Addressing the impact of fishbones on core turbulence with gyrokinetic simulations

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

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INTRODUCTION AND MOTIVATIONS

In order to reach fusion-relevant temperatures in the core of fusion devices more easily, a reduction of outward fluxes is would be beneficial. Since these fluxes are mainly driven by **microturbulence** (e.g. TEM, ITG) [1], the study of the interaction of these modes with **macroscopic plasma instabilities** (such as fishbones) is of fundamental importance.

Fishbones (FB) [2] develop around low order rational surfaces with $nq = m$, with q, n and m safety factor and toroidal and poloidal mode numbers. Recent results [3,4] show a link between FB trigger and turbulence level reduction. We investigate this physics with **GENE linear** and **nonlinear global simulations**.

TOOLS: THE GENE CODE

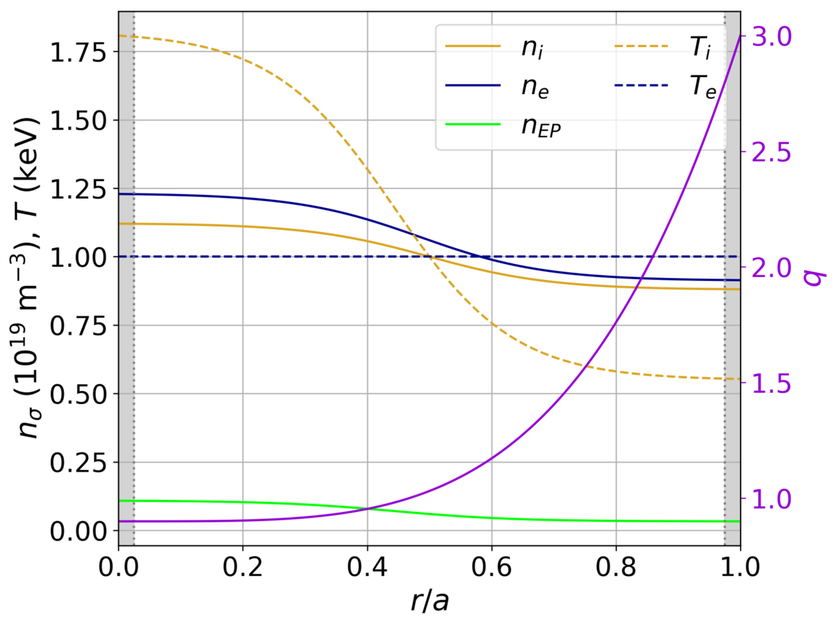
GENE [5] is a **eulerian gyrokinetic code** that solves the Vlasov-Maxwell system, composed by the **gyrokinetic equation**,

$$\frac{\partial F_\sigma}{\partial t} + \left[v_{||}\hat{b}_0 + \frac{B_0}{B_{0||}^*}\left(\vec{v}_{\xi} + \vec{v}_{\nabla B} + \vec{v}_C\right)\right] \cdot \left[\vec{\nabla} F_\sigma - \left(q_\sigma \vec{\nabla}\bar{\phi}_1 + \frac{q_\sigma}{c}\hat{b}_0 \dot{\bar{A}}_{1||} + \mu \vec{\nabla} B_0\right)\frac{1}{m_\sigma v_{||}}\frac{\partial F_\sigma}{\partial v_{||}}\right] = 0$$

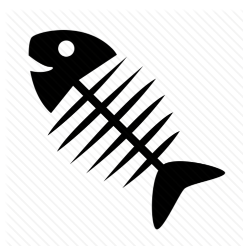
along with the **equations for the evolution of the potentials** ϕ_1 and $A_{1||}$ in the 5D phase space described by coordinates $\{x, y, z, v_{||}, \mu\}$. We can perform **linear runs** by neglecting the nonlinear interaction term $\propto \vec{v}_{\xi}$.

PLASMA PROFILES AND SETUP 1

Fishbones are triggered by the presence of **energetic particles** (EP) inside the tokamak. We consider a collisionless three species plasma: ions (H), electrons and EP (high-T D). Electron and EP temperatures are flat with T_e=T_i(0.5)=1 keV and densities n_i=1, n_{EP}=0.06 and n_e= 1.06×10^{19}m^{-3} hold at r/a=0.5. This setup is chosen in order to have only **n=1 FB** and **ITG** as unstable modes.



