Progress on the CDX-U *m*=1 mode test problem

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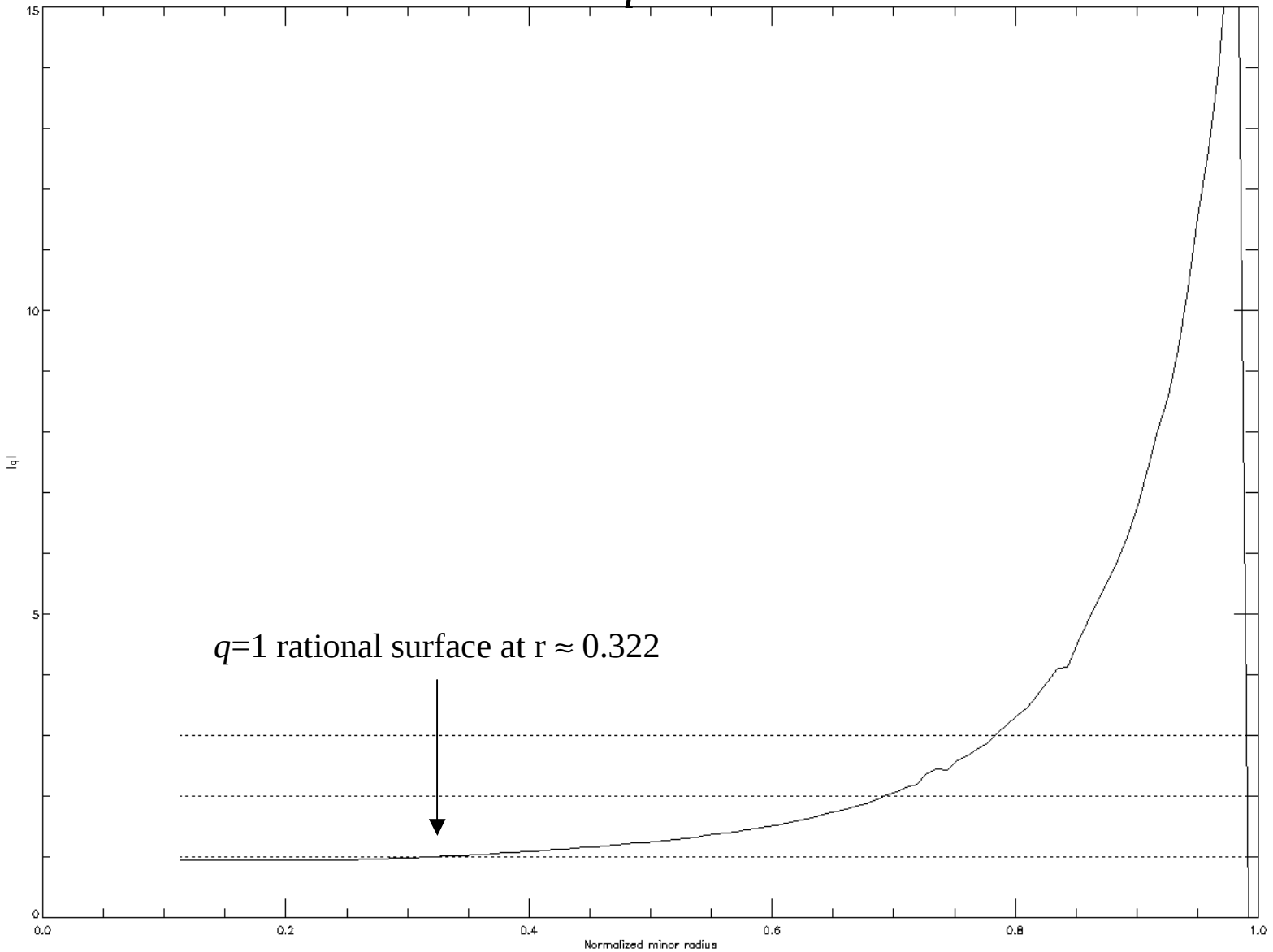
Outline

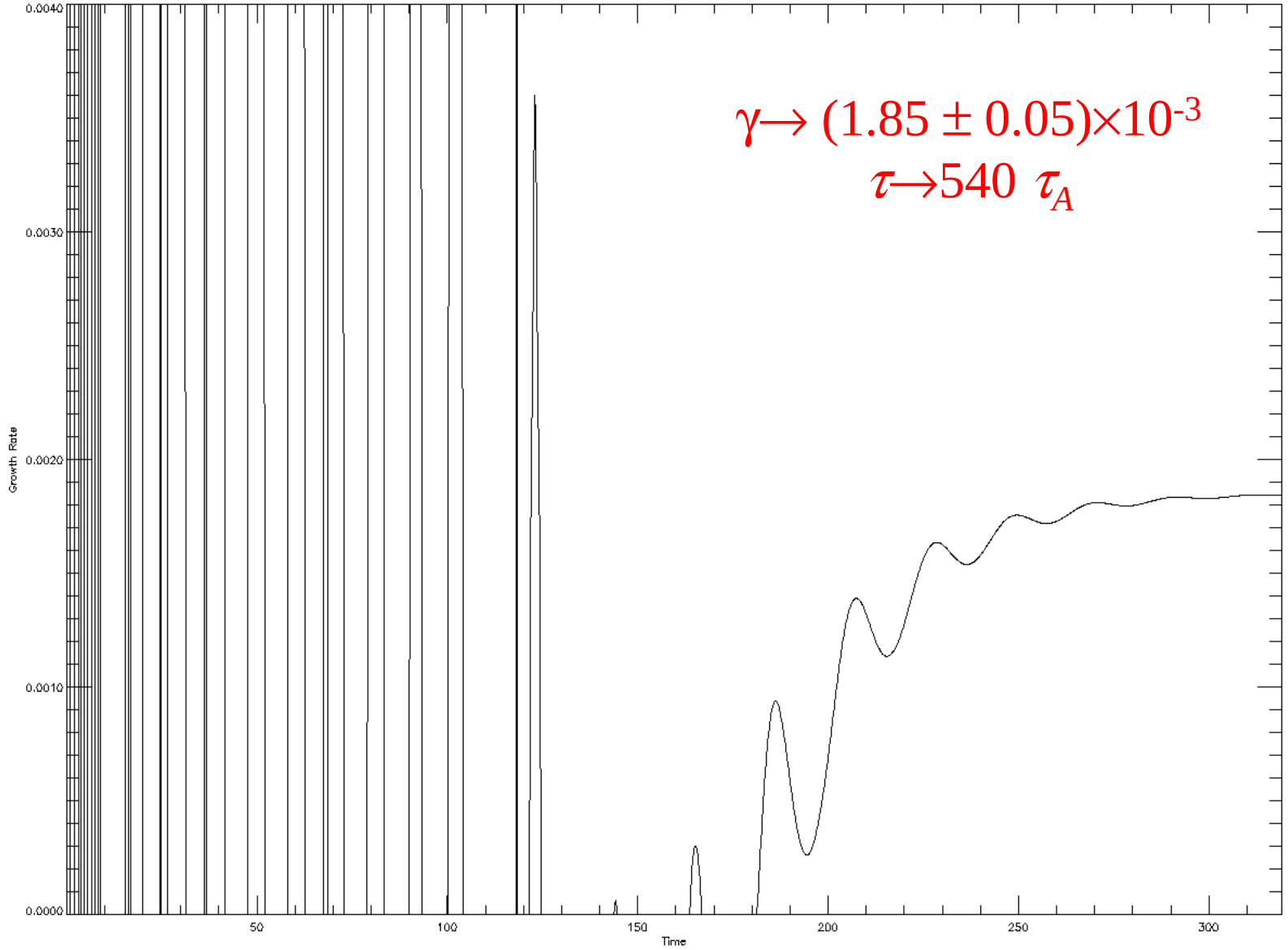
- Generate an evolving series of CDX equilibria with the Tokamak Simulation Code (TSC).
  - Aspect ratio R_0/a = 0.34 / 0.24 = 1.4
  - I_p = 55 kA
  - β in the range 2 - 4 %.
  - q profiles monotonic, increasing; q_0 decreases from 1.53 to 0.89 over series.
- Look for linear n=1 mode for select cases with M3D.
- Amplify 1,1 modes and evolve nonlinearly with M3D to observe sawtooth crash.
- Characterize dependence of orderliness of evolution on initial q profile.

