Kinetic effects of core plasma on the low frequency Alfvén and Acoustic eigenmodes in tokamaks

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Ilija Chavdarovski[1], Fulvio Zonca[2] and Liu Chen[3]

[1]Korea Institute of Fusion Energy, Daejeon, Republic of Korea

[2]C.R. ENEA Frascati, Rome, Italy

[3]Dept. of Physics and Astronomy, Univ. of California, Irvine CA, U.S.A.

chavdarovski@gmail.com

ABSTRACT

- Beta-induced Alfvén- Acoustic Eigenmodes (**BAAEs**) and Kinetic Ballooning Modes (**KBMs**) are examined in the framework of the generalized fishbone-like dispersion relation (GFLDR).
- Core plasma **diamagnetic effects and precession resonance** with trapped ions affect the excitation of low frequency modes, more effectively than the energetic particles. They also contribute to the coupling of the modes, affecting their excitation and polarization.
- Energetic particles can provide for a **non-resonant drive** for the reactive instabilities. BAAEs do not cause EP transport.

BACKGROUND

- Number of experiments misidentify Alfvénic modes with frequency related to ω_{*pi} driven by energetic particles, as "BAAEs".
- DIII-D tokamak has shown modes appearing at the m/n rational surface. in a "Christmas lights" pattern due to time evolution of the q-profile.
- Identification of the mode has to include the frequency, damping rate and its **polarization**

$$S(\omega, \omega_{Bi}, \overline{\omega_{Di}}, \omega_{Ti}) = \frac{k_\vartheta}{k_\perp}\frac{\delta\Phi_s(\theta_1)}{\delta\Phi^{(0)}}$$

where for Alfvénic modes $|\mathbf{S}|\sim\beta^{1/2}$, while acoustic and mixed $|\mathbf{S}|>>\beta^{1/2}$. Here

$$\delta\Phi \simeq \delta\Phi^{(0)} + \delta\Phi_s(\theta_1)\sin\theta_0$$

- The general description of the modes located in the Beta-induced gap, has to include resonant thermal ion effects, as well as background plasma parameters and non-resonant EP drive.

THEORETICAL MODEL

- **GFLDR** is a unifying picture for various Alfvénic fluctuations and EPMs, that contains all the relevant physics in the thermal ion kinetic gap necessary to explain the linear excitation of low frequency branches, reactive or resonant. The GFLDR reads:

$$i\Lambda(\omega) = \delta\bar{W}_f + \delta\bar{W}_k$$

where the LHS is the *general inertia* inside the inertial layer, while the RHS terms are the *ideal region background MHD* and *energetic particle kinetic* potentials, respectively.

• THE GENERAL INERTIA

Contains the thermal ions transit/bounce resonances and diamagnetic effects of the core plasma:

$$\Lambda^2/I_\Phi = \frac{\omega^2}{\omega_A^2}\left(1-\frac{\omega_{*pi}}{\omega}\right) + \Lambda^2_{cir} + \Lambda^2_{tra}$$

with $\delta\Phi^{(0)} = I_\Phi(\omega, \omega_{Di,e}, \omega_{*i,e})\delta\Psi^{(0)}$.

• DRIVE FROM PRECESSION RESONANCE

Thermal ion and electron precessional resonant drive is described by:

$$\delta\bar{W}_{kt} = \frac{2\pi^2}{|s|}\frac{e^2}{mc^2}qR_0B_0\int d\varepsilon\int d\mu\left(\frac{\overline{\omega}_D}{k_\vartheta}\right)^2\left(1-\frac{\Delta_{b0}}{(1+\Delta_{b0})^{1/2}}\right)\frac{\tau_b QF_0}{\overline{\omega}_D-\omega}$$

Background plasma effects $(s,\alpha,q,T_e/T_i,\eta_i)$ and **non-resonant EP** effects $(\beta_E \text{ and } \nabla n_E)$ are given in:

$$\delta\bar{W}_f \simeq \frac{\pi}{|s|}\left[\frac{s^2}{4}-\frac{3\alpha|s|}{2}+\frac{5\alpha^2s^2}{32}+\frac{45\alpha^4}{128}-(1+\frac{\alpha}{2})e^{-\frac{1}{|s|}}\right]$$

