Flow Suppression of Magnetic Islands

Josh Breslau

CEMM Meeting

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Motivation

- Left uncorrected, the NSTX error field produces magnetic islands that can mode lock, braking plasma rotation and destabilizing RWMs.

- Analysis with IPEC has helped to predict these effects and design effective mitigation strategies.

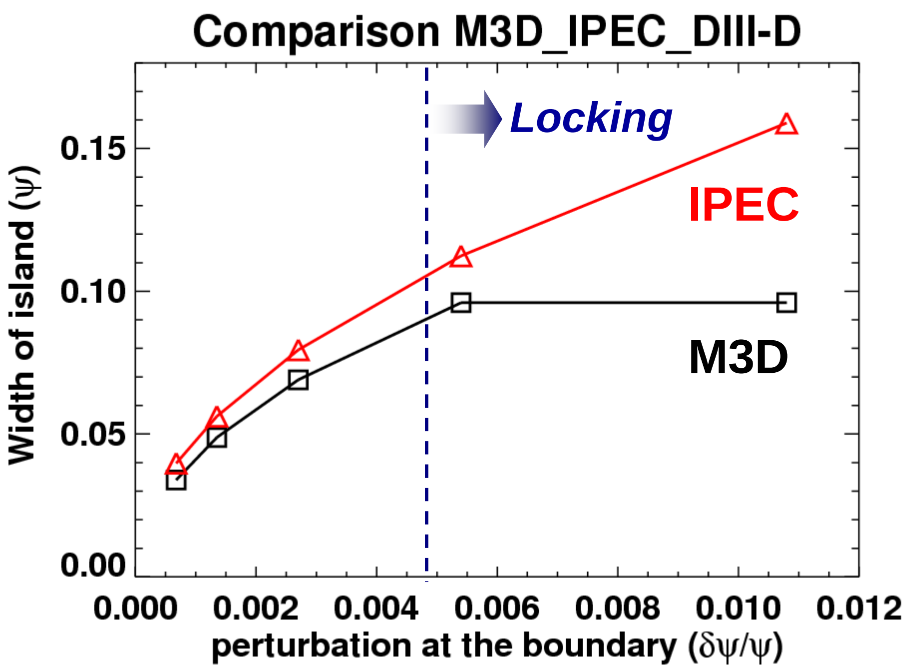
- Analysis with M3D can extend these results to the nonlinear, resistive, rotating plasma regime inaccessible to the ideal linear code.

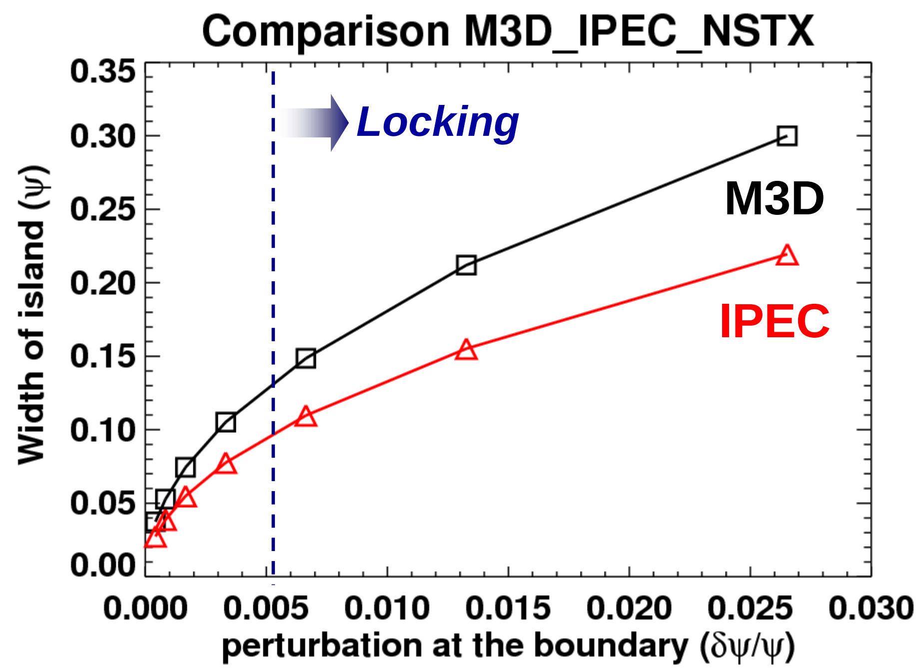
- M3D analysis should be extensible to other RMP effects, such as potential ELM mitigation or destabilization.

2,1 Island Widths agree with Inferred IPEC Widths in Linear Regime

IPEC prediction is inferred from formula based on singular current sheet at rational surface in ideal model, shielding interior. No obvious singular current sheet appeared in M3D for the parameters used ($S=10^6$).

m=2, *n*=1 perturbation applied at boundary





J.K. Park

Isolating Physics Responsible for Current Sheet Formation

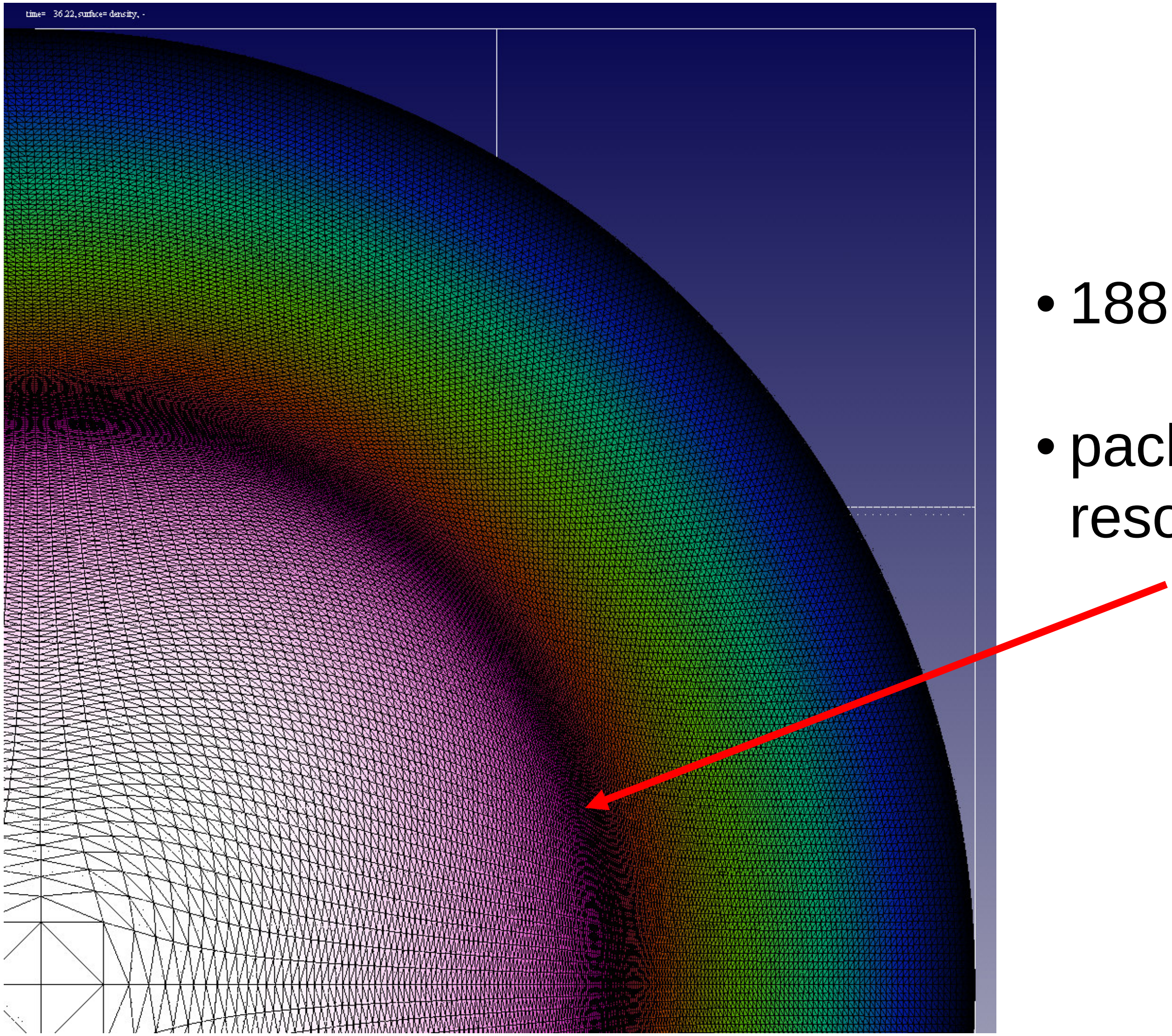
- Connect to analytic theory by approaching straight circular cylinder limit as aspect ratio $A \to \infty$.

- Equilibrium: R_{maj}=30, minor radius=1, cylinder length=6π, B_{ax} = 10 T, q_{min}=0.125.

- Perturbation: m=2, n=# of field periods=10, `pmag`=7×10^{-2}, t_{ramp} = 4.0 τ_A. (Gives zero-plasma-response island width ~20% of minor radius).

- Parameters: $\eta_{interior}$ =10^{-5}; $\mu_{interior}$=$10^{-3;}$ η_{edge} =10^{-2}; μ_{edge}=1

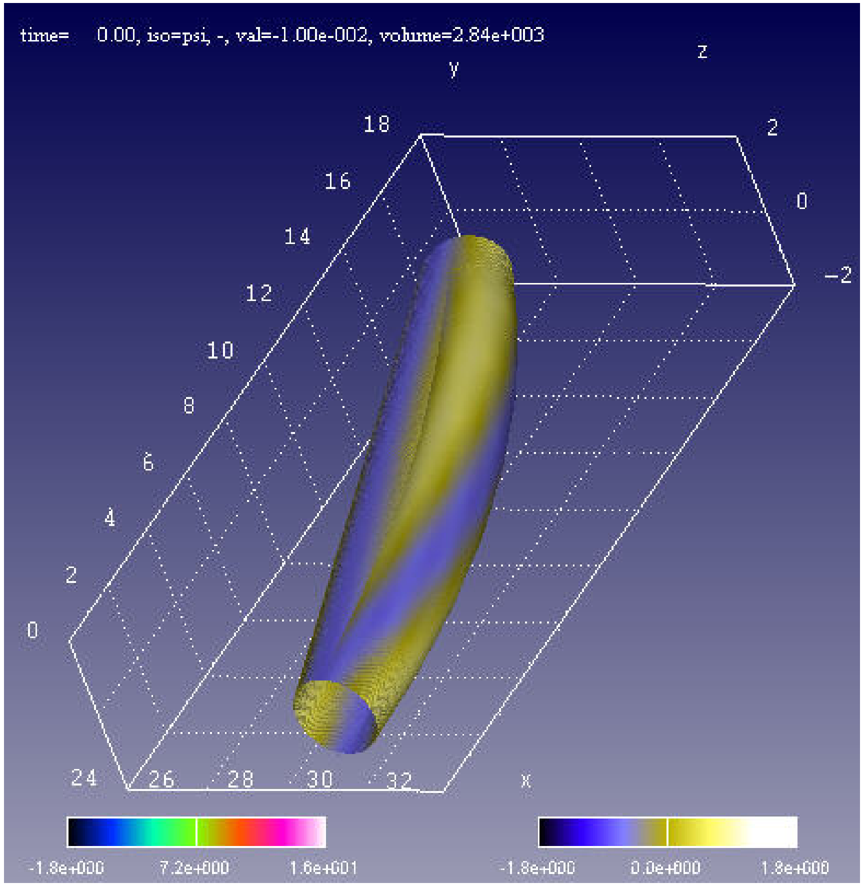
Use High Resolution, Mesh Packing to Resolve Current Sheets

