

# M3D CDX-U Nonlinear Simulation

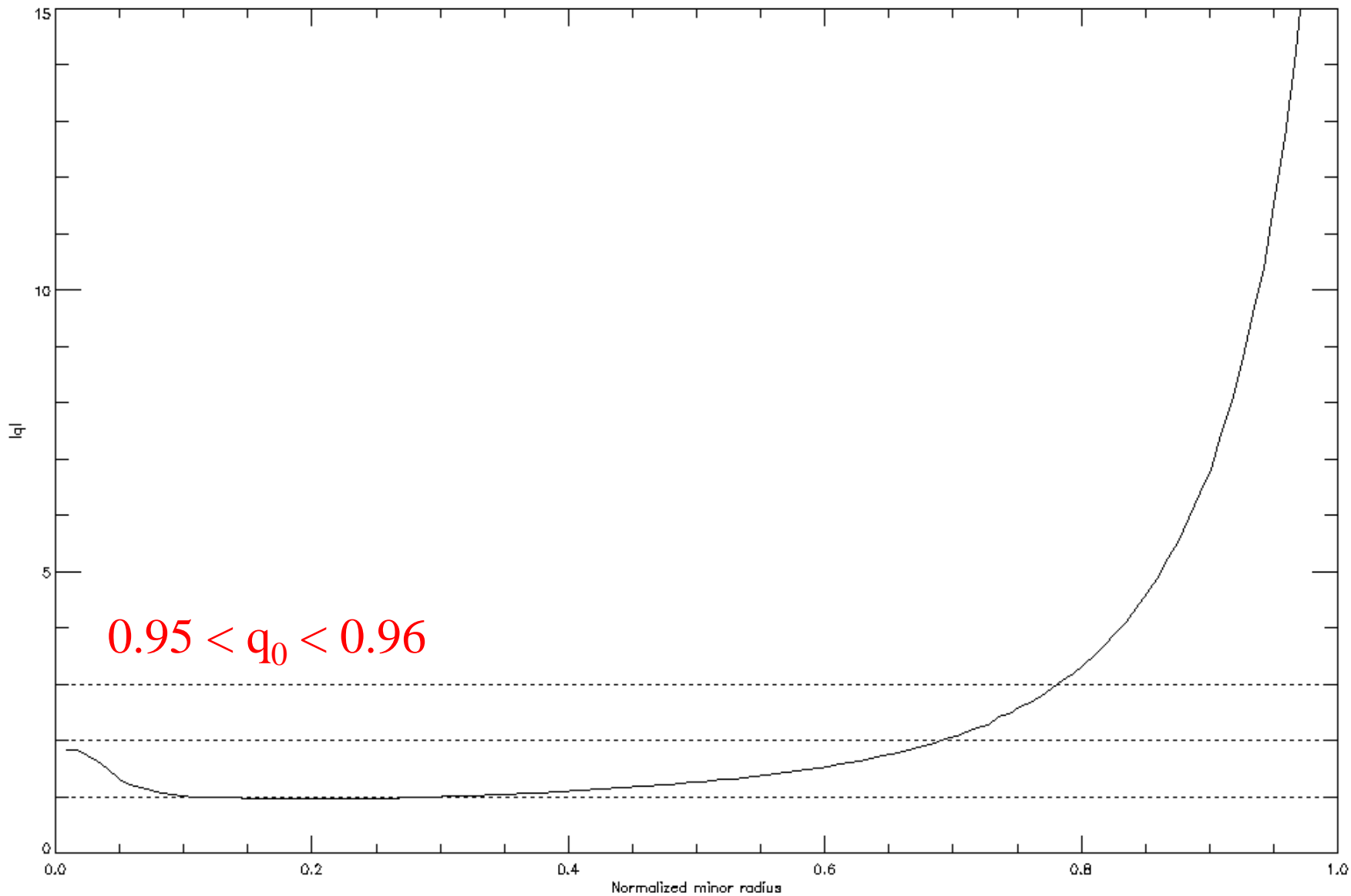
Josh Breslau

CEMM Project Meeting

Albuquerque, NM

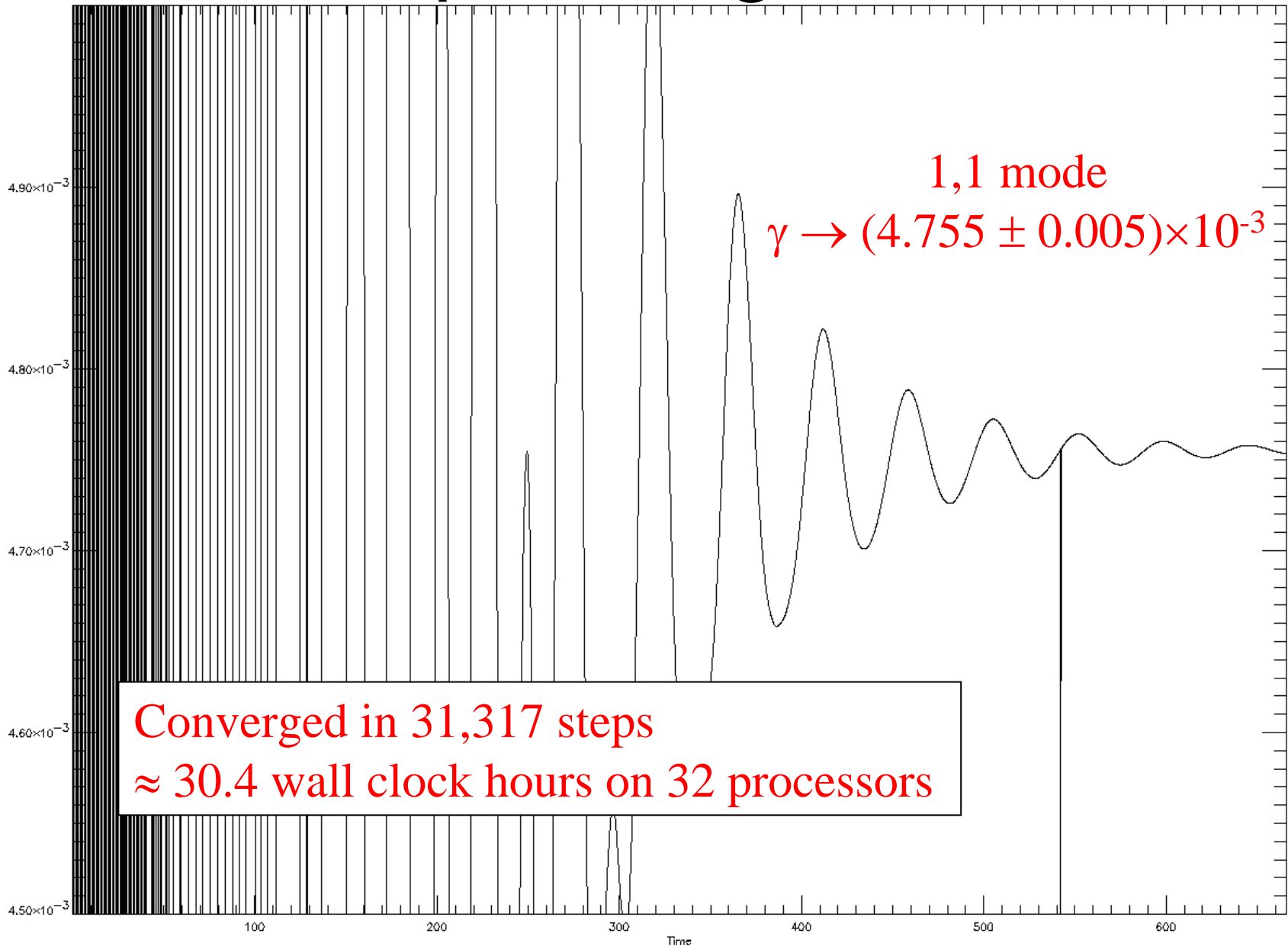
October 26, 2003

# CDX Series: Initial q profile

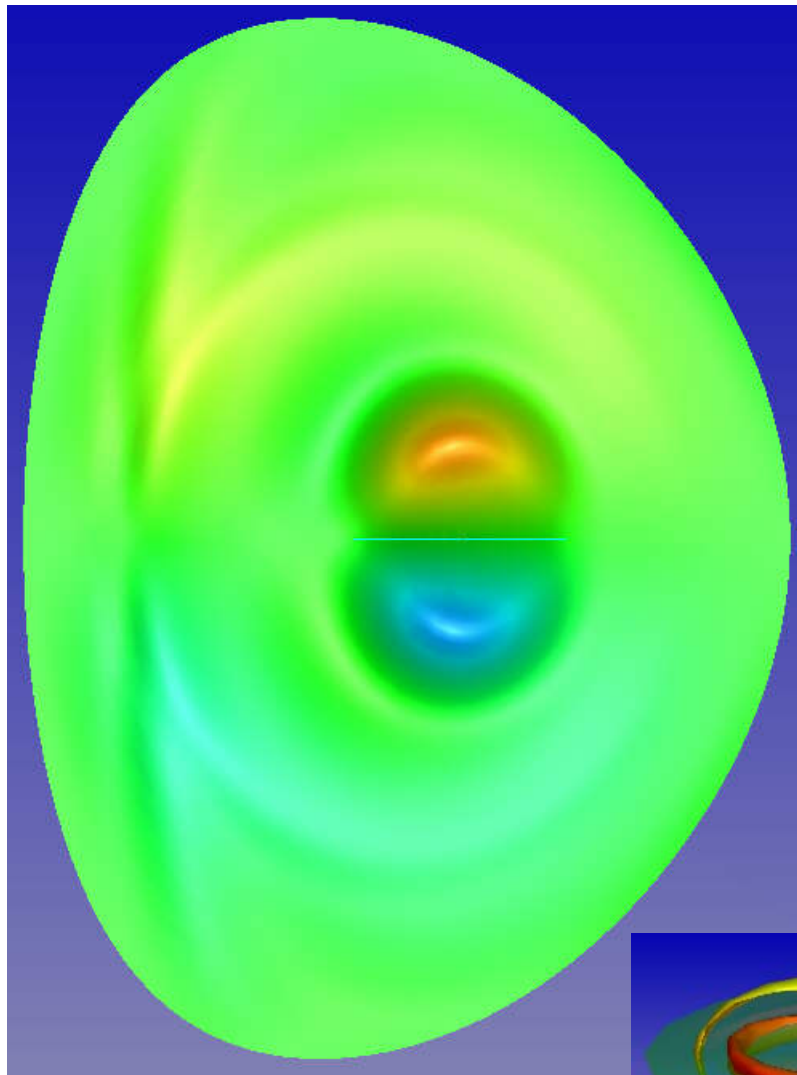


JSolver CDX run05, time09

# Linear phase: growth rate

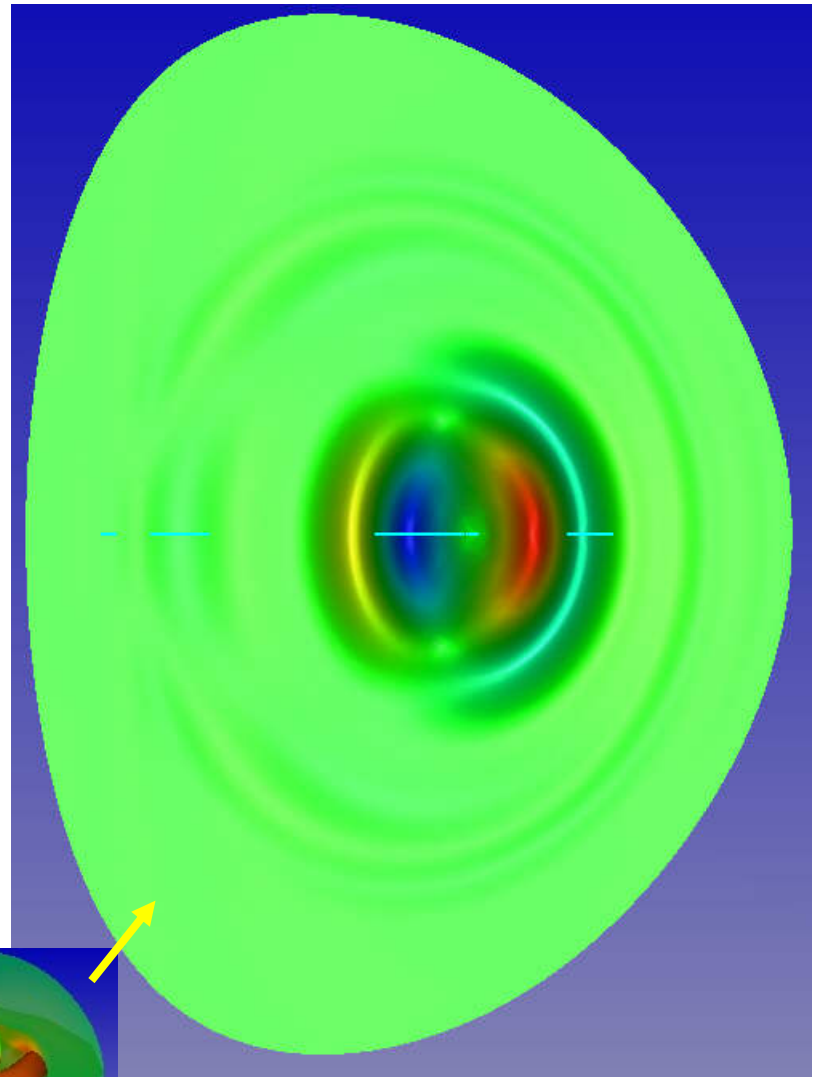


# Mode Structure

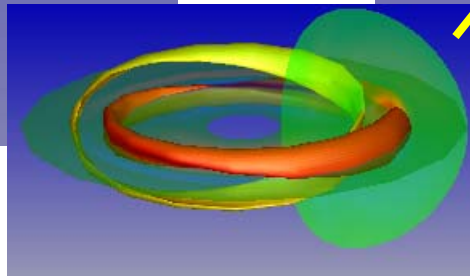


U

1,1



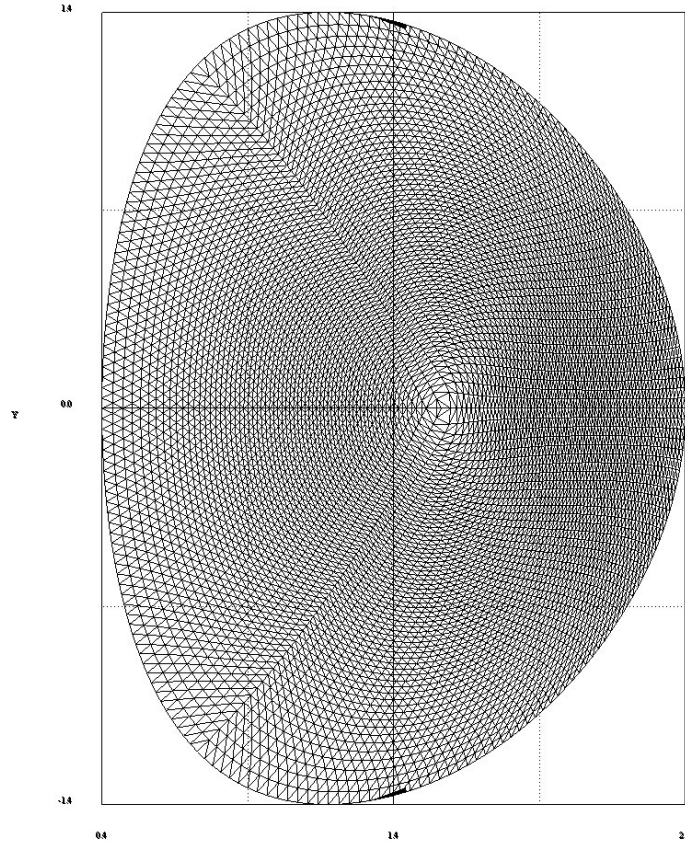
perturbed  $J_\phi$



# Poloidal Meshes for the Benchmark

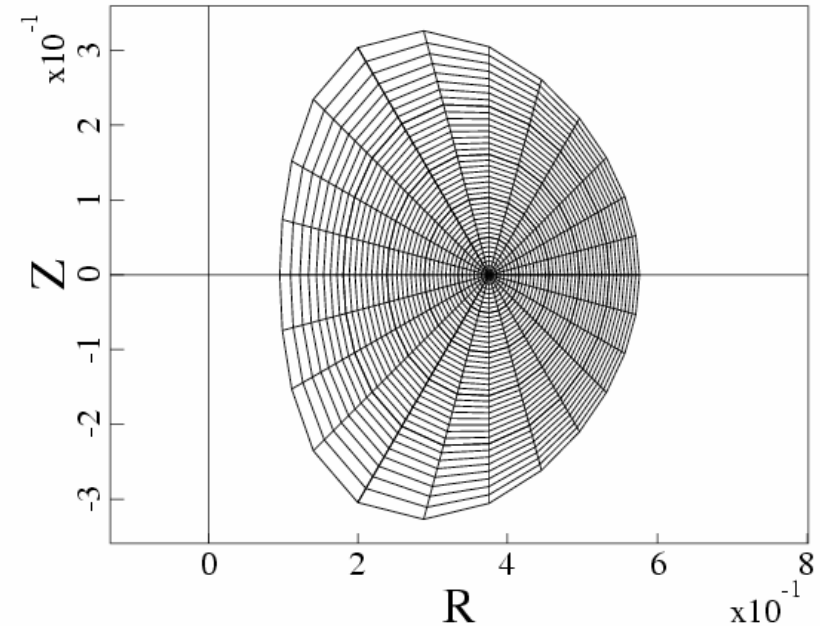
## Case

M3D



- 70 radial zones, up to 210 in  $\theta$  in unstructured mesh
- Linear basis functions on triangular elements
- Conducting wall
- Finite differences toroidally; 16 or more planes

