Nonlinear Tearing Modes in Finite-Beta Tokamaks with Noncircular Cross-Sections

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Background

Cause of disruption

Nonlinear interactions of the (m,n)=(2,1) tearing mode with other tearing modes.

Finite beta effects

gives rise to shift of the magnetic axis, which can decrease the distance between two islands and cause stronger interactions.

Motivation

Earlier studies:

Nonlinear interactions of the (m,n)=(2,1) and (3,2) tearing modes ,the (1,1) and other m components in circular poloidal cross sections

Ref. J.A.Holmes, et al.PoF(1982)

Ref. B.Carreras, et al.PoF(1980)

Aim of this study:

Nonlinear interactions of the (m,n)=(2,1) and (1,1) tearing modes in non circular poloidal cross sections

Reduced MHD equations

$$\frac{\partial}{\partial t}\nabla_\perp^2\phi = [\phi, \nabla_\perp^2\phi] + [\nabla_\perp^2\psi, \psi] + \frac{\partial}{\partial z}\nabla_\perp^2\psi + [x, P] + \upsilon\nabla_\perp^2(\nabla_\perp^2\phi)$$

$$\frac{\partial\psi}{\partial t} = [\phi, \psi] + \frac{\partial\phi}{\partial z} + \eta\nabla_\perp^2\psi$$

$$\frac{\partial P}{\partial t} = [\phi, P] + \kappa\nabla_\perp^2 P$$

where

$$[f,g] = \frac{\partial f}{\partial x}\frac{\partial g}{\partial y} - \frac{\partial f}{\partial y}\frac{\partial g}{\partial x} = (\nabla f \times \nabla g)\cdot\hat{\mathbf{z}},\quad \mathbf{u} = \nabla\phi\times\hat{\mathbf{z}},\quad \mathbf{B} = \nabla\psi\times\hat{\mathbf{z}} + B_0\hat{\mathbf{z}}$$

ϕ : stream function, ψ : poloidal flux

η : resistivity, υ : viscosity, κ : thermal diffusivity

We choose η=1.0e-5, υ=1.0e-7, κ=1.0e-7.

Normalization

$$t = \frac{at}{v_{PA}}, \quad r = \frac{r}{a}, \quad z = \frac{z}{R_0\ q(a)},$$

$$\phi = \frac{\phi}{a\ v_{PA}}, \quad \psi = \frac{\psi}{a\ B_\theta(a)}, \quad P = \frac{P}{\{B_\theta(a)\}^2 / 2\mu_0\varepsilon}, \quad \eta = \frac{\eta}{a\ v_{PA}\ \mu_0}$$

where $v_{PA} = (B_\theta^2 / \mu_0\rho)^{1/2}$.

