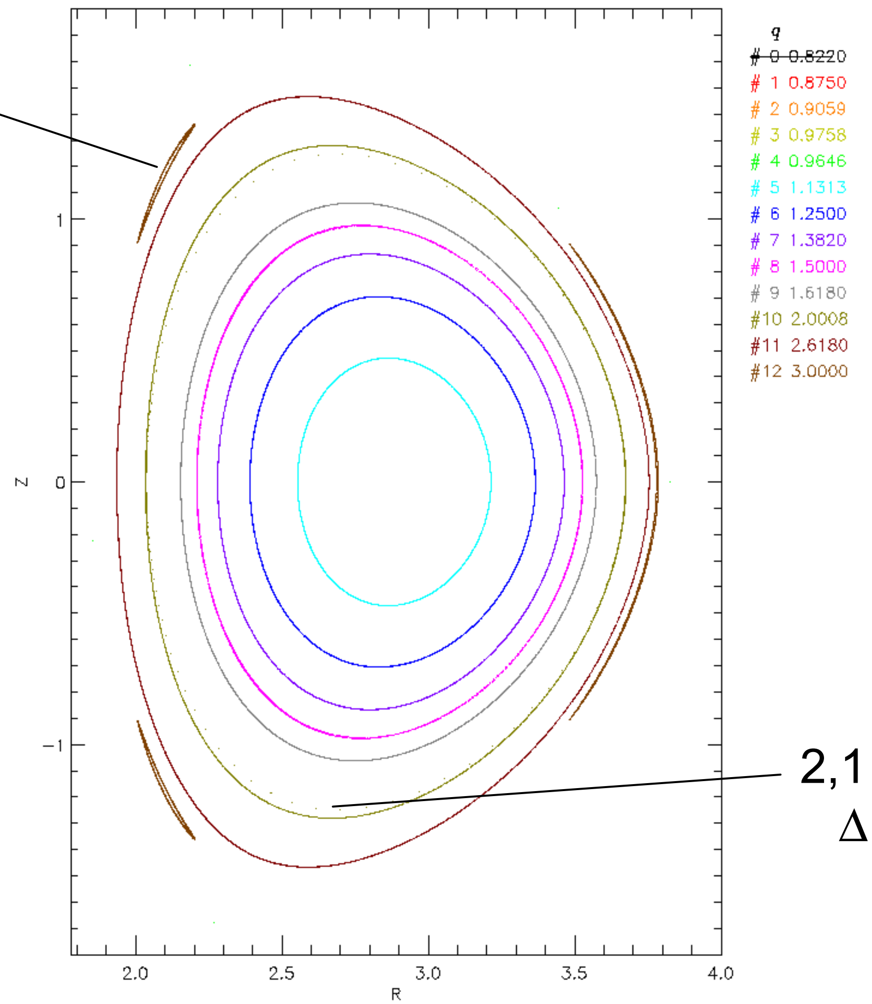
Instantaneous Perturbed Flux



Initial State Has Magnetic Islands

Poincaré section, φ=0 plane