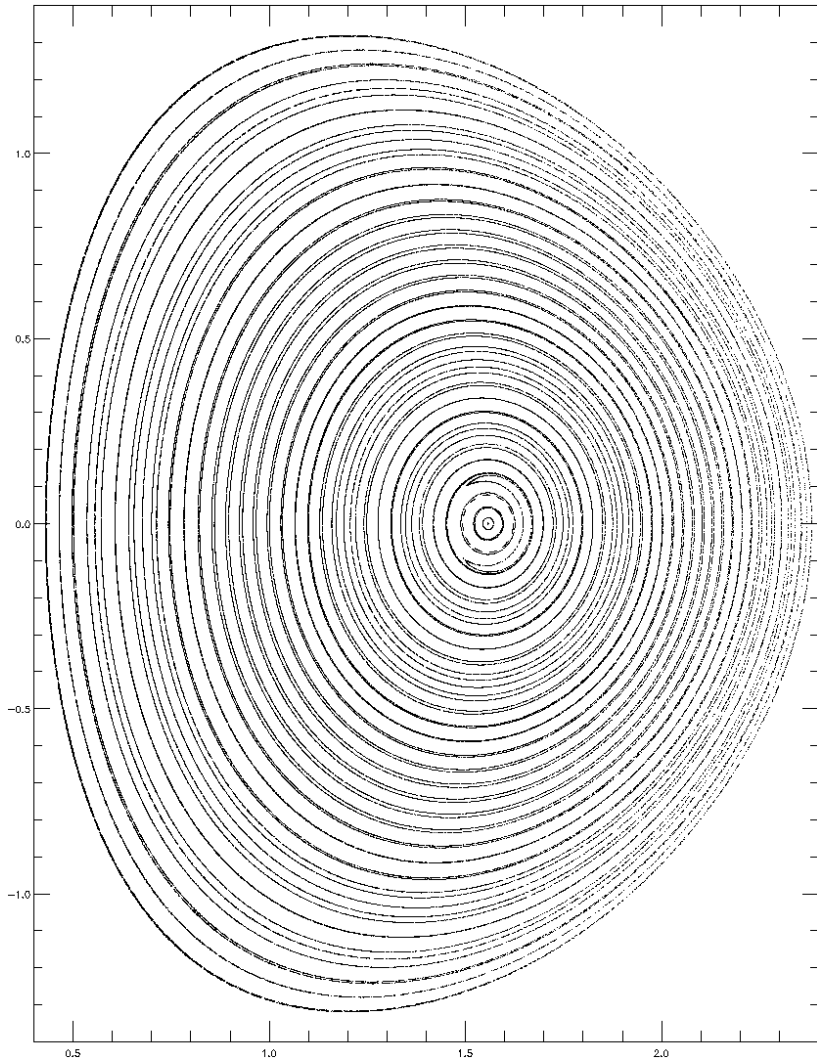
NIMROD



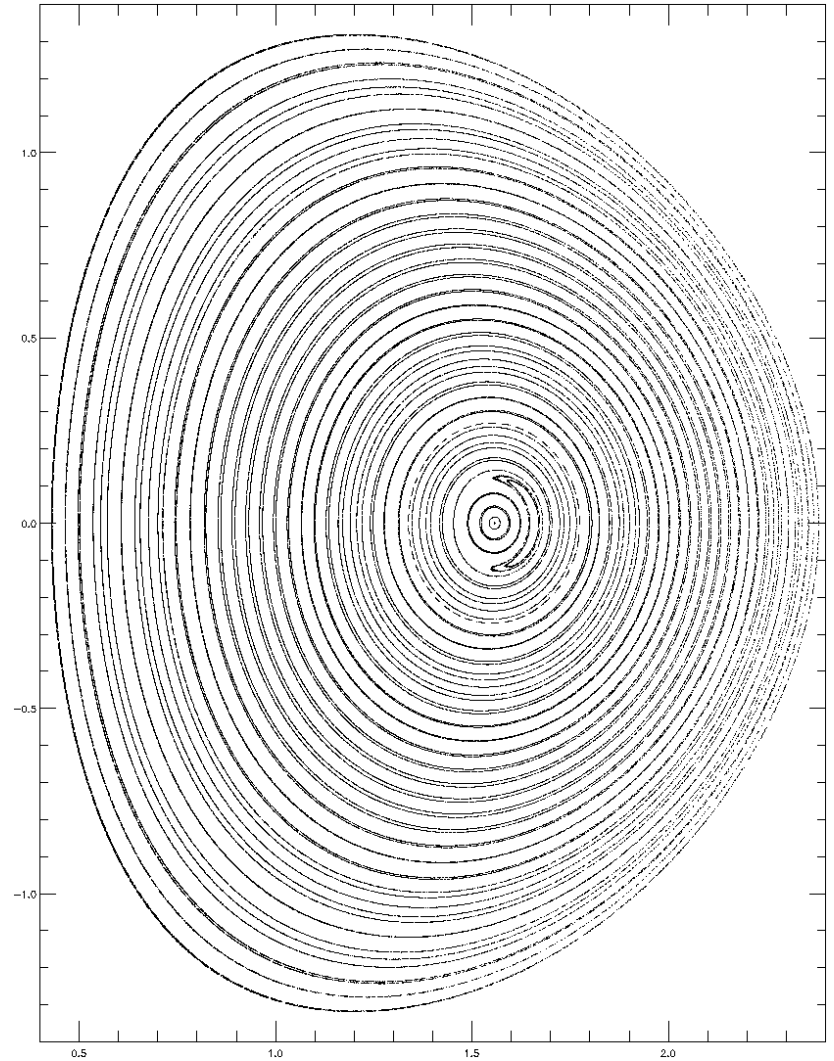
- $40 \times 24$  structured grid
- 4th order basis functions on quadrilateral elements
- Conducting wall
- Fourier decomposition

# CDX Series ( $0.95 < q_0 < 0.96$ )

constant density



Initial state,  $t=666.04$



$t=666.06$ , chopped  $\times e$

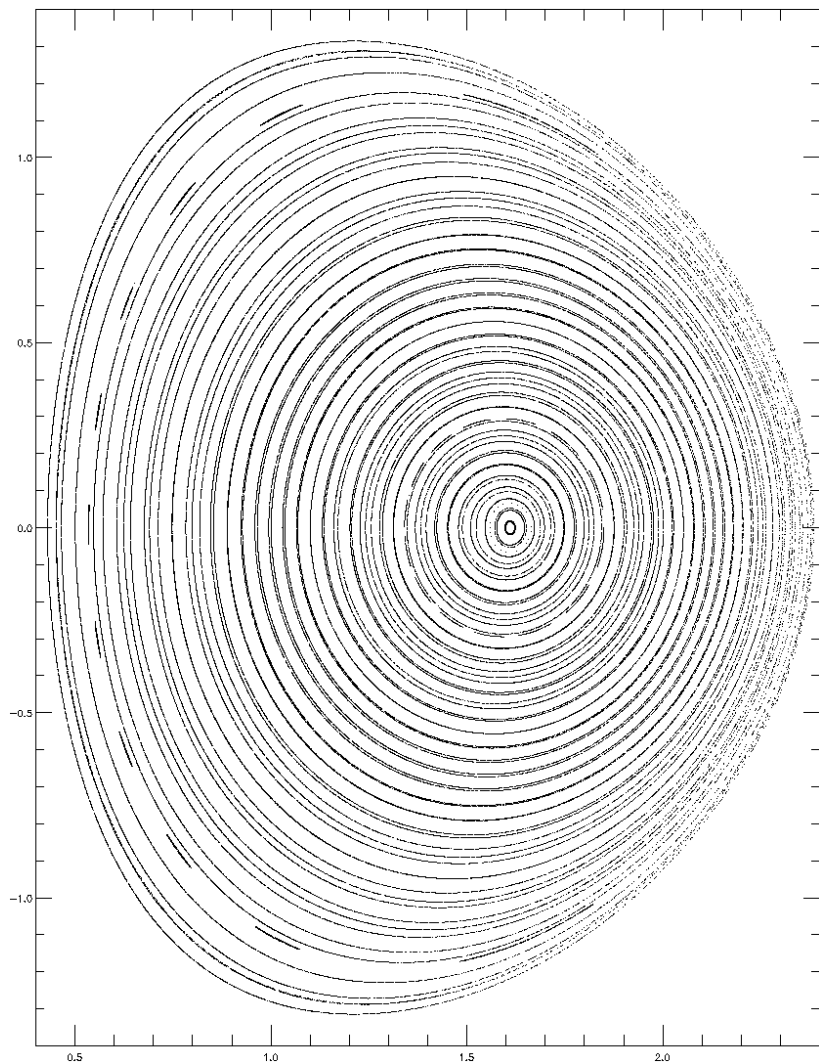
$\gamma=0.004755 \rightarrow \tau \approx 210.3$

16 planes, 71 radial grids

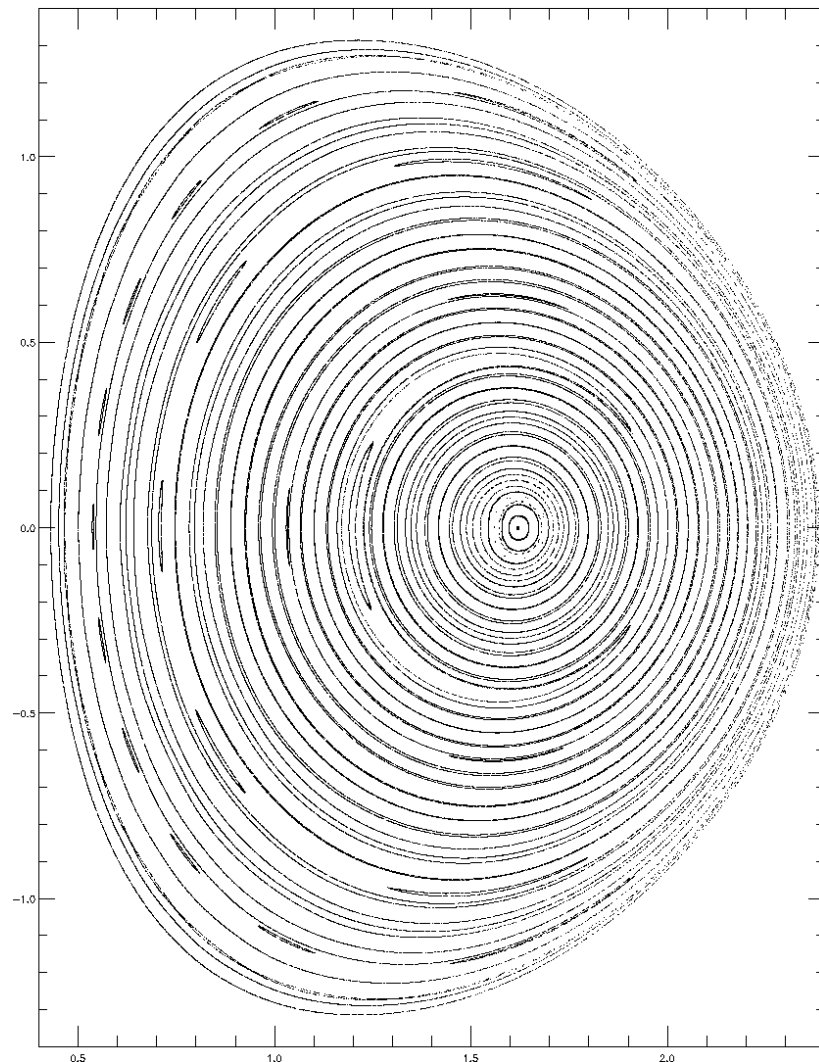
$\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-4}$ ;  $\kappa=9.09 \times 10^{-4}$

# CDX Series ( $0.95 < q_0 < 0.96$ )

constant density



$t=1045.93$



$t=1099.13$

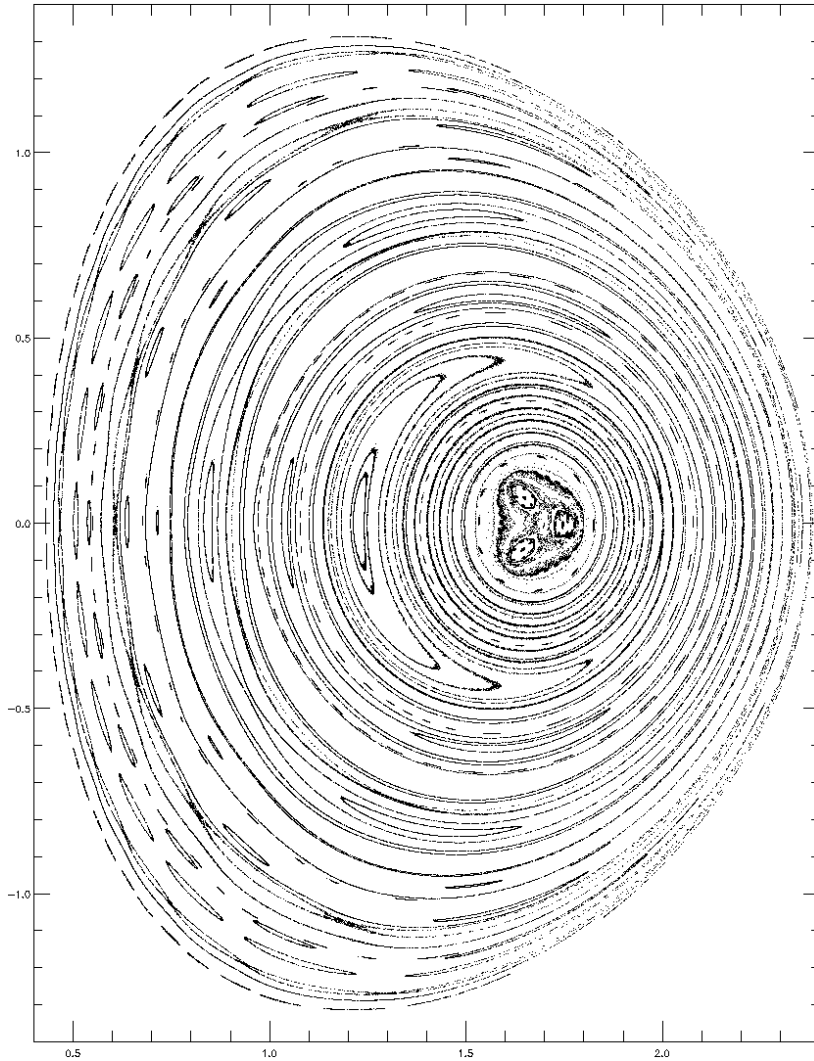
$\gamma=0.004755 \rightarrow \tau \approx 210.3$

16 planes, 71 radial grids

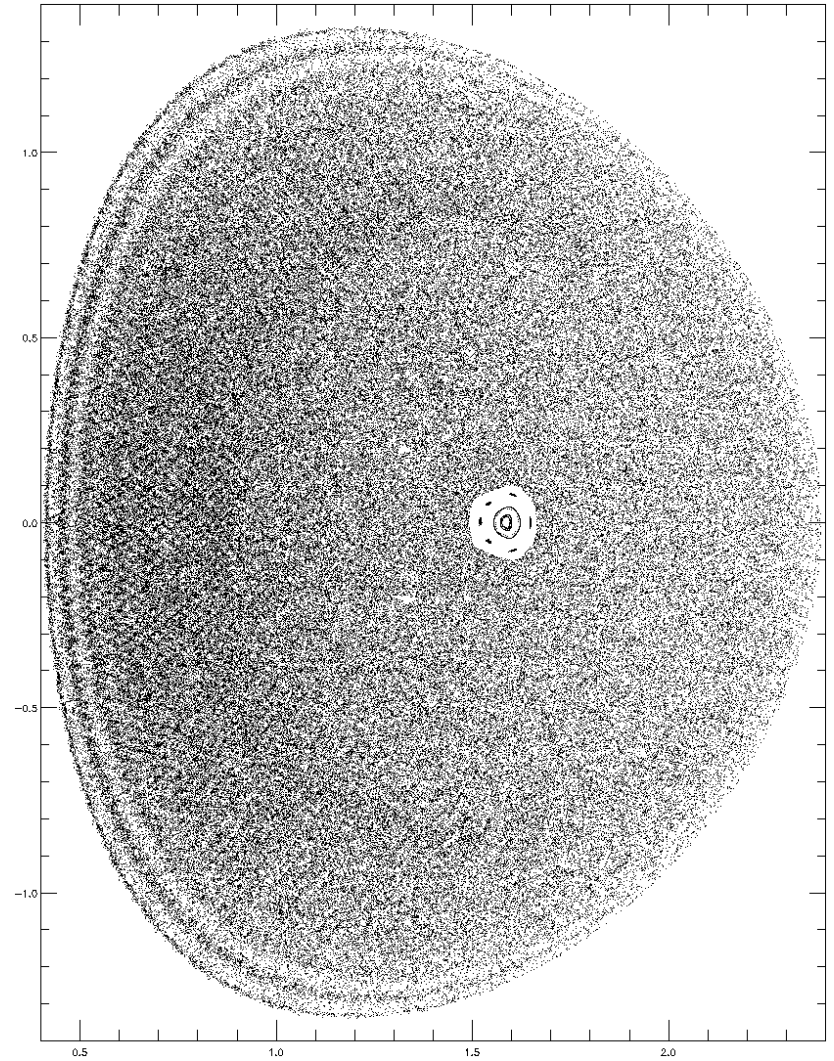
$\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-4}$ ;  $\kappa=9.09 \times 10^{-4}$

# CDX Series ( $0.95 < q_0 < 0.96$ )

constant density



t=1153.44



t=1202.55

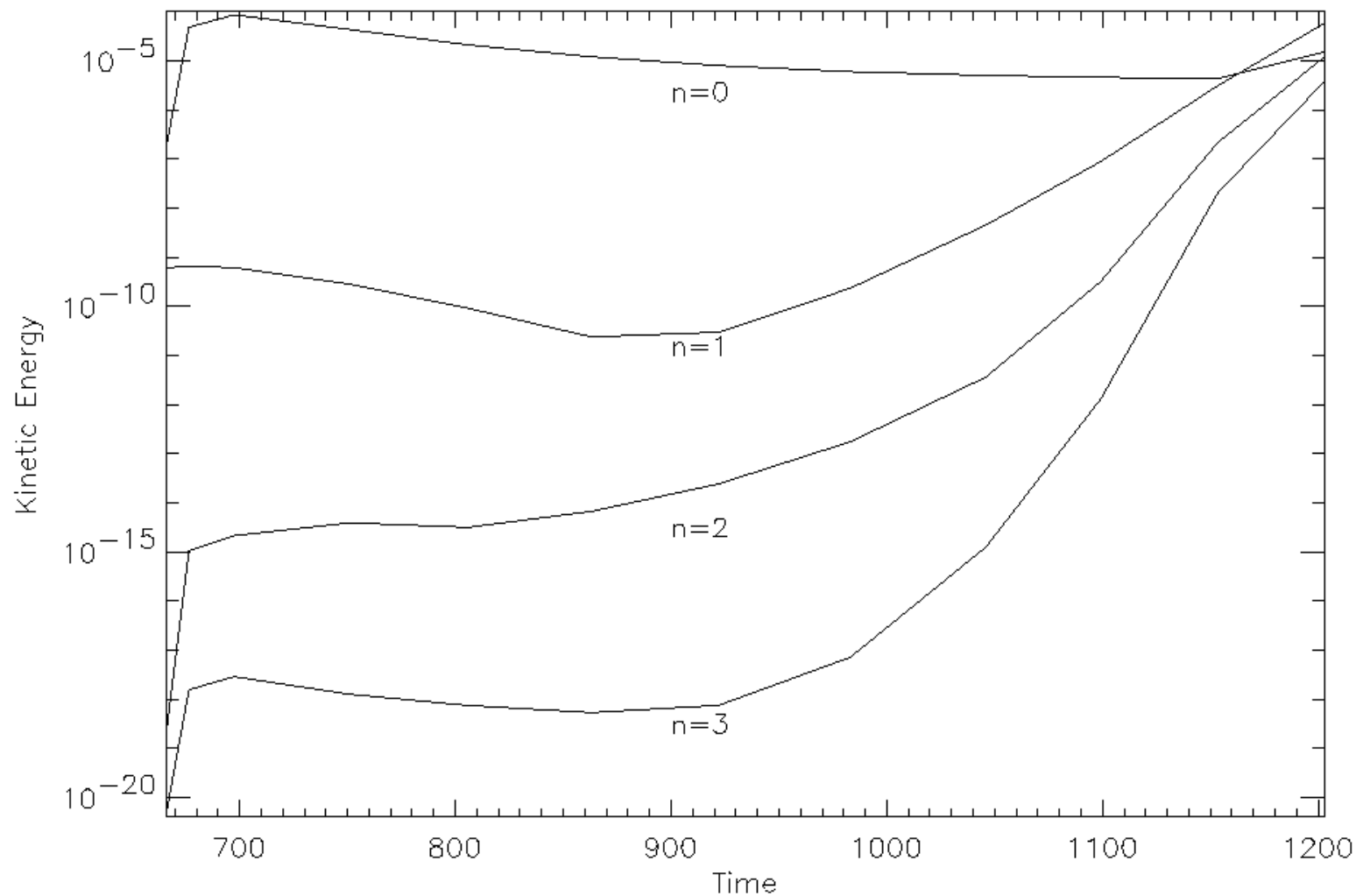
$\gamma=0.004755 \rightarrow \tau \approx 210.3$

