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Recent Progress in Numerical Modeling of Relaxation Phenomena in ST

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Contents

ntroduction

"relaxation" —— spontaneous collapse & reorder

mechanism, constraint,...

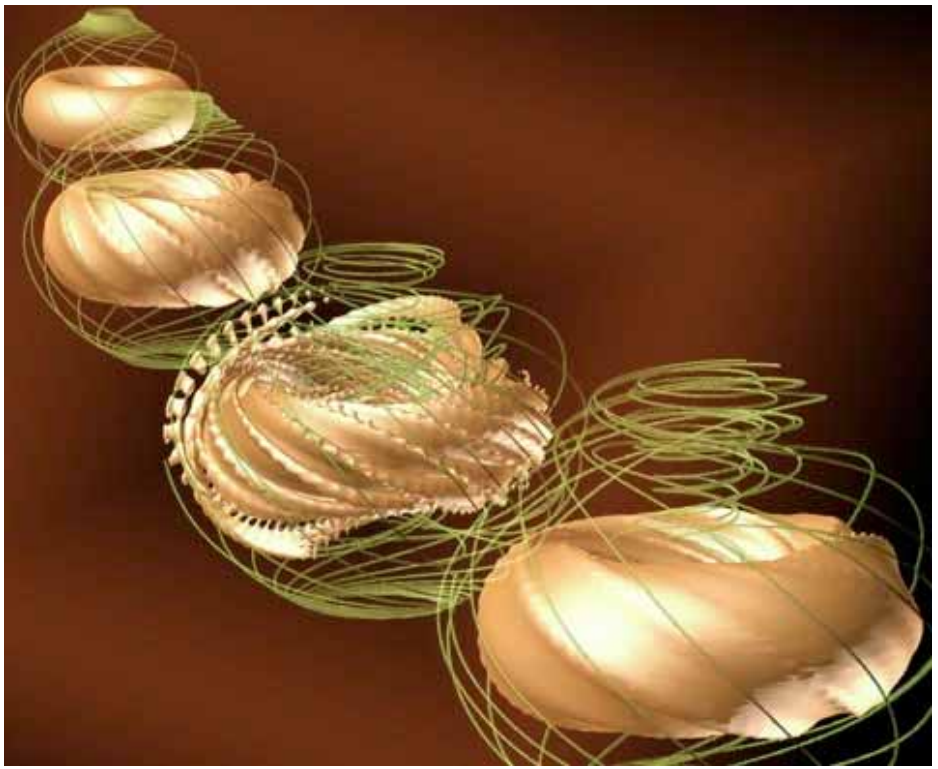
objective

understanding and prediction of non-linear relaxation phenomena

topics :

