EUROPEAN FUSION DEVELOPMENT AGREEMENT

Fishbones Activity in JET Low Density Plasmas

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Outline

Experimental results → New fishbones regimes are observed in JET ICRH-only low densities discharges.

Qualitative analysis → New fishbones regimes are explained using a variational formalism.

Numerical analysis → Orbits of resonant particles and frequency dependence are analysed

Introduction

- Fishbones (and sawteeth) are caused by the internal kink mode
- They correspond to different solutions of the dispersion relation

Dispersion relation for the internal kink mode:

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

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

(Large aspect ratio aproximation)

Usual solutions for the internal kink dispersion relation

	Unstable branches	Instability	Frequency
High β_h	Fishbone branch	Precessional fishbones	$\omega \approx \omega_D$
Low β_h: $\gamma_I / \omega_{*i} > 1/2$	Kink branch	Sawteeth	
Low β_h: $\gamma_I / \omega_{*i} < 1/2$	Ion branch	Diamagnetic fishbones	$\omega \approx \omega_{*i}$
Intermediate β_h	—	—	

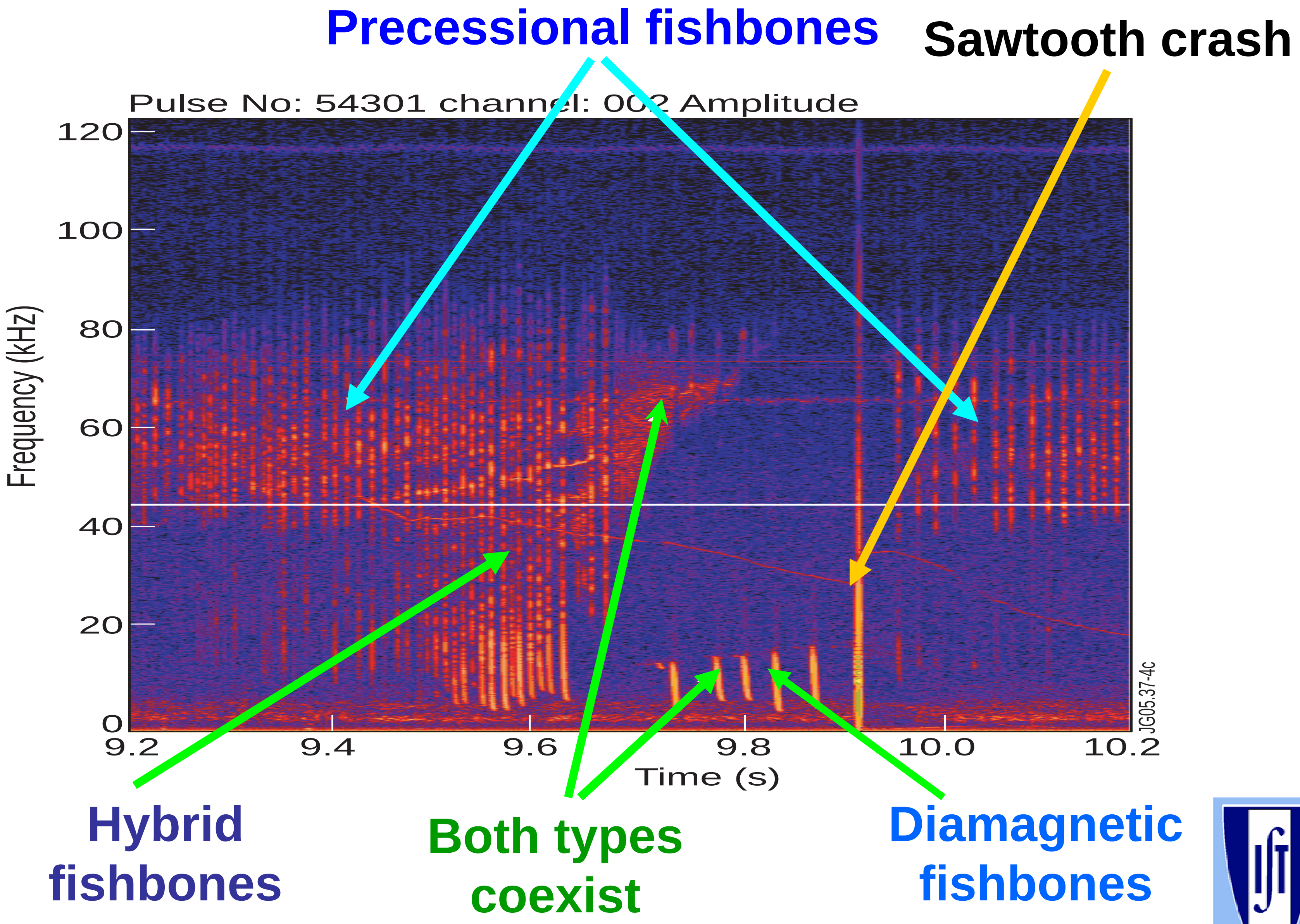
New fishbones regimes in low density plasmas