CONTINUOUS SPECTRUM

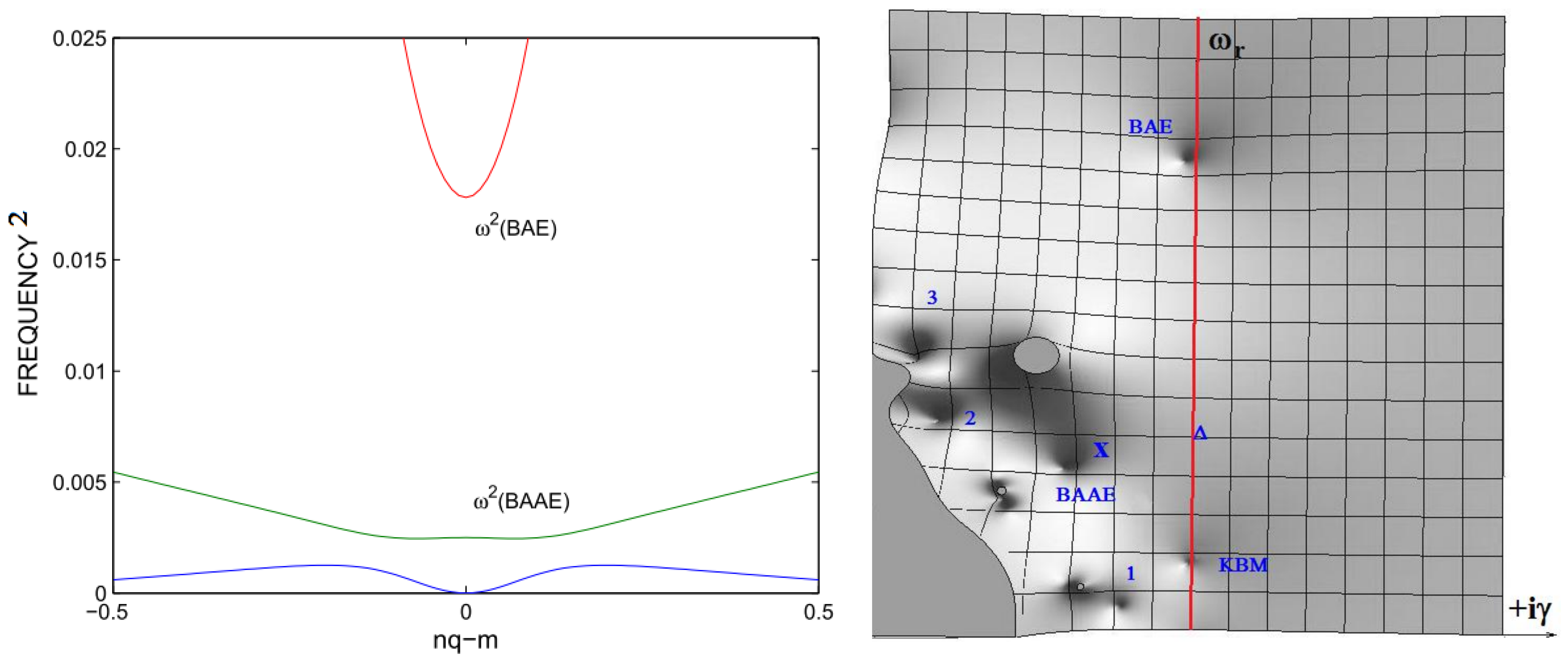

FIG.1.Continuous spectrum and accumulation points of low frequency modes 'x' is KBM and 'Δ' -BAAE for high ∇T_i .

RESULTS

The modes are **coupled** via diamagnetic effects. Their coupling affects the real frequency, growth rate and their polarization.

