# Simulations of Energetic Particle Modes In Spherical Torus

G.Y. Fu, J. Breslau, J. Chen, E. Fredrickson, S. Jardin, W. Park

Princeton Plasma Physics Laboratory

H.R. Strauss -- New York University

L.E. Sugiyama -- MIT

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# Introduction

- Recent NSTX experimental observations show rich beam-driven instabilities: fishbone, TAEs, CAEs etc and associated hot particle losses.
- Alfven modes in STs are less understood as compared to those in conventional tokamaks.
- Need to study possible new features of beam-driven Alfven modes associated with ST's unique parameter regime: low aspect ratio, high beta, large energetic ion speed and gyroradius.
- In this work we investigate stability and nonlinear dynamics of beam-driven Alfven modes (TAE/EPM) via hybrid simulations using M3D code.

# M3D Code

- M3D is an extended MHD code which has multi-level of physics: resistive MHD, two fluids, particle/MHD hybrid etc.
- 3D and nonlinear.
- unstructured mesh in poloidal planes and finite difference in toroidal direction. Valid for 3D stellarator geometry.
- massive parallel with MPI.

# Particle/MHD Hybrid Model

$$\rho_b \frac{d\mathbf{v}_b}{dt} = -\nabla P_b - (\nabla \cdot \mathbf{P}_h)_\perp + \mathbf{J} \times \mathbf{B}$$

$$\mathbf{J} = \nabla \times \mathbf{B}$$

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}$$

$$\mathbf{E} + \mathbf{v}_b \times \mathbf{B} = \eta \mathbf{J}$$

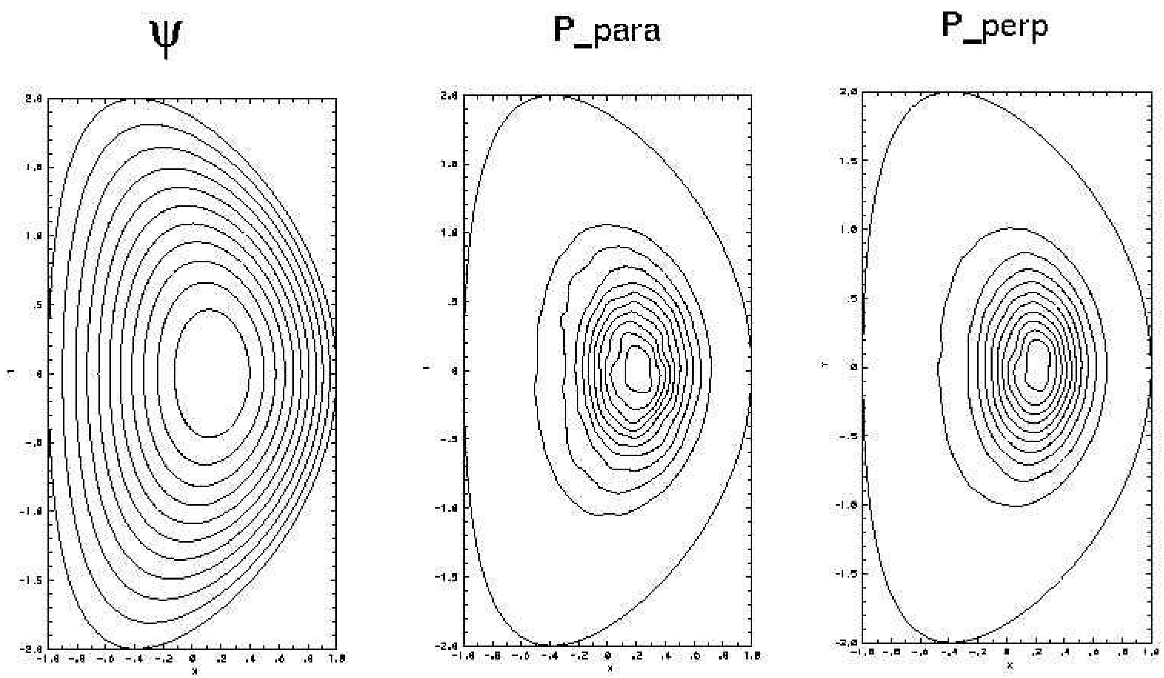
# Beta-induced Alfven Eigenmode in STs

- It is known that fluid compression results in a beta-induced continuum gap below the usual toroidicity-induced gaps in shear Alfven continuum in a tokamak.
- We investigate the finite beta effects on fast ion-driven Alfven eigenmodes in STs.
- It is found that a TAE is excited at low plasma beta and an low-frequency EPM is excited at a high beta. This EPM can be called beta-induced Alfven eigenmode (BAE) since its frequency is inside the beta-induced continuum gap.

