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Recent Progress in Numerical Modeling of Relaxation Phenomena in ST

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Introduction

"relaxation" — spontaneous collapse & reorder
mechanism, constraint,...

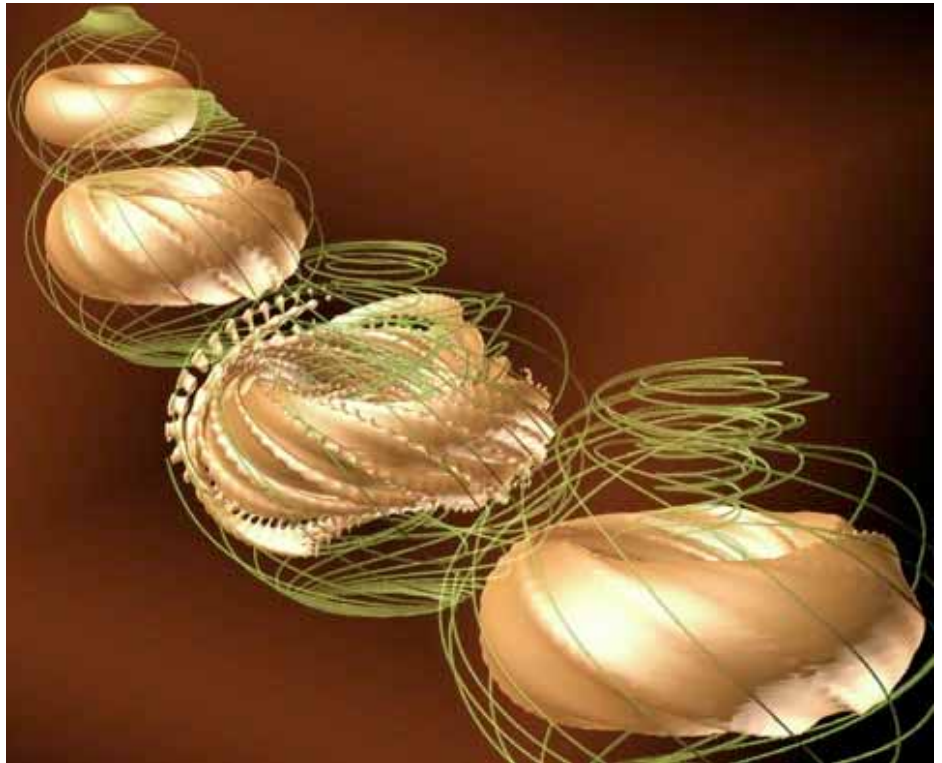
objective

understanding and
prediction of non-
linear relaxation
phenomena

topics :

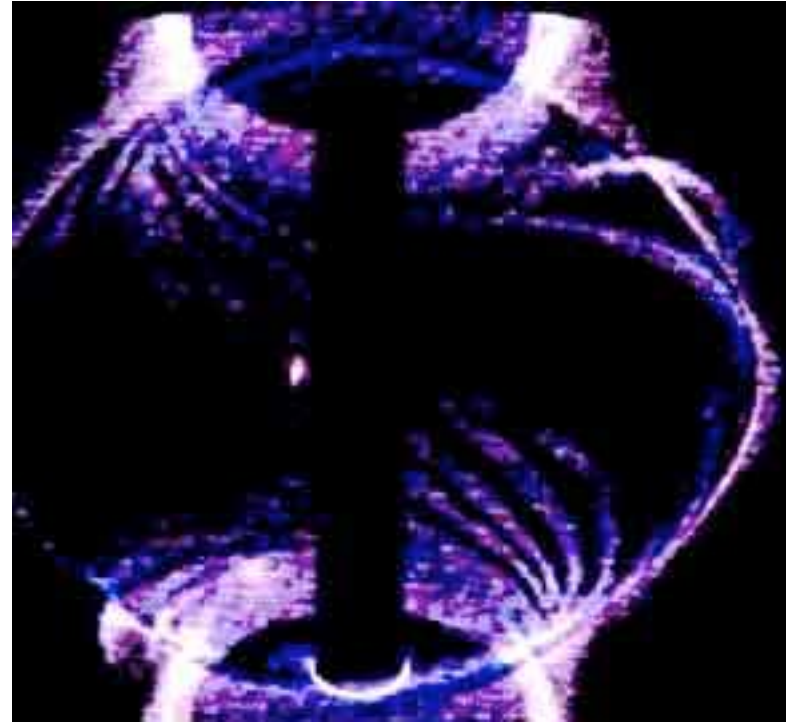
ELM

current hole



ELM in MAST

- filament-like structure along field lines
- time scale $\sim 100\mu\text{sec}$
- erupt from outboard
-> back into the plasma
- **ballooning**