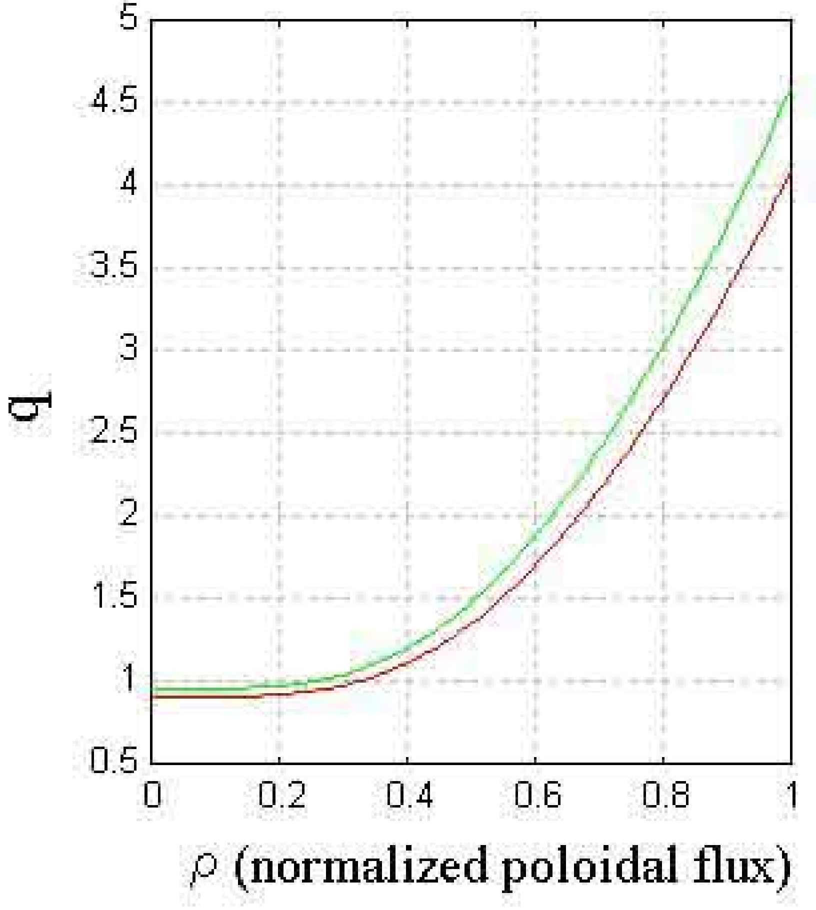
a : minor radius

R_0 : major radius

$q(a)$: the safety factor at the plasma surface

$B_\theta(a)$: the poloidal magnetic field at the plasma surface

q profile



$$q(\rho) = q(0)\left\{1+\rho^{2\lambda}\left[\left(\frac{q(1)}{q(0)}\right)^{\lambda}-1\right]\right\}^{1/\lambda}$$