Case 1: $q_0 = 0.955$

Initial q Profile



Linear phase: growth rate



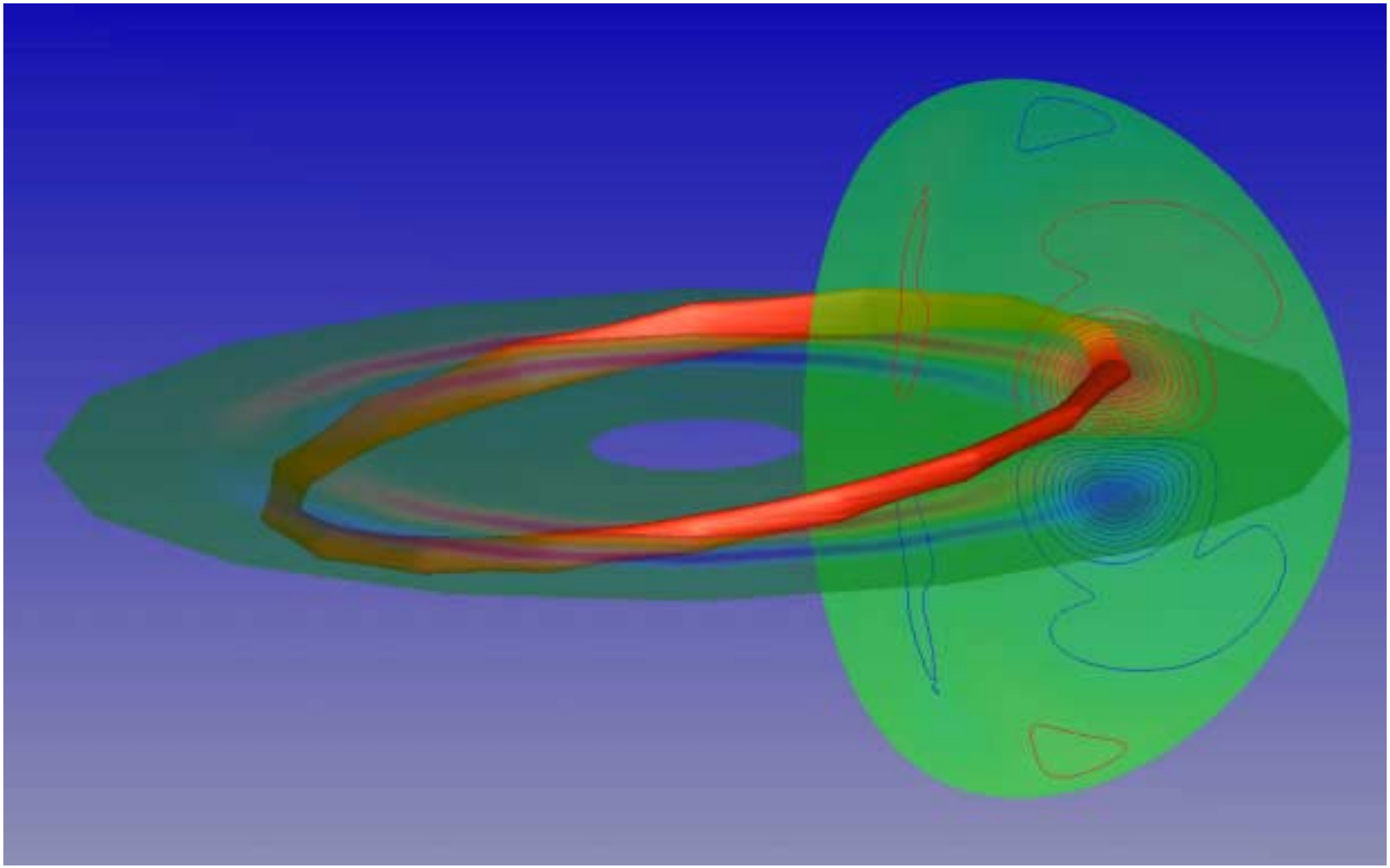
$\gamma \rightarrow (1.85 \pm 0.05) \times 10^{-3}$

$\tau \rightarrow 540\ \tau_A$

16 planes, 91 radial grids

$\eta = 10^{-4}$; $\mu = 10^{-3}$

Dominant n=1 mode is m=1

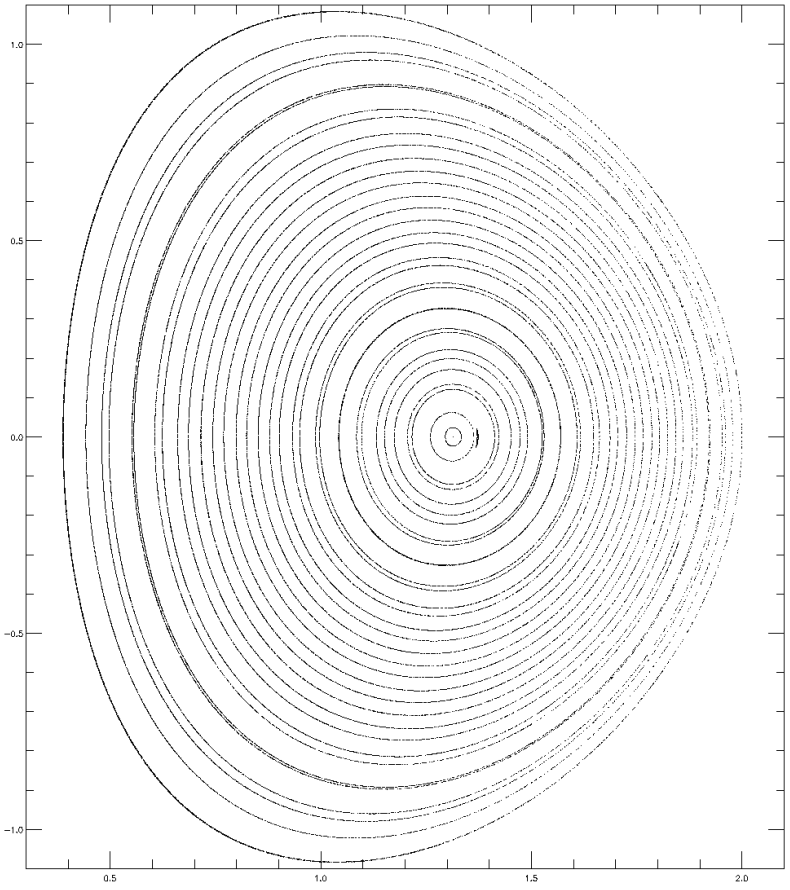


Isosurface and contour plots at ϕ=0 and z=0 planes of incompressible velocity stream function U for the n=1 mode.

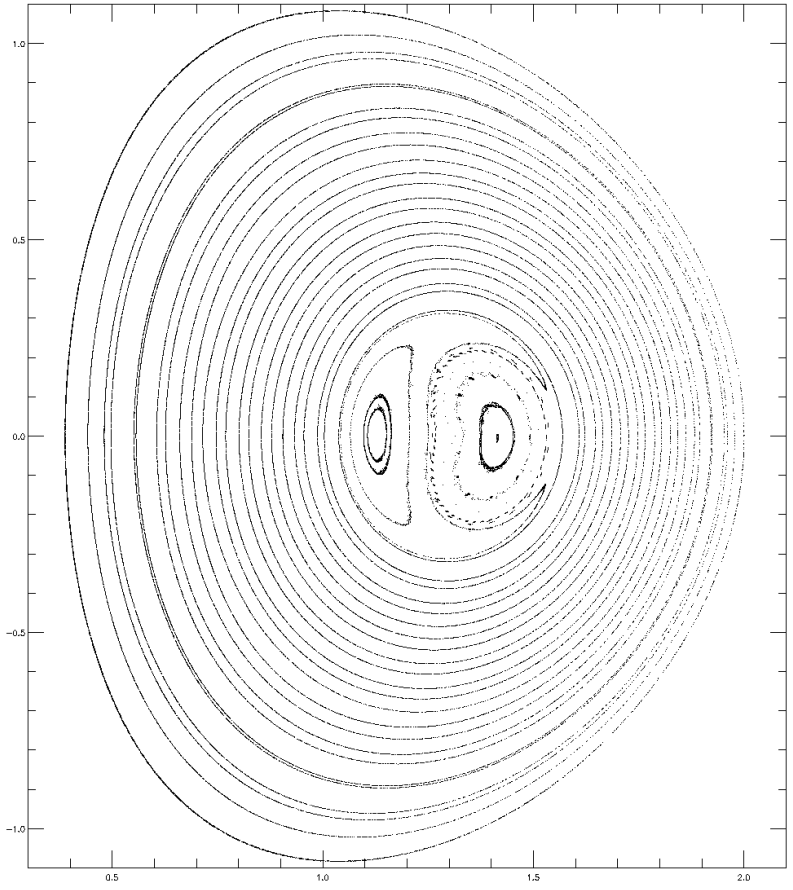
Accelerate nonlinear evolution by "chopping" mode up

(Multiply all non-equilibrium quantities by a constant.)

