Hybrid Simulations of Alpha Particle Effects on MHD Modes in ITER

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Outline

- Introduction
- M3D code: hybrid model
- Recent highlights
- Internal kink, fishbone and TAE in ITER
- Summary

Introduction

- We investigate stability of internal kink, fishbone and TAE in ITER by particle/MHD hybrid simulations;
- Our main tool, M3D, is a 3D global nonlinear extended MHD code.

M3D code

M3D is an extended-MHD (XMHD) code which has multi-level of physics:

Resistive MHD;
Two fluids;
Particle/MHD hybrid;

M3D XMHD Model

$$\rho \frac{d\mathbf{v}}{dt} + \rho(\mathbf{v_i^\star} \cdot \nabla)\mathbf{v}_\perp = -\nabla P - \nabla \cdot \mathbf{P}_h + \mathbf{J} \times \mathbf{B} - \mathbf{b} \cdot \nabla \cdot \Pi_i$$

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

$$\mathbf{E} + \mathbf{v} \times \mathbf{B} = \eta \mathbf{J} - \nabla_\parallel P_e/en - \mathbf{b} \cdot \nabla \cdot \Pi_e$$

$$\partial P/\partial t + \mathbf{v} \cdot P = -\gamma P \nabla \cdot \mathbf{v} + ...$$

$$\partial P_e/\partial t + \mathbf{v} \cdot P_e = -\gamma P_e \nabla \cdot \mathbf{v} + ...$$

- Pressure tensor

$$\mathbf{P}_h = P_\perp \mathbf{I} + (P_\parallel - P_\perp)\mathbf{bb}$$

$$f = \sum_i \delta(\mathbf{R} - \mathbf{R}_i)\delta(v_\parallel - v_{\parallel,i})\delta(\mu - \mu_i)$$

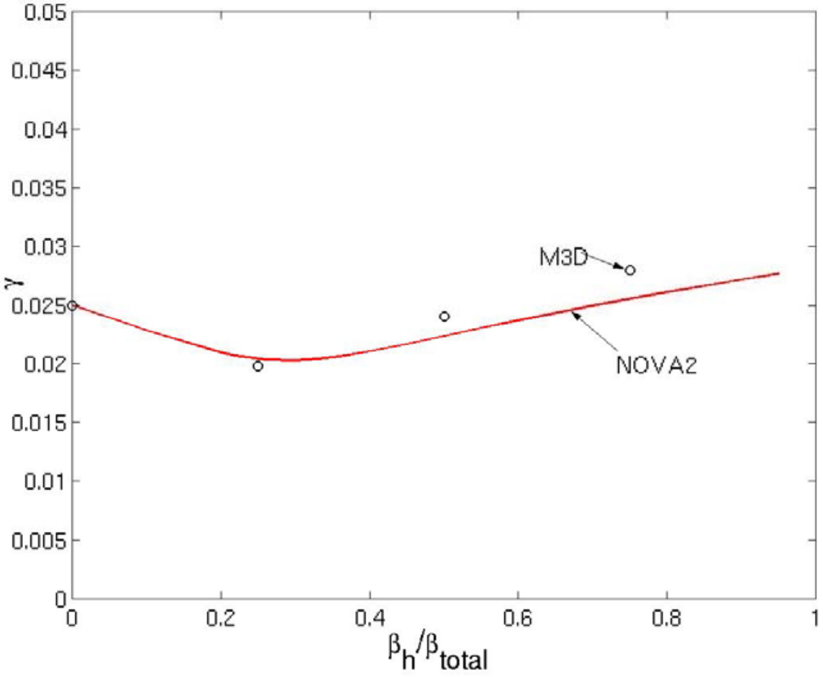
- Gyrokinetic Equations

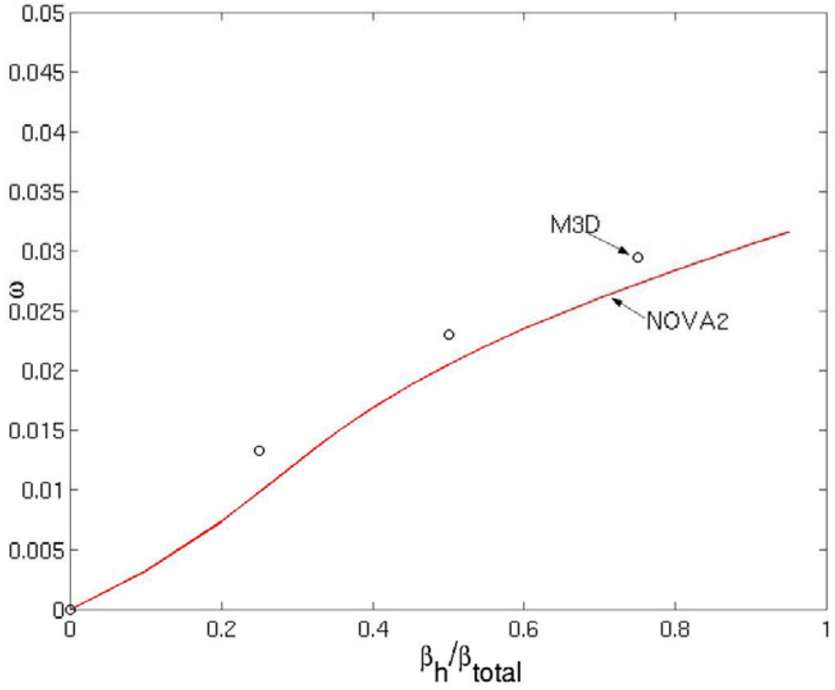
$$\frac{d\mathbf{R}}{dt} = \frac{1}{B^{\star\star}}\left[v_\parallel(\mathbf{B}^\star - \mathbf{b_0} \times (< \mathbf{E} > -\frac{1}{q}\mu\nabla(B_0 + < \delta B >))\right]$$

$$m\frac{dv_\parallel}{dt} = \frac{q}{B^{\star\star}}\mathbf{B}^\star \cdot (< \mathbf{E} > -\frac{1}{q}\mu\nabla(B_0 + < \delta B >))$$

