Internal kink mode stability in the presence of ICRH driven fast ions populations

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Outline

Fast ions →

$$\delta W_{MHD} \rightarrow \delta W_{MHD} + \delta W_{HOT}$$

Effect of ICRH driven populations on
Internal kink mode n=1, m=1

MHD energy functional

Fast ions energy functional

Perturbative method **(F. Porcelli *et al*. Phys. Plasmas,1 (3), 470 (1994))**	Quantitative results	Sawteeth
Variational method **(R. White et al. Phys. Fluids B 2, 745 (1990))**	Qualitative results	Sawteeth, Fishbones

Objective : Explain experimental observations in JET

Perturbative method

$$\longrightarrow \delta W = \delta W_{MHD} + \delta W_{HOT} \qquad \gamma = \gamma_I + \gamma_{HOT}$$

δW_{MHD} ↓ **eigenfunction**

δW_{HOT} ↓ **perturbation**

Relevant equations, which include Finite Orbit Width effects,

$$\delta W_{HOT} = \delta W_{HOT}^{ad} + \delta W_{HOT}^{na}$$

(F. Porcelli *et al*. Phys. Plasmas,1 (3), 470 (1994))

$$\delta W_{HOT}^{ad} = \frac{2\pi^2}{\Omega m^2} \sum_{\sigma} \int dE d\mu dP_\varphi \left(\xi_\perp \cdot \nabla \psi\right) \frac{Ze}{c} \frac{\partial F}{\partial P_\varphi}$$

Adiabatic part - destabilizing

Perturbative method

$$\delta W_{HOT}^{na} = -\frac{2\pi^2}{\Omega m^2}\sum_{\sigma}\int dE\,d\mu\,dP_{\varphi}\tau_b(\omega - n\omega_*)\frac{\partial F}{\partial E}\sum_{p=-\infty}^{\infty}\frac{\left|Y_p\right|^2}{\omega + n\langle\dot{\varphi}\rangle + p\omega_b}$$

Non-adiabatic part - stabilizing

CASTOR-K ⟶ δW_{HOT}

- Safety factor on axis
- Fast ions temperature
- Location of the ICRH resonant layer
- Fast ions radial profile

$\omega << \omega_D$ ⟶ $\gamma_{HOT} = -\frac{1}{2\gamma}\frac{\mathrm{Re}\,\delta W_{HOT}}{E_k}$

