Nonlinear Simulations of MHD Activities in Spherical Tokamak

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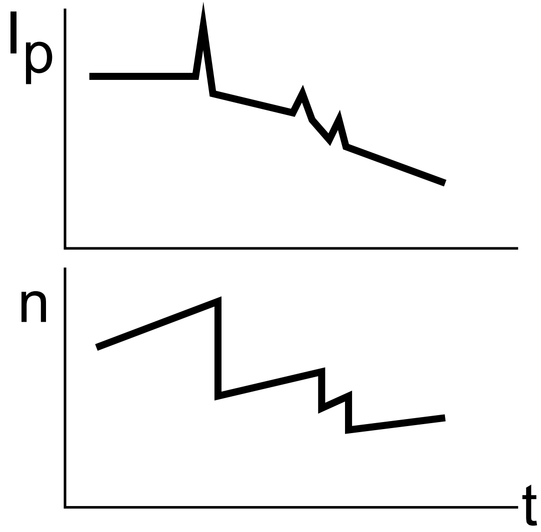
- Evolution of Relaxation Phenomena in Spherical Tokamak

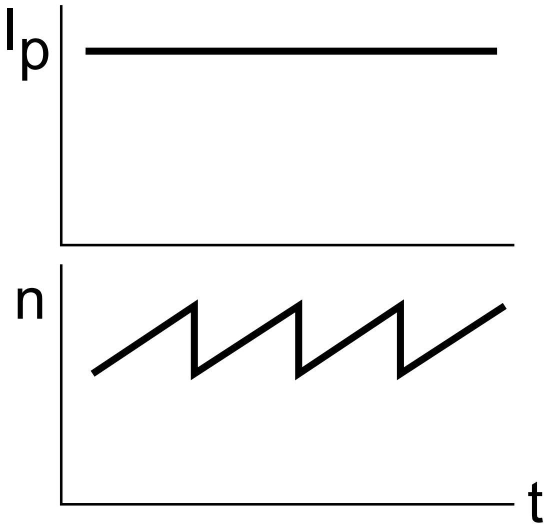
Relaxation phenomena in spherical tokamak (ST) plasma

