Simulations of Energetic Particle Driven Geodesic Acoustic Mode and Global Alfvén Eigenmode in 3-dimensional LHD Equilibrium

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Outline

- Introduction
- Simulation Results
- Summary

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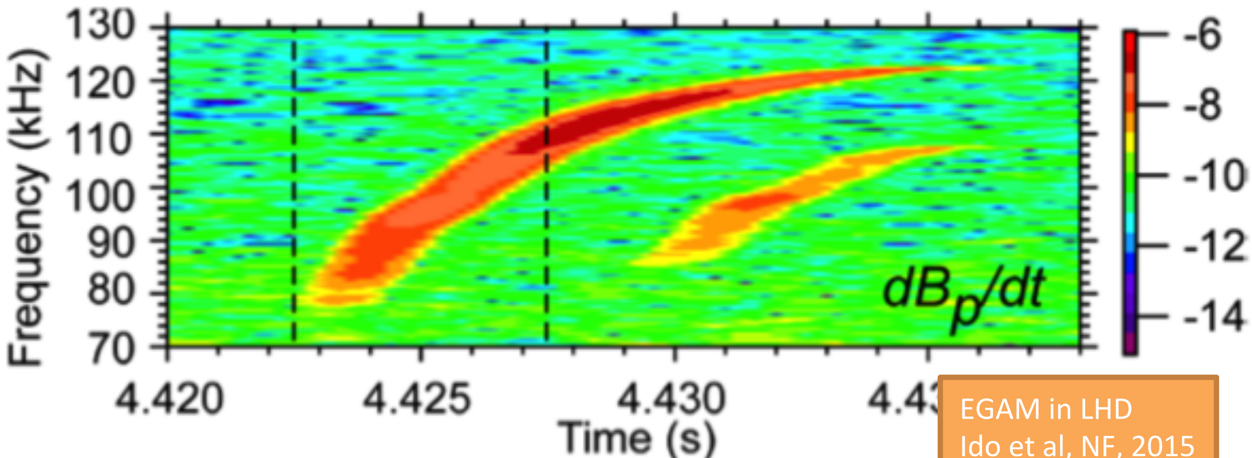
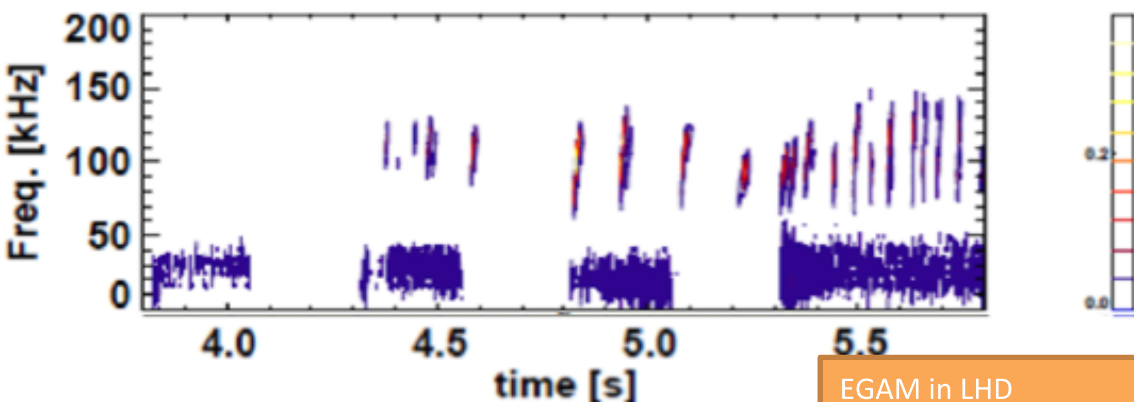
Energetic Particle Driven Geodesic Acoustic Mode (EGAM) in LHD