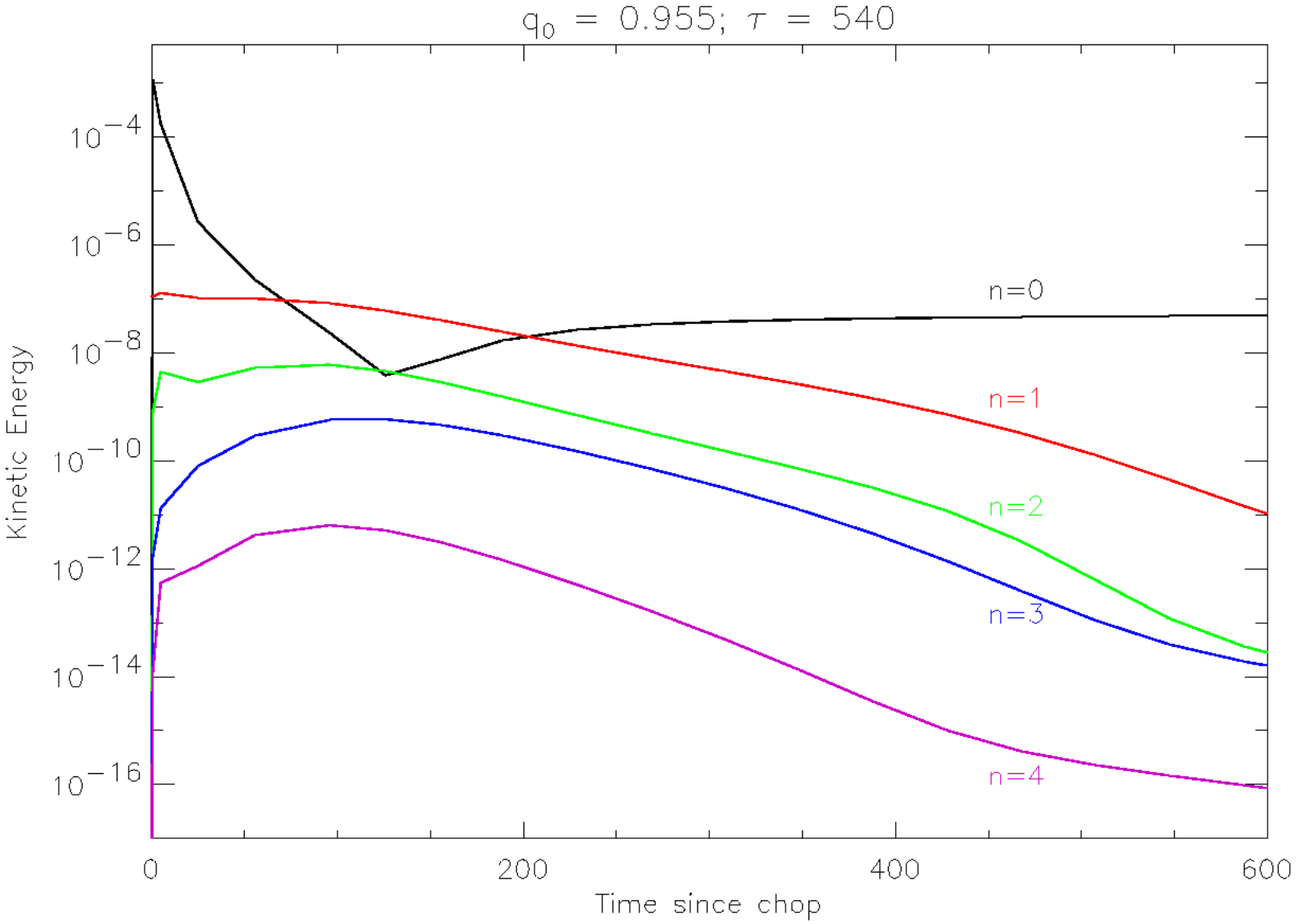
Flux surfaces before chop



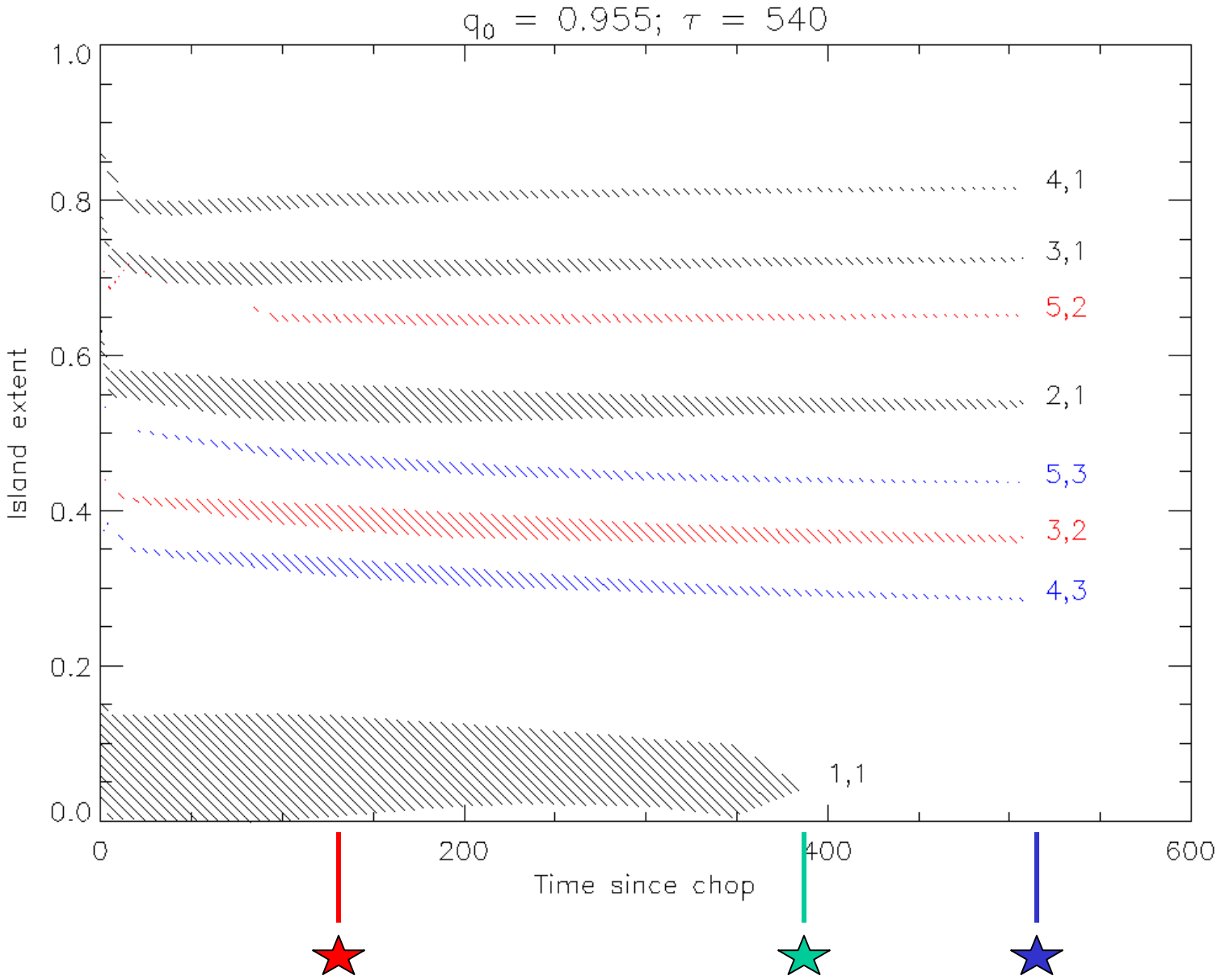
After chopping x 200



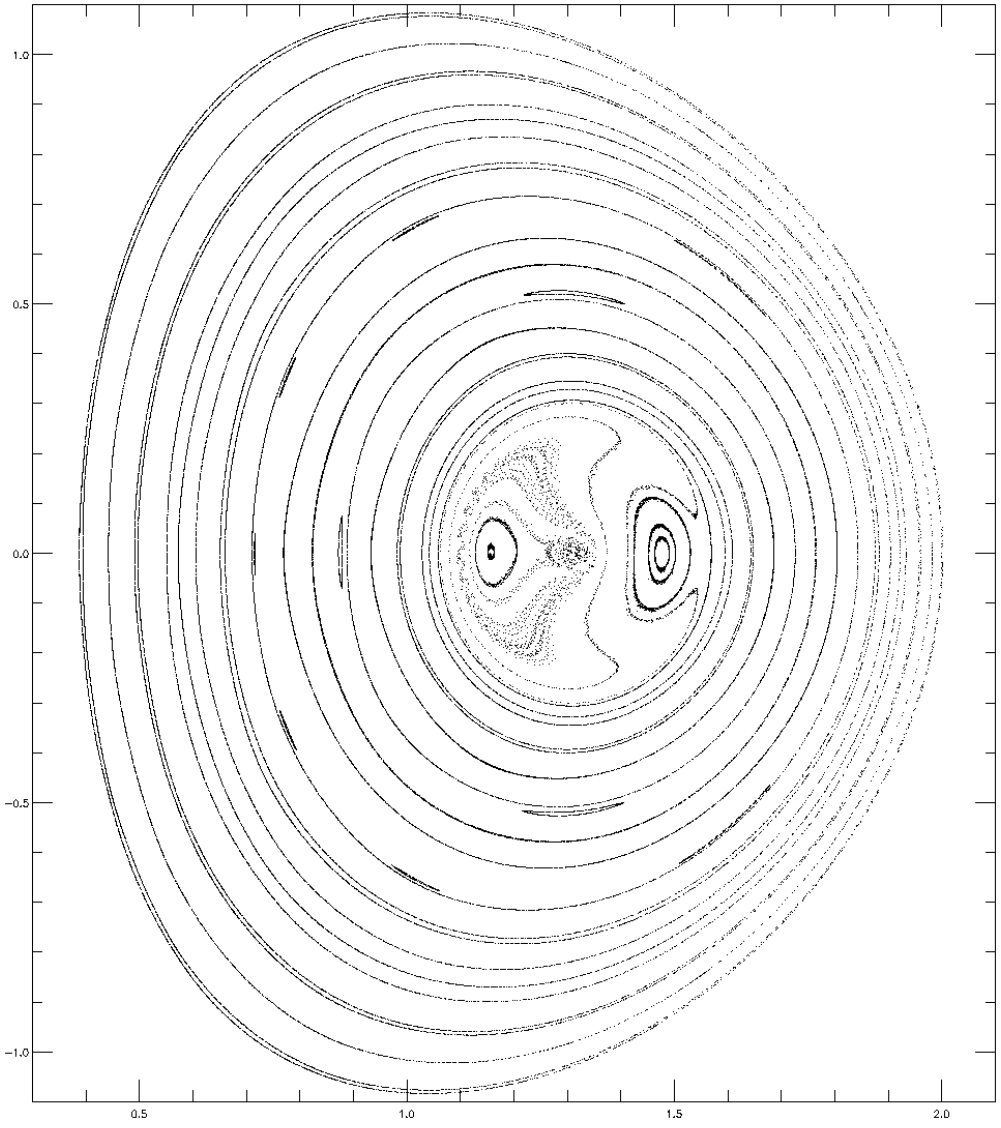
Kinetic energy history, by toroidal mode number



