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Study of Alfvénic modes driven by energetic particles using the code HYMAGYC for the NLED AUG testcase and DTT equilibria

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INTRODUCTION / MOTIVATION

One of the major challenges in magnetic confinement thermonuclear fusion research concerns the confinement, inside the reaction chamber, of the energetic particles (EPs) produced by fusion reactions and/or by additional heating systems: electron and ion cyclotron resonant heating, and neutral beam injection. In such experiments EPs can resonantly interact with the shear Alfvén waves, having velocities of the order of the Alfvén velocity. In order to predict and, eventually, minimize the EP transport in the next generation fusion devices, several numerical models, based on different theoretical approaches, have been developed.

HYMAGYC

HYBRID MAGNETOHYDRODINAMIC GYROKINETIC CODE [1]

- Suited to study the interaction between EPs and Alfvénic modes
- For high-β axisymmetric equilibria
- Electromagnetic fields are fully retained: electrostatic potential φ and vector potential **A**
- Thermal plasma is described as a single fluid by full resistive linear MHD equations.
- The fields solver originates from the code MARS [2] transformed from an eigenvalue solver to an initial value one.
- Energetic particles are described by nonlinear gyrokinetic Vlasov equations [3] expanded up to order $O(\varepsilon^2)$ and $O(\varepsilon\varepsilon_B)$ and solved by particle-in-cell (PIC) techniques.
- The MHD and the gyrokinetic modules, are coupled toghether by inserting the divergence of the EP pressure tensor in the MHD momentum equations [4]

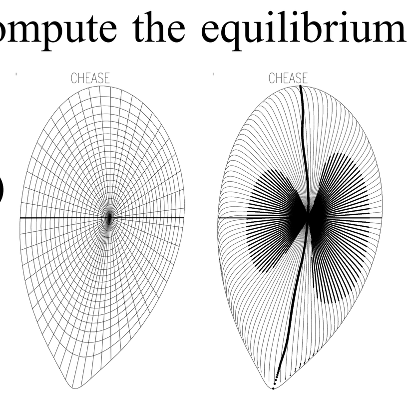
ORDERING and DEFINITIONS

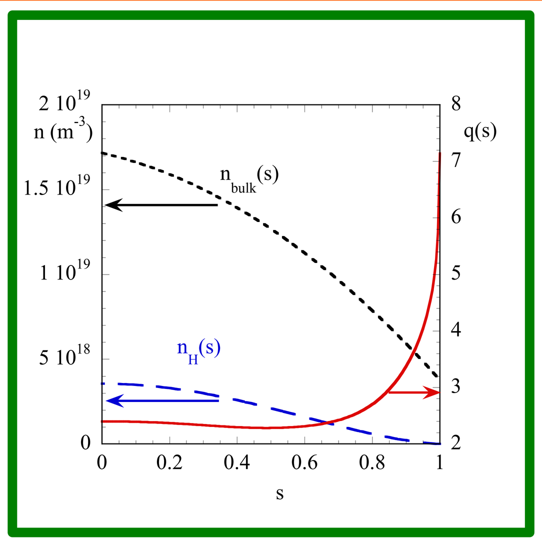
- gyrokinetic ordering parameter $\varepsilon \simeq \rho_H/L_n$
- $\varepsilon_B \simeq \rho_H/L_B$,
- ρ_H the EP Larmor radius
- L_n/L_B the characteristic length scales of the equilibrium plasma density/magnetic field.
- Space-time ordering for the fluctuating electromagnetic fields: $k_\perp\rho_H=O(1)$, $k_\parallel\rho_H=O(\varepsilon)$, $\omega/\Omega_H=O(\varepsilon)$
- $k_\perp$ the perpendicular (to the equilibrium magnetic field) wave vector
- $k_\parallel$ the parallel one
- ω: characteristic fluctuation frequency and Ω_H the EP gyrofrequency.