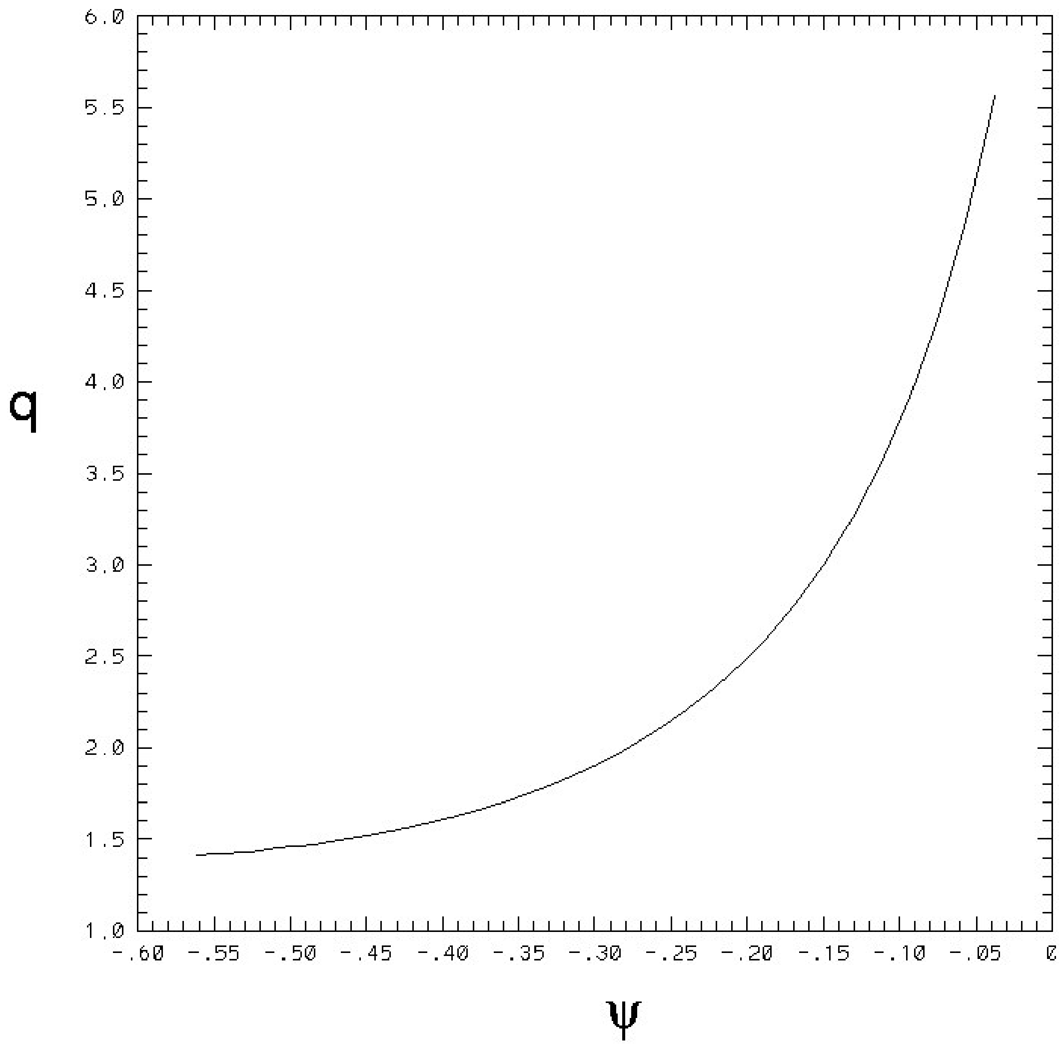
# Parameters and Profiles for BAE in STs

- aspect ratio $R/a = 1.3$, elongation $E = 2.0$, triangularity $\delta = 0.4$, $q(0) = 1.4$, $q(a) = 7.3$, $\rho_{fast}/a = 0.085$, $v_{fast}/v_A = 3.9$.

**Poloidal Flux and Fast Ion Pressure Profiles**



# q profile



# Example of Unstructured Mesh

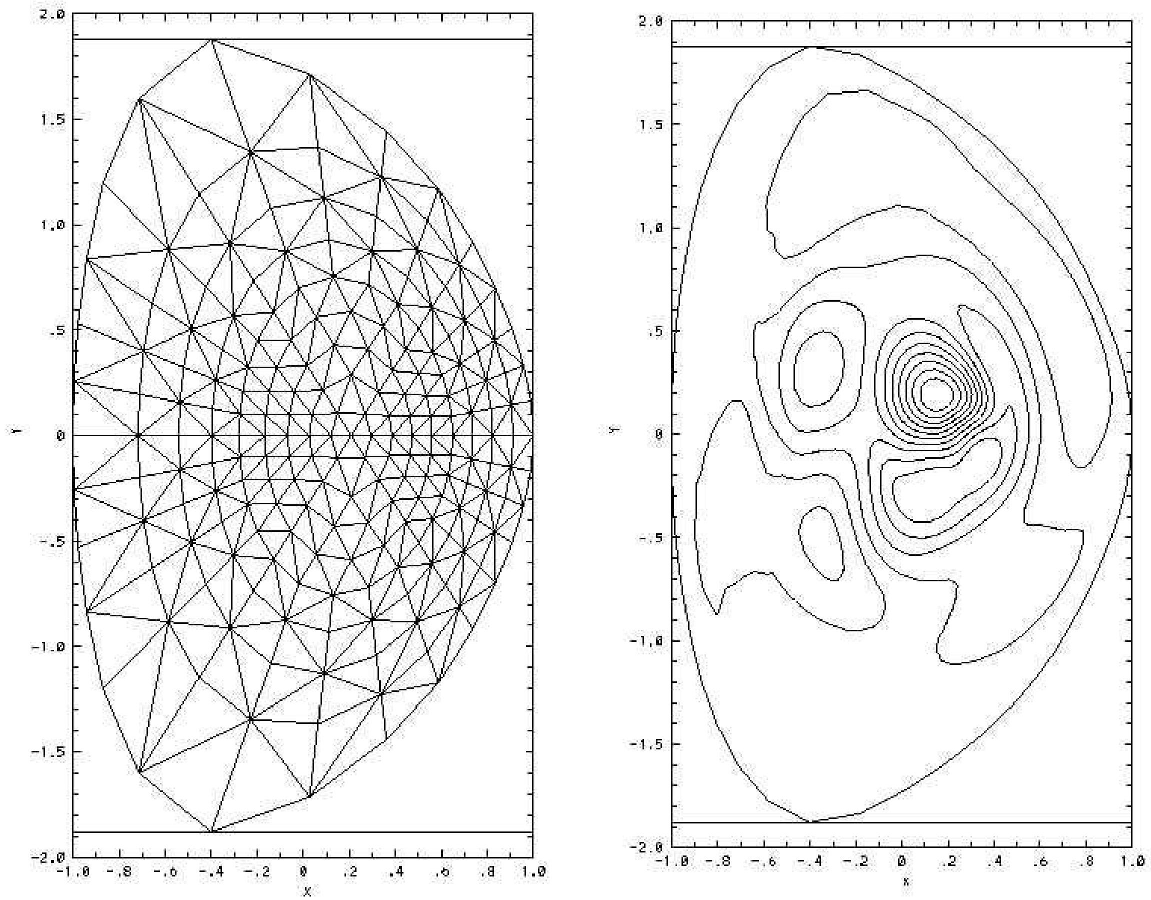


Figure 1: *An example of unstructured mesh and fast ion driven* $n = 1$ *mode in a spherical tokamak.*