Magnetic island history



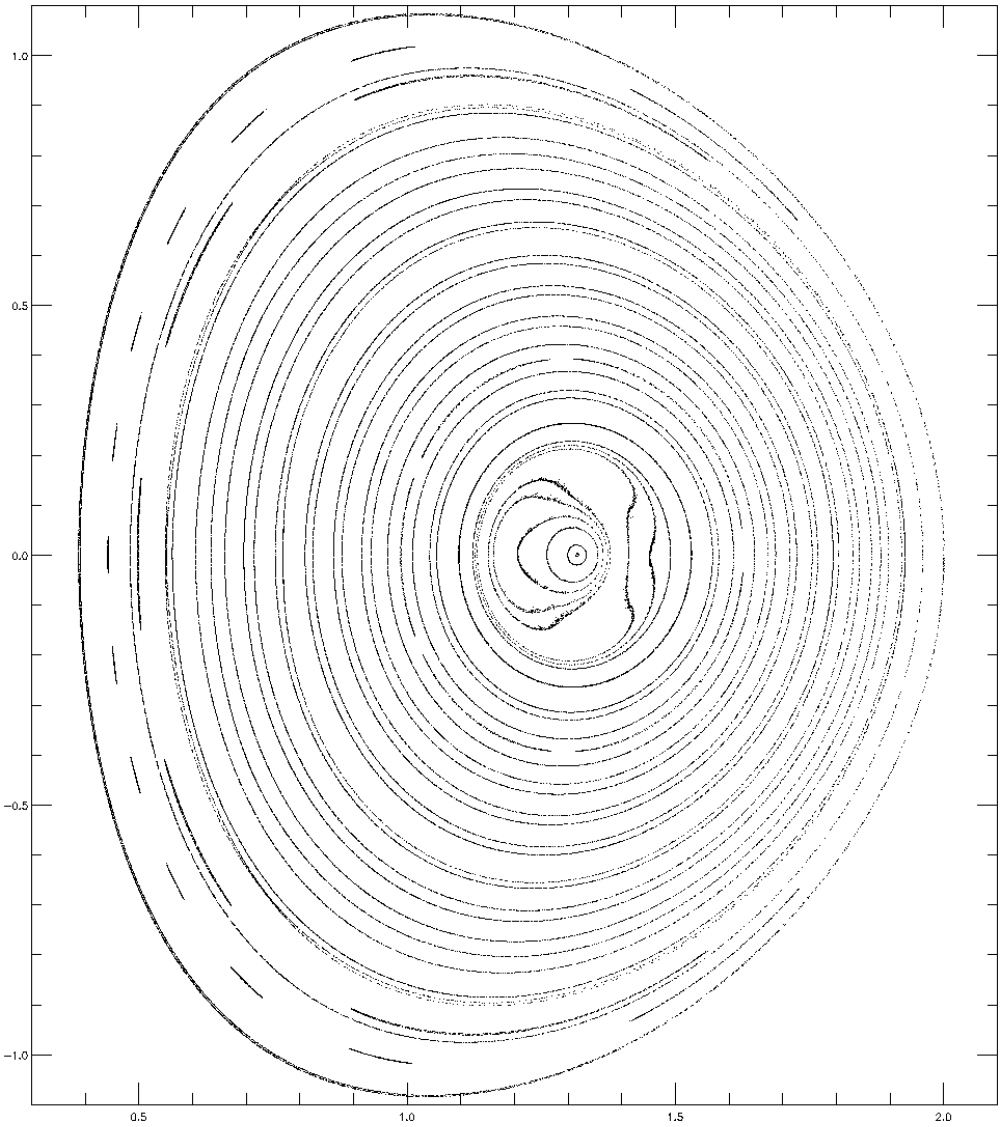
Poincaré surfaces at $t\star$



$t = t_{chop} + 125.78$

- Maximum energy in n>0 modes.
- Maximum sideband width.
- Good surfaces still predominate.