Usually observed

- Precessional drift fishbones $\omega \approx \omega_D$
- Diamagnetic fishbones $\omega \approx \omega_{*i}$

New regimes observed

- Hybrid fishbones $\omega \approx \omega_D \text{ to } \omega_{*i}$
- Both types occuring simultaneously



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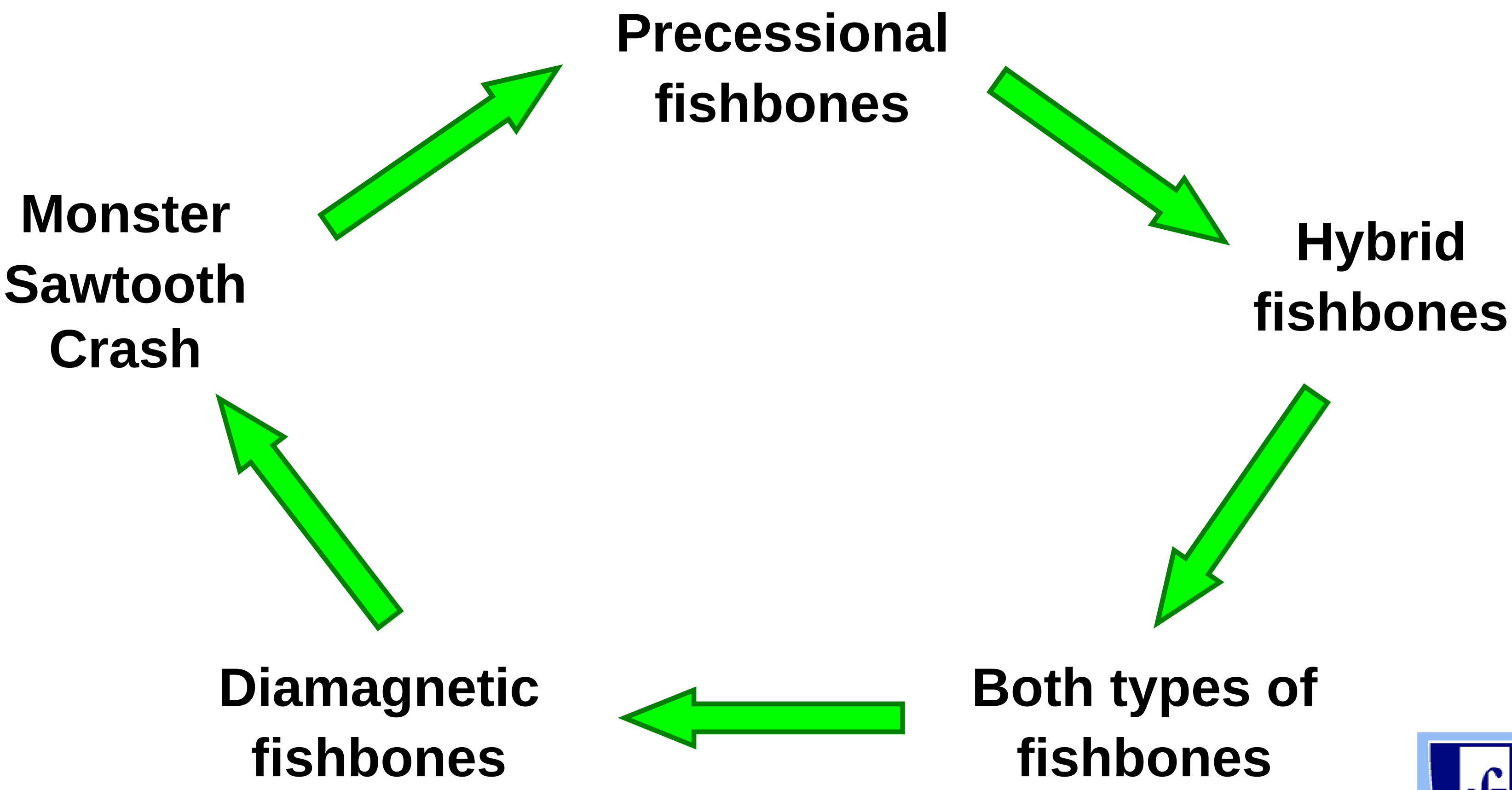
The different instabilities occur in sequence !



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Objective: explain observed fishbones behaviour

Solutions of the dispersion relation depend on three parameters ⇒

- γ_I Ideal growth rate
- ω_{*i} Diamagnetic frequency
- β_h Fast particles beta

Step 1: Determine the range of parameters for which each branch of the dispersion relation is unstable.

Step 2: Determine the evolution of each parameter during the monster sawtooth.

