A benchmark between HYMAGYC, MEGA and ORB5 codes using the NLED-AUG test case to study Alfvénic modes driven by energetic particles

G. Vlad[1] (gregorio.vlad@enea.it), X. Wang[3], F. Vannini[2], S. Briguglio[1], N. Carlevaro[1], M. Falessi[1], G. Fogaccia[1], V. Fusco[1], F. Zonca[1,3], A. Biancalani[2], A. Bottino[2], T. Hayward-Schneider[2], P. Lauber[2]

[1]ENEA, Fusion and Nuclear Safety Department, C. R. Frascati, Via E. Fermi 45, 00044 Frascati (Roma), Italy

[2]Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching, Germany

[3]IFTS and Department of Physics, Zhejiang University, Hangzhou 310027, People's Republic of China

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ABSTRACT

- In the frame of the EUROfusion ENR project MET [1](Multi-scale Energetic particle Transport in fusion devices), a detailed benchmark activity has been undertaken among few of the state-of-the-art codes available to study the self-consistent interaction of an EP population with the shear Alfvén waves, in real magnetic equilibria and in regimes of interest for the forthcoming generation devices
- The codes considered are HYMAGYC [2], MEGA [3], and ORB5 [4], the first two being hybrid MHD-Gyrokinetic codes (bulk plasma is represented by MHD equations, while the EP species is treated using the gyrokinetic formalism), the third being a global electromagnetic gyrokinetic code (both bulk and EP species are treated using the gyrokinetic formalism)
- Here we decided to use a realistic, shaped cross section, equilibrium from AUG proposed by Philipp Lauber (so-called NLED-AUG [5] test case), considering both peaked on-axis and off-axis EP density profiles

Benchmark equilibrium and code parameters

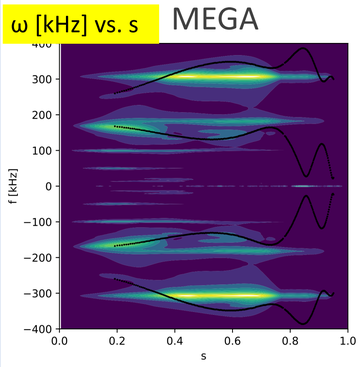
- the same input equilibrium file (EQDSK) has been considered for all the codes
- ion density profile has been obtained by imposing quasi-neutrality ($n_i + n_H = n_e$), as required by ORB5 (n_i, n_e, n_H being the bulk ions, electrons, and EP densities, respectively, both bulk ions and EPs are assumed to be Deuterons)
- finite resistivity $\eta/(\mu_0 R_0 v_{A0})=5\times10^{-7}$, and adiabatic index $\Gamma=5/3$ have been assumed for both the hybrid codes (HYMAGYC and MEGA); MEGA also consider finite viscosity $\nu/(R_0 v_{A0})=5\times10^{-7}$
- only Finite orbit width (FOW) effects has been retained and isotropic Maxwellian EP distribution function of Deuterons with T_H =93 keV, constant in radius
- Other typical parameters for the two scenarios considered (AUG peaked on-axis, and AUG peaked off-axis EP density profiles) are (”0” pedix means on-axis values):

B_0 = 2.208 [T], $I_p = 8.1434\times10^5$ [A],
R_0/a =1.666 [m]/0.483 [m],
n_{e0} = 0.171587 [10^{20}/m^3],
n_{H0} = (0.03552, 0.00458182) [10^{20}/m^3],
n_{i0} = (0.136067, 0.16700518) [10^{20}/m^3],
ω_{A0} = (5.53876, 4.99947) [10^6 rad/s],
$v_{H,th0}$ = 2.1111 [10^6 m/s],
ϱ_{H0} = 0.0199221 [m],
n_{H0}/n_{i0} = (0.261048, 0.0274352),
$v_{H,th0}/v_{A0}$ = (0.228782, 0.253461),
ϱ_{H0}/a = 0.041279.

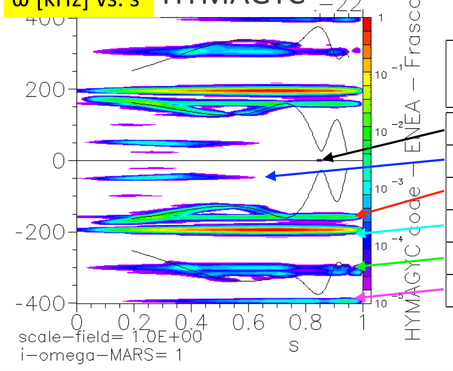
Characterization of Alfvénic spectra ($|\varphi(s,\omega)|^2$) in MHD limit

- Toroidal mode number n=1, no EP drive • MEGA (left) and HYMAGYC (right) show very similar spectra
- MEGA exhibits larger damping.