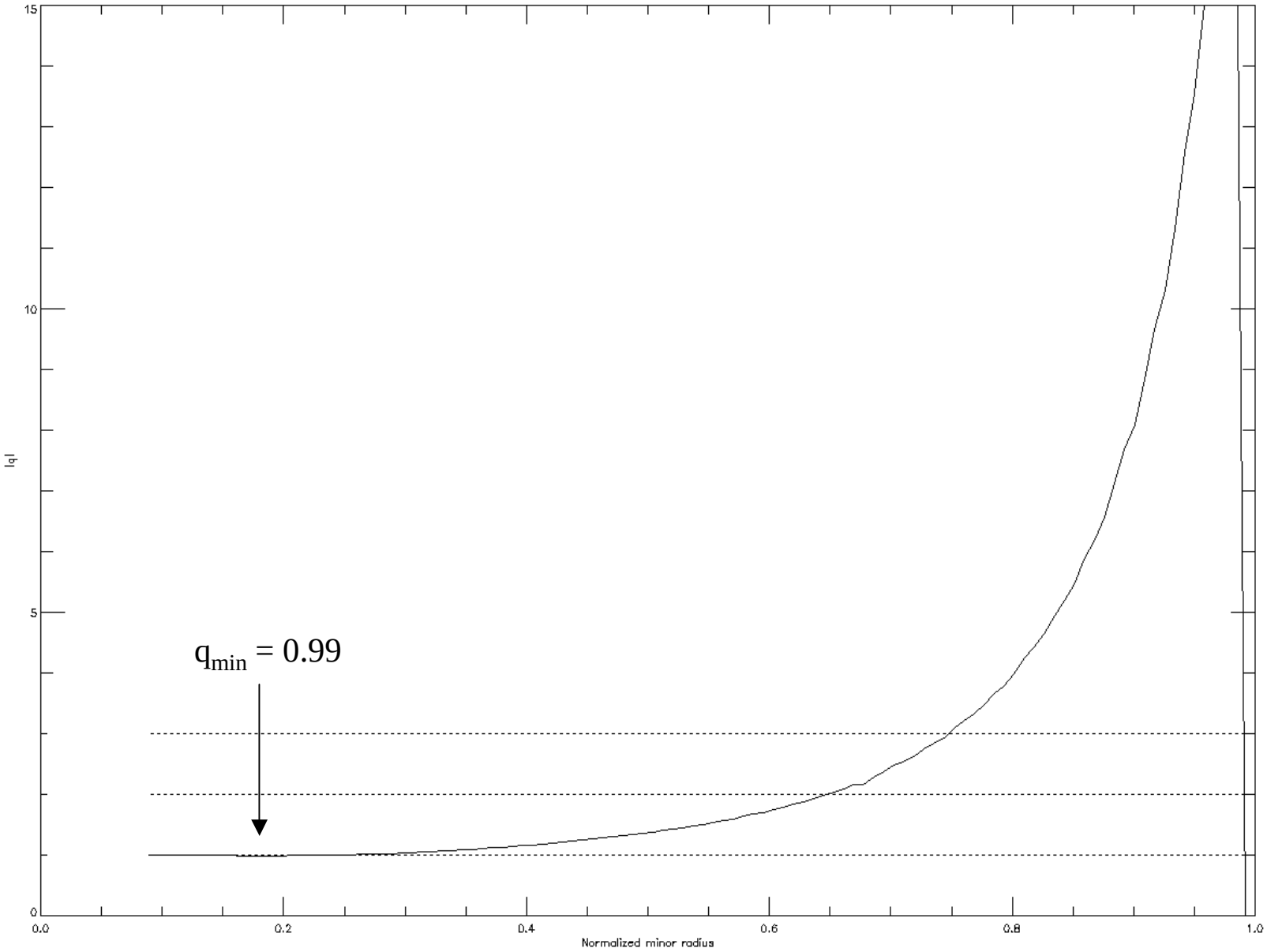
Poincaré surfaces at $t\star$



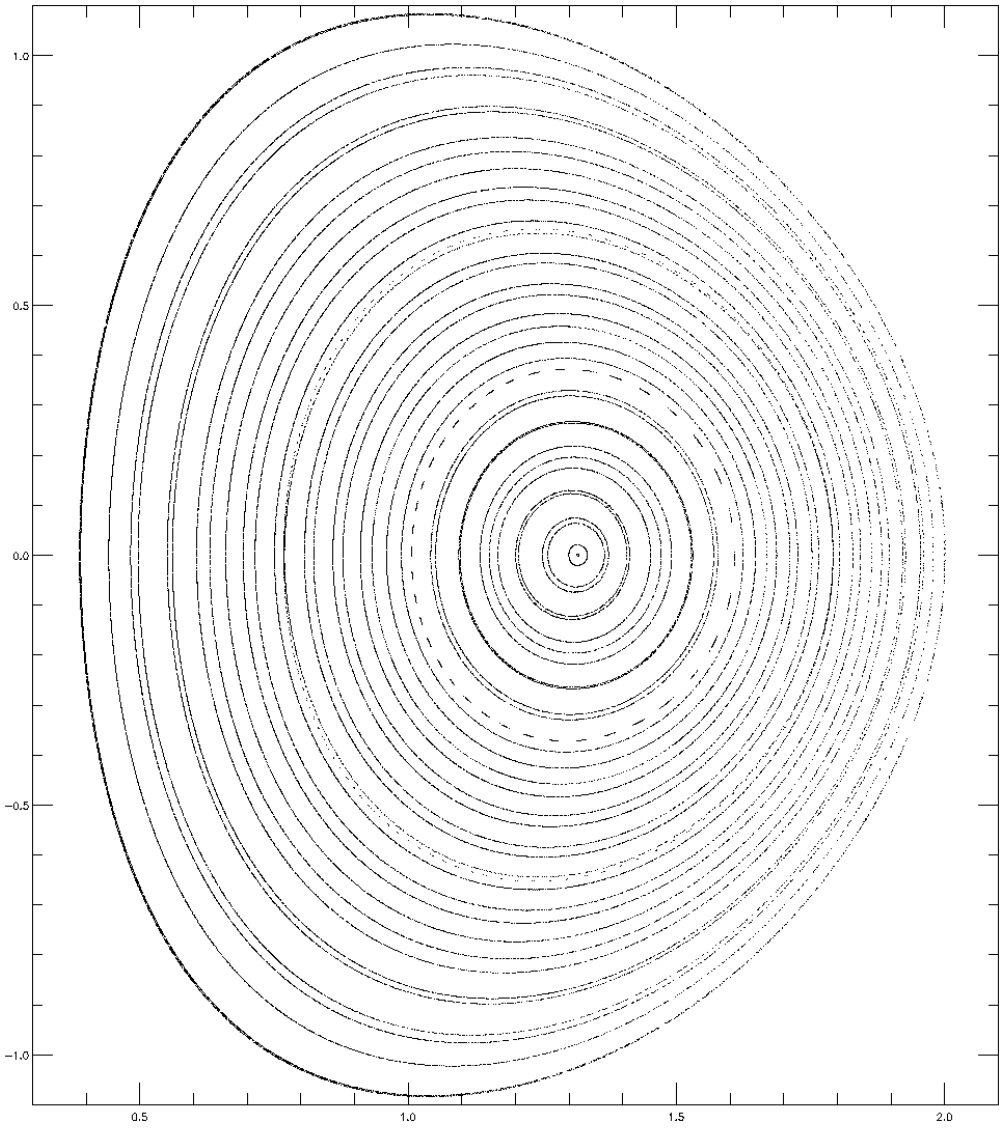
$t = t_{chop} + 387.86$

- Original magnetic axis vanishes.
- Surface shapes still distorted.
- Good surfaces still predominate.

q profile at t★



Poincaré surfaces at $t_\star$

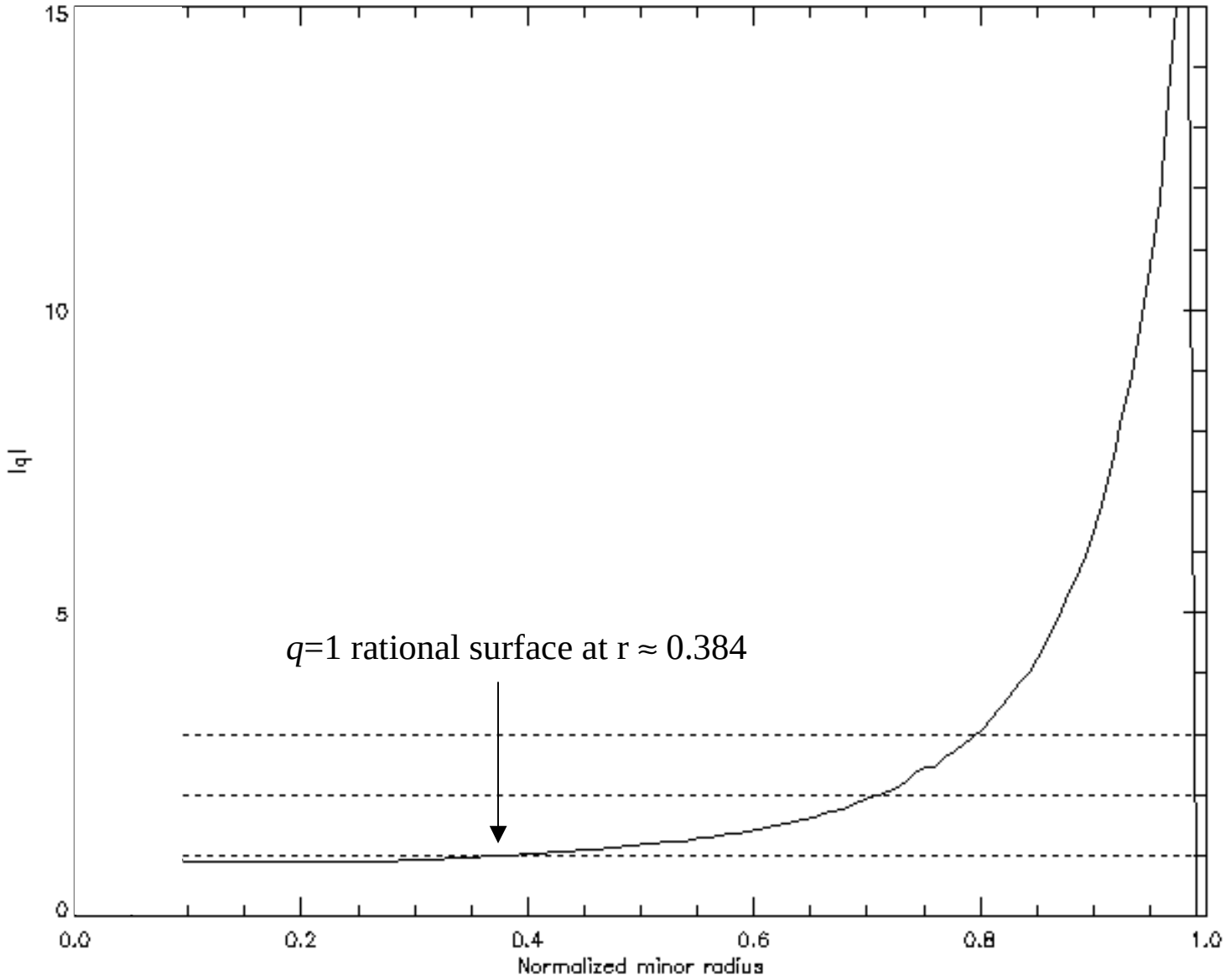


$t = t_{chop} + 507.43$

- Equilibrium is restored.
- Applied loop voltage should eventually produce a second sawtooth crash.

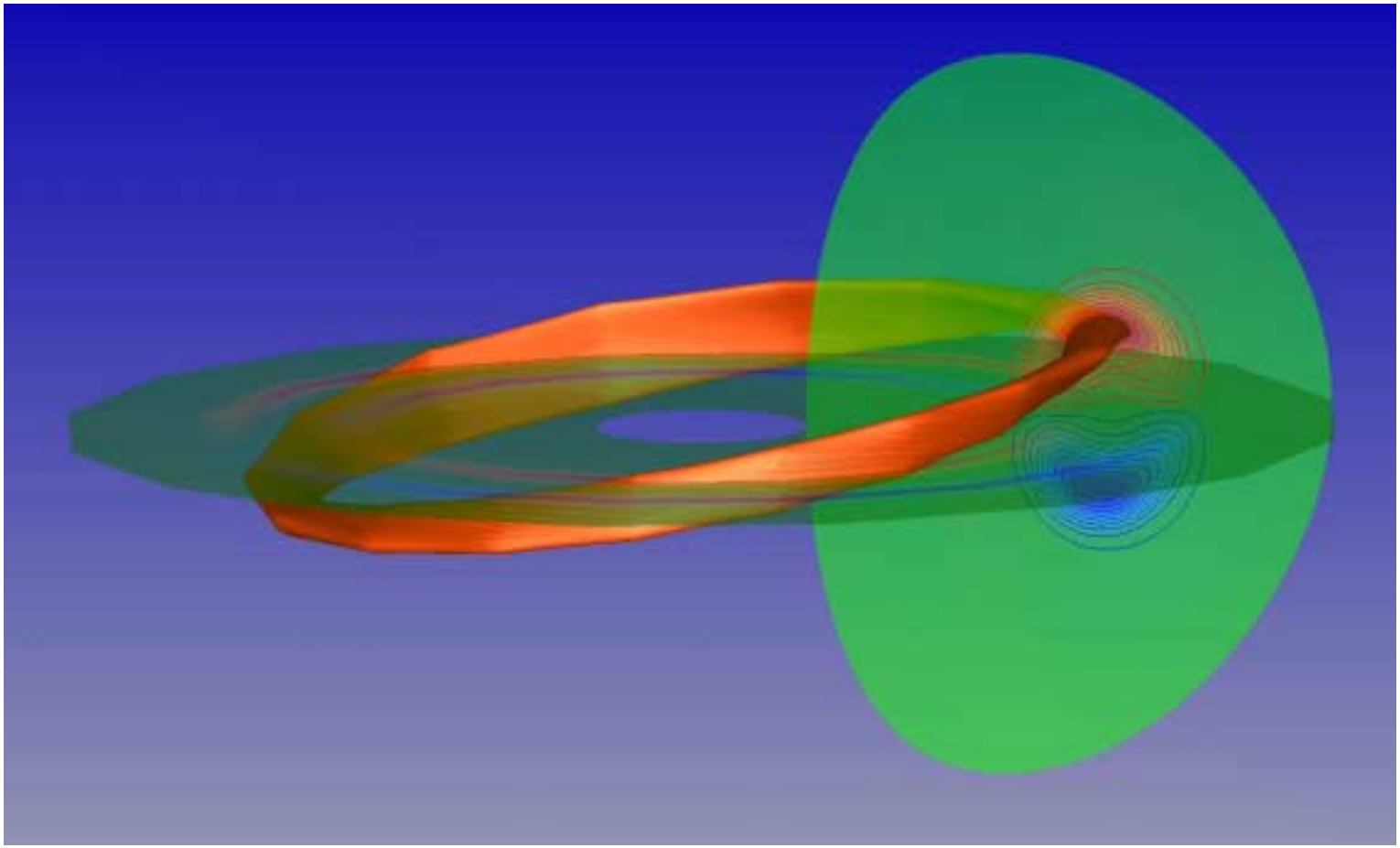
Case 2: $q_0 = 0.89$

Initial q Profile



Dominant n=1 mode is again m=1

Projected growth time for $\eta=10^{-4}$, $\mu=10^{-3}$: 330 τ_A



Isosurface and contour plots at ϕ=0 and z=0 planes of incompressible velocity stream function U for the n=1 mode.