# Transition from TAE to BAE at High Beta

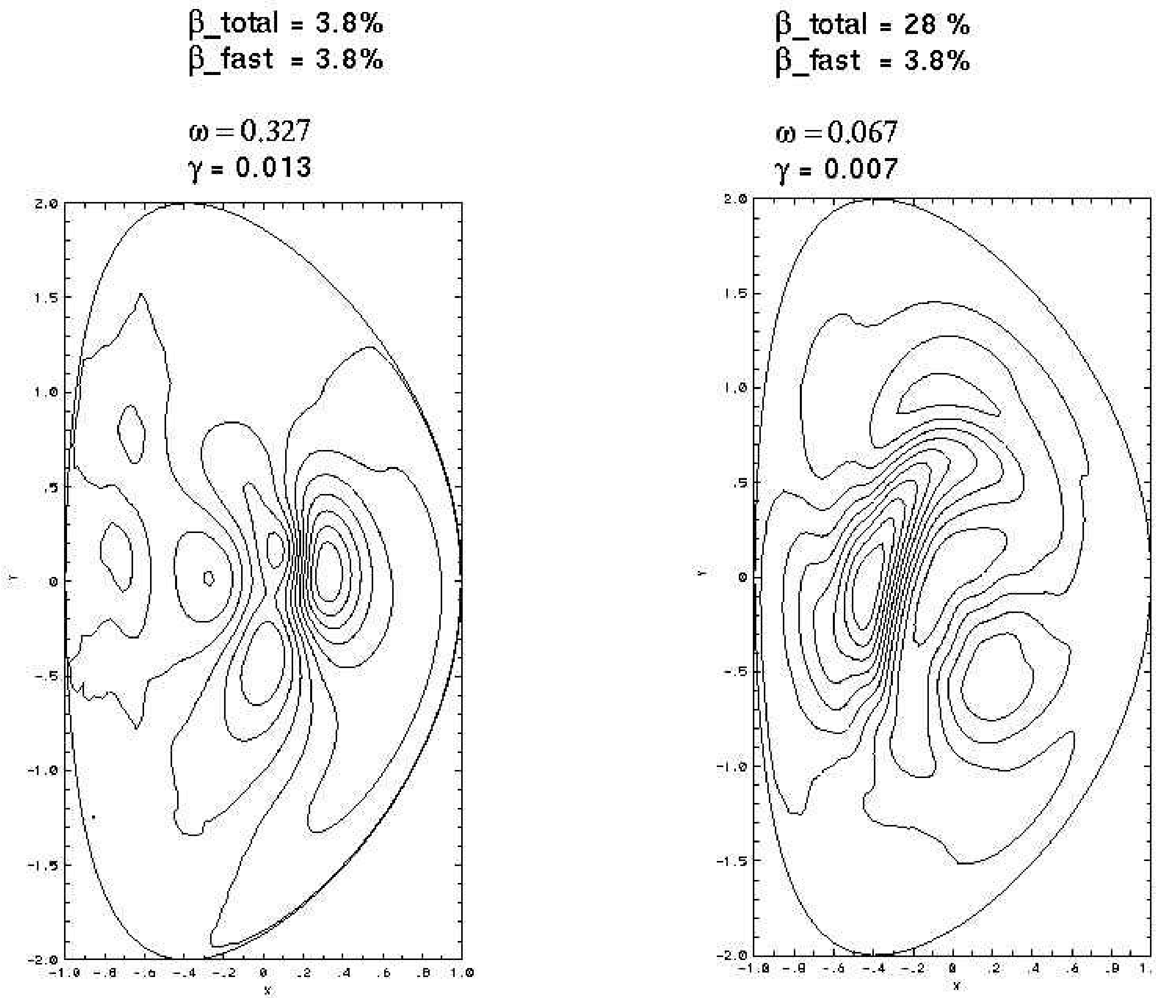



Figure 2: *Comparison of fast ion-driven modes at two different plasma beta values.*