Step 3: Determine how the evolution of these parameters affect fishbones behaviour

Step 1: Determination of the regions of stability

To determine the regions of stability we need only to know when mode stability changes, i.e, Im(ω)=0

- Introducing this condition in the dispersion relation,

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

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

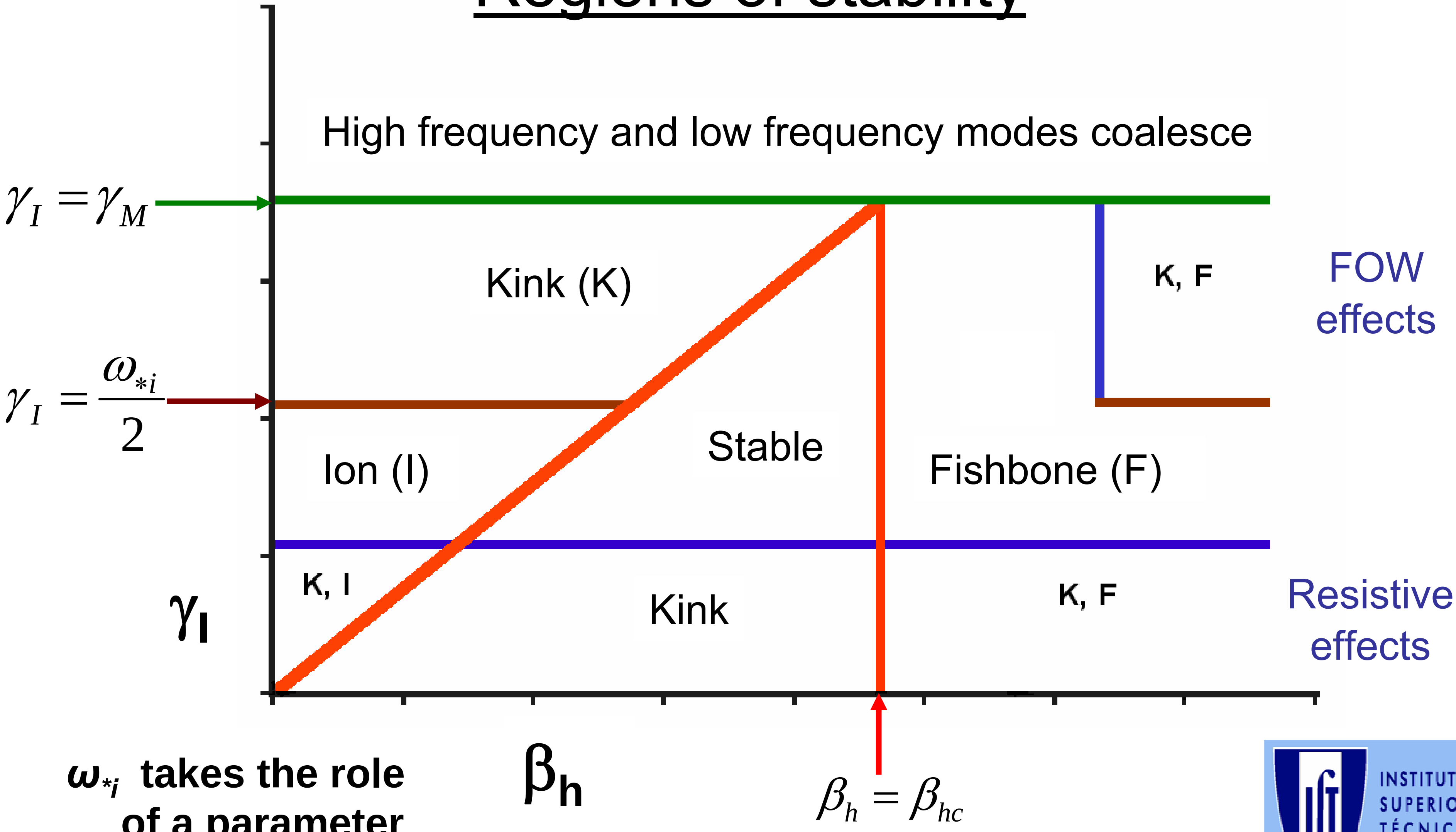
- Two solutions

$$\gamma_I < \gamma_M$$

(ideal limit, ICRH population)

And ω_{*i} takes the role of a parameter

Regions of stability



ω_{*i} takes the role of a parameter

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Step 2: Temporal evolution of the parameters

