M3D Simulation Studies of NSTX

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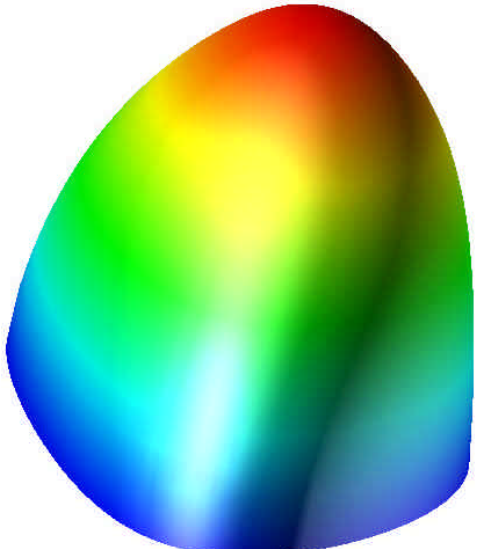
Outline

- M3D code
  - MHD, two-fluids, hybrid models.
- NSTX studies including flow effects
  - 2D steady states.
  - Evolutions of IRE's.
  - TAE modes.

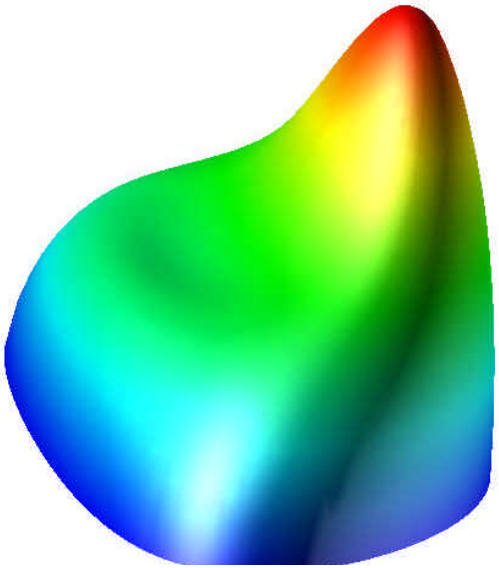
Density profile dependence on sheared Rotation

MHD

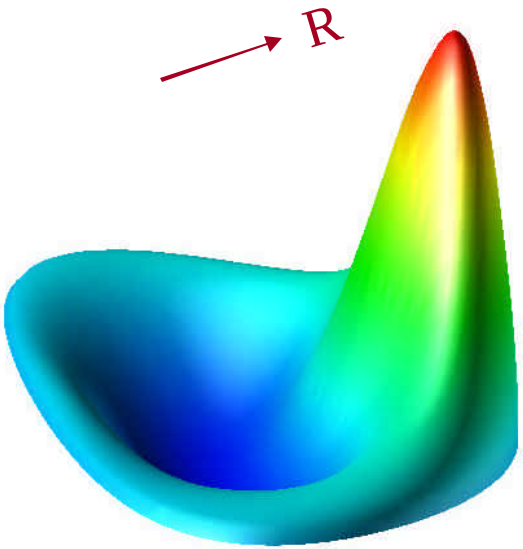
$\varepsilon=1.3 \quad q_o=0.8 \quad q_b=5$



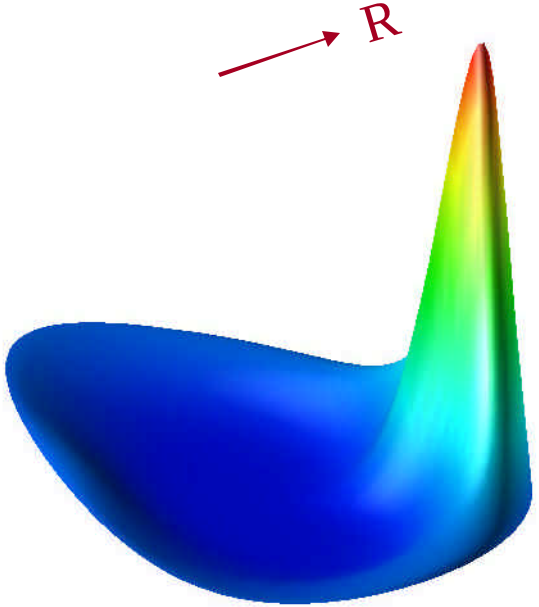
$M_A=0$
Sh=0
$\rho_{max}=1$
$\rho_{min}=0.5$