$q(0) = 0.90$ and $q(0) = 0.95$

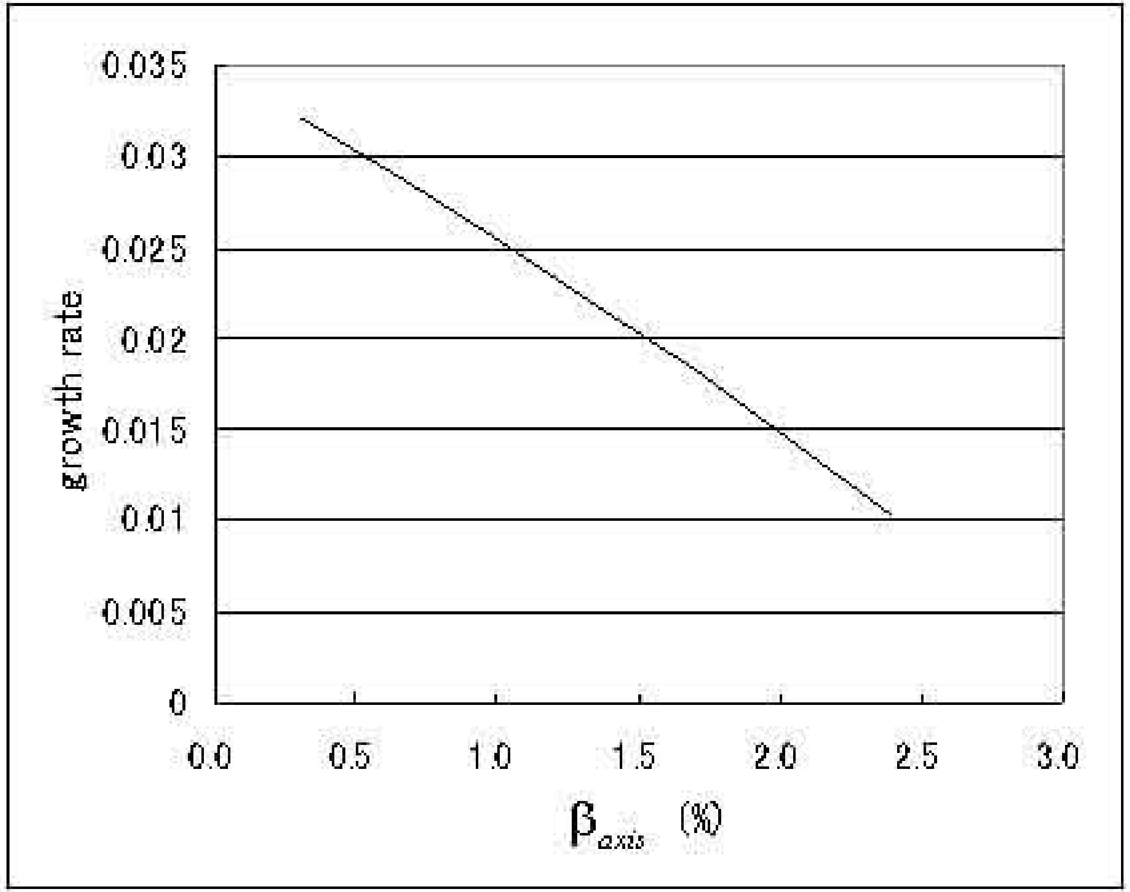
$q(1) = 4.1$ and $q(1) = 4.6$

$\lambda = 2.0$ and $\lambda = 2.0$

Aspect ratio = 6

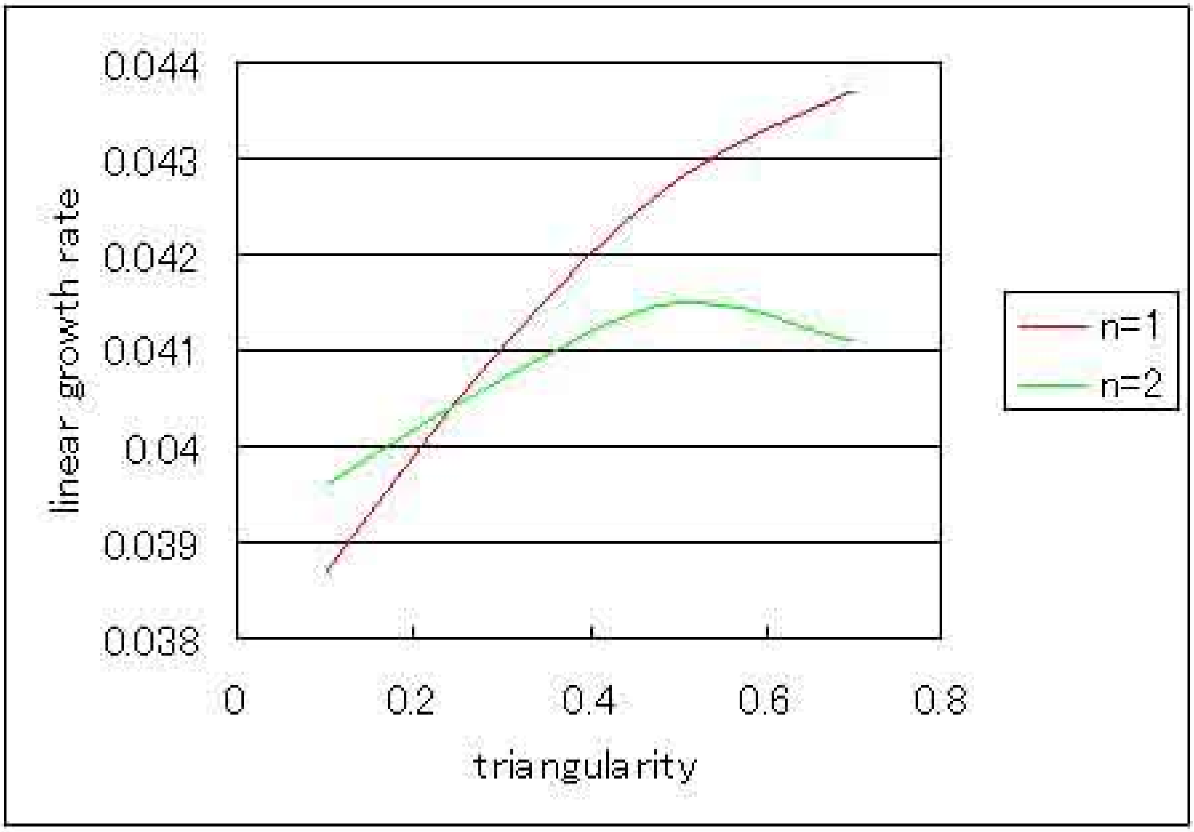
Results of linear calculations 1