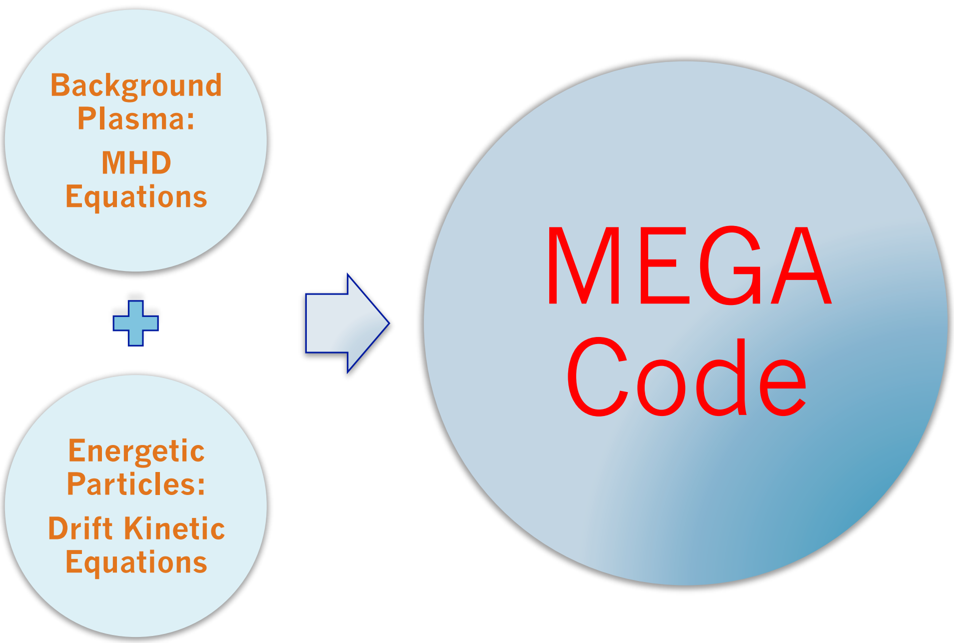
EGAM in LHD
Ido et al, NF, 2015

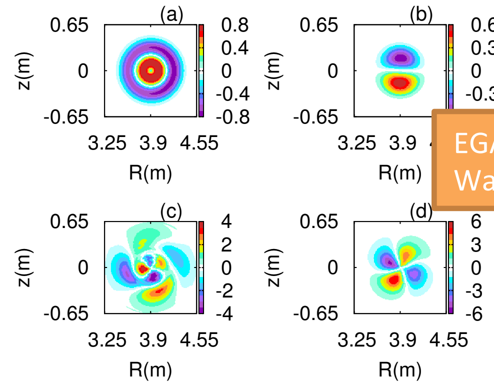


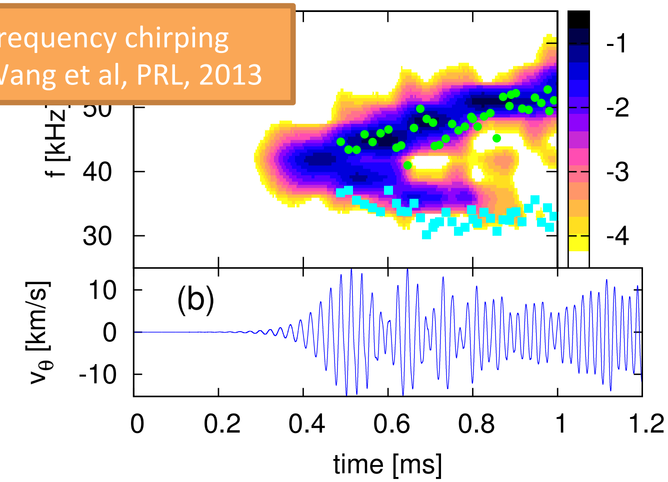
EGAM in LHD
Osakabe et al, IAEA FEC 2014

- In LHD, the EGAM frequency chirps, and the initial frequencies are 50~100 kHz.
- The frequency chirping rate dω/dt decreases with time.
- Some low frequency mode (less than 40kHz) appears.