$M_A=0.2$
Sh=0.3
$\rho_{max}=1.1$
$\rho_{min}=0.5$



$M_A=0.5$
Sh=0.4-0.07=0.33
$\rho_{max}=1.9$
$\rho_{min}=0.2$

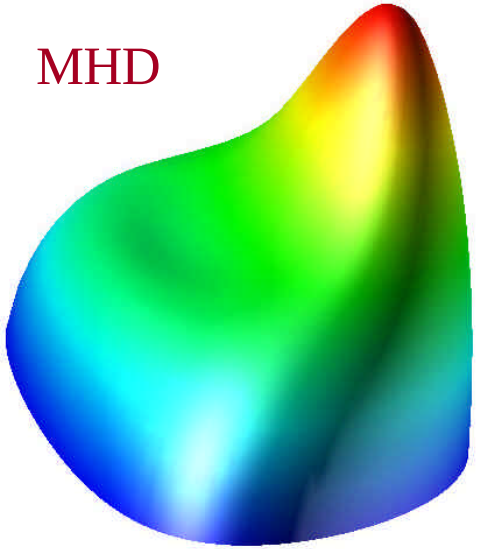


$M_A=0.8$
Sh=0.5-0.15=0.35
$\rho_{max}=5.2$
$\rho_{min}=0.005$

Density profile dependence on Physics model

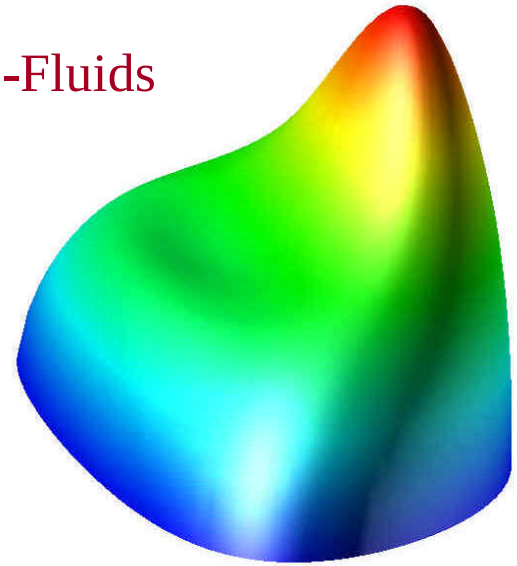
NSTX ε=1.3 q_o=0.8 q_b=5

MHD



M_A=0.2
Sh=0.3
ρ_{max}=1.1
ρ_{min}=0.5
RelSh=1

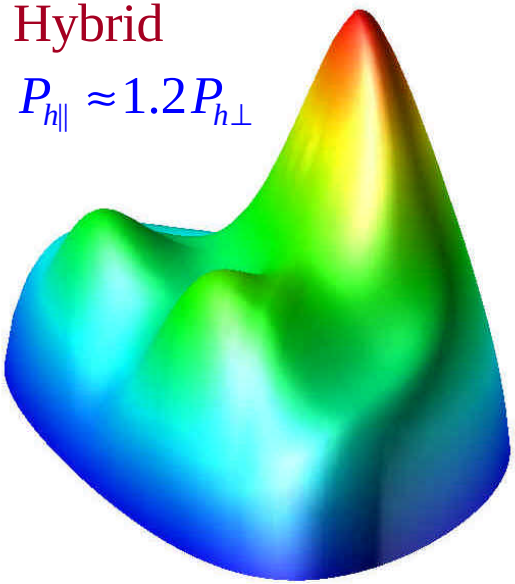
Two-Fluids



M_A=0.2
Sh=0.3
ρ_{max}=1.1
ρ_{min}=0.5
RelSh=1