NLED AUG TESTCASE

The AUG NLED model equilibrium scenario [5] has been used and analyzed by the CHEASE code, in order to compute the equilibrium quantities required by HYMAGYC

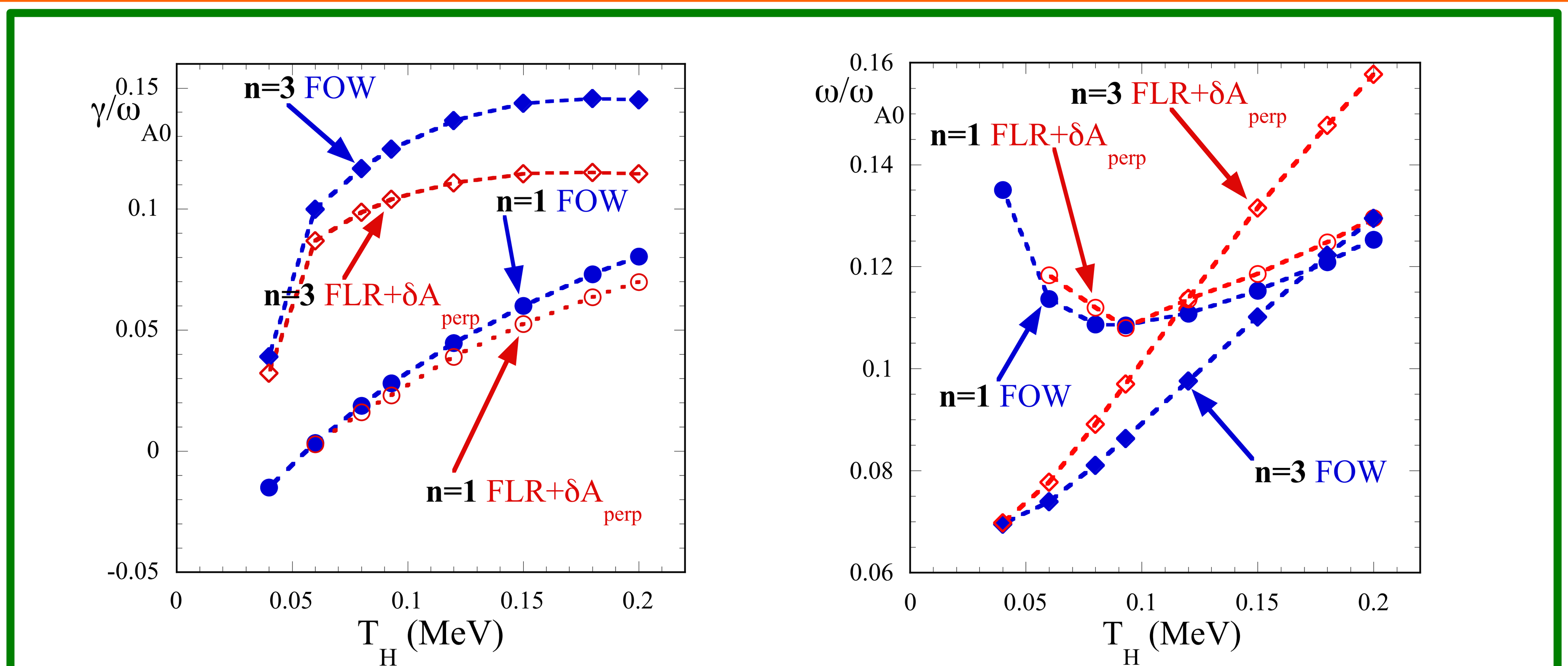
- on-axis magnetic field $\mathbf{B_0=2.208T}$,
- magnetic axis radius $\mathbf{R_0=1.67m}$ ($\mathbf{R_{geo}=1.62m}$)
- minor radius **a=0.482m**