various kinds of low-n MHD relaxations are observed in STs

◎ *IRE (RE)*

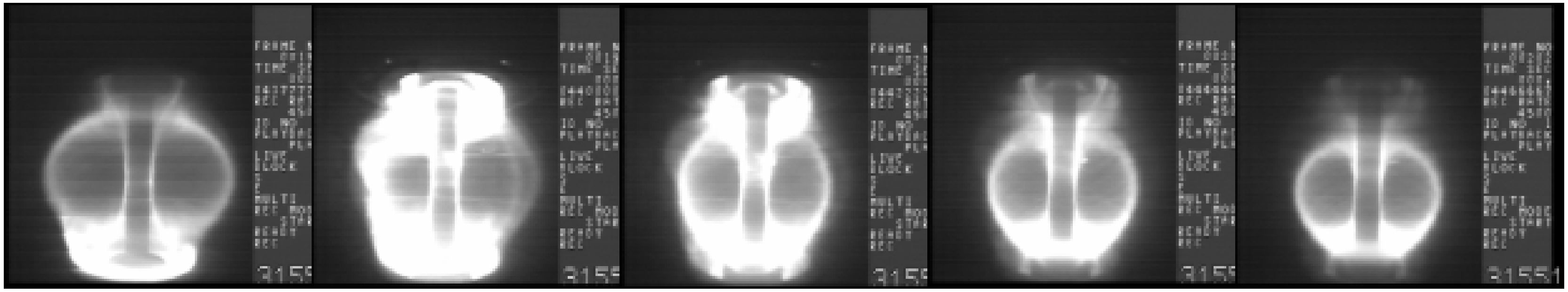


◎ Internal activities



- increase of Ip
- interval
- deformation
- resiliency

- CCD camera image on an IRE in START

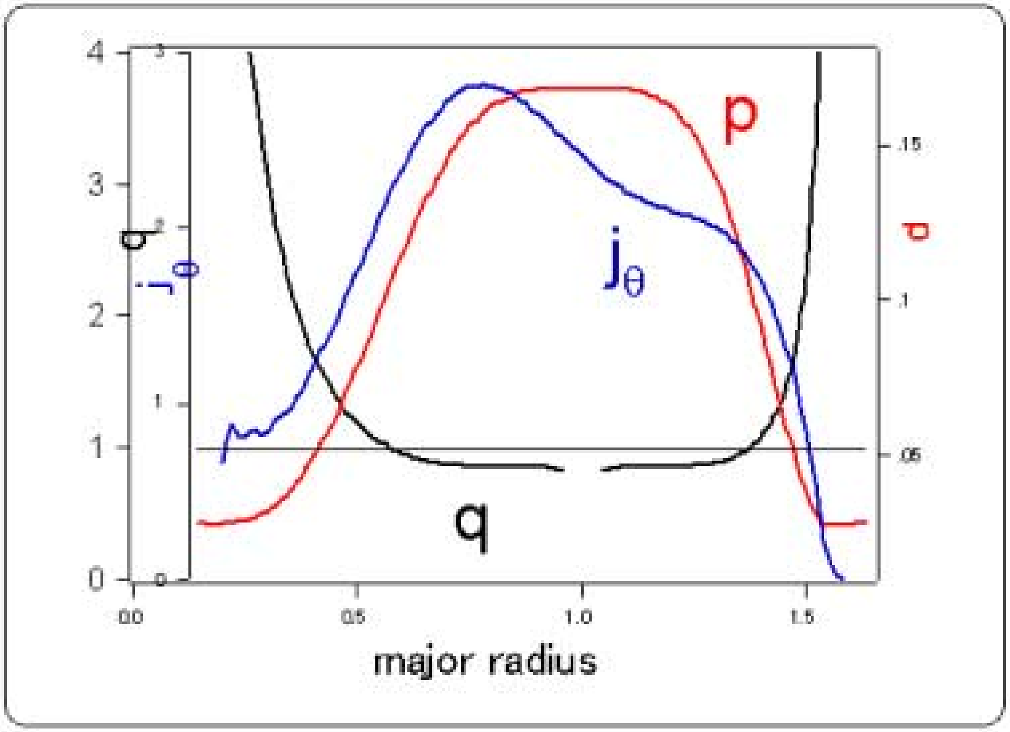


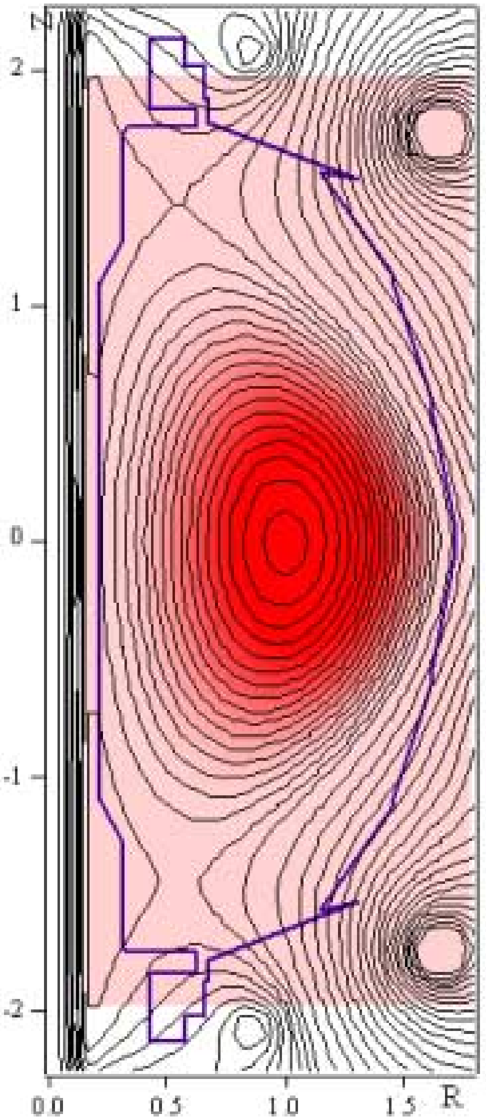
→ time

(by courtesy of Dr. A. Sykes and M. Gryaznevich)

Profile of initial equilibrium

—— EFIT reconstruction data of NSTX





Shot number	#103701
Time	238 msec
Aspect ratio	1.4
Central q	0.89
Central β	28 %

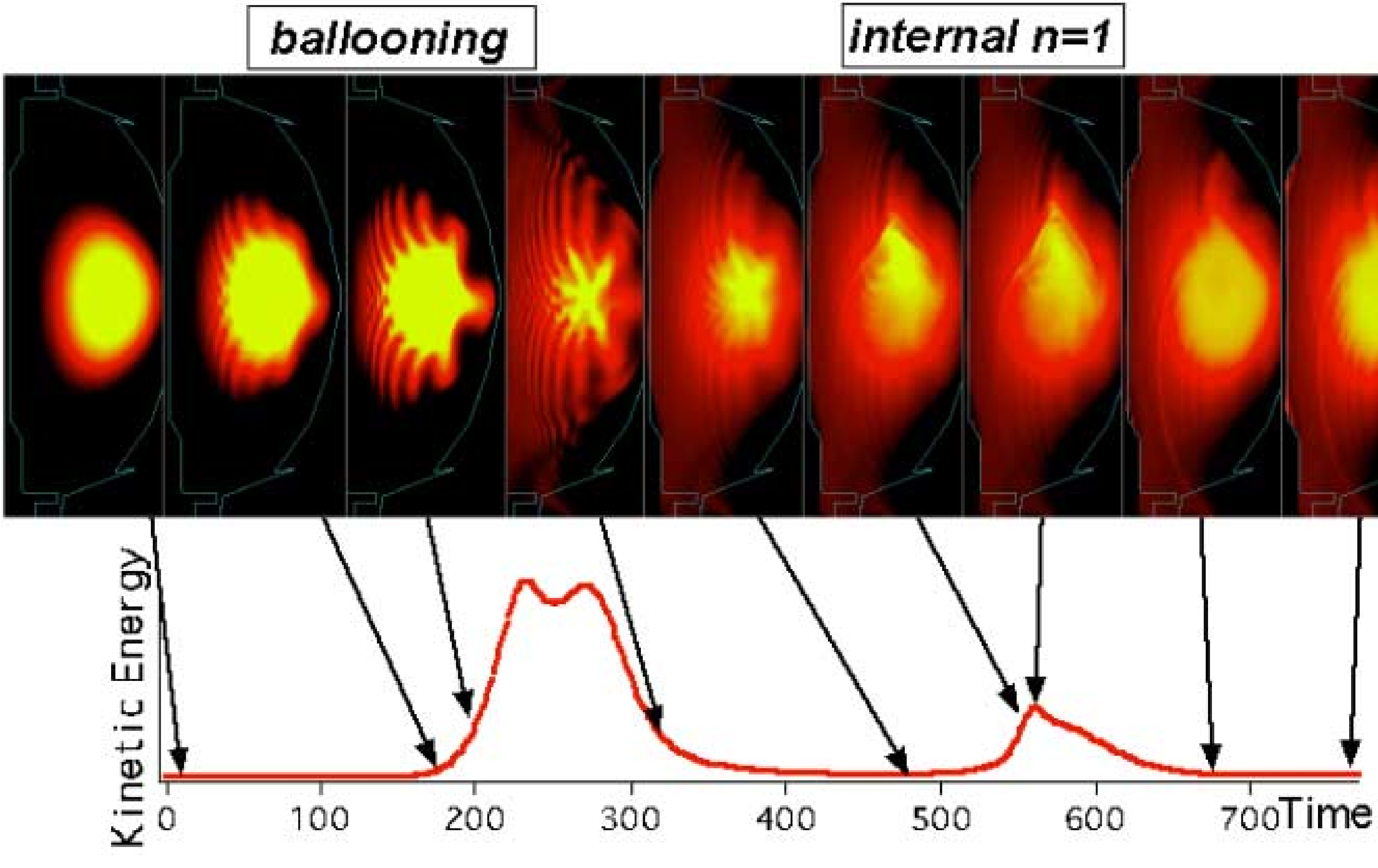
by courtesy of Dr.S.Sabbagh,
Dr.F.Paoletti, and Dr.S.Kaye