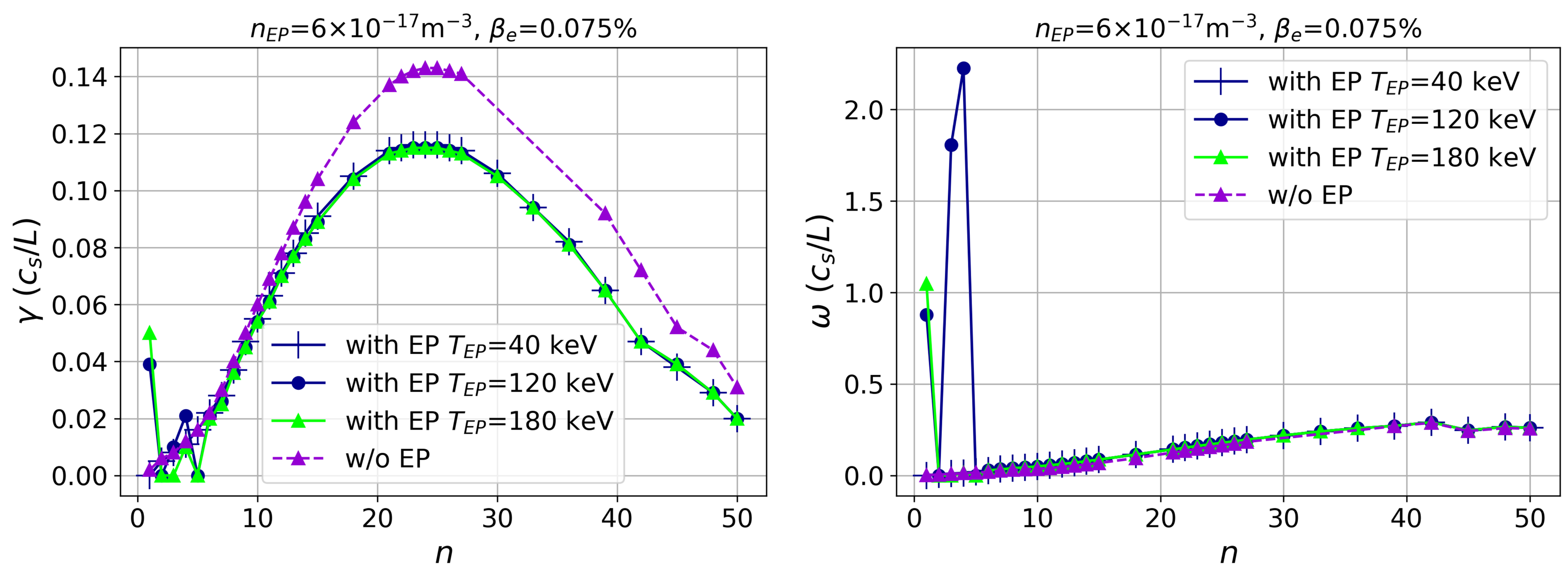
We consider a circular geometry with R=10 m and a=1 m. On-axis magnetic field is B_T=1 T, safety factor profile $q(r)$=0.9+2.1$(r/a)^4$. **q=1 at r/a=0.47** holds. **β_e=0.075%** and the simulation domain is **0.025≤ r/a ≤0.975**.