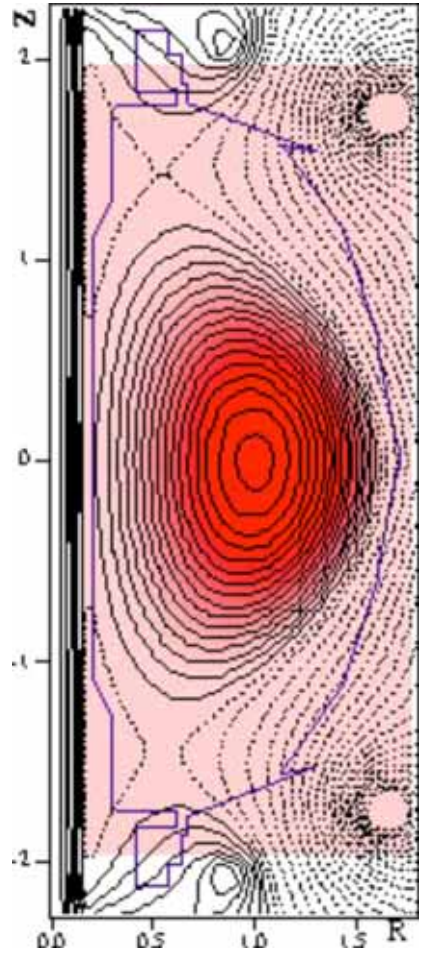


<http://www.fusion.org.uk/mast/news/dec03.html>



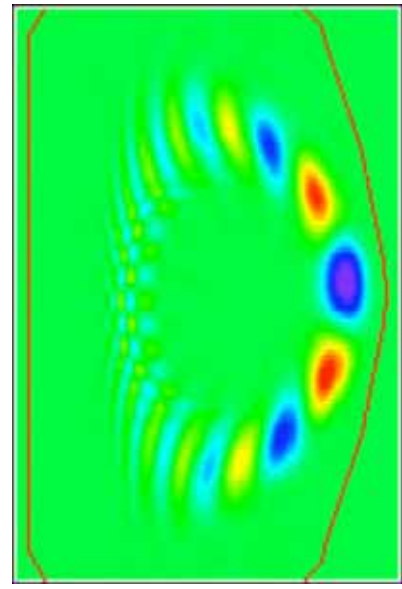
A.Kirk et al., PRL **92**, 245002

Example of nonlinear simulation



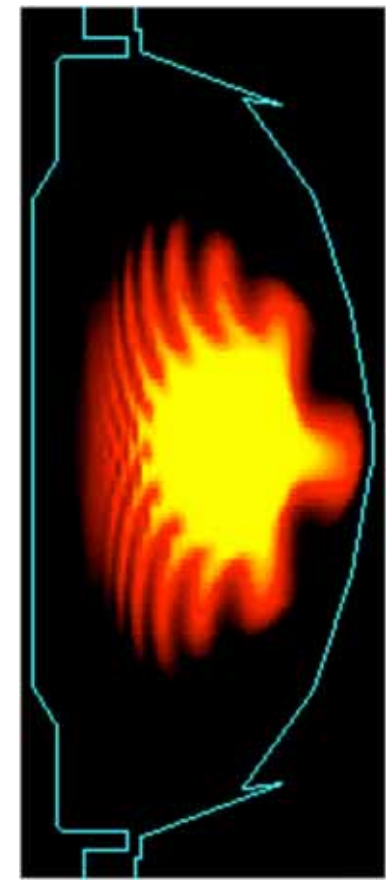
initial condition

- experimental data from NST



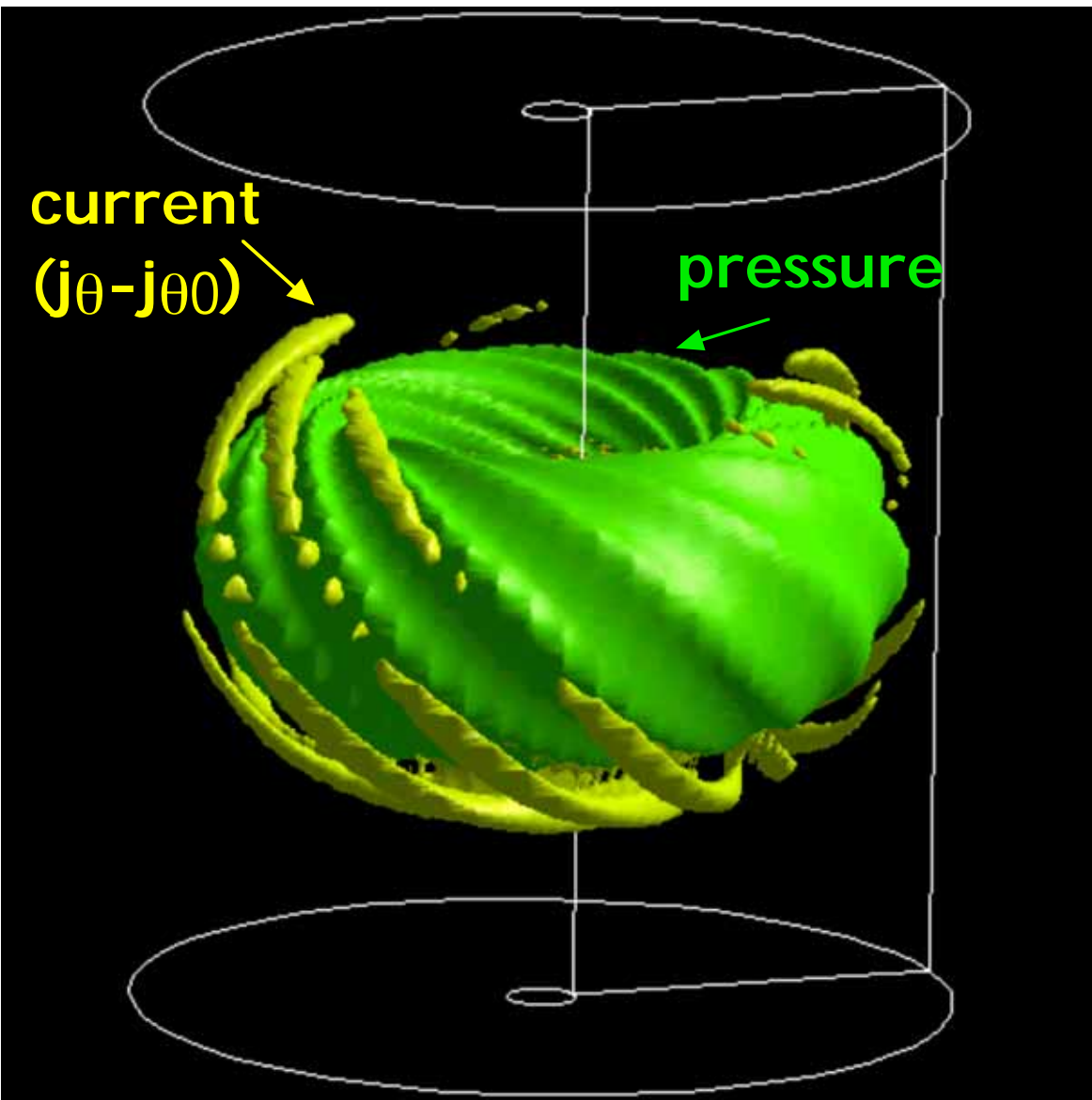
linear mode structure
- n=12 ballooning mode