Linear growth rate vs β_{axis}



Results of linear calculations 2

Linear growth rate vs triangularity



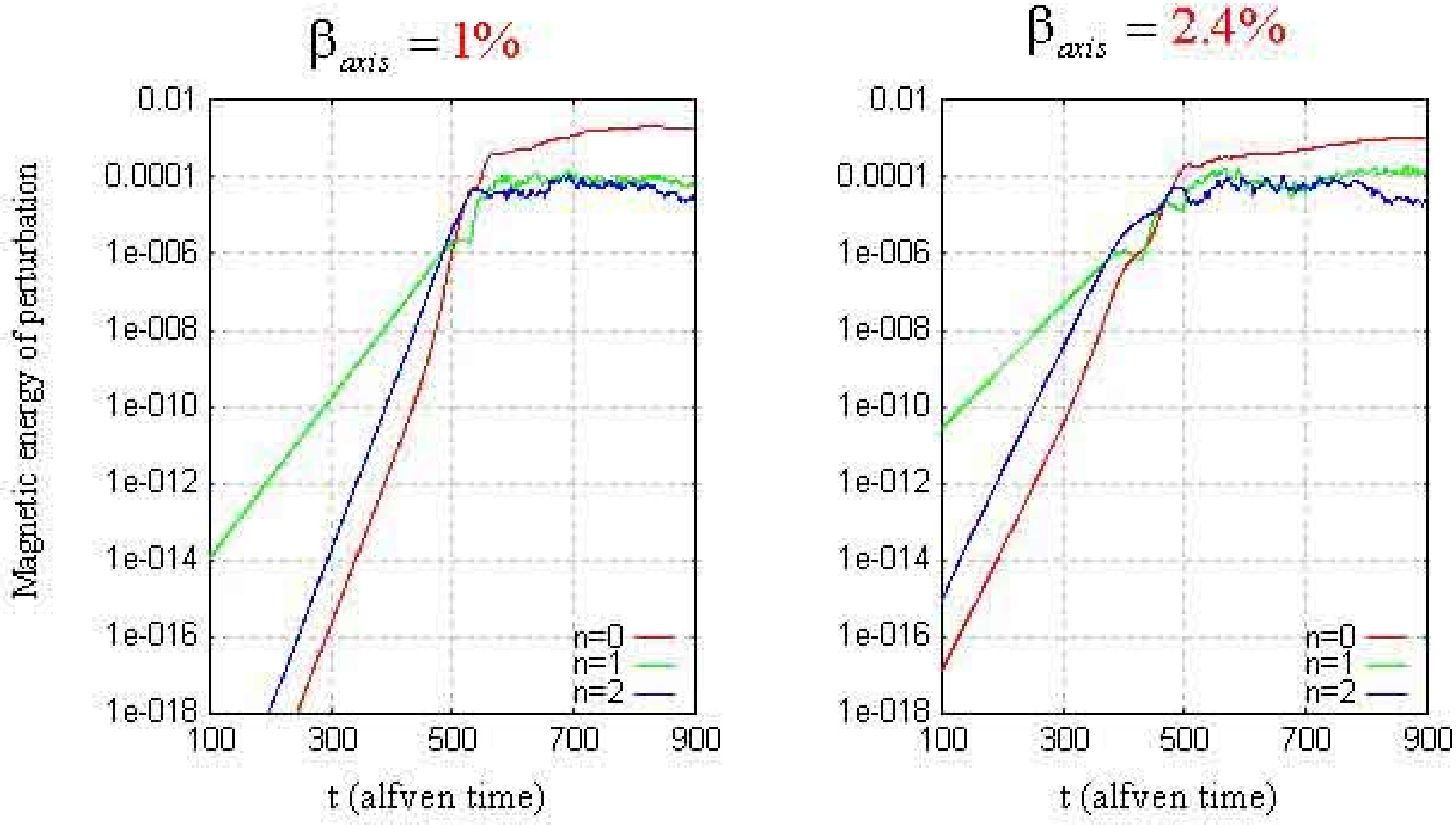
$$x = \cos\{\theta + \sin^{-1}(\delta \sin\theta)\}, \quad y = \sin\theta$$