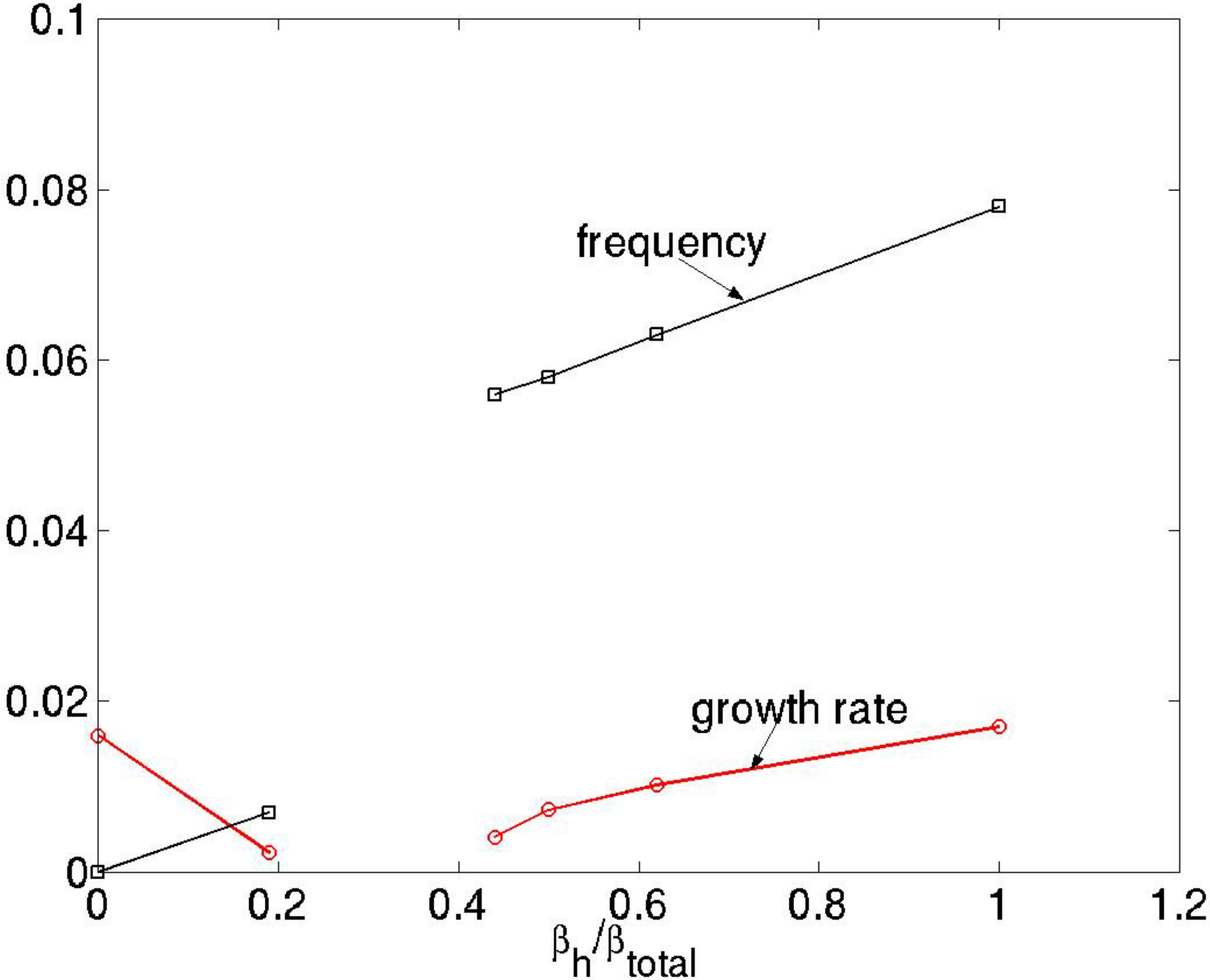
$$\mathbf{B}^\star = \mathbf{B_0} + < \delta\mathbf{B} > + \frac{mv_\parallel}{q}\nabla \times \mathbf{b_0}, \qquad B^{\star\star} = \mathbf{B}^\star \cdot \mathbf{b_0}$$