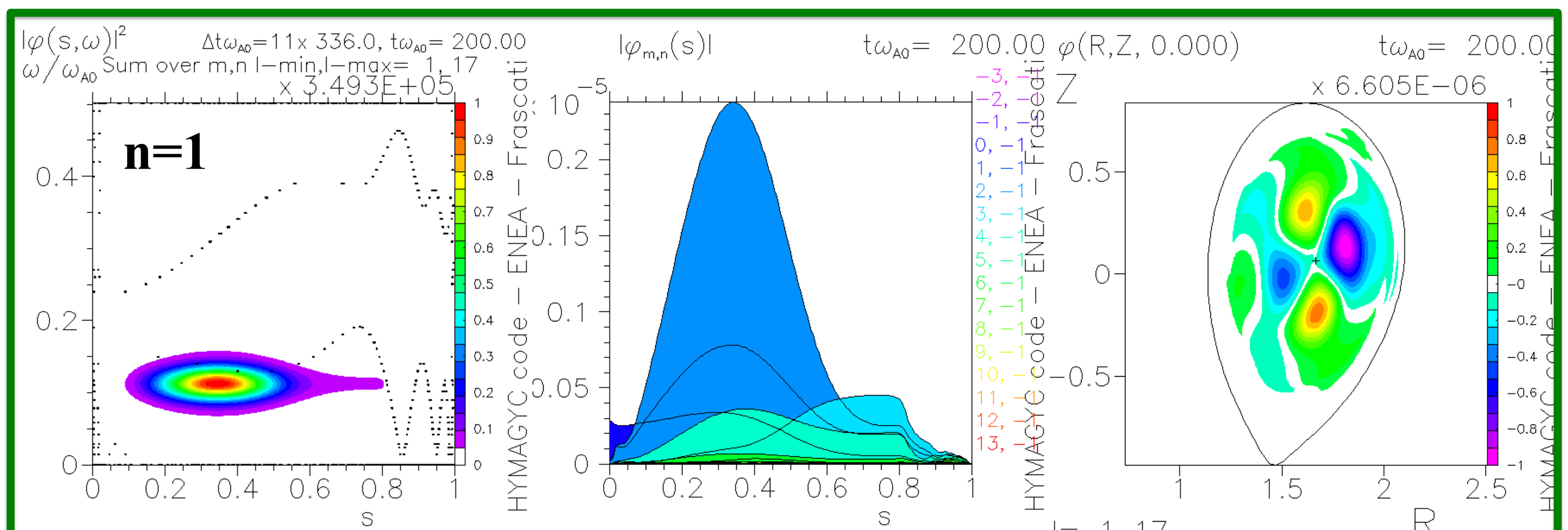


HYMAGYC DATA

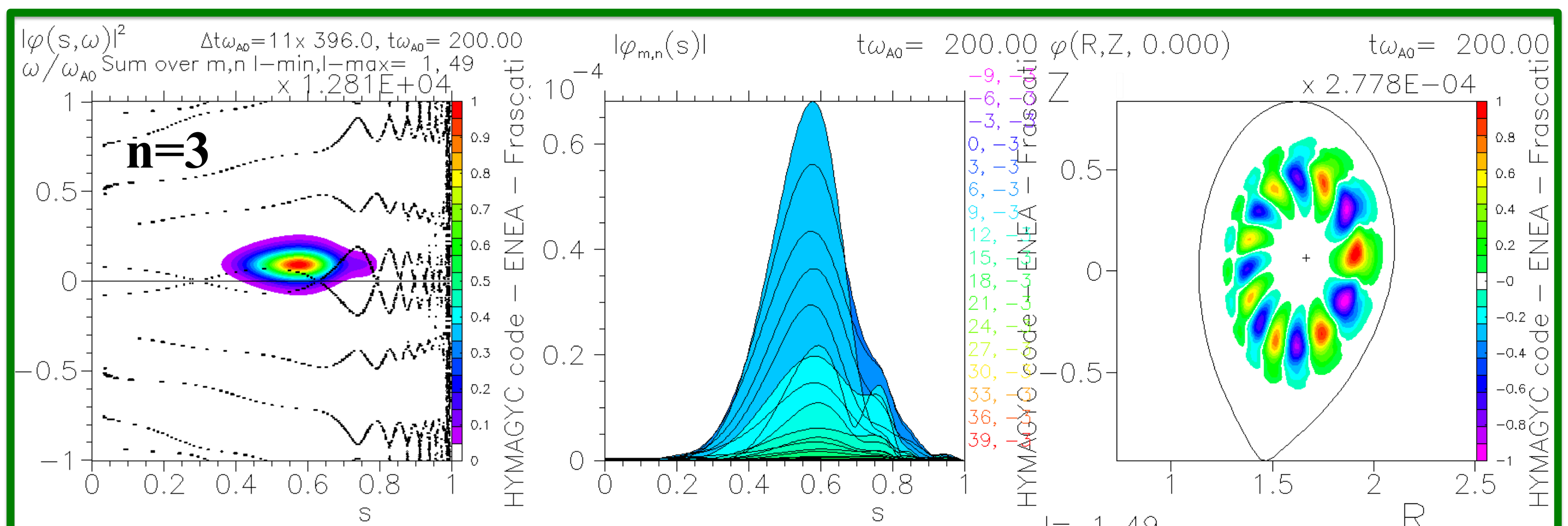
- metric tensor components, equilibrium magnetic field, current and pressure components
- Deuterium bulk plasma $n_i(s)$, $s \propto (\psi_{norm})^{1/2}$ (ψ_{norm} is the normalized poloidal flux function)
- Maxwellian EP population of deuterium, monotonic radial profile, $\mathbf{n_{H0}/n_{i0} \simeq 0.207}$; $\mathbf{m_H/m_i=1}$
- flat nominal temperature $\mathbf{T_H=0.093}$ MeV; $\mathbf{v_{H0}/v_{A0} \simeq 0.257}$ (with $v_H=(T_H/m_H)^{1/2}$)
- ratio of the on-axis EP Larmor radius to the minor radius $\mathbf{\rho_{H0}/a \simeq 0.04}$; adiabatic index $\Gamma=0$.