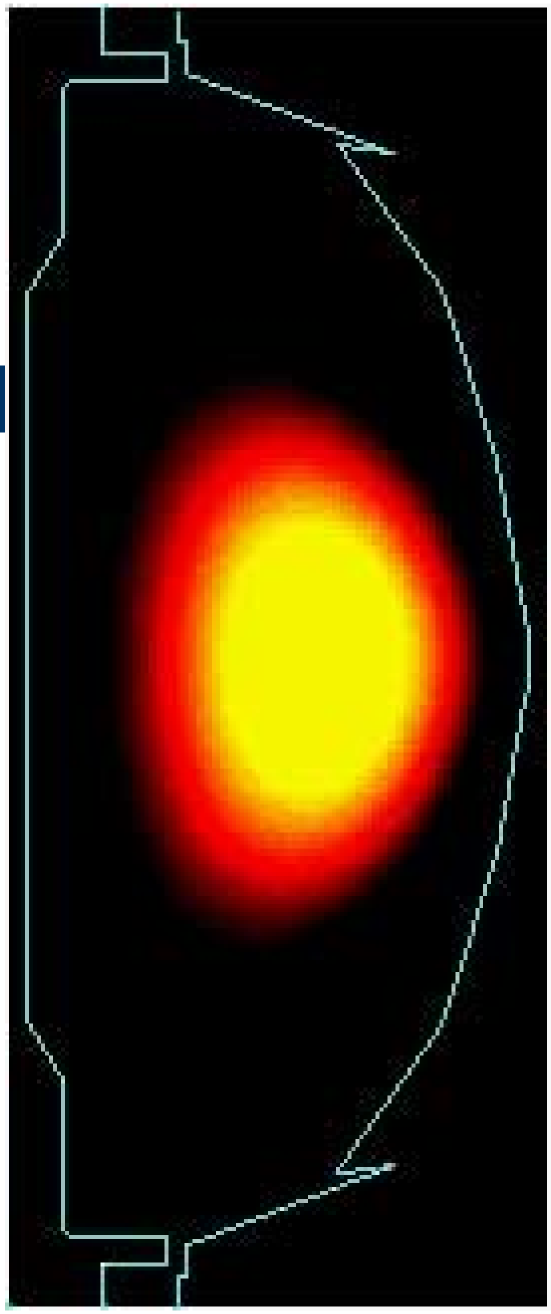
Nonlinear MHD equations

$$\begin{aligned}
\frac{\partial \rho}{\partial t} &= -\nabla \cdot (\rho \boldsymbol{v}), \\
\frac{\partial}{\partial t}(\rho \boldsymbol{v}) &= -\nabla \cdot (\rho \boldsymbol{v}\boldsymbol{v}) - \nabla p + \boldsymbol{j} \times \boldsymbol{B} + \mu(\nabla^2 \boldsymbol{v} + \frac{1}{3}\nabla(\nabla \cdot \boldsymbol{v})), \\
\frac{\partial \boldsymbol{B}}{\partial t} &= -\nabla \times \boldsymbol{E}, \\
\frac{\partial p}{\partial t} &= -\nabla \cdot (p\boldsymbol{v}) - (\gamma - 1)p\nabla \cdot \boldsymbol{v} + (\gamma - 1)(\eta \boldsymbol{j}^2 + \Phi - \nabla \cdot \boldsymbol{q}),
\end{aligned}$$

$$\begin{aligned}
\boldsymbol{j} &= \nabla \times \boldsymbol{B}, \\
\boldsymbol{E} &= -\boldsymbol{v} \times \boldsymbol{B} + \eta \boldsymbol{j}, \\
\Phi &= 2\mu(e_{ij}e_{ij} - \frac{1}{3}(\nabla \cdot \boldsymbol{v})^2), \\
e_{ij} &= \frac{1}{2}(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i}), \\
\boldsymbol{q} &= -\kappa \nabla \ (p/\rho).
\end{aligned}$$

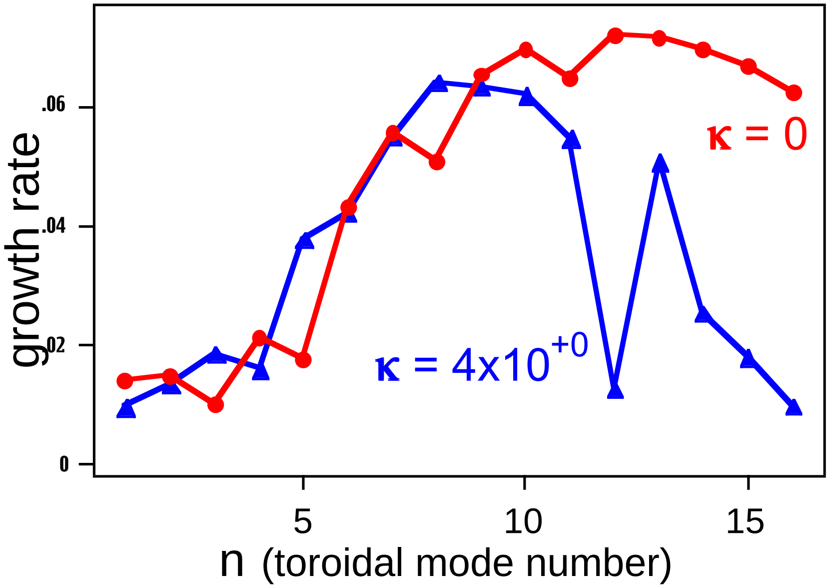
Time development of pressure profile and total kinetic energy