M3D agrees with NOVA2 code



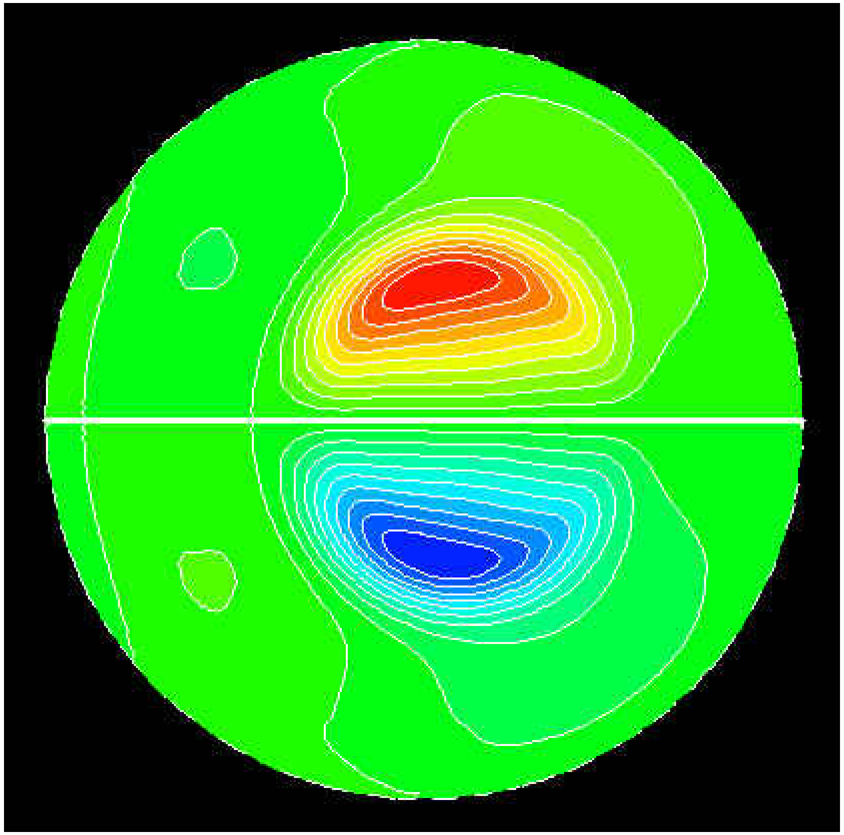


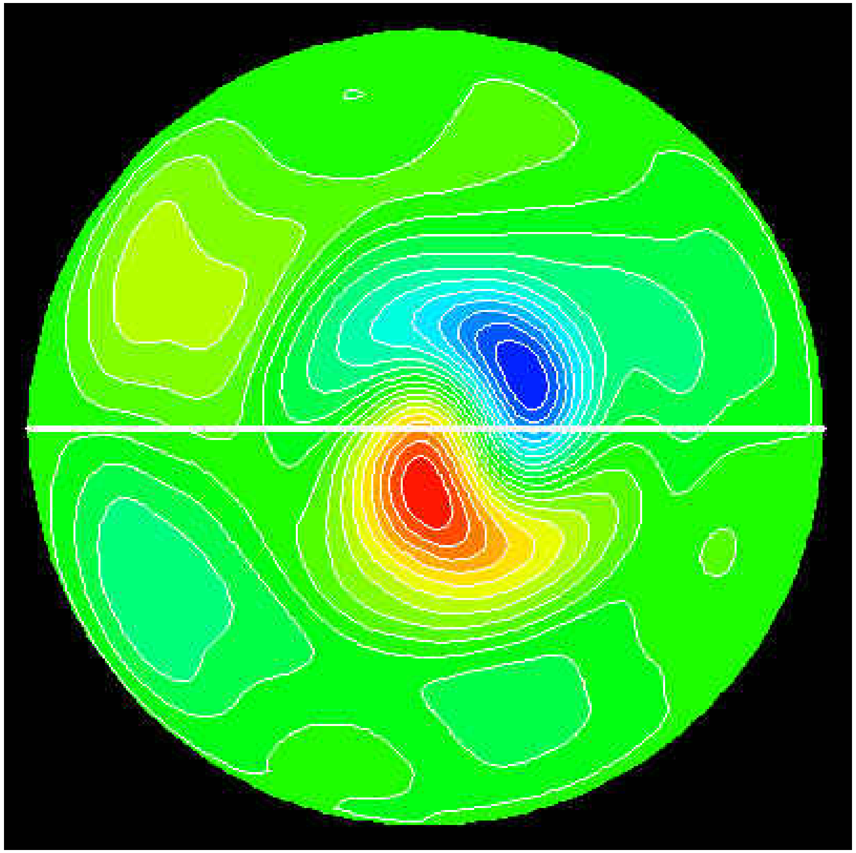
Excitation of Fishbone at high β_h