Hybrid

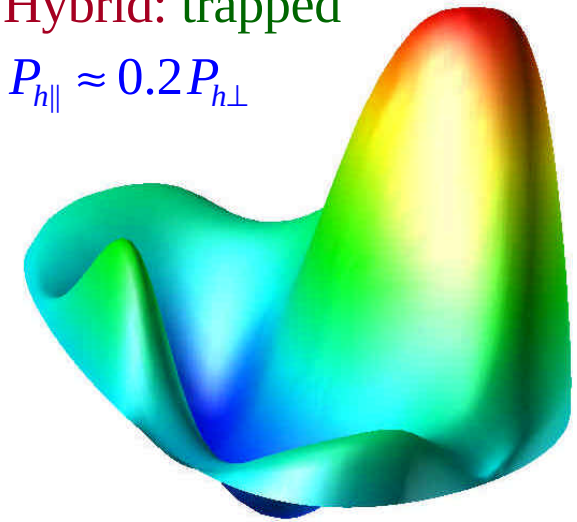
$P_{h\|} \approx 1.2 P_{h\perp}$



M_A=0.2
Sh=0.3
ρ_{max}=1.2
ρ_{min}=0.5
RelSh=0.8

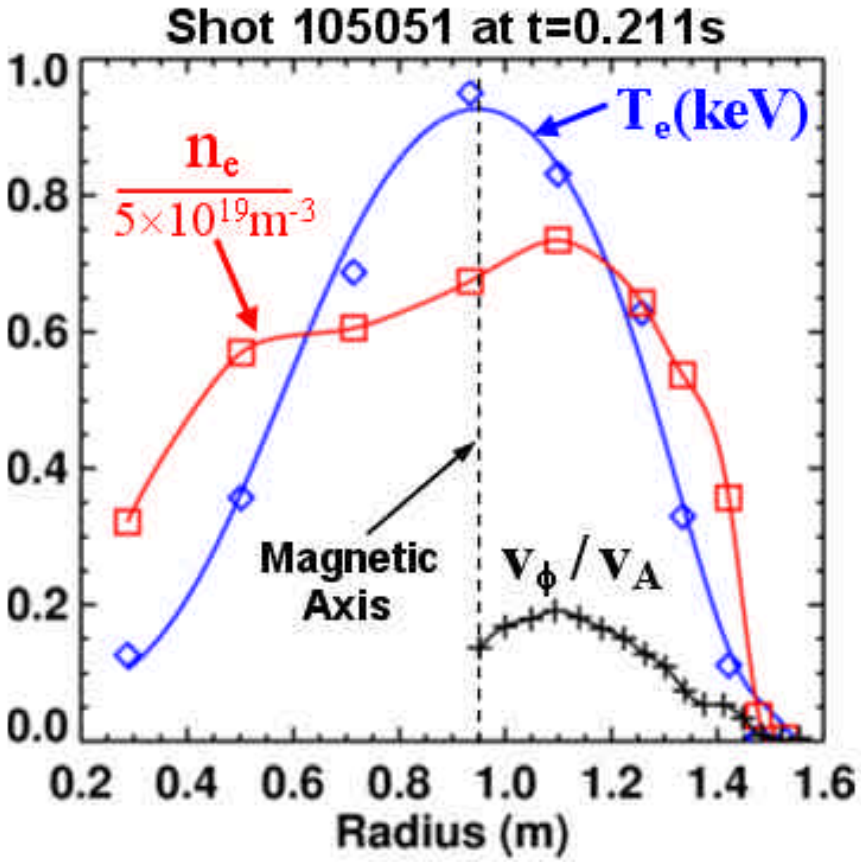
Hybrid: trapped

$P_{h\|} \approx 0.2 P_{h\perp}$



M_A=0.2
Sh=0.3
ρ_{max}=1.8
ρ_{min}=0.15
RelSh=1.9

NSTX experimental data



agrees with MHD derived

Relative shift of r

$$\frac{R\partial r}{r\partial R} = \frac{2M_A^2}{b}$$

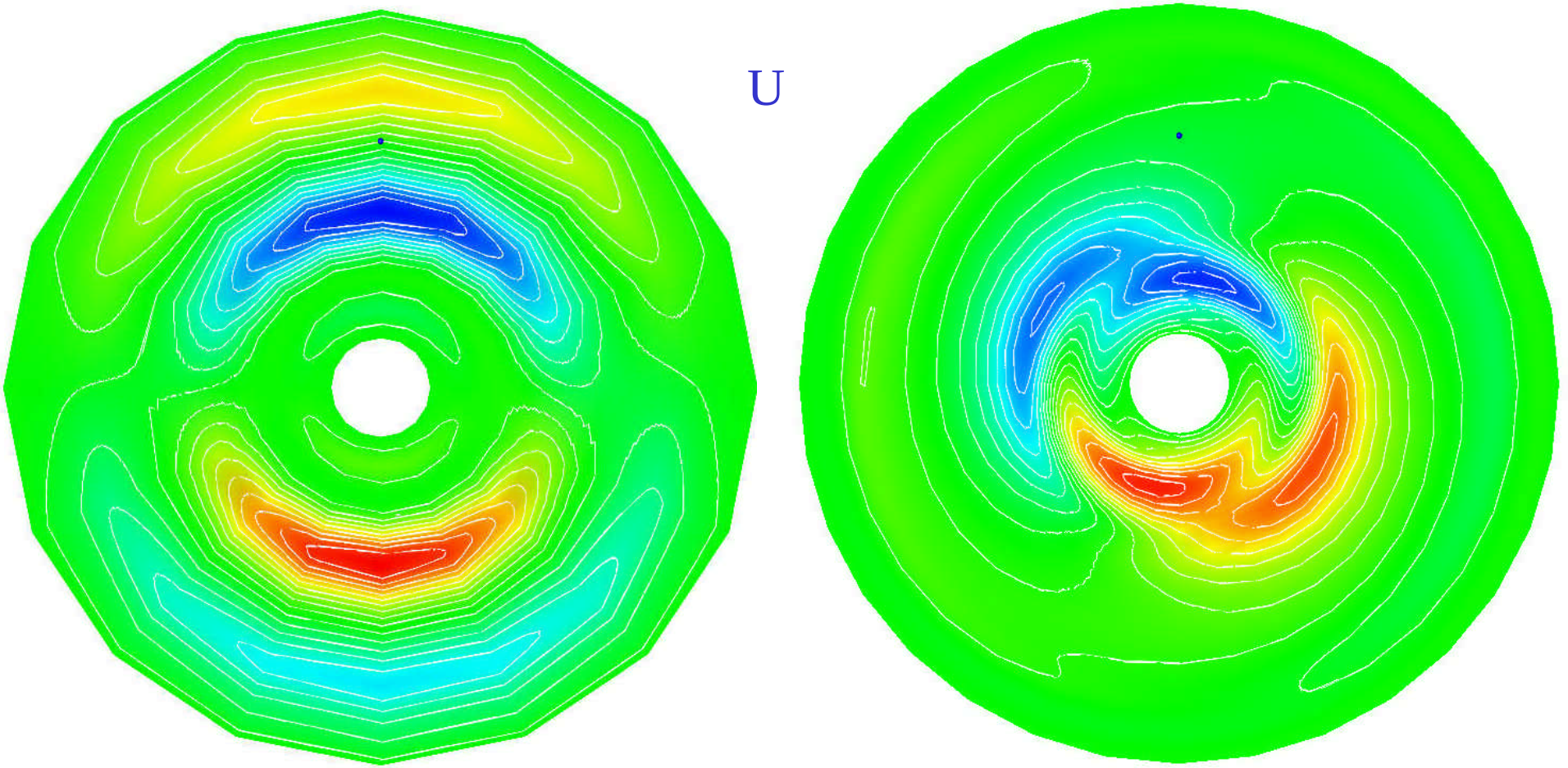
Hot particle centrifugal force ~ Bulk plasma