nonlinear development

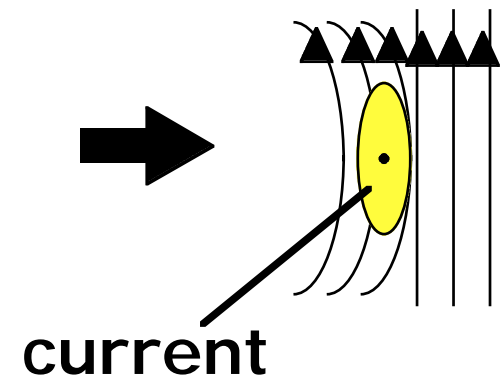
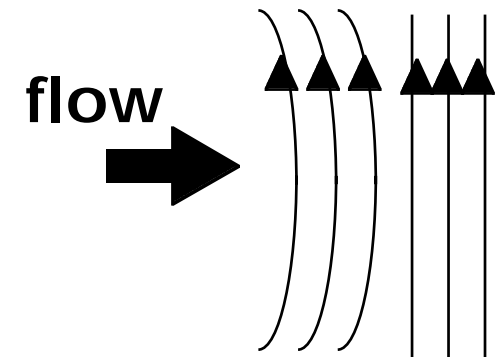


(movie)

Formation of current filament



plasma vacuum



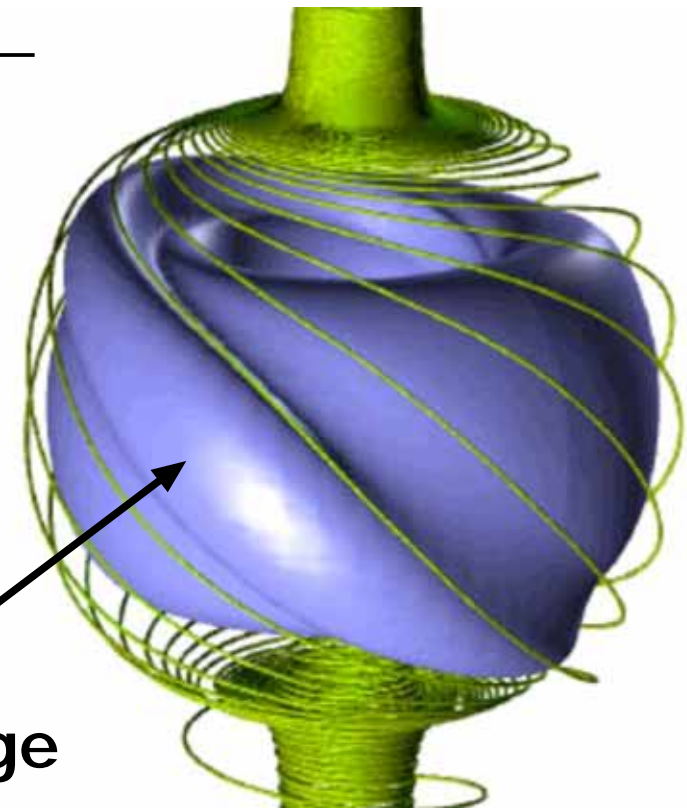
- appear on the ridge
- nonuniform
- partial reconnection

Mechanism of filament formation (low-n case)