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

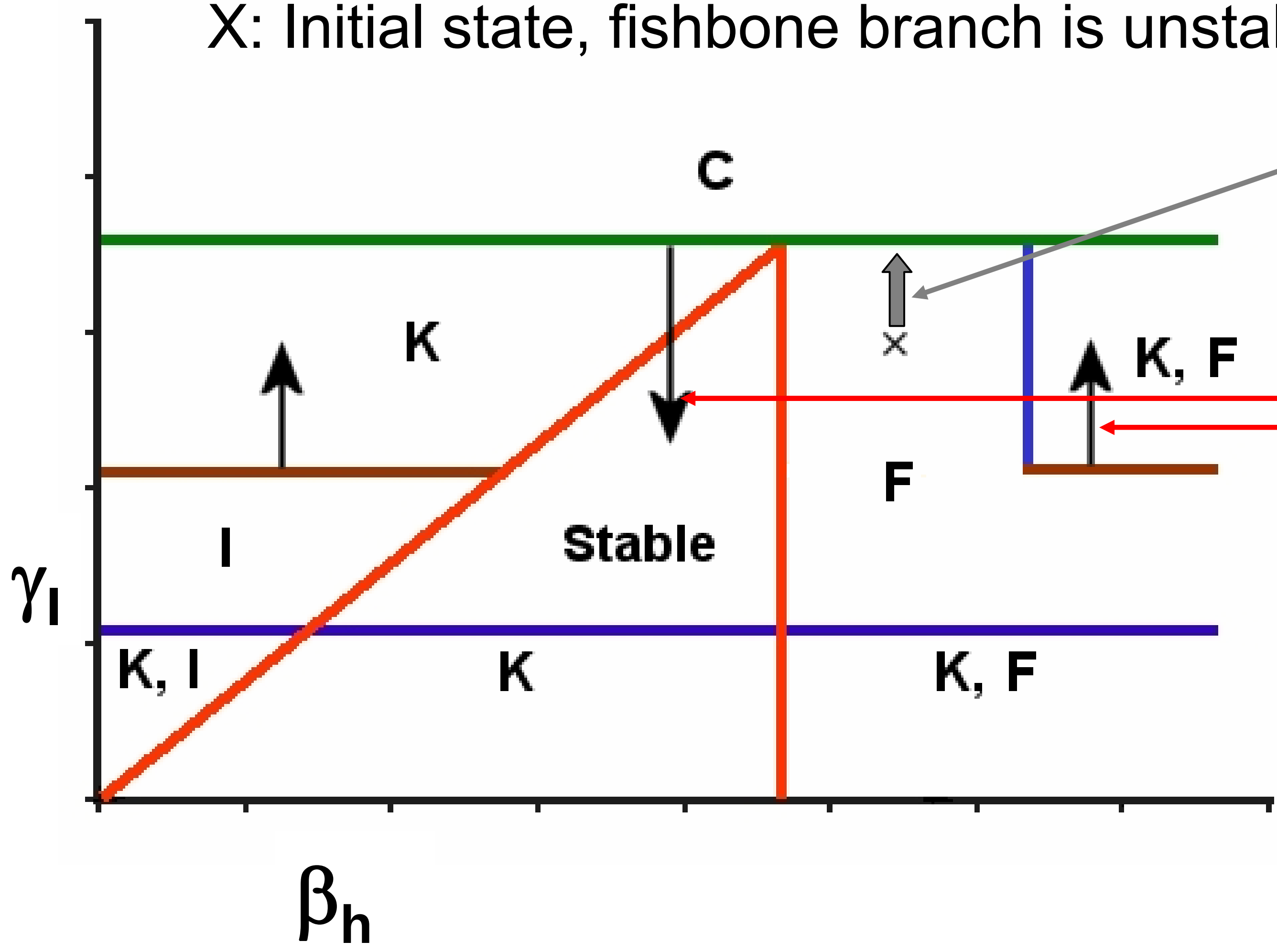
ω_{*i} → **Increases** — In between crashes the ion bulk profile peaks