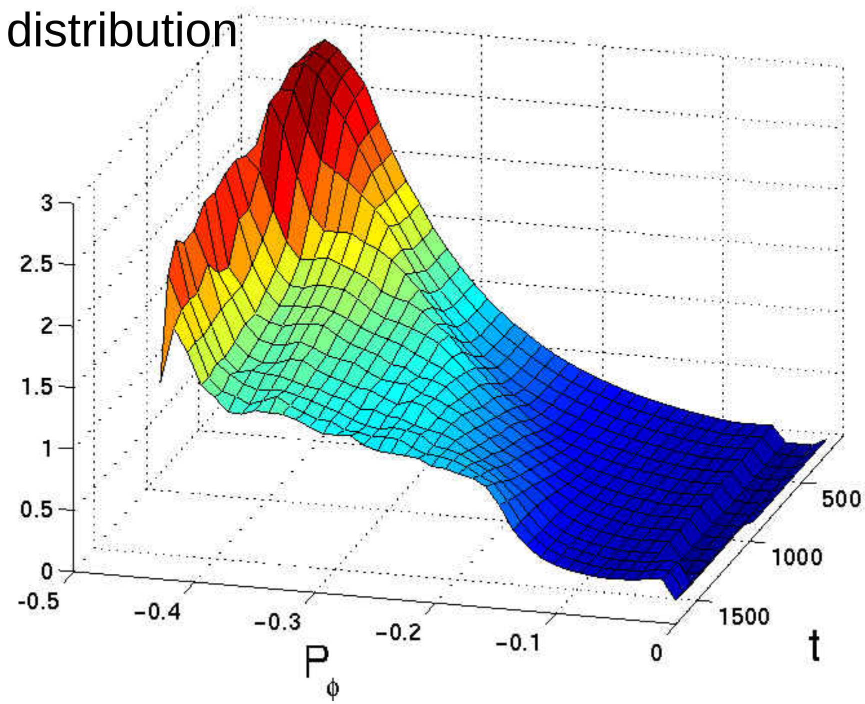
Circular
R/a=2.76
q(0)=0.9,
q(a)=2.5
β_(0) = 5.7%

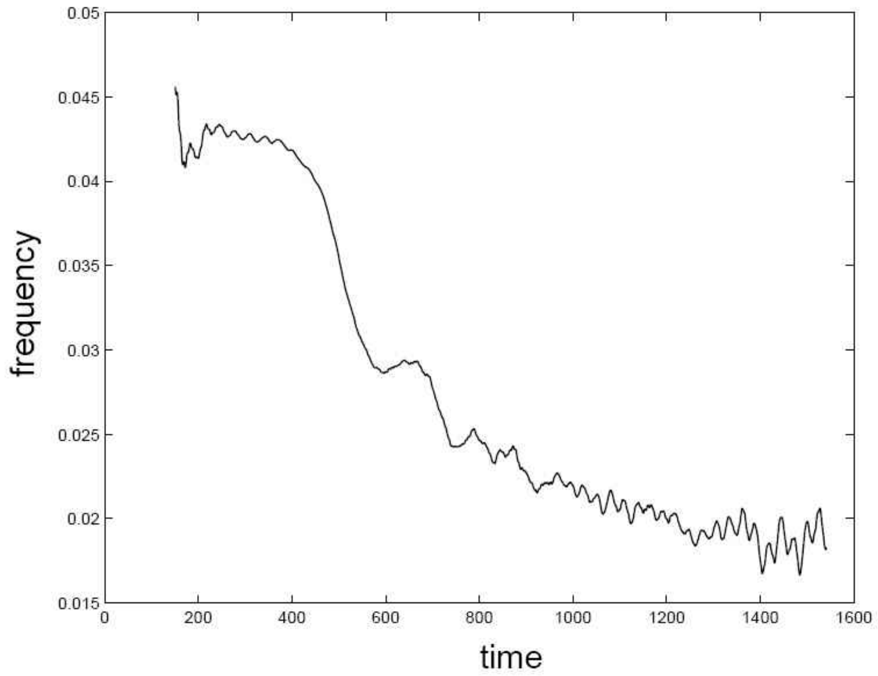
Mode Structure: Ideal Kink v.s. Fishbone