Sawteeth

Effect of the ICRH fast ions on sawteeth

Non-adiabatic

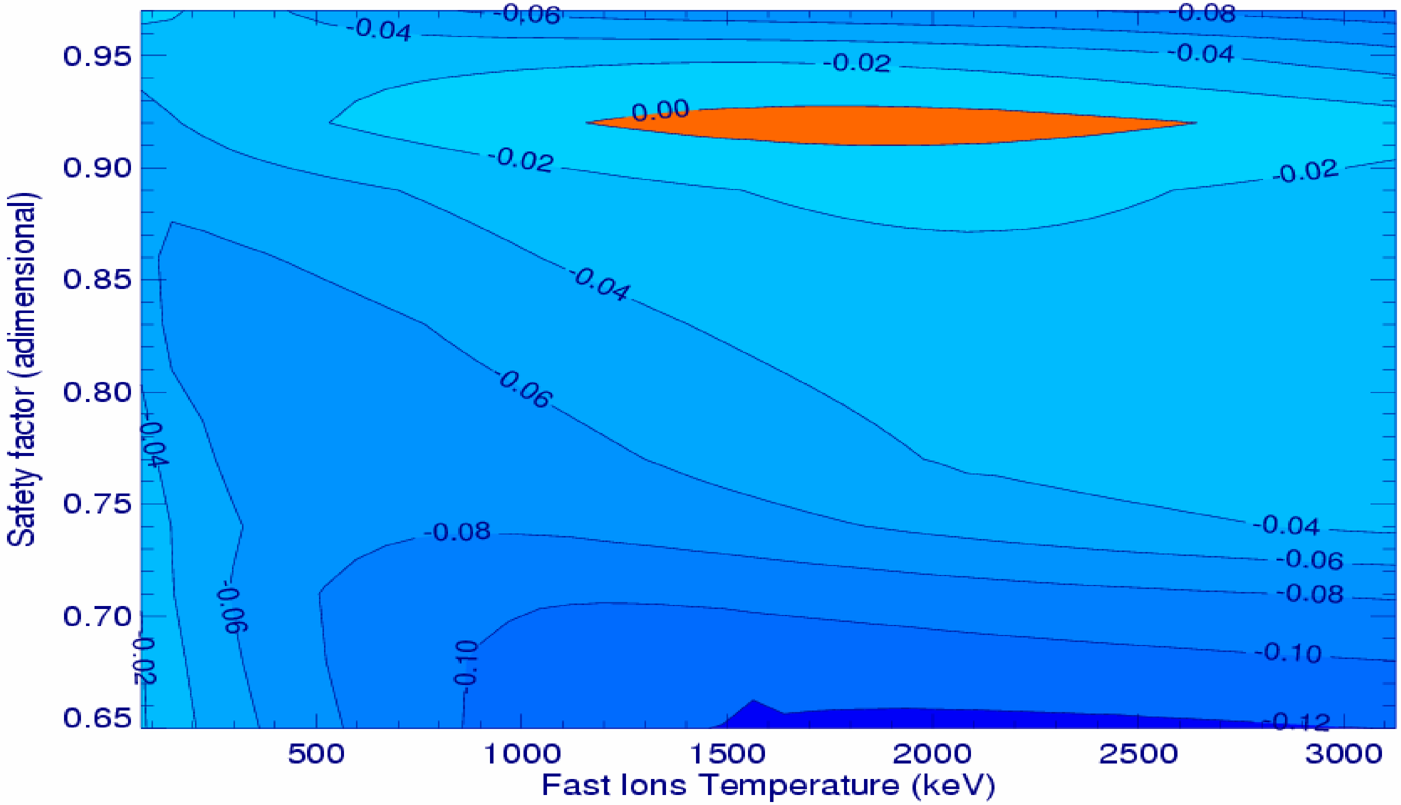
γ_{HOT}

as function of q_0 and T_{HOT}

on-axis heating

Blue regions: stabilizing

Red regions: destabilizing



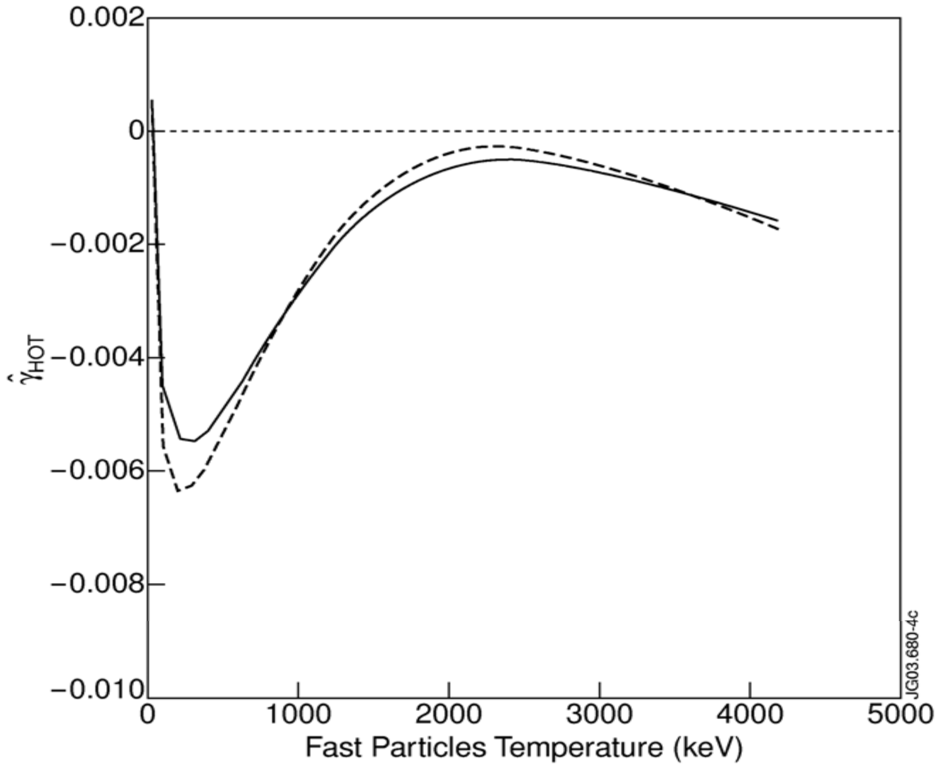
Adiabatic part of δW_{HOT} (Preliminar results)

$\left\{ \right.$ Destabilizing

δW_{HOT}^{ad} increases with $\mathbf{T}_{\mathbf{HOT}}$

Application to experiments

- Experiments with low plasma densities



Sawteeth destabilization occurred when:

- ICRH power increases
- Plasma density decreases

$$\Rightarrow \quad T_{HOT} \sim \frac{P_{ICRH}}{n_e}$$

Non-adiabatic γ_{HOT} as function of T_{HOT}

Application to experiments

- Sawteeth destabilization coincides with an increase in T_{HOT}

Numerical results show:

- The stabilizing effect of the non-adiabatic part of δW_{HOT} decreases as T_{HOT} increases, so this mechanism for sawtooth stabilization is weakened.