$$\text{triangularity} = \delta$$

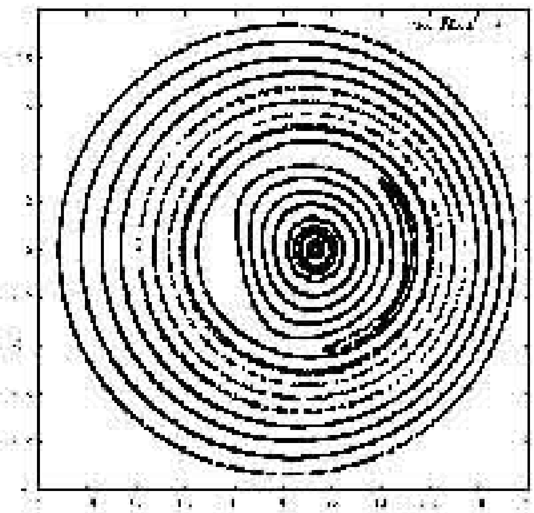
Results of nonlinear calculations

Evolution of magnetic energy

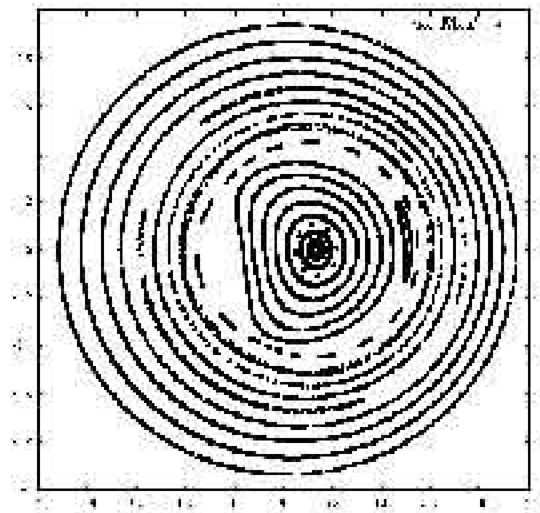
(comparing different beta cases)