Linear Instability Eigenmodes

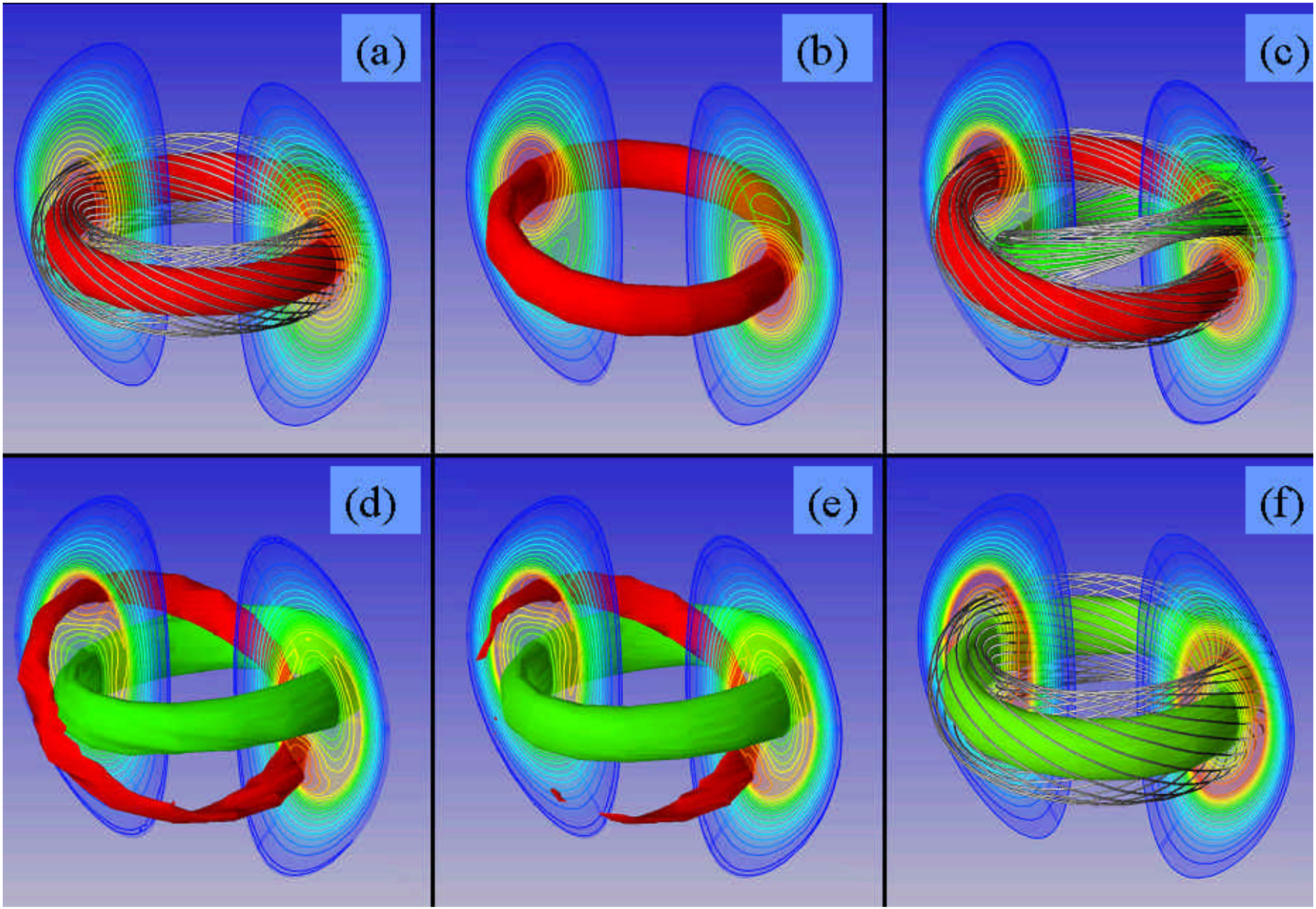
Top view on the horizontal mid-plane

$M_A=0$
$\gamma=0.03$
$\Omega m=0$

With shear flow: $M_A=0.2$
Reduced growth: $\gamma=0.01$
Rotating mode: $\Omega m=0.13$