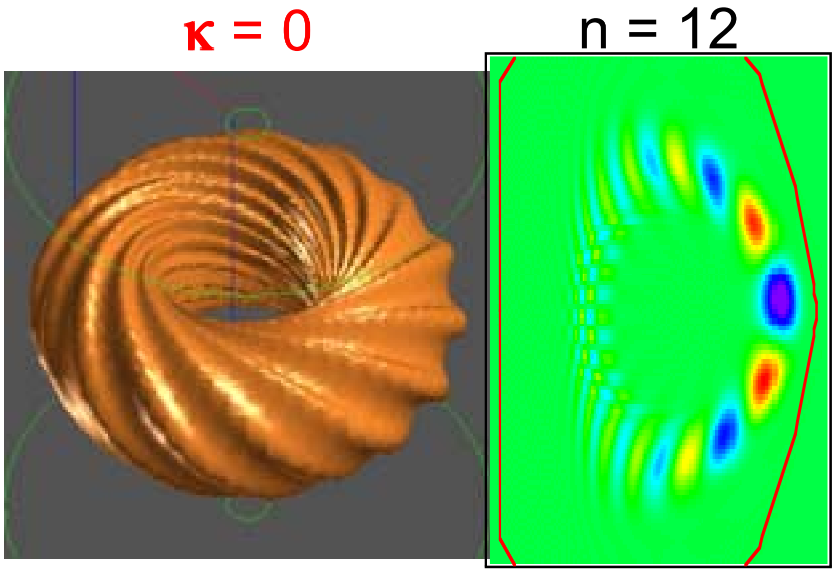


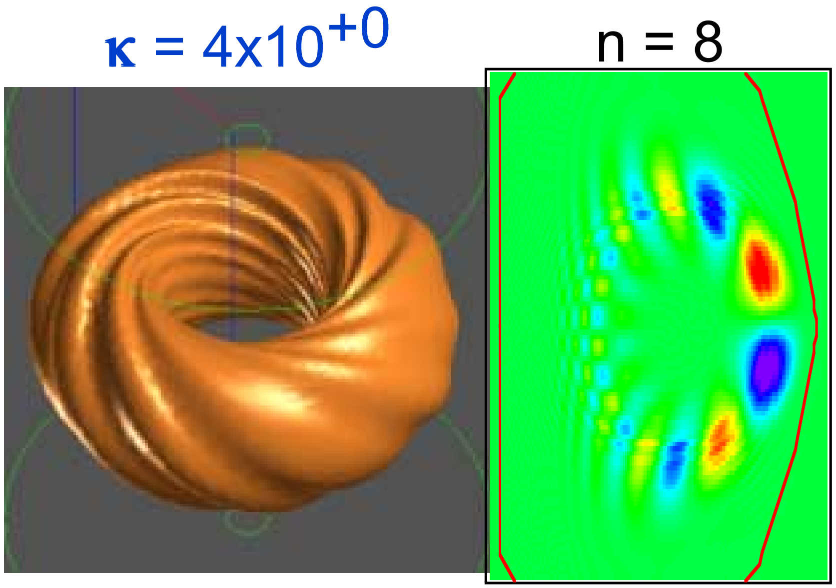


Growth of ballooning mode

- medium n
- localized in bad curvature region
- pressure driven
- dependency on _
  thermal conductivity