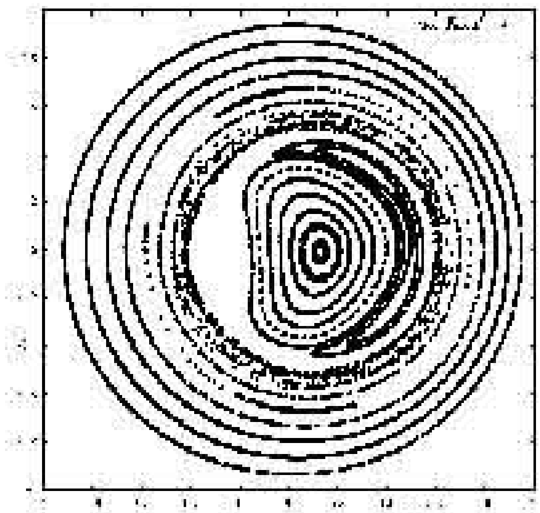
Traced magnetic fields for $\beta_{axis} = 1\%$



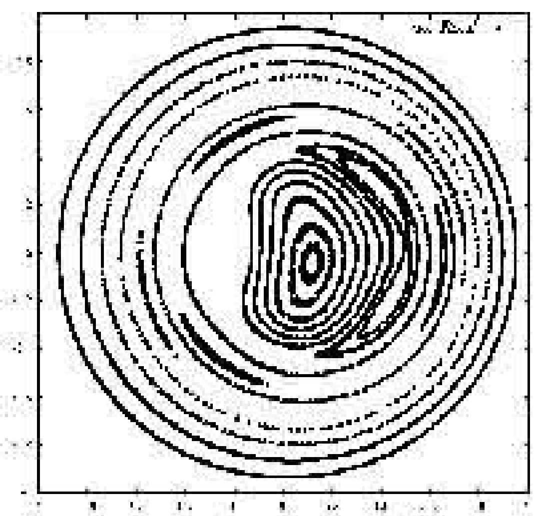
t=500



t=510



t=520



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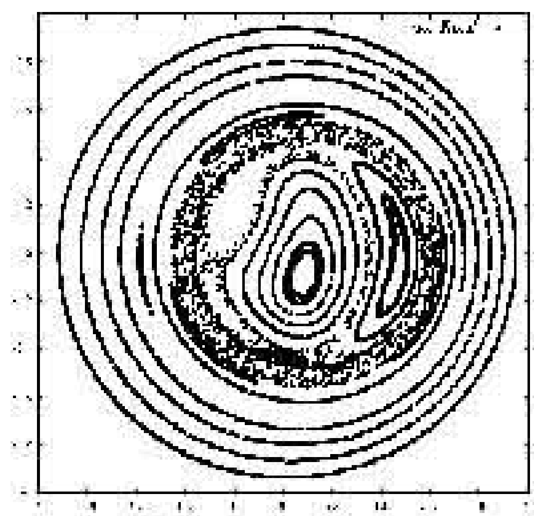
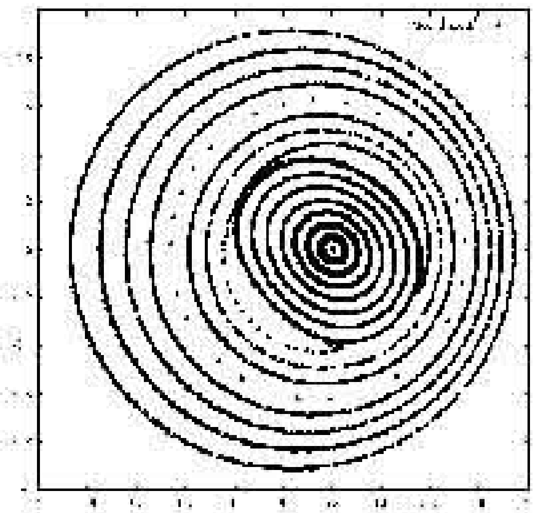


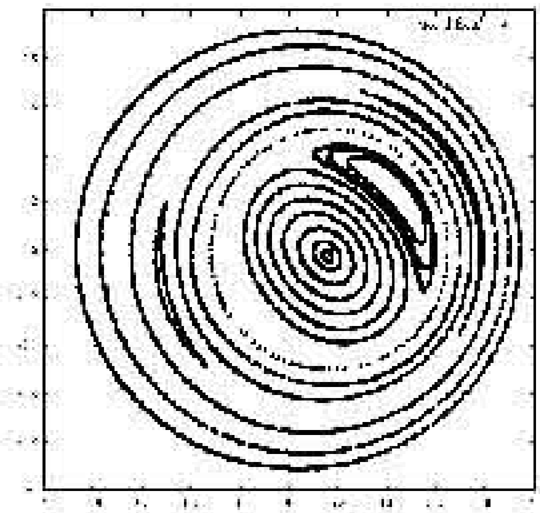
t=540

The (1,1) and (3,2) modes appear, then the ergotic layer appears.