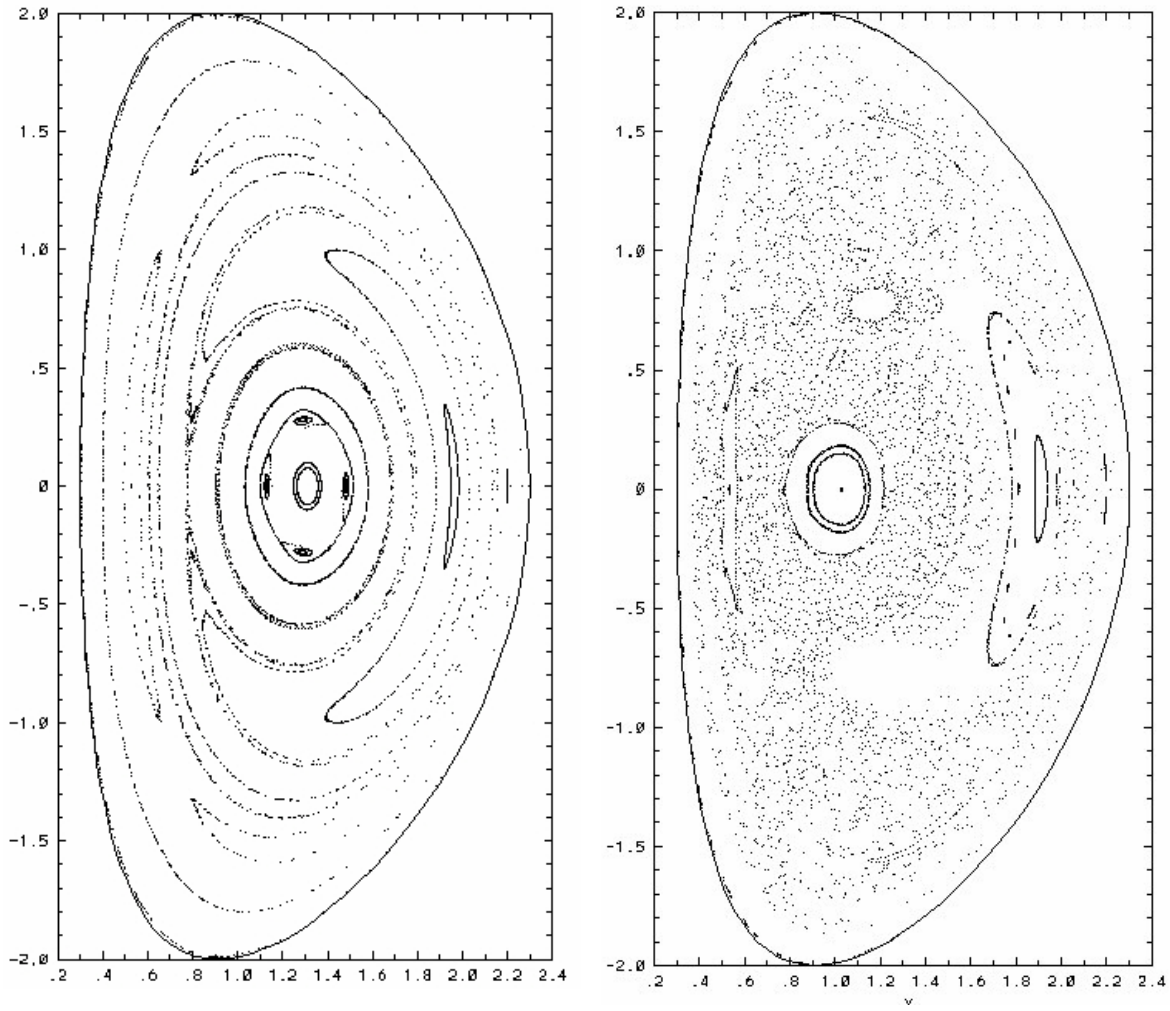


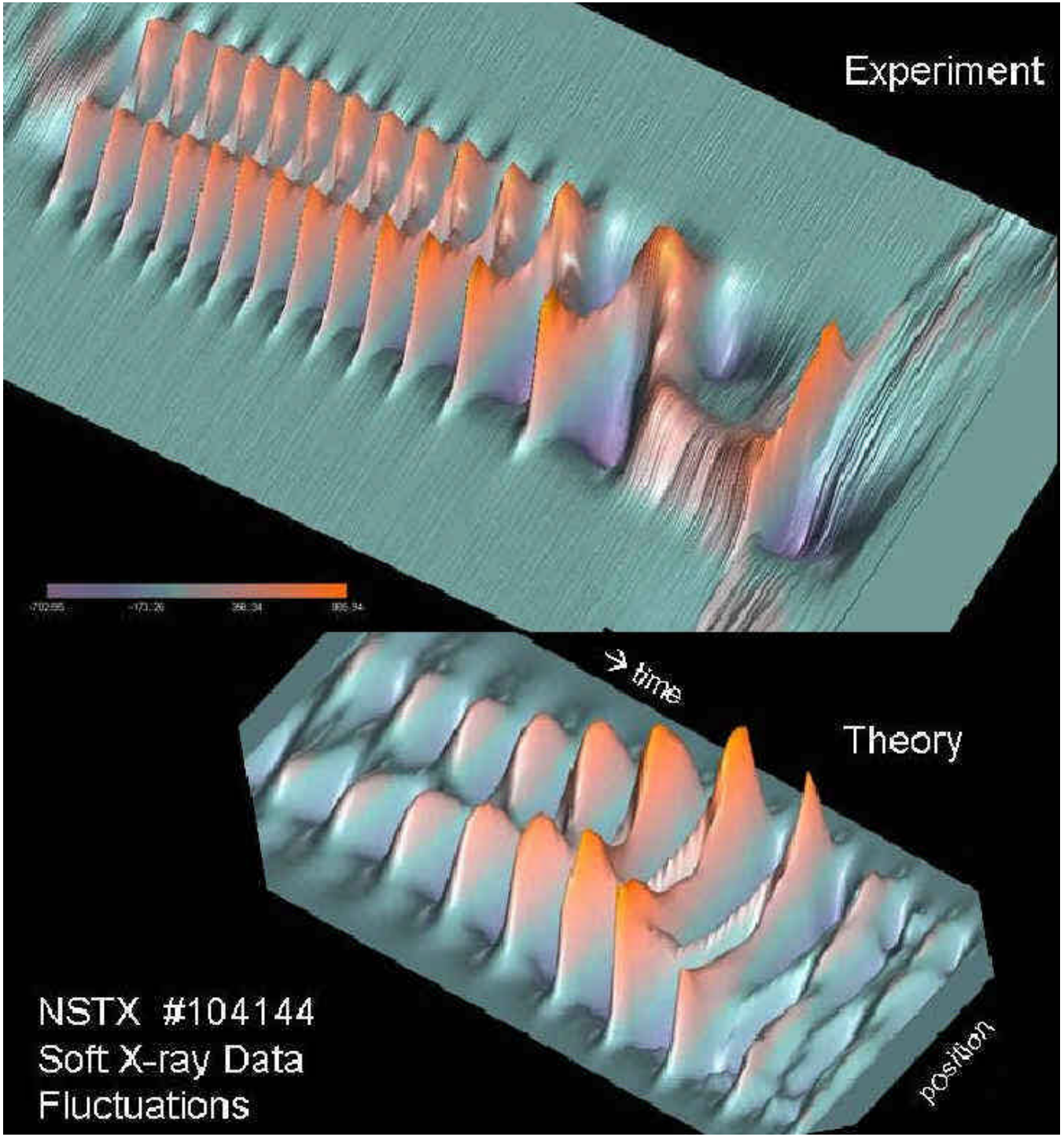
Nonlinear Evolution without strong flow: similar to a sawtooth crash



When the inversion radius is large or the plasma β is increased, magnetic islands overlap and become stochastic.