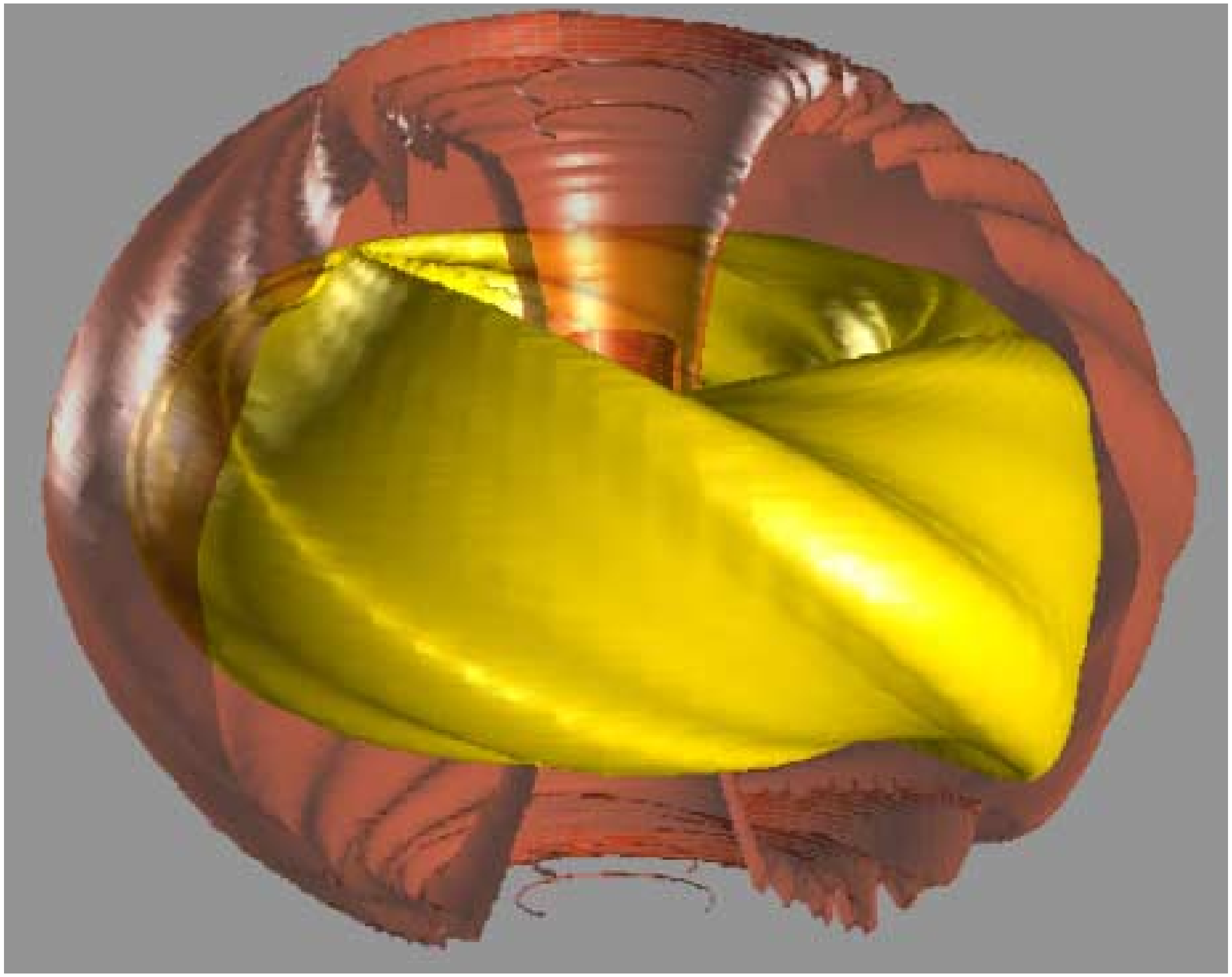






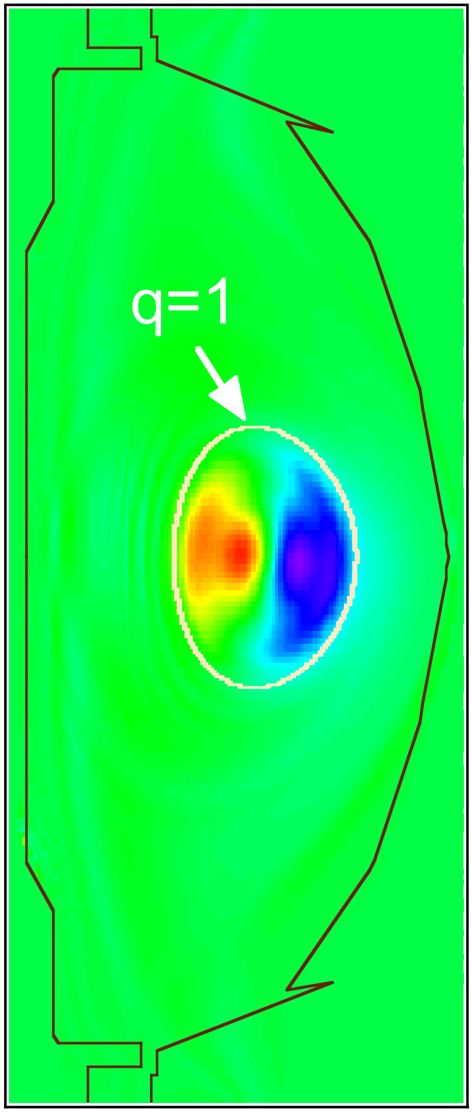
Internal n=1 activity

- current driven mode
- m/n = 1/1   - exist inside the q=1 surface

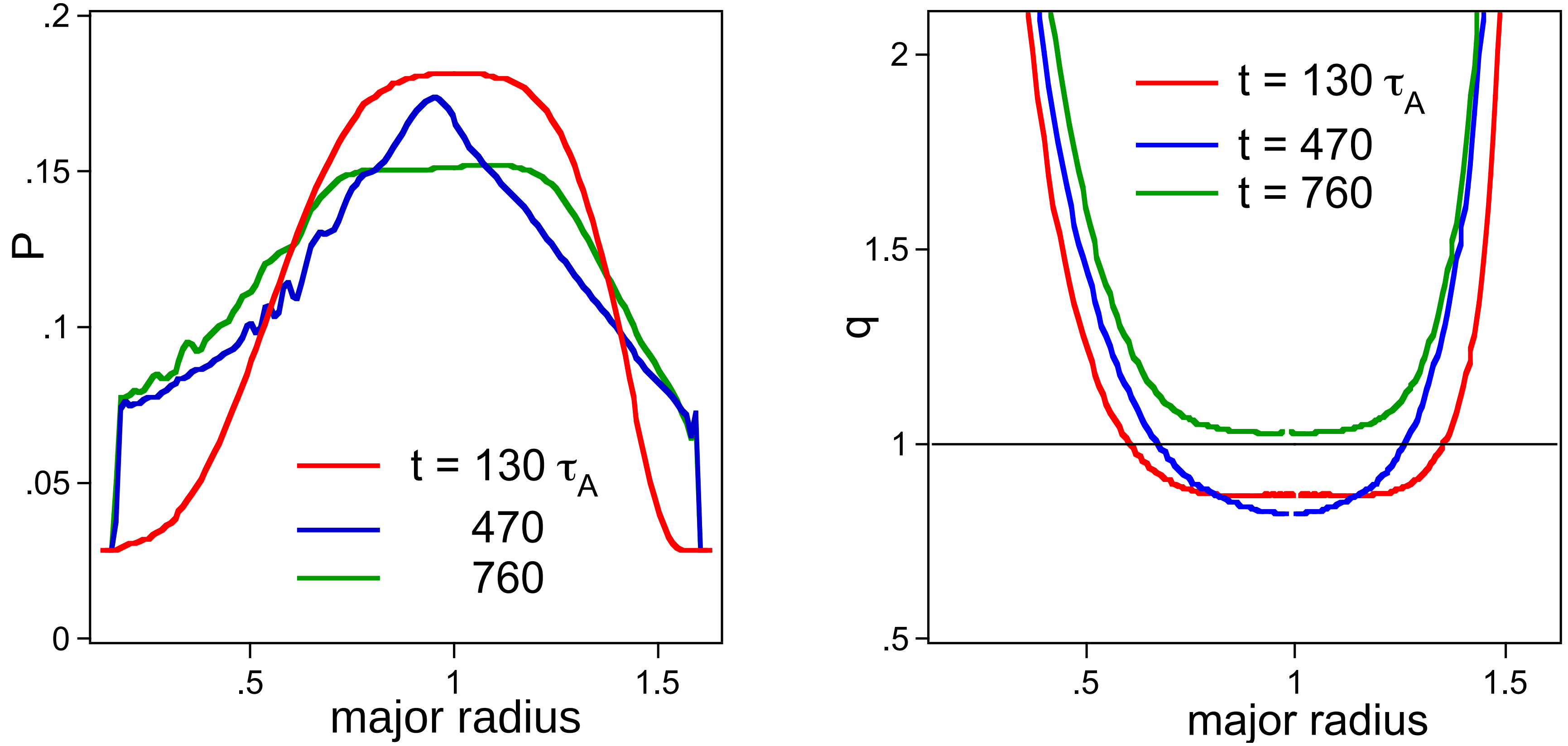


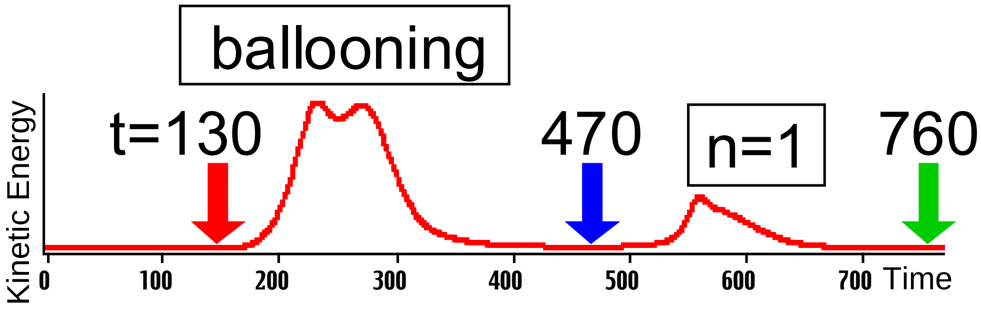
$t = 550\ \tau_A$

δP (n = 1)



Temporal change in radial pressure and q profiles on relaxed states





Comparison with experiments

- observation of ballooning mode
and beta degradation in TFTR supershot plasma
(Y.Nagayama, et al.(1993))

Y. Nagayama, S.A. Sabbagh, J. Manickam, E.D. Fredrickson, M. Bell,
R.V. Budny, A. Cavallo, A.C. Janos, M. E. Mauel, K.M. McGuire, G.A. Navratil,
G. Taylor, and M. Yamada:
"Observation of ballooning modes in high-temperature tokamak plasmas",
Physical Review Letters, Vol.69 (1992), pp.2376-2379.

Y. Nagayama, M. Yamada, S.A. Sabbagh, J. Manickam, E.D. Fredrickson,
M. Bell, R.V. Budny, A. Cavallo, A.C. Janos, M.E. Mauel, K.M. McGuire,
G. A. Navratil, and G. Taylor:
"Investigation of ballooning modes in high poloidal beta plasmas
in the Tokamak Fusion Test Reactor",
Physics of Fluids B, Vol.5, (1993), pp.2571-2577.