16 planes, 71 radial grids

$\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-4}$ ;  $\kappa=9.09 \times 10^{-4}$

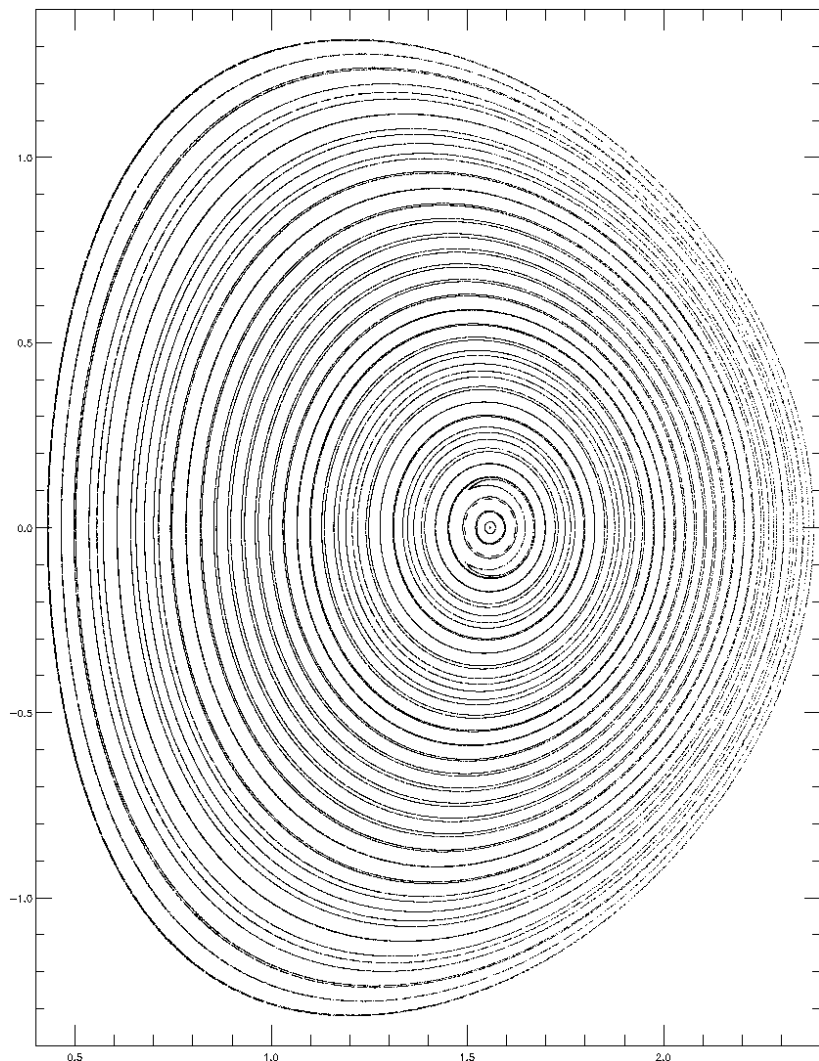


# Kinetic Energy History by Toroidal Mode Number

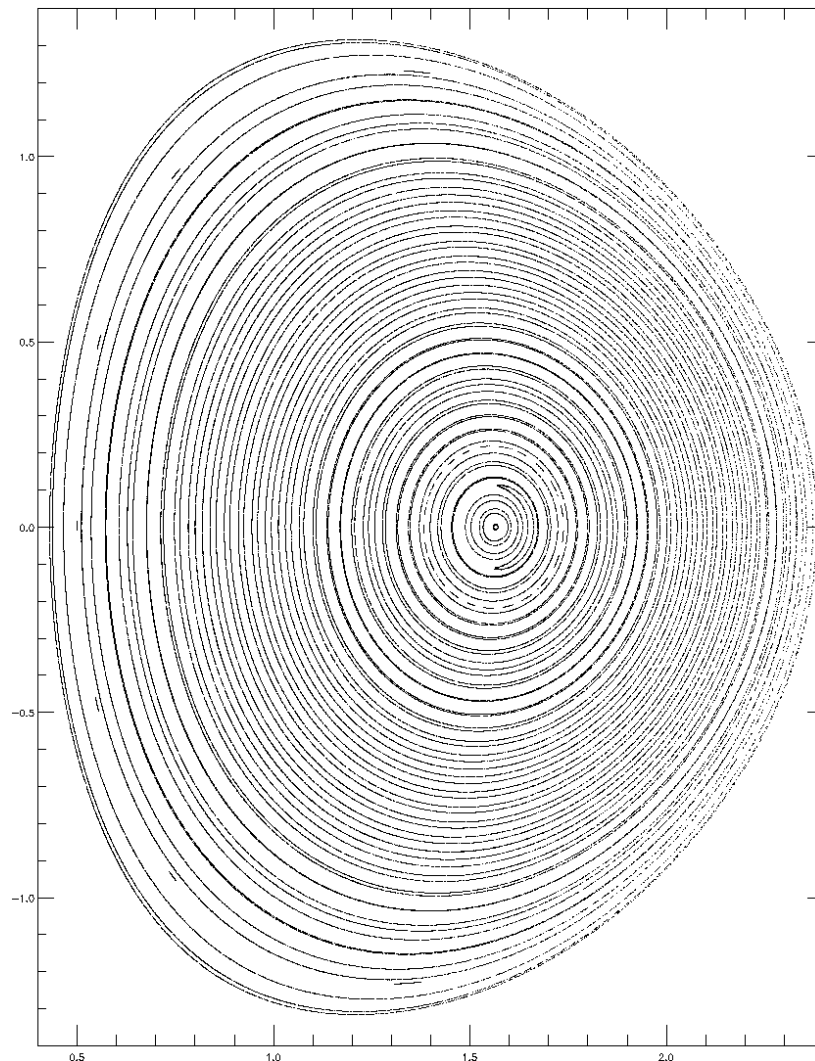


# Try again with no chop

constant density



Initial state,  $t=666.04$



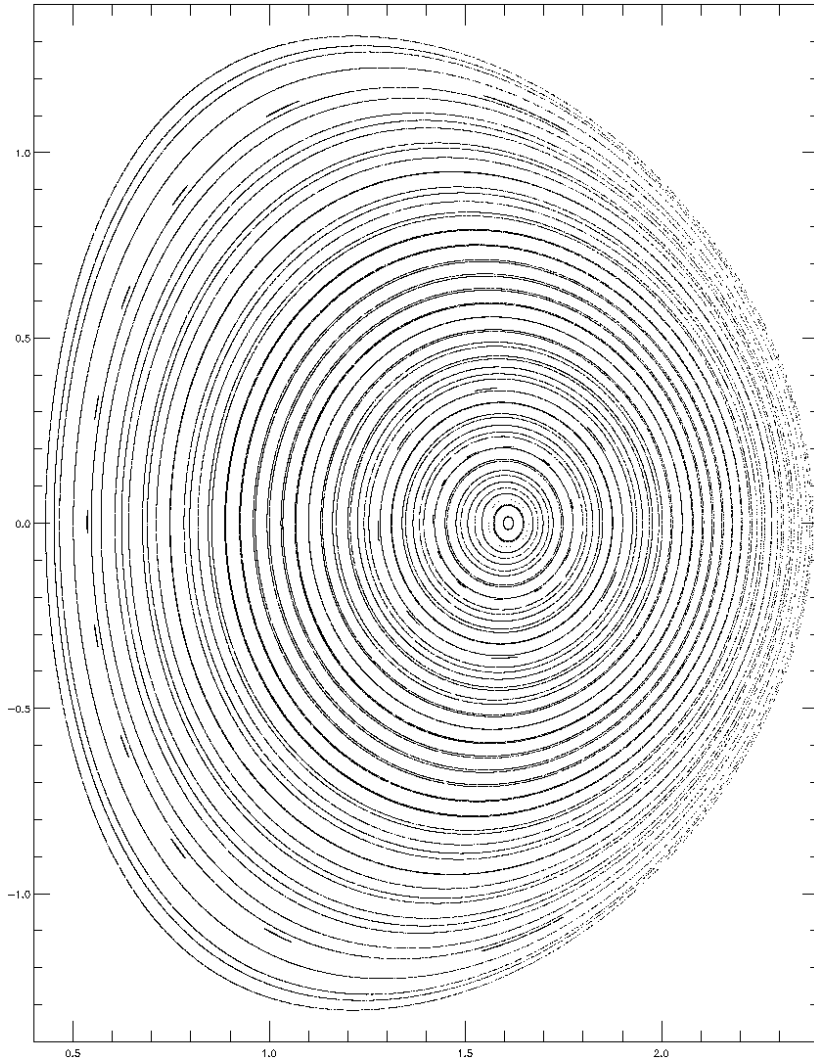
$t=676.04$

$\gamma=0.004755 \rightarrow \tau \approx 210.3$

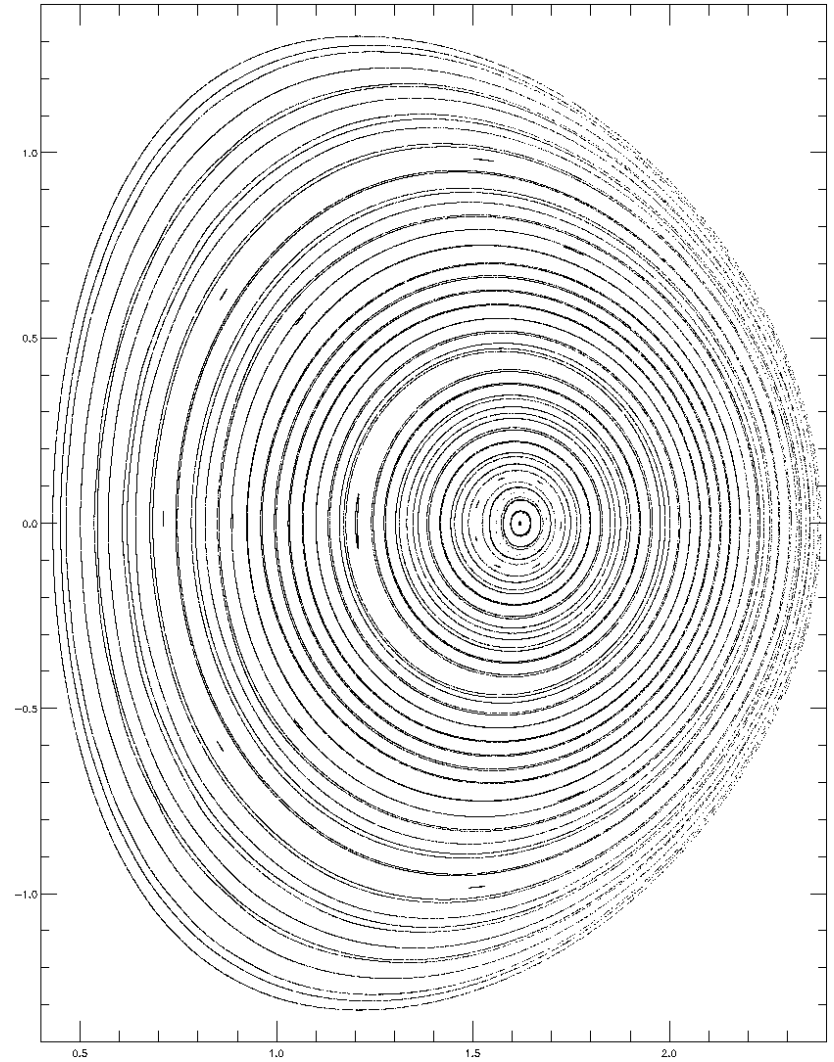
16 planes, 71 radial grids

$\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-4}$ ;  $\kappa=9.09 \times 10^{-4}$

# Constant density, no chop, cont.



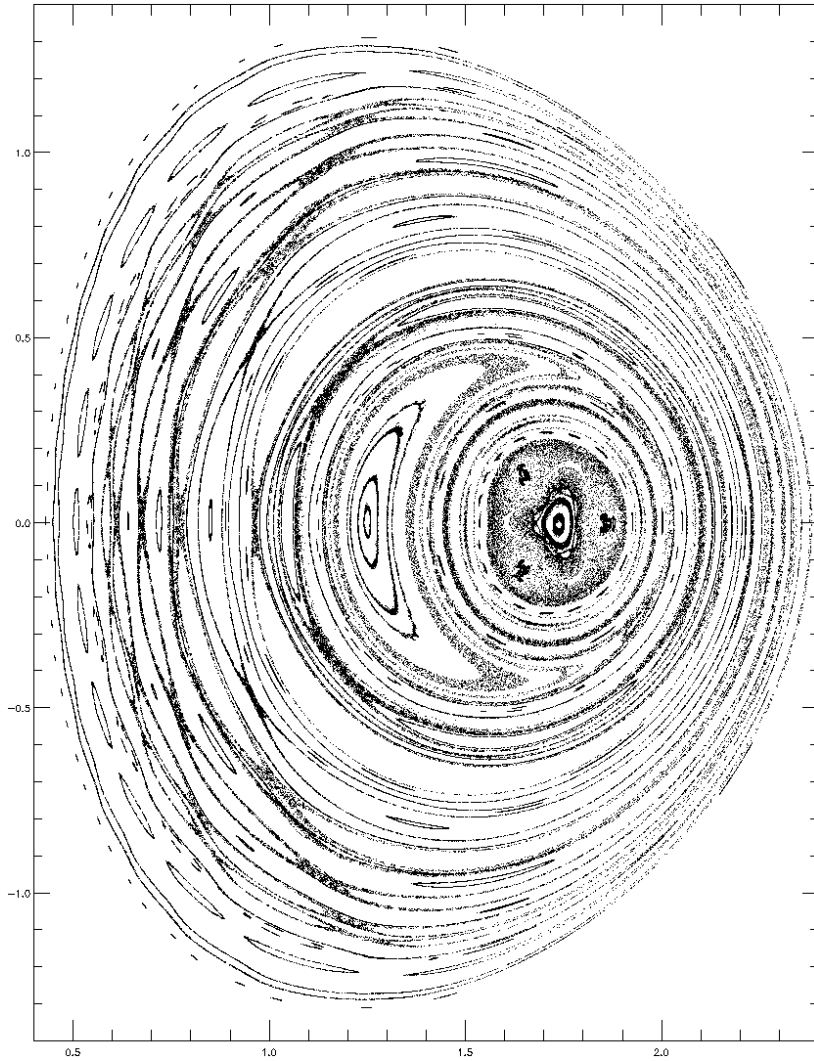
t=1066.92



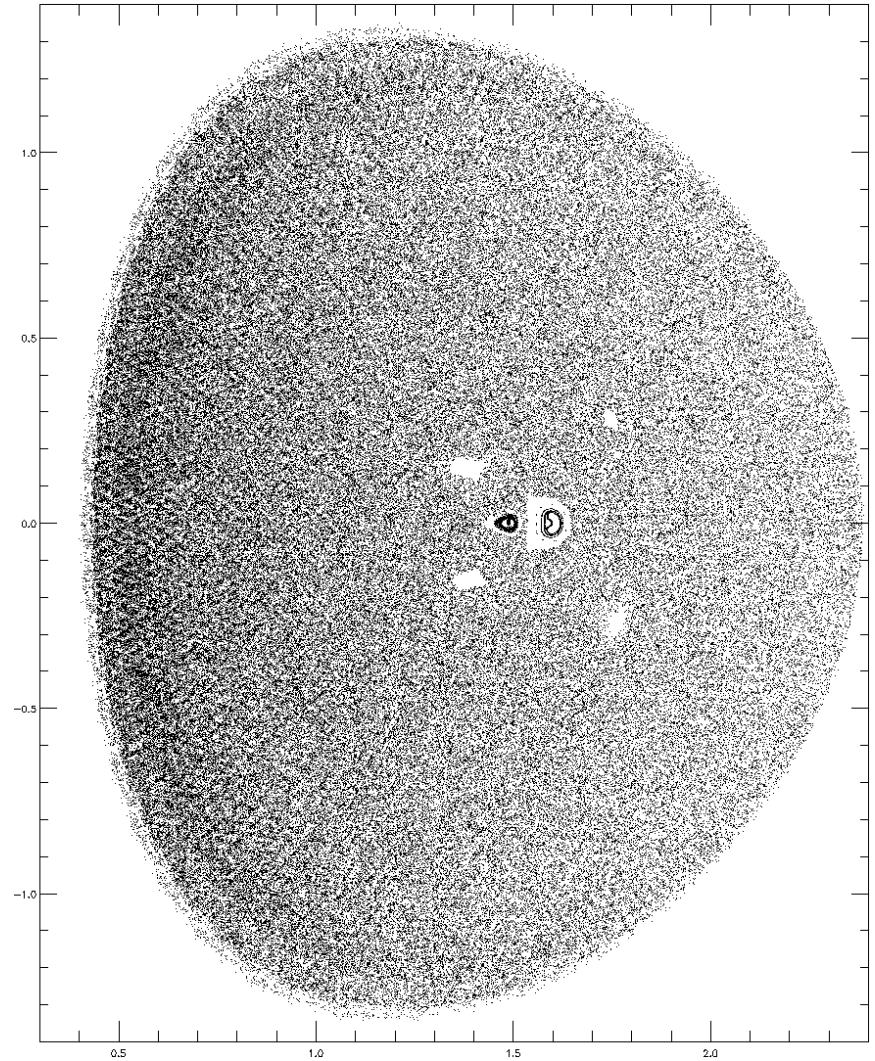
t=1131.57

$\gamma=0.004755 \rightarrow \tau \approx 210.3$       16 planes, 71 radial grids       $\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-4}$ ;  $\kappa=9.09 \times 10^{-4}$