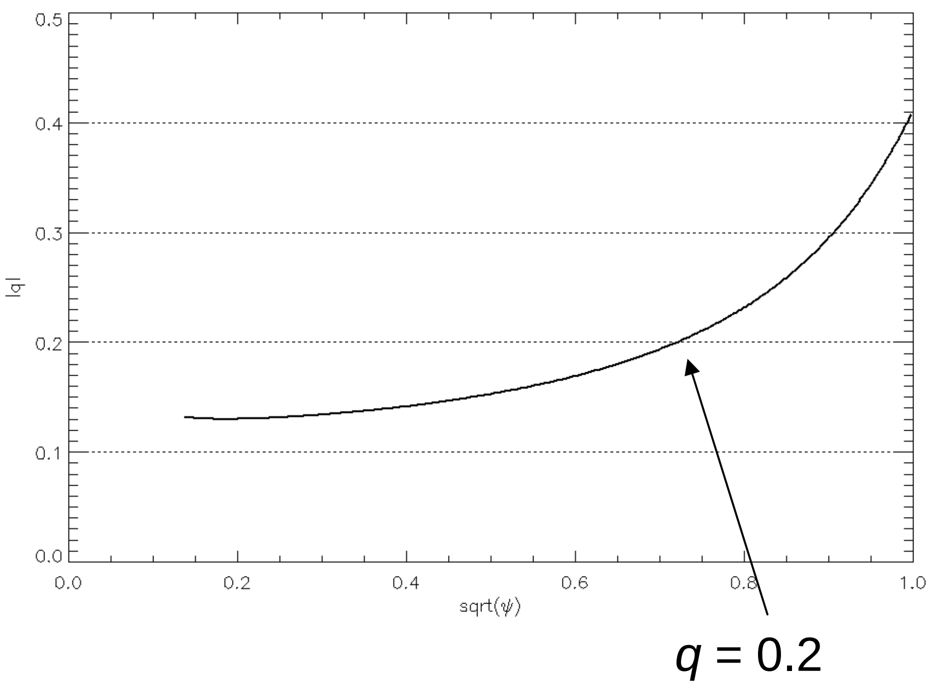


- 188 radial zones
- packing factor 4.0 at resonant surface

Perturbed Equilibrium

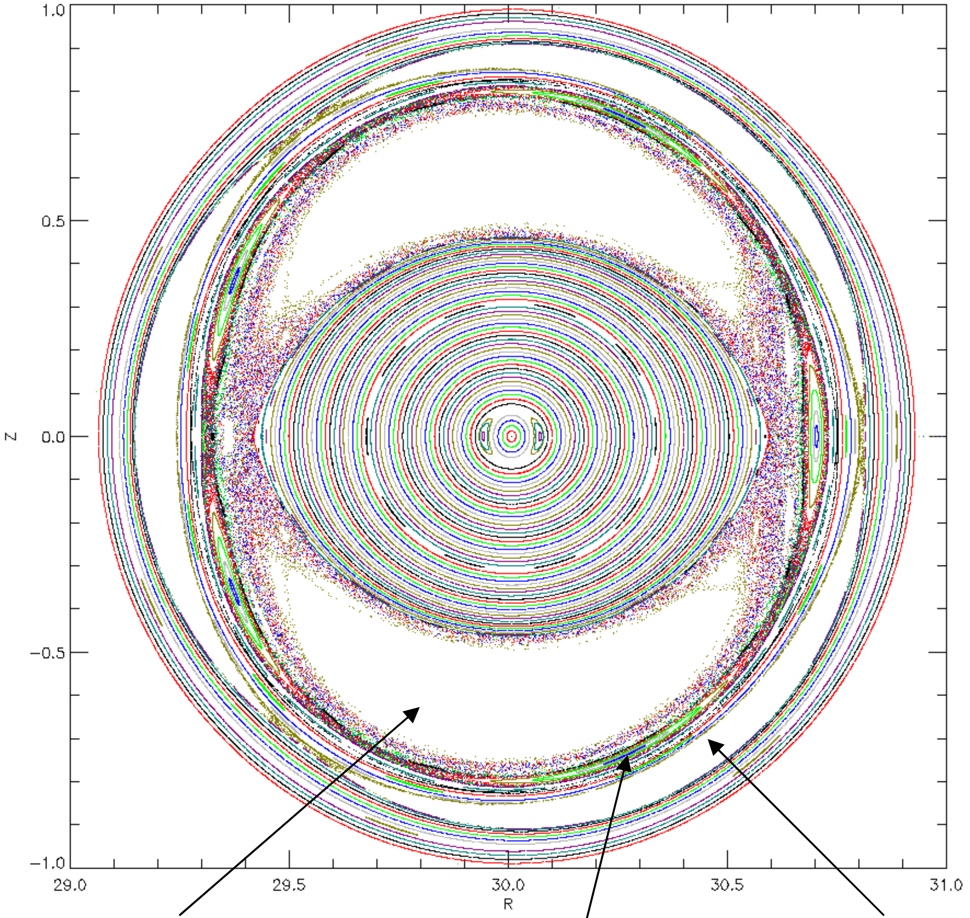
A=30





Zero plasma response: Poincaré plot

A=30, $\phi=\pi/10$

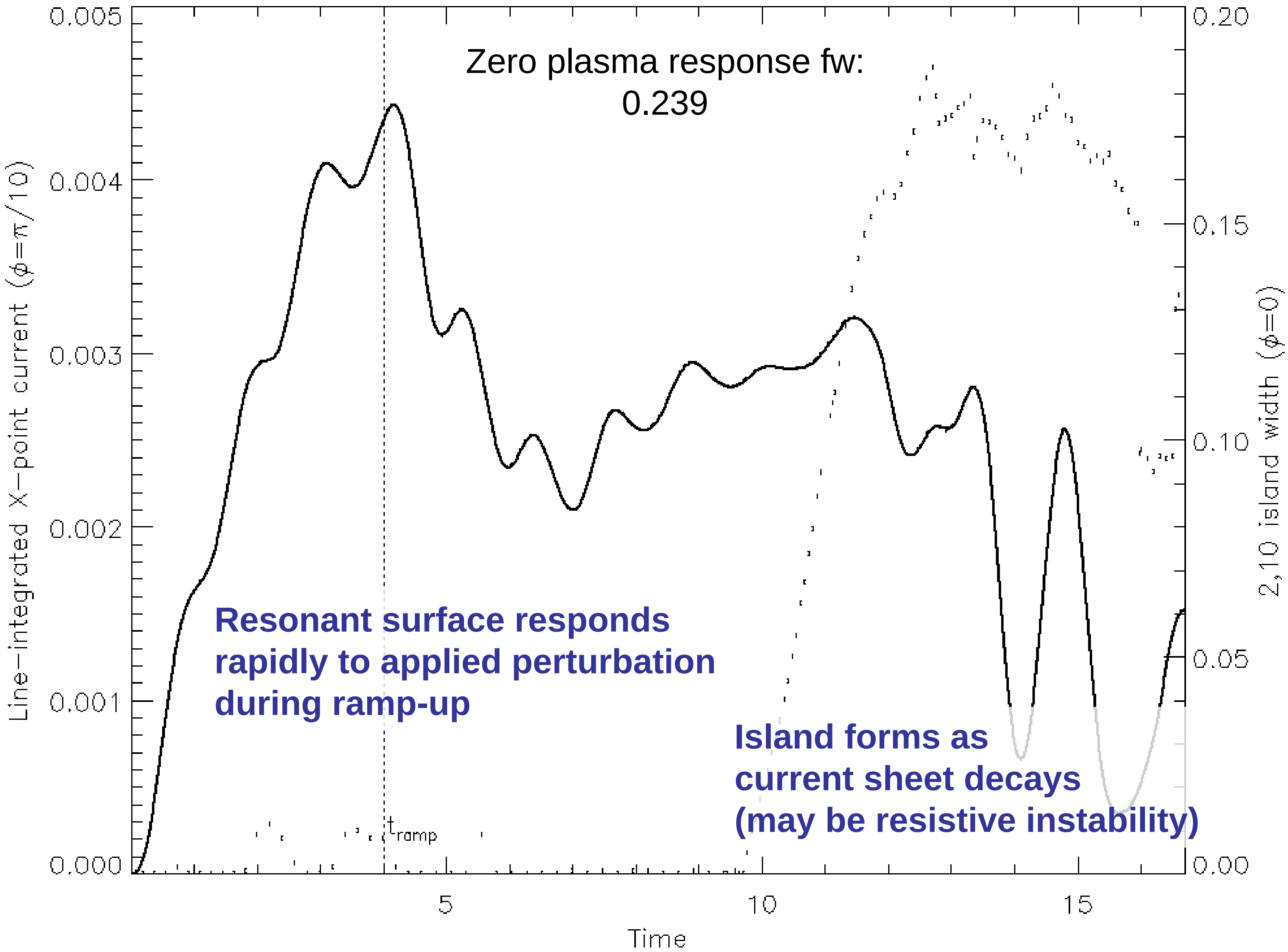


2,10 island
fw = 0.239

5,20 island

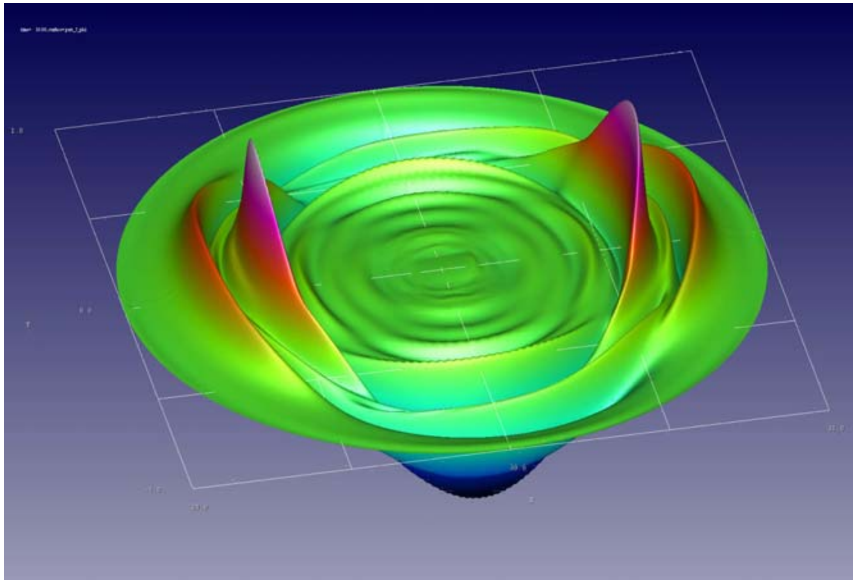
3,10 island

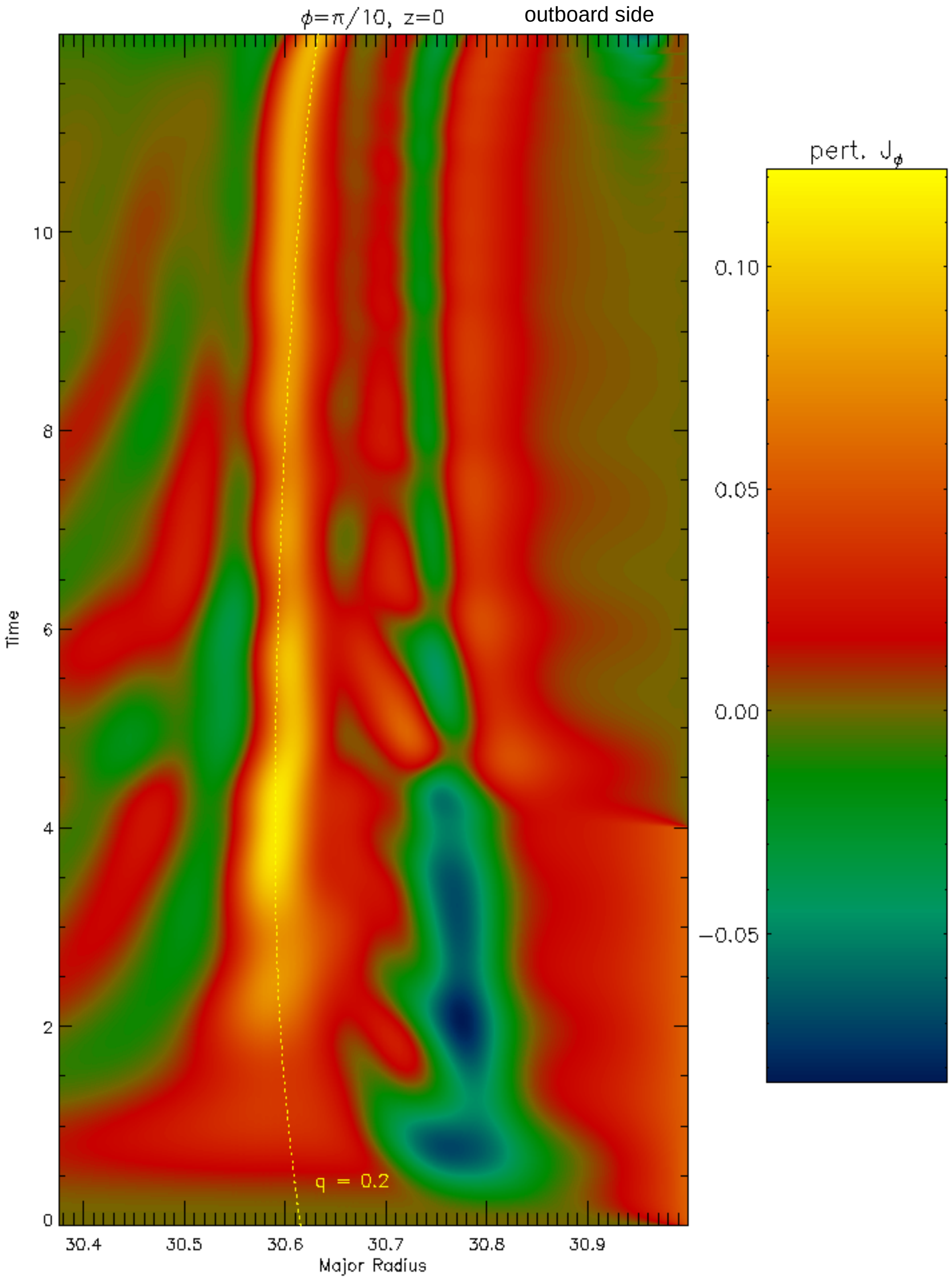
Plasma Response



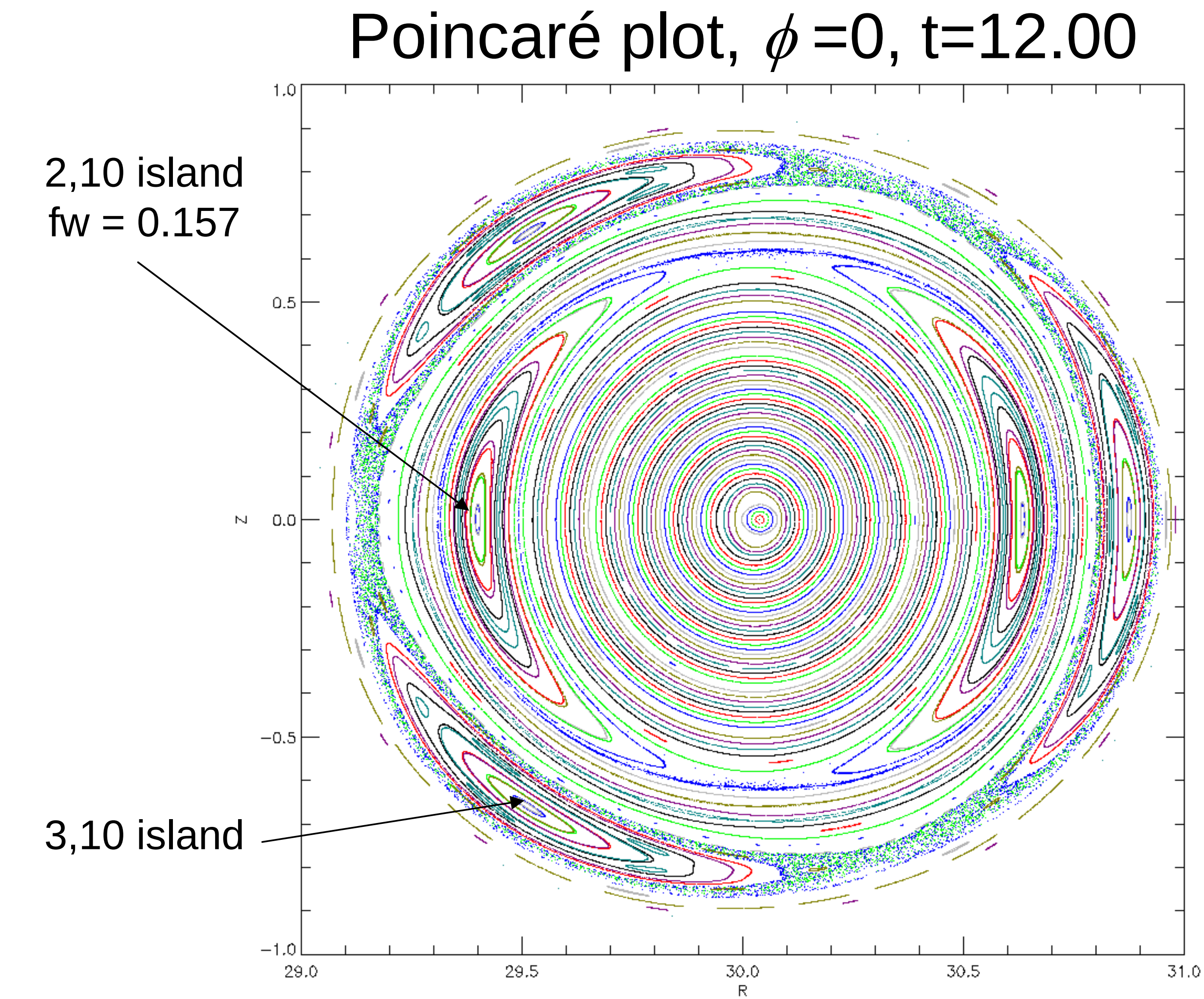
Current sheet formation

Perturbed component of J_ϕ,
$\phi=\pi/10$, $t=10.00$





Island formation

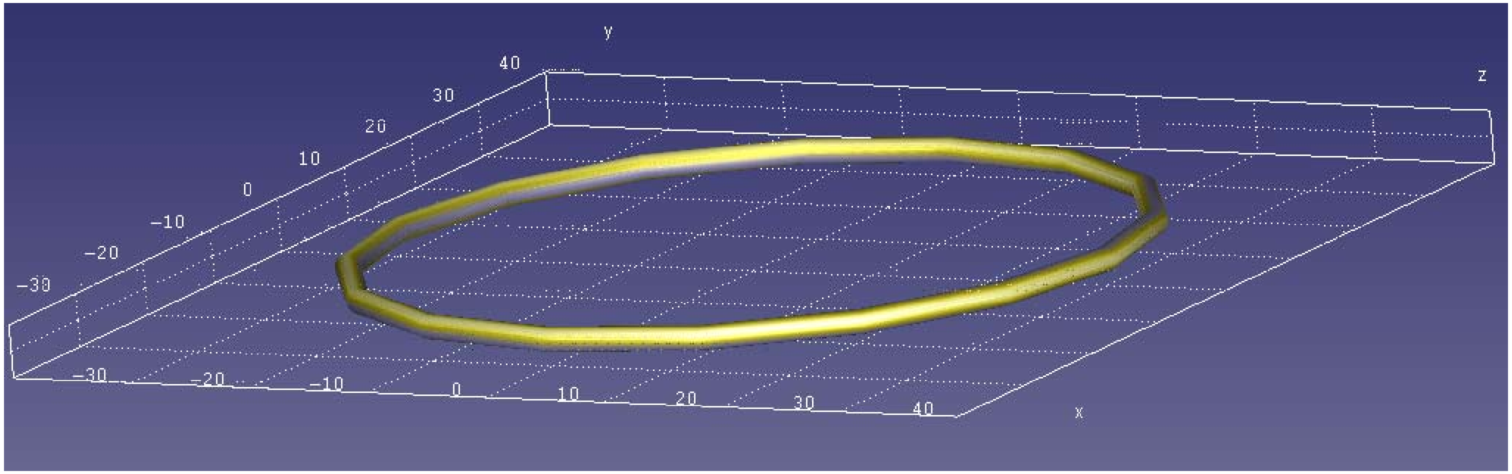


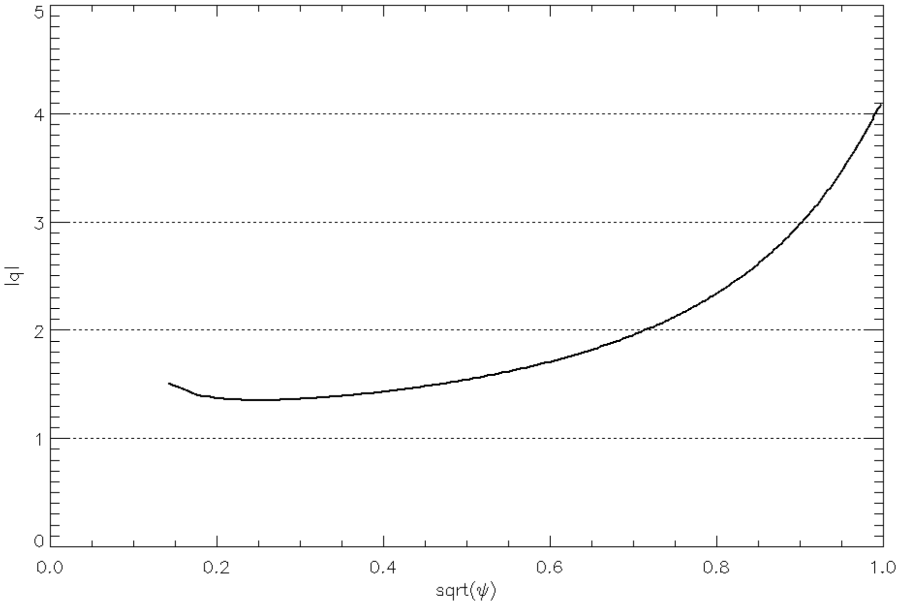
- Plasma response reduces island width compared to vacuum value.
- Width at later times is limited by overlap, stochasticity.
- q<1 makes the equilibrium unstable: rotation will not suppress islands!