f_{*i} : 3 kHz → 20 kHz

β_h → **Decreases during a burst** / **Increases between bursts**

Step 3: Changes due to the evolution of the parameters

X: Initial state, fishbone branch is unstable



γ_I increases

The horizontal lines move due to the increase in ω_{*i}

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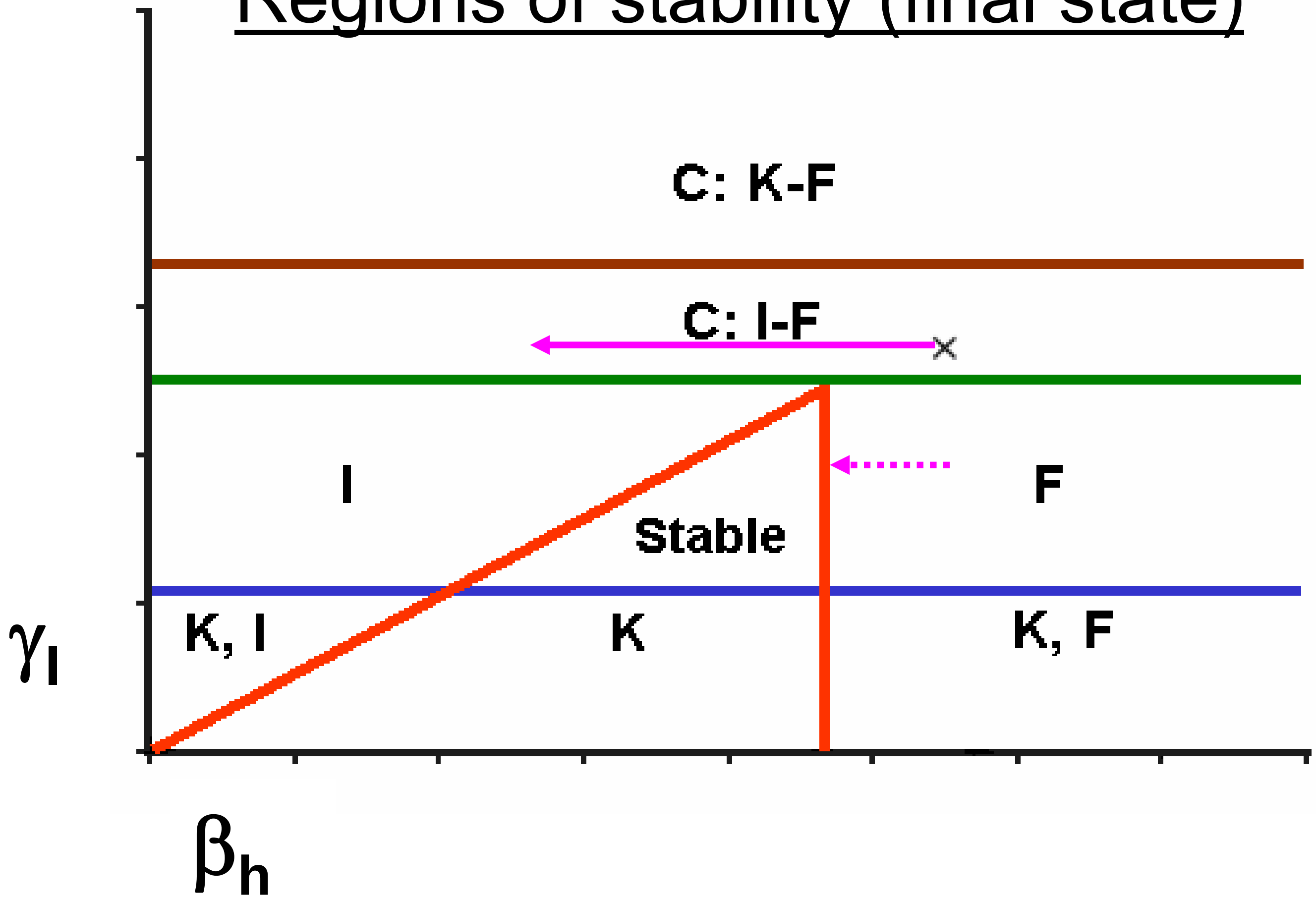
Regions of stability (final state)