Comparison with experiments (tokamak e.g. TFTR)

- ballooning mode and beta degradation (Y.Nagayama, et al.(1993))

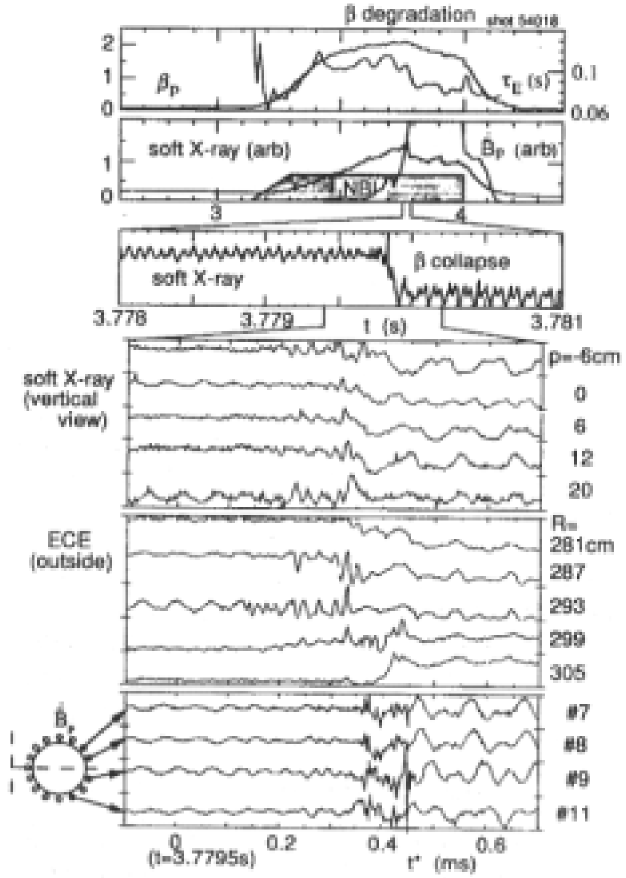


FIG. 2. Summary of the time dependence of various plasma parameters and MHD fluctuations for a high β_p plasma with a β collapse. Here,^{t} is a time base with the origin at $t=3.7795$ sec. In the soft x-ray signals, p is a chord radius (Ref. 16) from the magnetic axis ($R=271$ cm). Negative p indicates that the view line passes through the high toroidal field side of the plasma major radius.

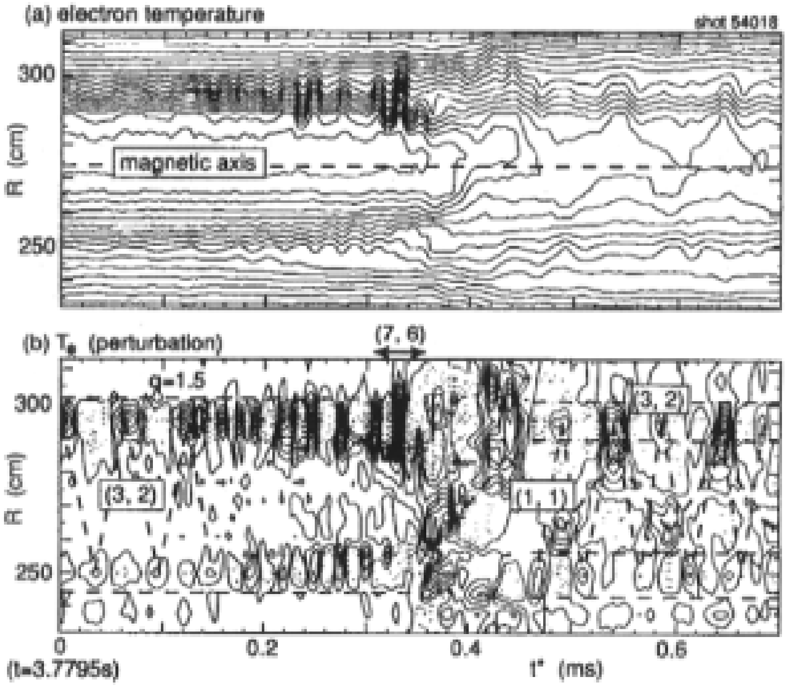
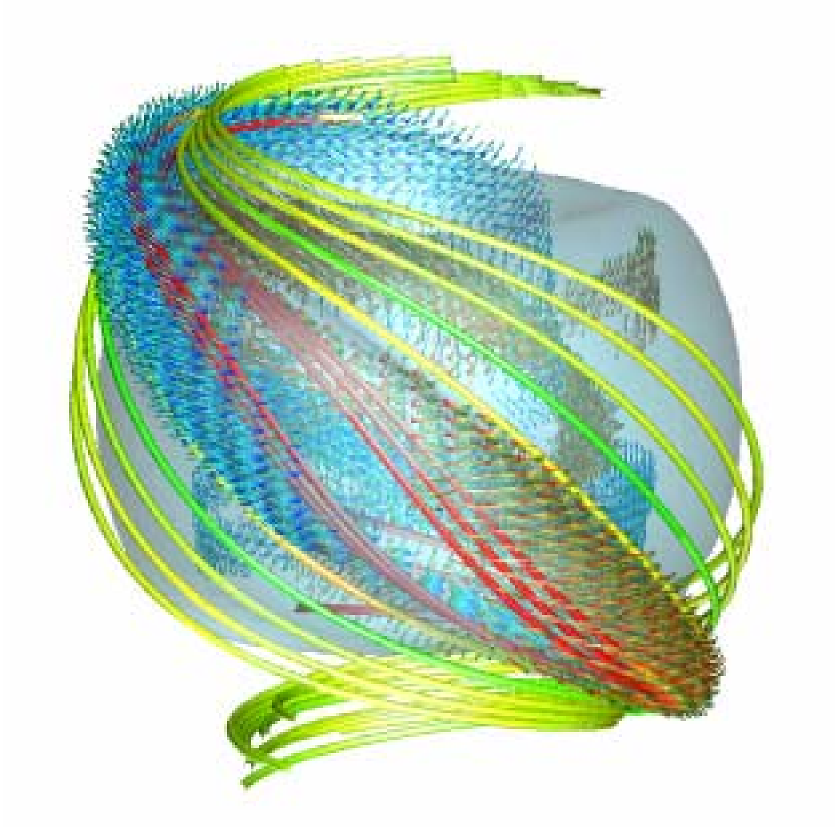


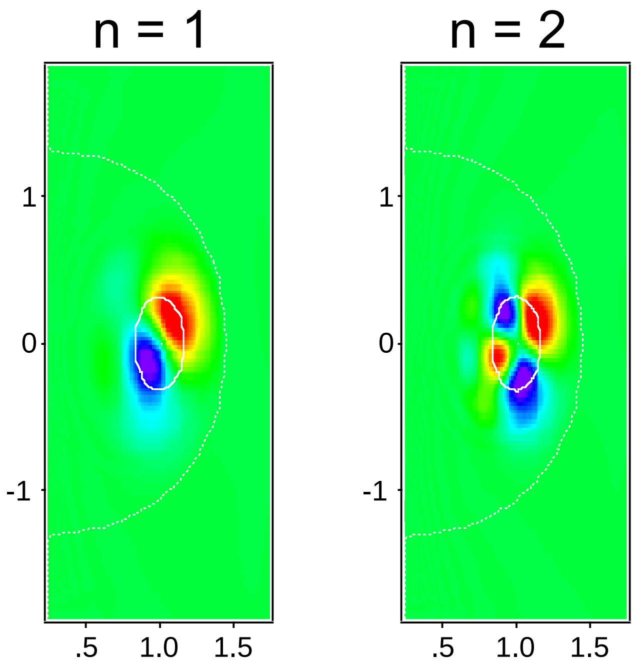
FIG. 3. Contour plots of the time evolution of the soft x-ray and ECE profiles in shot 54018: (a) electron temperature; the contour step size is 300 eV, and (b) perturbation of electron temperature.