ELM

current hole



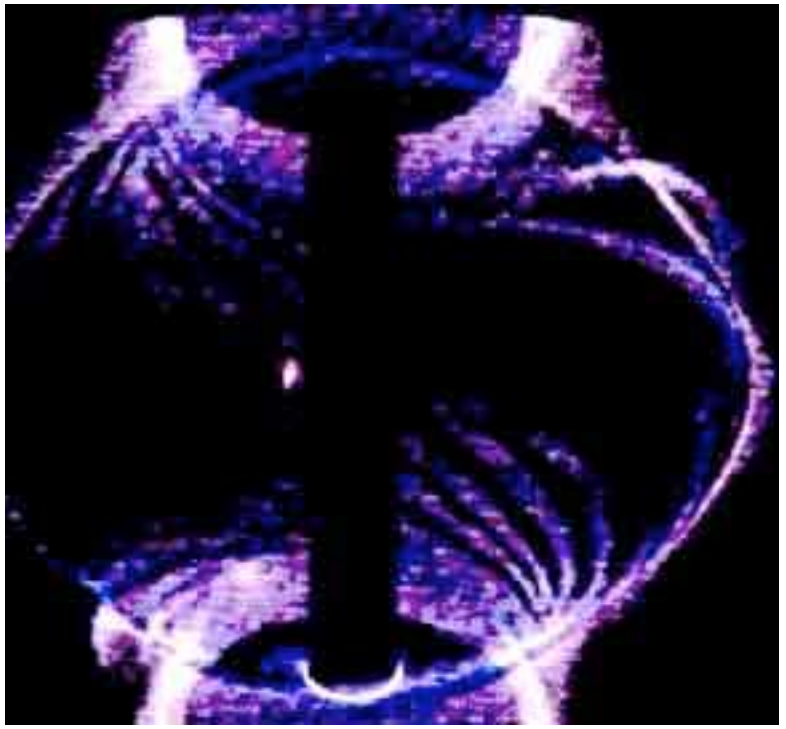
ELM in MAST

- filament-like structure
  along field lines

- time scale ~100μsec

- erupt from outboard
  -> back into the plasma

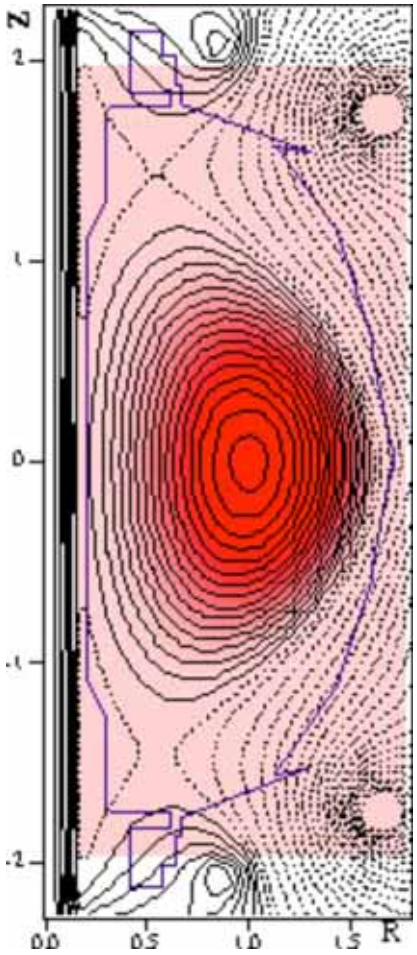
- ballooning



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

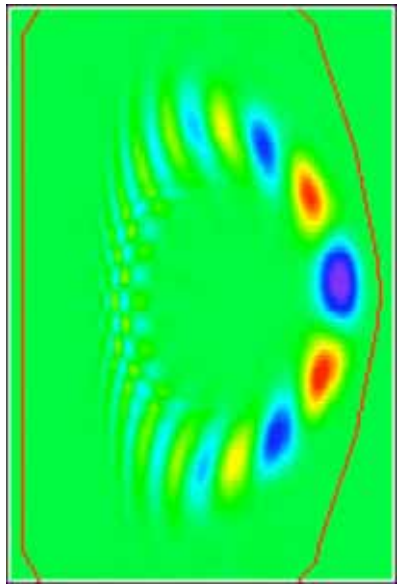
A.Kirk et al., PRL **92**, 245002

Example of nonlinear simulation



initial condition