# Constant density, no chop, cont.



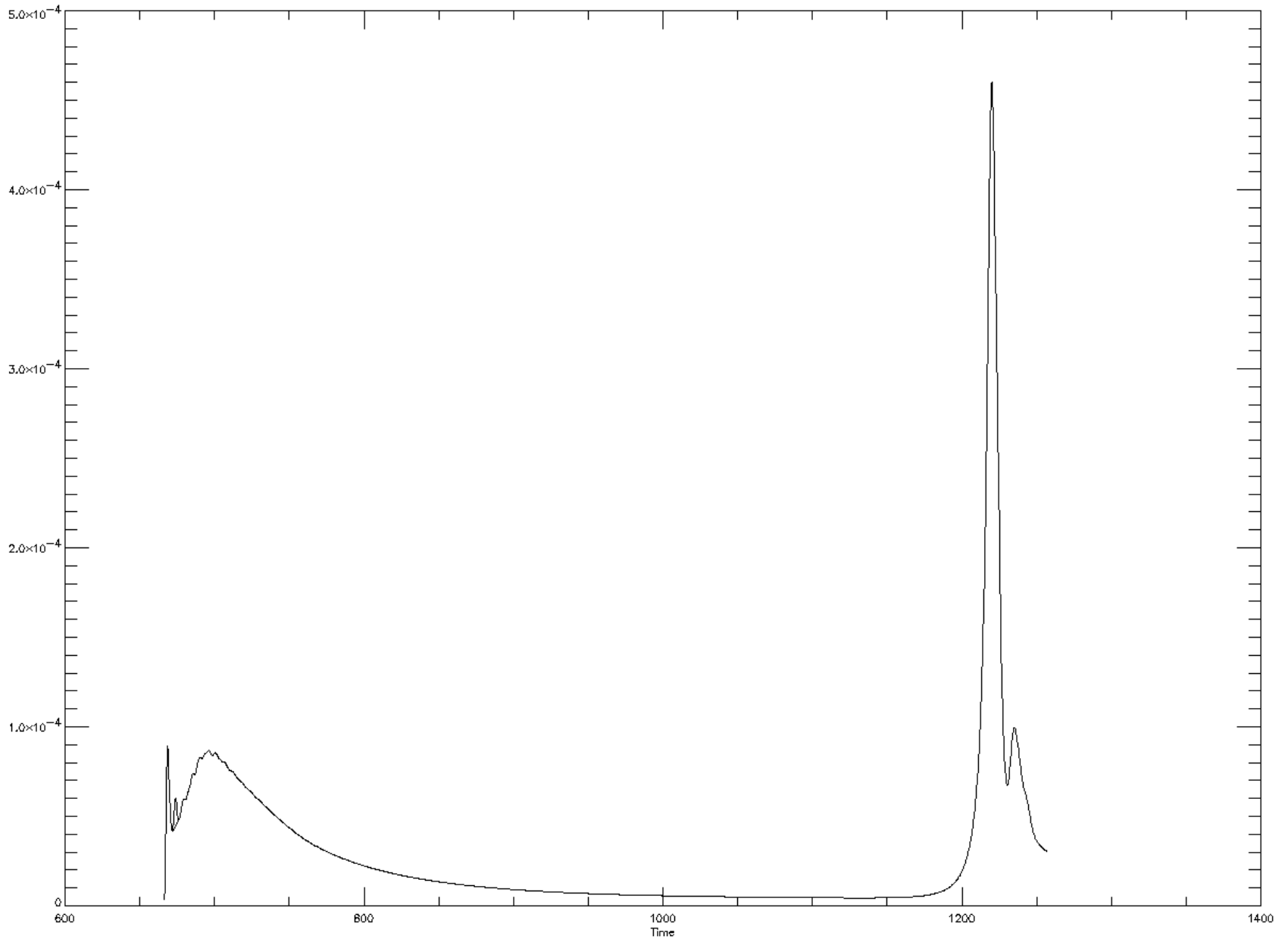
$t=1197.70$



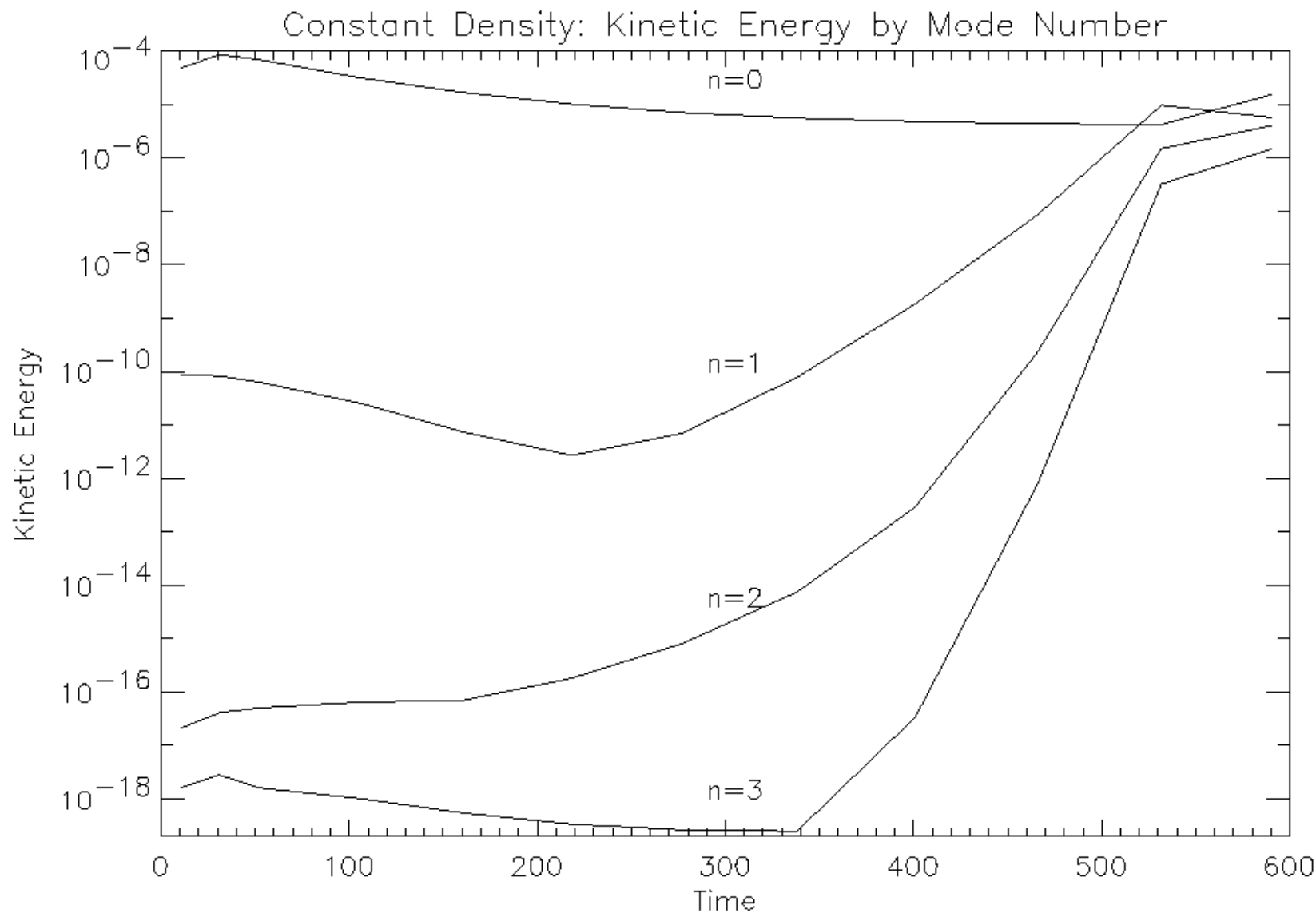
$t=1256.85$

$\gamma=0.004755 \rightarrow \tau \approx 210.3$       16 planes, 71 radial grids       $\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-4}$ ;  $\kappa=9.09 \times 10^{-4}$

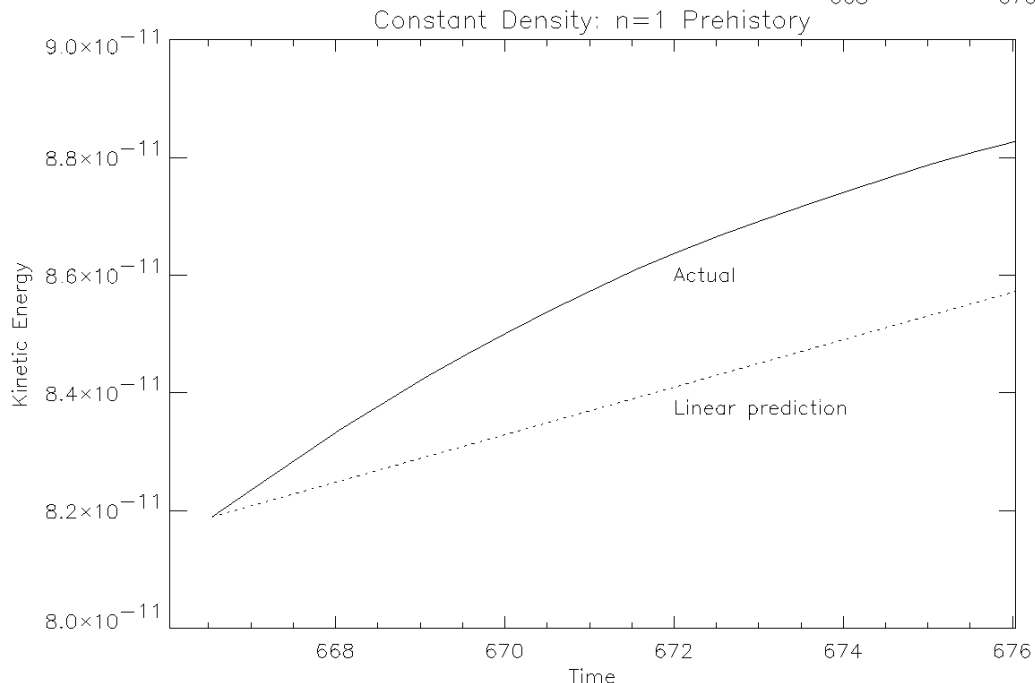
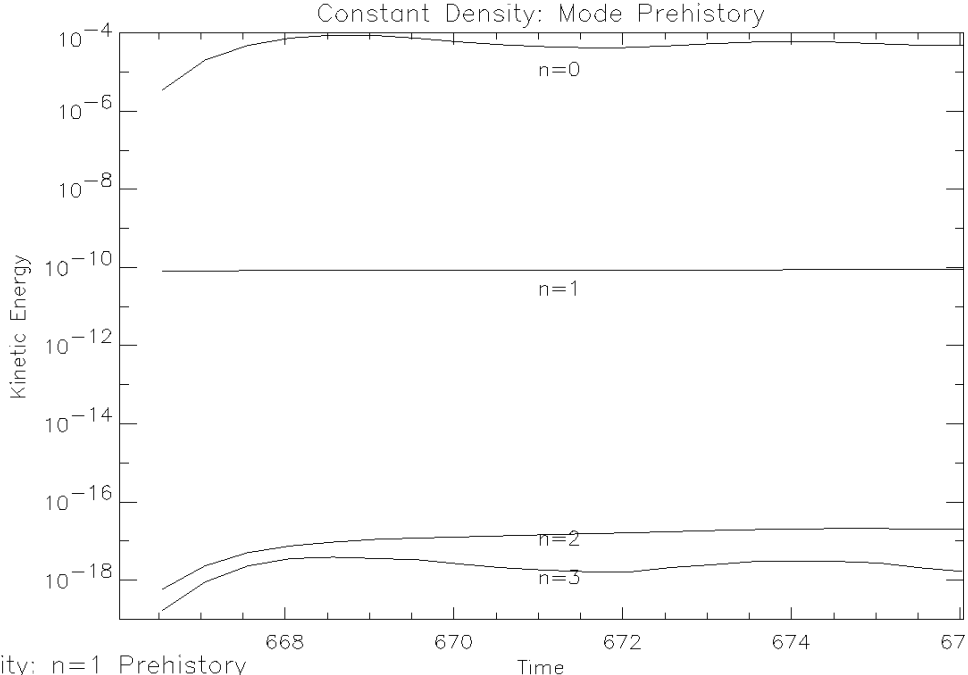
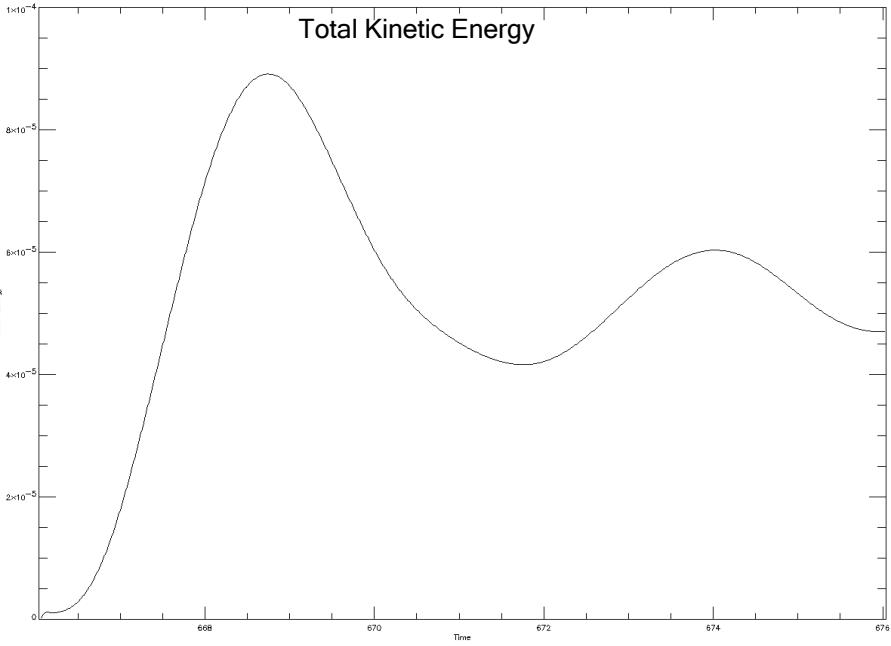
# Kinetic Energy History