Linear growth-rate (left) and frequency (right) vs. T_H, for **n=1** (circle symbols) and **n=3** (diamond symbols). Results obtained considering only FOW effects are shown in blue, filled symbols, while results retaining full FLR and $\delta A_\perp$ effects are shown in red, open symbols.



Results retaining only **FOW** effects. Left: power spectrum of the fluctuating electrostatic potential φ in the plane (s,ω); Alfvén continua have been obtained with the MHD linear stability eigenvalue code MARS and they are shown with black dots. Center: poloidal Fourier components $|\varphi_{m,n=1}|$ vs. s. Right: φ(R,Z) for the toroidal angle ϕ=0.Nominal temperature $\mathbf{T_H=0.093}$ MeV. The mode is a RSAE.



Results retaining only **FOW** effects (same quantities as in the **n=1** plots). The mode is a TAE.

AUG n=1 non-linear simulations for monotonic and non-monotonic EP density profile

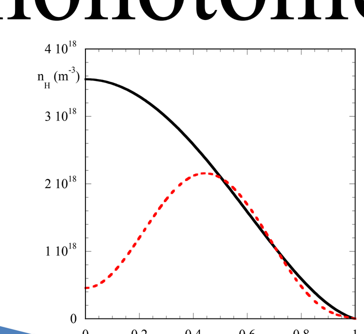
Monotonic EP density profile, full FLR and $\delta A_\perp$ effects retained

- $n_{H0}/n_{i0} \simeq 0.207$, $T_H = 0.093$MeV

Linear phase:

$\gamma_{lin}/\omega_{A0} \approx 0.026$; $\omega_{lin}/\omega_{A0} \approx +0.113$

$\gamma_{lin} \approx 127923[s^{-1}]$; $\omega_{lin} \approx +88.4$ [kHz]