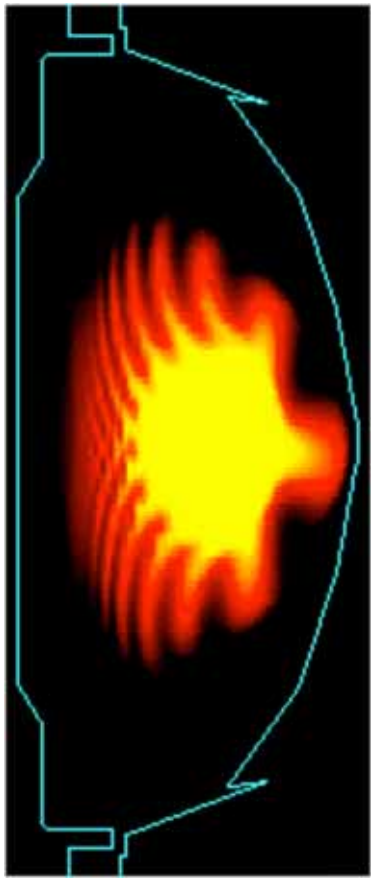
- **experimental data from NSTX**



linear mode structure

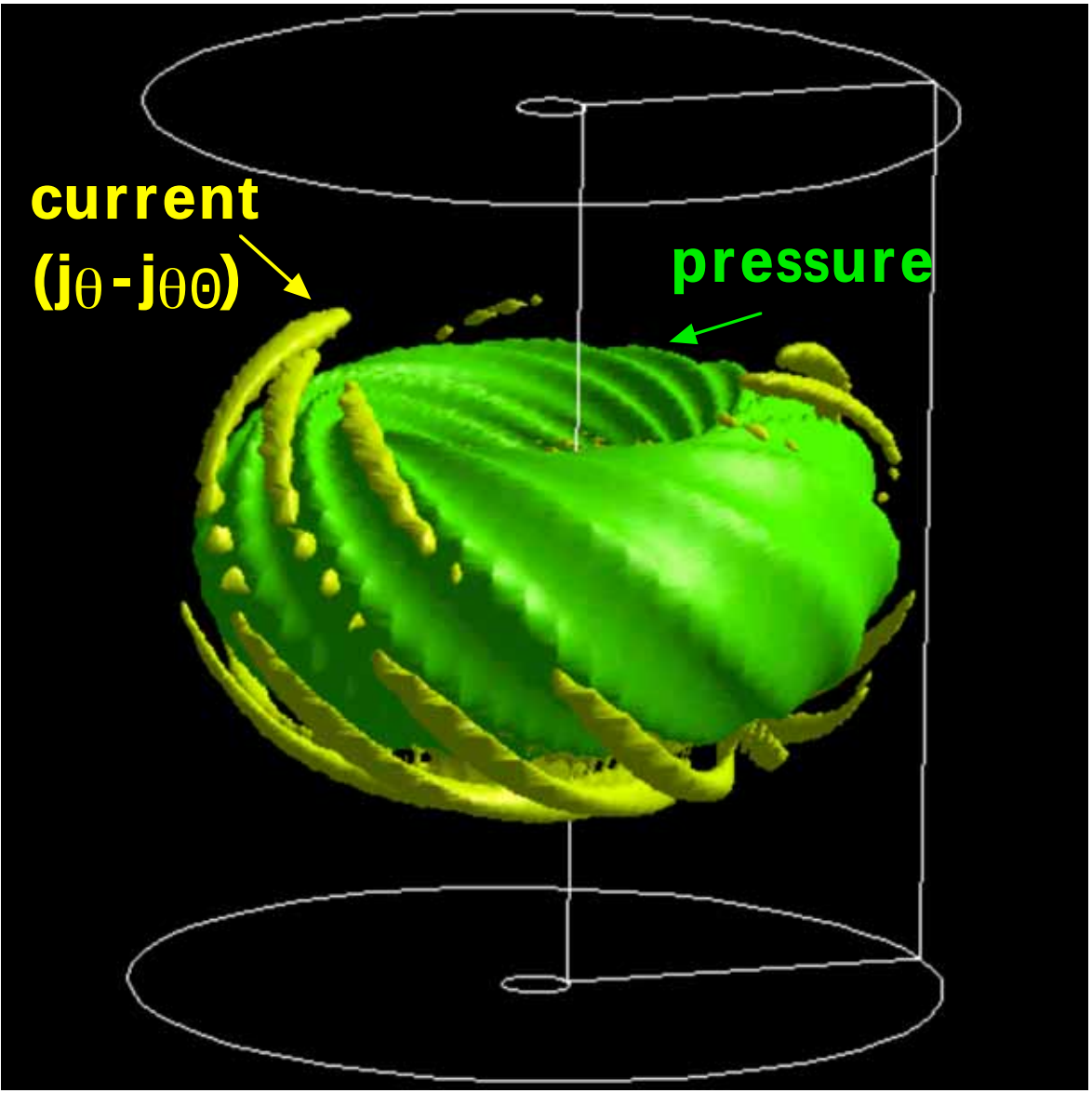
- **n=12 ballooning mode**

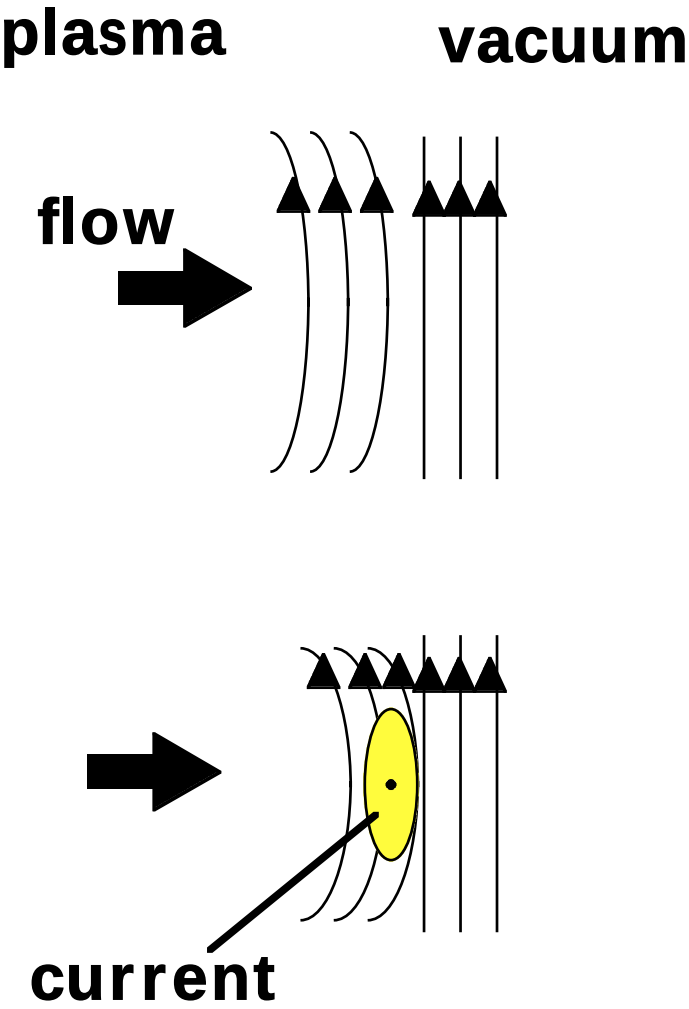
nonlinear development



(movie)

Formation of current filament





- appear on the ridge
- nonuniform
- partial reconnection

Mechanism of filament formation

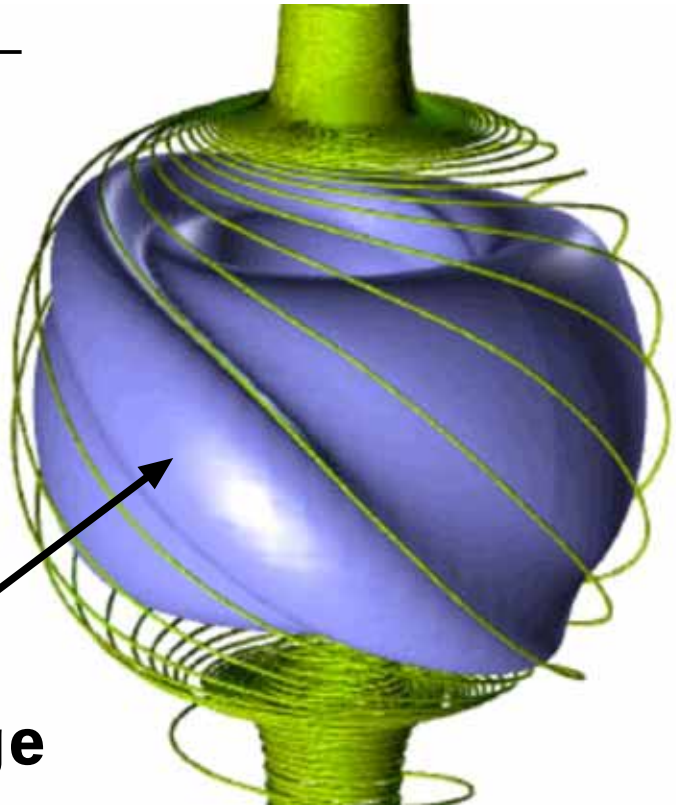
(low-n case)