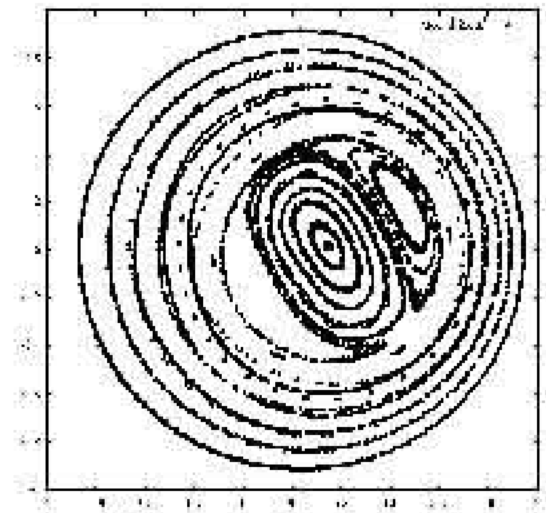
Traced magnetic fields for $\beta_{axis} = 2.4\%$



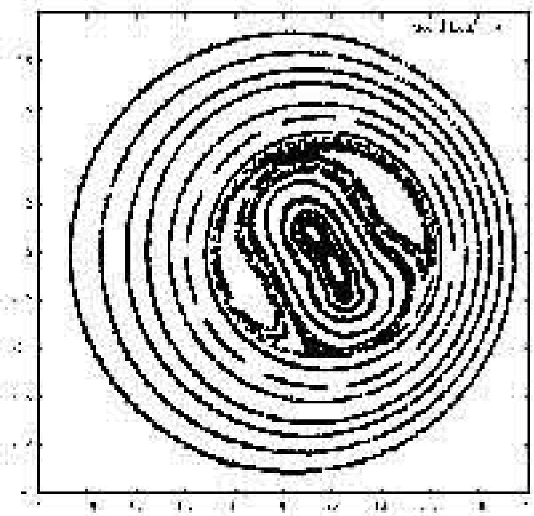
t=420



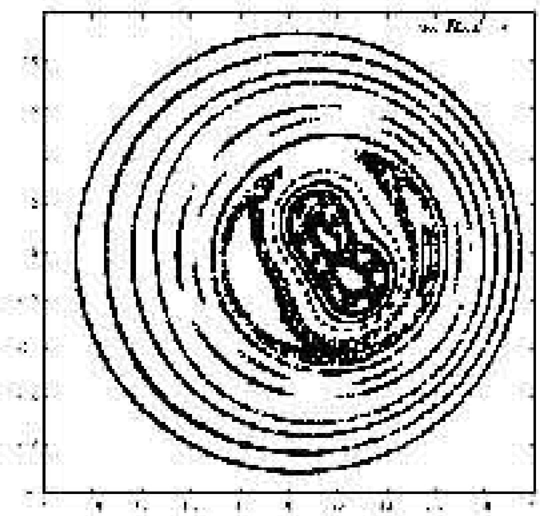
t=460



t=480



t=490



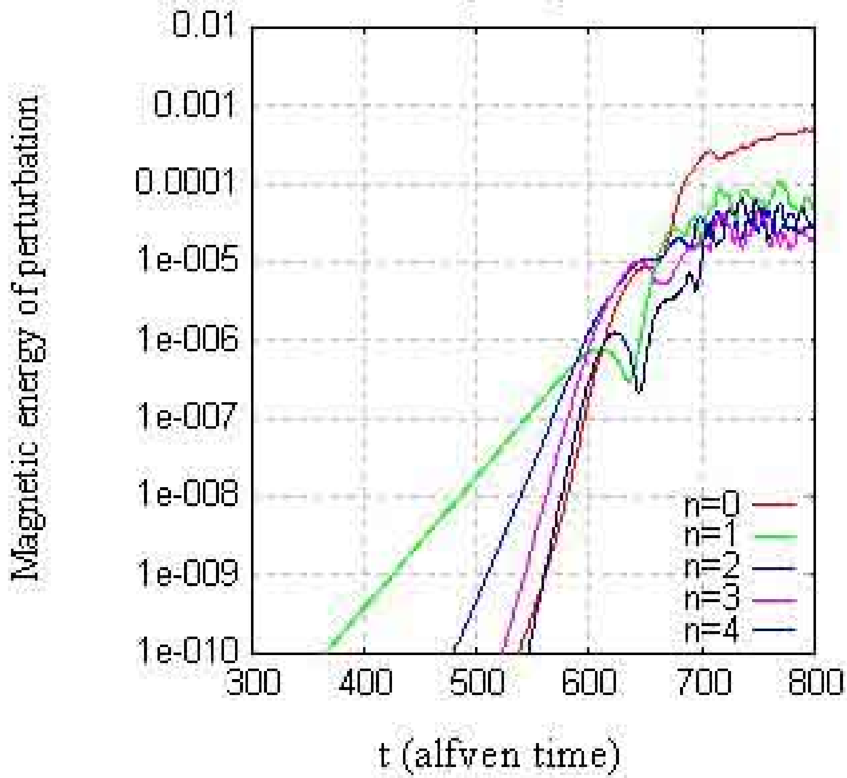
t=500

The (1,1) and (2,2) modes appear, then the ergotic layer appears.

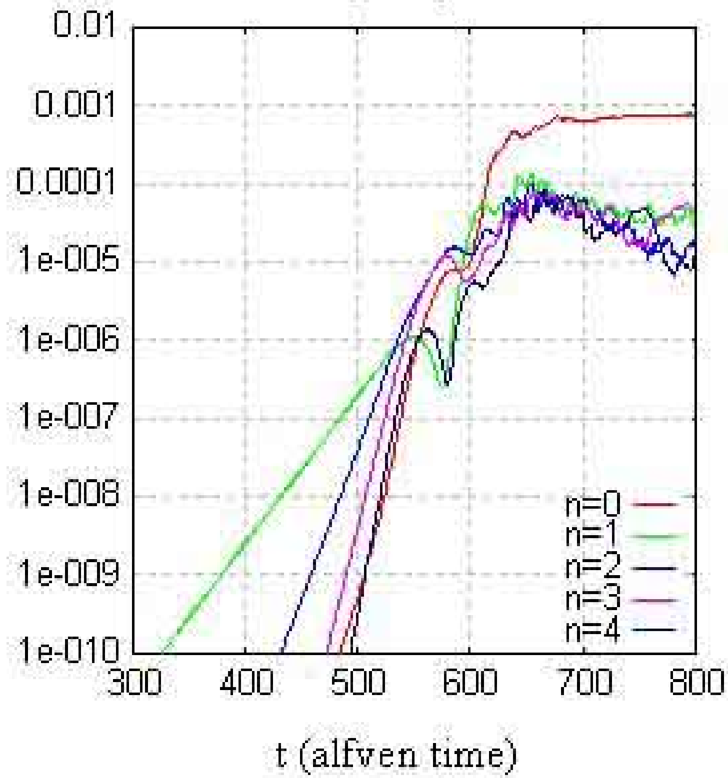
Evolution of magnetic energy (comparing different triangularity cases 1)

$$q(0) = 0.90, q(1) = 4.1, \lambda = 2.0$$

Triangularity = 0.1

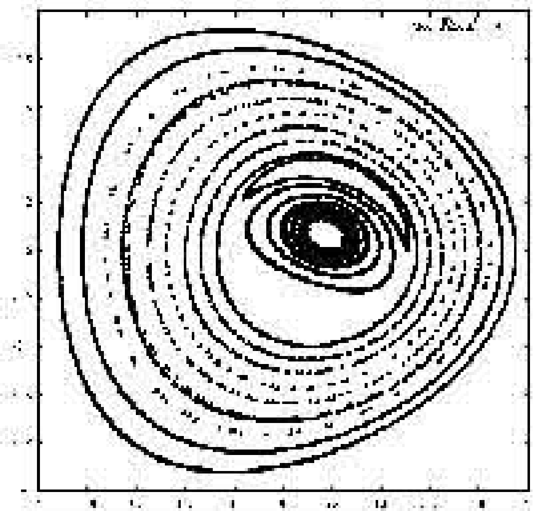


Triangularity = 0.7



Traced magnetic fields for triangularity = 0.3 (continued)