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(Multiply all non-equilibrium quantities by a constant.)

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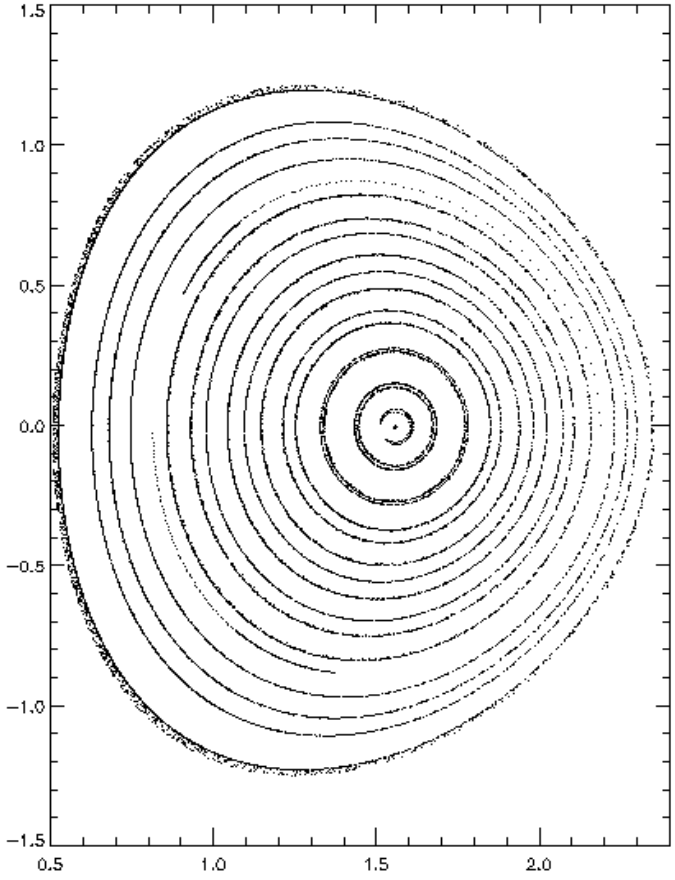
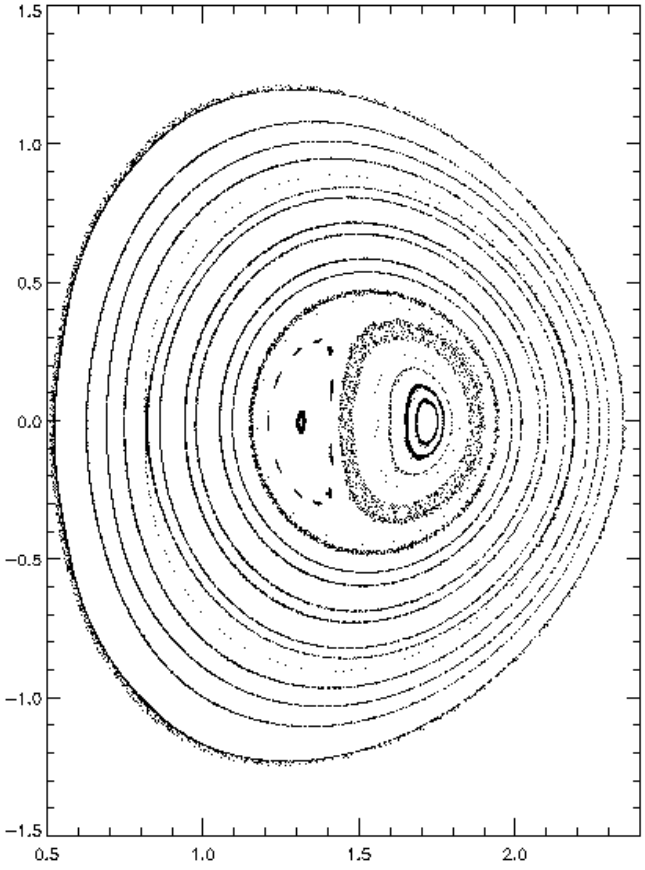