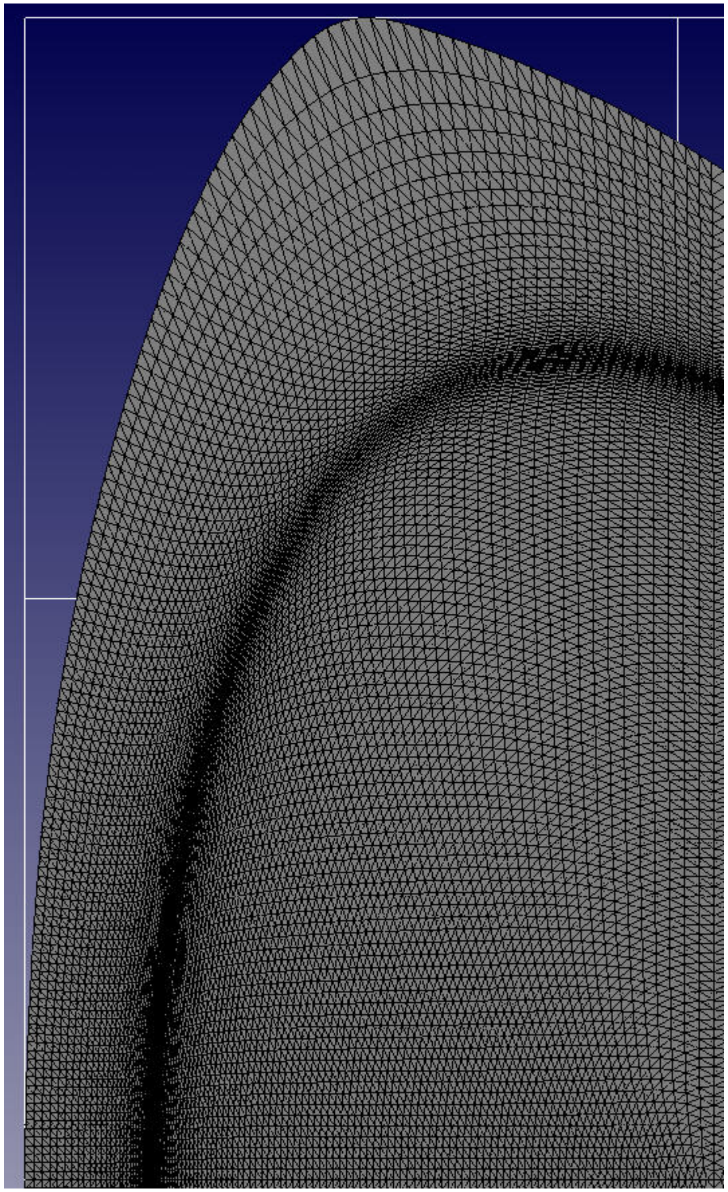
3,1 island width
$\Delta\psi$ = 1.33%



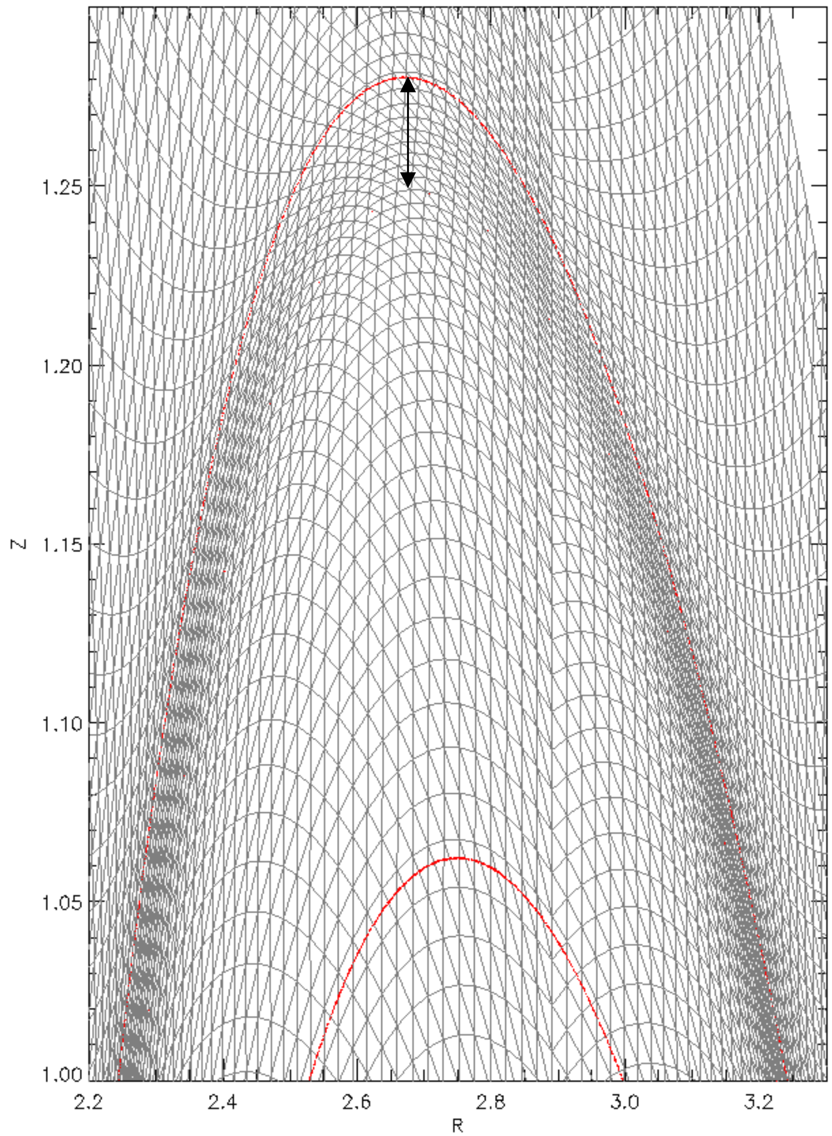
2,1 island width
$\Delta\psi$ = 1.09%