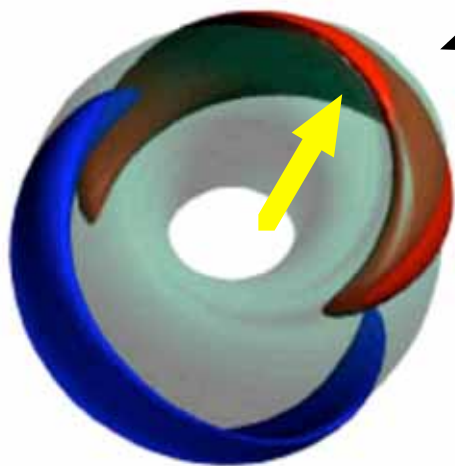
positive pileup of multiple modes



nonuniform growth
due to the phase resonance



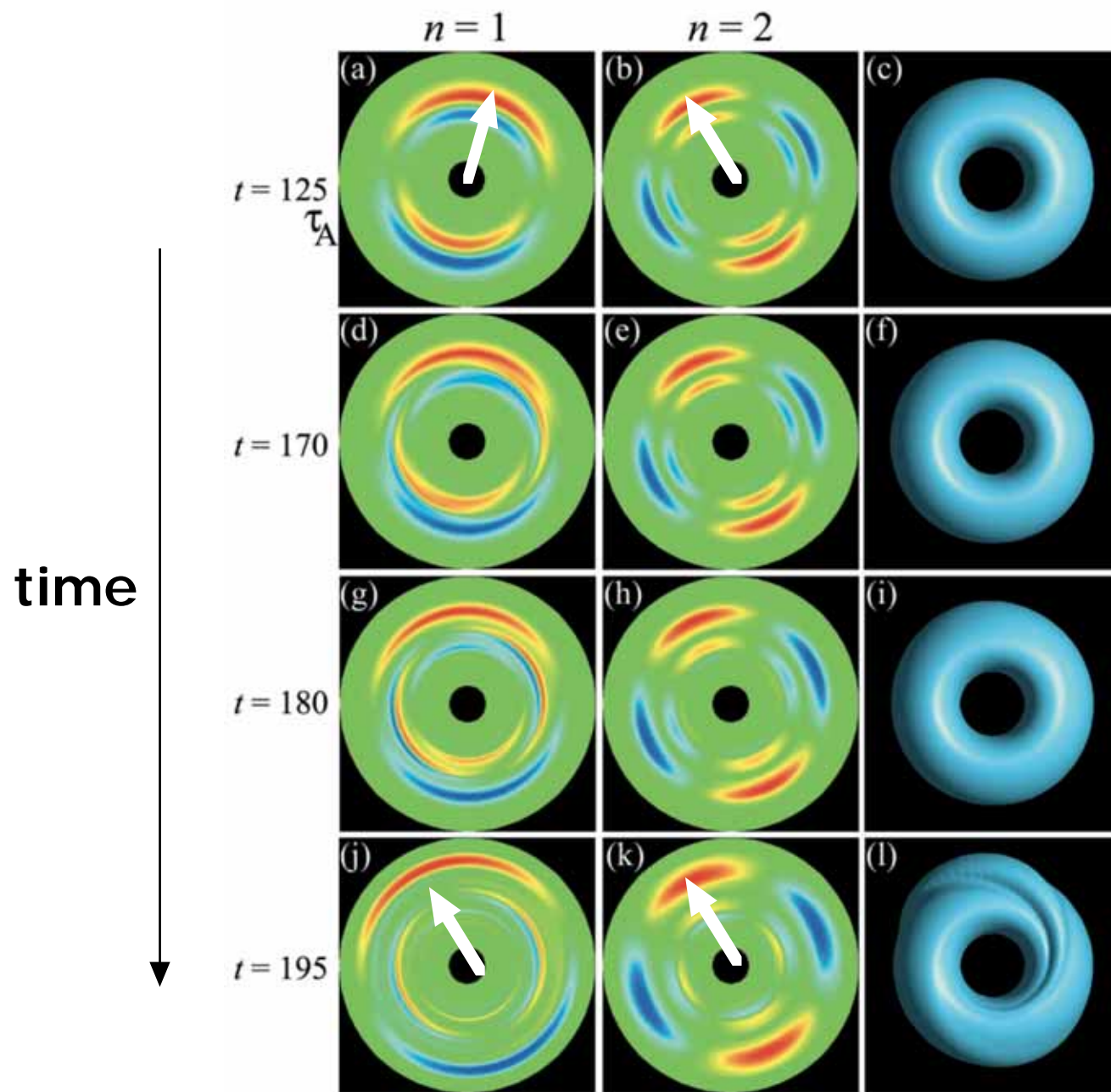
bulge



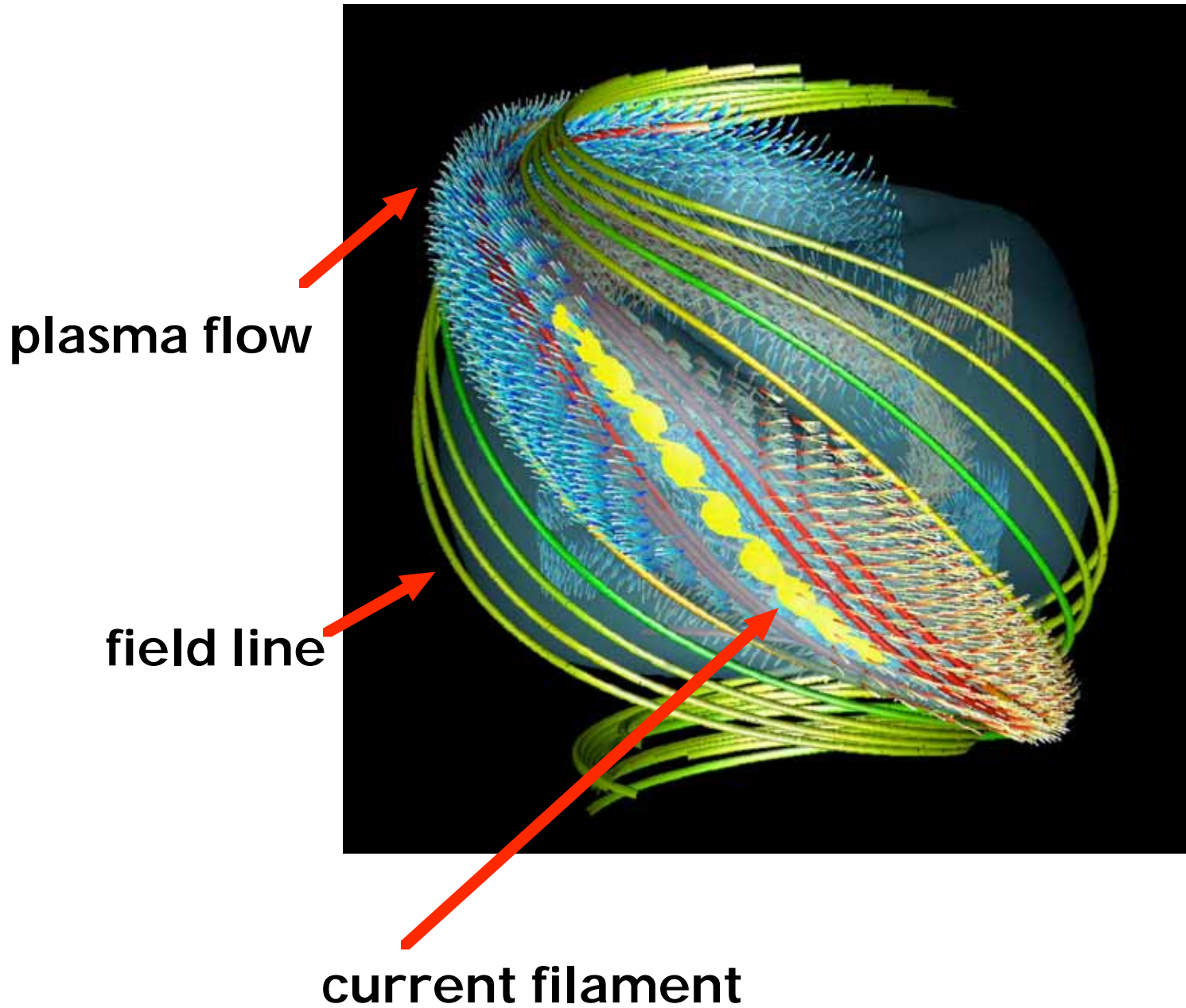
n=1 component

n=2 component

Spontaneous phase alignment



Filament formation and partial reconnection



ELM in MAST ~ summary and future work

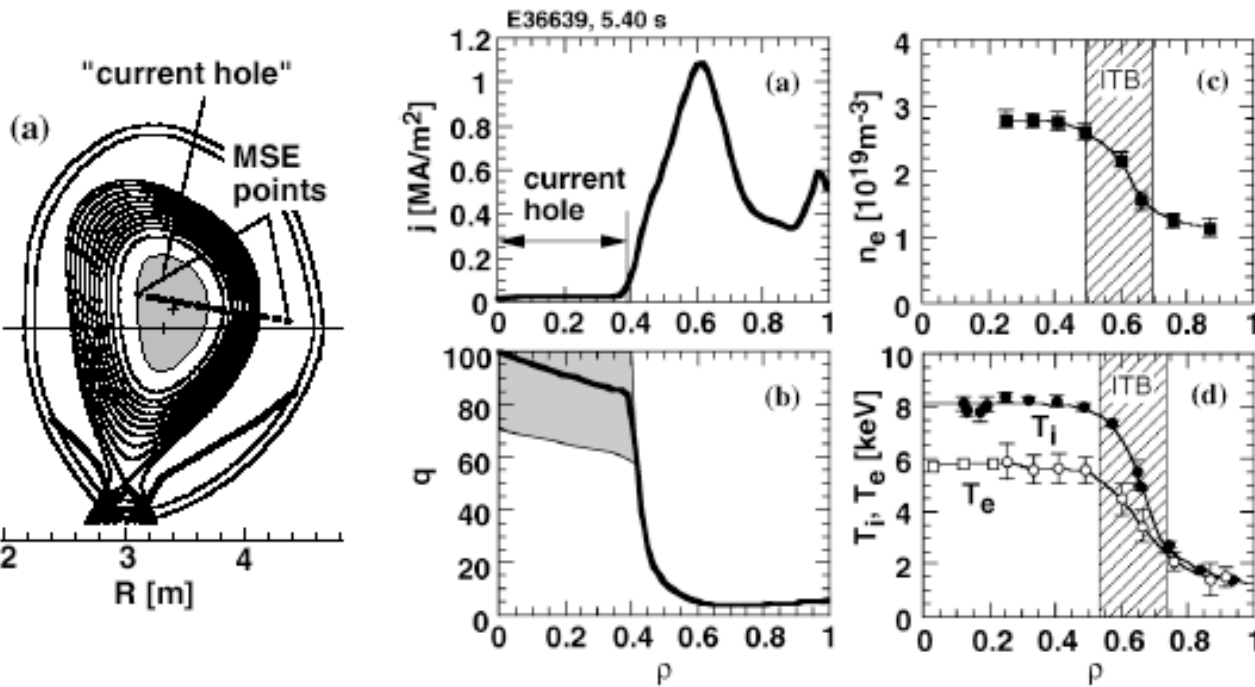
- nonlinear development of ballooning mode
- ↓
- nonuniform formation of current filament
- ↓
- partial loss of plasma through reconnection
- ↓
- relaxed

rapid and steep nature → FLR correction -- ongoing

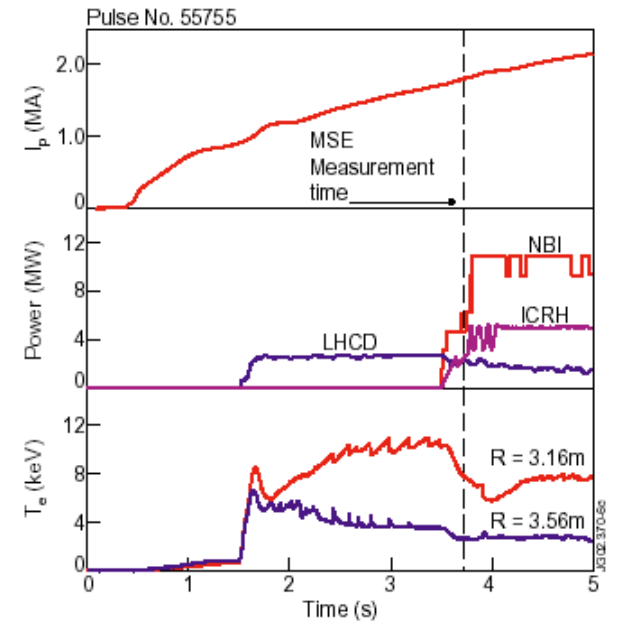
T with current hole?

"current hole"

- observed in auxiliary heated large tokamak
- sometimes accompanied by MHD activities
- good confinement and high beta



Experimental observation of current hole in JT-60U
(T. Fujita et al. PRL **87**,245001(2001))



Current hole accompanying
MHD oscillations observed
in JET

→ in ST ? availability/stability/NL dynamics

MHD equilibrium with stationary flow

(axisymmetric 2D, toroidal flow)

$$-\nabla p + \mathbf{j} \times \mathbf{B} - \rho(\mathbf{v} \cdot \nabla)\mathbf{v} = 0 \quad : \text{EOM for steady state}$$



$$\left\{ \begin{array}{l} \Delta^* \psi = -r^2 \frac{p_r}{\psi_r} - FF' - \frac{r^3 f^2}{\psi_r} \\ \Delta^* \psi = -r^2 \frac{p_z}{\psi_z} - FF' \end{array} \right. \quad : \text{modified Grad-Shafranov eqs.}$$
$$\left(\Delta^* = r \frac{\partial}{\partial r} \frac{1}{r} \frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2} \right)$$