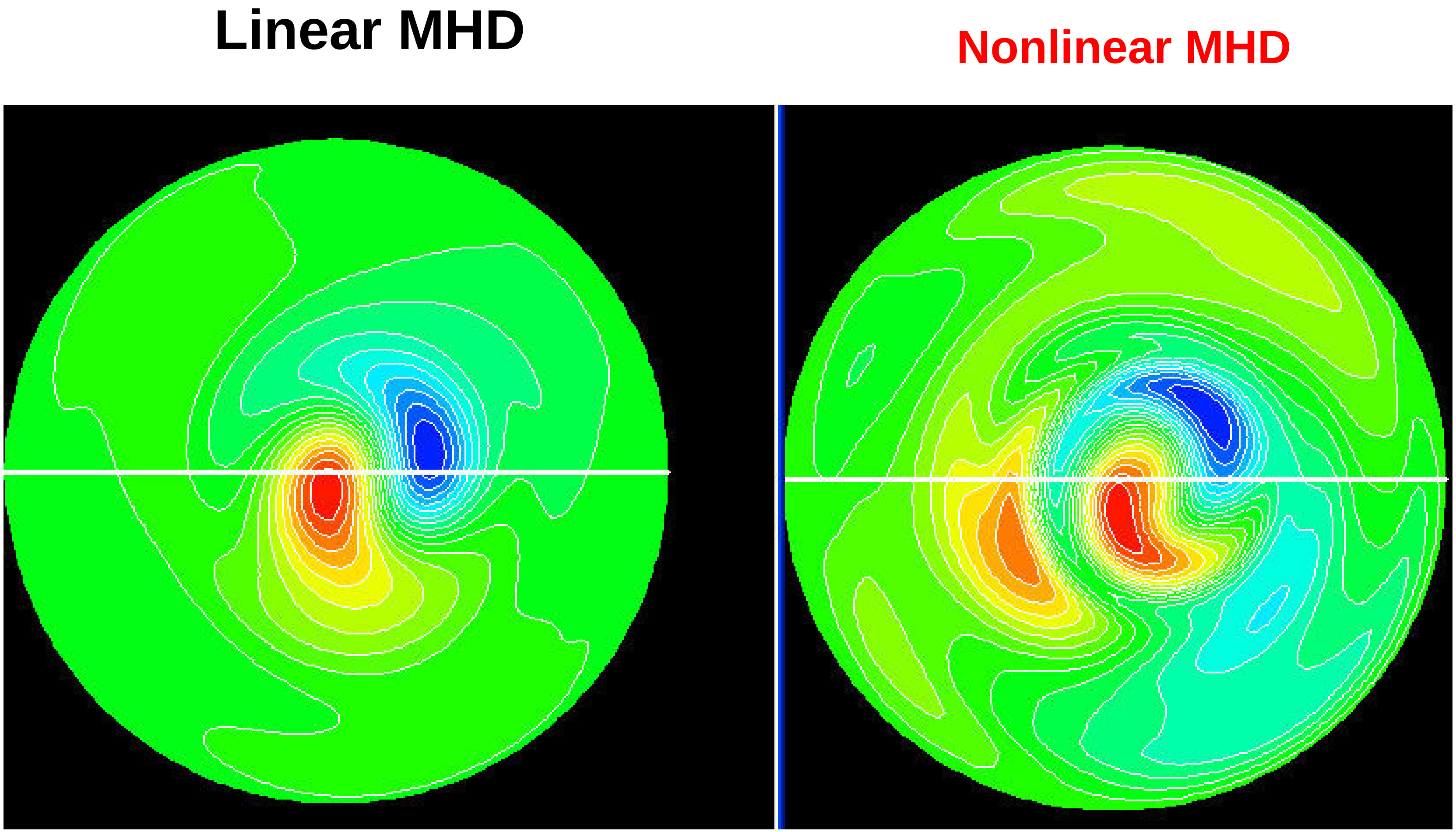


As flattening region of distribution function increases, the mode frequency chirps down.