Resolving the Islands

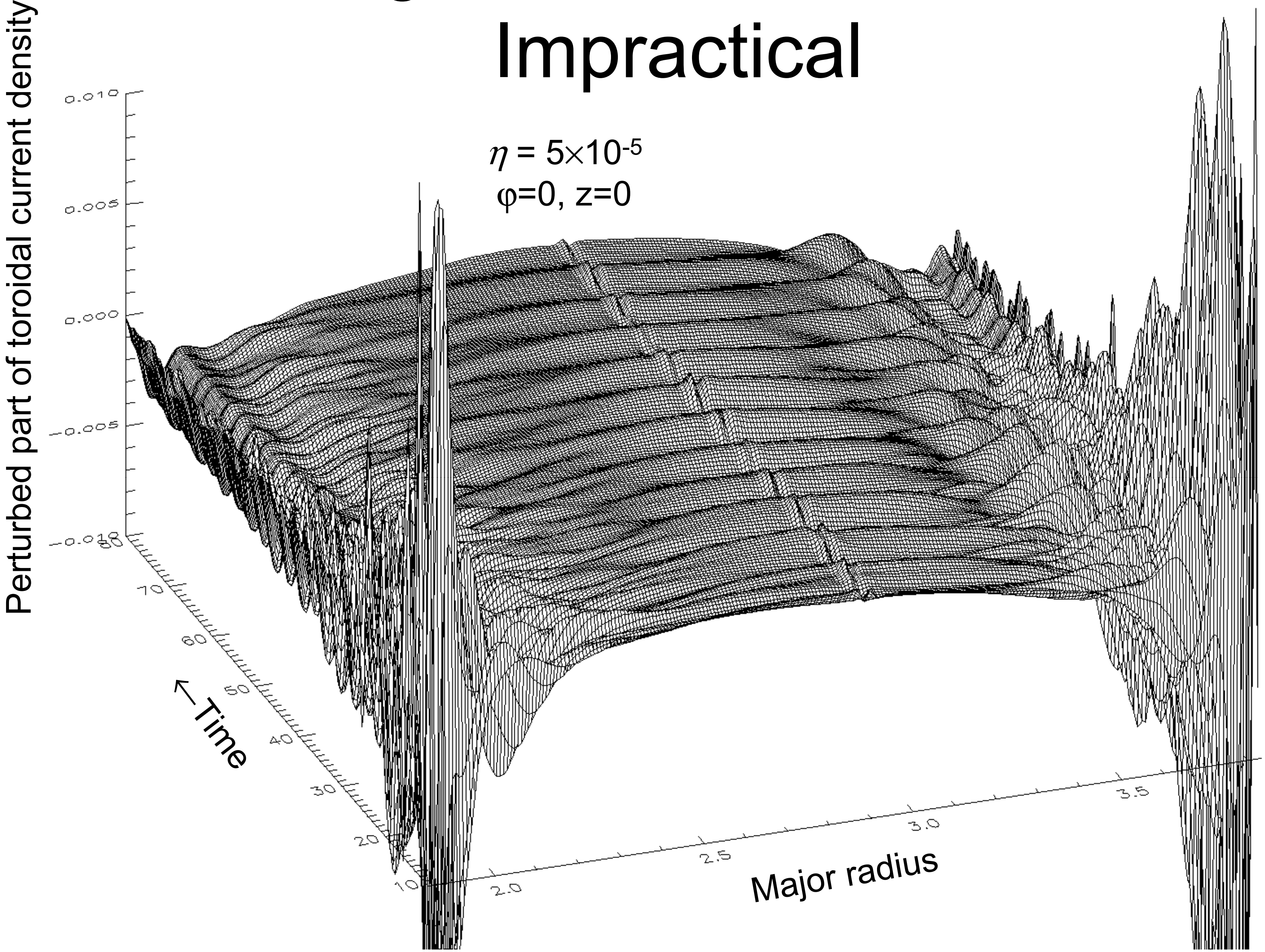
Poloidal mesh has 128 radial, 512 θ zones; packed x9 around q=2 surface.