positive pileup of multiple modes

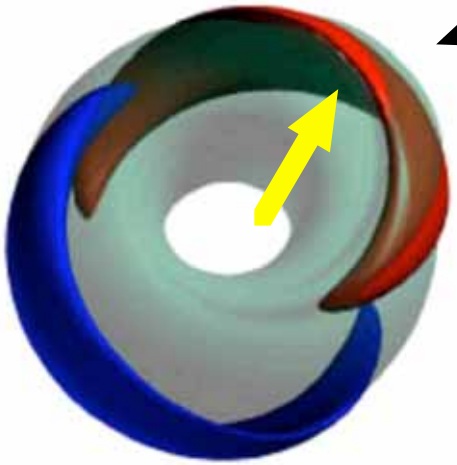
↓

nonuniform growth

due to the phase resonance



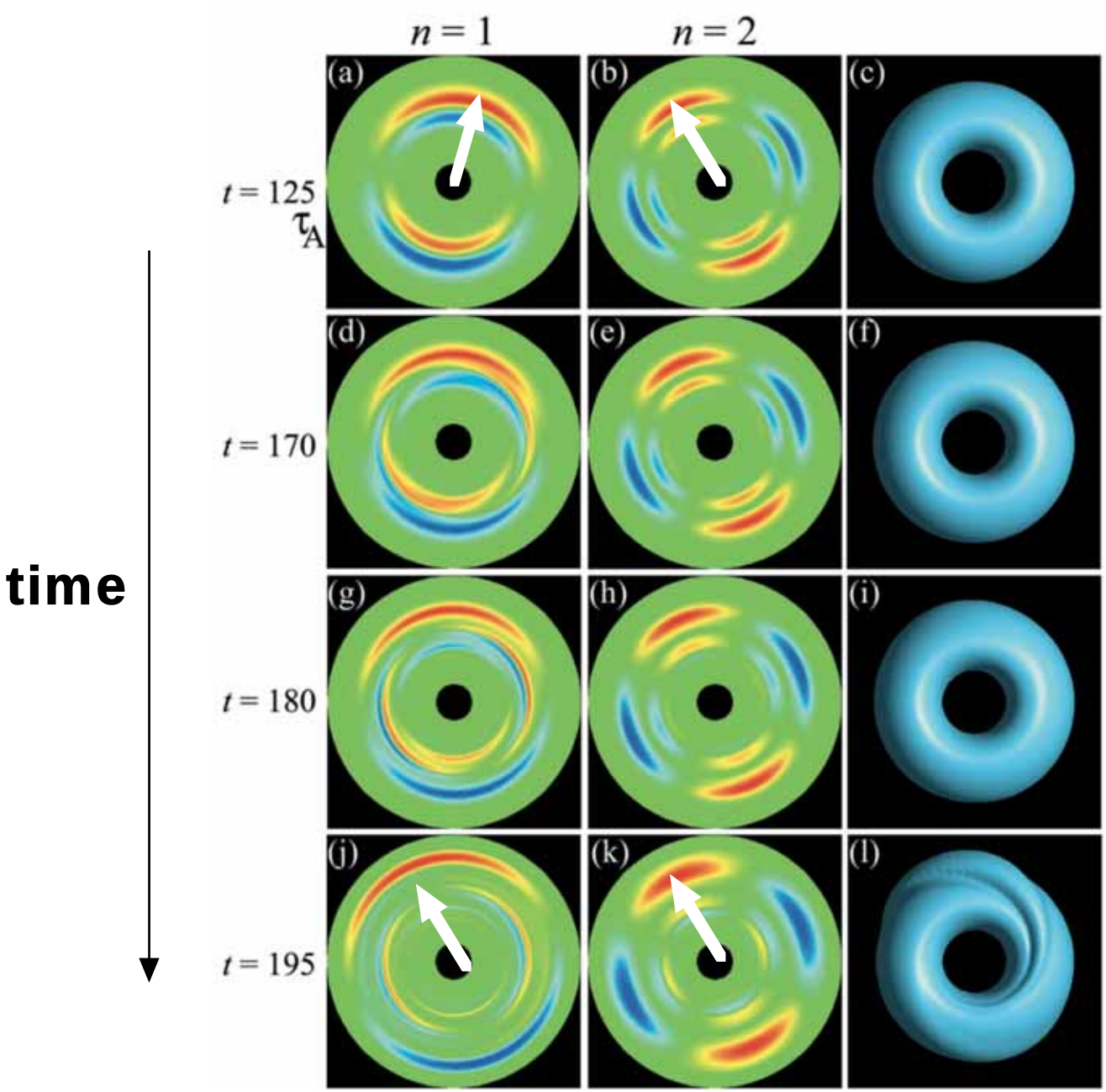
bulge



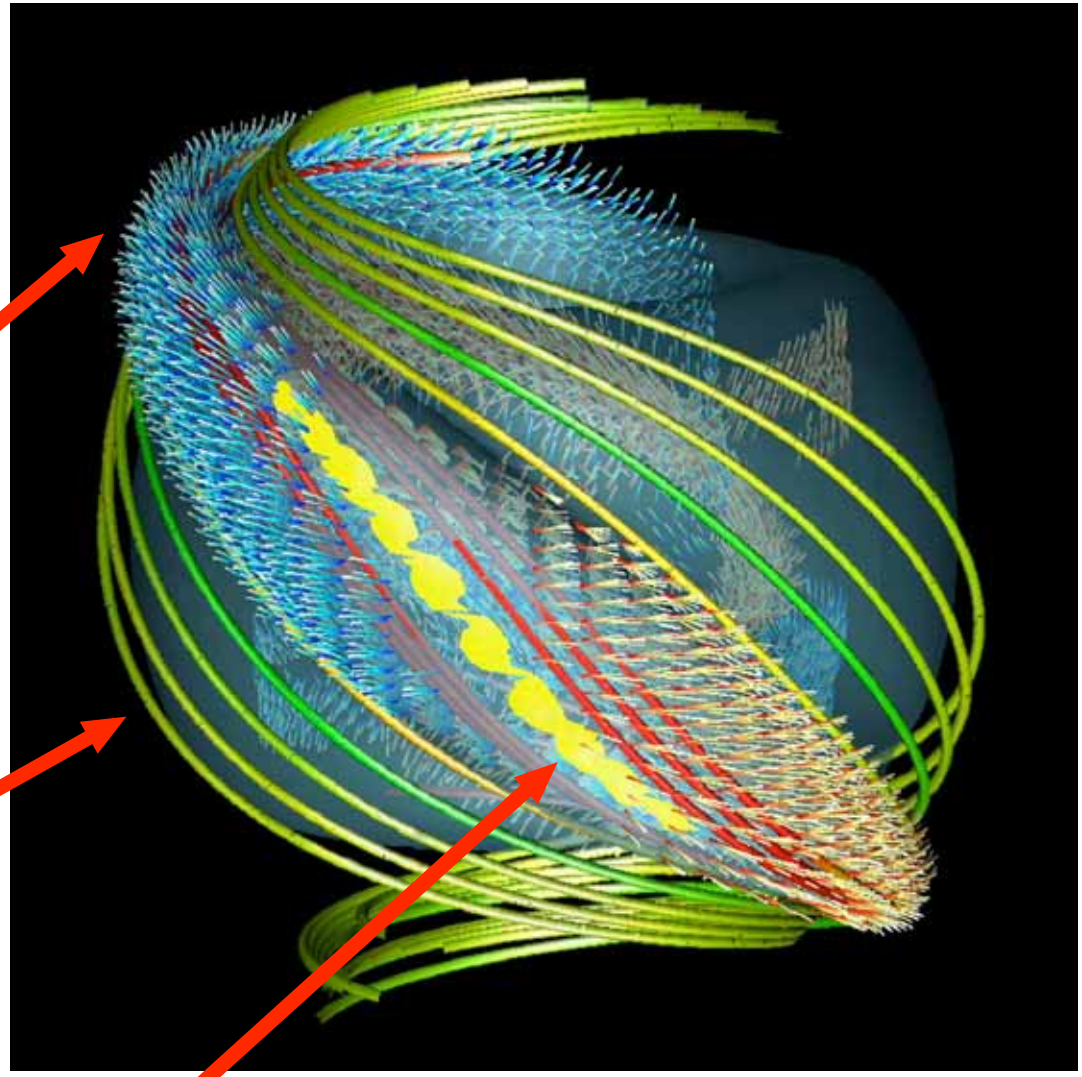
n=1 component

n=2 component

Spontaneous phase alignment



Filament formation and partial reconnection