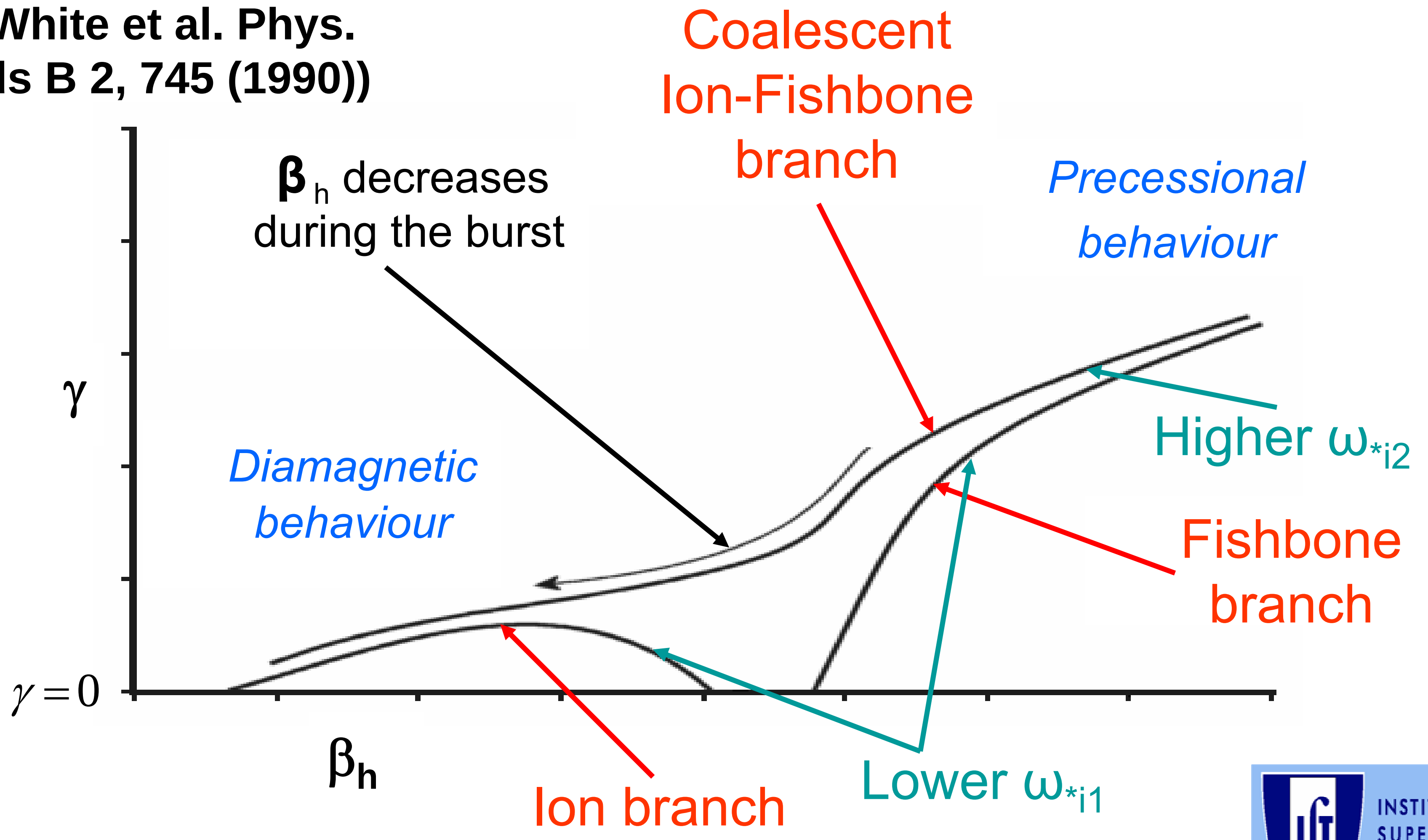


The unstable branch is now the ion-fishbone branch

During the monster sawtooth, the region where the high and low frequency modes coalesce is reached.

Solutions of the dispersion relation

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



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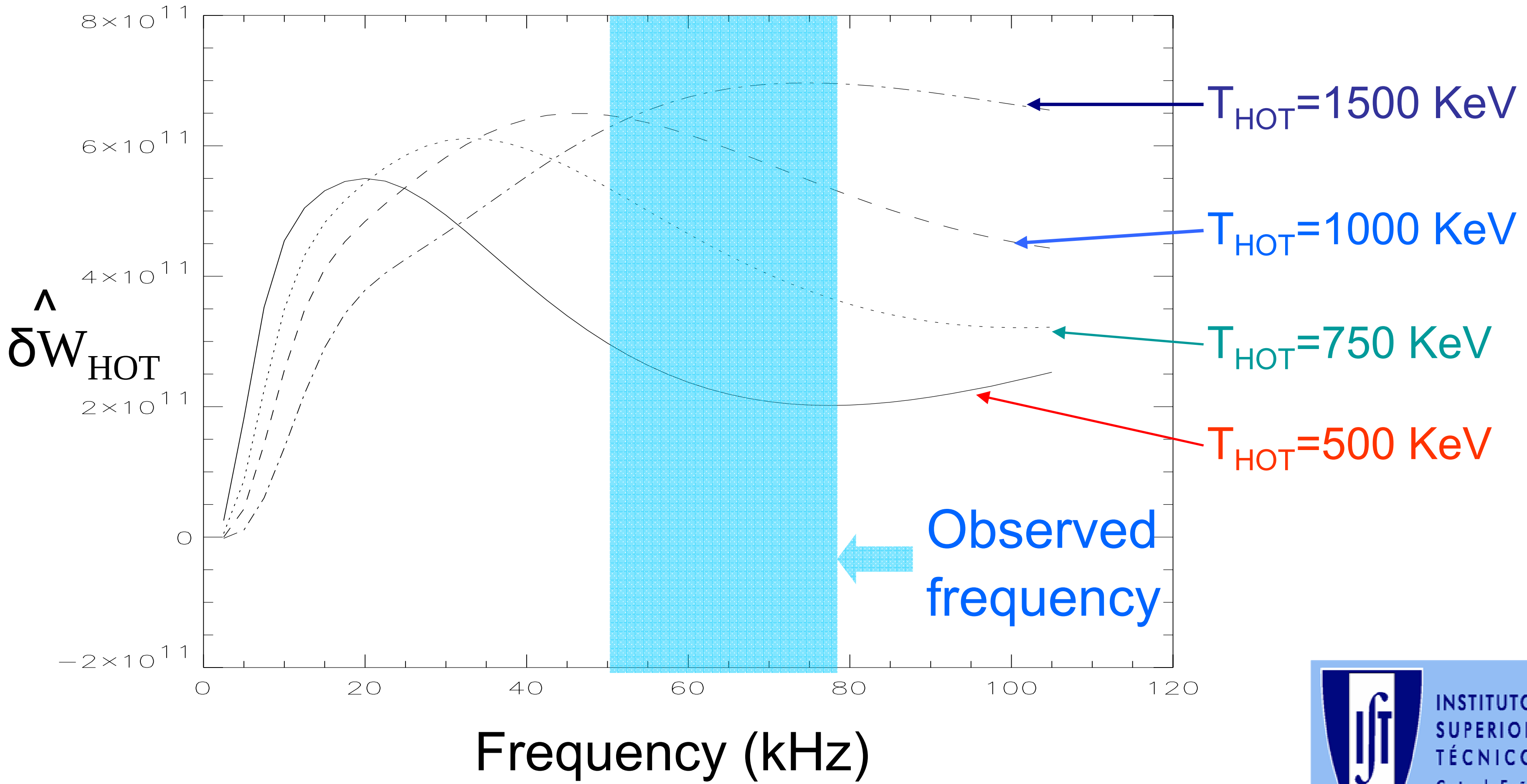
Resonant transference of energy between between an internal kink mode (top hat structure) and an ICRH driven fast ions population as function of the frequency