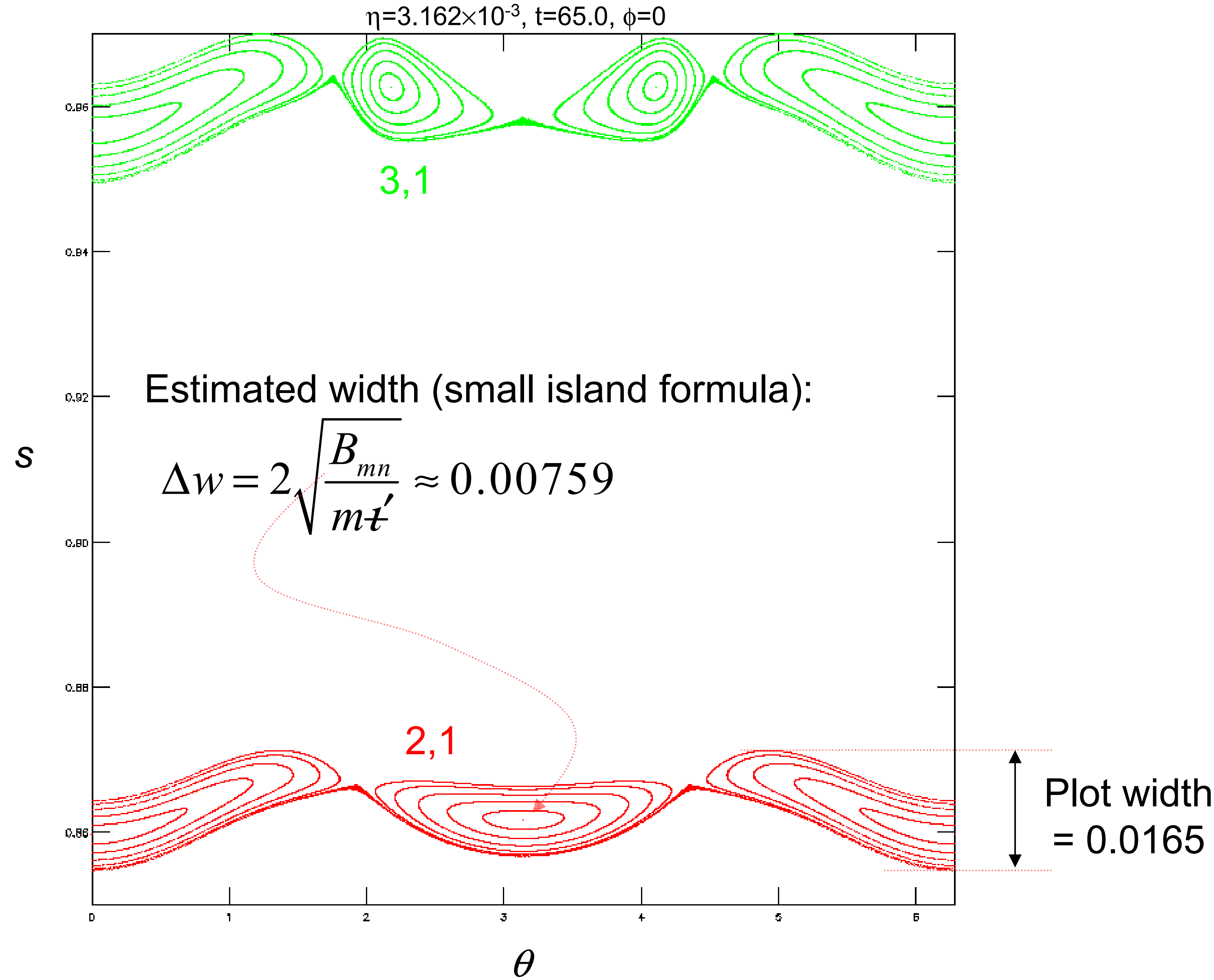
2,1 island spans nine zones → resolved.