ELM in MAST ~ summary and future work

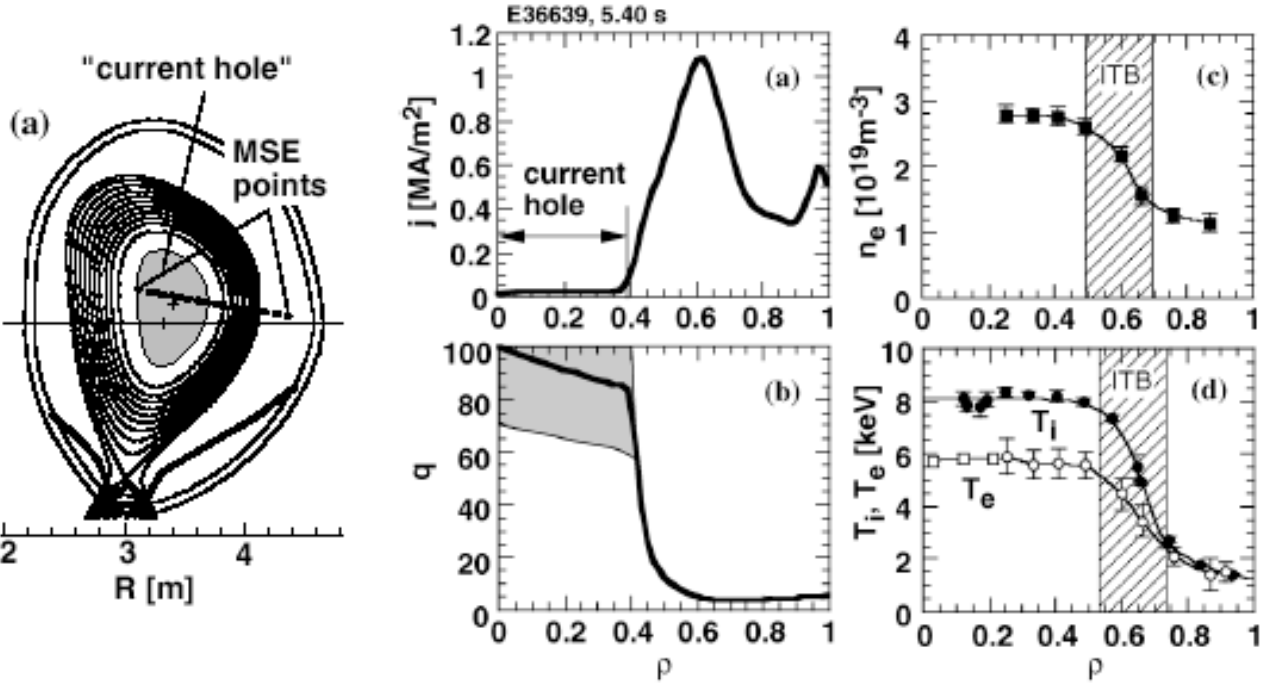
- nonlinear development of
  ballooning mode
  ↓
- nonuniform formation of
  current filament
  ↓
- partial loss of plasma
  through reconnection
  ↓
- relaxed

rapid and steep nature ⟶ FLR correction - - ongoing

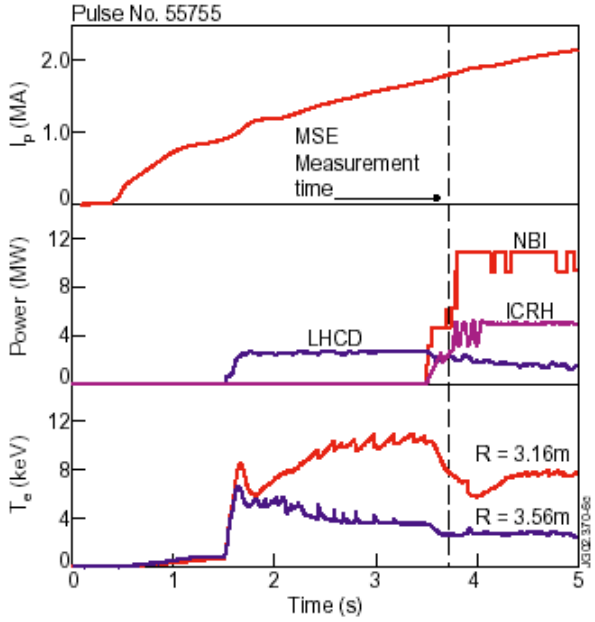
T with current hole?