$$rB_\theta = F = F(\psi)$$

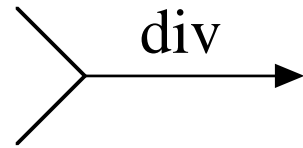
$$\frac{v_\theta}{r} = f = f(\psi)$$

$$p \neq p(\psi)$$

numerical solution

scheme

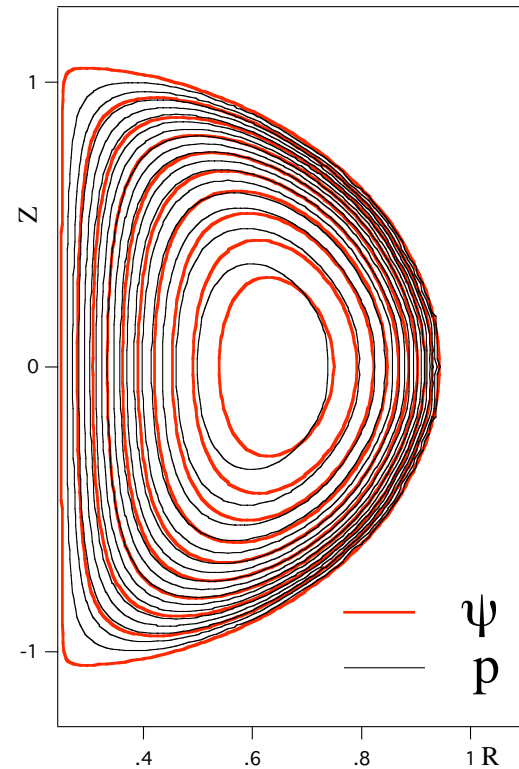
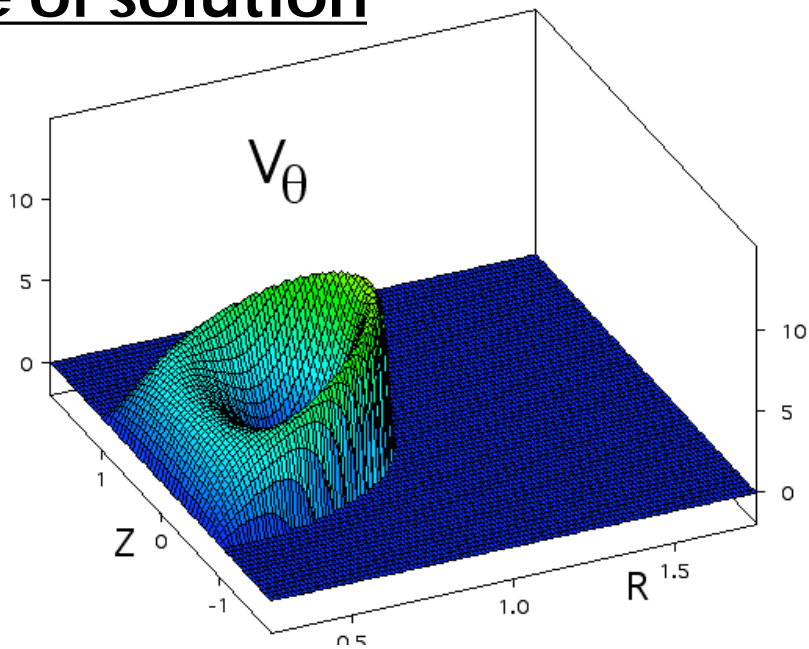
$$\left\{ \begin{array}{l} \Delta^* \psi = -\frac{r^2}{|\nabla \psi|^2} (p_z \psi_z + p_r \psi_r) - FF' - \frac{r^3 \psi_r}{|\nabla \psi|^2} f^2 \quad \bullet \\ p_r = -\frac{\psi_r}{r^2} (\Delta^* \psi + FF') - rf^2 \\ p_z = -\frac{\psi_z}{r^2} (\Delta^* \psi + FF') \end{array} \right.$$



$$\Delta p = -\phi \quad \bullet$$

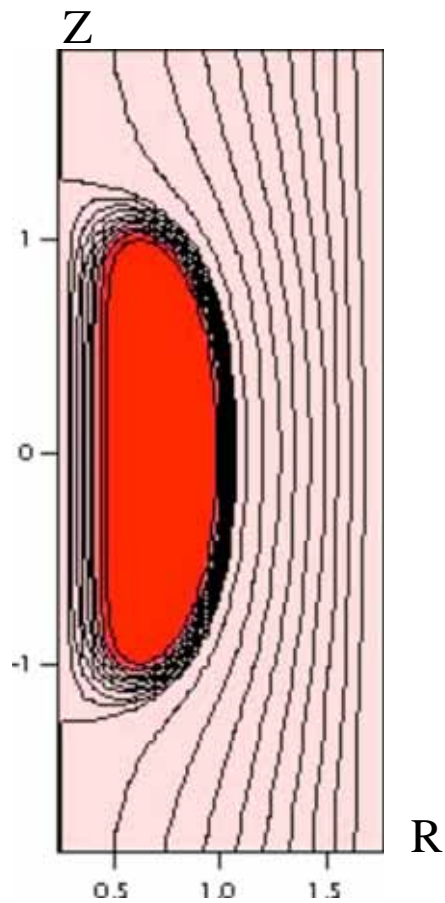
**solve two(●) Poisson's eqs.
simultaneously by iterations**