Disruption due to field line stochasticity.



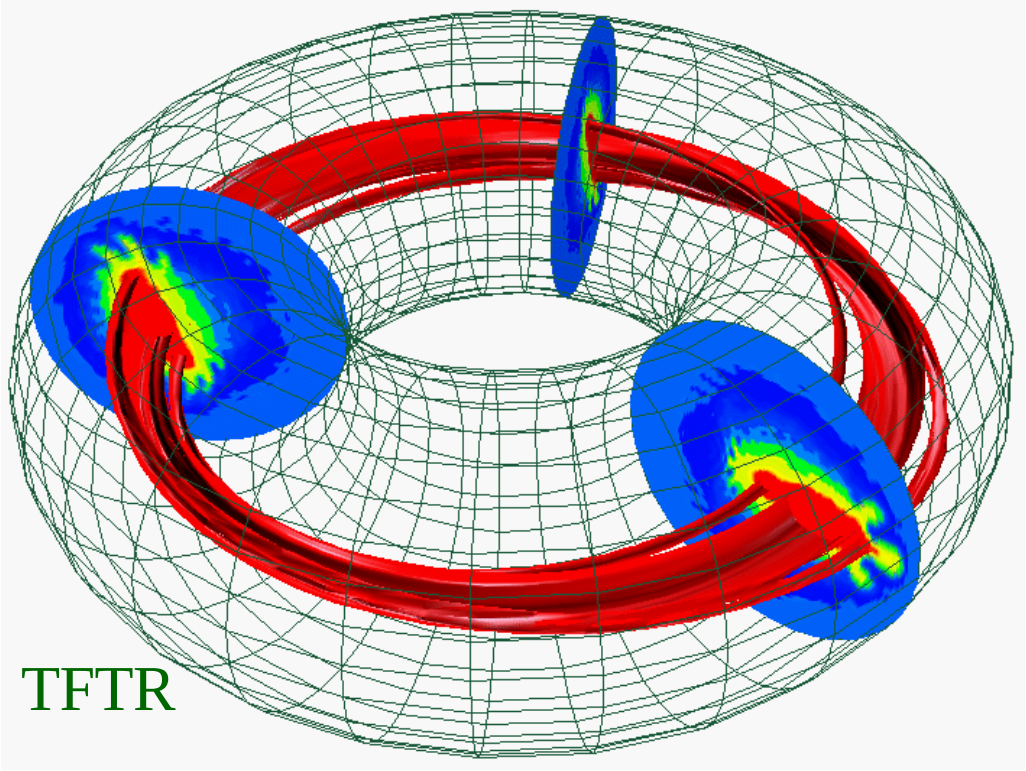


Soft X-ray signals compared:

Theory agrees with experiment on general characters, but does not have wall locking and a saturation phase.

IRE

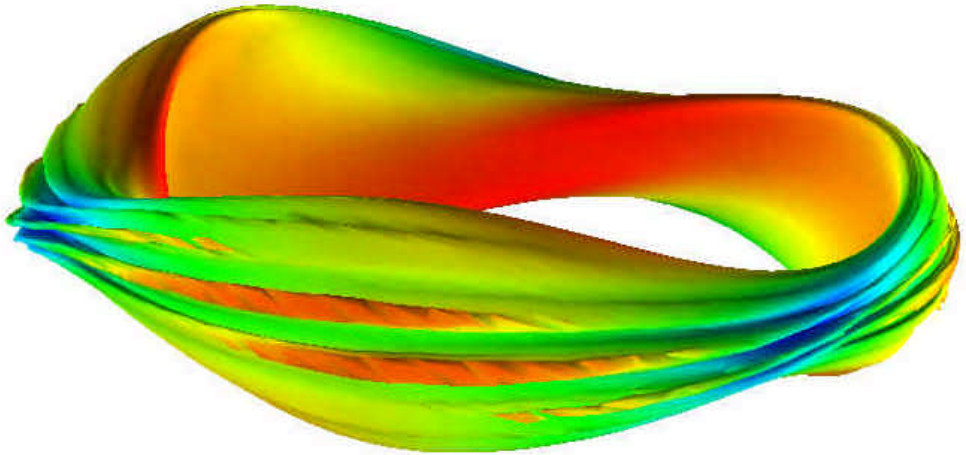
- Sawtooth
- Disruption due to stochasticity.
- Disruption due to localized steepening of *P* driven modes, as in Tokamaks