Simulation Model







- The hybrid code MEGA is used to simulate EGAM. [Todo, Phys. Plasmas, 2006]
- The EGAM simulation under the 2-dimensional equilibrium is already carried out.
- The equilibrium data is generated by HINT2 code. [Suzuki et al, NF, 2006]

Simulation Parameters

- **The equilibrium data is based on LHD shot #109031, at time=4.94s.**
- The energy of neutral beam injection (NBI) is 170 keV.
- The energetic particle distribution function in the pitch angle Λ space f(Λ) is Gaussian-type.
- The energetic particle distribution function in velocity space **f(v) is a bump-on-tail type** due to the charge exchange with neutral particles in the experiment.
- The safety factor q profile has a negative shear with q_0=2.8 on the magnetic axis, and q_{edge}=0.8 on the plasma edge.
- The simulations are implemented under 2 different conditions of energetic particle beta **β_h=5% and β_h=4%**.

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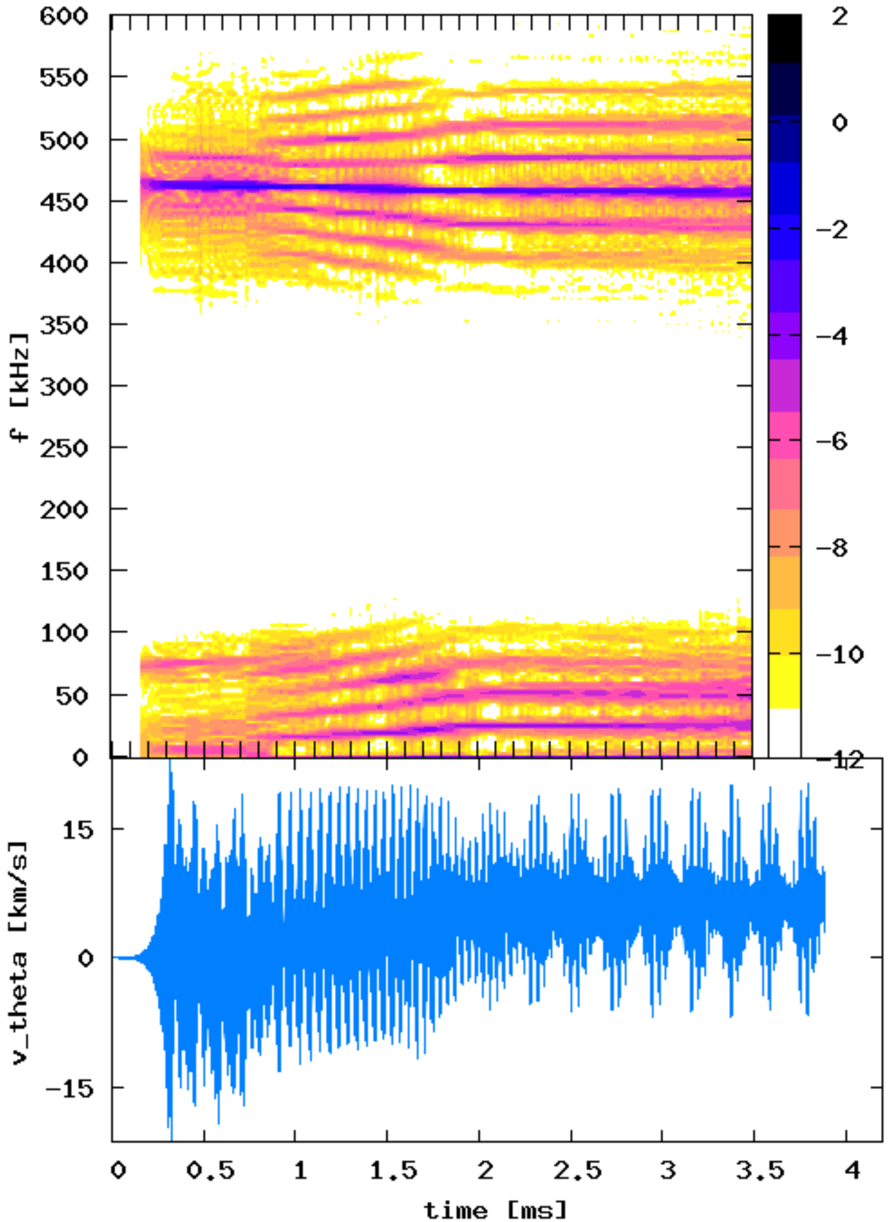
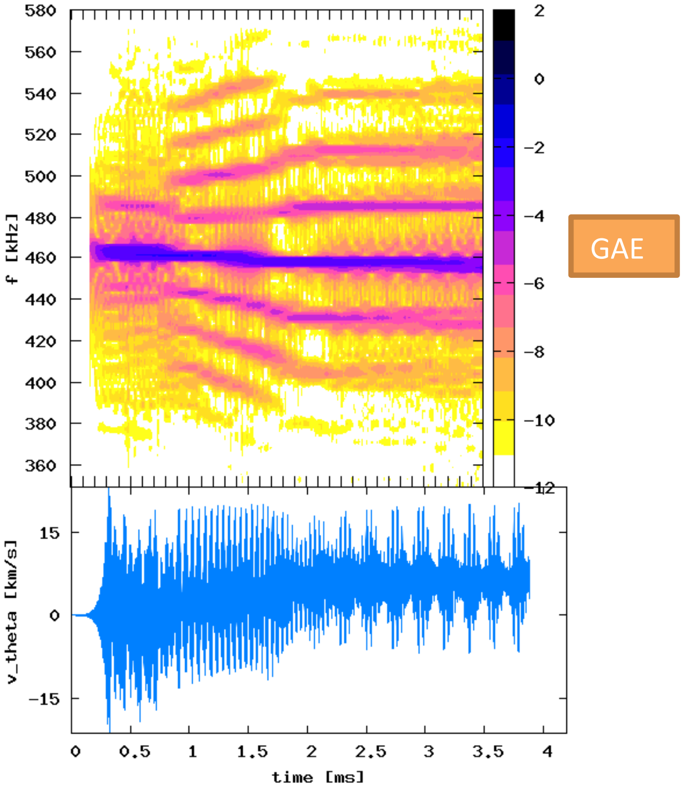
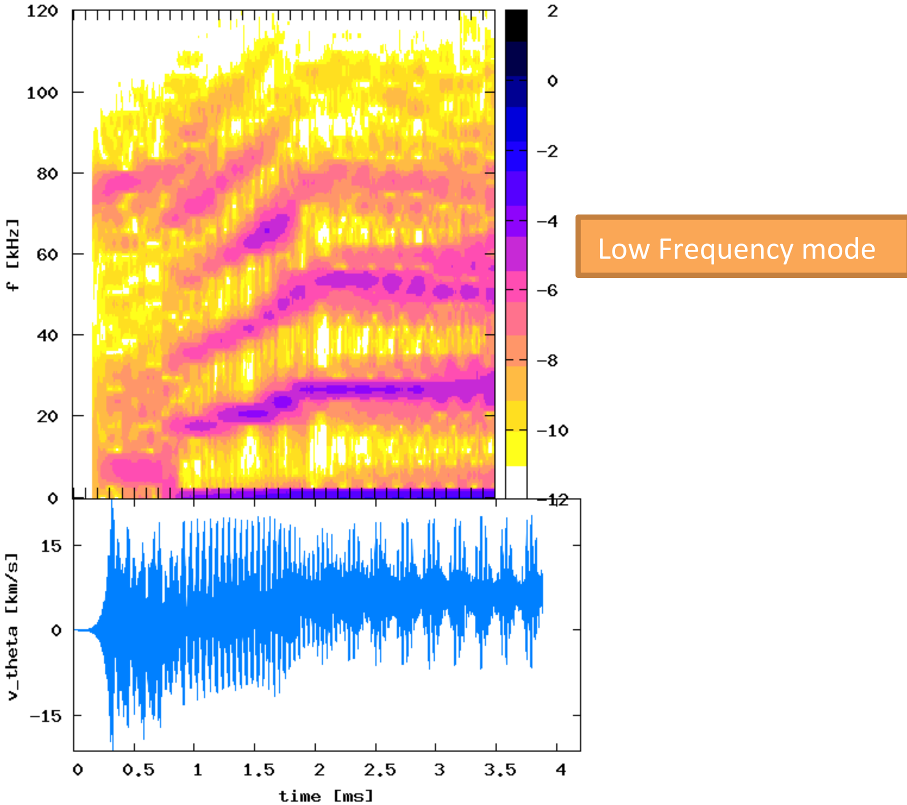
Time Evolution of the modes (β_h=5%)