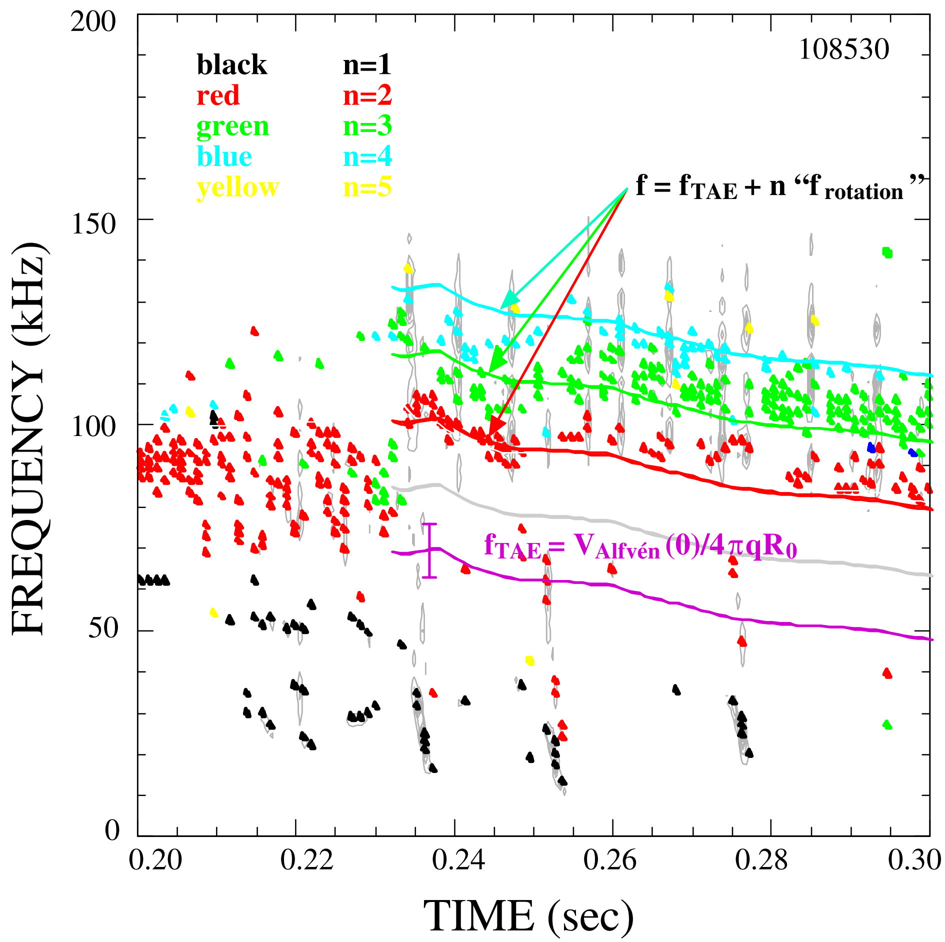
# NBI-driven TAEs in NSTX

- In the NBI-heated NSTX plasmas, beam-driven modes were observed with mode number n=1~5 and frequencies similar to TAE's.
- The M3D code is used to simulate these modes for experimental parameters. Unstable TAEs are excited in the simulations with frequencies similar to the observed values.
- Initial nonlinear simulations indicate n=2 TAE mode frequency chirps down and the mode moves out radially.

E. Fredrickson

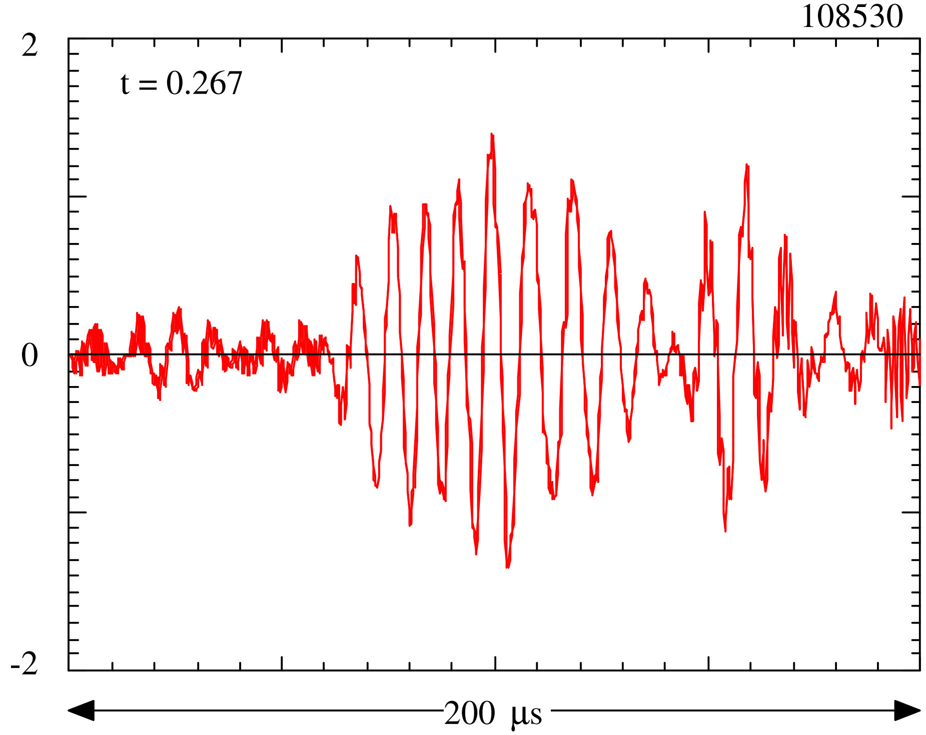
# The bursting modes are in the TAE frequency range (NSTX)

- Multiple modes burst at the same time.
- Toroidal mode number, n, ranges from 2 - 5 with the dominant mode being n=2 or 3.
- Mode frequencies in reasonable agreement with expected TAE frequencies.



# The final mode growth and decay is very fast

- Some of the mode amplitude modulation represents "beating" of the multiple modes.
- Mode growth and decay times are approximately 50 - 100 µs.