"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)

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

$$\downarrow$$

$$\begin{cases} \Delta^*\psi = -r^2\dfrac{p_r}{\psi_r} - FF' - \dfrac{r^3 f^2}{\psi_r} \\ \Delta^*\psi = -r^2\dfrac{p_z}{\psi_z} - FF' \end{cases}$$ **: modified Grad-Shafranov eqs.**

$$\left(\Delta^* = r\frac{\partial}{\partial r}\frac{1}{r}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2}\right)$$

$$rB_\theta = F = F(\psi) \qquad \frac{v_\theta}{r} = f = f(\psi) \qquad p \neq p(\psi)$$

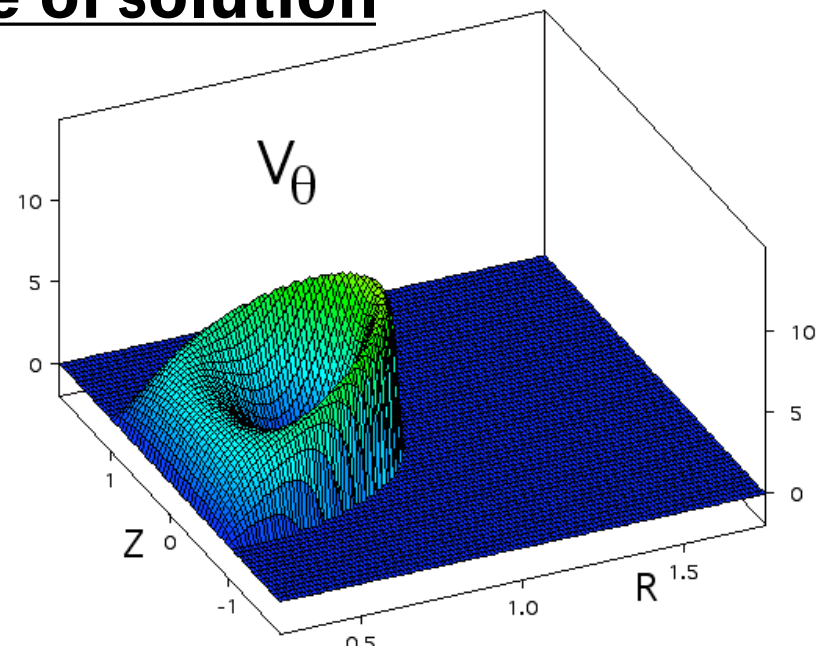
umerical solution

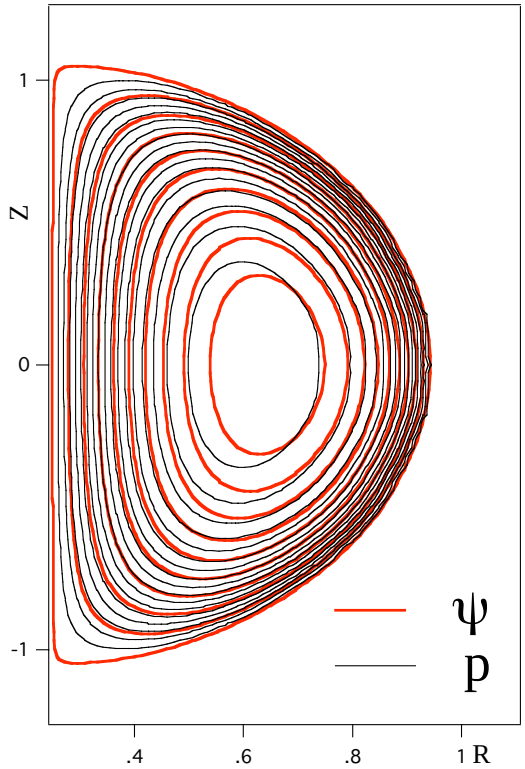
scheme

$$\begin{cases} \Delta^*\psi = -\dfrac{r^2}{|\nabla\psi|^2}\left(p_z\psi_z + p_r\psi_r\right) - FF' - \dfrac{r^3\psi_r}{|\nabla\psi|^2} f^2 \\ p_r = -\dfrac{\psi_r}{r^2}\left(\Delta^*\psi + FF'\right) - rf^2 \\ p_z = -\dfrac{\psi_z}{r^2}\left(\Delta^*\psi + FF'\right) \end{cases} \xrightarrow{\text{div}} \Delta p = -\phi$$