- The destabilizing effect associated with the adiabatic part of δW_{HOT} is increased.

- The non-adiabatic part of δW_{HOT} is dominant.

Variational method

$$\delta W_{MHD} + \delta W_{HOT} - \frac{8i\Gamma\left[\left(\Lambda^{3/2}+5\right)/4\right]\left[\omega\left(\omega-\omega_{*i}\right)\right]^{1/2}}{\Lambda^{9/4}\Gamma\left[\left(\Lambda^{3/2}-1\right)/4\right]\omega_A} = 0$$

(R. White et al. Phys. Fluids B 2, 745 (1990))

Solutions of the internal kink dispersion relation:

(Ideal limit)

- Low frequency
  - Kink Branch
    - Sawteeth
  - Ion Branch
    - $\omega \approx \omega_{*i}$
    - Low frequency (diamagnetic) fishbones
    - **(B. Coppi and F. Porcelli P. R.L, 57, 2272 (1986))**
- High frequency
  - Fishbone Branch
    - $\omega \approx \langle\omega_{Dhi}\rangle$
    - High frequency (precessional) fishbones
    - **(L. Chen et. al P. R.L 52, 1122 (1984))**

Determination of the regions of stability

Stability governed mainly by

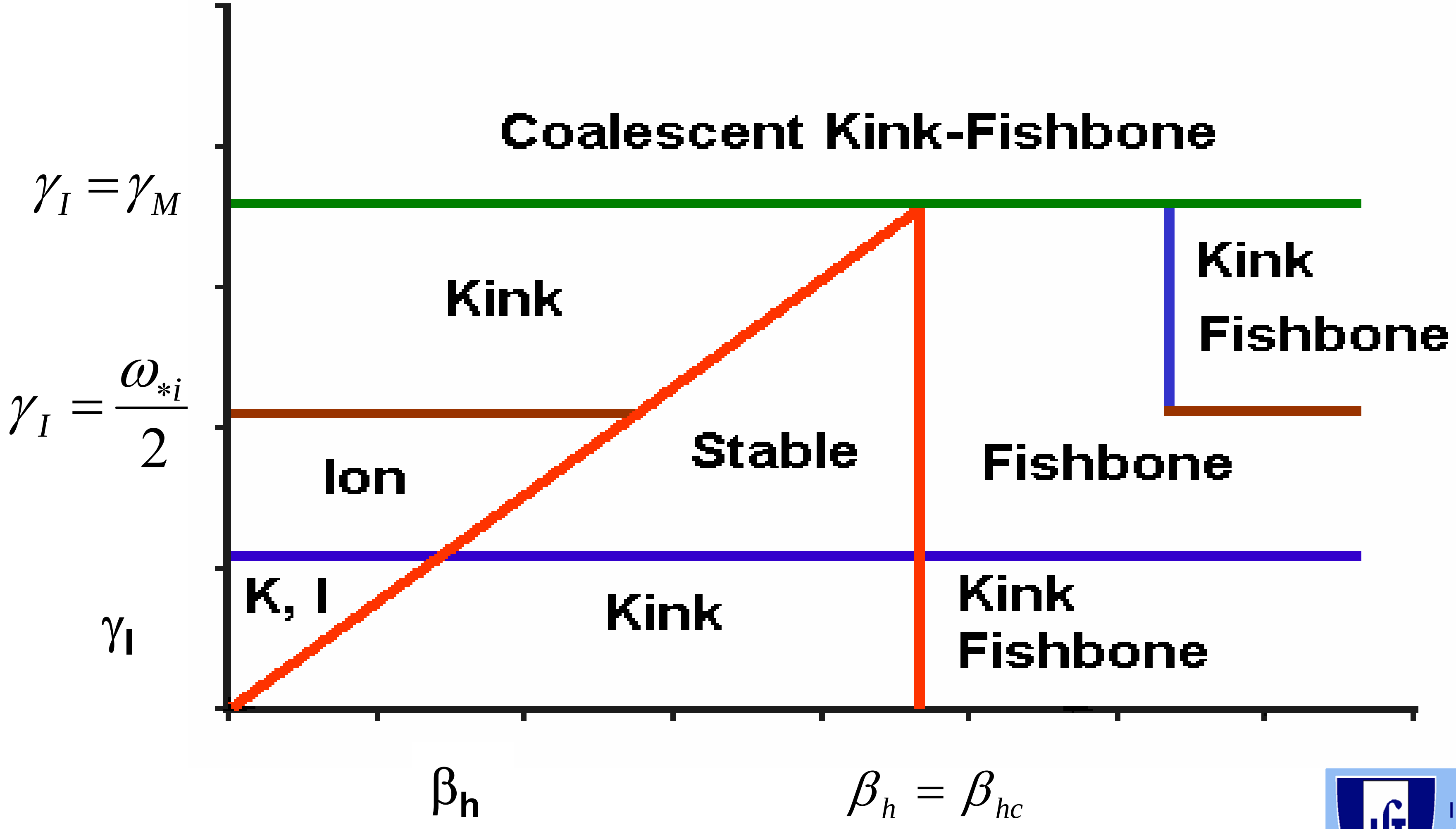
- γ_I Ideal (MHD) growth rate $\gamma_I \equiv -\omega_A \delta W_{MHD}$
- ω_{*i} Diamagnetic frequency
- β_h Fast particles beta

