Interaction of Alfvénic modes and turbulence via the nonlinear modification of the equilibrium profiles

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1 Introduction and motivation

◇ Alfvén Modes (AM) [1, 2] are electromagnetic (EM) oscillations, driven unstable in tokamaks by energetic particles (EP).

◇ Ion-temperature-gradient (ITG) modes [3], are dominantly electrostatic (ES) modes driven unstable by the gradients of plasma temperature.

◇ The study of the interaction of EPs, macroscopic AMs and microscopic ITG-turbulence is a numerically demanding problem due to its multi-scale character.

◇ A kinetic treatment is necessary to properly include wave-particle interactions.

◇ Dynamics slower than gyrofrequencies → gyrokinetic (GK) ordering valid.

◇ Interaction of EPs and turbulence has been observed
↪ in experiments [4, 5, 6, 7]
↪ investigated by means of analytical theory [8, 2, 9, 10]
↪ investigated by means of flux-tube numerical simulations [11, 12, 13, 14, 15, 16]
↪ recently, first investigations by means of global EM numerical simulations [17]

◇ AMs nonlinearly modify the equilibrium profiles [2, 18, 19, 17], therefore we ask: *can we isolate and study numerically how this affects ITG turbulence?*

◇ In this work: first, we run global selfconsistent EM simulations of AMs and turbulence with ORB5 (similarly to Ref. [17]) to save the profiles modified by the AM; secondly, we use the modified profiles, for ES simulations of ITG turbulence.

2 Model and equilibrium

◇ ORB5 is a multispieces EM GK particle-in-cell code [20, 21].

◇ ORB5 is global, i.e. it resolves modes with structure comparable with the minor radius → appropriate for studying AMs with low toroidal mode number

◇ A Krook operator is used as a source for the thermal species. It acts by slowly restoring the initial thermal plasma profiles (not the EPs here).

◇ Magnetic equilibrium with circular concentric flux surfaces. Monotonic safety factor profile here (instead of reversed shear as in Ref. [17]).

◇ Large aspect ratio and gradients peaked at mid-radius for simplicity.

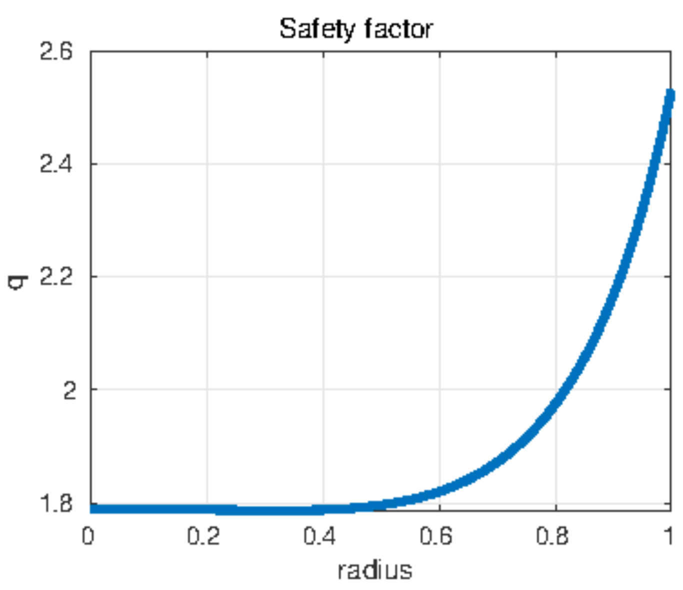

Fig.1. *Safety factor profile.*

◇ $\rho^* = \rho_s/a = 2/350$, $\beta = 8\pi n(T_i + T_e)/B^2 = 1 \cdot 10^{-3}$.

3 First part of the numerical experiment: study of the profiles modified by the AM

◇ In this section: results of selfconsistent nonlinear global EM simulations

◇ EPs are switched on at $t = 6 \cdot 10^4 \, \Omega_i^{-1}$, driving AMs on top of turbulence.