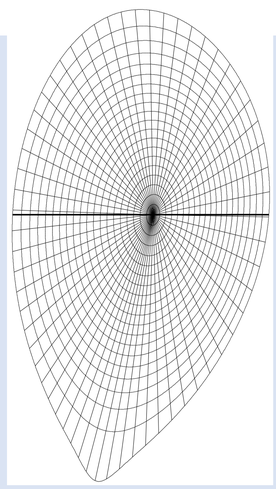
ω [kHz] vs. s — MEGA



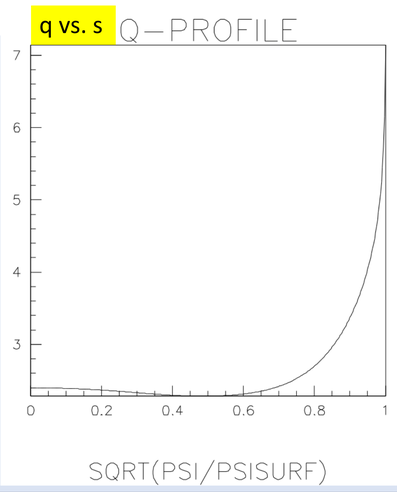
ω [kHz] vs. s — HYMAGYC



	HYMAGYC $\gamma_{HYMAGYC}$ [s^{-1}]	HYMAGYC $\omega_{HYMAGYC}$ [kHz]	MEGA γ_{MEGA} [s^{-1}]	MEGA ω_{MEGA} [kHz]	ORB5 $\gamma^{\dagger}_{ORB5}$ [s^{-1}]	ORB5 $\omega^{\dagger}_{ORB5}$ [kHz]
Tearing	4080.2	0.0				
BAE	-9267.0	-49.3				
TAE-2	-14594.6	-159.2	-45060.0	-171.9	≈ −10000.	-146.
TAE-1	-6455.3	-195.8	-36057.0	-185.2	≈ −6000.	-206.
TAE-3	-29484.2	-301.4	-30120.0	-304.2		
EAE	-13542.3	-395.8				



q vs. s — Q–PROFILE

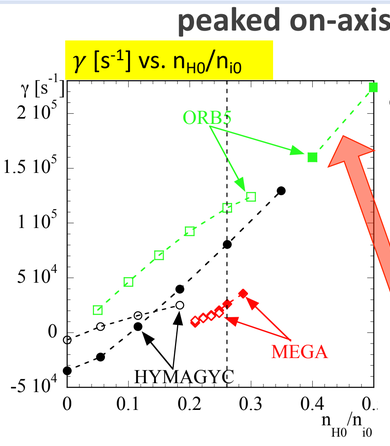


peaked on-axis EP density profile

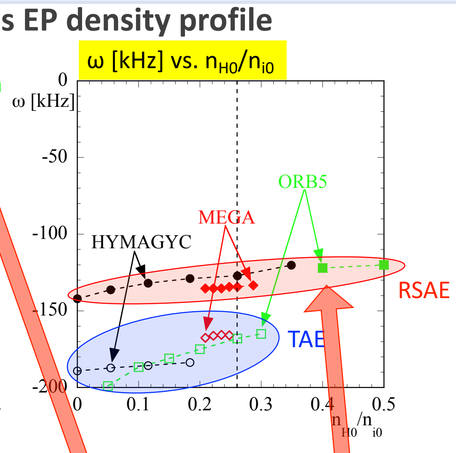
EP density scan

peaked on-axis EP density profile

γ [s^{-1}] vs. n_{H0}/n_{i0}



ω [kHz] vs. n_{H0}/n_{i0}

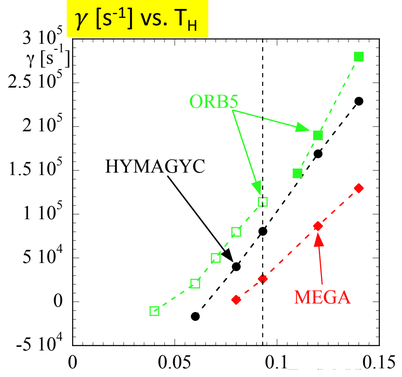


- All codes observe as most unstable mode:
  - a TAE for low values of n_{H0}/n_{i0},
  - a RSAE for high values of n_{H0}/n_{i0}.