sample of solution

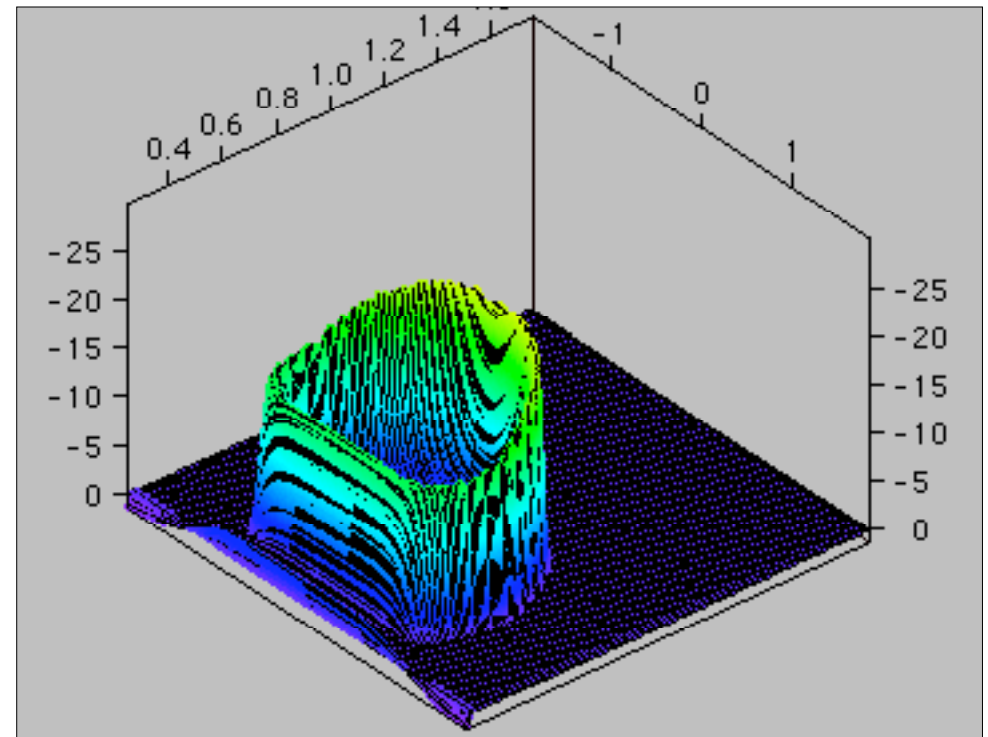
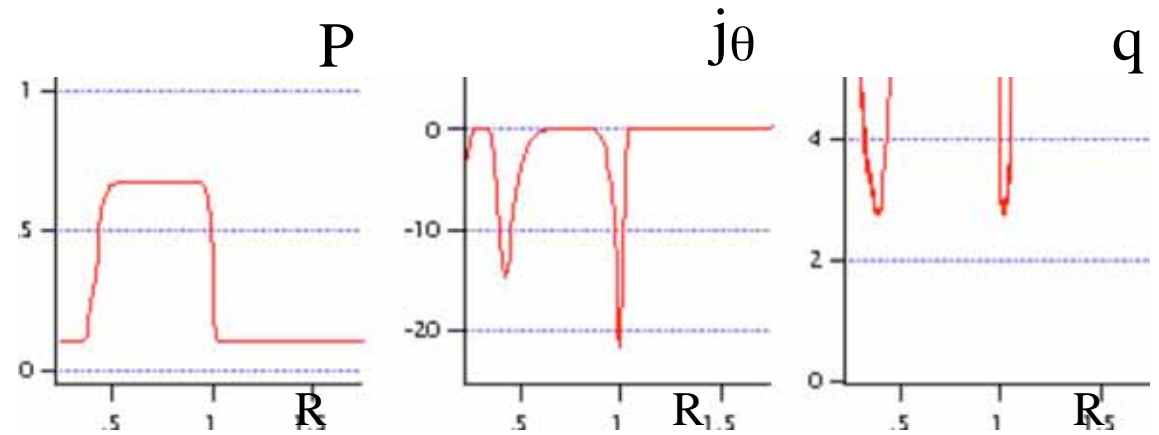


Numerical solution

radial profiles



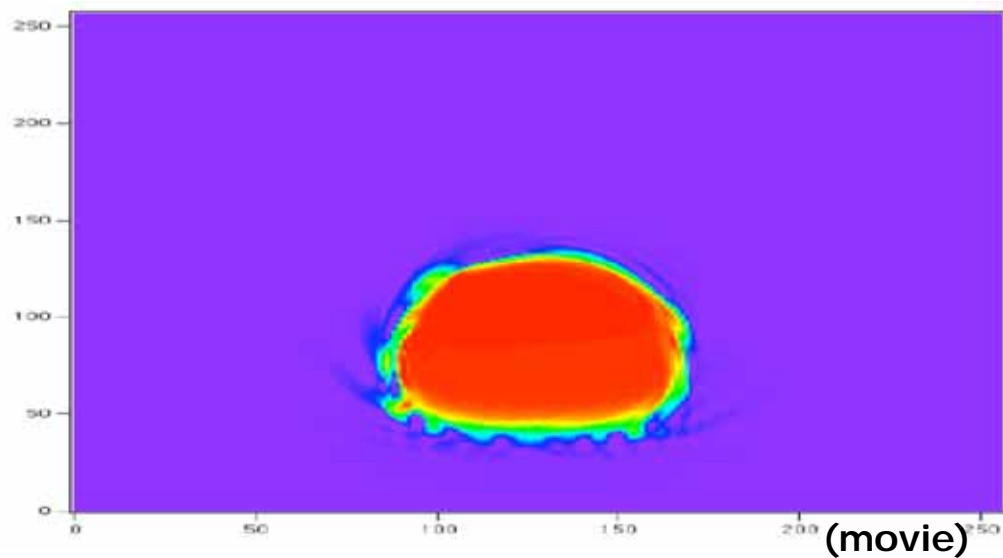
poloidal flux & pressure



toroidal flow

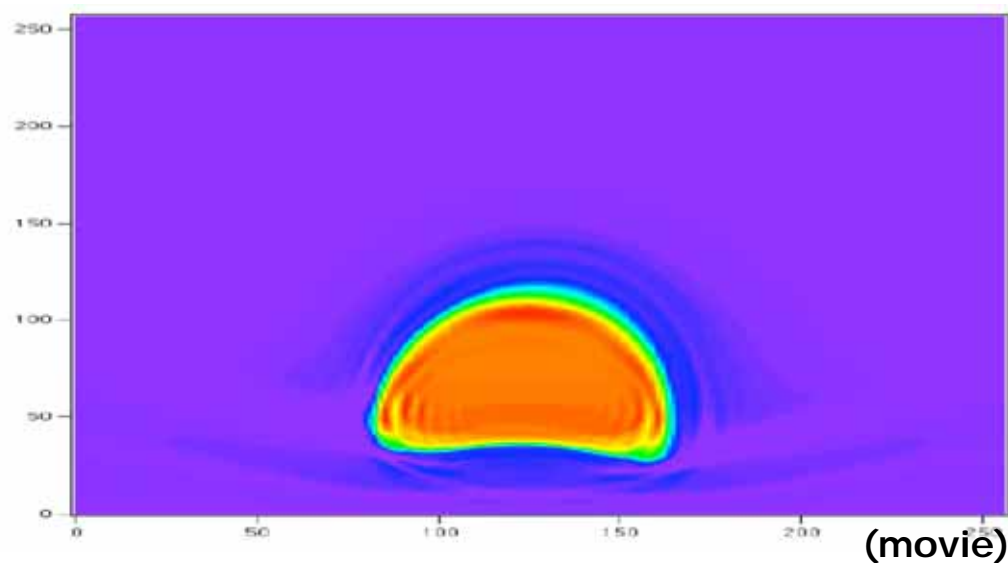
Nonlinear simulation result

(V=0 case)