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

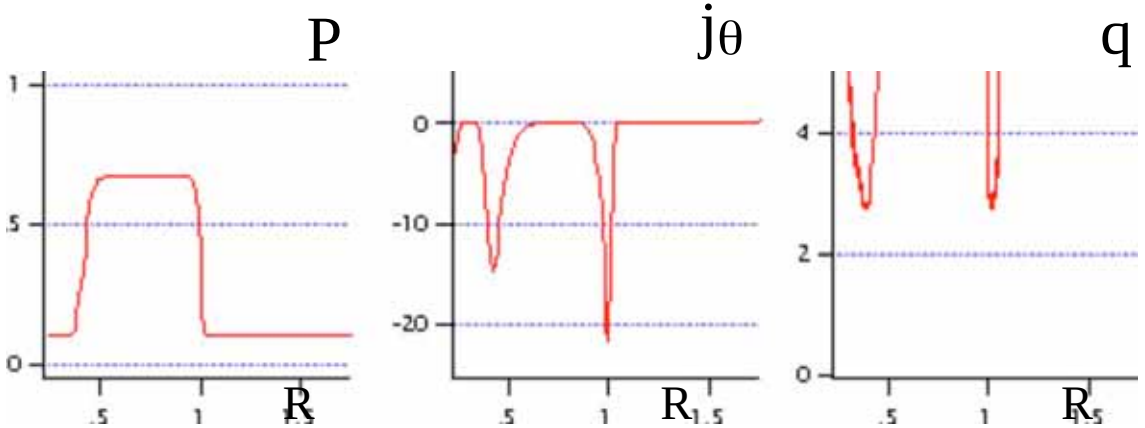
ample of solution

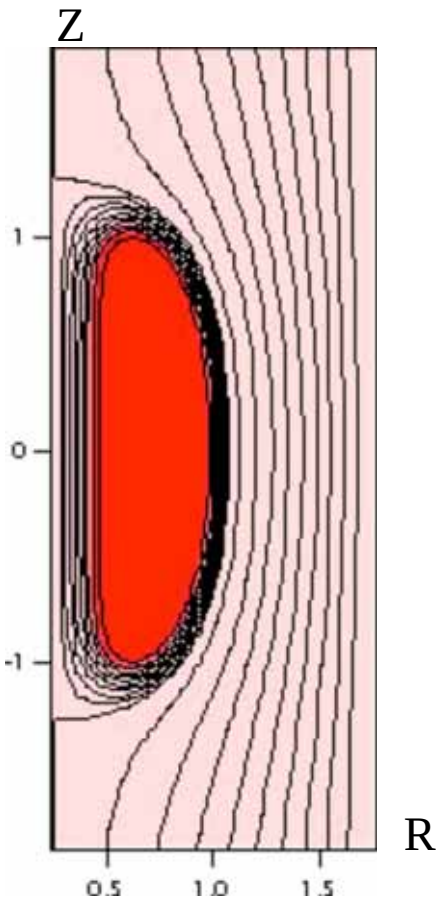




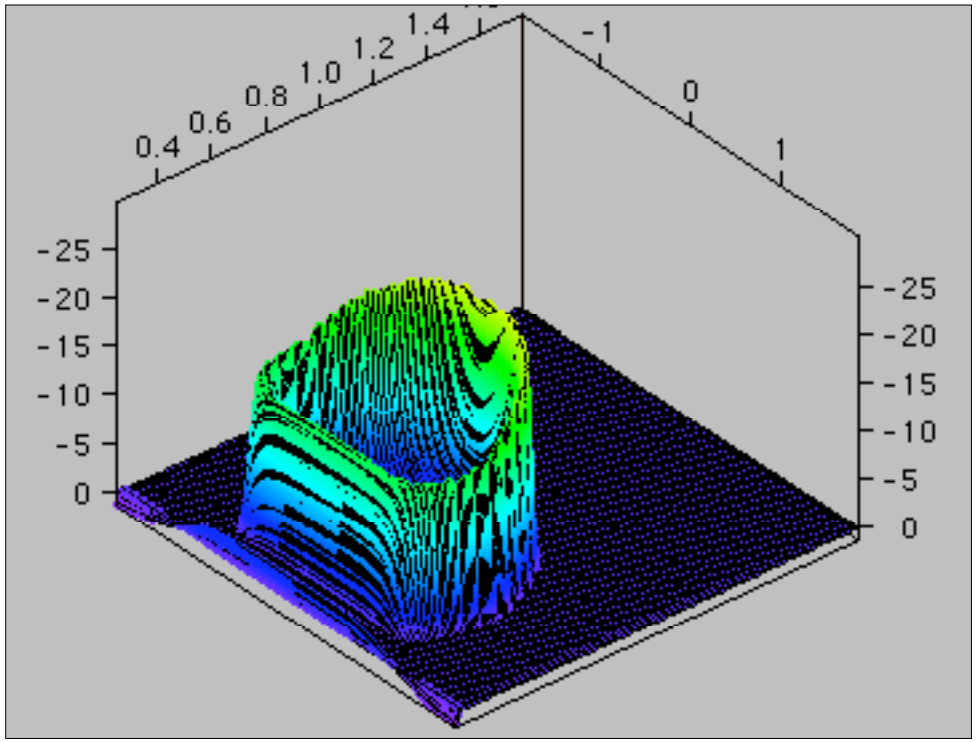
Numerical solution

radial profiles





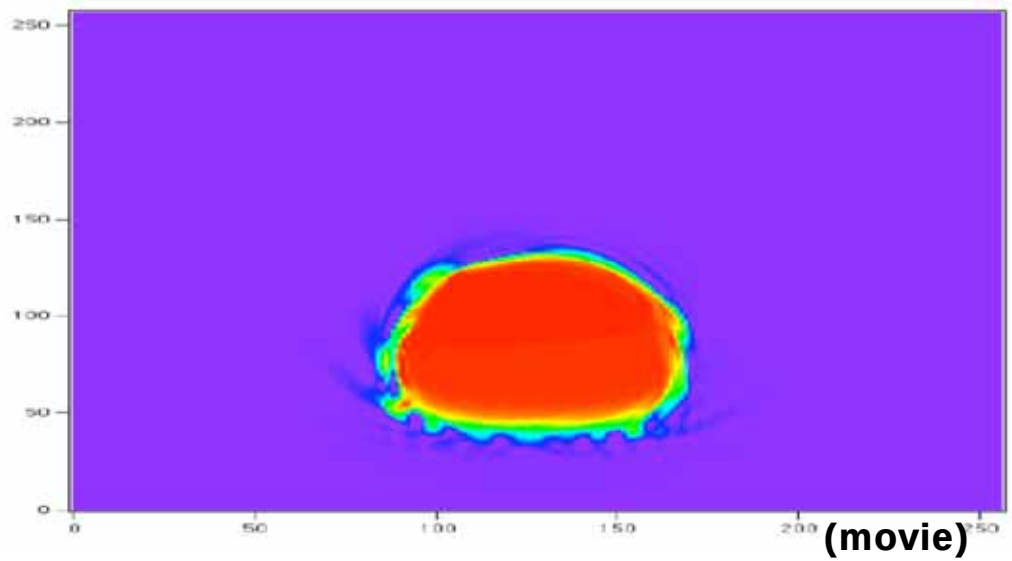
poloidal flux & pressure



toroidal flow