Non-monotonic EP density profile, full FLR and $\delta A_\perp$ effects retained

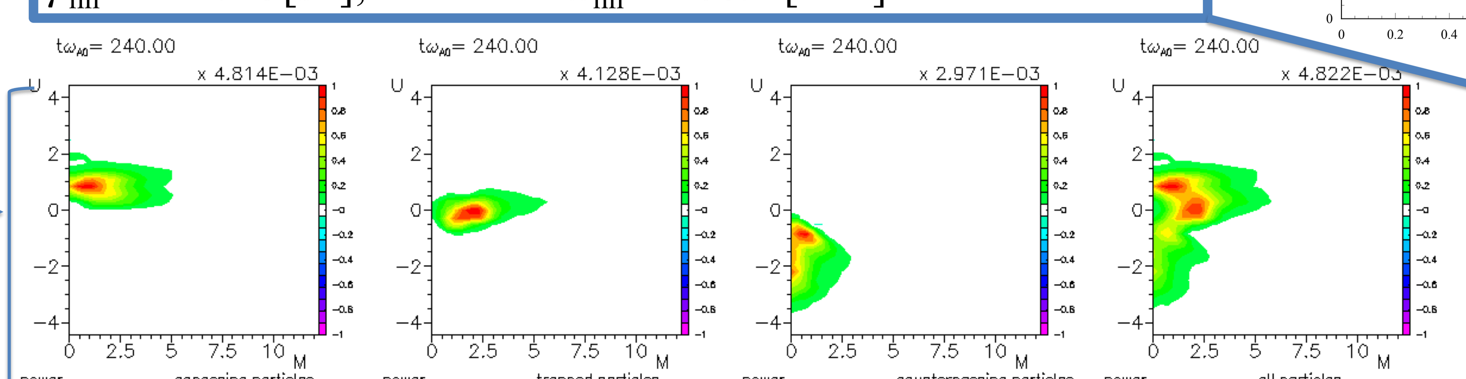
- $n_{H0}/n_{i0} \simeq 0.0267$, $T_H = 0.093$MeV

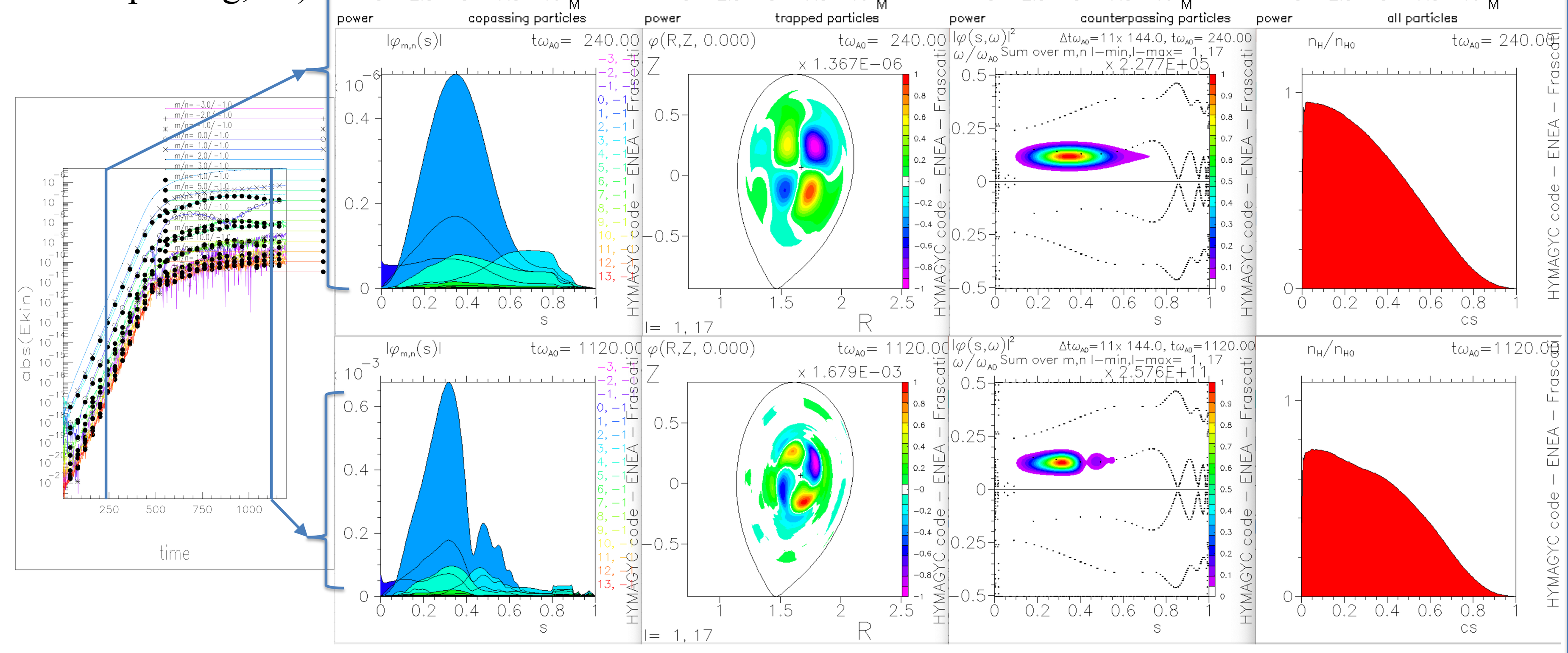
Linear phase:

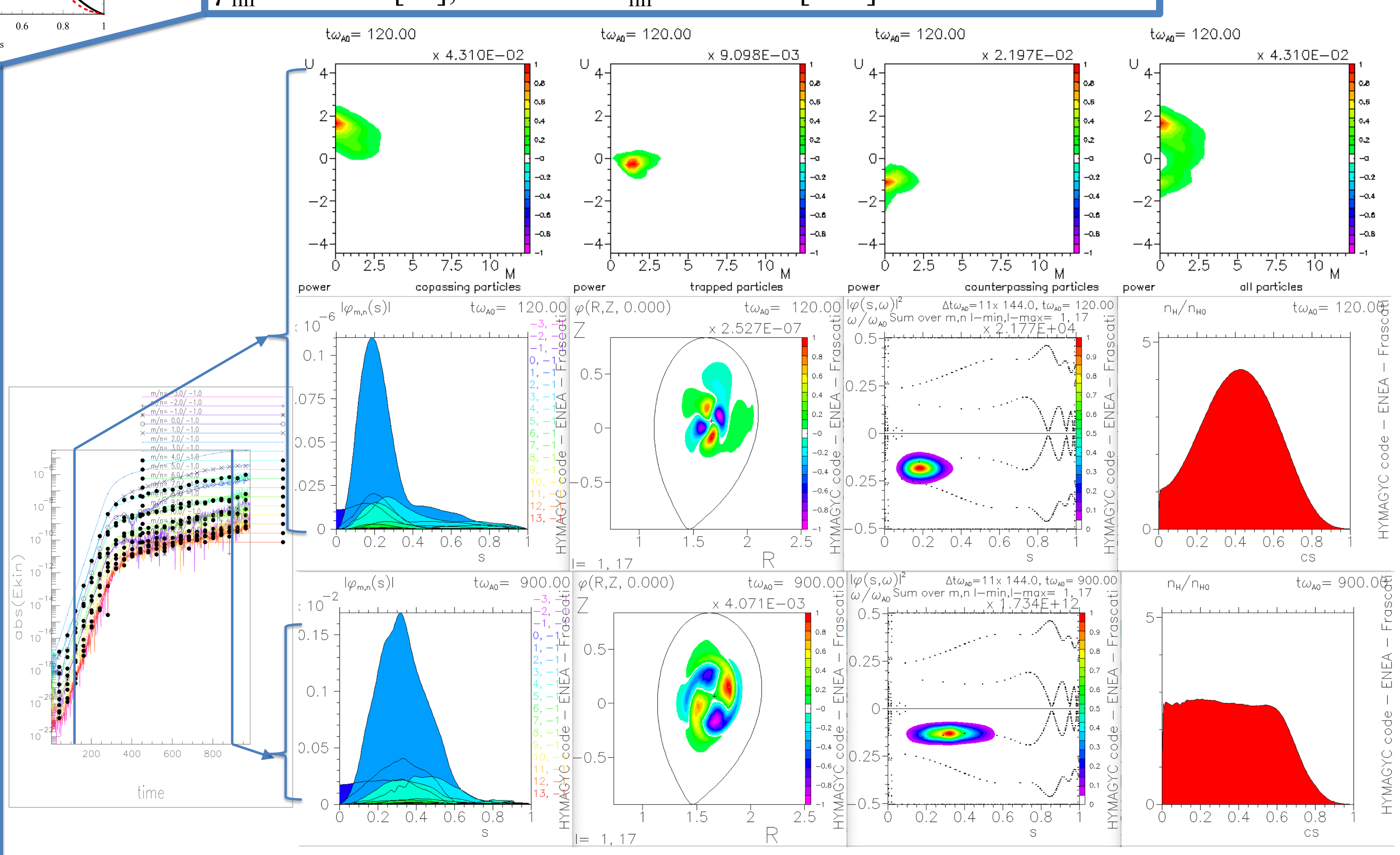
$\gamma_{lin}/\omega_{A0} \approx 0.044$; $\omega_{lin}/\omega_{A0} \approx -0.187$