# Kinetic Energy History by Toroidal Mode Number

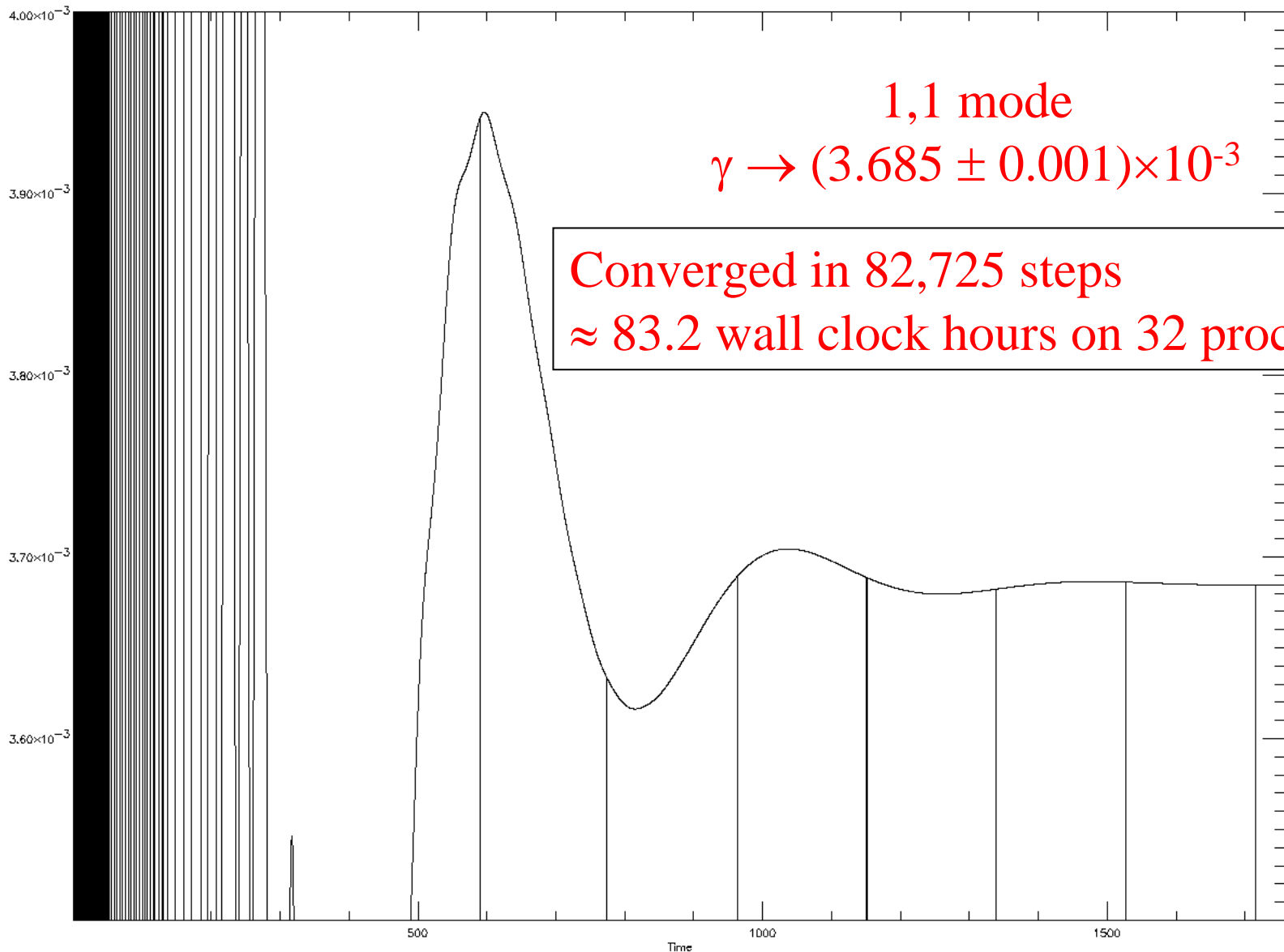


# Constant Density Kinetic Energy "Pre-history" (1<sup>st</sup> 10 Alfvén times)



# Evolving Density, $p_{diss}=1e-3$

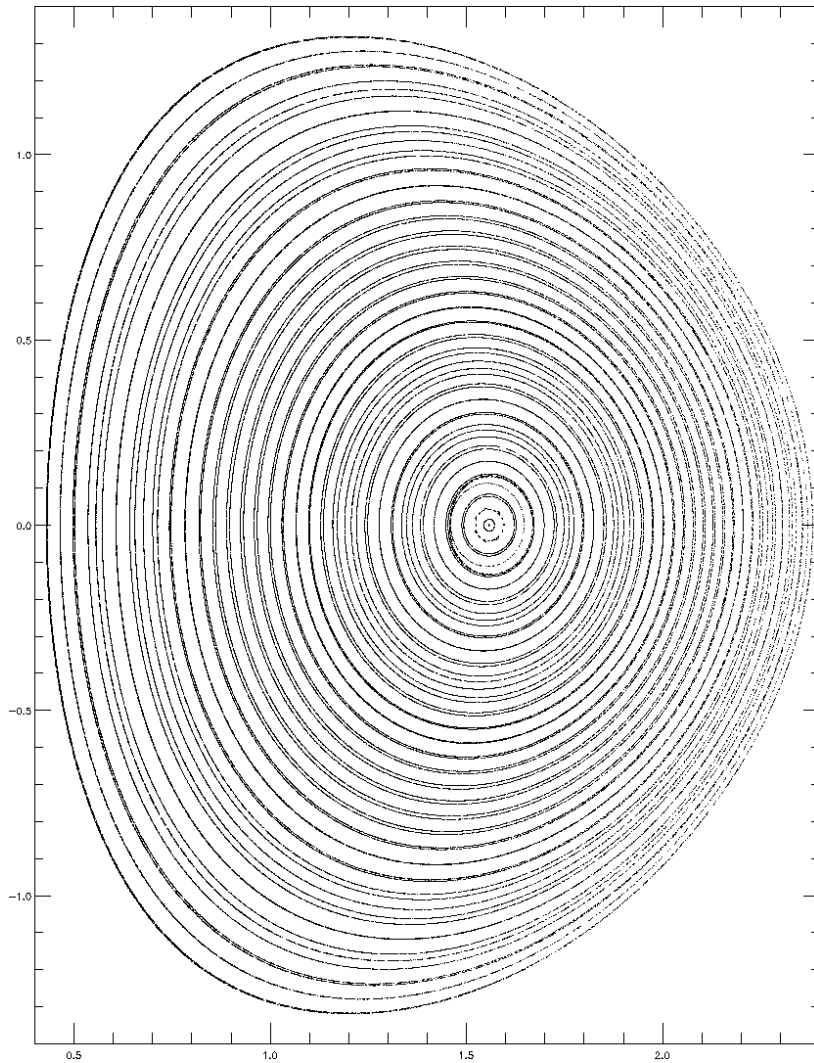
## Linear phase: growth rate



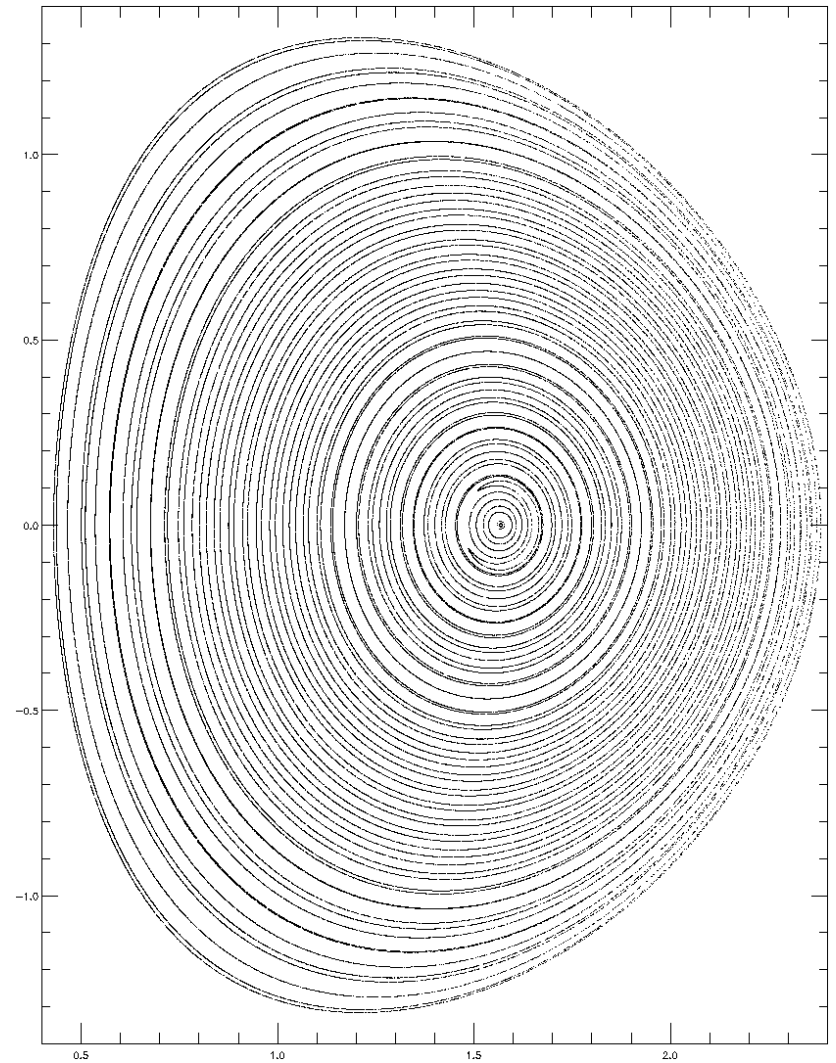


# CDX Series ( $0.95 < q_0 < 0.96$ )

evolving density,  $p_{\text{diss}}=1e-3$



Initial state,  $t=1760.72$

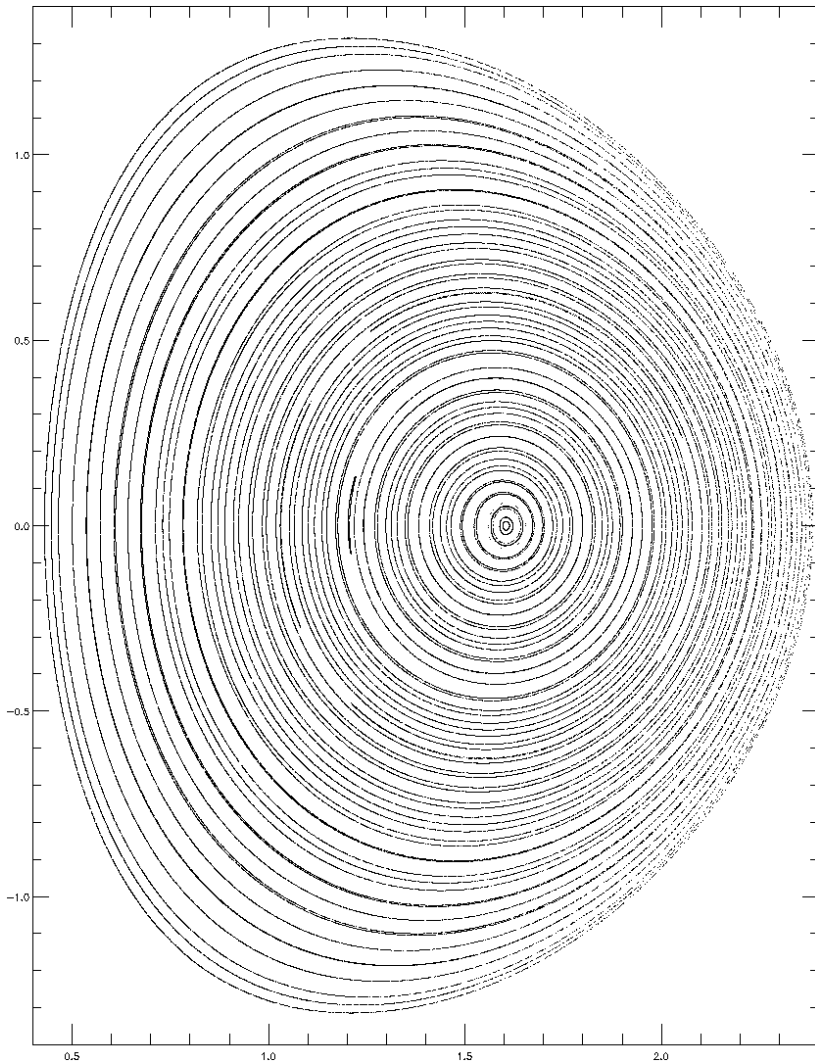


$t=1770.54$ , no chop

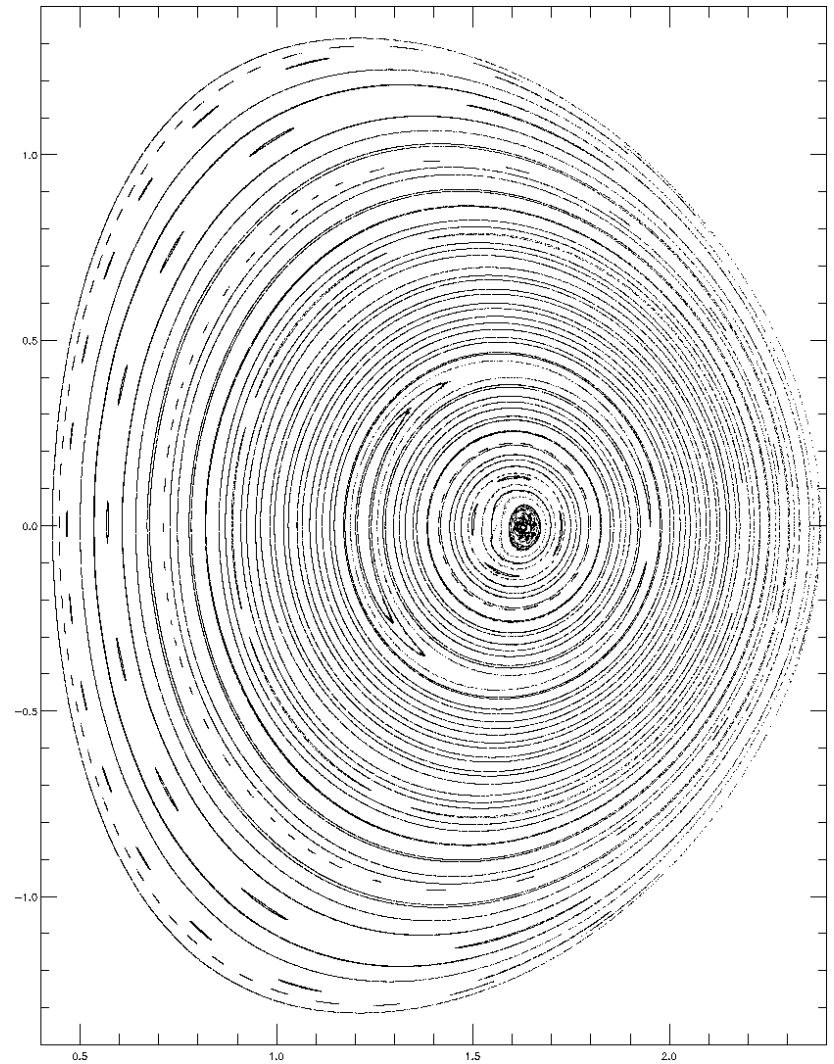
$\gamma=0.003685 \rightarrow \tau \approx 271.37$     16 planes, 71 radial grids     $\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-4}$ ;  $\kappa=9.09 \times 10^{-4}$

# CDX Series ( $0.95 < q_0 < 0.96$ )

evolving density,  $pdiss=1e-3$



$t=2185.45$

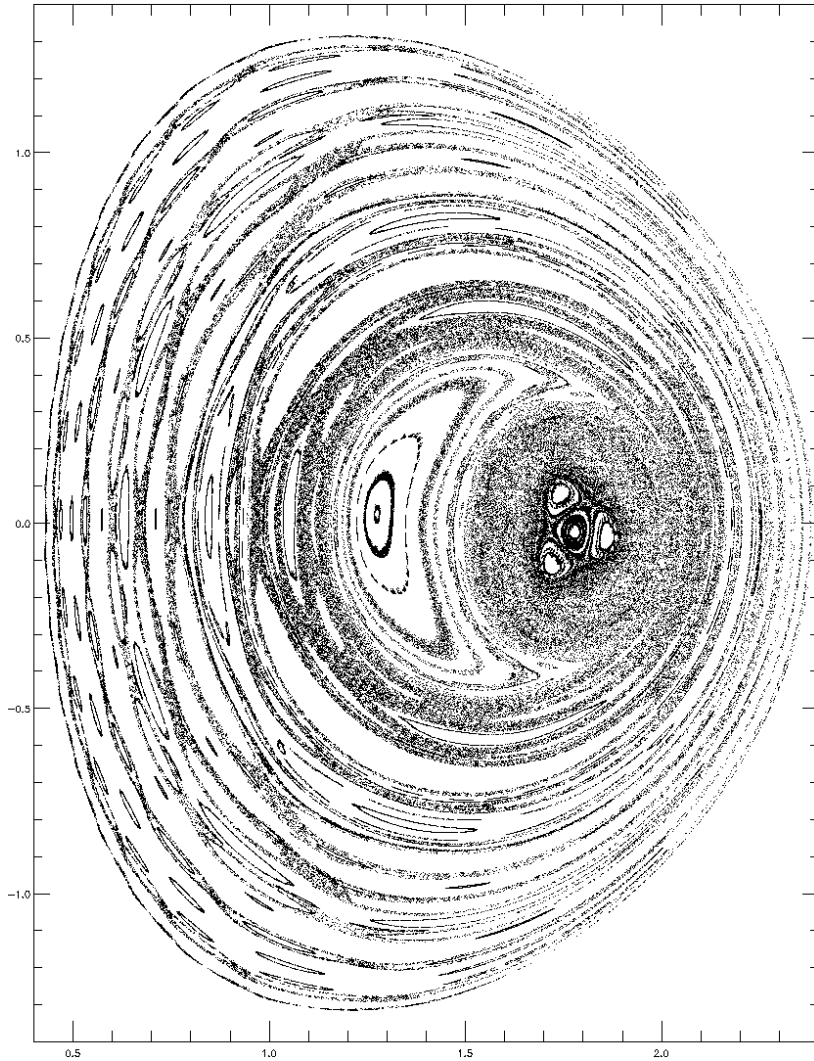


$t=2251.95$

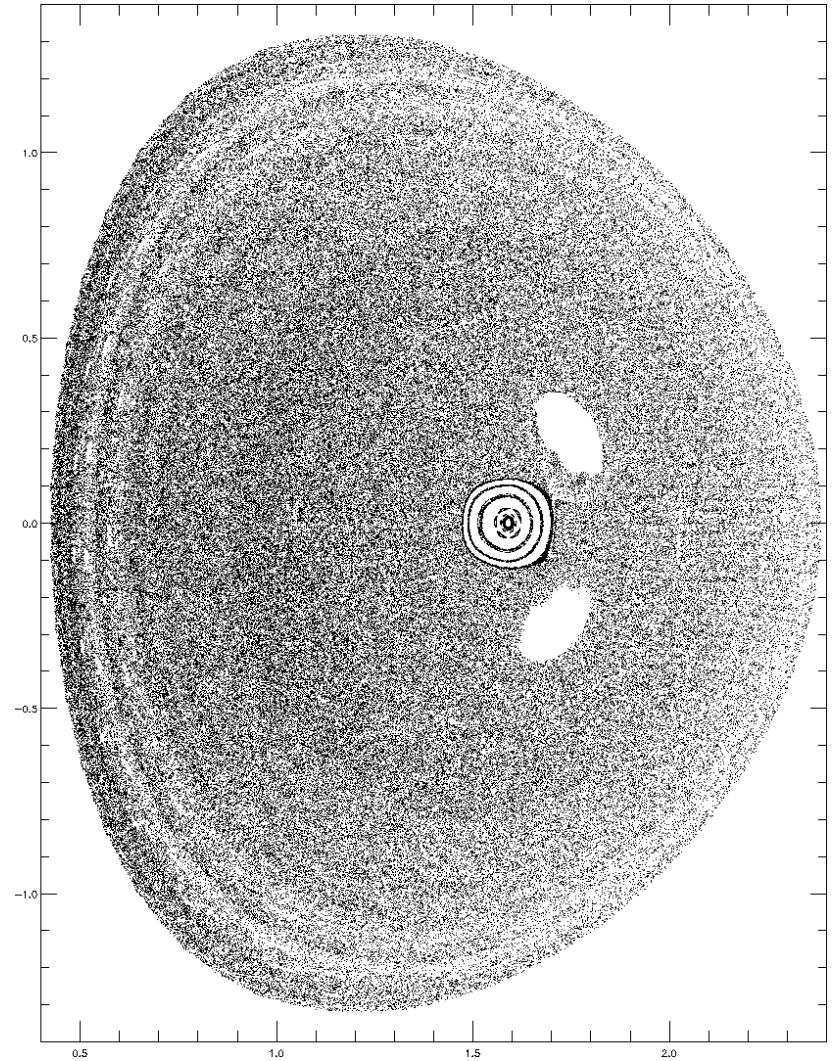
$\gamma=0.003685 \rightarrow \tau \approx 271.37$     16 planes, 71 radial grids     $\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-4}$ ;  $\kappa=9.09 \times 10^{-4}$