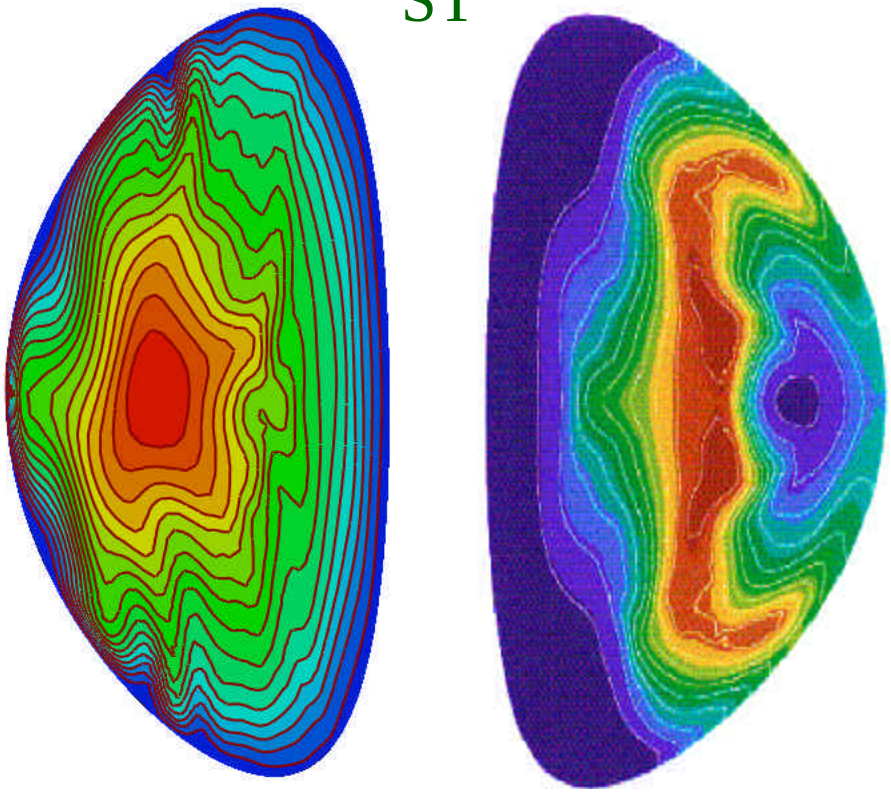
TFTR

Stellarator

P profiles



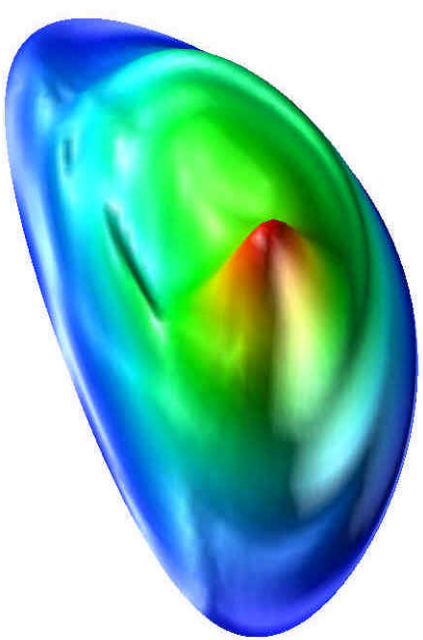
ST



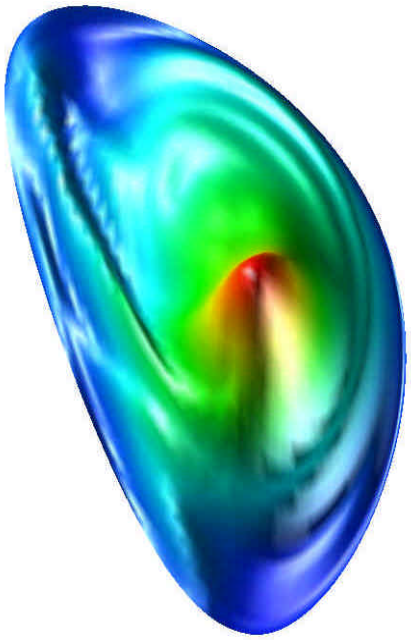
Nonlinear Evolution with peak rotation of M_A=0.2

Sheared rotation causes mode saturation,
if rotation profile is roughly maintained.

However, with a normal momentum source rate,
$V\phi$ profile flattens with reconnection,
and full reconnection usually occurs.