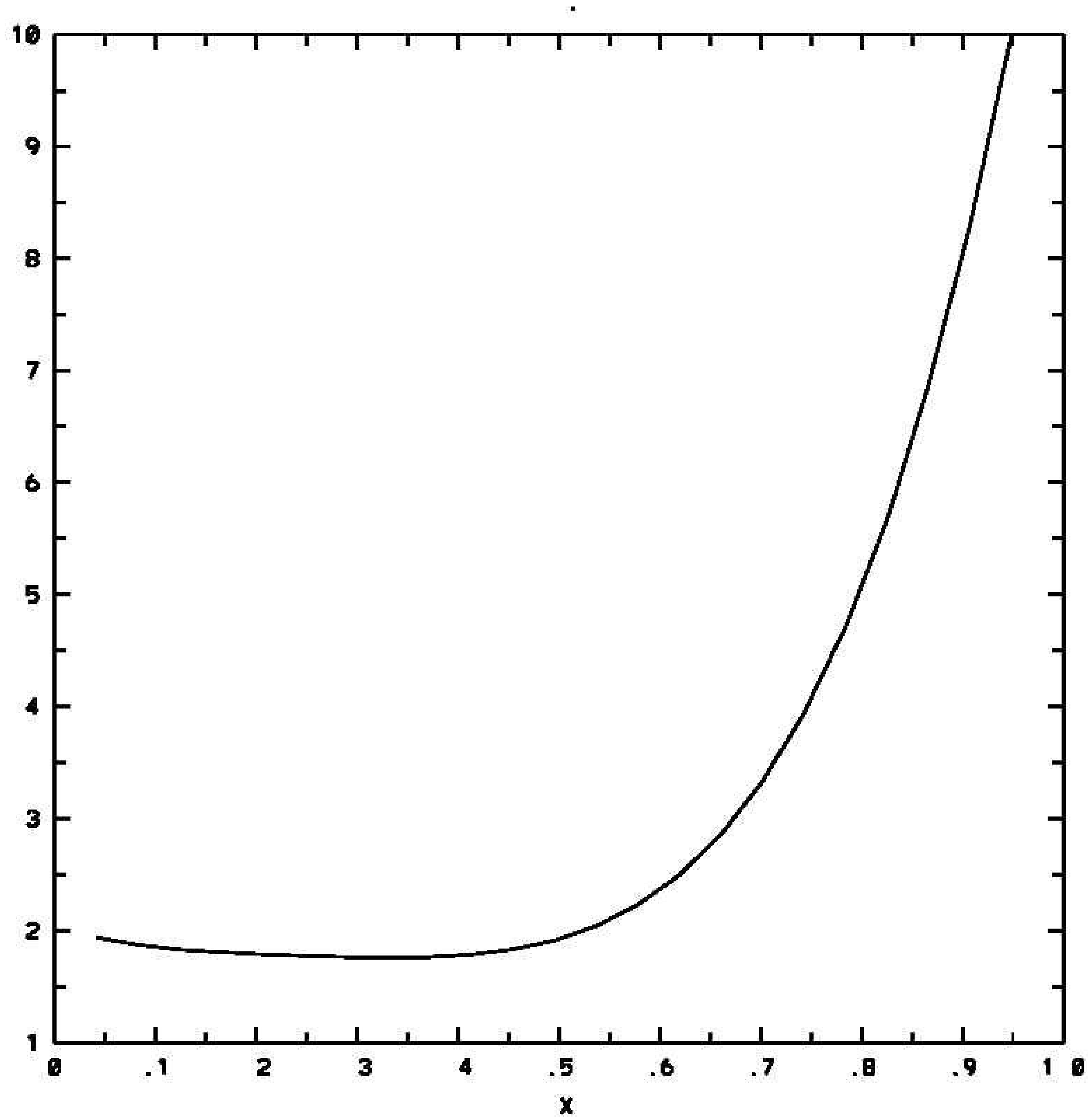


# NSTX Parameters and Profiles

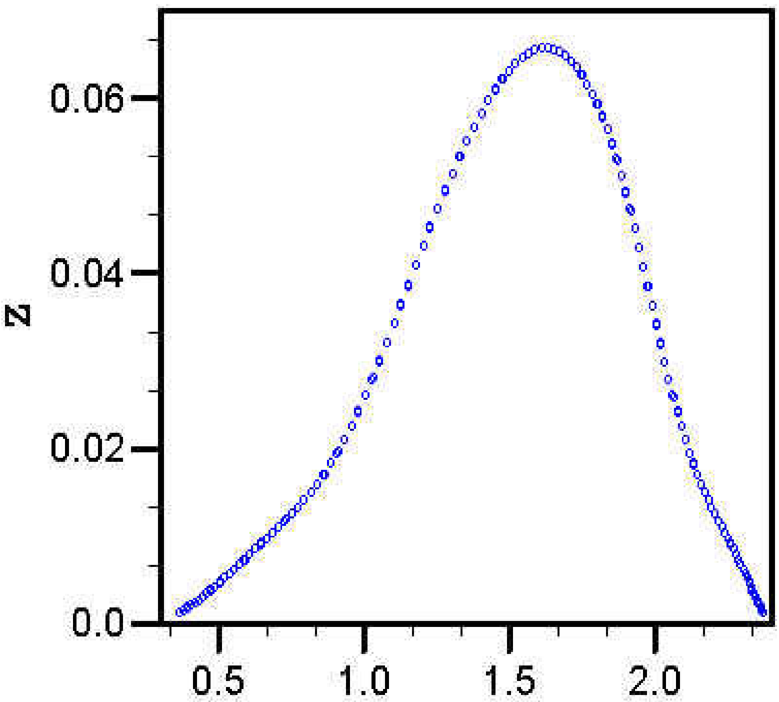
- NSTX shot #108530 at t=0.267sec:

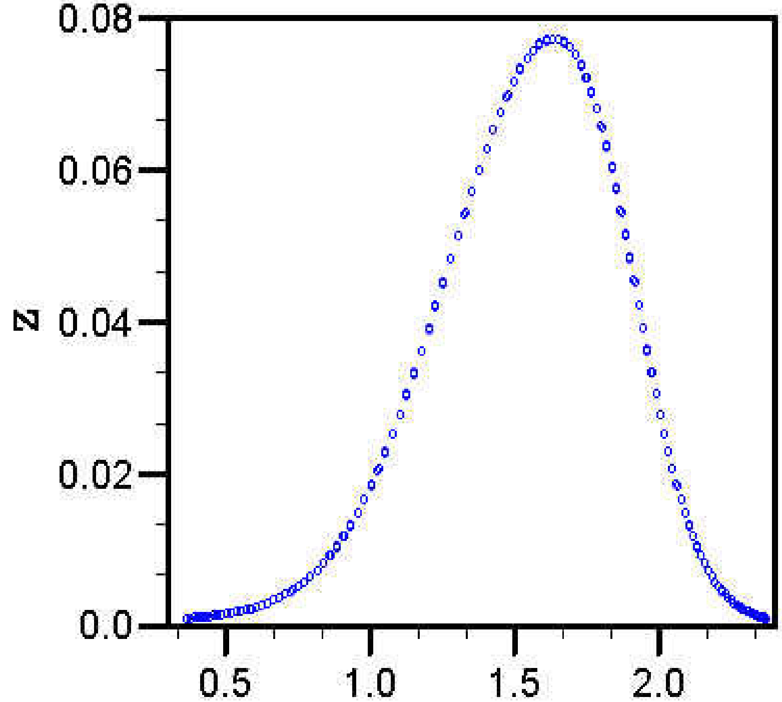
- R=87cm, a=63cm, B=0.43T, $n_e(0)$=2.5e13, Ti=1.7kev, Te=1.4kev;
- q(0)=1.82, q(a)=12.9, weakly reversed; $\beta(0)$=21%, $\beta_{beam}(0)$=13%;
- $v_{beam}/v_{Alfven}$ = 2.1, $\rho_{beam}/a$ =0.17