New Equilibrium

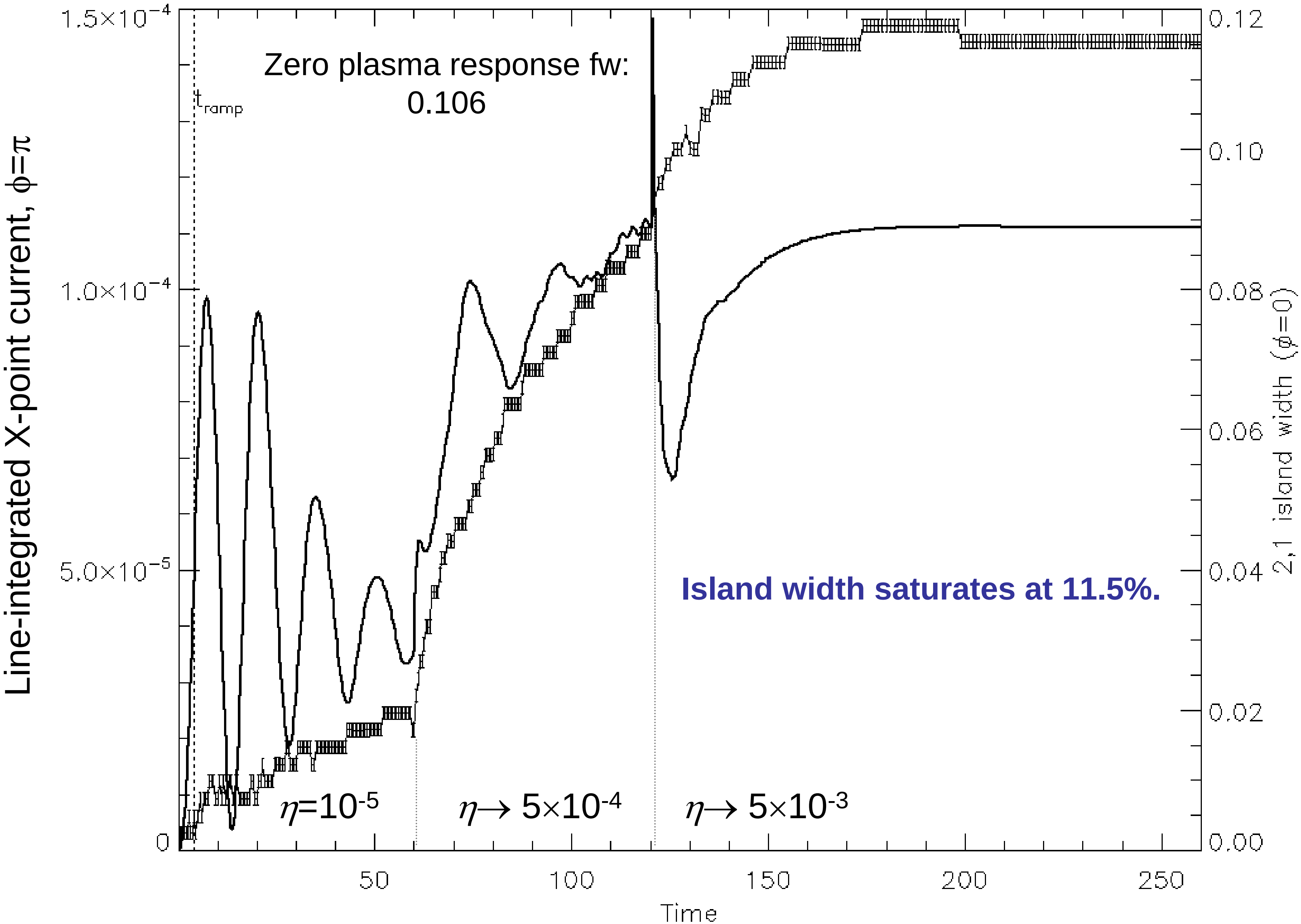
A=30, full torus

Hold *q* fixed from NSTX-like small A case



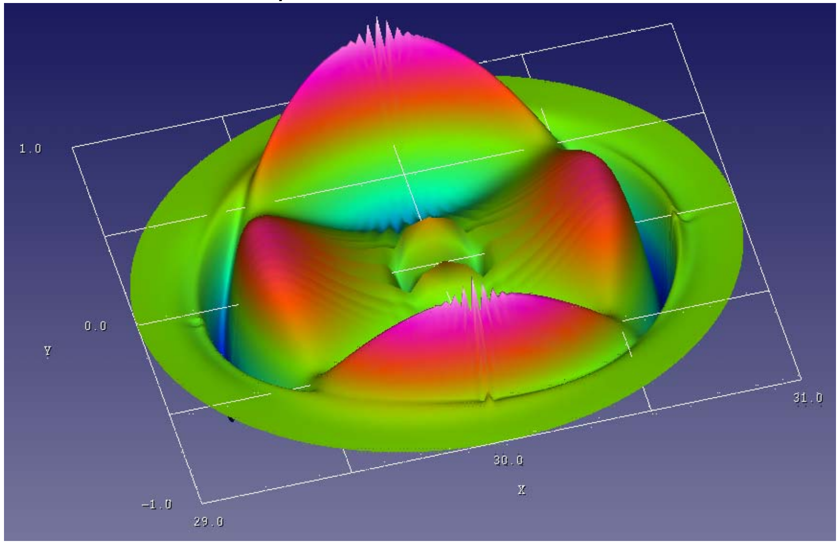


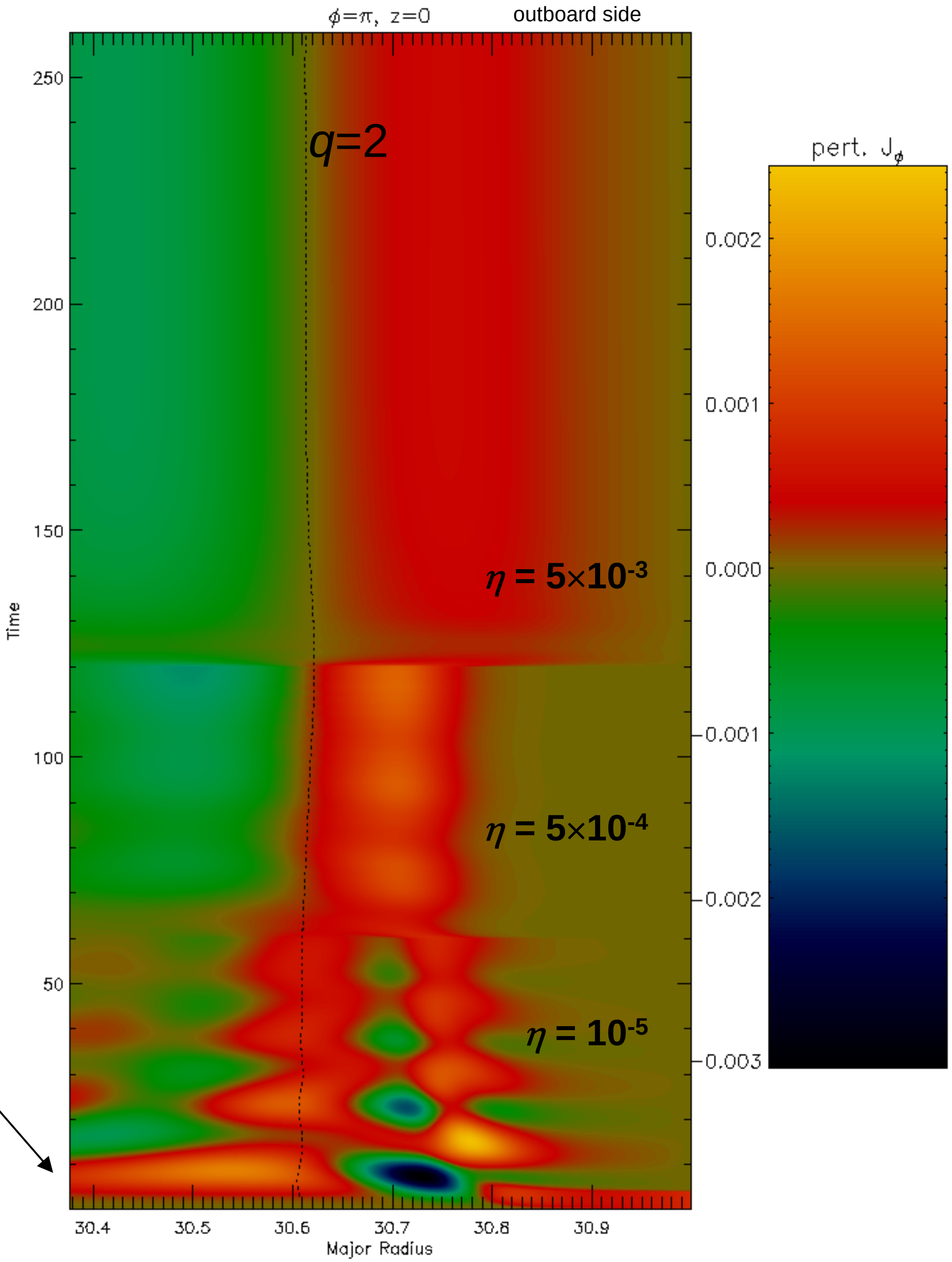
Plasma Response



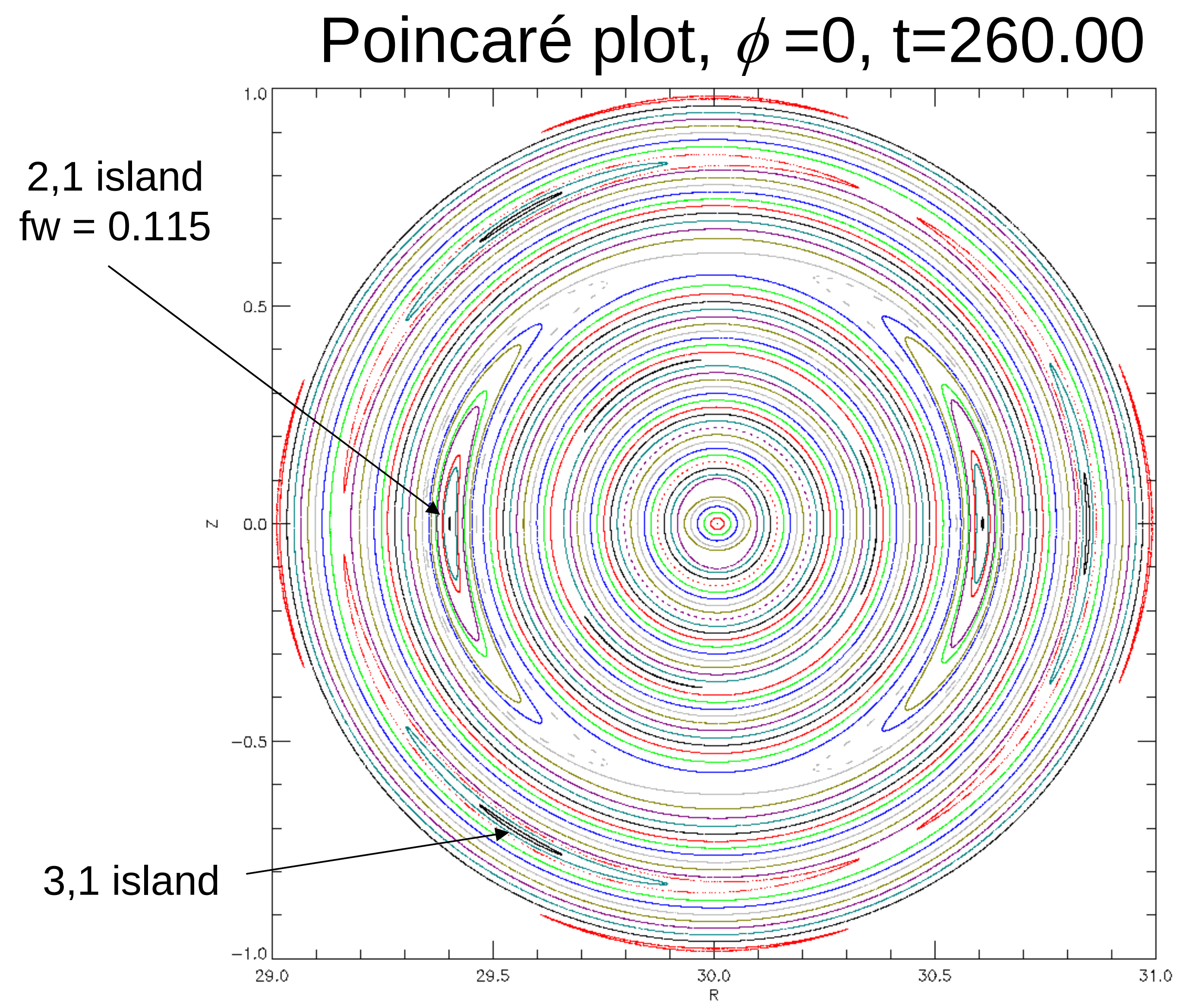
Current sheet formation

Perturbed component of J_ϕ,
$\phi=\pi$, $t=7.00$



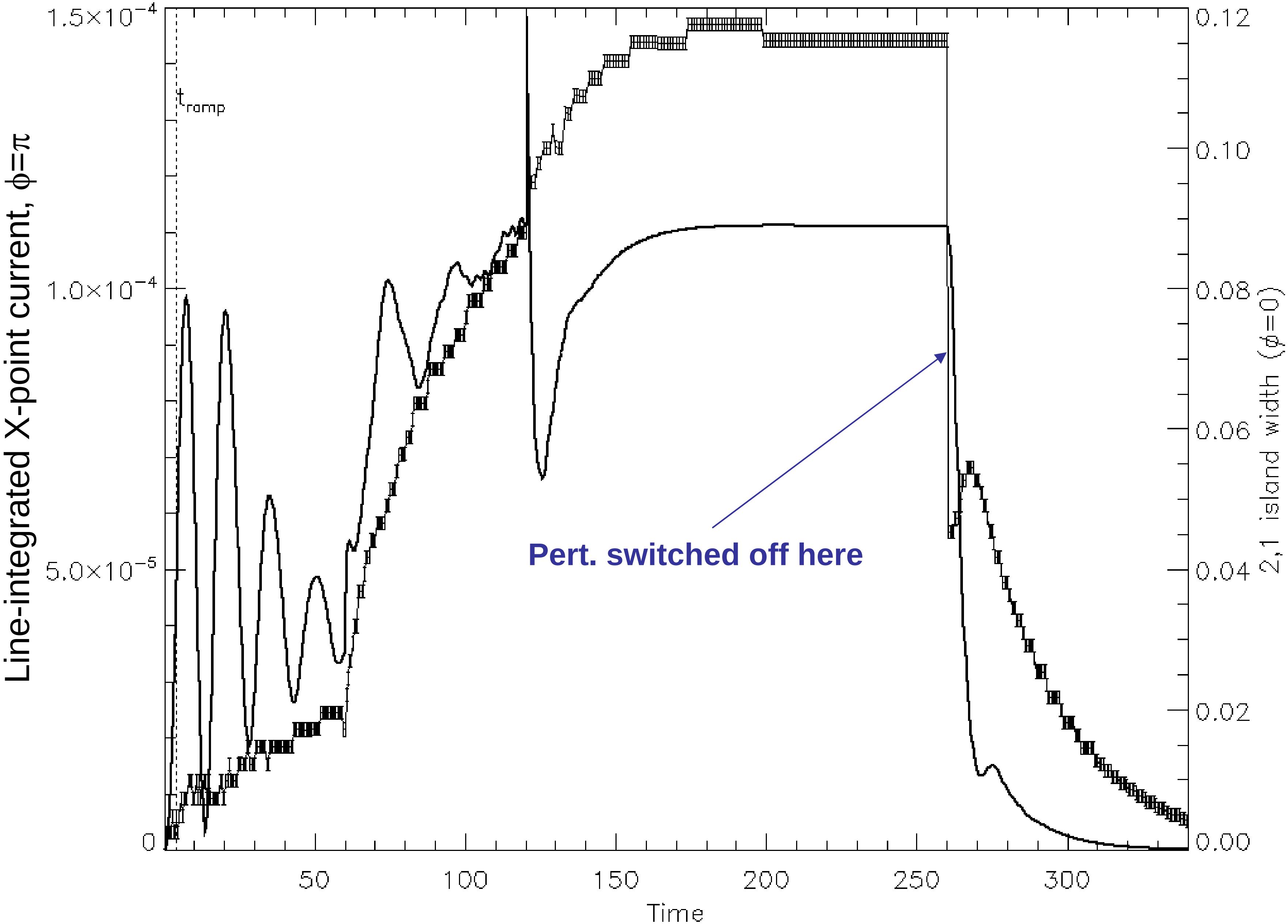


Island formation



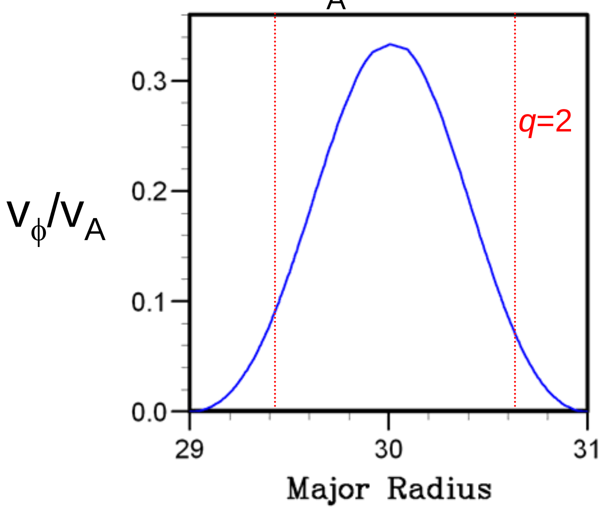
- Plasma response increases island width slightly compared to vacuum value.

Removing Perturbation Kills Island

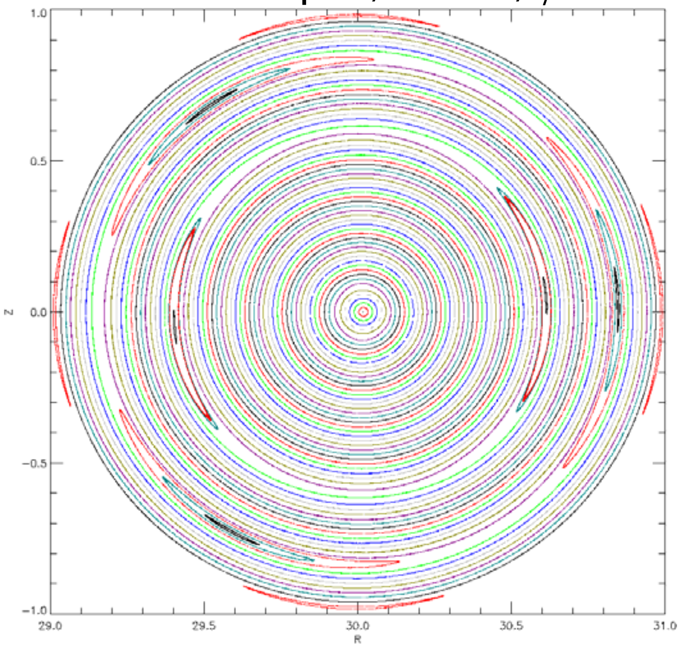


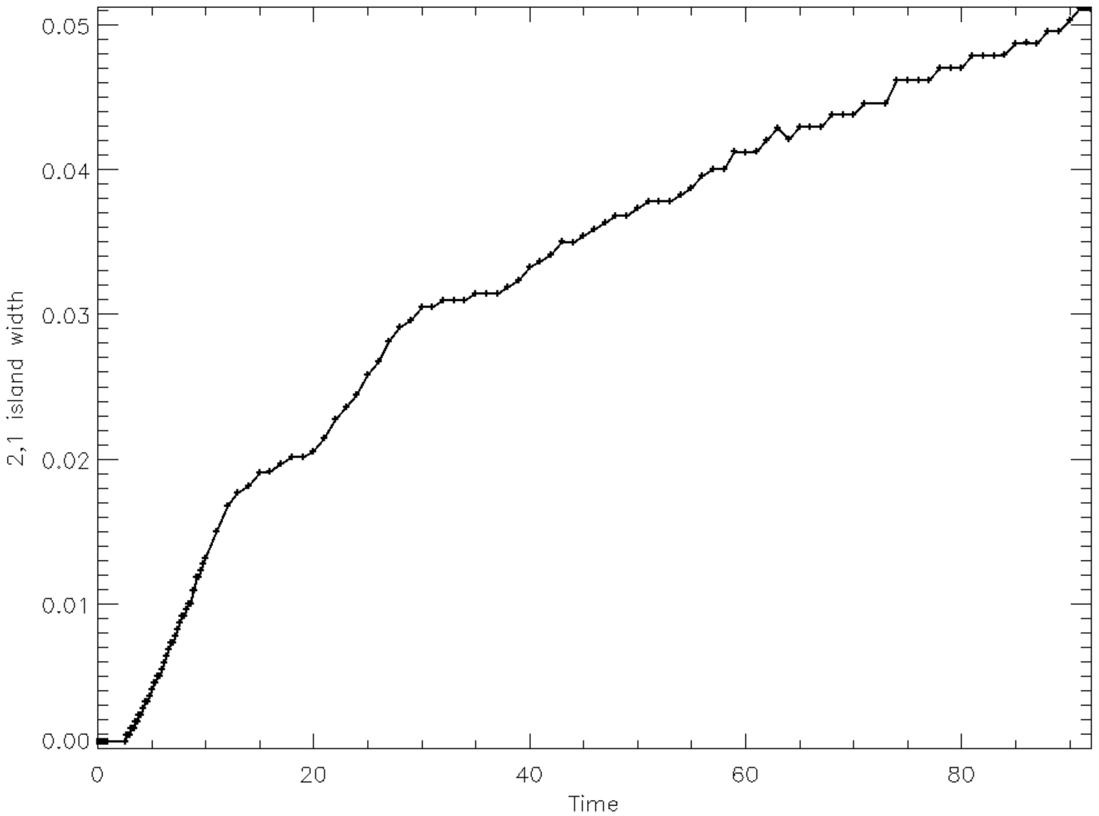
Effect of Slow Rotation

$\omega\tau_A$ = 1/90



Poincaré plot, *t*=92.5, ϕ=0

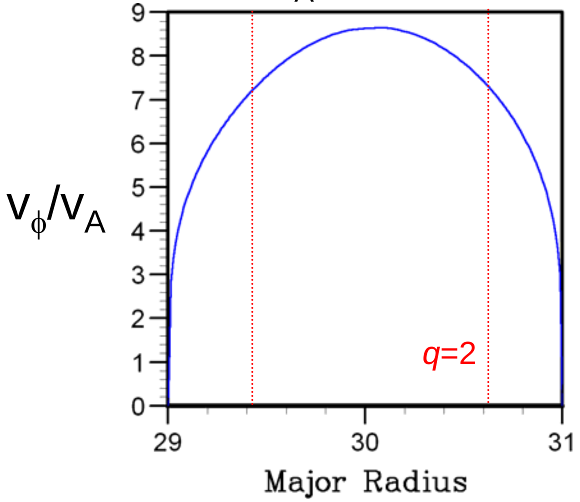




At this rate of rotation, the *q*=2 surface rotates less than one degree toroidally during one island growth time; rotation stalls and the island grows.