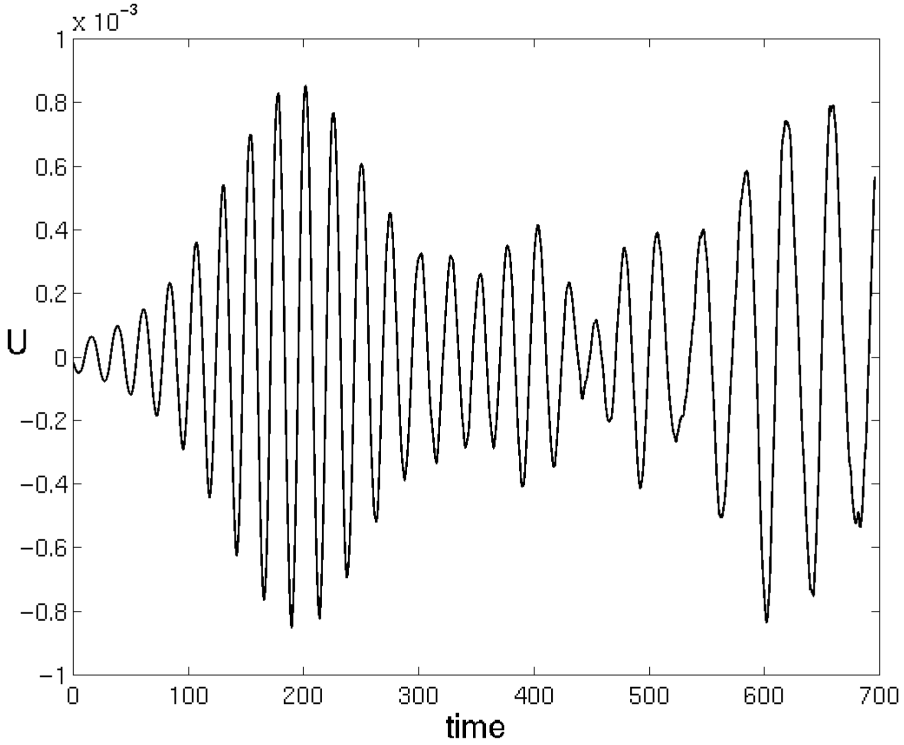


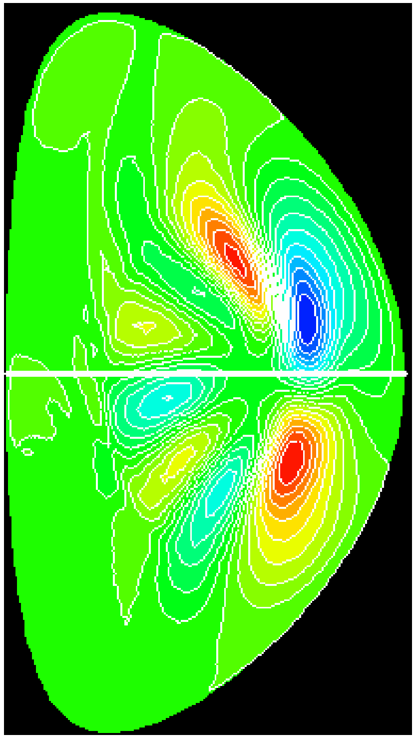


MHD nonlinearity changes mode structure significantly

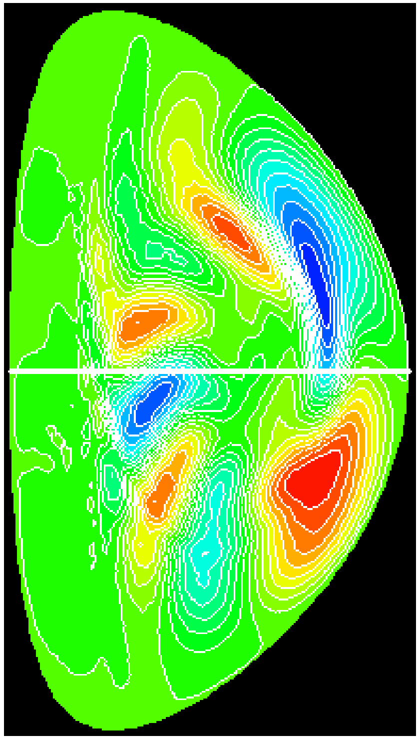


M3D Nonlinear hybrid simulations of beam-driven modes in NSTX shows a bursting n=2 TAE as the mode moves out radially.





t=0.0

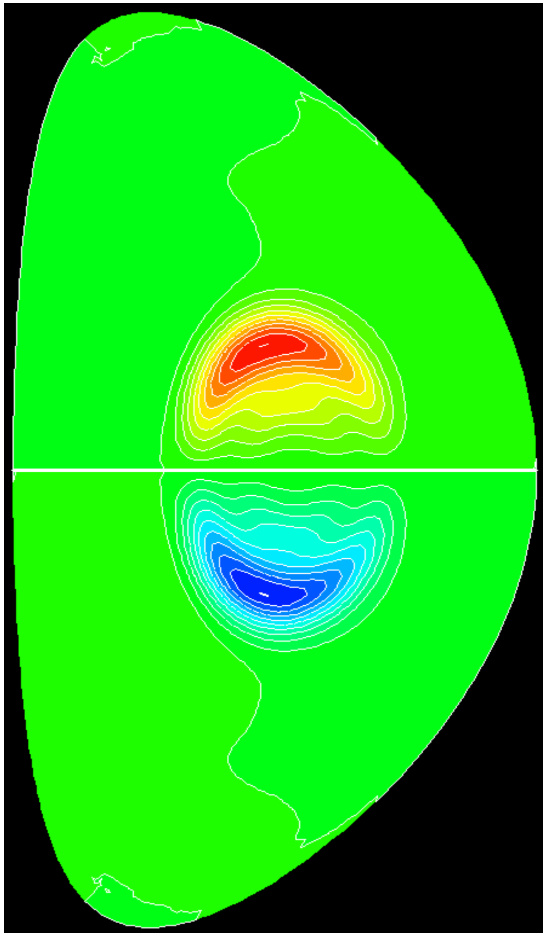


t=336

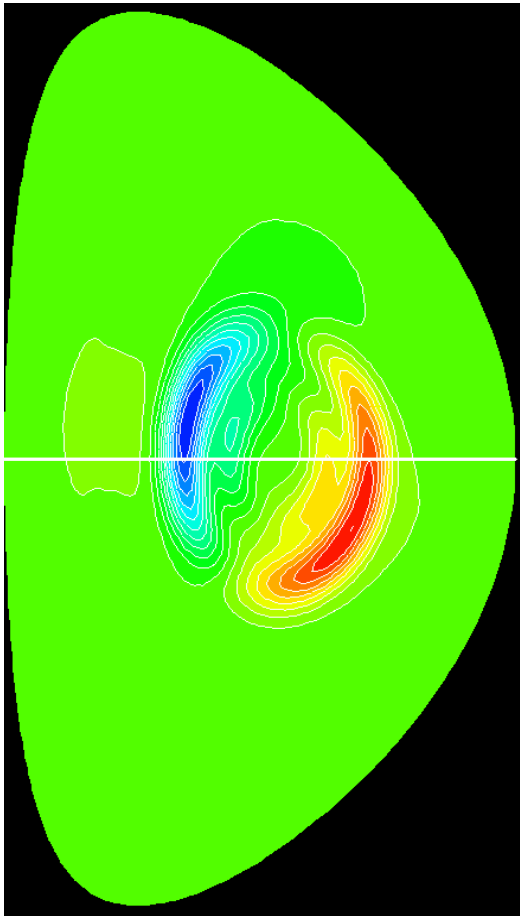
G.Y. Fu et al., IAEA Fusion Energy conference. 2004

Alpha Particle Stabilization of Internal Kink Mode for ITER:
Internal Kink Mode Structure