After chopping x 450



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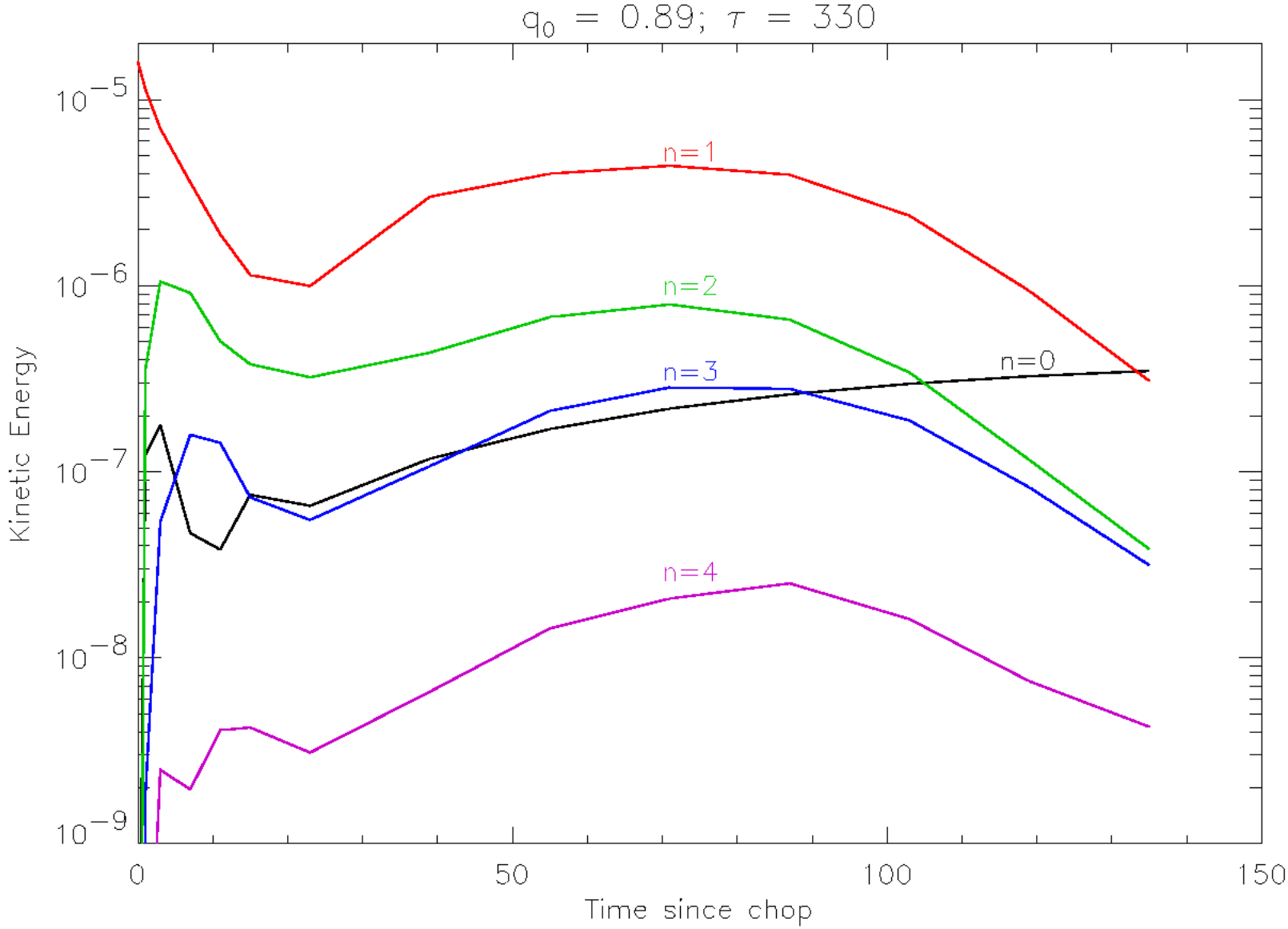
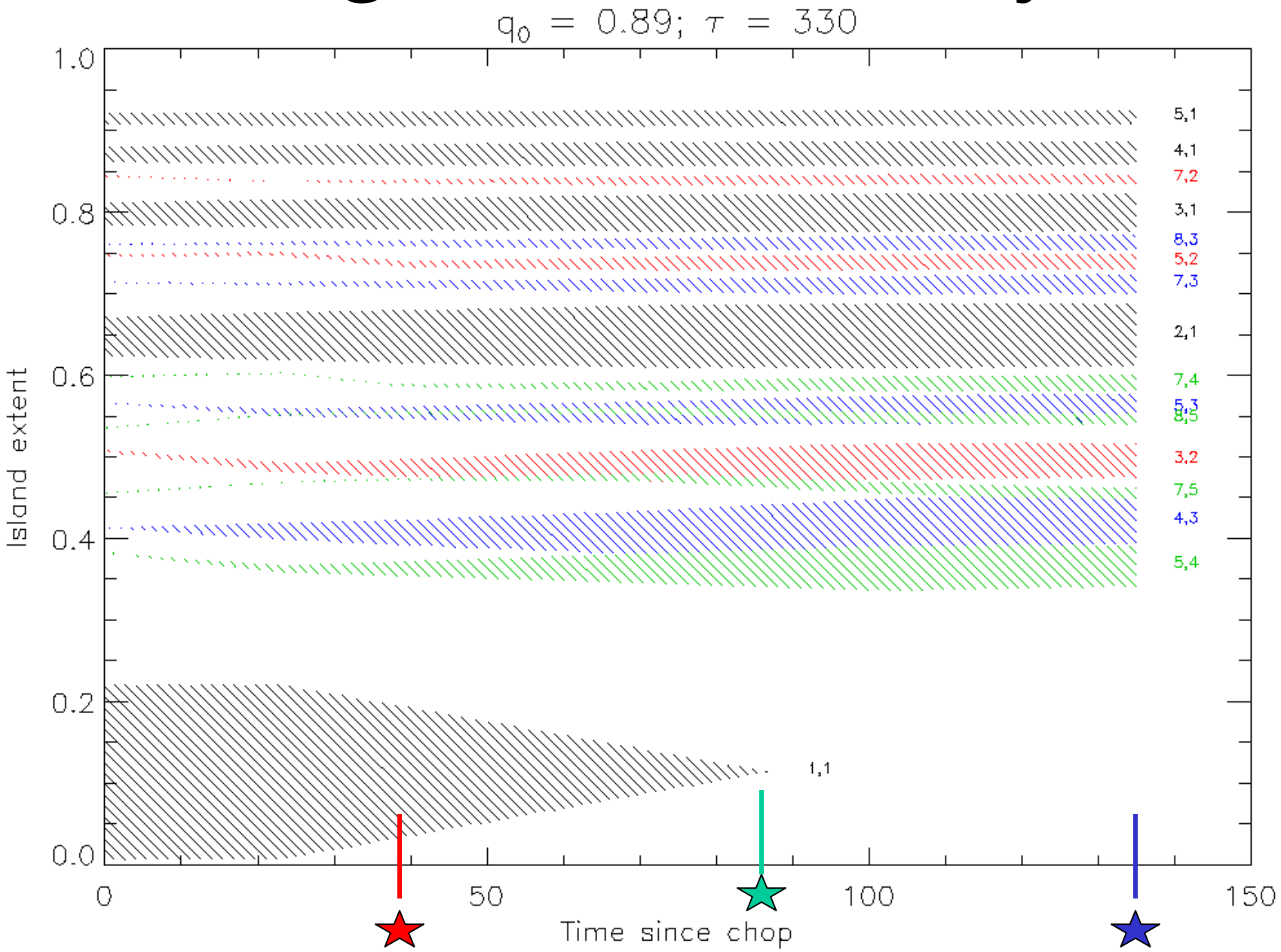
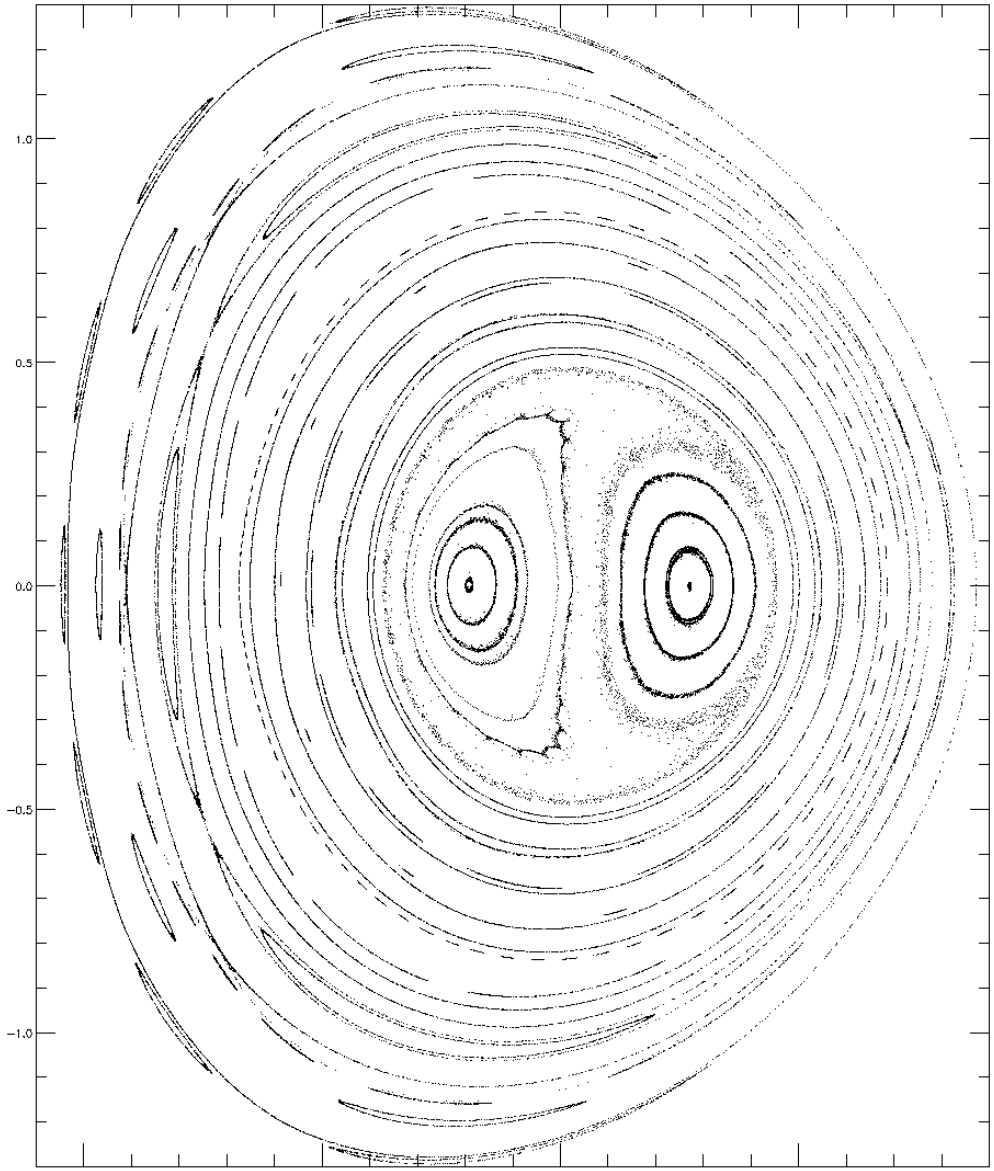


Magnetic island history



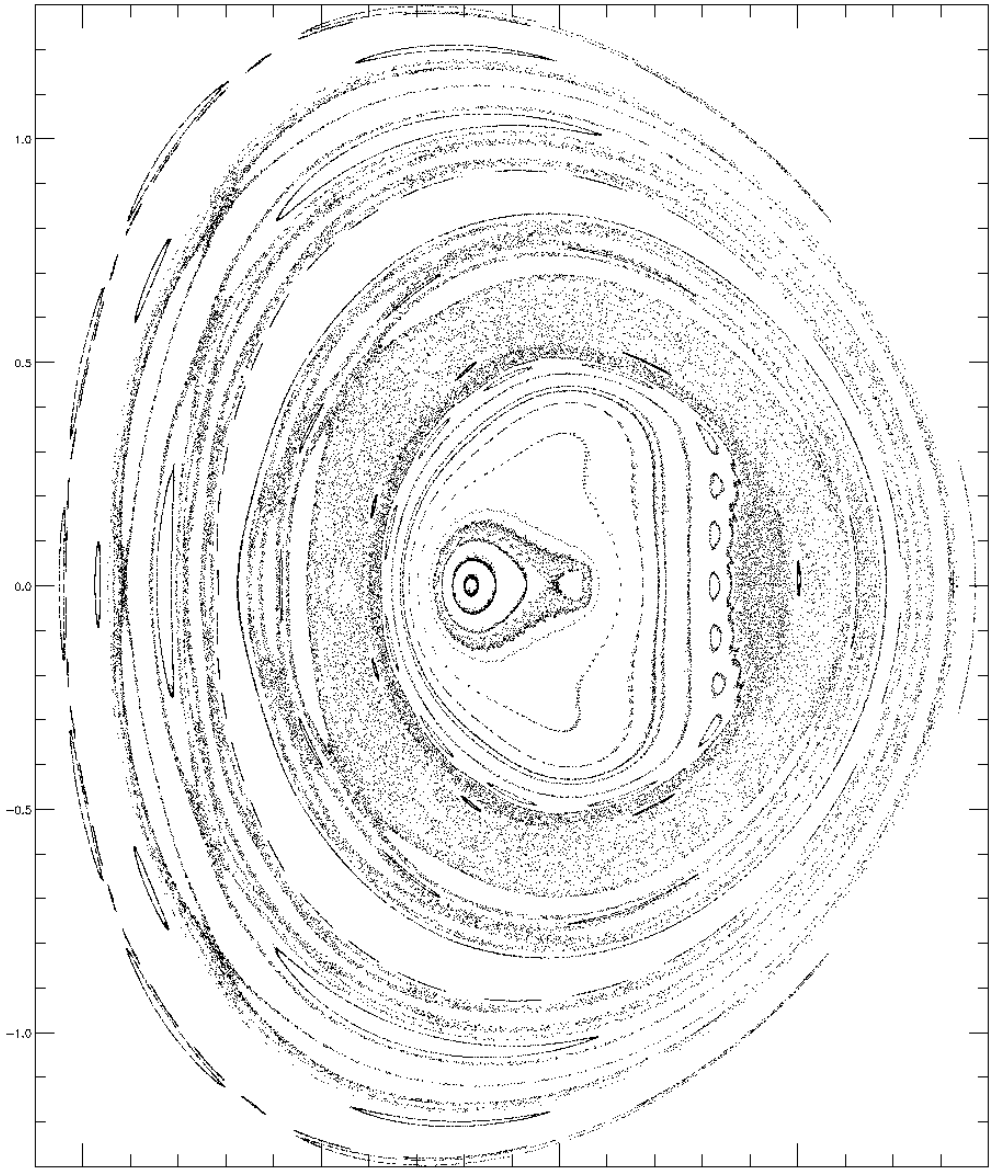
Poincaré surfaces at t★



$t = t_{chop} + 38.98$

- Reconnection is proceeding.
- Islands are large and growing.
- Stochasticity appears only in limited regions.