Effect of Rapid Rotation

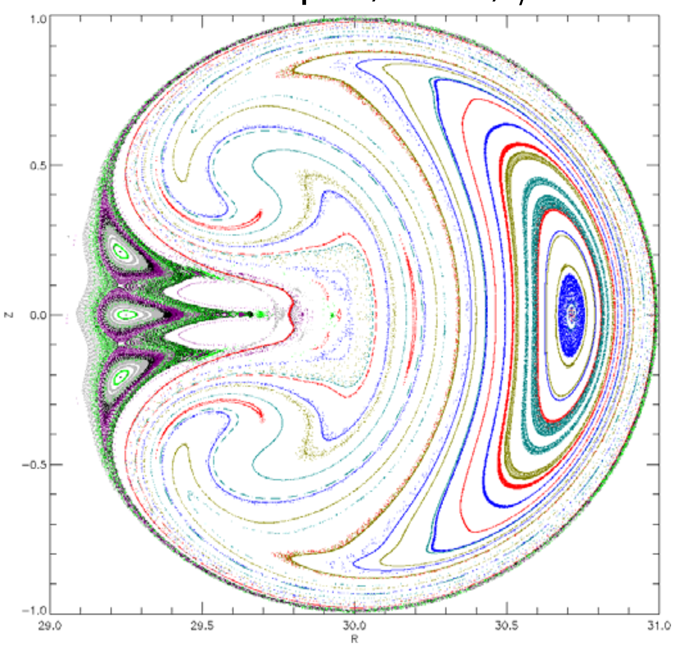
$\omega\tau_A = 0.288$



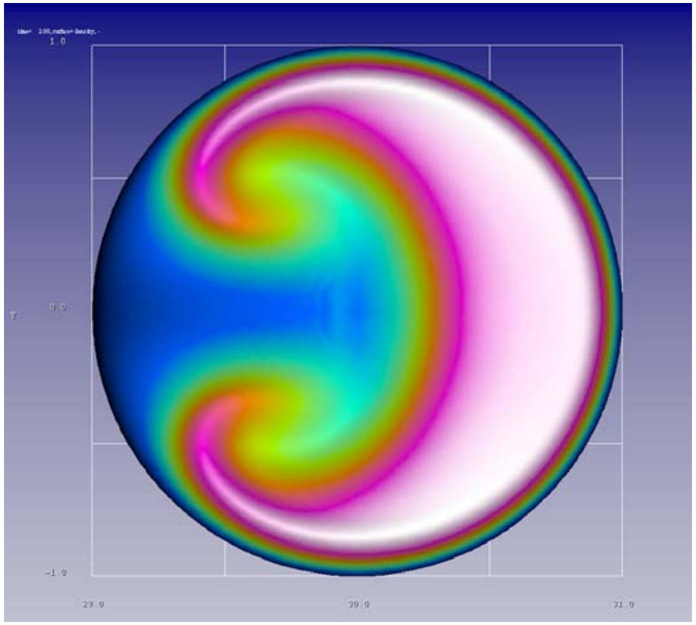
At this rate of rotation, the q=2 surface rotates about 60 degrees toroidally during one island growth time. However at this major radius, the centrifugal force is sufficient to distort the equilibrium beyond recognition.

Rotation studies should be done at low aspect ratio.