LINEAR SIMULATIONS 2

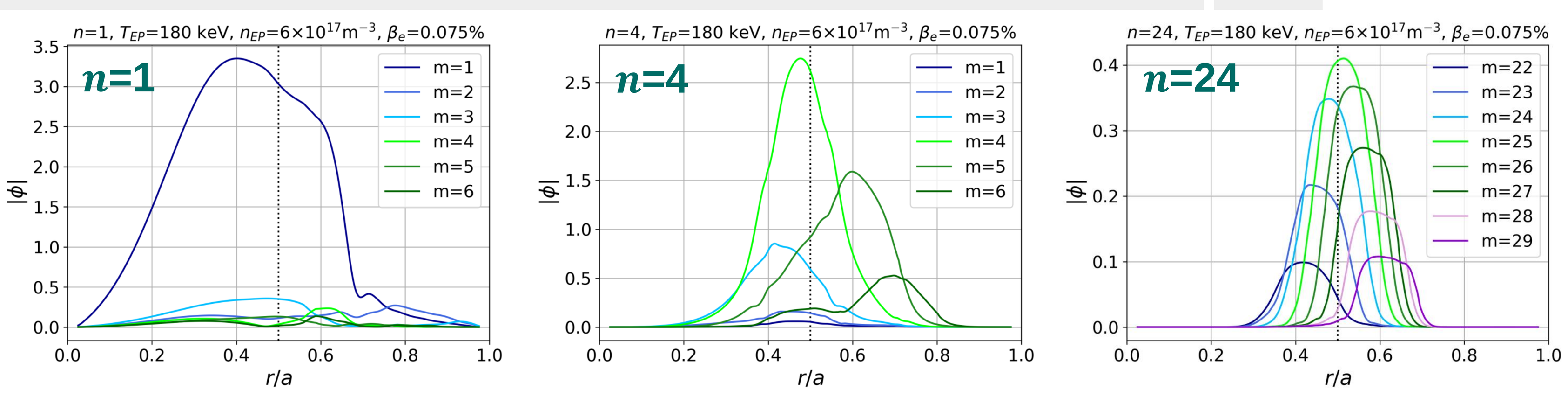
An analysis of the modes which develop in the setup is performed with GENE linear simulations. **Different flat EP temperatures** are considered.

Linear mode spectra 2.1



- An **ITG mode** branch peaks around n=24 for each setup.
- At **T_{EP}=180 keV** the n=1 mode is the only MHD instability.
- When **T_{EP}=120 keV**, n=3 and 4 are unstable along with the n=1 mode.
- The cases with **T_{EP}=40 keV** and **without EP** show no low-n mode. A **dilution effect** [6] of EP is observed in γ when removing them and $n_i \to n_e$.

Single mode analysis for T_{EP}=180 keV 2.2



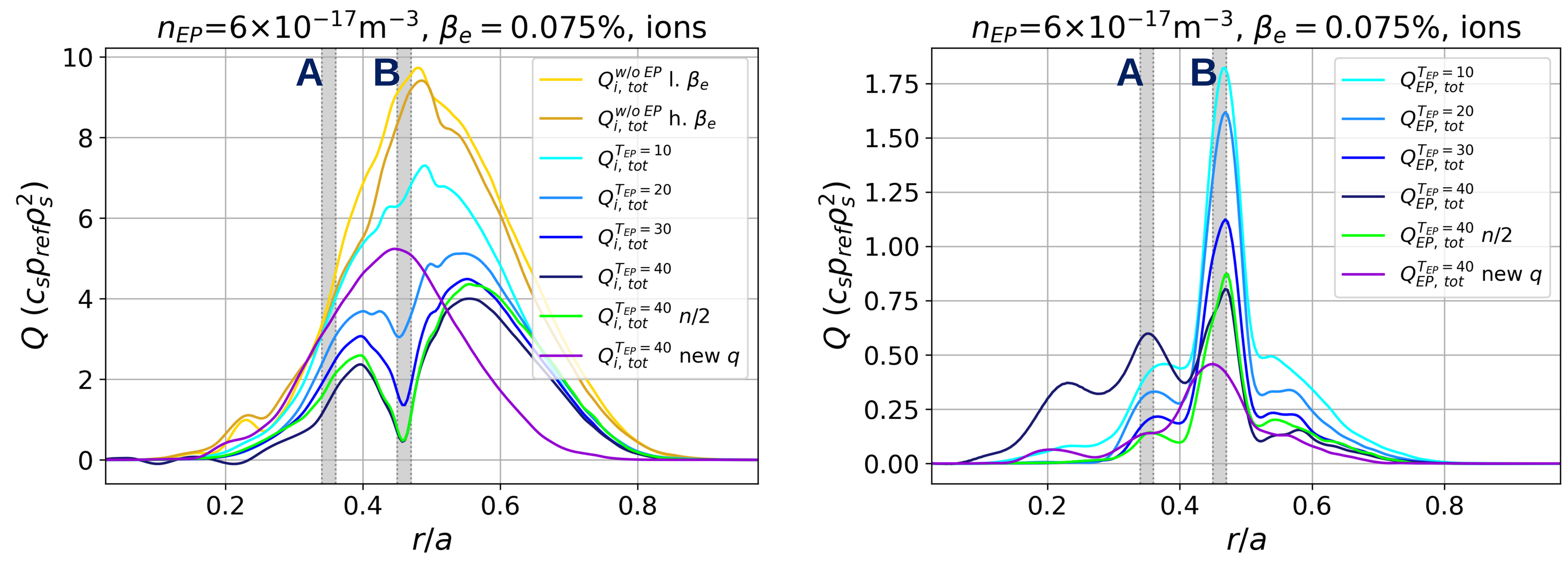
- The **m=1** structure is clearly dominant for the n=1 mode.
- Different m values contribute to the mode for **higher n**.