$$q(0) = 0.95, q(1) = 4.6, \lambda = 2.0$$



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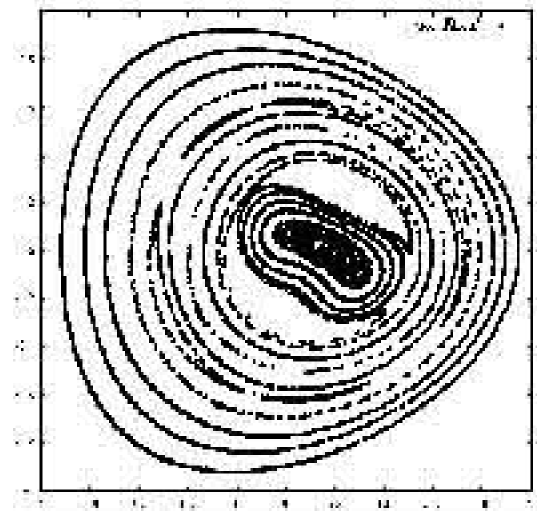
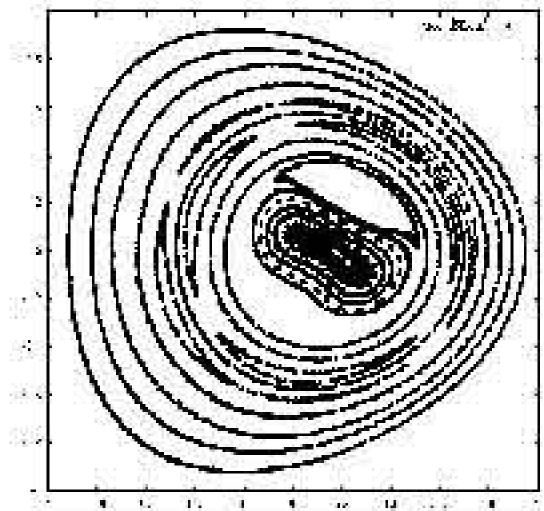
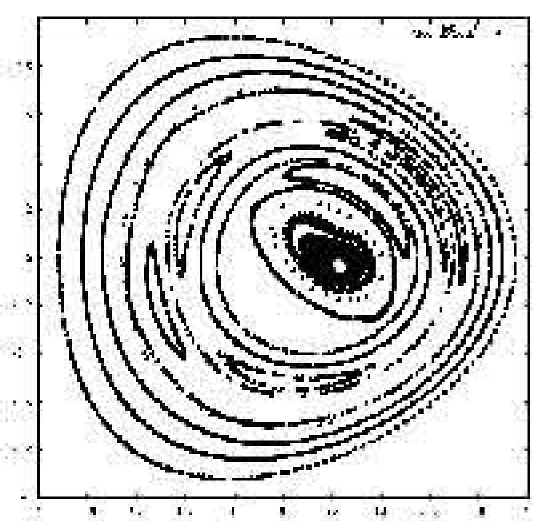


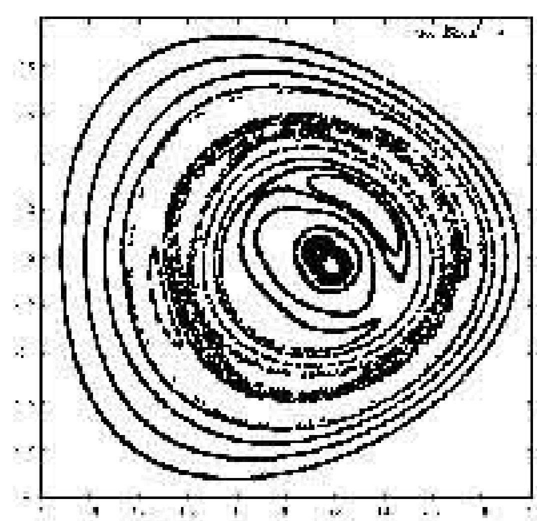
t=590



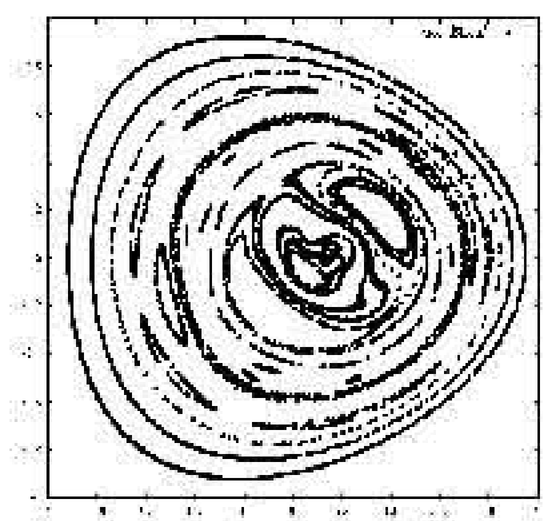
t=600



t=650



t=680



t=690

Summary

- Linear Calculations
  - The higher the β_{axis} is, the lower the growth rate becomes.
  - As the triangularity is increased, the growth rate is increased.
- Nonlinear Calculations
  - The higher the β_{axis} is, the lower the saturation levels becomes.
  - The triangularity raises the saturation level.