Tracking Ideal Current Sheets is Impractical

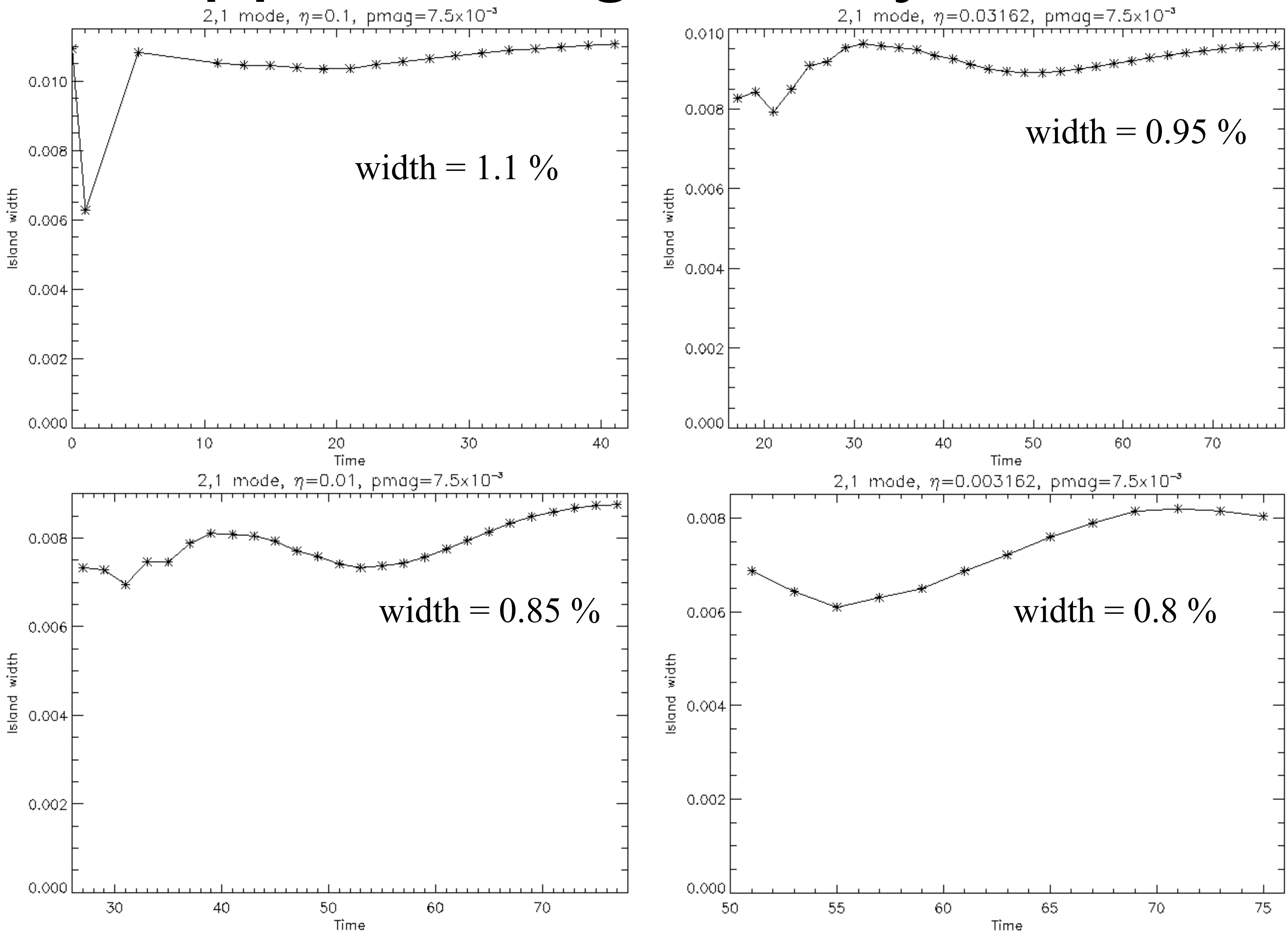


Measuring Island Widths

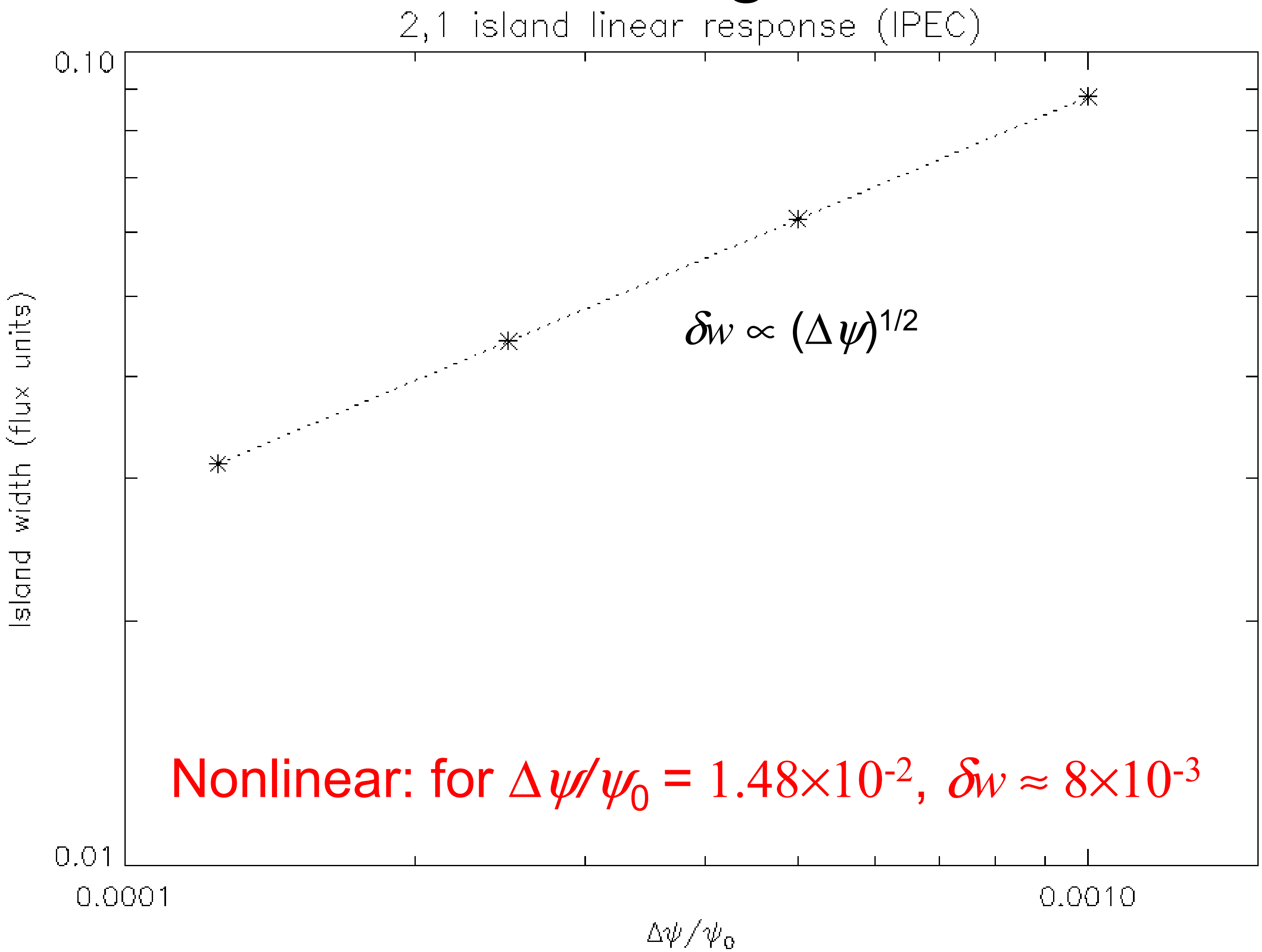


$$\Delta w = 2\sqrt{\frac{B_{mn}}{m \iota\!\!\!-'}} \approx 0.00759$$

Approaching Steady States



Nonlinear Results Disagree with Linear Scaling



Conclusions

- Nonlinear island width decreases as η decreases.
- Disagreement may be due to differences in boundary conditions, lack of nonlinear convergence, or inadequacy of linear model (nonlinear island saturation).
- More work is needed to resolve disagreement.
- Additional future work to include further scaling studies, and investigate effects of plasma rotation.