NONLINEAR SIMULATIONS 3

GENE nonlinear simulations are perfromed inlcuding **n=0-47 modes** for the cases **T_{EP}=10–40 keV**, and **w/o EP**, with same β_e ('l. β_e') and β_{tot} ('h. β_e') of the case with EP. A run with T_{EP}=40 and **n=0,2,…,46** is also considered, along with a setup with **shifted q profile**, $(r/a|_{q=1}$=0.7) do not coincide with the gradients maximum.

Flux radial profiles and spectra 3.1

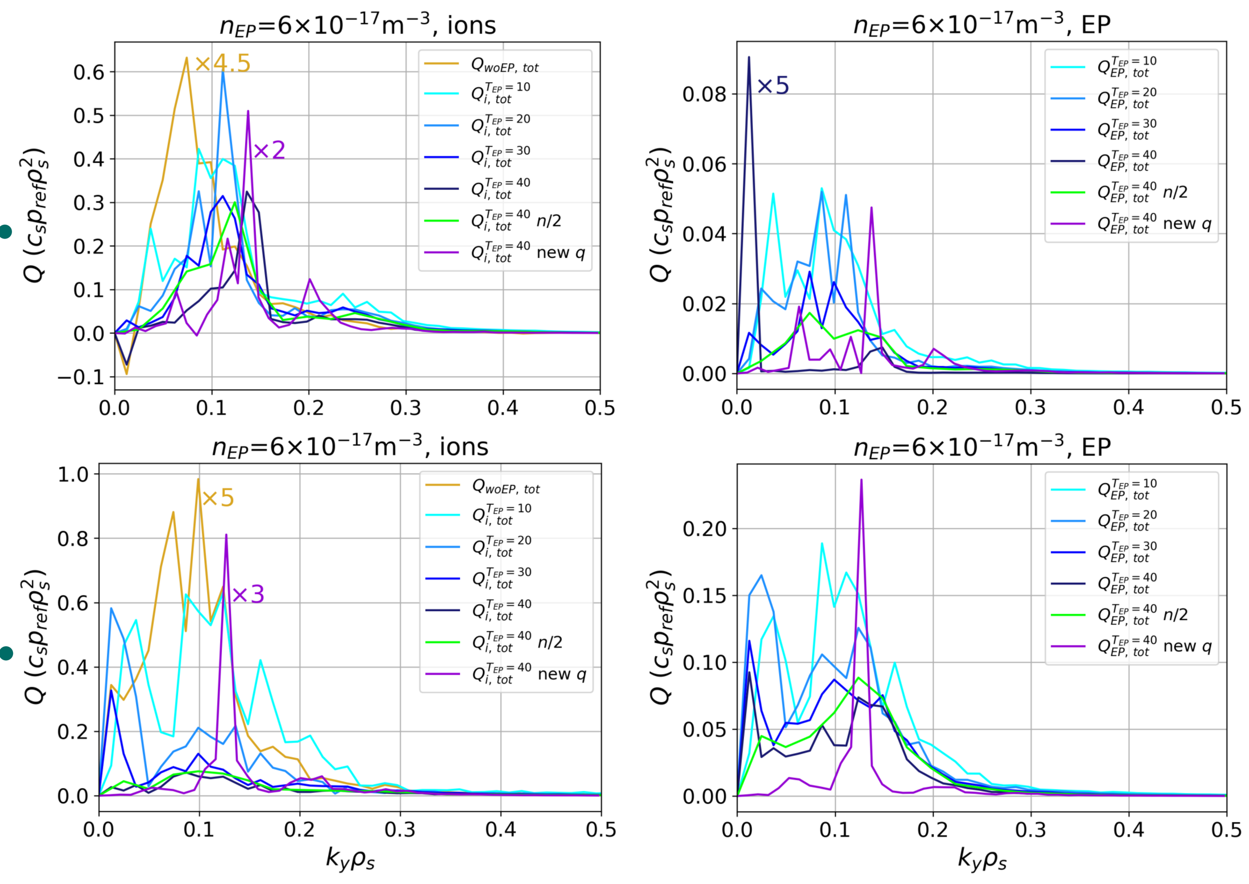
Total (ES+EM) **heat fluxes Q_{tot}** are studied *vs* the radial position r/a and the wave number $k_y\rho_s$ (in regions **A** and **B**) for ions and EP.