Marginal equation *ω*=real, ideal limit, ICRH population

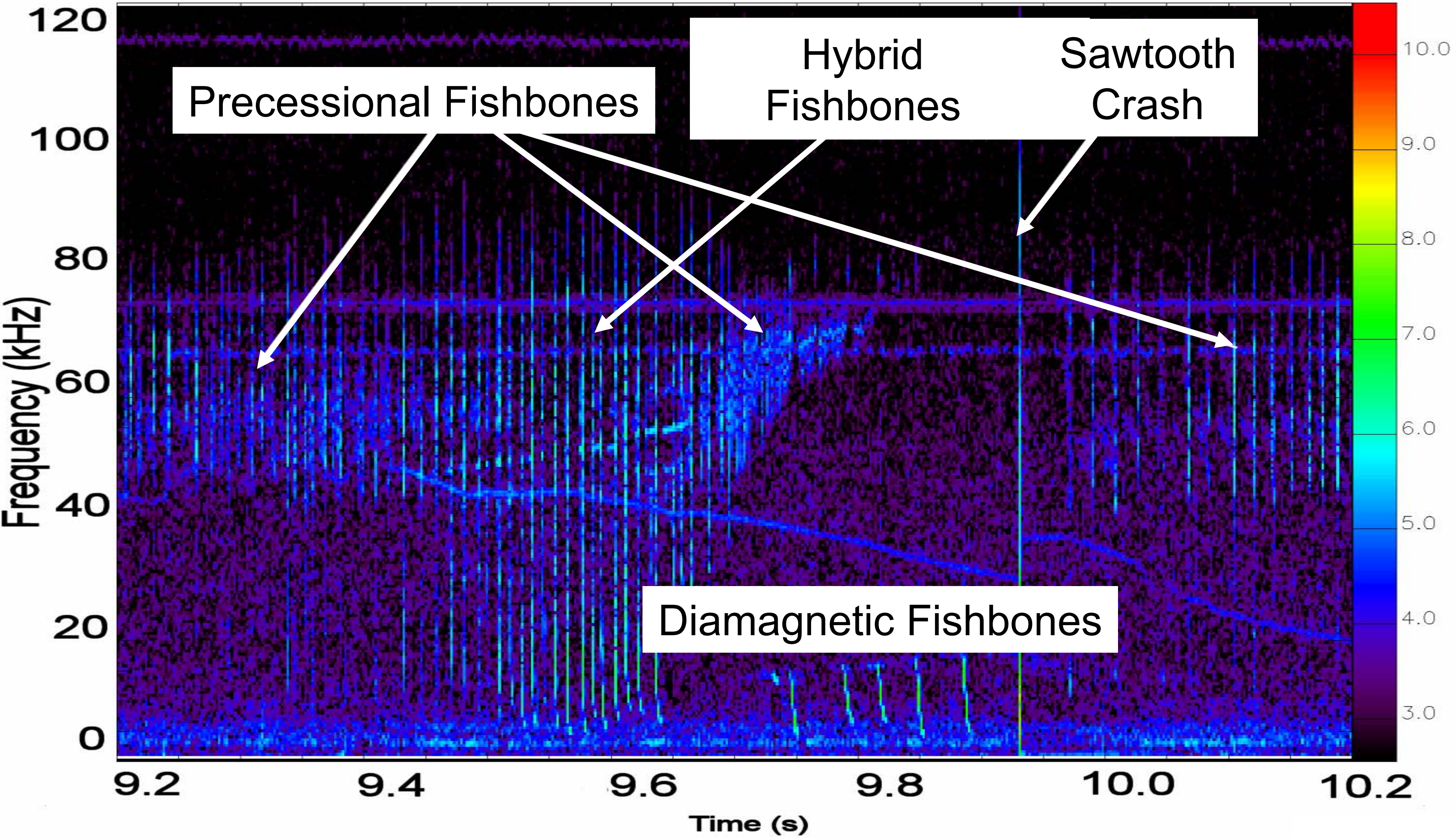
$$\gamma_I = \frac{3}{4}\left[\frac{\omega}{\langle\omega_D\rangle}\left(\frac{\omega}{\langle\omega_D\rangle}-\frac{\omega_{*i}}{\langle\omega_D\rangle}\right)\right]^{\frac{1}{2}}\left(\frac{\omega}{\langle\omega_D\rangle}\right)^{-\frac{3}{2}}\left[\frac{1}{2}+\frac{\omega}{\langle\omega_D\rangle}+\left(\frac{\omega}{\langle\omega_D\rangle}\right)^{\frac{3}{2}}\operatorname{Re} Z\left[\left(\frac{\omega}{\langle\omega_D\rangle}\right)^{\frac{1}{2}}\right]\right]$$