- The GAE with f~460kHz is dominant, and the EGAM with frequency f~75kHz also appears with relatively weak amplitude.
- The average of the poloidal flow takes a positive value, which indicates the generation of the negative radial electric field due to the redistribution of energetic ions.

The Low Frequency Mode is Induced by the GAE

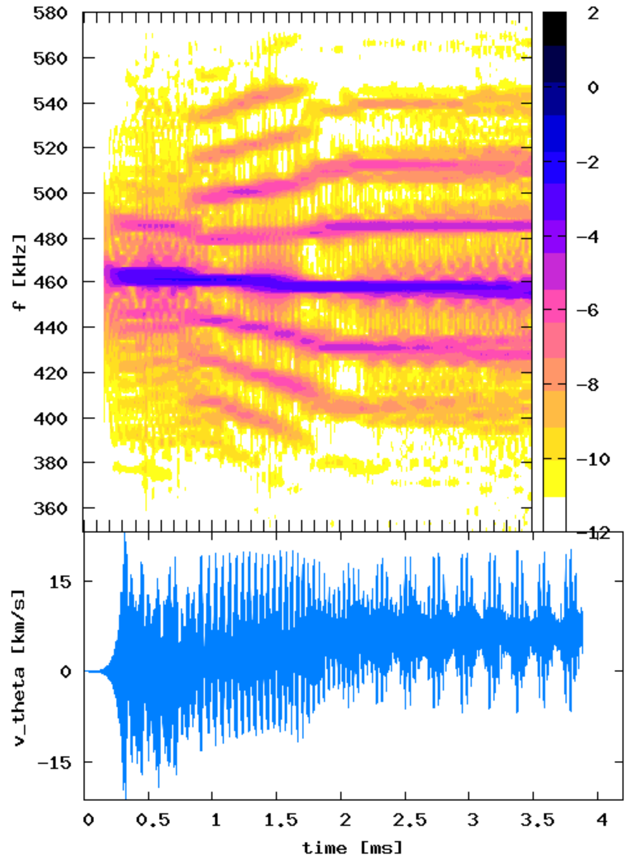


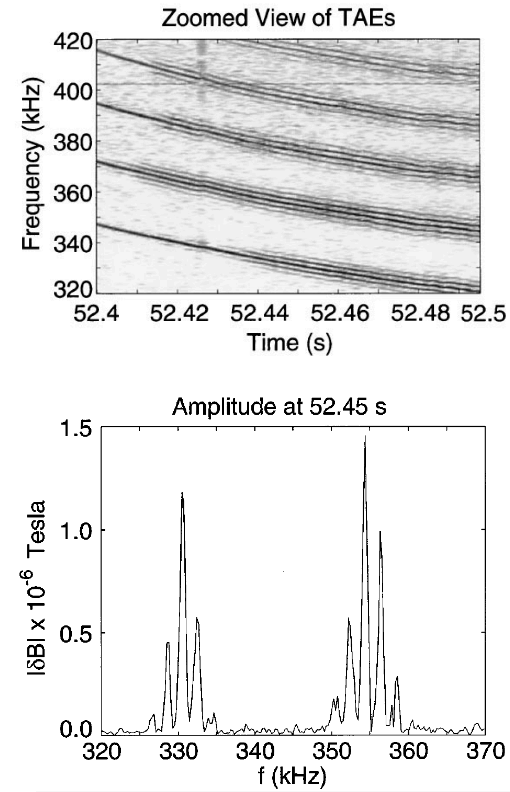


- Both the GAE branches and the low frequency mode chirp from 0.9ms to 2ms.
- Both the GAE branches and the low frequency mode have 25kHz mode frequency differences ($\Delta\omega/2\pi$=25kHz).
- The low frequency mode is induced by the GAE.