- A reduction of fluxes is observed with increasing **T_{EP}**, in particular around **q=1**. No relevant effect of removing the **n=1** mode can be observed in ion fluxes. Shifting the **q profile**, the ion flux depression in **B** disappears.

Averaged in A

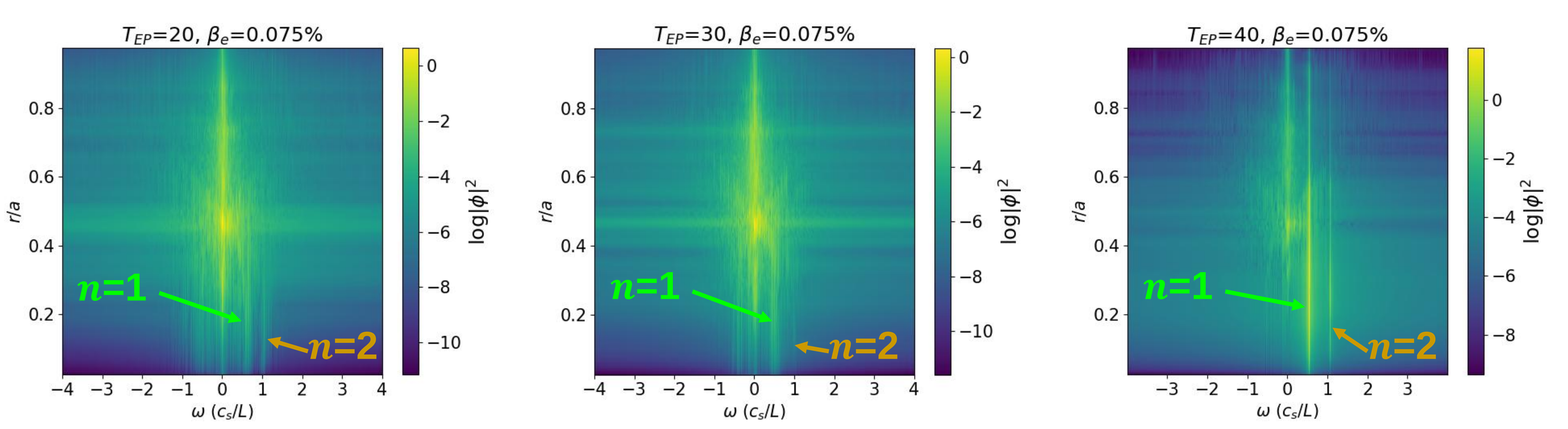
Averaged in B



- In **A** the **n=1** mode is the main driver of EP transport for **T_{EP}=40 keV** with ref. q.
- In **B**, **low-n modes** concur with the ITG branch to drive transport when EP are included and q=1 coincides with the maximum of gradients.

Frequency analysis 3.2

Spectrograms for **n=1,2** are computed *vs* r/a for **T_{EP}=20, 30, 40 keV**.



- **The n=1 mode intensifies as T_{EP} increases**, along with an expansion to higher r/a values of the radial domain of both modes.
- No definite frequencies can be identified for the **n=1,2** modes in the setup with T_{EP}=40 keV and shifted q (spectrogram not reported here).

CONCLUSIONS AND PERSPECTIVES

- **Linearly** low-n high frequency modes are unstable for **high enough T_{EP}** values.
- **Nonlinearly**, ion fluxes are reduced by the inclusion of EP. The flux depression around the **q=1** position increases with the value of T_{EP}.
- **Low-n** modes are the main drivers of EP transport, with an **n=1** dominace in **A** for T_{EP}=40. Their contribution is suppressed when the q profile is shifted.
- As T_{EP} increases, **n=1,2** modes expand towards region **B** and the n=1 mode becomes more and more relevant. It is not clear yet if these modes are linked to the ion heat flux reduction observed at q=1 with increasing T_{EP}. Further analysis (e.g. bicoherence) and simulations (cases with T_{EP}>40 keV) are ongoing.
- n=1 runs with **ORB5** [7] are ongoing for comparison with GENE results.

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