$$\beta_h = \frac{3}{4}\frac{\varepsilon\omega_A}{\pi^{1/2}\langle\omega_D\rangle}\left[\frac{\omega}{\langle\omega_D\rangle}\left(\frac{\omega}{\langle\omega_D\rangle}-\frac{\omega_{*i}}{\langle\omega_D\rangle}\right)\right]^{\frac{1}{2}} e^{\omega/\omega_D}\left(\frac{\omega}{\langle\omega_D\rangle}\right)^{-\frac{5}{2}}$$

Regions of stability



Magnetic spectrogram from JET



Variation of the relevant parameters

γ_I → **Increases** In between crashes the *q*=1 surface expands

ω_{*i} → **Increases** In between crashes the ion bulk profile peaks

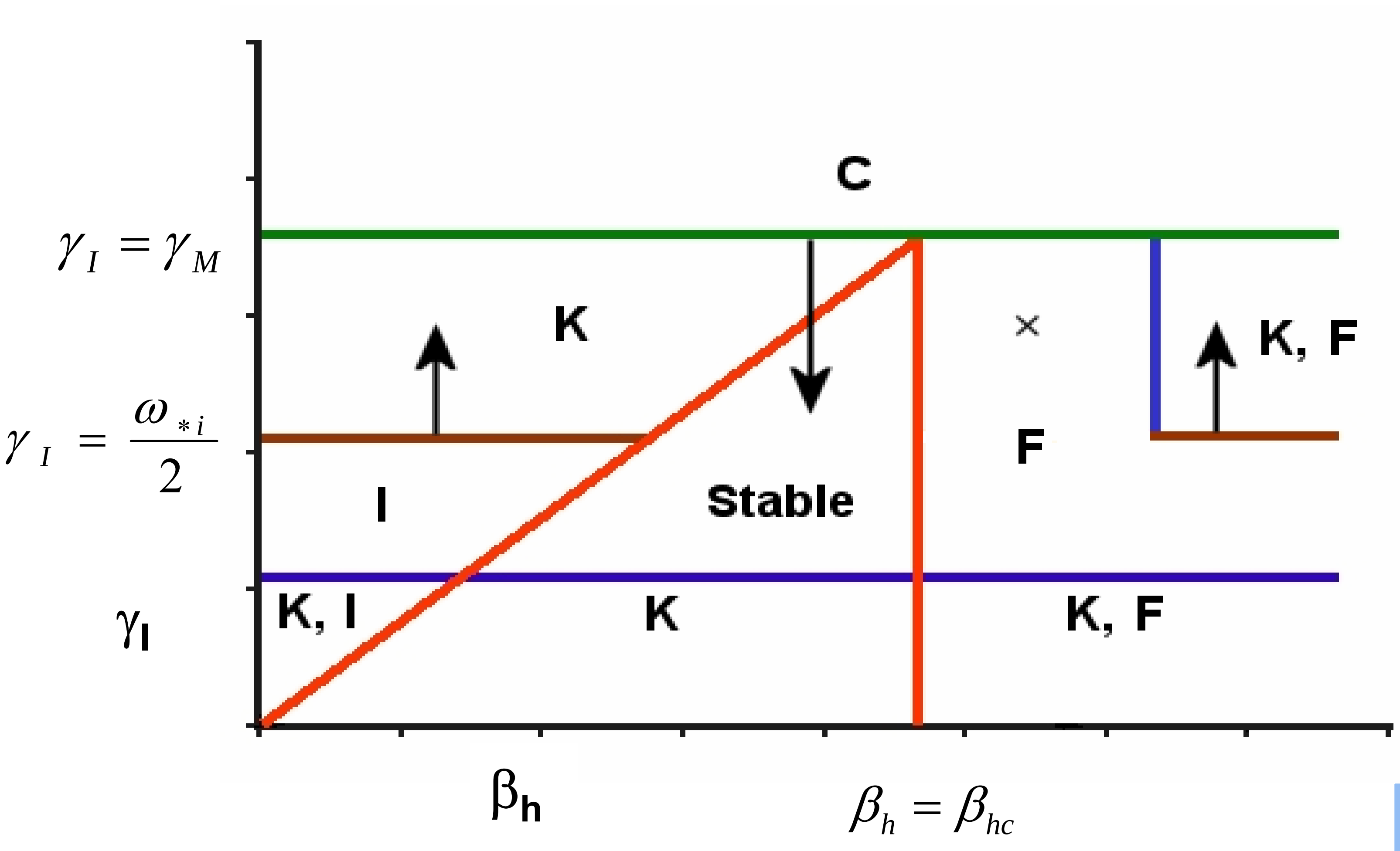
f_{*i} : 3 kHz → 20 kHz