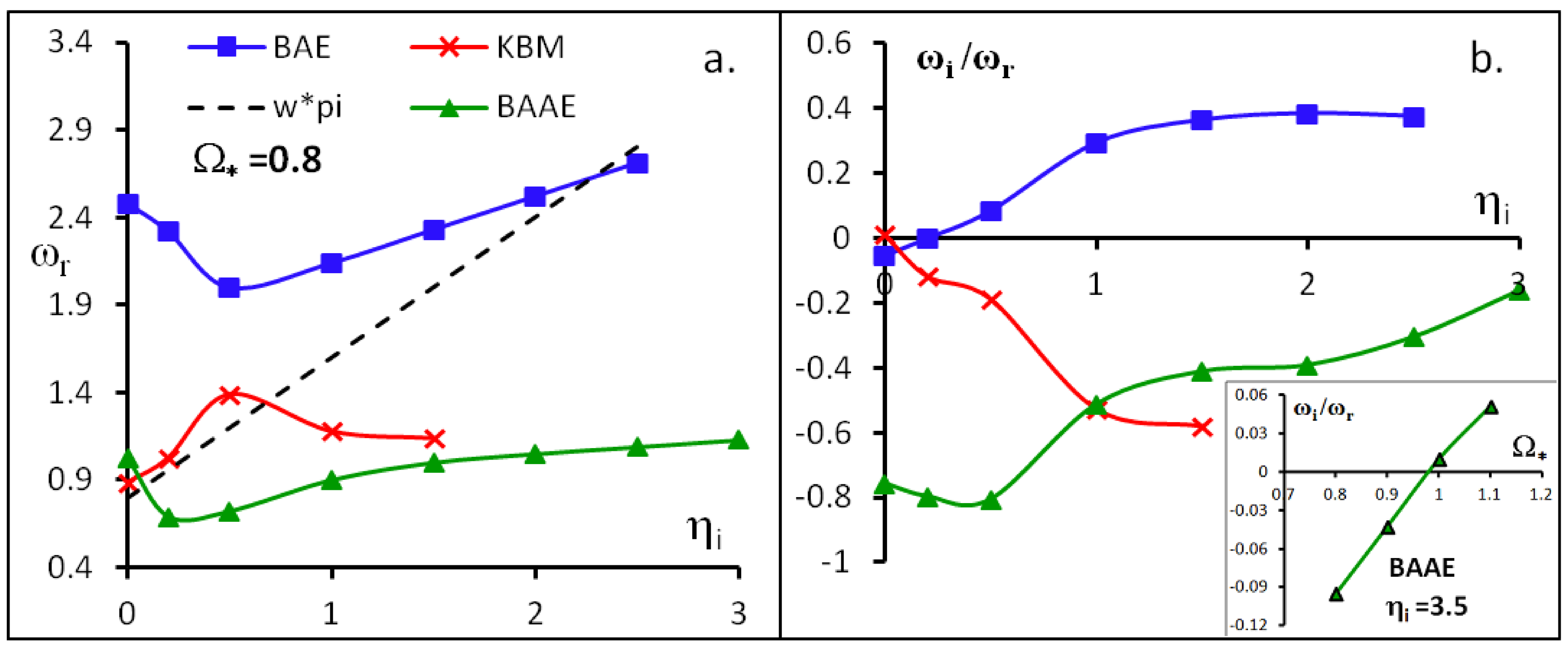

FIG.2. Coupling of the Alfven and acoustic modes (see also P1-643)

•BAAE

For low ω_{*pi} the mode is heavily damped. Its coupling to KBM decreases the damping rate. It can be destabilized by thermal particles at high ∇T_i, with thermal precession resonance, or non-resonant drive by EPs.

•KBM

For low ω_{*pi} the mode is marginally stable with frequency around ω_{*pi} Damping rate is growing with T_i and ∇T_i . The accumulation point is not correlated with T_e, but electrons can affects the drive from RHS of GFLDR.

• LFEM

Belong to the same branch as KBM in the dispersion relation, they are excited non-resonantly (reactive instability), located around q=m/n, driven by high T_e (from $\delta\bar{W}_f+\delta\bar{W}_k$) and damped by high T_i and ∇T_i .

CONCLUSIONS

- GFLDR contains all the necessary ingredients to describe the low frequency Alfvén and acoustic modes and give explanation to experimental results, as well as make predictions.
- GFLDR can analytically track the origin of the modes and their polarization, thus offering a better understanding of the experimental data.
- The modes in the BAE gap are **coupled via the ion diamagnetic frequency**, with the ion temperature gradient playing an essential role.
- The modes identified as BAAEs in experiments are driven non-resonantly by EPs, and **do not cause significant EP transport**.