# q profile

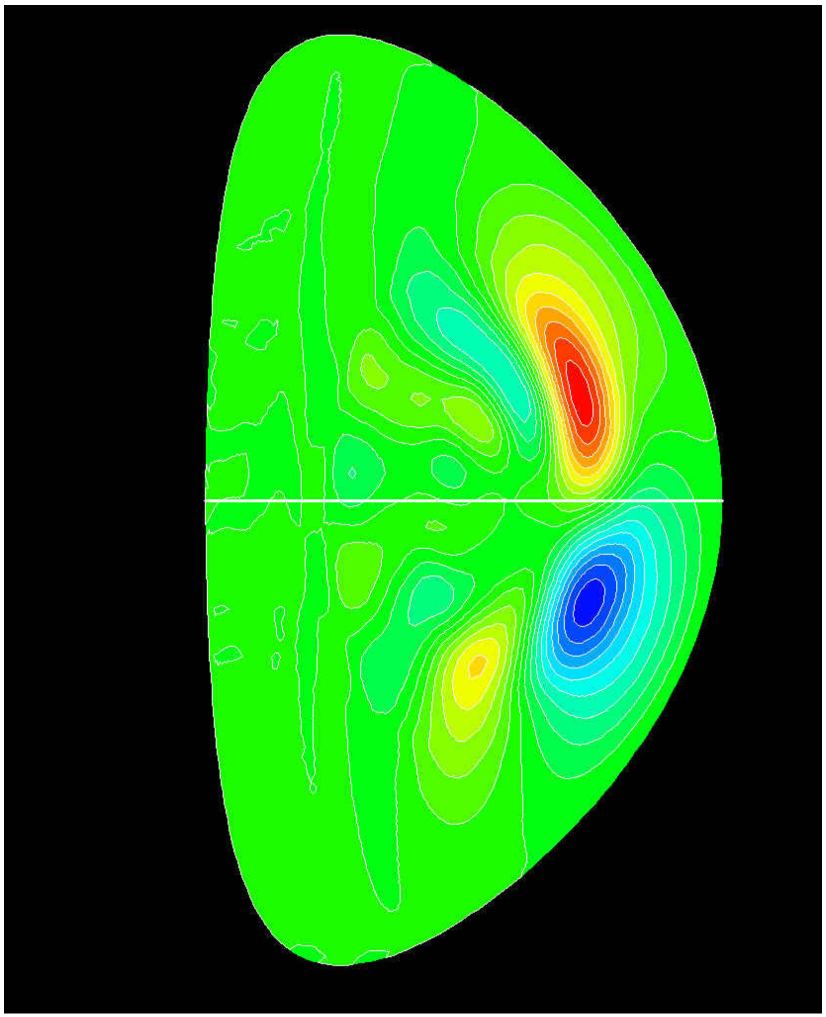


# Pressure Profiles: $P_{thermal}$ and $P_{beam}$



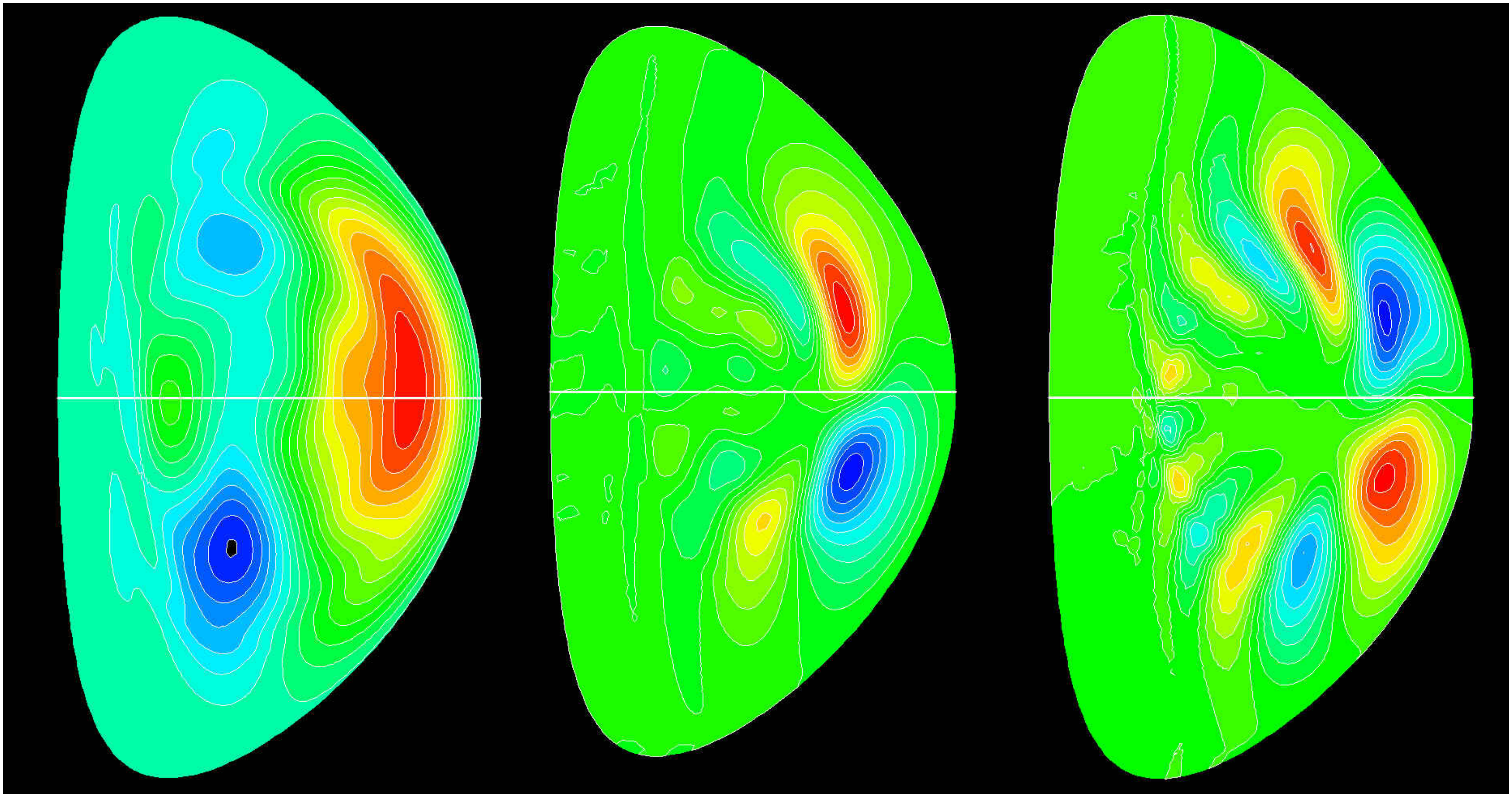



# The simulation of an NSTX plasma show unstable TAEs consistent with observations

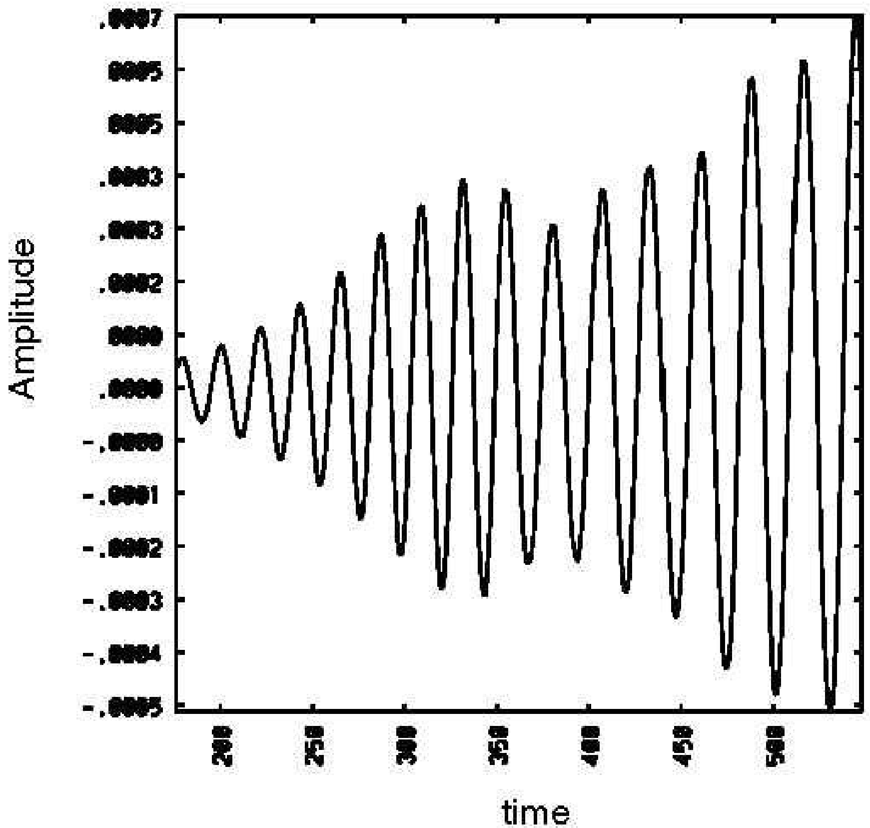


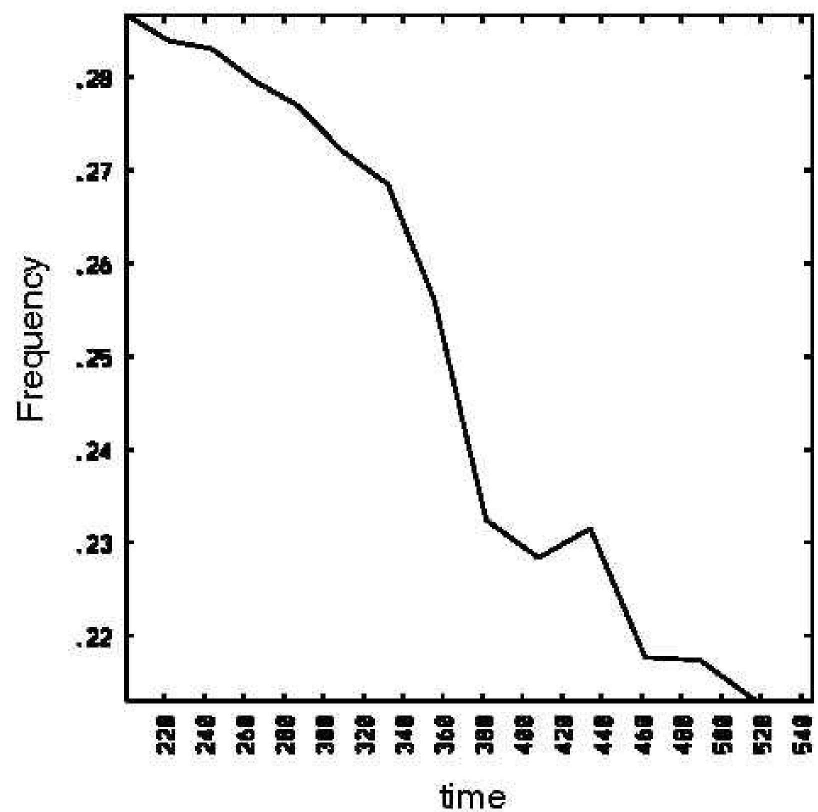
- NSTX shot #108530 at t=0.267sec;
- The calculated n=2 TAE mode frequency is 73 kHz which is close to the experimental value of 70 kHz (assuming 15kHz toroidal rotation)