β_h →

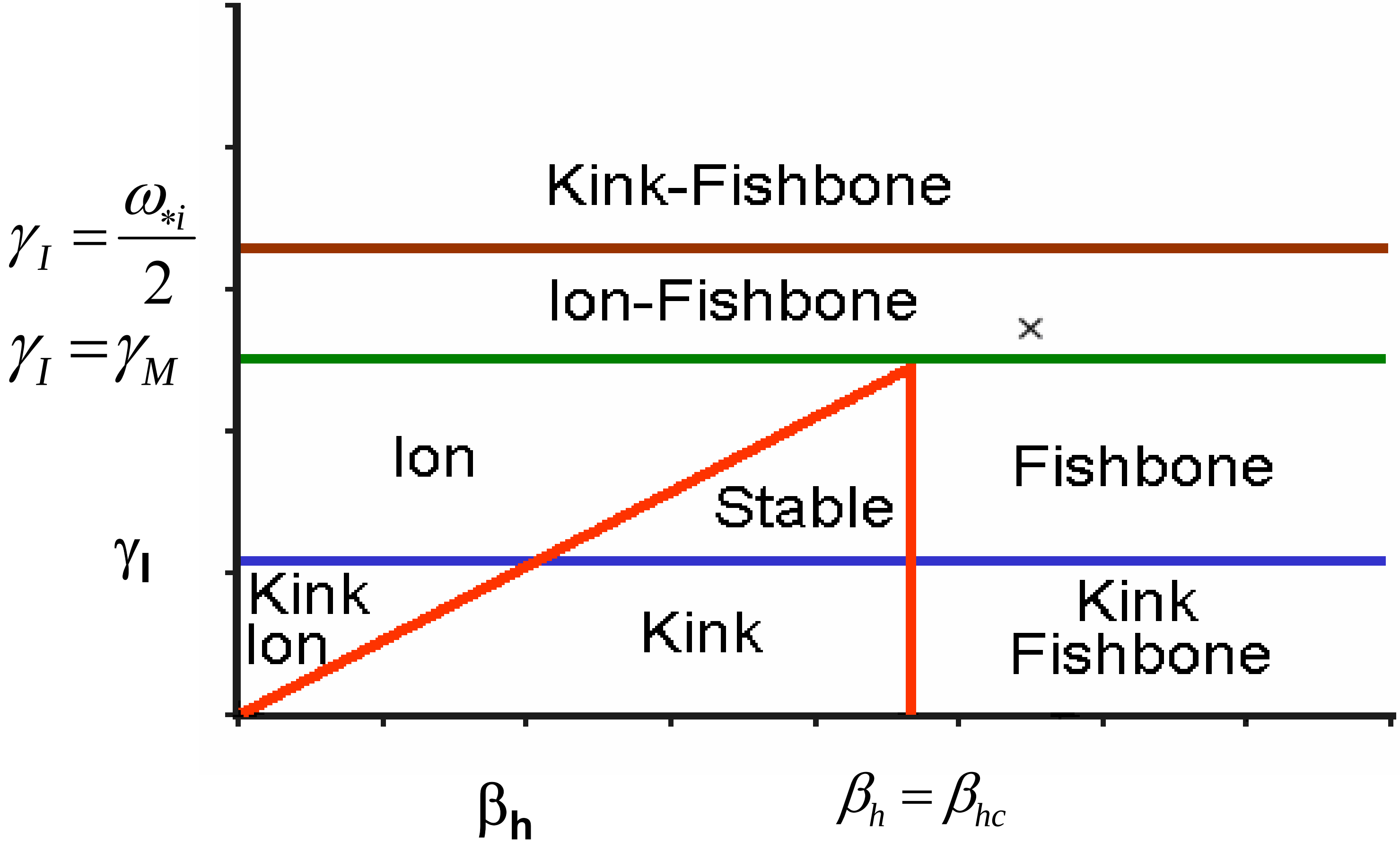
Decreases during a burst

Increases between bursts

Variation of the regions of stability

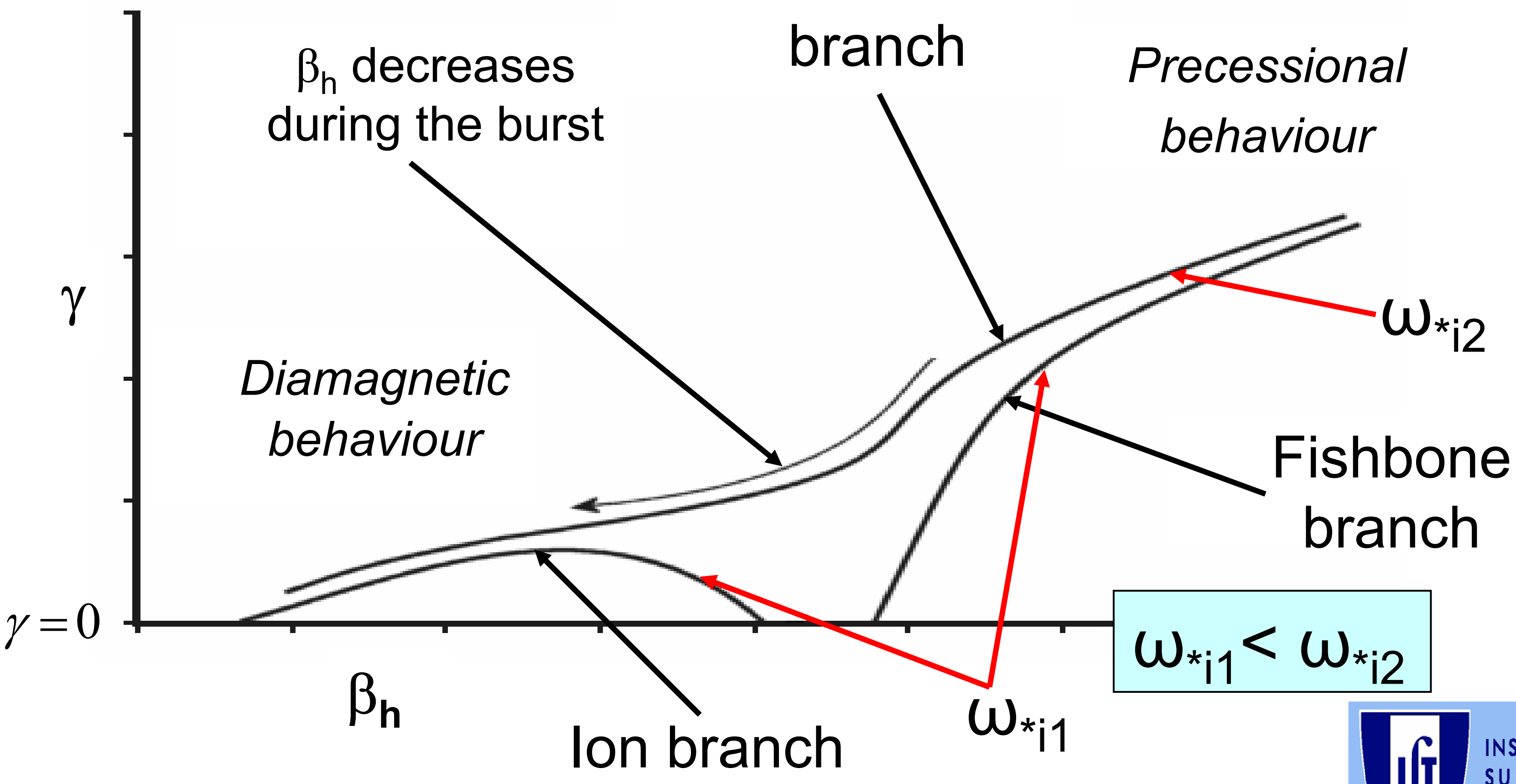


Regions of stability



Solutions of the dispersion relation

(R. White et al. Phys. Fluids B 2, 745 (1990))