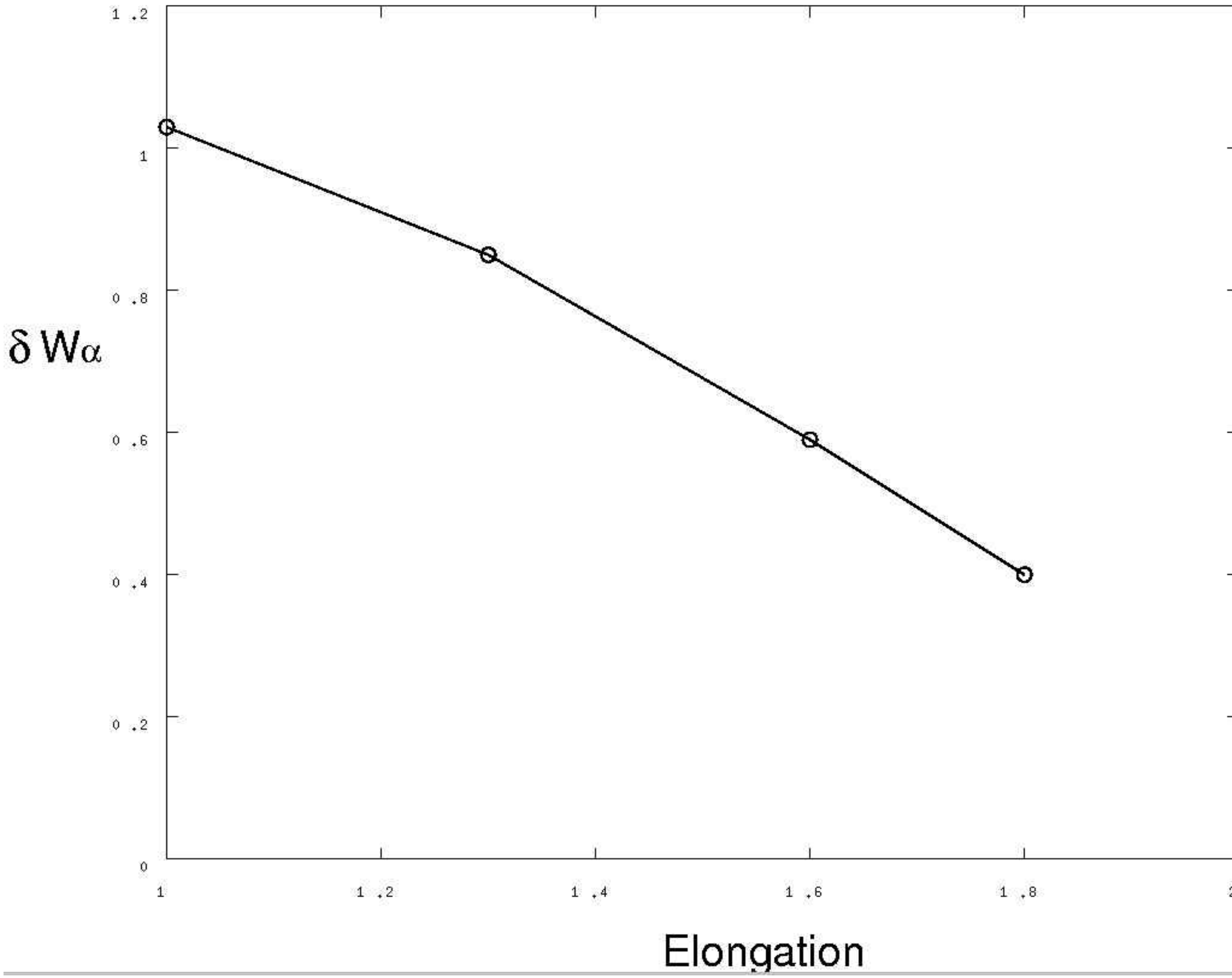
β_α=0.0



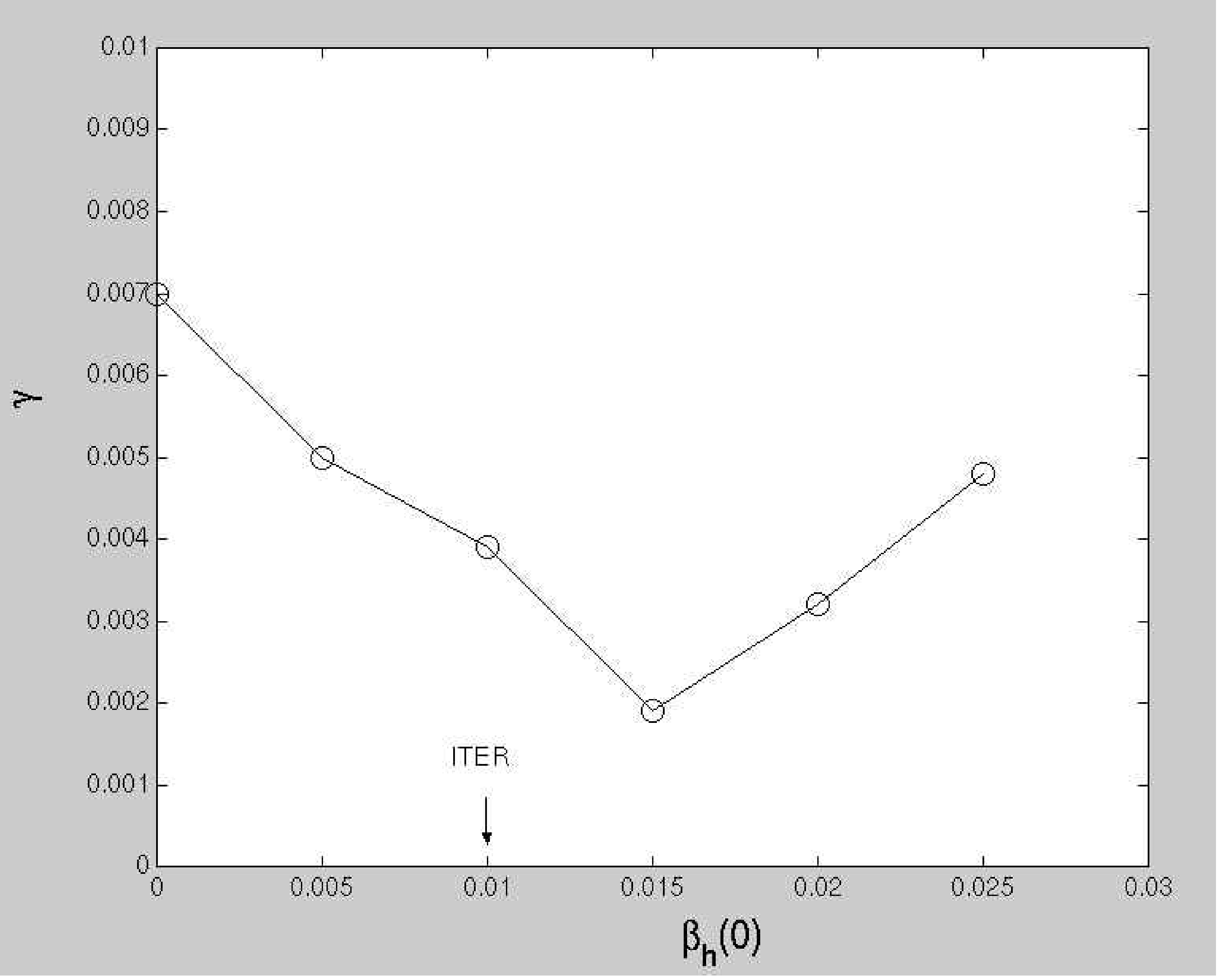
β_α=1.0%



Plasma shaping reduces alpha particle stabilization significantly



The fishbone mode is calculated to be stable in ITER

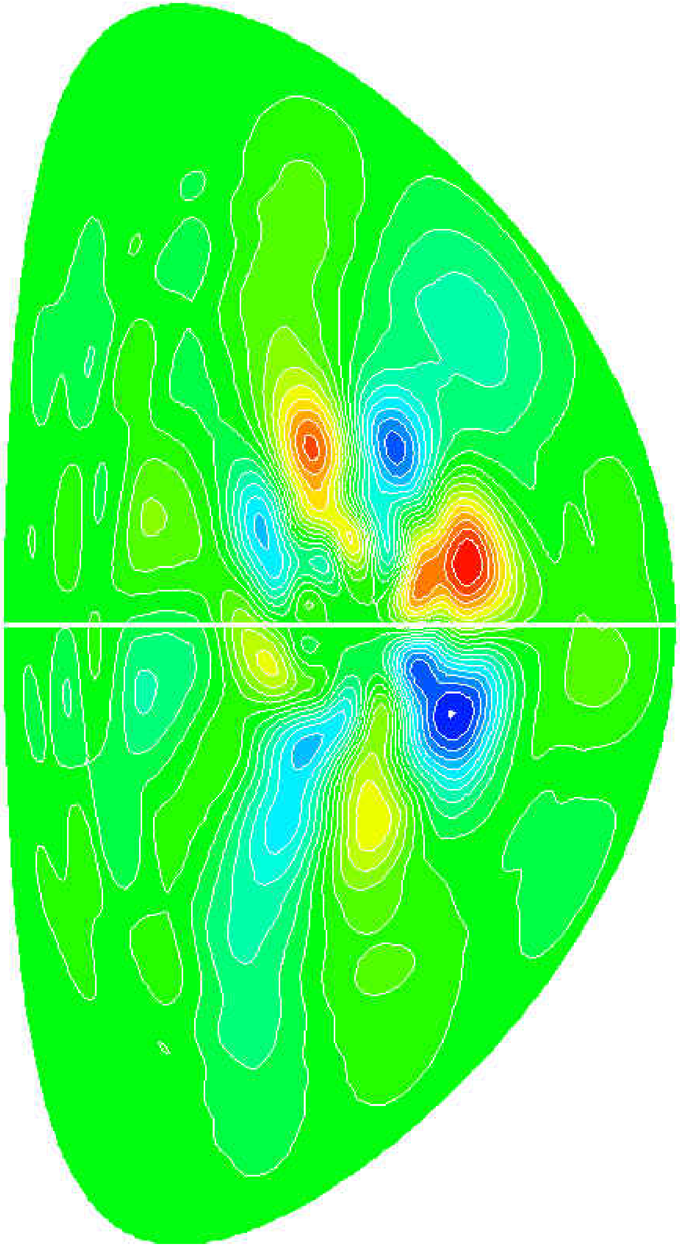


Thermal ion kinetic effects are stabilizing

- M3D can also treat thermal ions as particles
- For an ITER case, the internal kink mode growth rate is reduced by half due to thermal ion kinetic effects.

n=3 TAE in ITER

q(0)=1.4
mode peaks at q=1.5



Summary

- Comprehensive hybrid simulations have been carried out to investigate kinetic effects of alpha particles and thermal ions on internal kink and TAE.
- Elongation of ITER reduces the alpha particle stabilization of internal kink mode
- Thermal ion kinetic effects are strongly stabilizing for internal kink
- Fishbone is found to be stable in ITER.
- Initial results show an alpha-driven n=3 TAE in ITER.