$\gamma_{lin} \approx 215624[s^{-1}]$; $\omega_{lin} \approx -147.03$ [kHz]

Wave-particle power exchange during linear phase in the (μ,u) plane (co-passing, trapped, counter-passing, all)



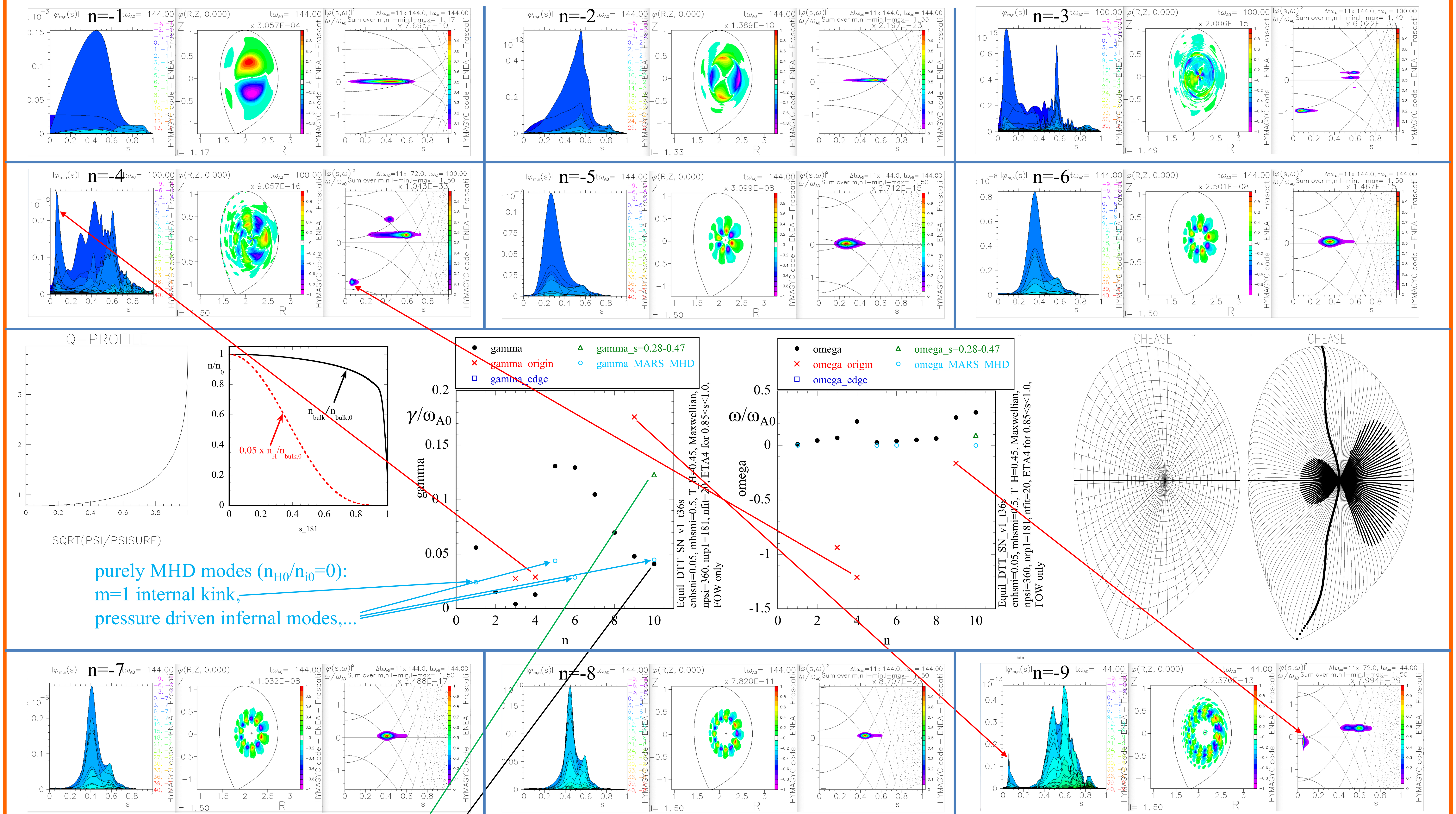


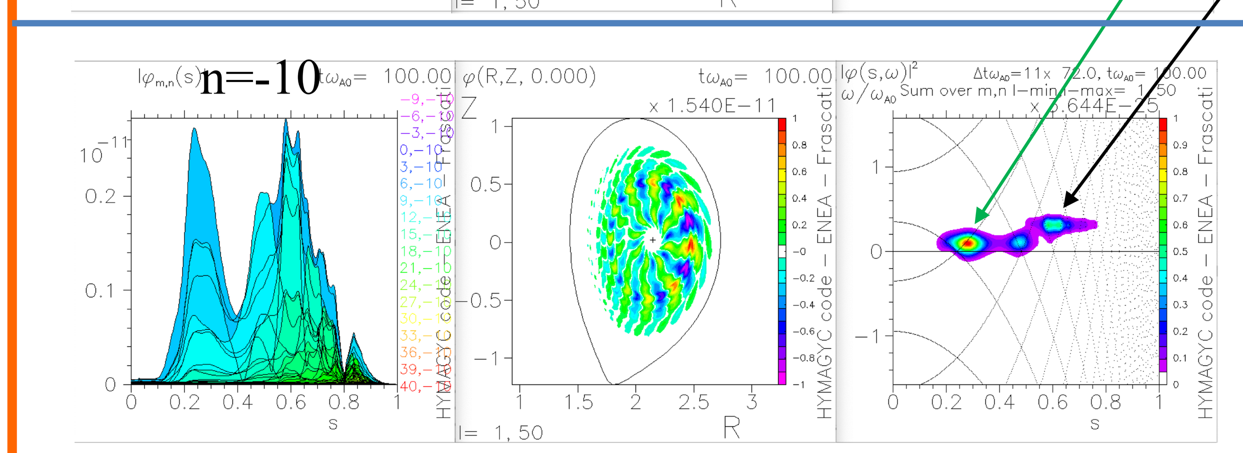


The mode driven by the monotonic EP radial density profile rotates clockwise, is located at mid radius close to the maximum EP radial gradient and to the minimum of the q profile, and just below the toroidal gap lower continuum (RSAE).The mode driven by the non-monotonic EP radial density profile rotates, on the contrary, in the opposite direction (counter-clockwise), being located radially more internally, where the radial density gradient has opposite sign, and within the toroidal gap in frequency. Both the modes saturates while flattening the EP radial profile in the radial region where the modes are located.

DTT, the Divertor Tokamak Test facility, is the new plasma physics research device under construction in Italy, which will benefit from a substantial support from EUROfusion to specifically address the problem of heating and power exhaust in ITER and DEMO