Coalescent Ion-Fishbone branch

β_h decreases during the burst

Precessional behaviour

γ

ω_{*i2}

Diagnetic behaviour

Fishbone branch

$\gamma = 0$

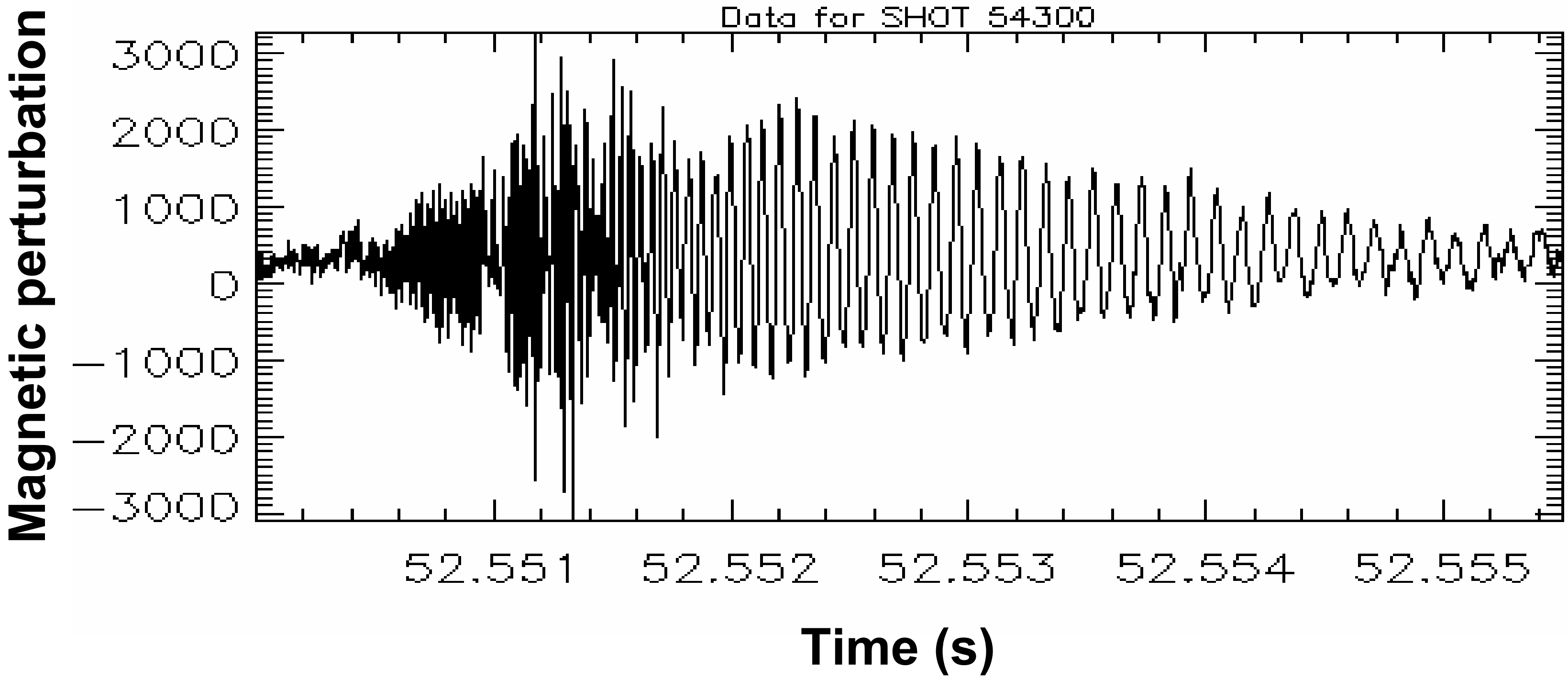
$\omega_{*i1} < \omega_{*i2}$

β_h

Ion branch

ω_{*i1}

Magnetic perturbation for an hybrid fishbone



Modes and regimes

Ion mode → Low frequency fishbones

Fishbone mode → High frequency fishbones

(Gorolenkov *et al*. "Fast ions effects on fishbones and n=1 kinks in JET simulated by a non-perturbative NOVA-KN code, this conference)

Coalescent ion-fishbone mode →

- Hybrid fishbones
- Both types of fishbones occuring simultaneously

Summary

Perturbative Method

- Accurate calculation of γ_{HOT} for a realistic geometry
- Only for the “kink mode”

→ Stabilizing term vanishes for high fast ions temperatures

Variational Method

- All branches of the dispersion relation
- Predicts changes in instabilities behaviour knowing the relevant parameters
- Simplified geometry and fast ions’ distribution function, suitable only for a qualitative approach

→ Hybrid fishbones and both types of fishbones occuring simultaneously