The Simulated Splitting Phenomena is Similar with TAE in JET

MEGA Simulation

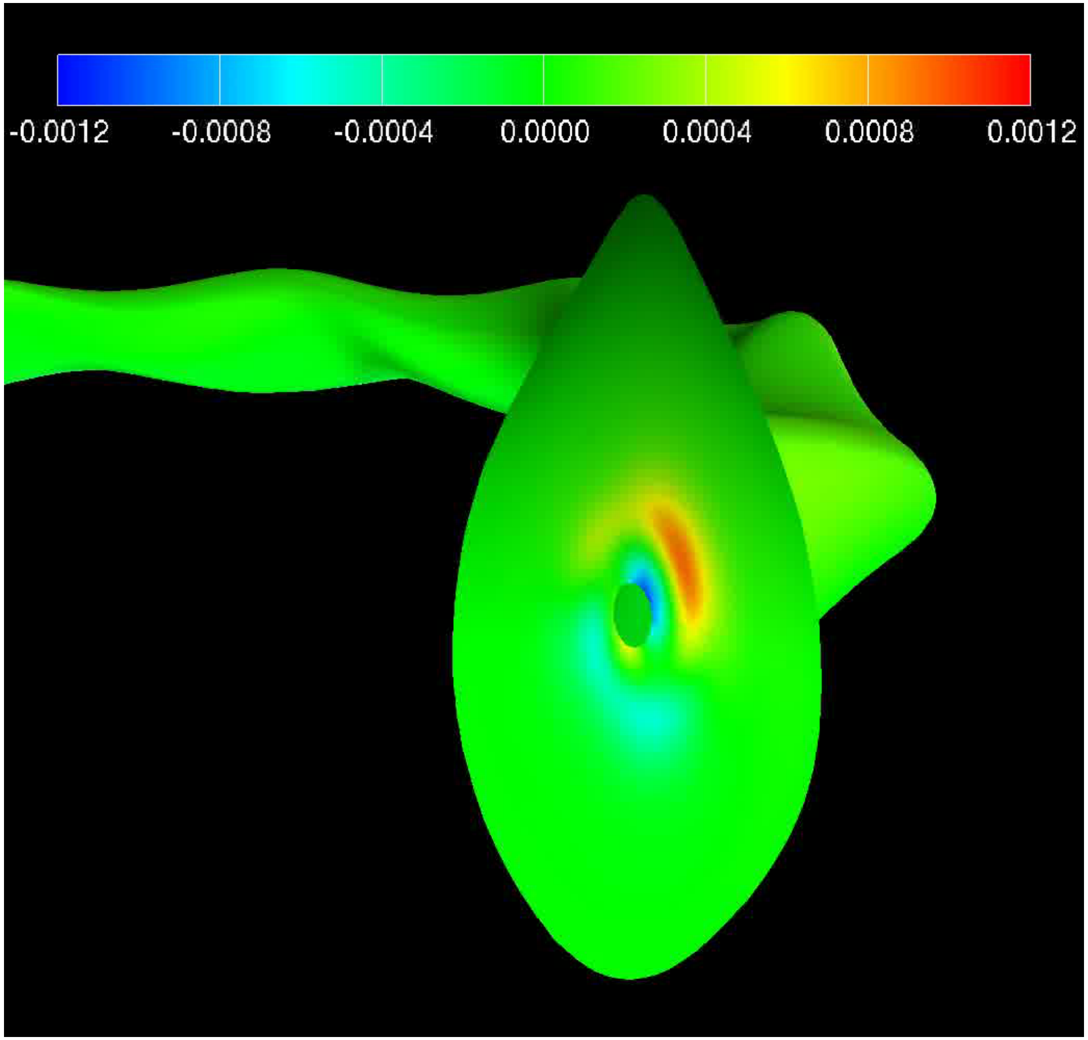




TAE in JET
A. Fasoli, PRL, 1998