Poincaré plot, t=2.0, ϕ=0

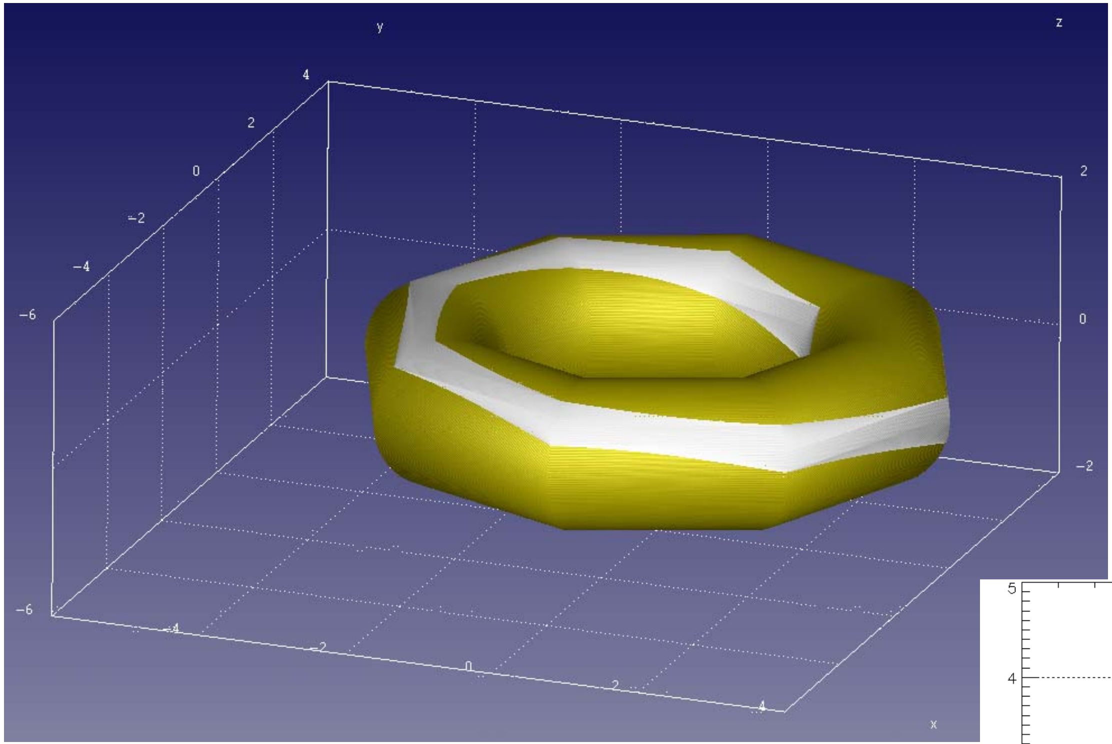


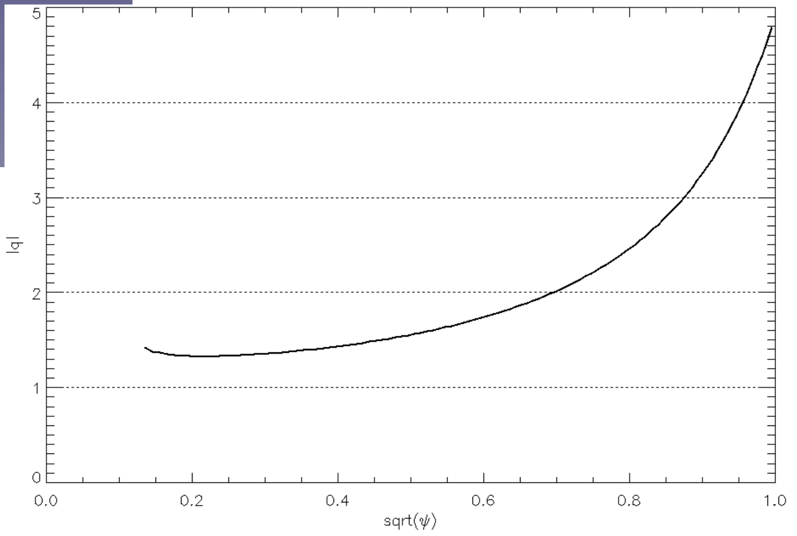
Density contours, t=2.0, ϕ=0



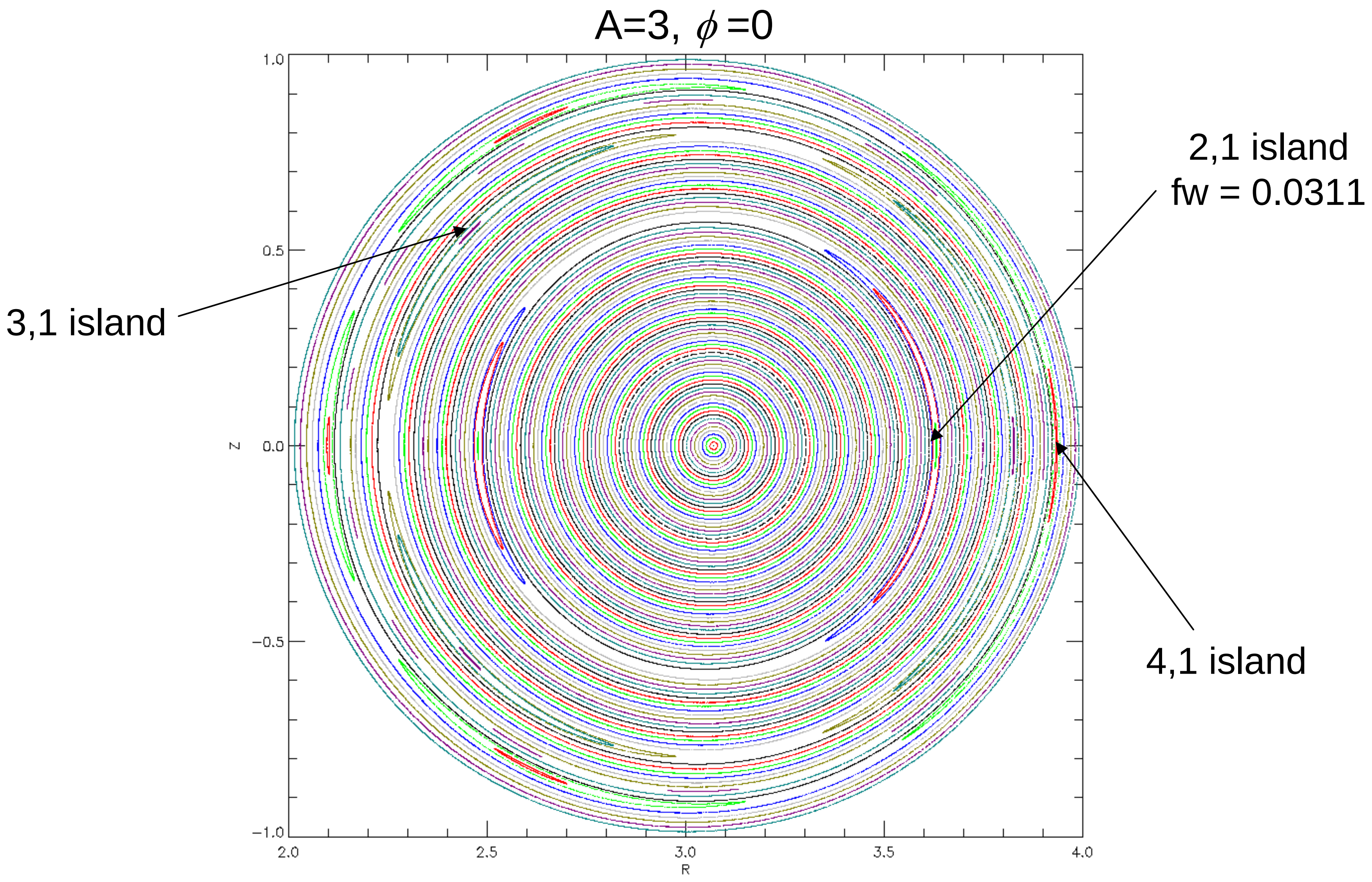
Low Aspect Ratio Equilibrium

A=3, full torus

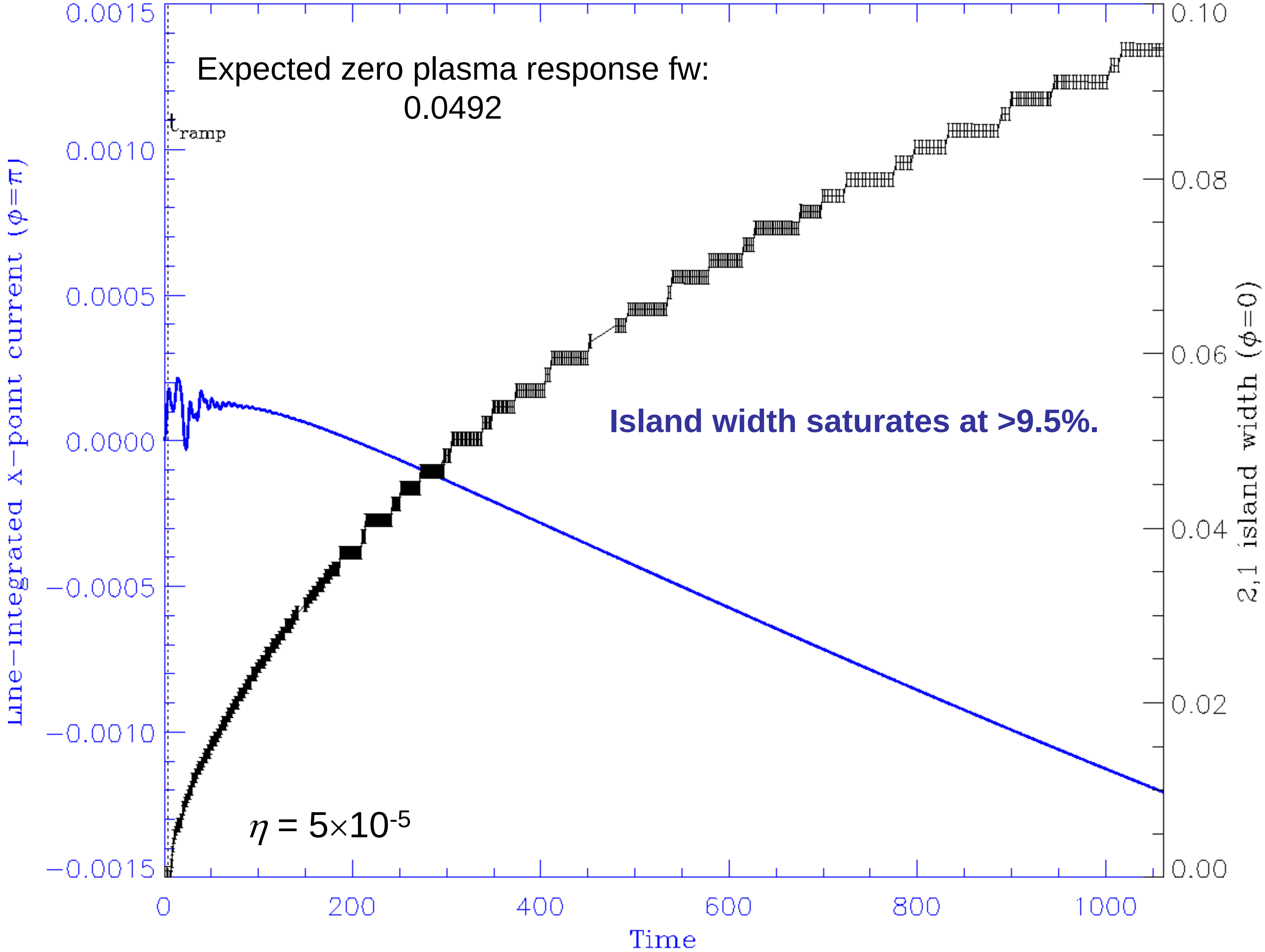




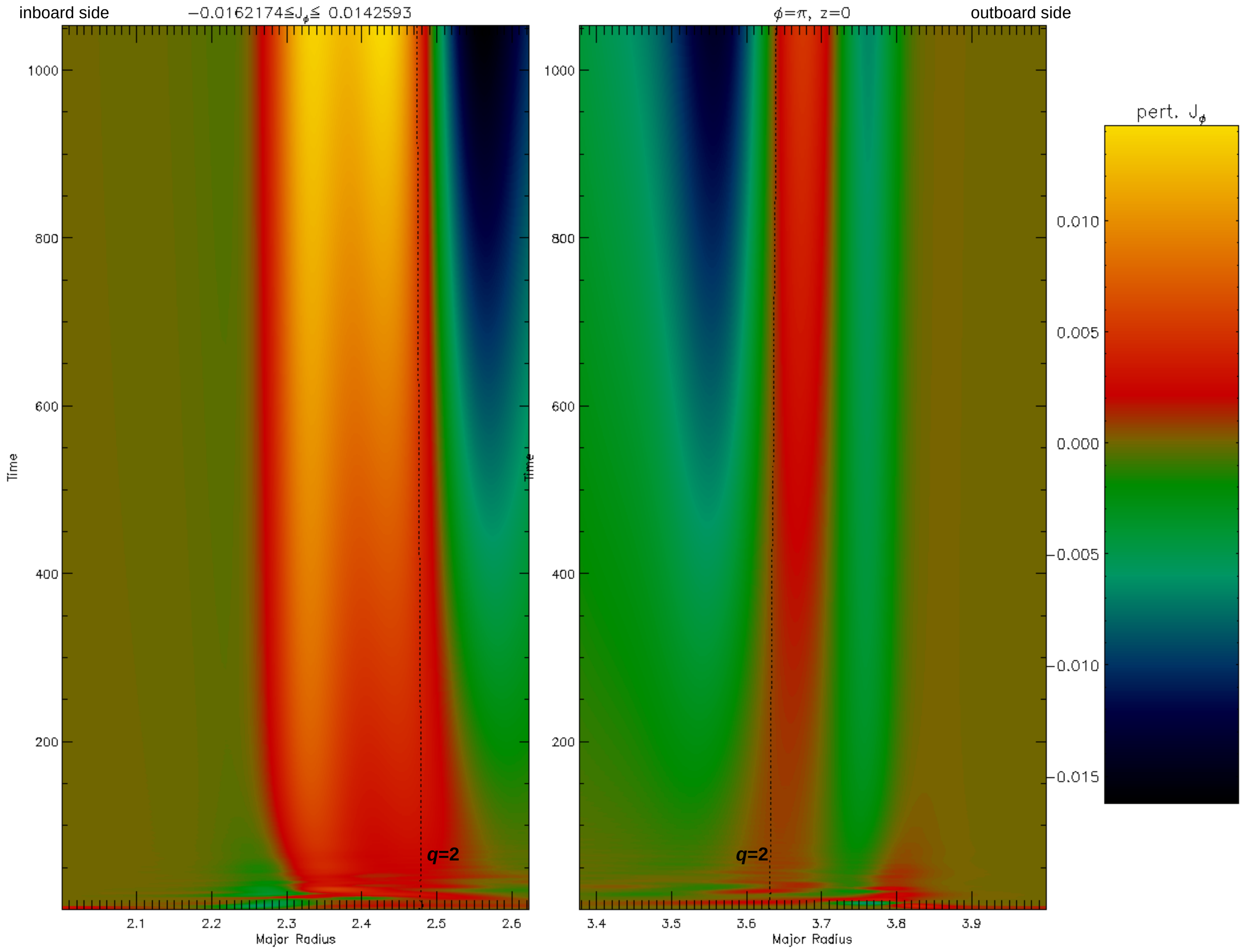
Zero plasma response: Poincaré plot



Plasma Response with no Rotation

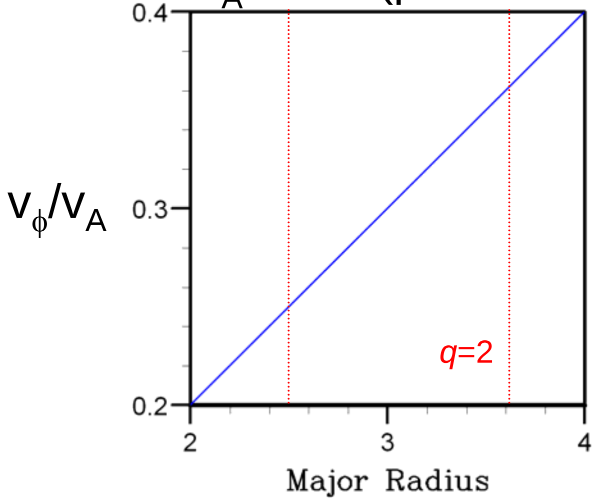


Midplane Current Density



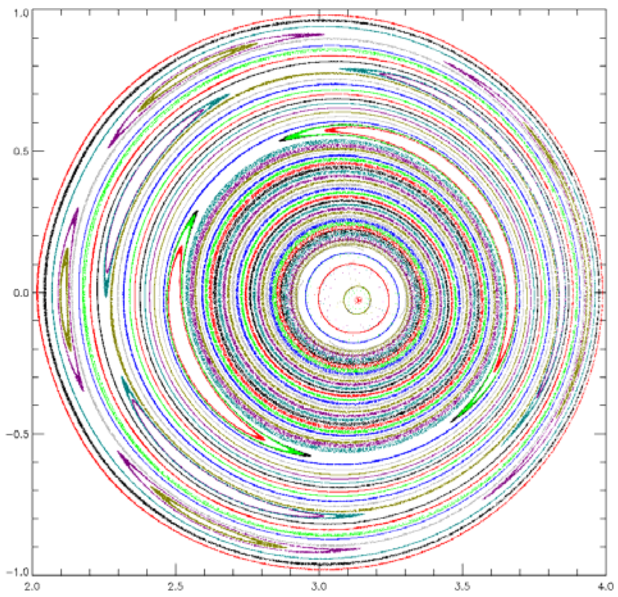
Effect of Rapid Rotation

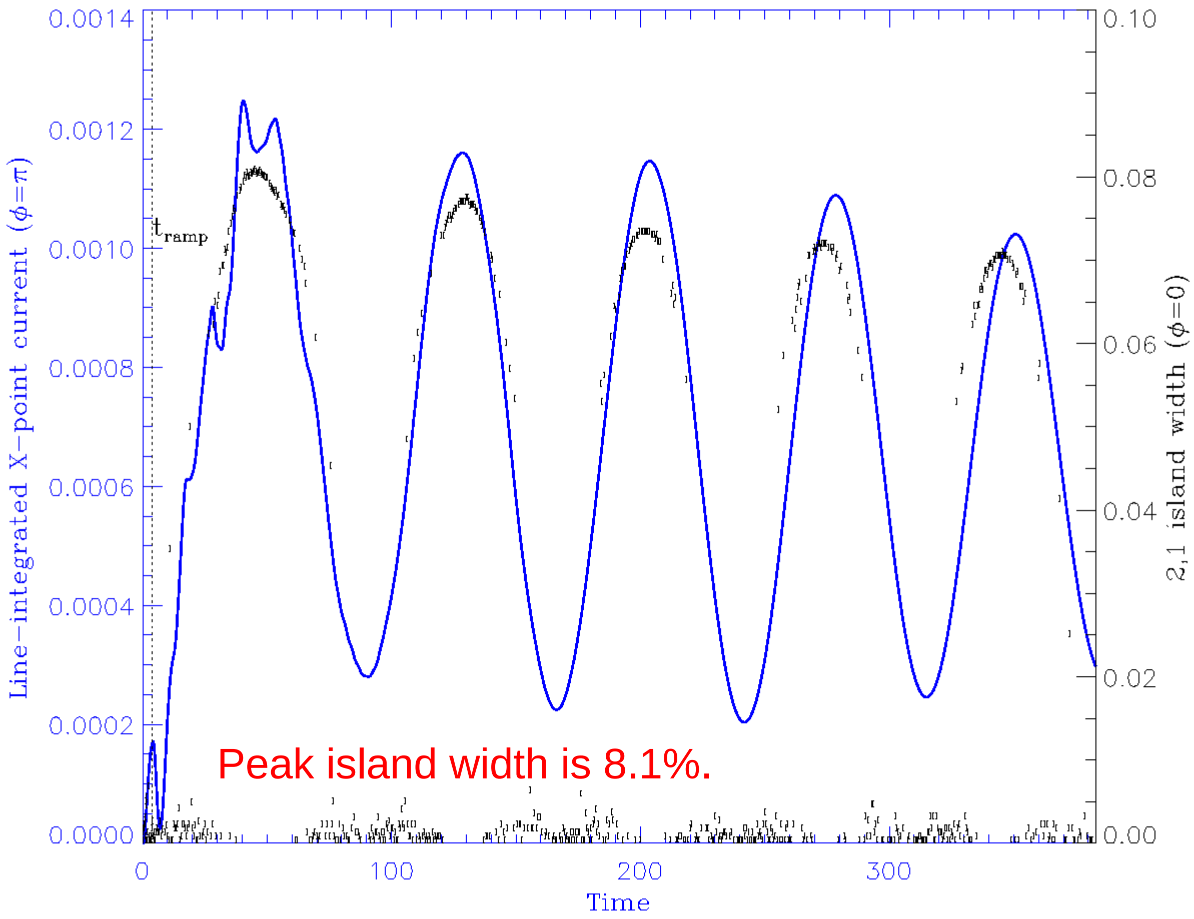