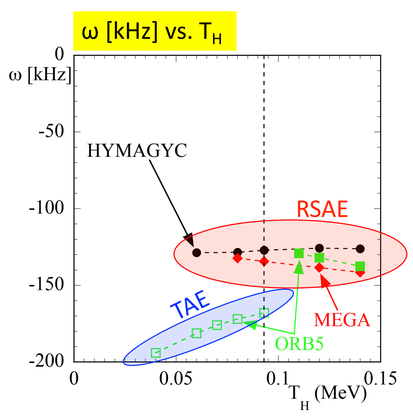
EP T_H scan

peaked on-axis EP density profile

γ [s^{-1}] vs. T_H

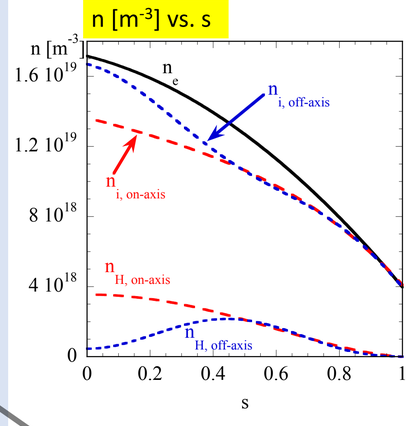


ω [kHz] vs. T_H



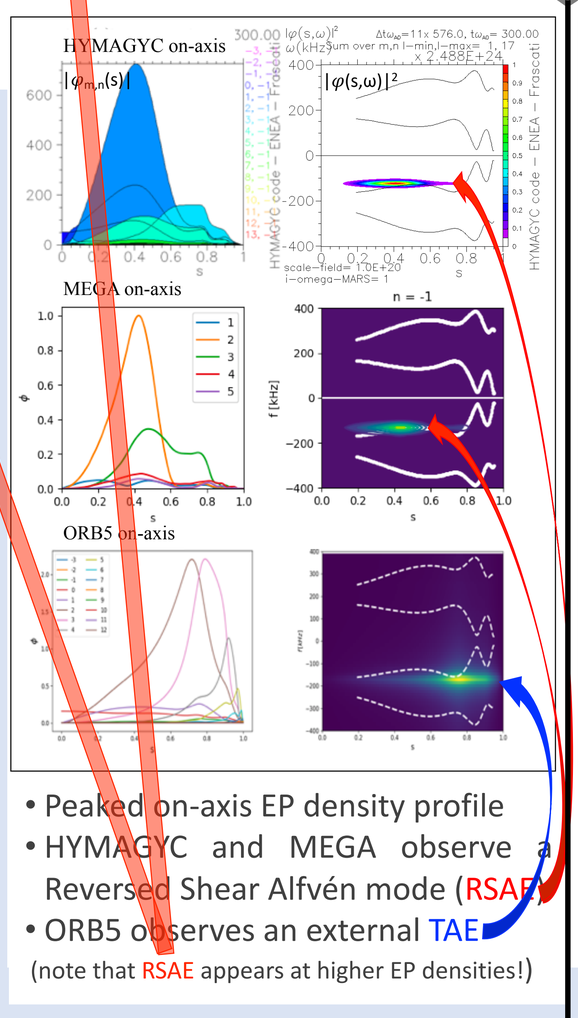
Density profiles

n [m^{-3}] vs. s



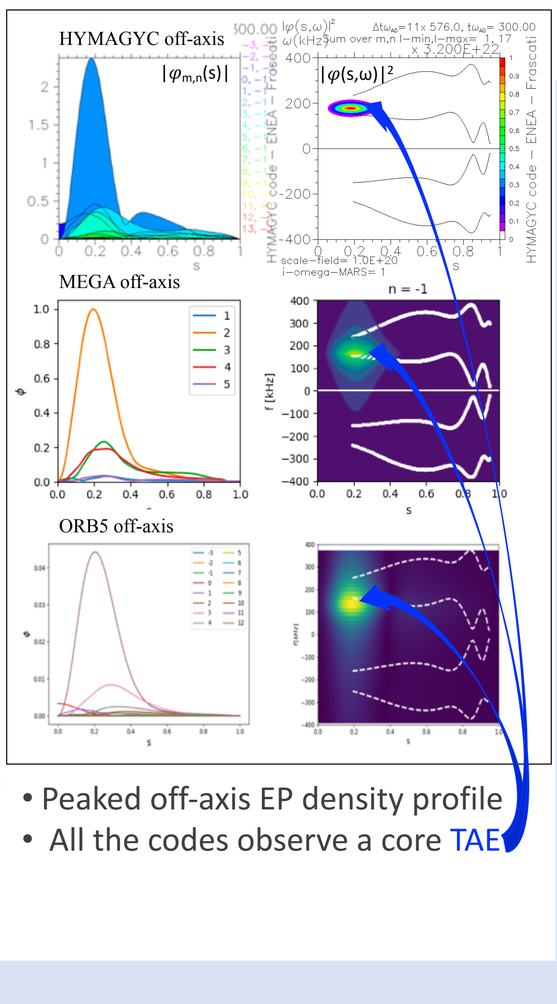
Nominal cases comparison, n=1

- Toroidal mode number n=1



- Peaked on-axis EP density profile
- HYMAGYC and MEGA observe a Reversed Shear Alfvén mode (RSAE)
- ORB5 observes an external TAE

(note that RSAE appears at higher EP densities!)



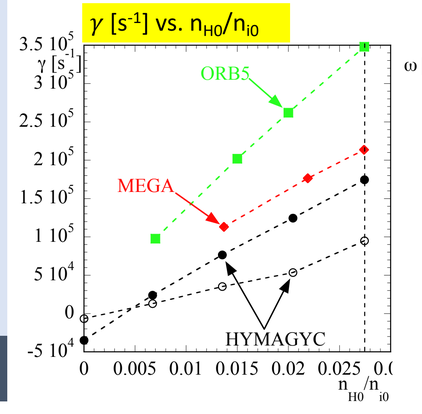