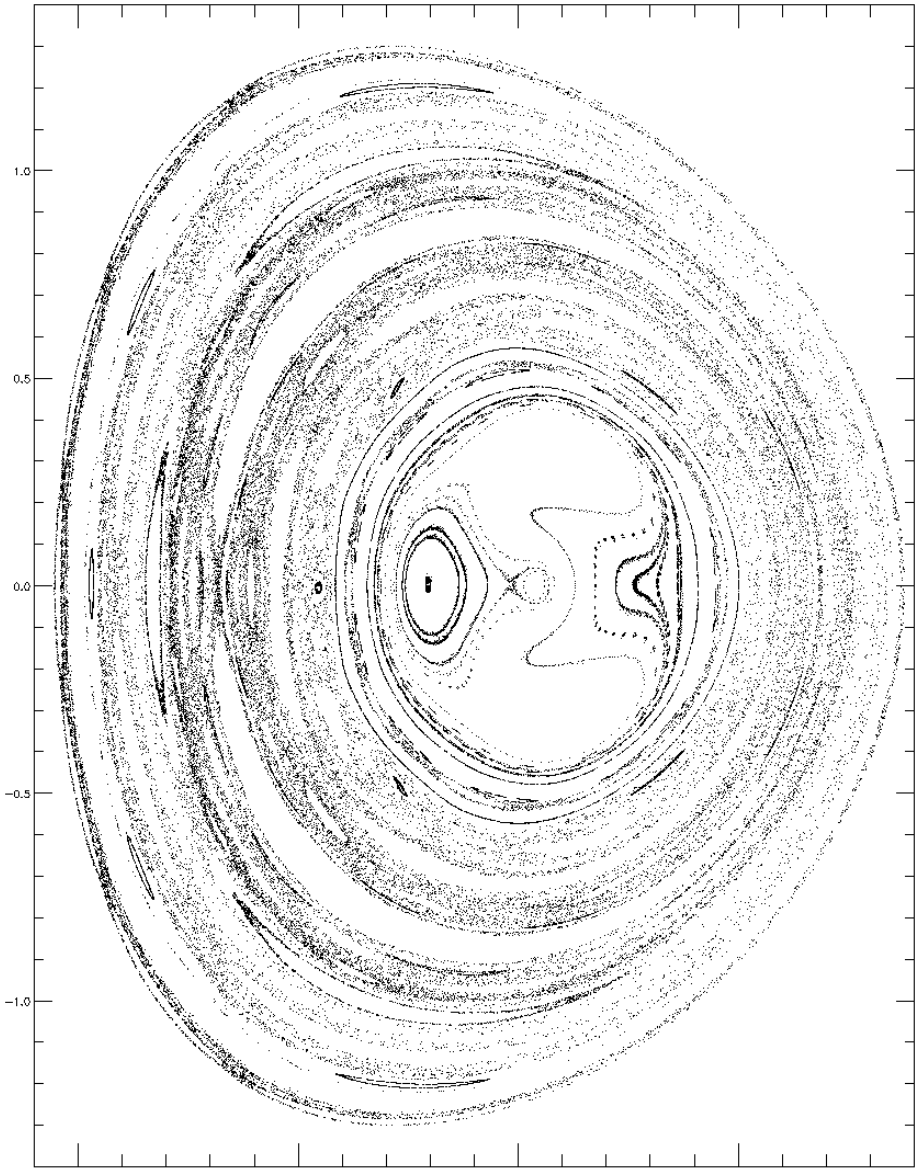
Poincaré surfaces at $t\star$



$t = t_{chop} + 86.99$

- Original magnetic axis vanishes.
- Large stochastic regions separate the few remaining good surfaces.

Poincaré surfaces at $t\star$



$t = t_{chop} + 134.97$

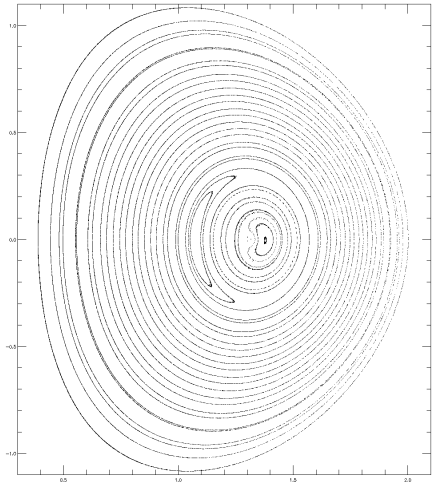
- Islands overlap.
- Stochastic regions predominate.
- Plasma has effectively disrupted.

Case 3: $q_0 = 0.927$

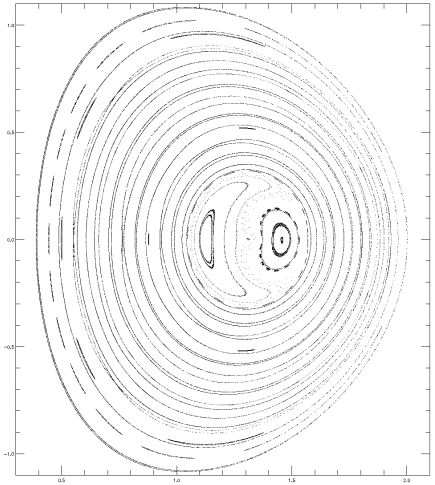
$\eta = 10^{-4}$; $\mu = 10^{-3}$

Growth time for 1,1 mode ≈ 252.8 τ_A

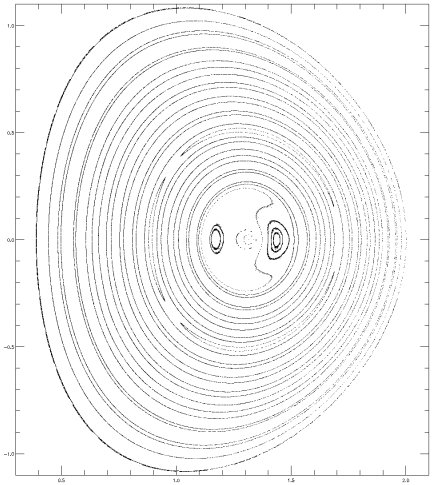
Behavior is similar to case 1 ($q_0 = 0.955$)



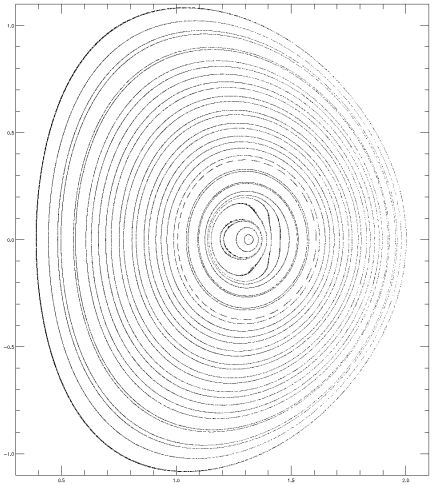
$t = t_{chop}$



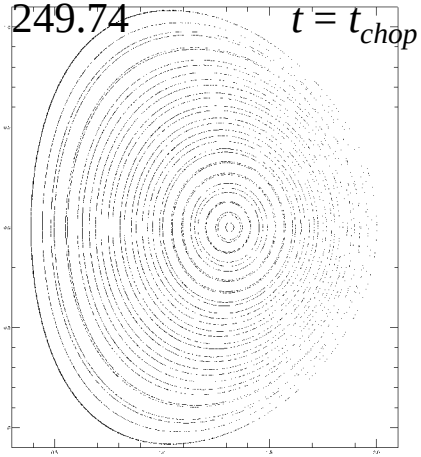
$t = t_{chop} + 249.74$



$t = t_{chop} + 496.56$



$t = t_{chop} + 622.54$



$t = t_{chop} + 747.86$

Conclusions

- The tendency of the plasma to disrupt is sensitive to the precise value of q_0.
- For the particular conditions of this study the threshold value has been bracketed between 0.89 and 0.927.
- Below the threshold q_0, sideband islands grow until they overlap, resulting in stochasticity and disruption.
- Above the threshold q_0, the driven islands heal following the disappearance of the 1,1 island and orderly Kadomtsev sawtooth reconnection is observed.

Future Work

- Investigate sensitivity of disruption threshold to plasma shaping (elongation), aspect ratio.
- Repeat study with two-fluid and/or kinetic effects added.
- Follow evolution for an entire sawtooth cycle (crash to crash) to check accuracy of period estimate.