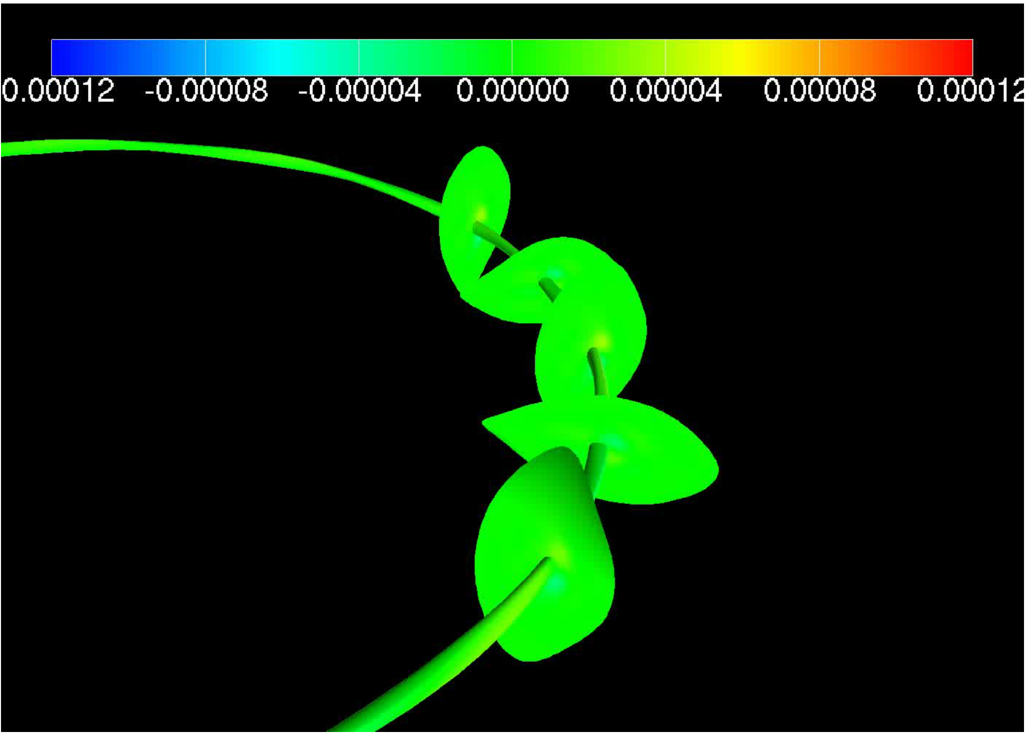
- The splitting phenomena can be interpreted via a nonlinear theory of near-threshold regimes. [H.Berk, Plasma Phys. Rep., 1997]