$\omega\tau_A$ = 0.1 (period = 20π)



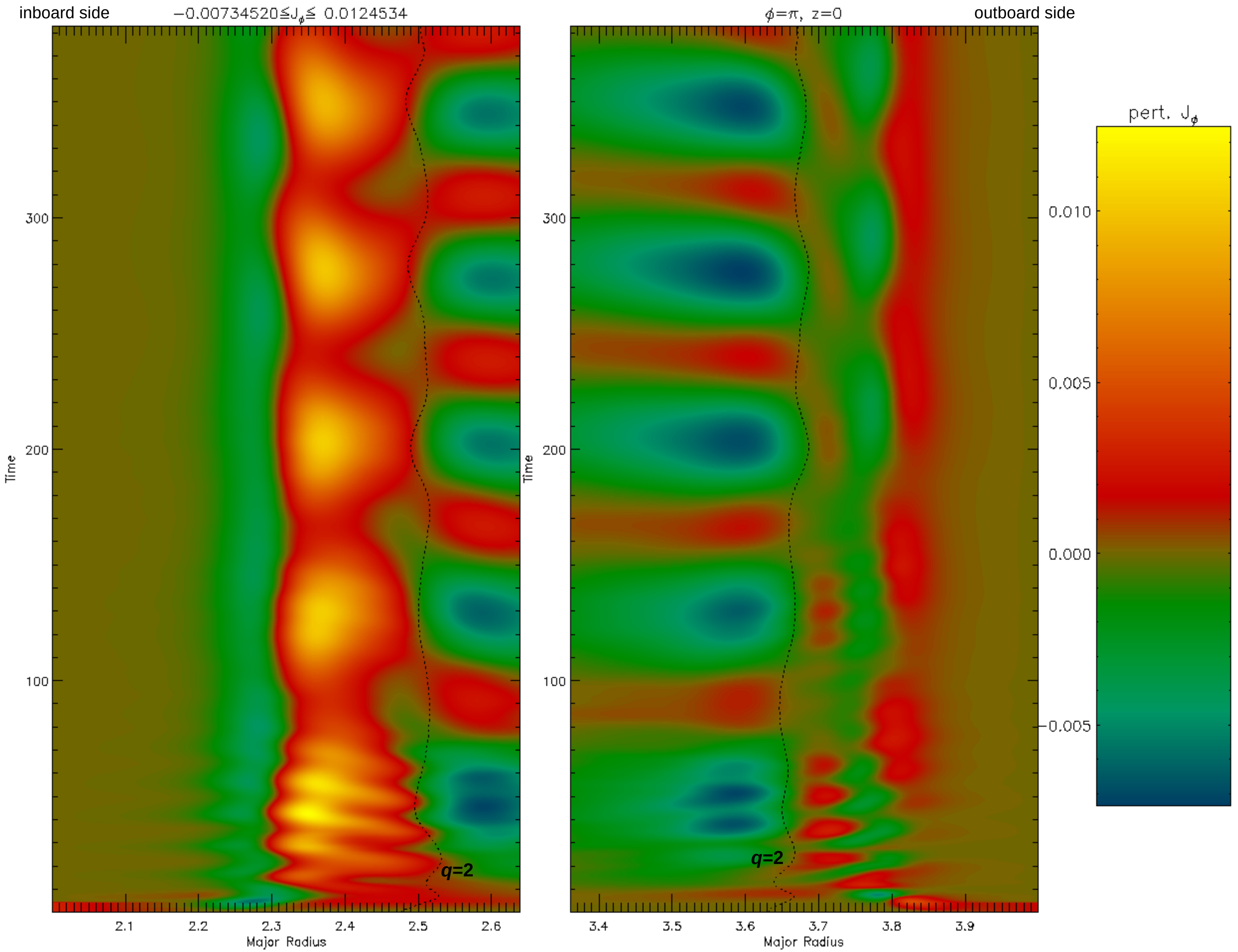
At this rate of rotation, the q=2 surface rotates through more than 360 degrees toroidally during one island growth time.

Poincaré plot, t=151.5, ϕ=0





Midplane Current Density



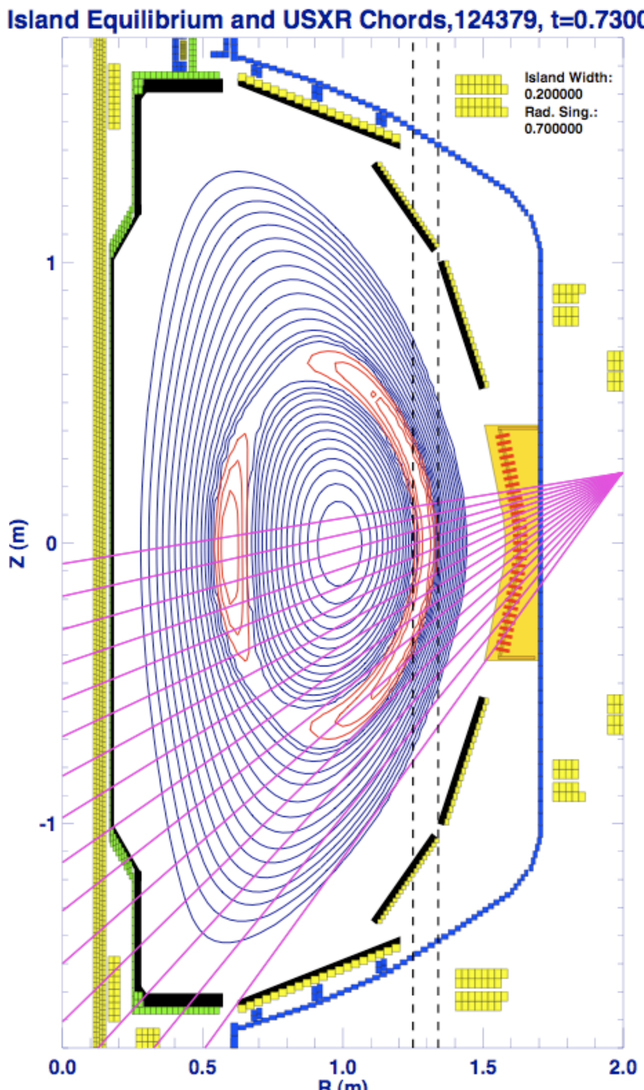
Conclusions

- M3D accurately predicts island response to RMP in the linear regime.
- Isolating current sheets requires high resolution, large aspect ratio.
- Large aspect ratio is not appropriate for rotation studies.
- Plasma rotation damps resonant islands.