- Peaked off-axis EP density profile
- All the codes observe a core TAE

peaked off-axis EP density profile

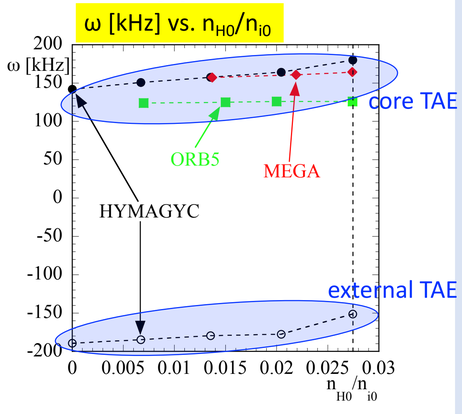
EP density scan

peaked off-axis EP density profile

γ [s^{-1}] vs. n_{H0}/n_{i0}



ω [kHz] vs. n_{H0}/n_{i0}

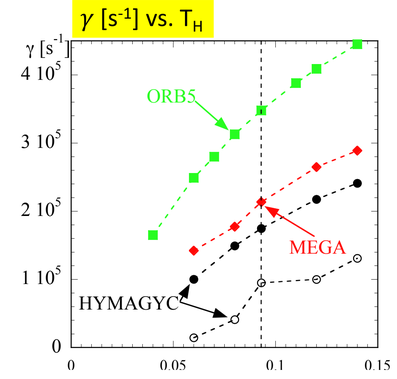


- All codes observe a core TAE;
- HYMAGYC observes also a (weaker) external TAE

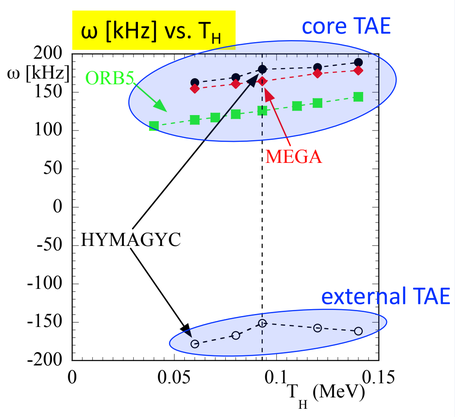
EP T_H scan

peaked off-axis EP density profile

γ [s^{-1}] vs. T_H



ω [kHz] vs. T_H



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