# CDX Series ( $0.95 < q_0 < 0.96$ )

evolving density,  $pdiss=1e-3$



t=2319.77



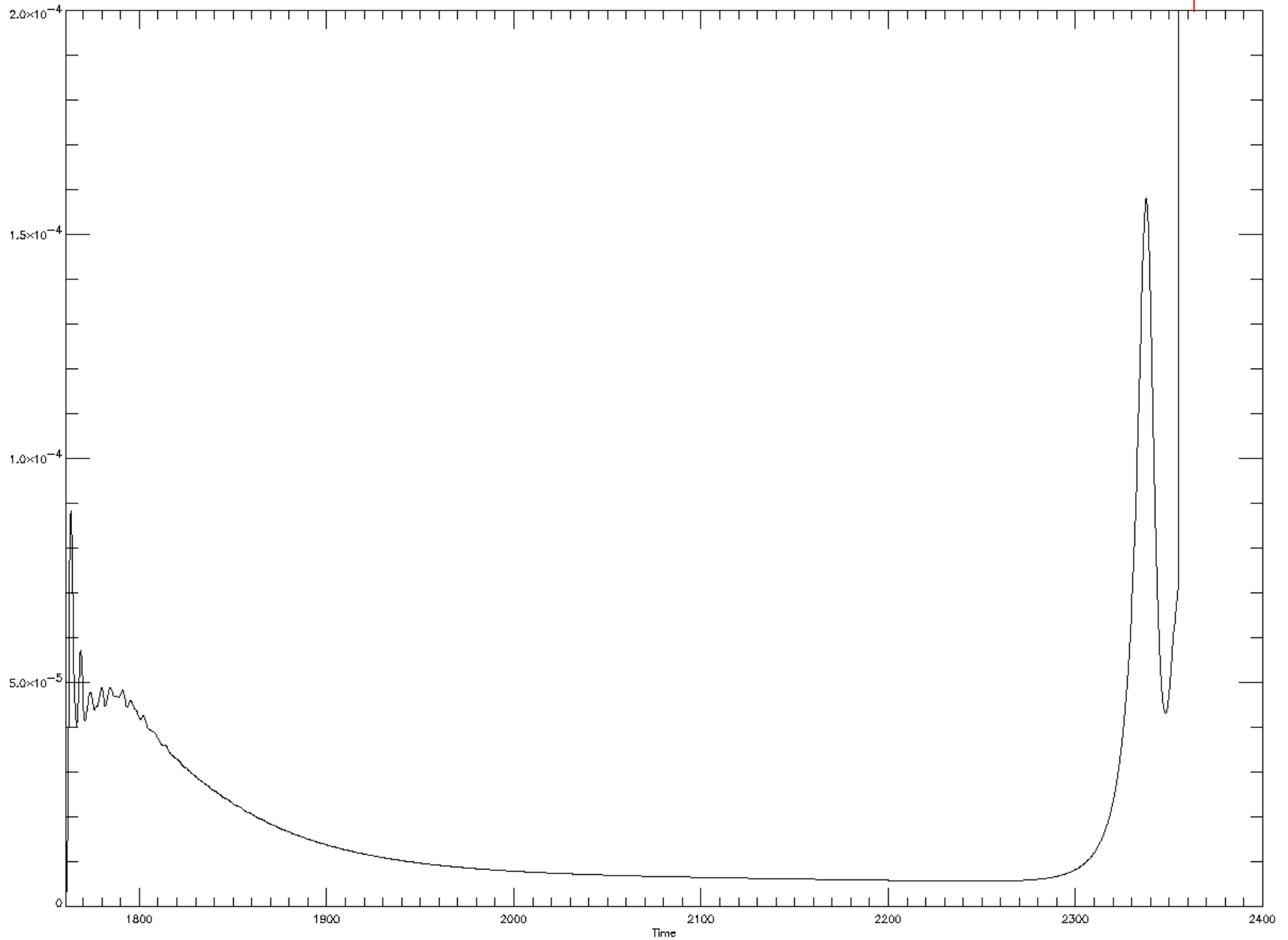
t=2349.88

$\gamma=0.003685 \rightarrow \tau \approx 271.37$

16 planes, 71 radial grids

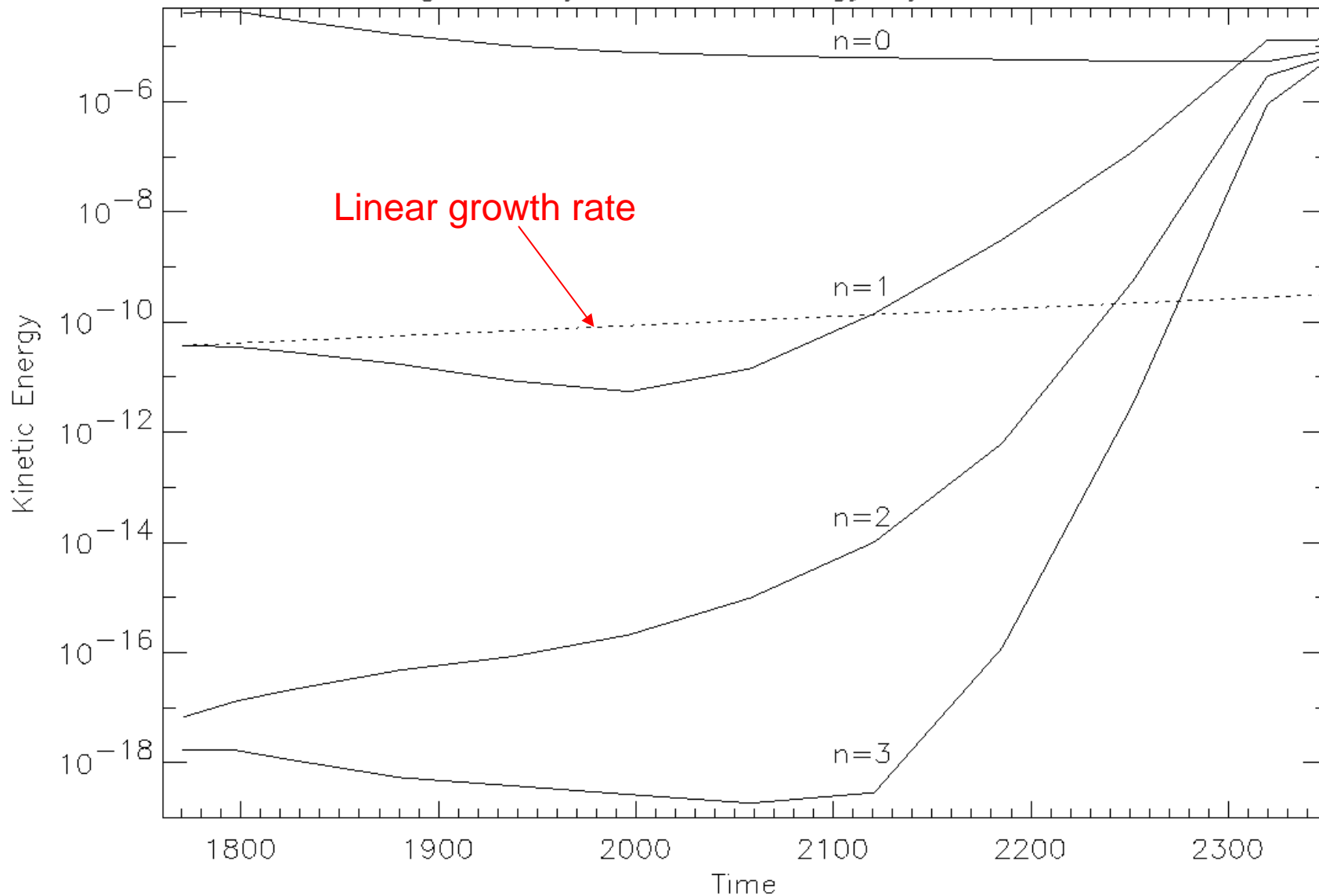
$\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-4}$ ;  $\kappa=9.09 \times 10^{-4}$

# Kinetic Energy History



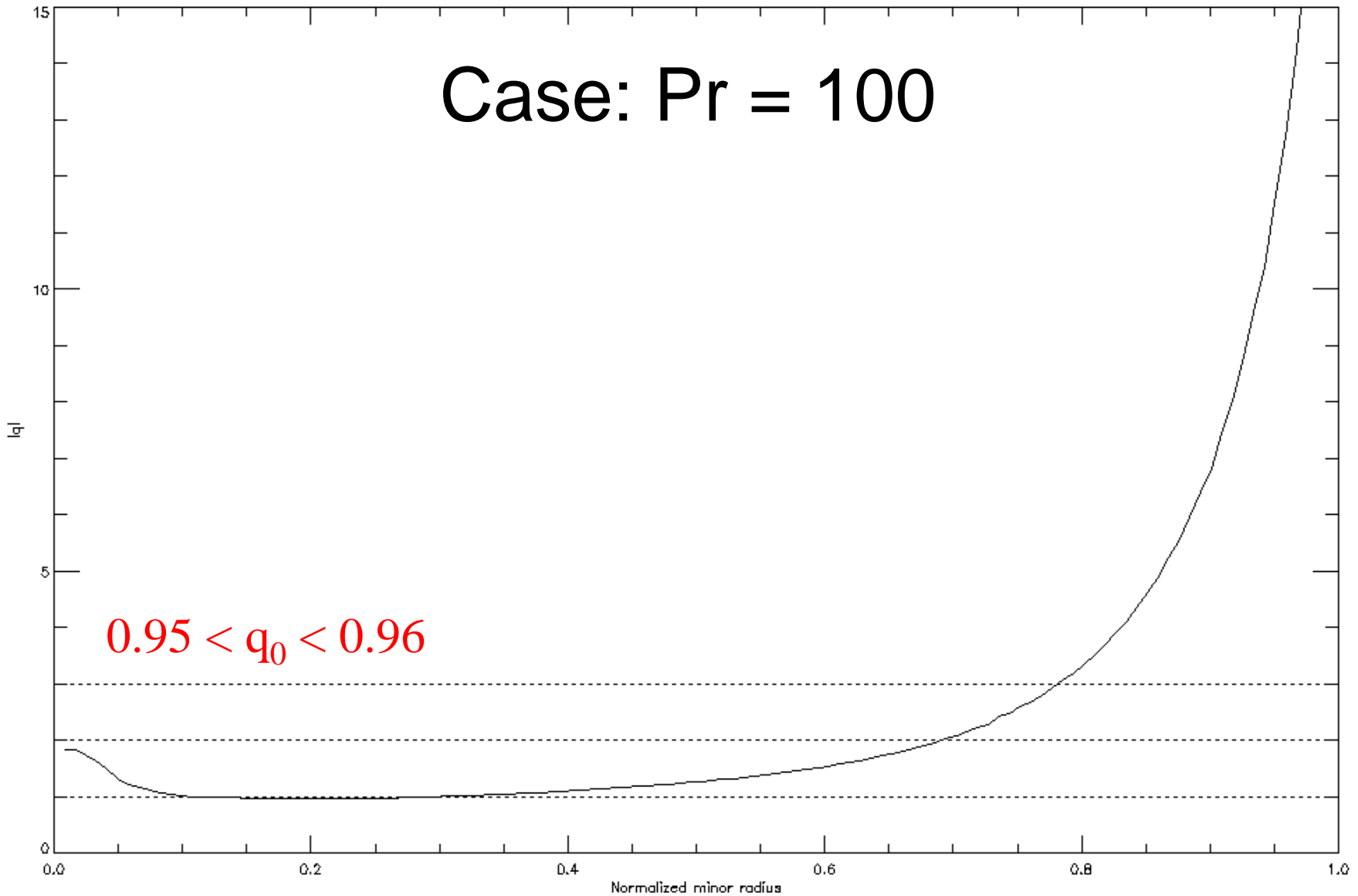
# Kinetic Energy History by Toroidal Mode Number