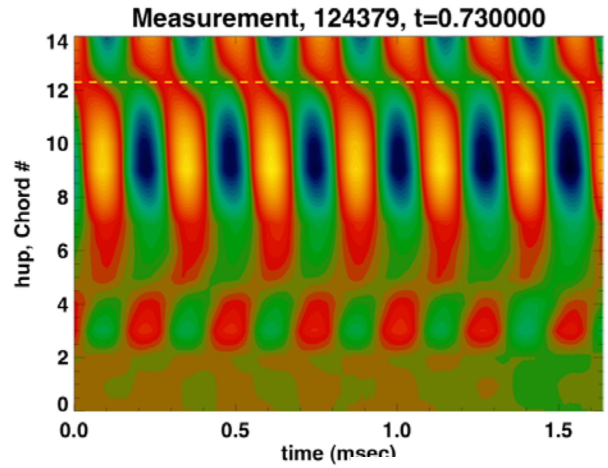
NSTX "Long-lived" Mode

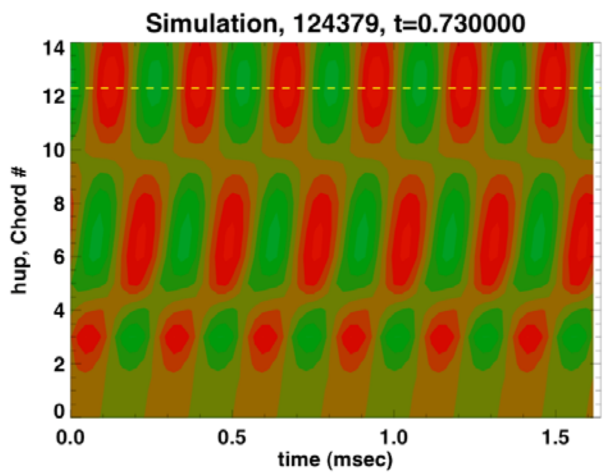
(2,1 mode without an evident trigger)

Eigenfunction Analysis of Multichord Data Suggests Coupling to 1,1 Ideal Kink

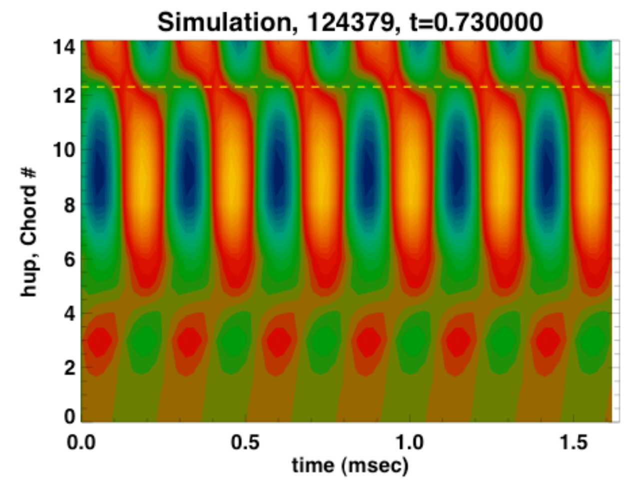


Gerhardt

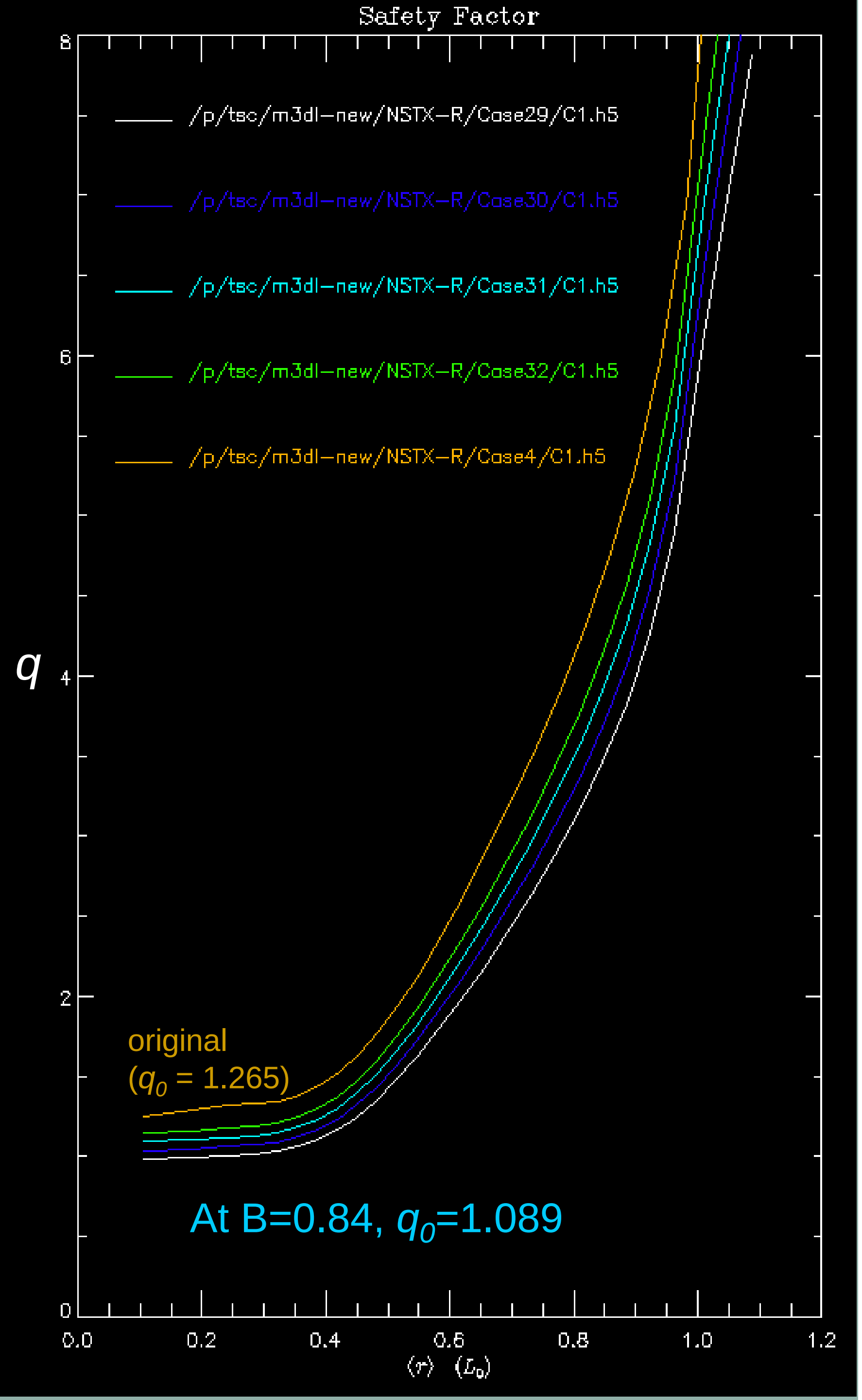




2,1 only

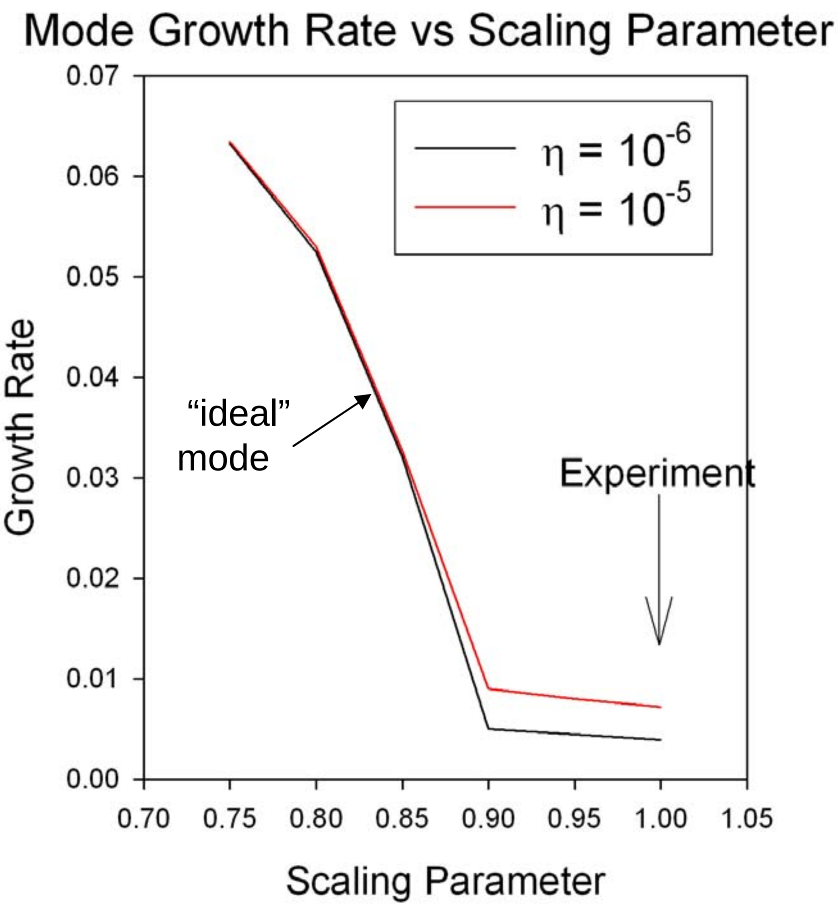


2,1 + 1,1 pert



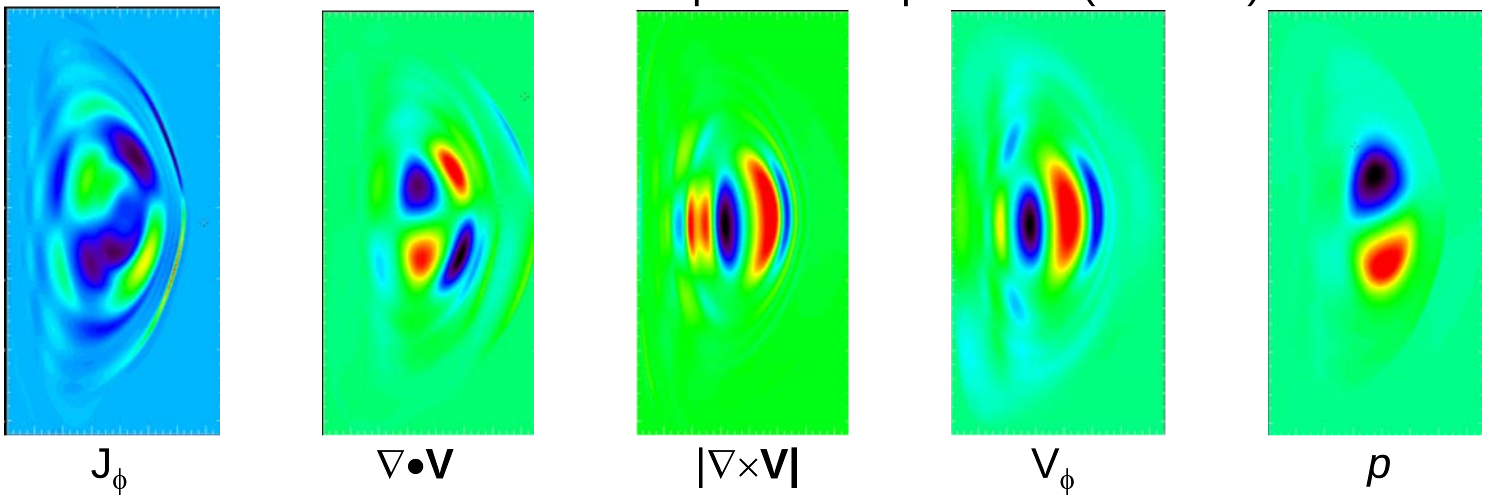
Toroidal field was scaled down, keeping current density constant. Scan of scaling parameter with *C¹* code shows equilibrium is close to marginal stability for ideal mode.

(q proportional to scaling factor)

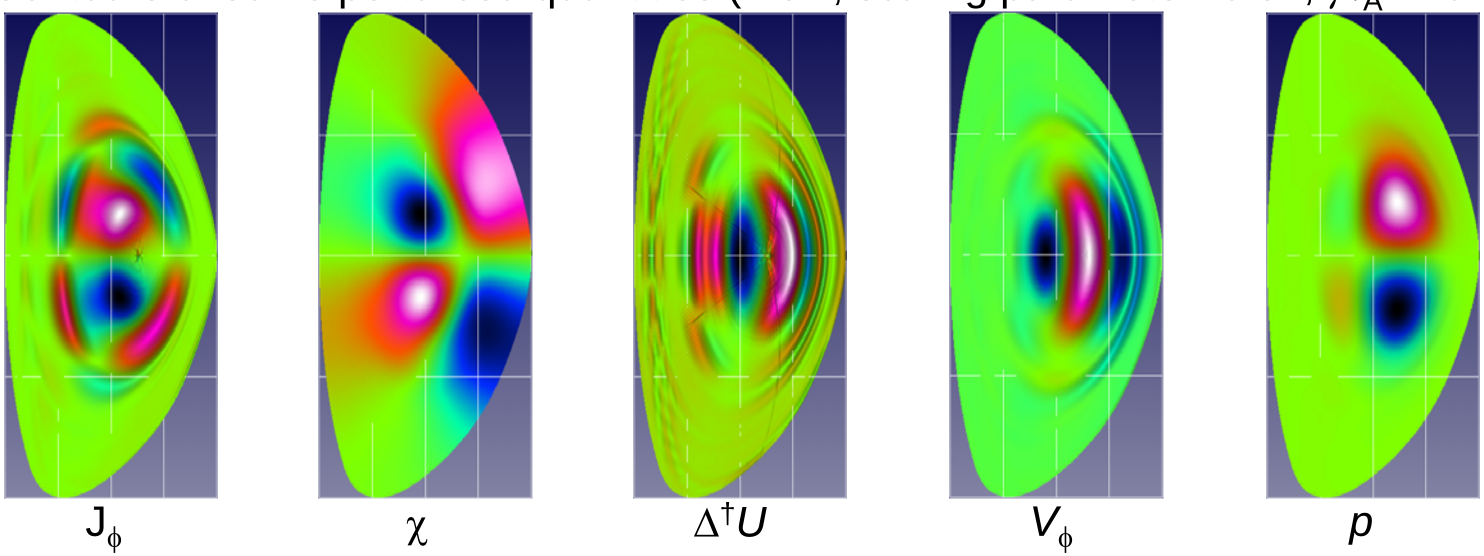


Ideal mode has strong *m*=1 and other low-*m* components

Contours of some perturbed quantities (M3D-*C*[1])