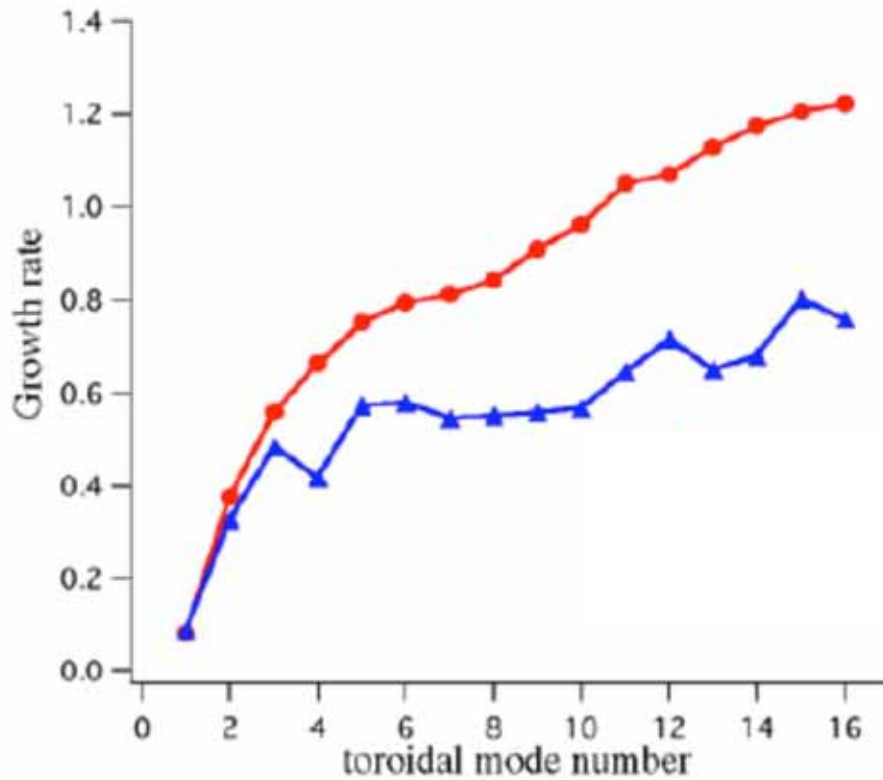
- disordered
- less restoring force

low-n components
are emphasized



Effect of toroidal flow

- linearized MHD eqs.
- time development
for each toroidal mode

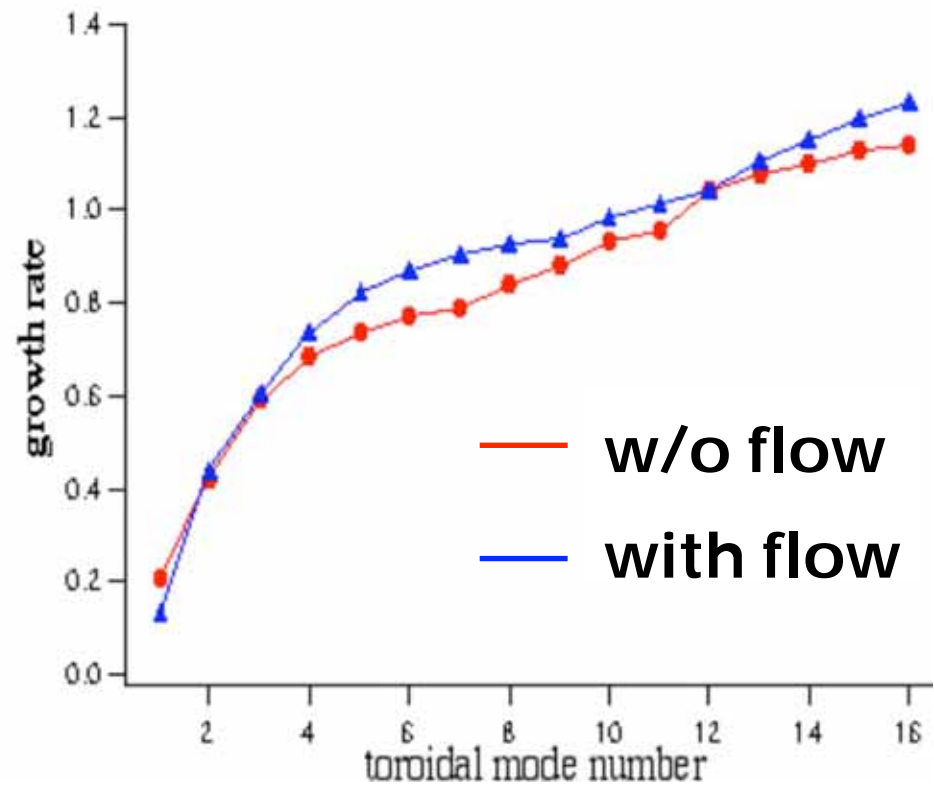


stabilized



destabilized

(another profile is used
for initial condition)



Summary

Recent topics on our nonlinear simulation research are reviewed.

- ELM in MAST
 - * nonuniform filament-like structure
 - * loss through reconnection

- ST with current hole
 - * less restoring force
 - * (de)stabilization by shear flow

Future work

- extend beyond resistive MHD model
 - FLR, fast particle,...
- comparison with experiments