Y. Nagayama, M. Yamada, S.A. Sabbagh, J. Manickam, E.D. Fredrickson, M. Bell, R.V. Budny, A. Cavallo, A.C. Janos, M.E. Mauel, K.M. McGuire, G. A. Navratil, and G. Taylor, Physics of Fluids B, 5,(1993) pp.2571.

Comparison with IRE (results)

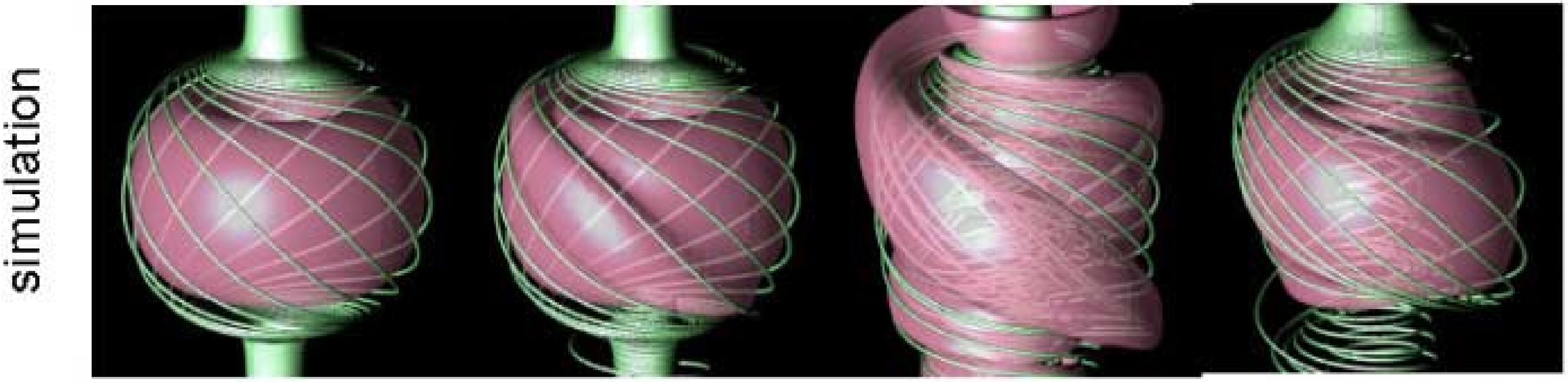


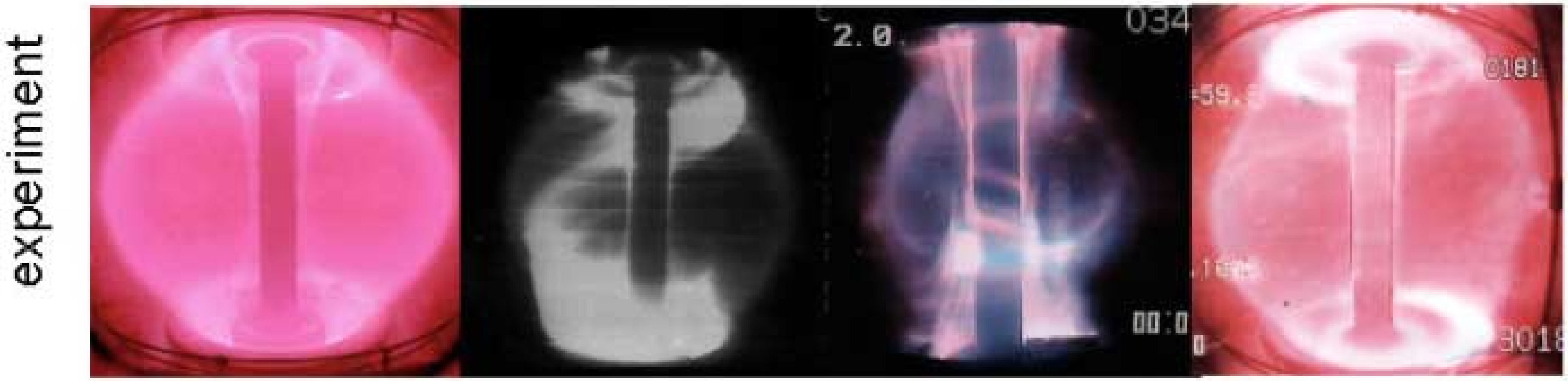
Magnetic reconnection
between the internal and external field



~ simultaneous growth of
the m/n = 1/1 and 2/2
interchange modes

Comparison with experiments for IRE case

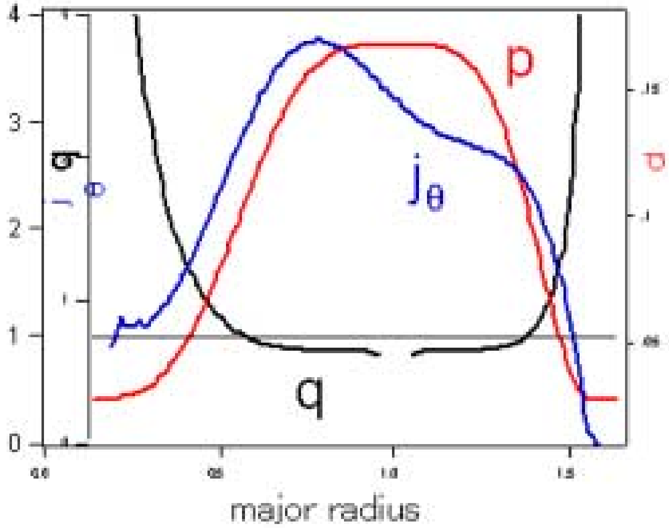




(START : courtesy of Drs. A. Sykes and M. Gryaznevich)