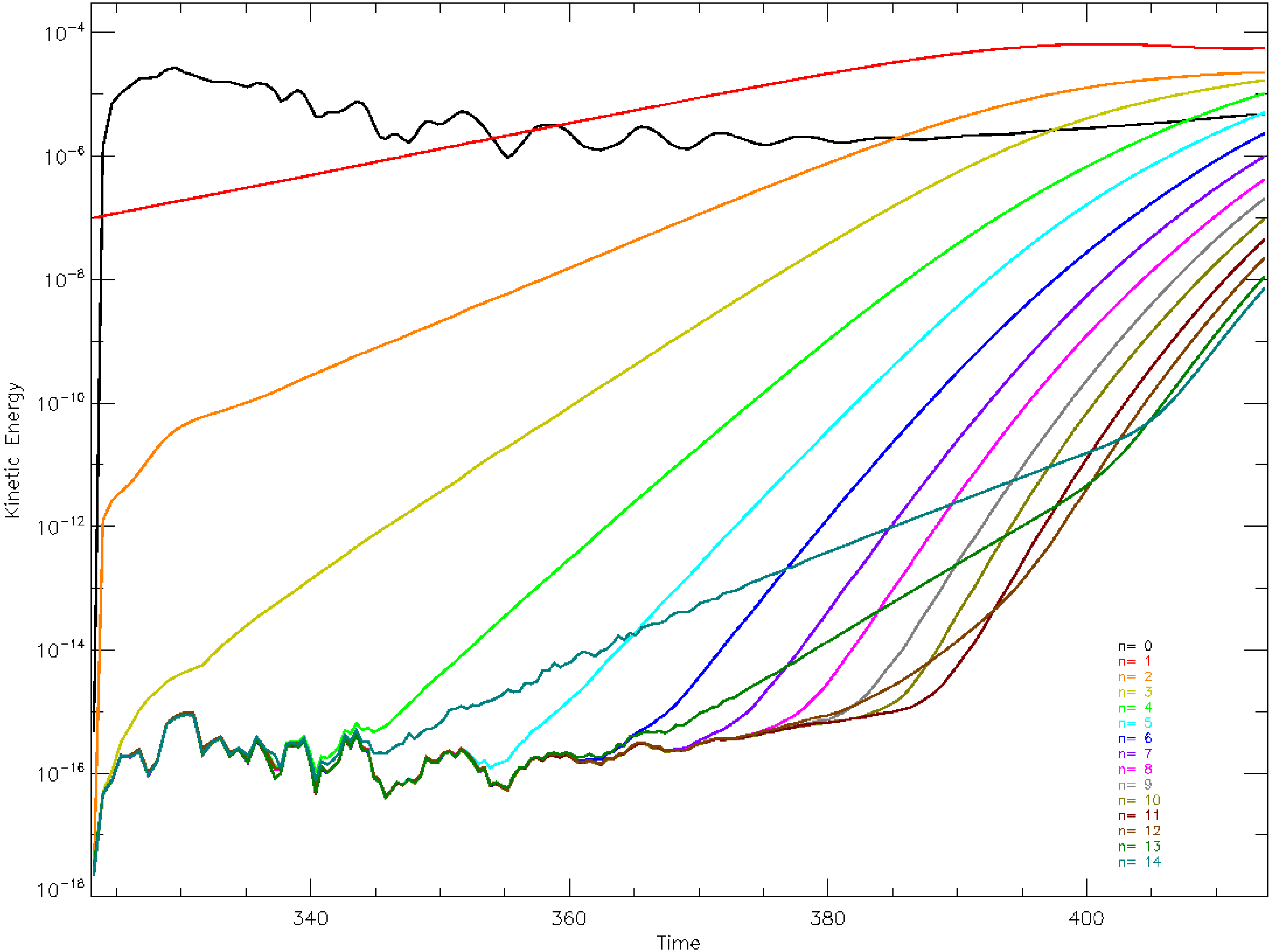


Contours of some perturbed quantities (M3D, scaling parameter=0.84, $\gamma\tau_A$=4.91×10^{-2})

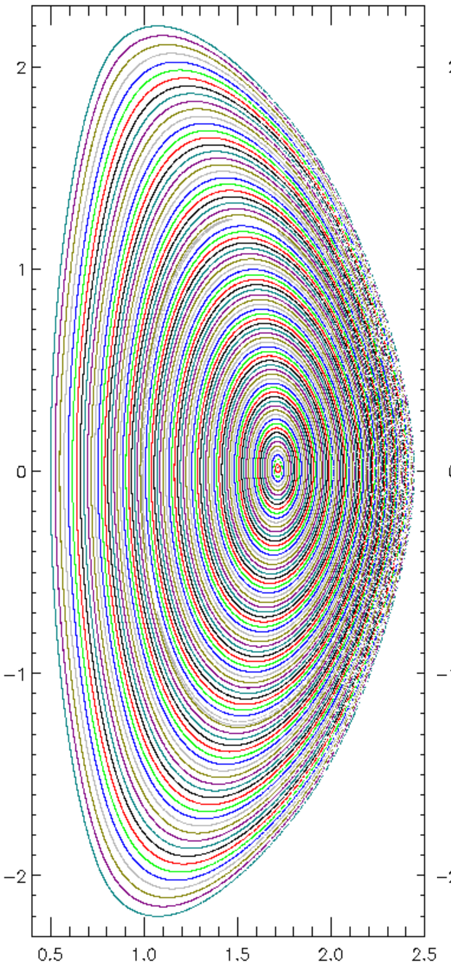


Nonlinear Evolution

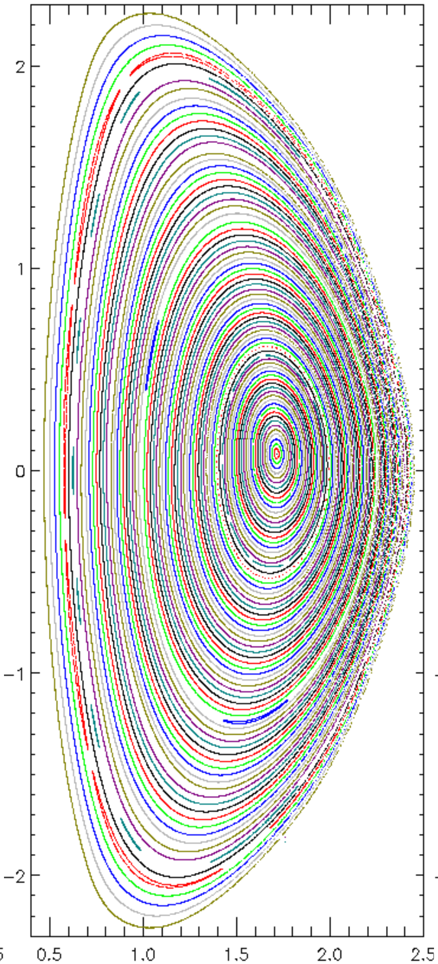
by mode number



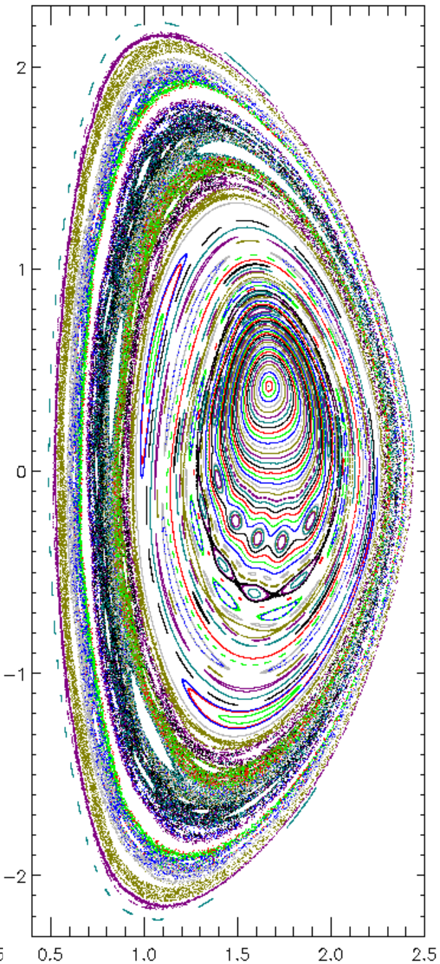
Poincaré Plots



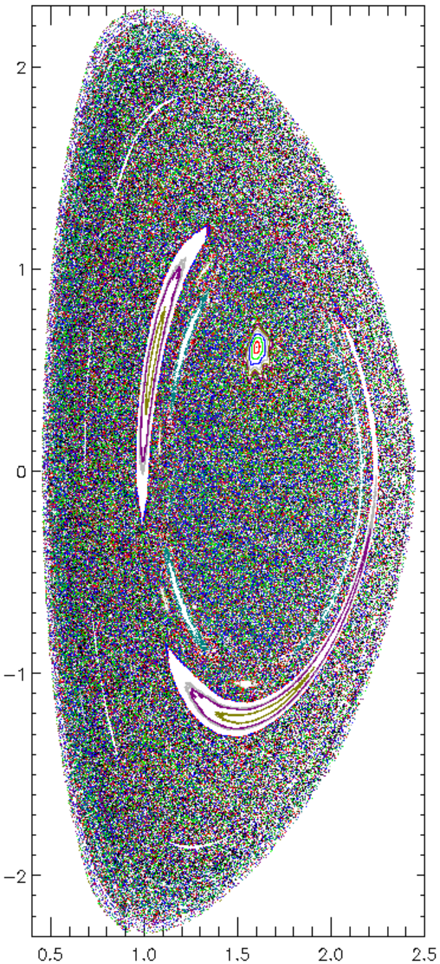
t = 323.23



t = 360.18



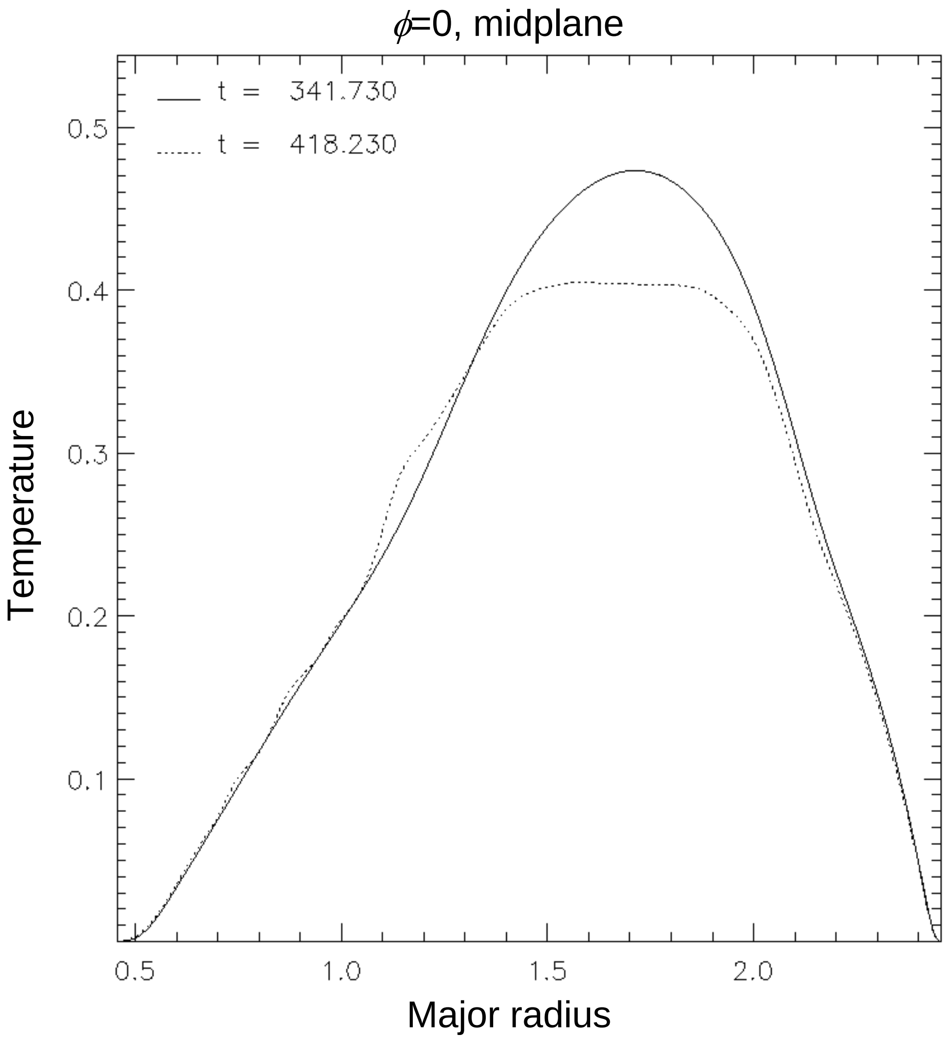
t = 395.73

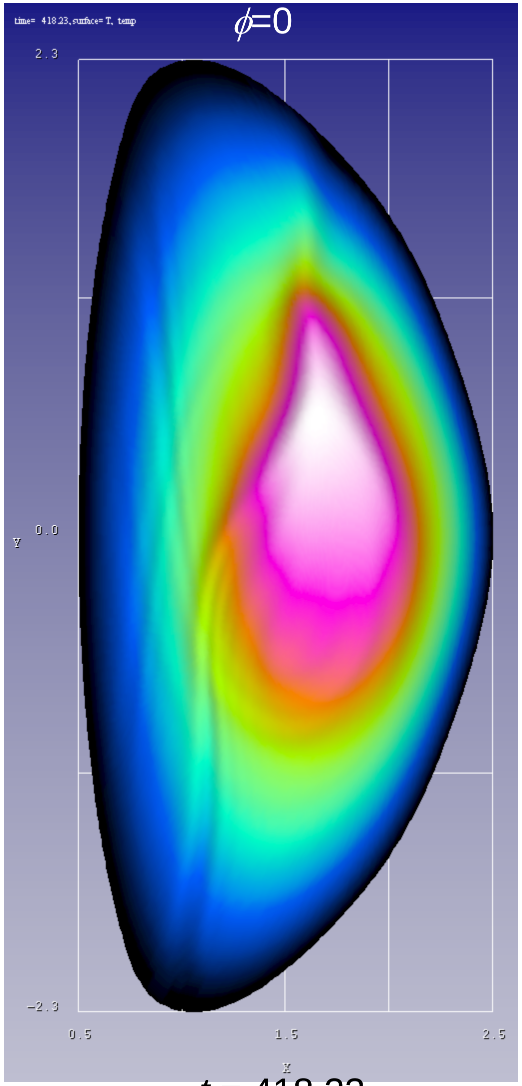


t = 418.23

2,1 island forms, persists

Stochasticicization leads to modest temperature flattening





t = 418.23