# N=1, 2 & 3 Modes in NSTX

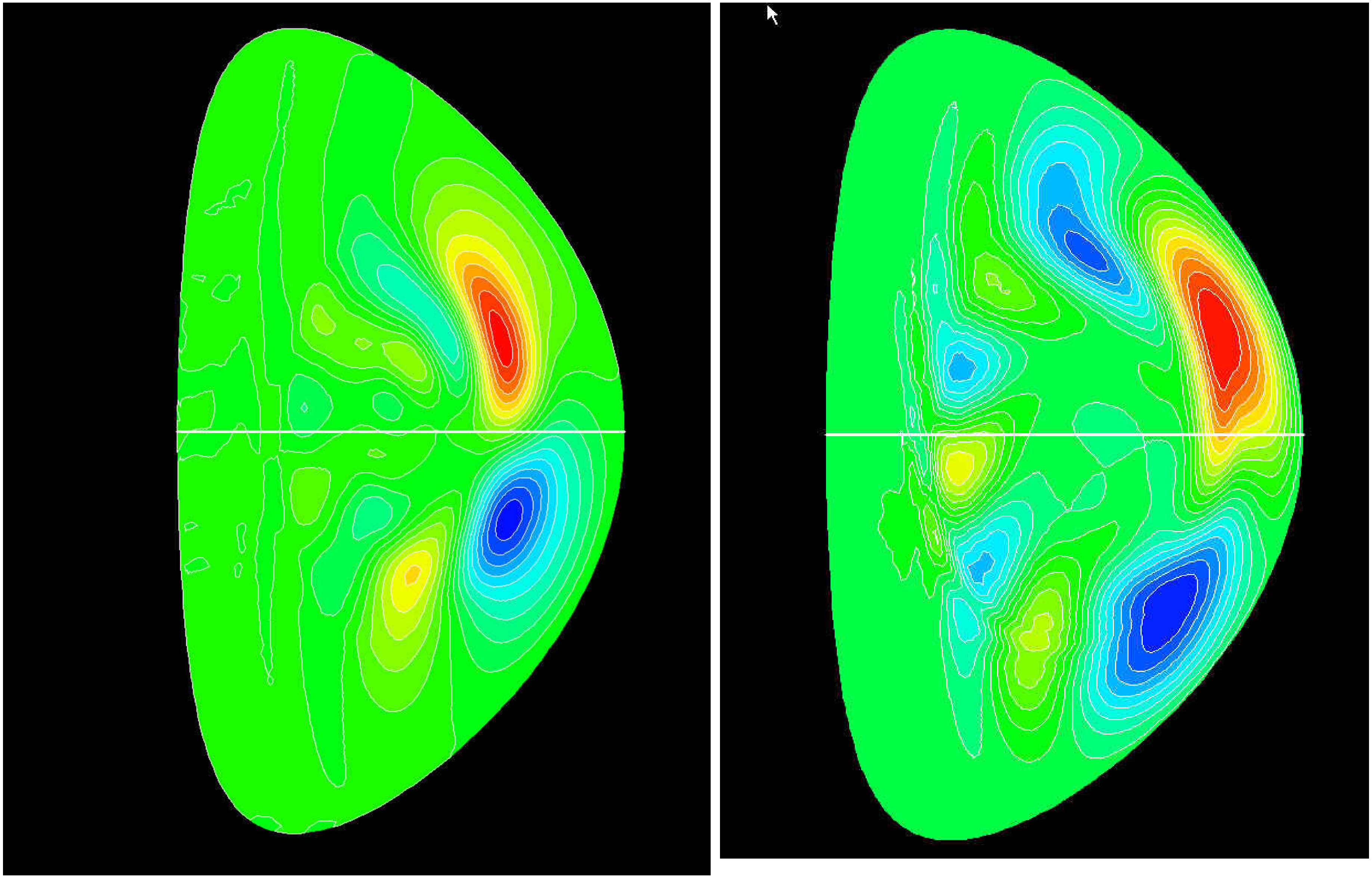


# Nonlinear Evolution of n=2 TAE:
# Mode Saturation and Frequency Chirping



# Mode Moving Out After Saturation



# Summary

- We have carried out first simulations of beam ion-driven Alfven modes in NBI-heated NSTX plasmas using extended MHD code M3D.
- The calculated TAE frequencies are consistent with experimental observations.
- Initial nonlinear simulations show the n=2 TAE mode frequency chirps down at saturation and the mode moves out radially.