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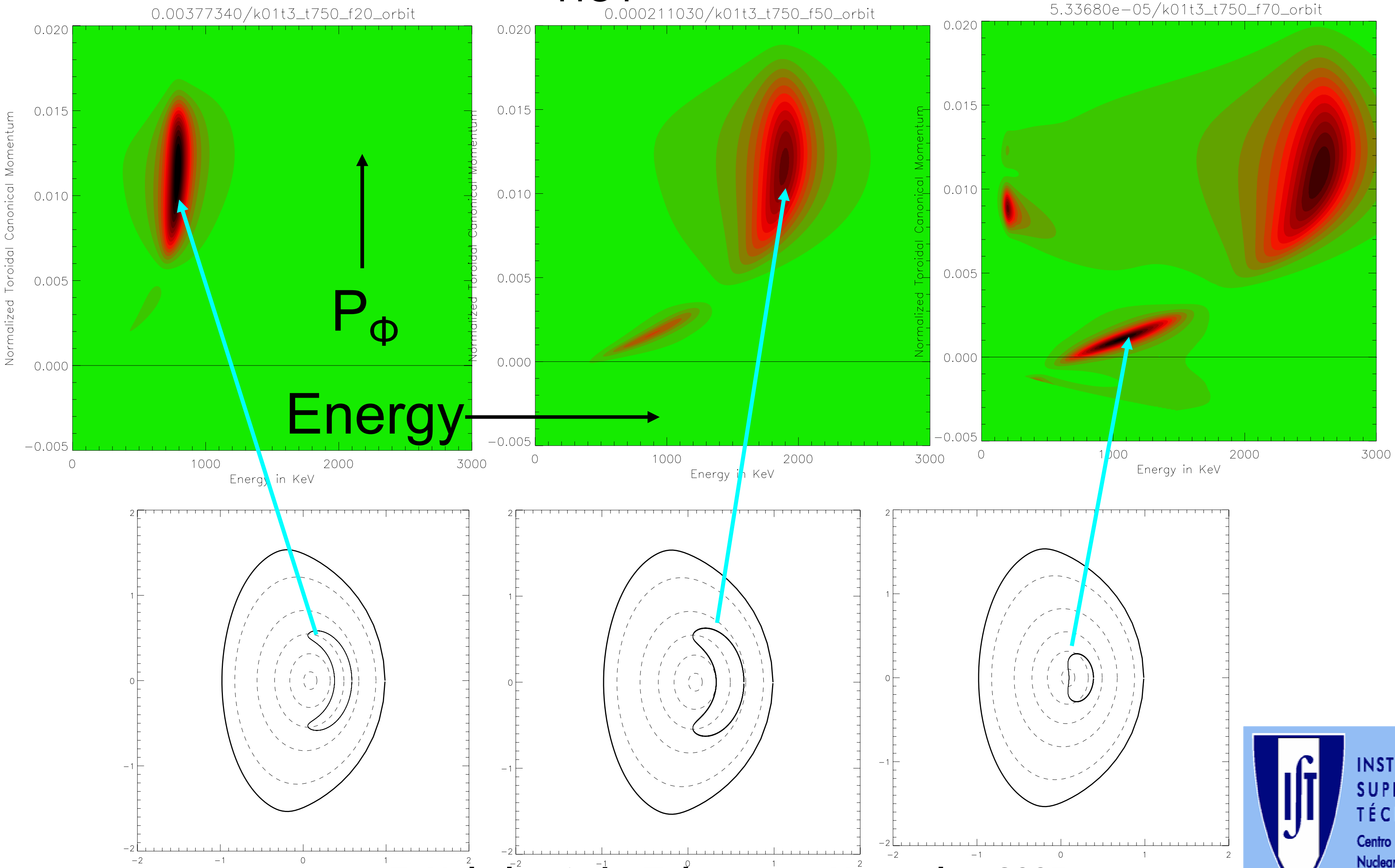
Resonant Particles, T_{HOT}=750 keV, f=20, 50 and 70 kHz