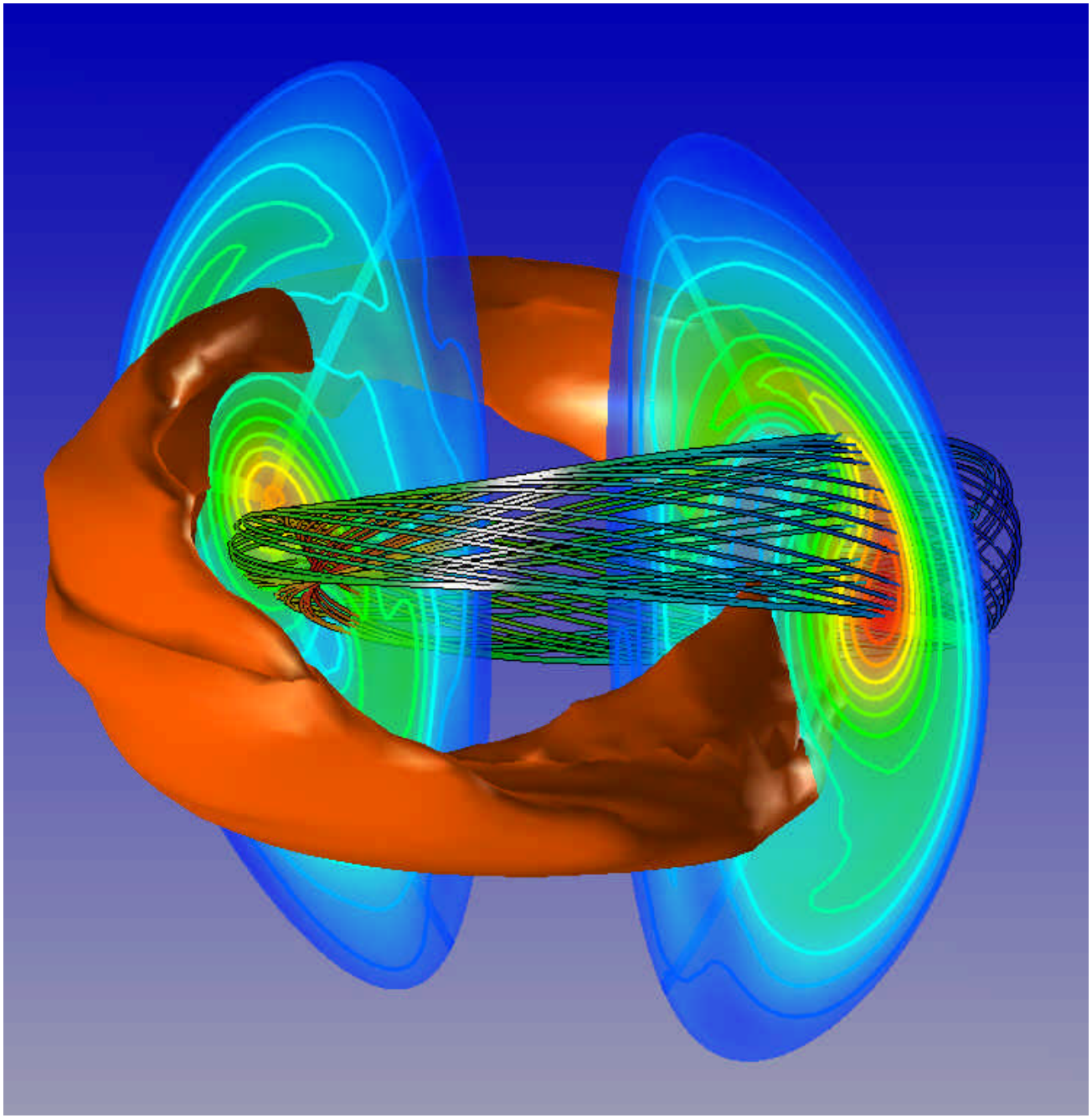
P



$V\phi$

Pressure and $V\phi$ profiles
are flattened inside island.
Also seen in experiment.

Saturated steady state with strong sheared flow

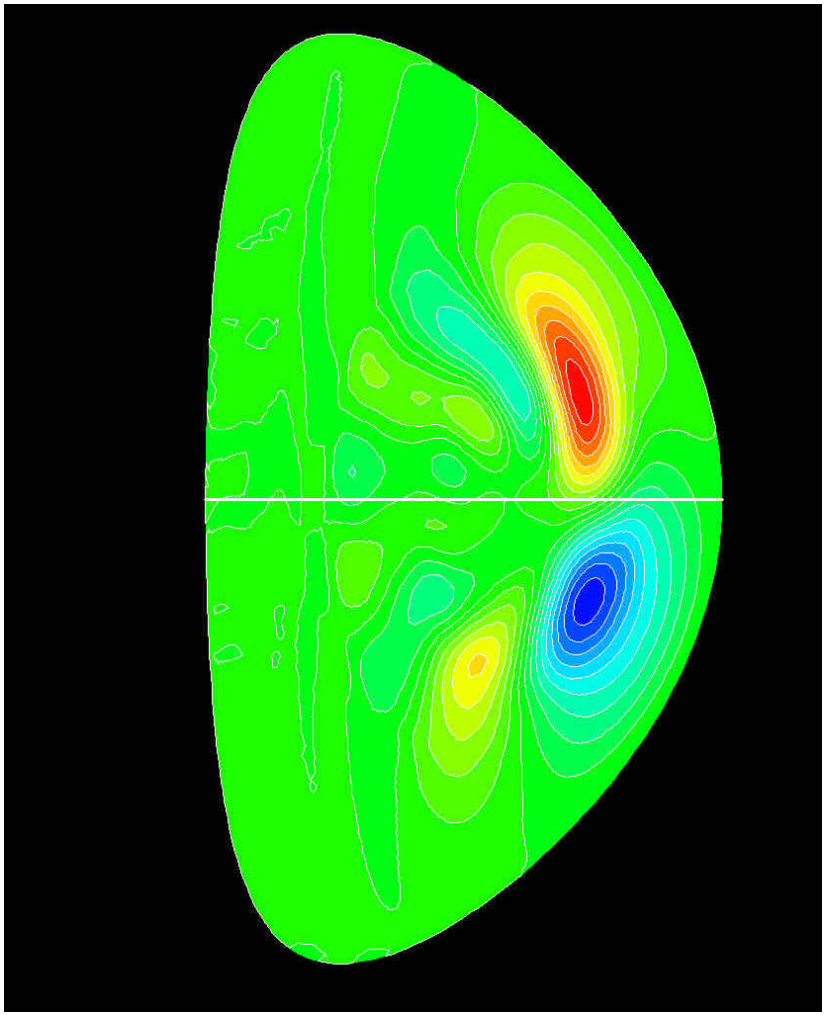


B Field line
in the island
Density (Pressure)
contours
Temperature
isosurface

Pressure peak inside the island together with shear flow causes the mode saturation.

Hot particle/MHD hybrid simulation

The simulation of an NSTX plasma show unstable TAEs consistent with observations



- NSTX shot #108530 at t=0.267sec;
- The calculated n=2 TAE mode frequency is 73 kHz which is close to the experimental value of 70 kHz (assuming 15kHz toroidal rotation)

Fu, et al., FP1.068

Summary

- M3D code studies of NSTX.
- The relative density shift relation holds both in the simulation and experiment, with the centrifugal force of the hot component included.
- Toroidal sheared rotation reduces linear growth of internal kink. It is strongly stabilizing nonlinearly, but is normally flattened by reconnection. In some cases, pressure peaking in the island causes a mode saturation.
- IRE: Sawtooth, Disruption due to stochasticity, and Disruption due to nonlinear steepening of pressure driven modes, as in tokamaks.
- Resistive wall and coil currents are being added.