Nonlinear simulation result

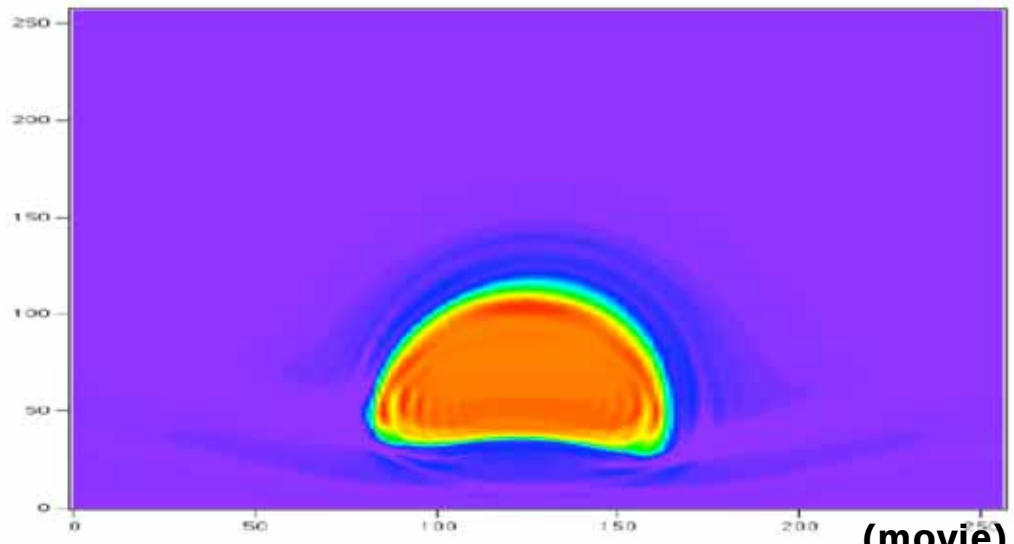
(V=0 case)



(movie)

- **disordered**
- **less restoring force**

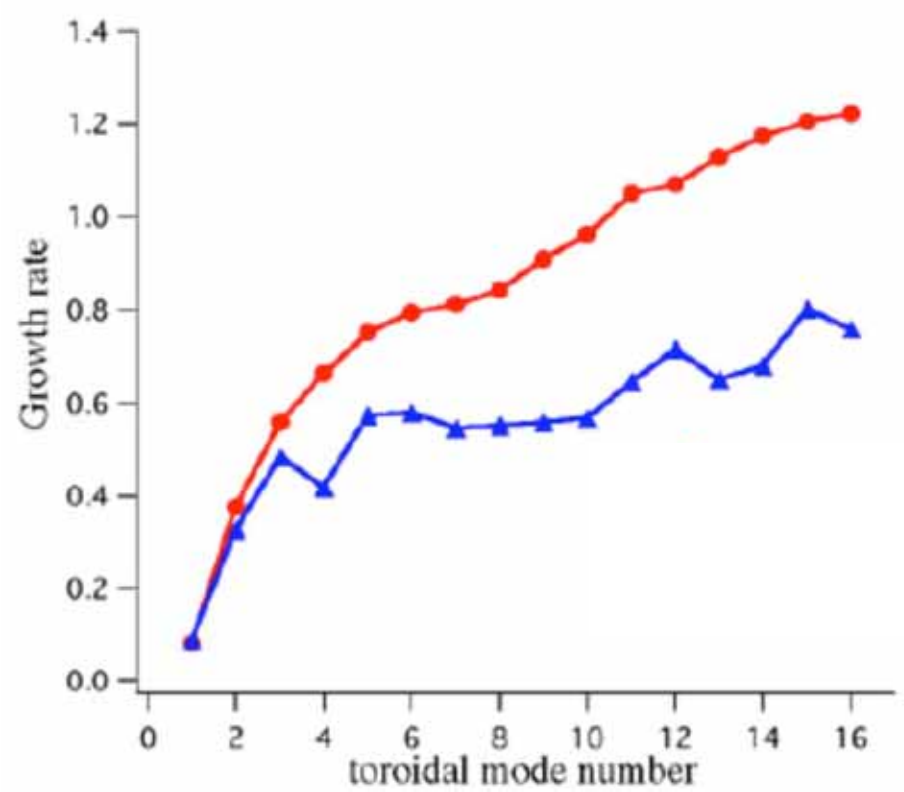
low-n components are emphasized →

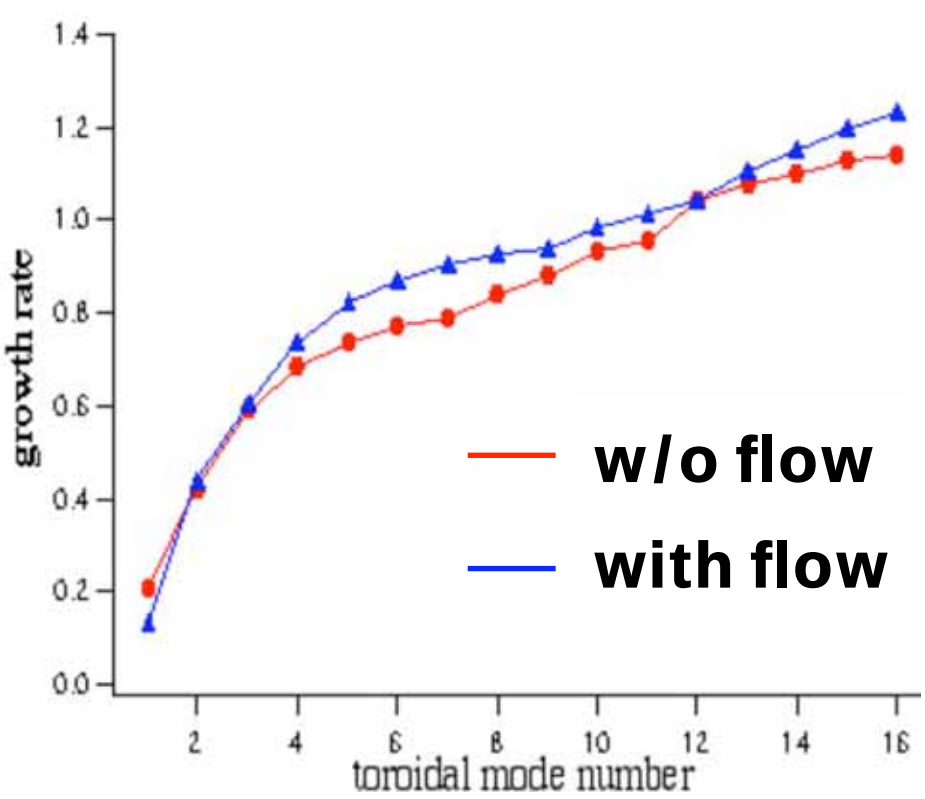


(movie)

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**