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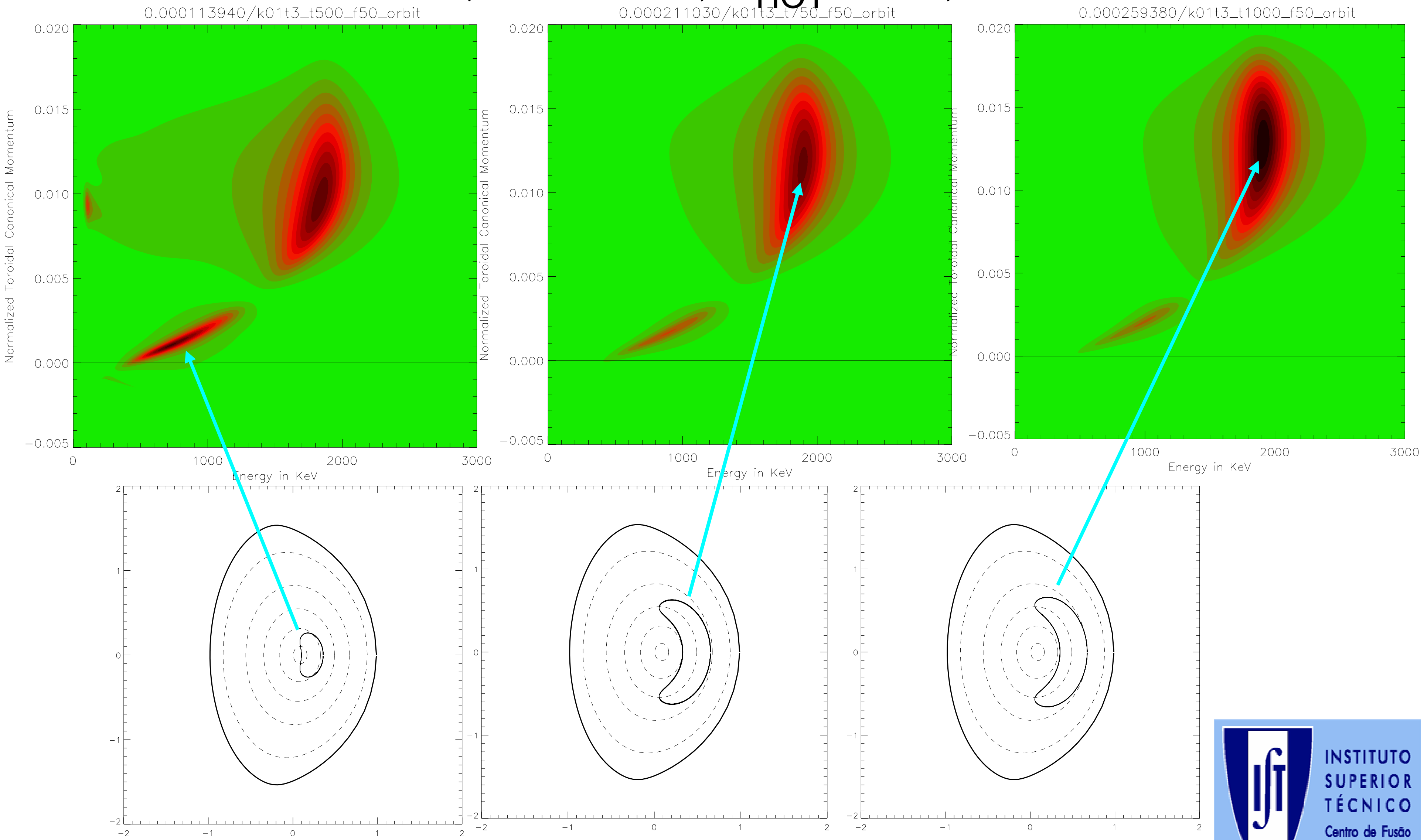
Resonant Particles, f=50 kHz, T_{HOT}=500, 750 and 1000 keV



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Summary and Conclusions

In low density plasmas the diamagnetic frequency has a significant increase:

Fishbone mode → High frequency fishbones

Coalescent ion-fishbone mode →

- Hybrid fishbones
  (Precessional behaviour dominant)
- Both types of fishbones occuring simultaneously
  (No dominant behaviour)
- Low frequency fishbones
  (Diamagnetic behaviour dominant)

Summary and Conclusions

- Fast ions temperature between 1 MeV and 1.5 MeV maximize the resonant exchange of energy for frequencies 50-80 kHz.
- Numerical simulations predict a rapid increase in the mode frequency as the fast ions temperature increase.
- This may be related with a change in the type of orbits that have stronger interaction with the mode.