Evolving Density: Kinetic Energy by Mode Number



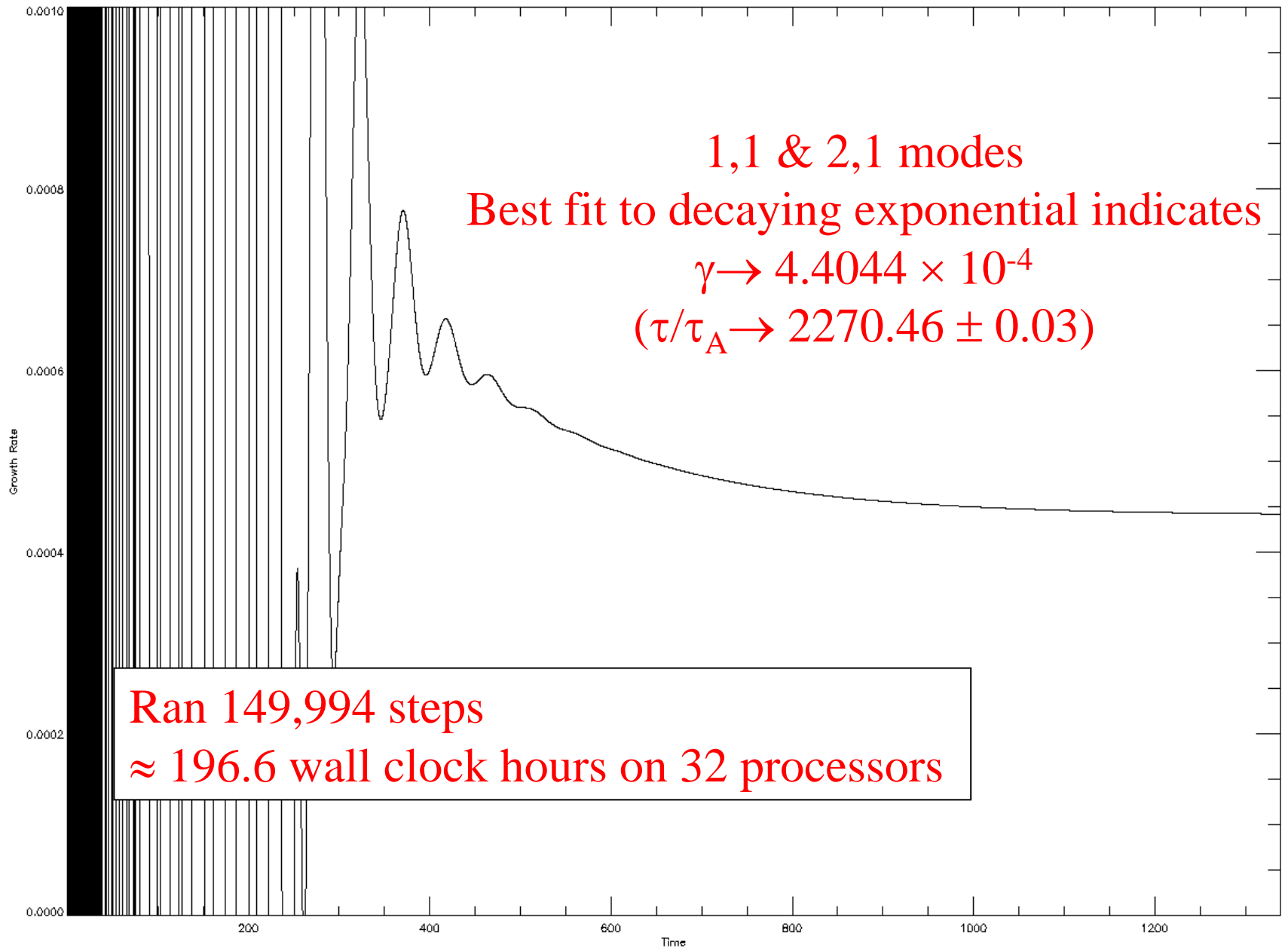
# CDX Series: Initial q profile

Case: Pr = 100

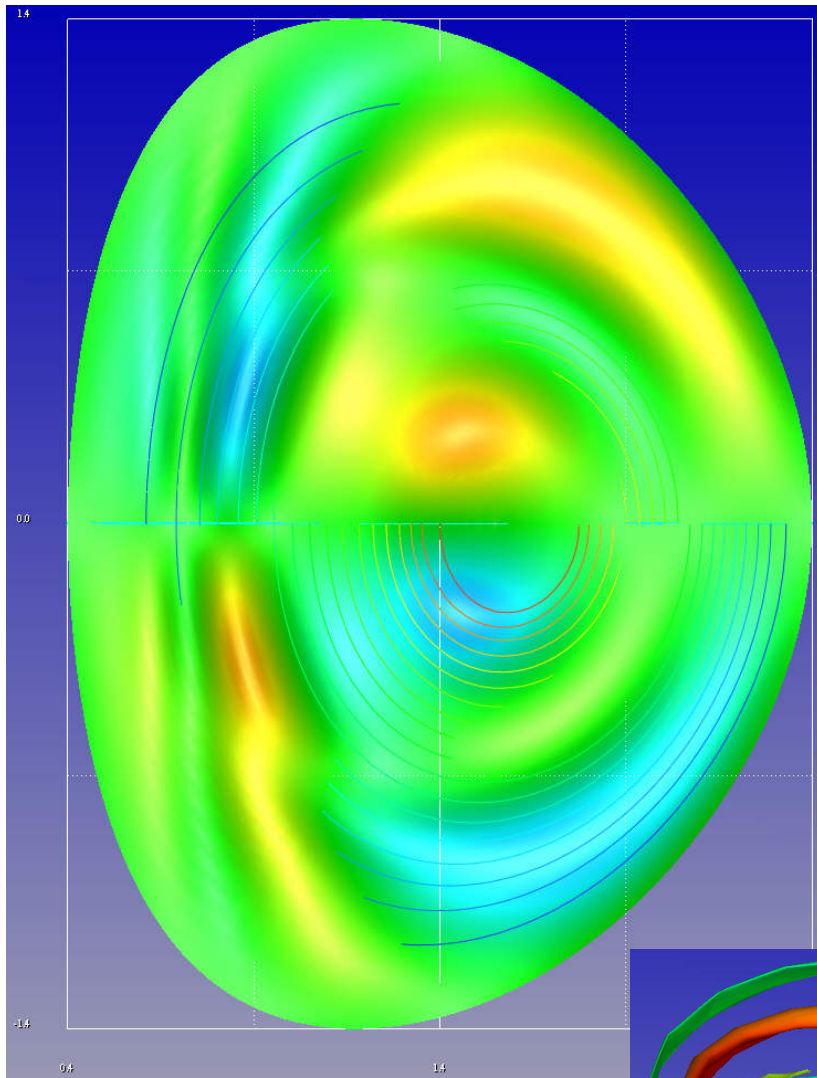


JSolver CDX run05, time09

# Linear phase: growth rate

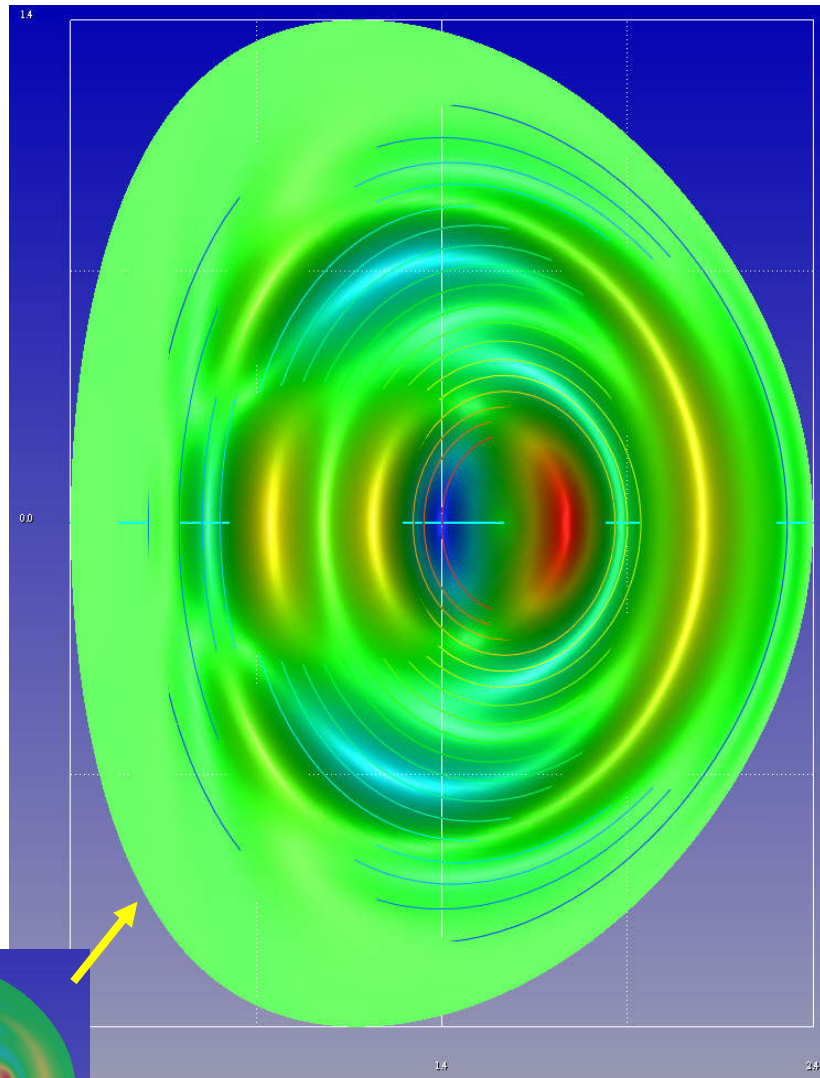


# Mode Structure

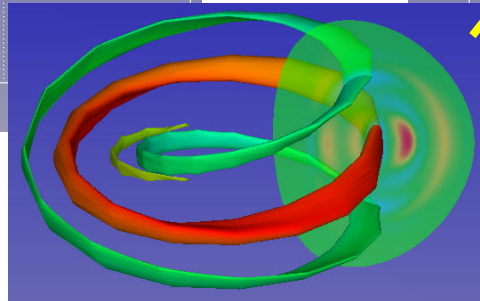


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&  
2,1

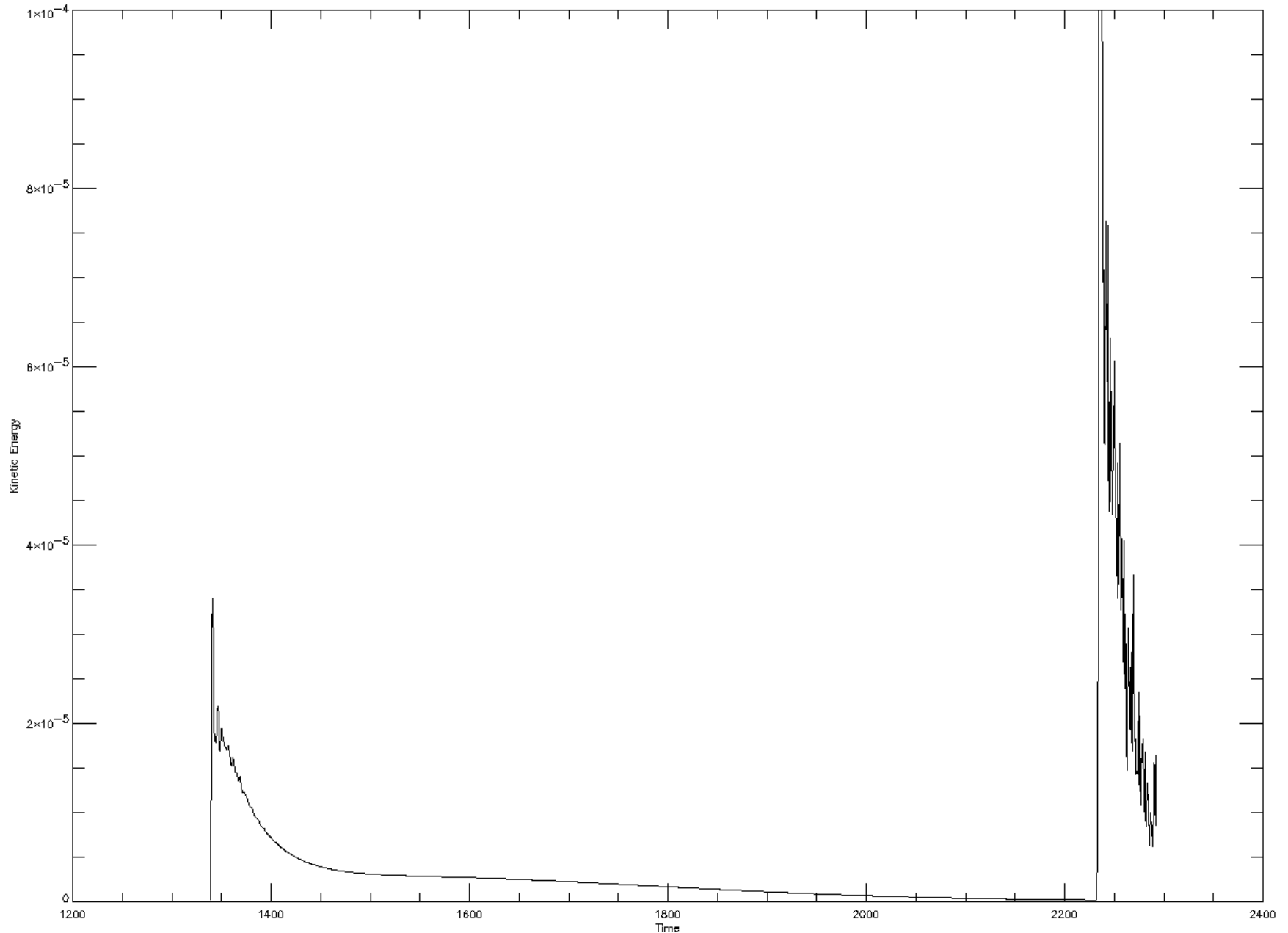


perturbed  $J_\phi$

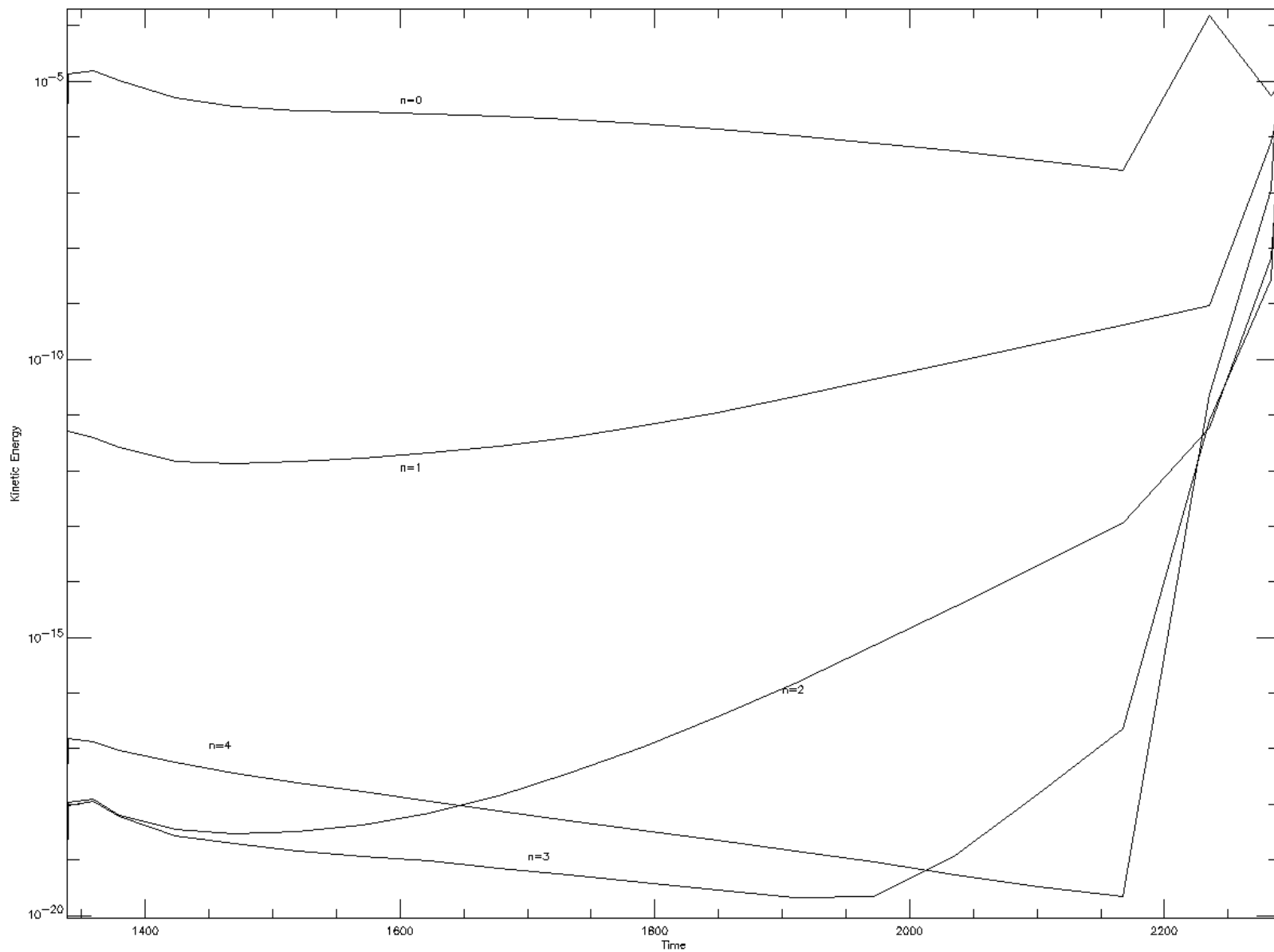




# Nonlinear Total Kinetic Energy History

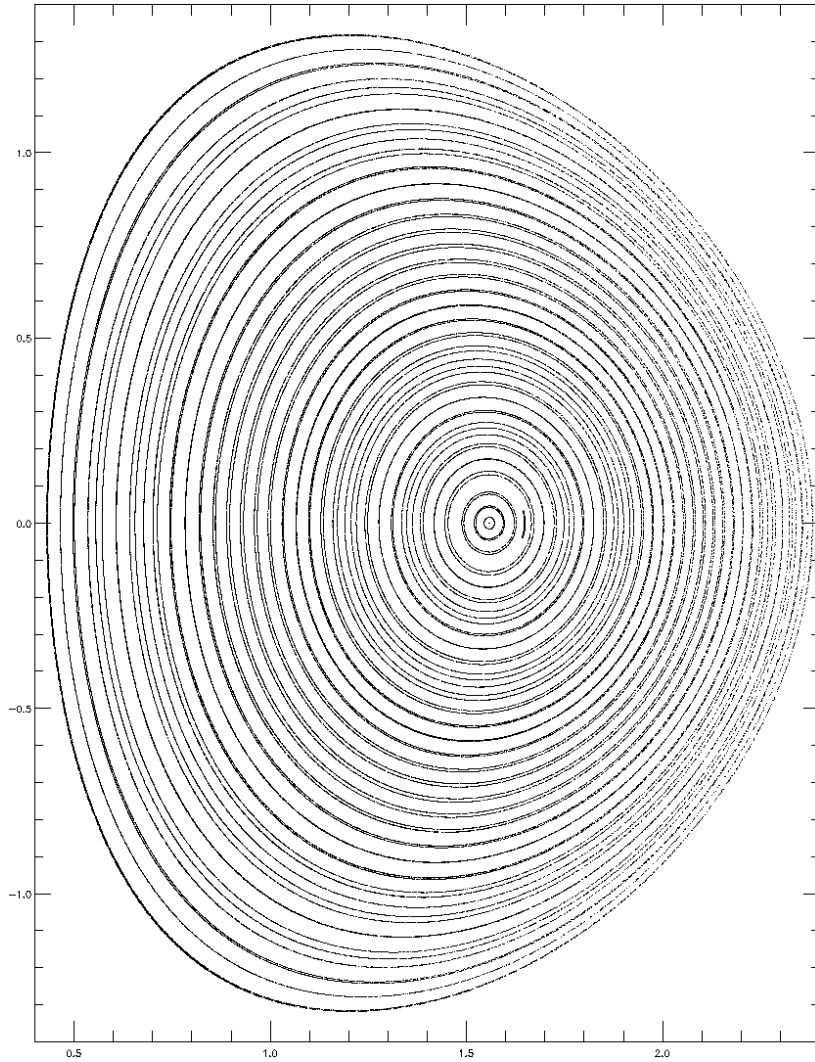


# Kinetic Energy History by Toroidal Mode Number

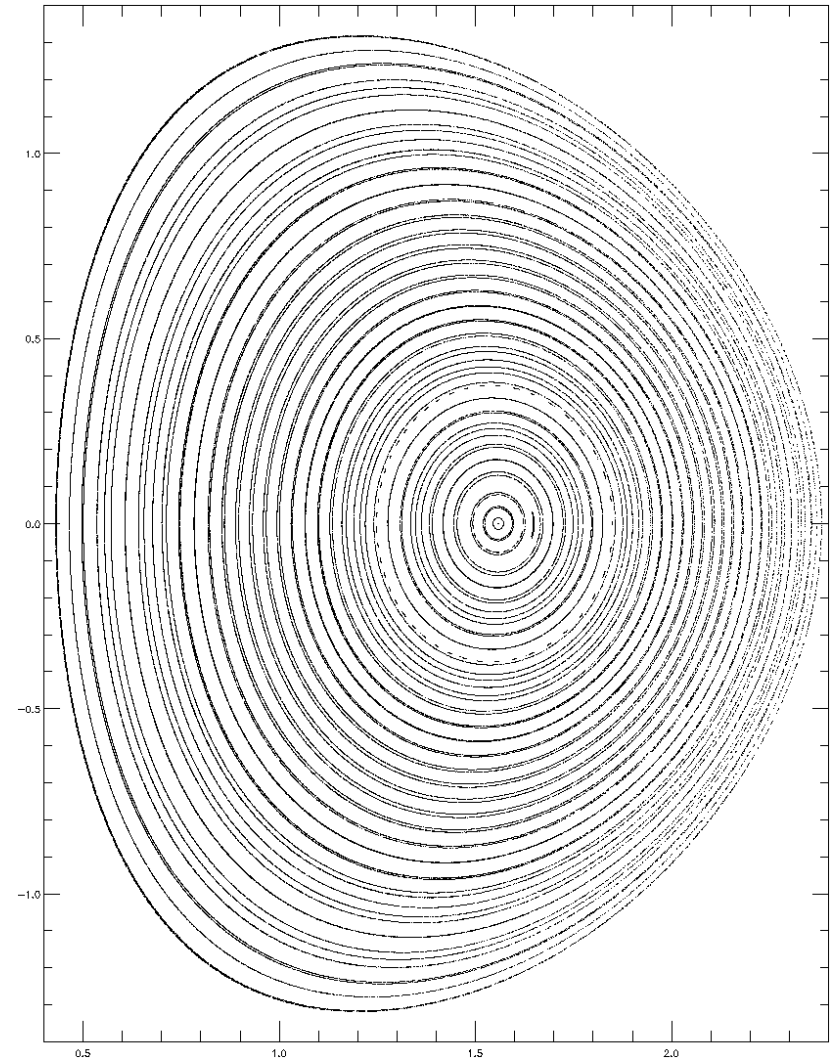


# CDX Series ( $0.95 < q_0 < 0.96$ )

$\text{pdiss} = 10^{-3}$



Initial state,  $t=1338.57$

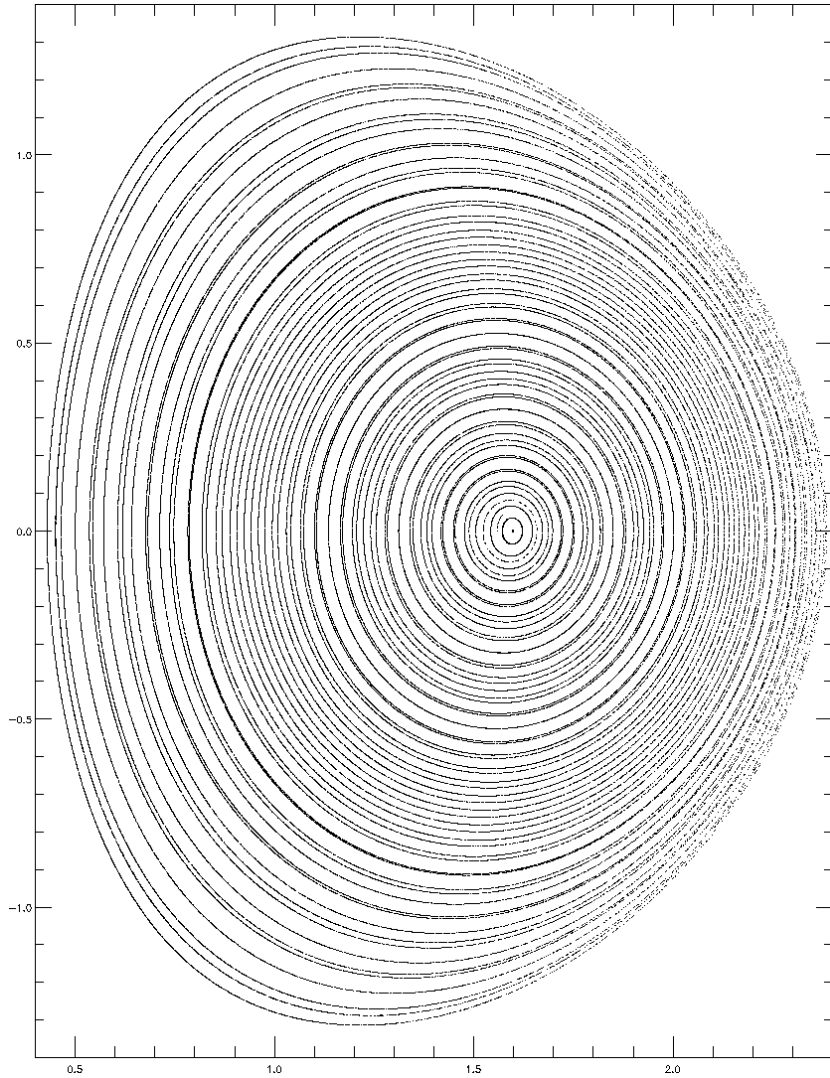


$t=1338.66$ , nonlinear, no chop

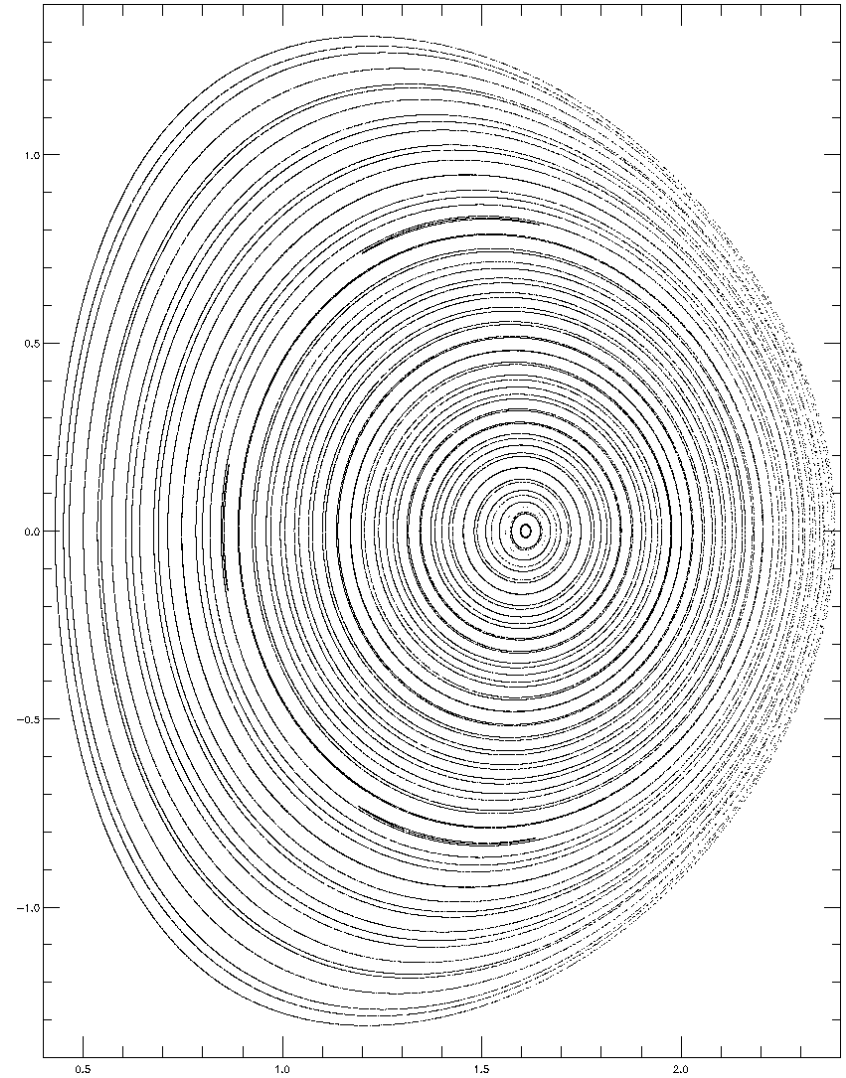
$\gamma=4.4044 \times 10^{-4} \rightarrow \tau \approx 2270.46$  16 planes, 81 radial grids  $\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-3}$ ;  $\kappa=9.09 \times 10^{-4}$