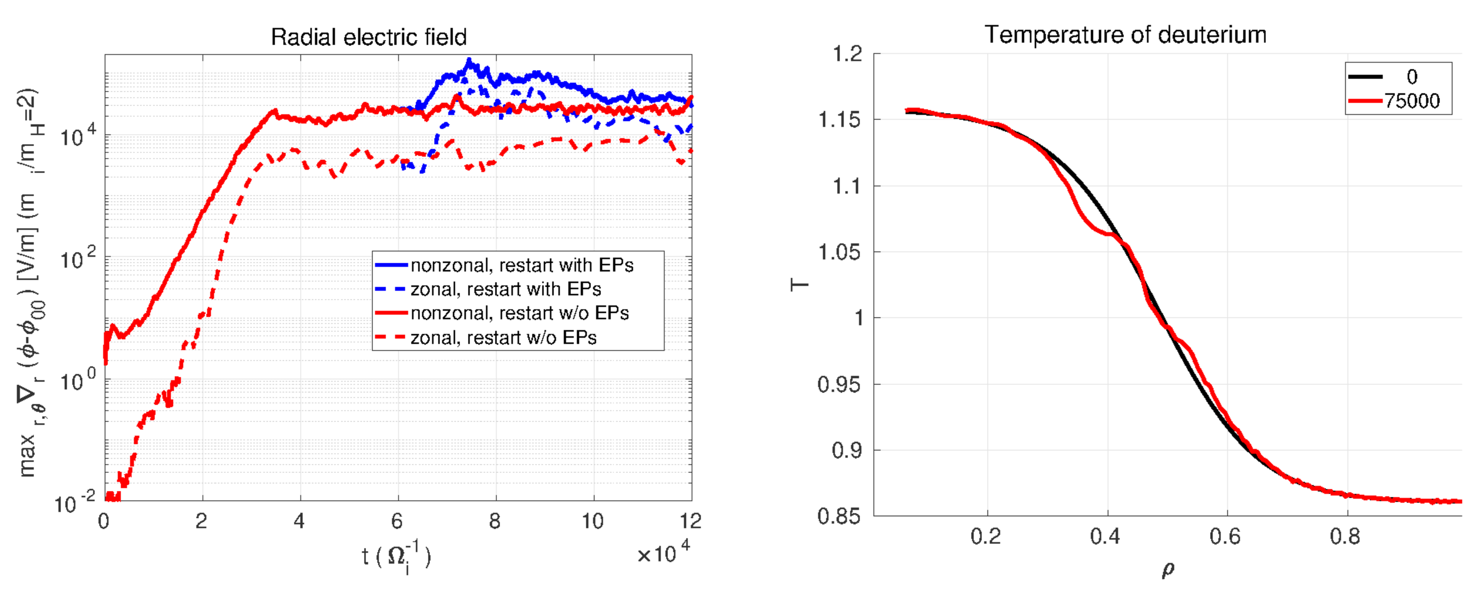

Fig. 2. *On the left, radial electric field for a simulation with EPs (blue) and without EPs (red). On the right, modified ion temperature profile (red) compared with the unperturbed profile (black).*

◇ The heat flux carried by the AM modifies the equilibrium profiles, like in Ref. [17].

◇ The modified profiles are saved, and used as input for ES ITG simulations.

4 Second part of the numerical experiment: effect of the modified profiles on the turbulence dynamics

◇ In this section: results of nonlinear global electrostatic simulations

◇ Only ITG turbulence here (and zonal flows). No EPs, no AMs.

◇ The profiles modified by the AM, are loaded here as input equilibrium profiles.

◇ Heat fluxes of the simulations with the modified profiles are about a factor 2 lower than the heat fluxes of the simulations with unperturbed profiles.

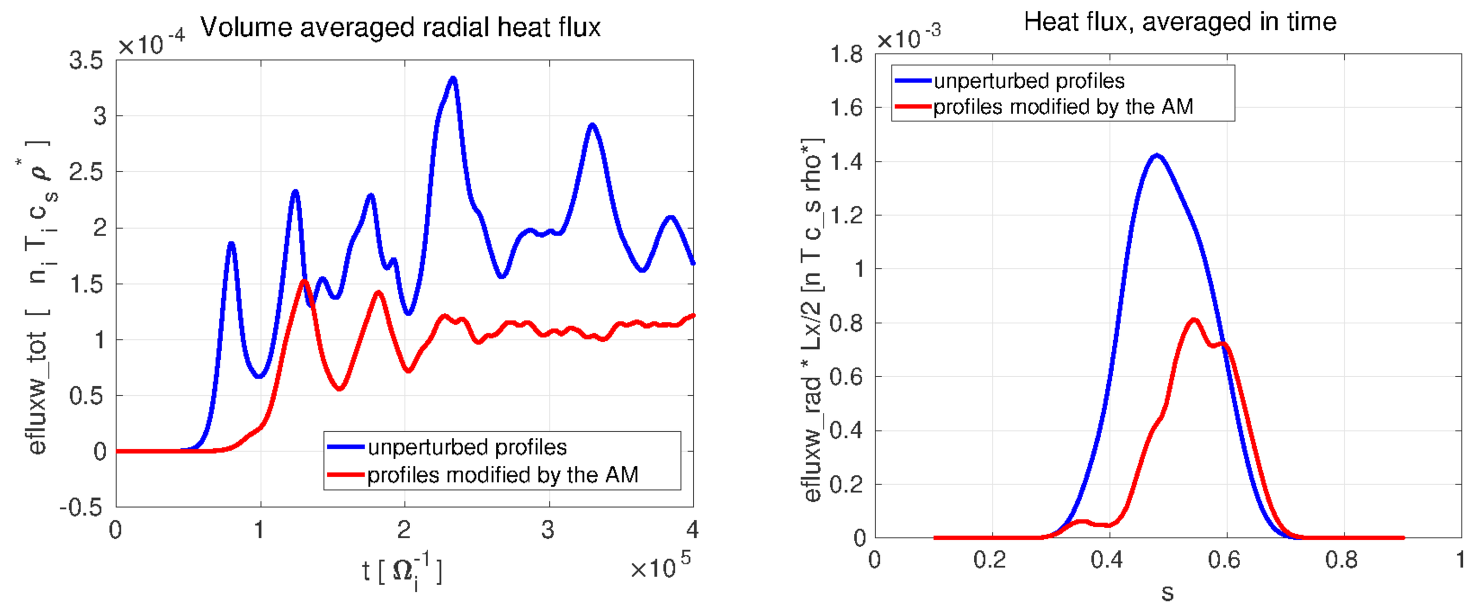

Fig. 3. *Turbulence intensity (estimated by means of heat fluxes) in the ES simulation for the unperturbed profiles (blue) and for the profiles modified by the AM (red).*

5 Conclusions and next steps

◇ Modification of the equilibrium profiles due to AMs studied with EM simulations

◇ Effect of the profile modification on turbulence studied with ES ITG simulations

◇ Turbulence found to be reduced when profiles modified by the AM are used, with respect to unperturbed profiles → indirect reduction of turbulence by AMs.

◇ Next step 1: measurement of phase-space zonal structures [18] in the simulations, to characterize the transport.

◇ Next step 2: relaxing some simplifications on the configuration, to be closer to the experiments, like in Refs. [22, 23, 24].

◇ Next step 3: effects on turbulence in self-consistent sims, with linearly unstable AMs (like in Ref. [17]) or marginally stable AMs (like in Ref. [16]), with ORB5.

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