Comparison with IRE (initial condition)

ballooning + n=1

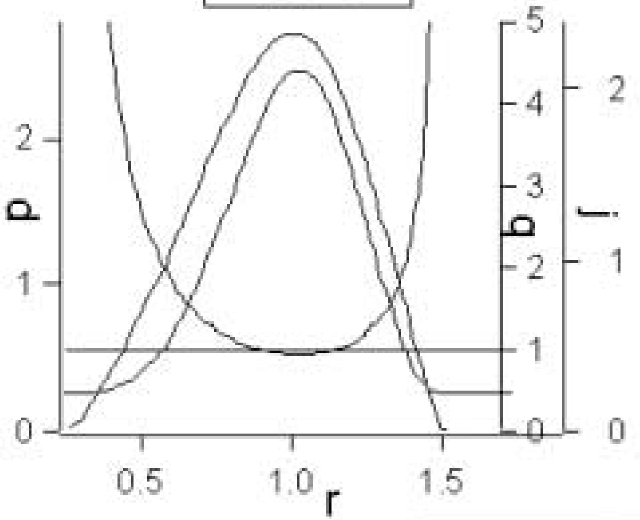


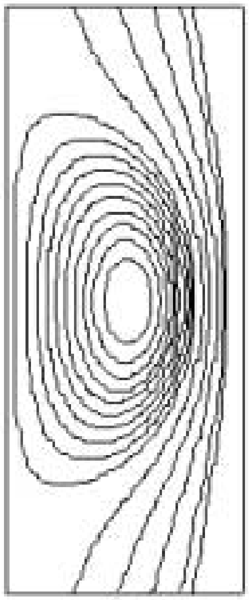
A = 1.4□

q_0= □0.89□

β_0= □ 28 %

IRE





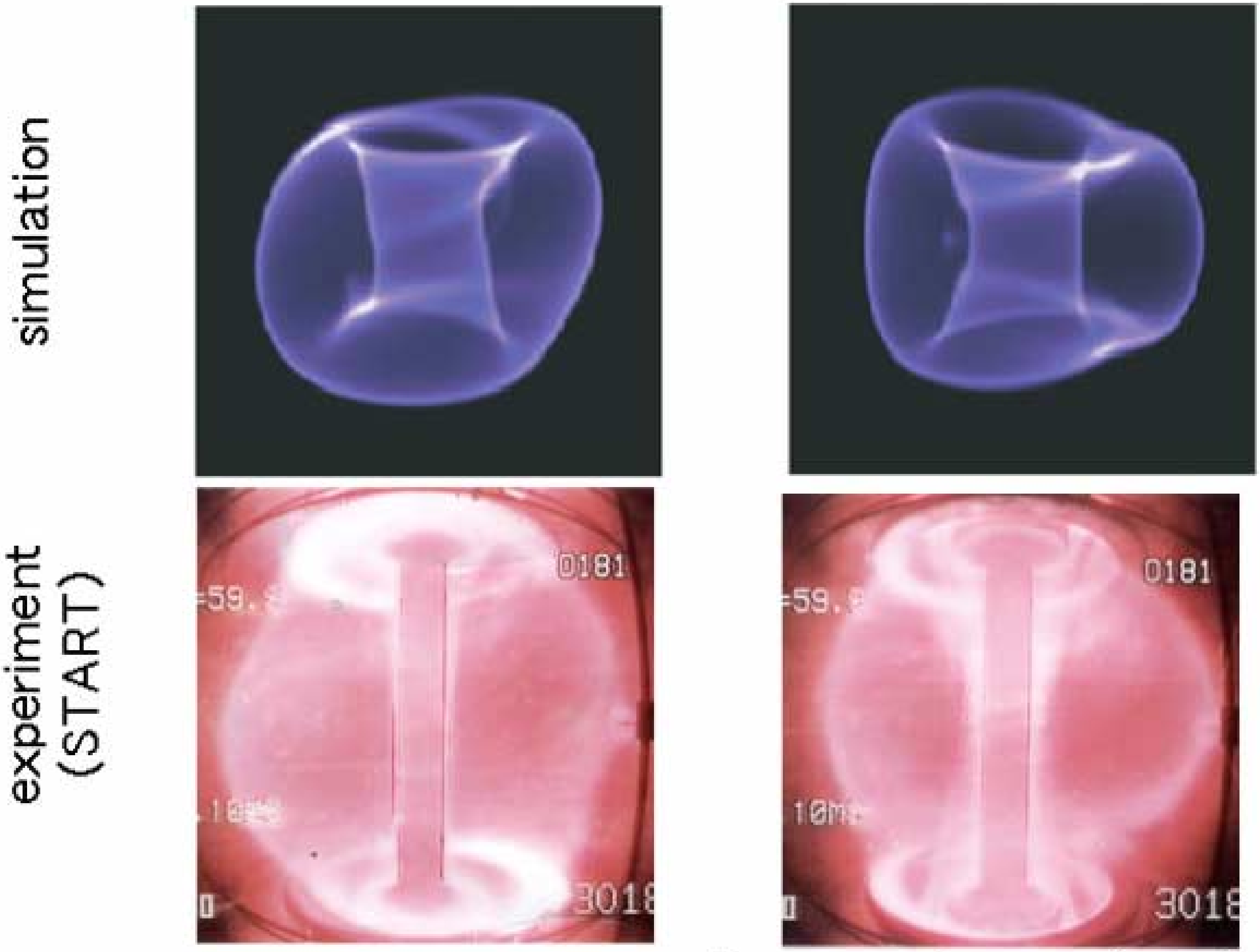
A = 1.4□

q_0= □0.91□

β_0= □ 44 %

Comparison with experiments

~ $m / n = 2 / 1$ *mode*



(by courtesy of Drs. A. Sykes and M. Gryaznevich)

Summary of spherical tokamak simulation

- **two-step relaxation**

  middle-n ballooning — collapse in the periphery

  changing the profiles

  \+

  internal n=1 ——— sawtooth-like crash & recovery

- **comparison with experiment**
  - ECE measurement on beta collapse in TFTR
  - agreement in multi-step mode structures
- **comparison with IRE**
  - less interaction with external field
    (energy loss , deformation, ...)
  - only slight difference between the initial conditions
- **numerical techniques**
  - effect of heat conduction
  - treatment of experimental non-rectangular system

Replacement of Supercomputer at NIFS

	New	Old
	NEC SX7/160M5	NEC SX4/64M2
Main Memory	1280 GB	32 GB
Total CPU Speed	1440 GFlops	128 GFlops
Node #	5	2
PE#/node	32	32
Mass data storage	100TB	10TB

(Shared memory, Vector-parallel)

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