# CDX Series ( $0.95 < q_0 < 0.96$ )

$\text{pdiss} = 10^{-3}$



$t=1423.60$

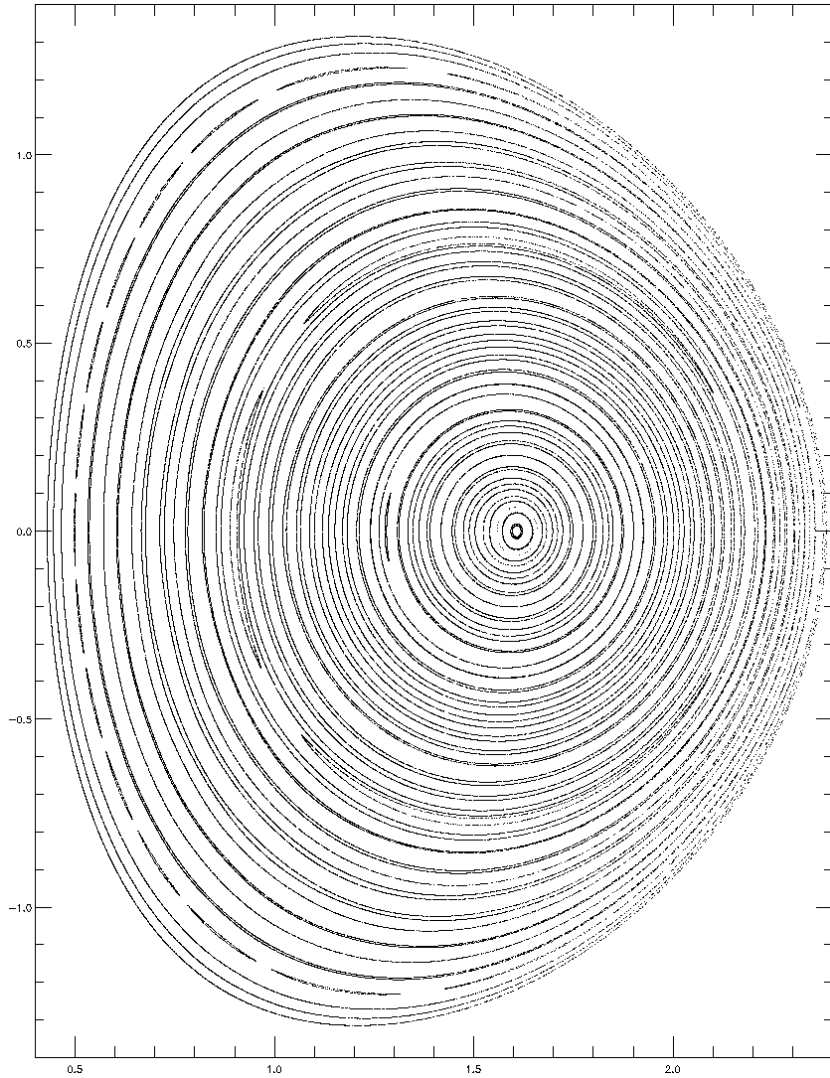


$t=1790.32$

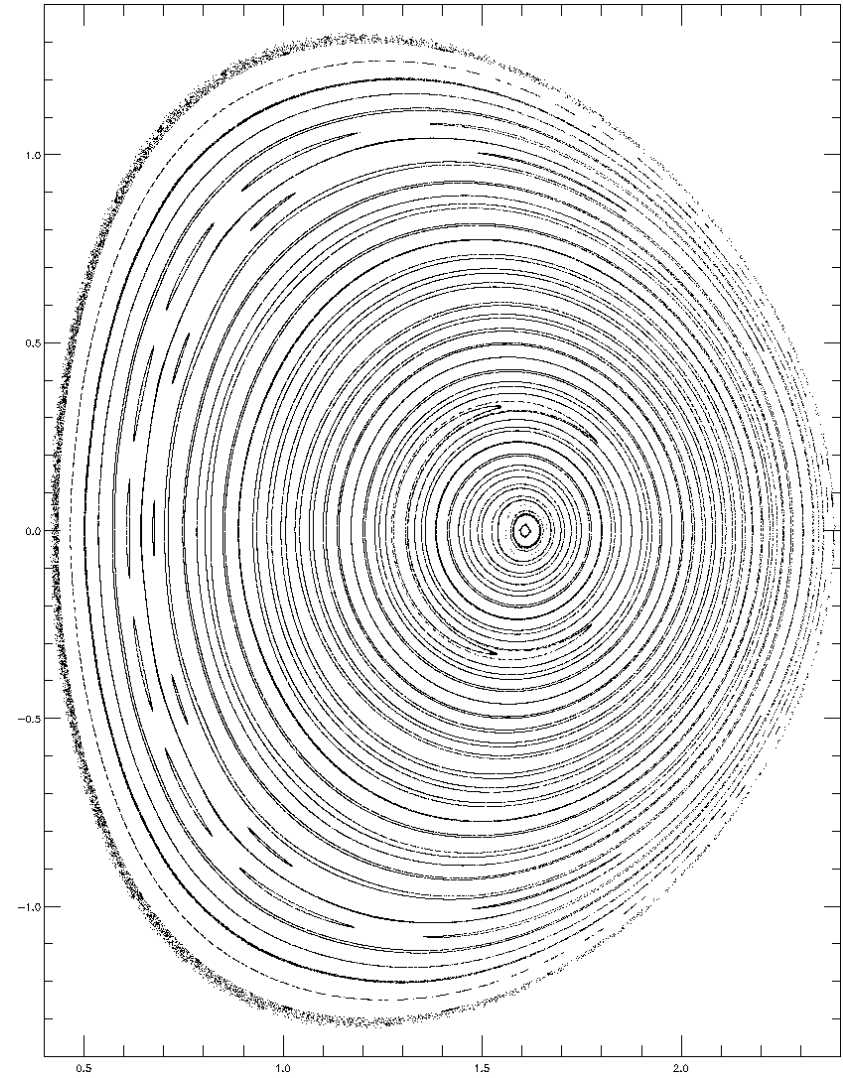
$\gamma=4.4044 \times 10^{-4} \rightarrow \tau \approx 2270.46$  16 planes, 81 radial grids  $\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-3}$ ;  $\kappa=9.09 \times 10^{-4}$

# CDX Series ( $0.95 < q_0 < 0.96$ )

$\text{pdiss} = 10^{-3}$



$t=2167.37$

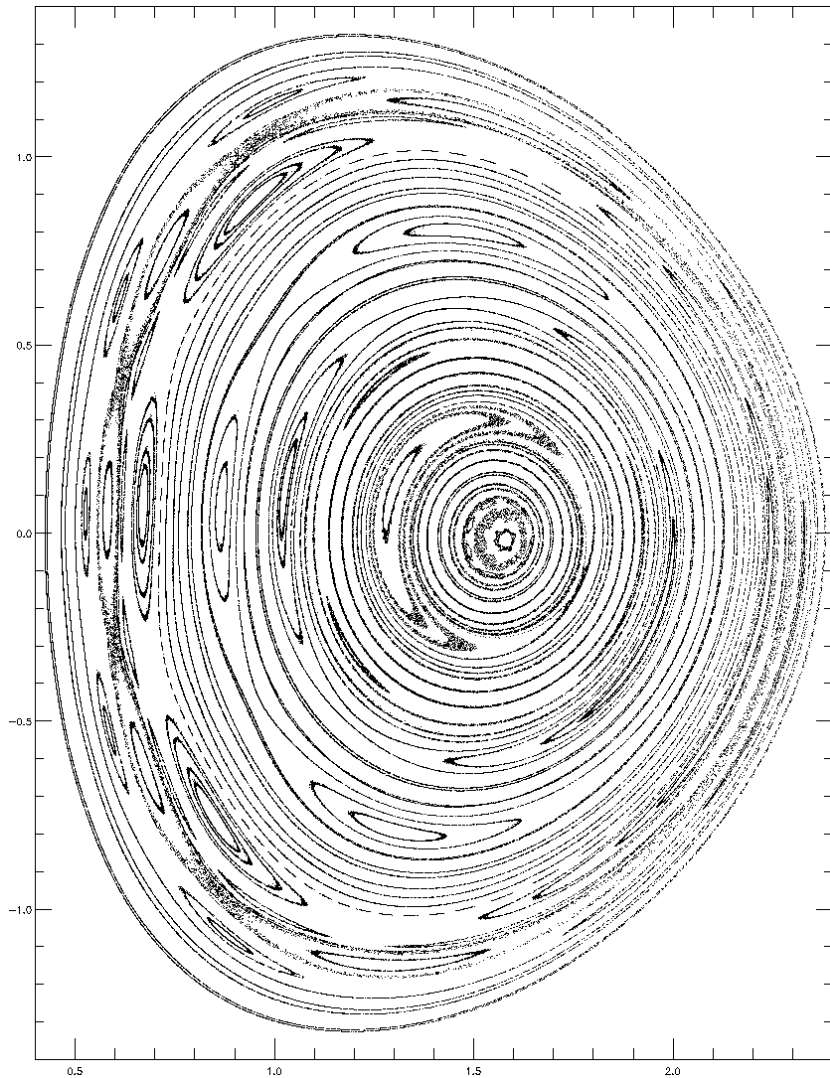


$t=2235.04$

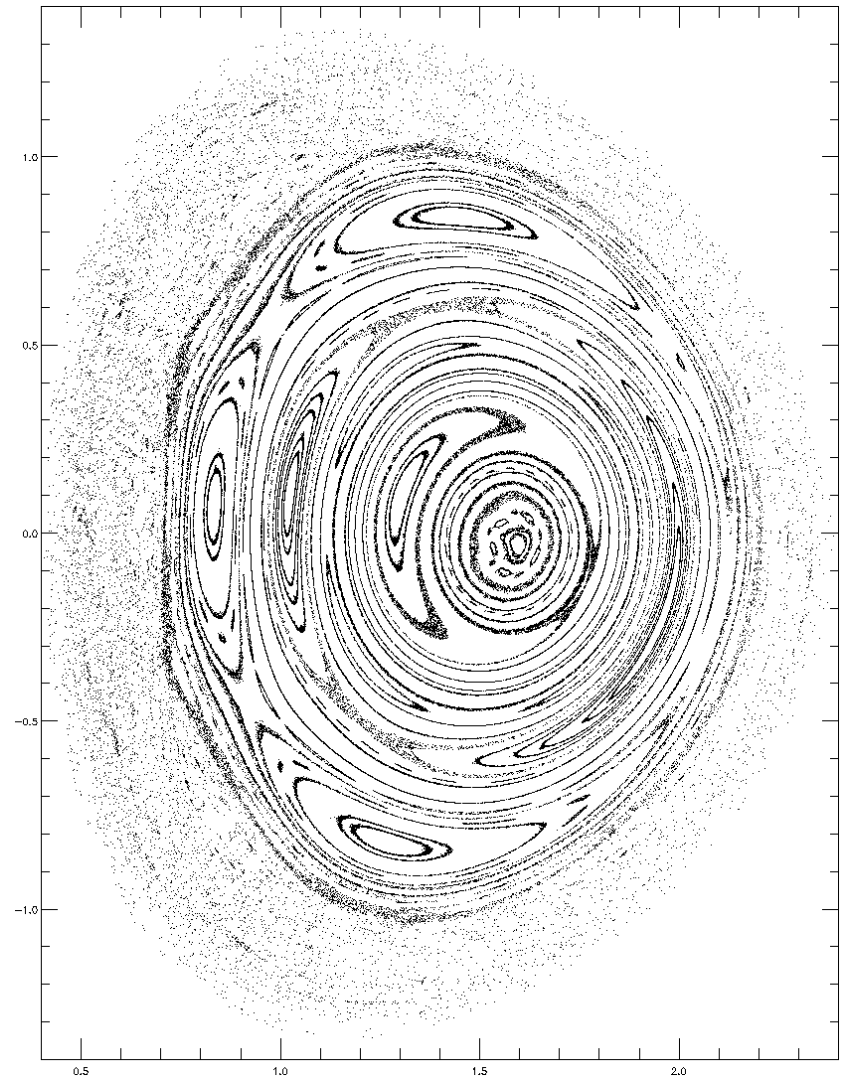
$\gamma=4.4044 \times 10^{-4} \rightarrow \tau \approx 2270.46$  16 planes, 81 radial grids  $\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-3}$ ;  $\kappa=9.09 \times 10^{-4}$

# CDX Series ( $0.95 < q_0 < 0.96$ )

$\rho_{\text{diss}} = 10^{-3}$



$t=2284.16$

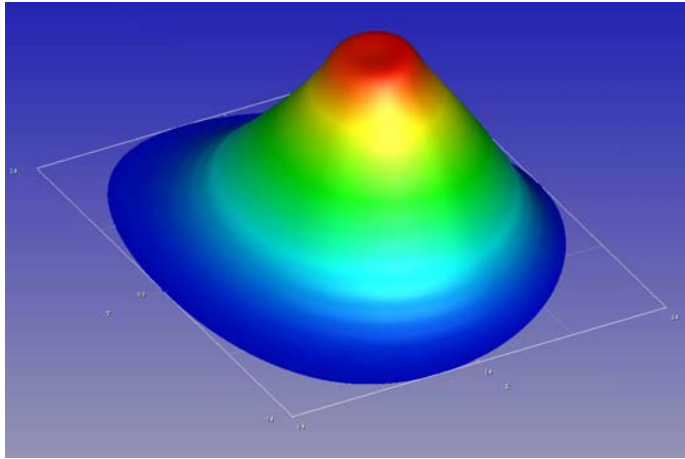


$t=2291.38$

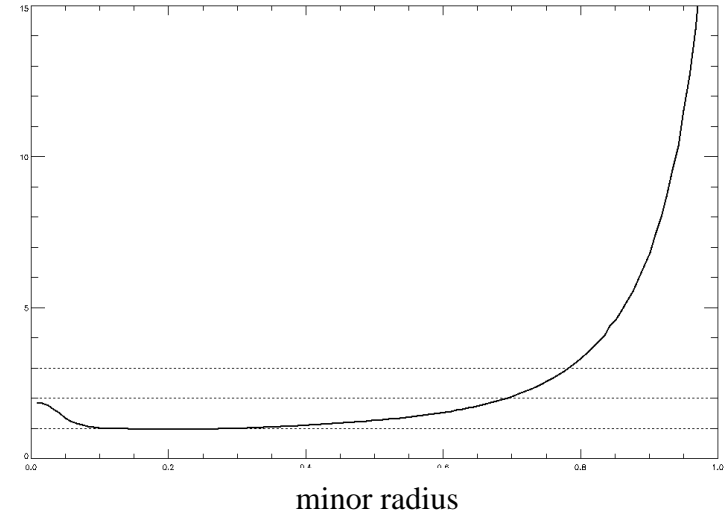
$\gamma=4.4044 \times 10^{-4} \rightarrow \tau \approx 2270.46$  16 planes, 81 radial grids  $\eta=5.1 \times 10^{-5}$ ;  $\mu=5.1 \times 10^{-3}$ ;  $\kappa=9.09 \times 10^{-4}$

# Current Flattening in the Nonlinear Phase

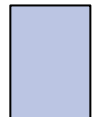
$J_\phi$  (surface plot)



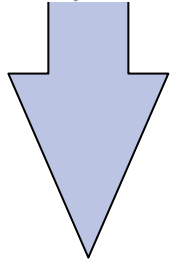
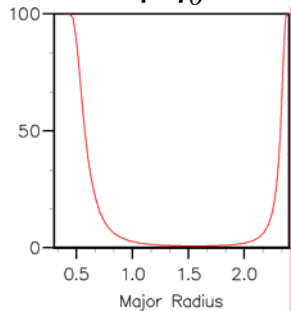
$q(r)$



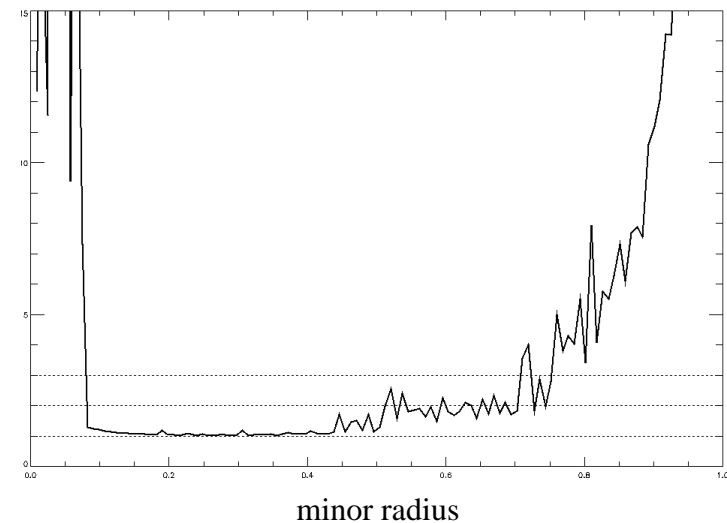
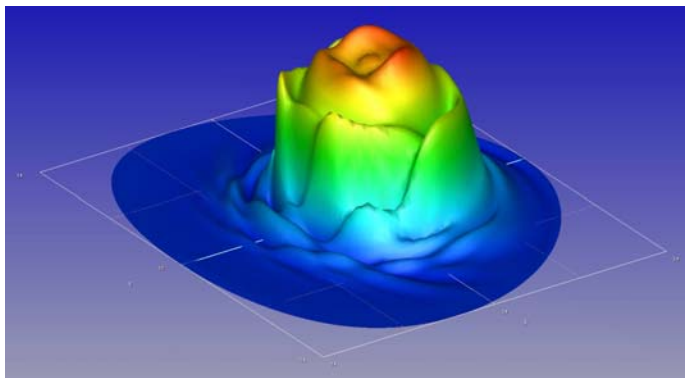
Before



$\eta/\eta_0$



After



# Calculated Error for run05time09 eq.