devices. DTT characteristic parameters are: toroidal field $B_0 = 6.0$T, major radius $R_0 = 2.08$m, aspect ratio $A \approx 3.2$, plasma current I_p=5.5 MA, additional power P_{Tot}=45 MW.

Here some preliminary results for the linear dynamics of EP driven Alfvén modes are shown, for a Single Null (SN) baseline scenario.





DTT, v1, Single Null, v1, t=36s

Key ingredients to get almost "clean" simulations:

- increase the radial MHD mesh (to control numerical instabilities at the edge, and, occasionally, at the center) =>use *parmhd* version of MHD solver of HYMAGYC
- add some diffusion (a resistivity step) locally at the edge to control edge instabilities
- increase "*nfit*": # points where the regularization of v^s close to the magnetic axis is imposed
- regularize also $\nabla \cdot \mathbf{\Pi_i}$ on the first "*nfit*" radial points

$B_0 = 6.0$T
$R_0 = 2.08$m
$\beta_{th,0} \approx 4\%$
$T_H = 0.45$MeV
$n_{H0}/n_{i0} \approx 0.05$
$\beta_{H,0}/\beta_{th,0} \gtrsim 1$
$m_H/m_i = 0.5$ (H/D)

$\rho_H/a \approx 0.017$
$v_H/v_{A0} = 1.$
Γ=5/3
Maxwellian EPs
FOW only

Acknowledgments

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