The Movie of v_θ in nonlinear phase



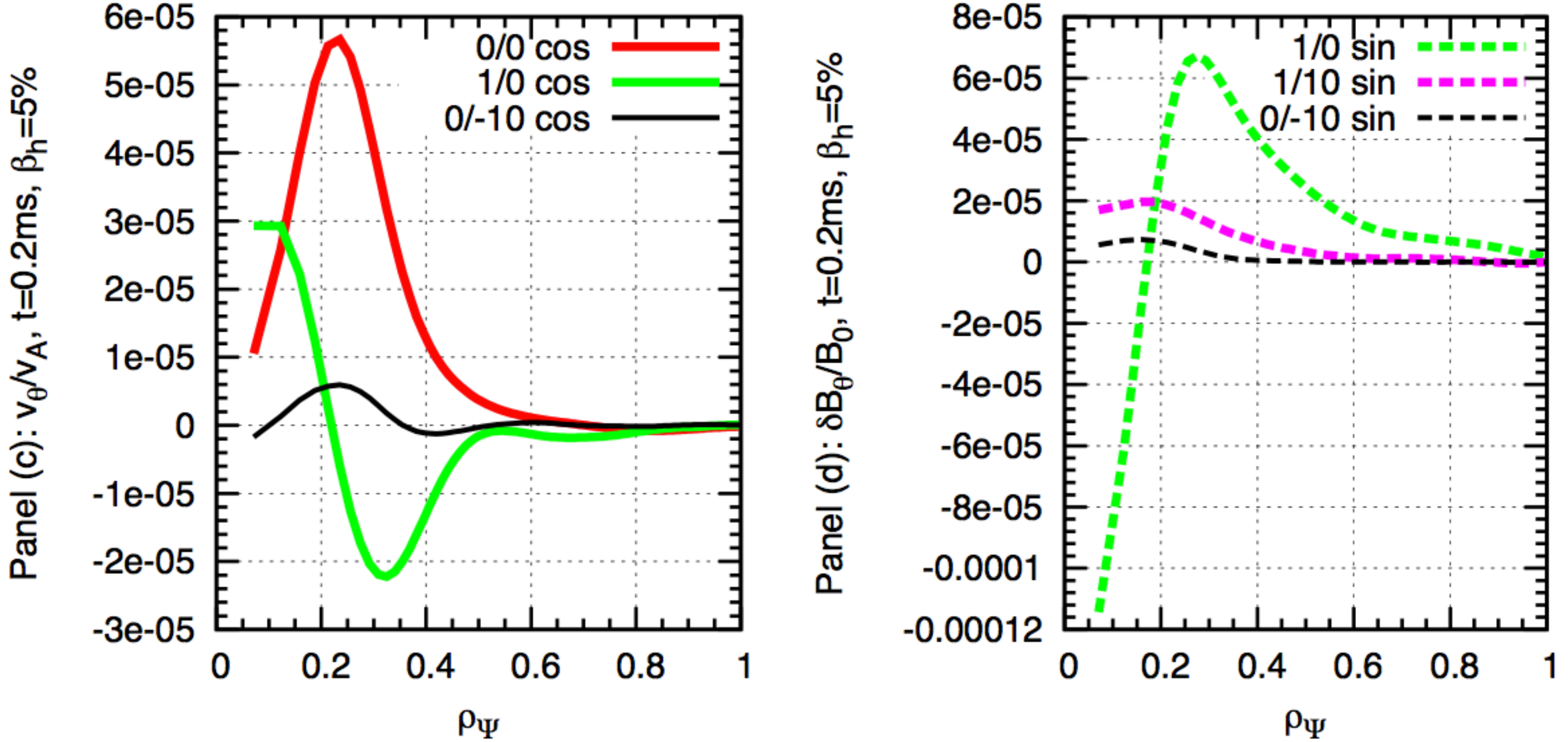
- The range of the color bar is fixed from -0.0012 v_A to 0.0012 v_A.
- Only the nonlinear phase is shown.
- The m/n=0/0 and 1/0 components are dominant.

The Movie of δP



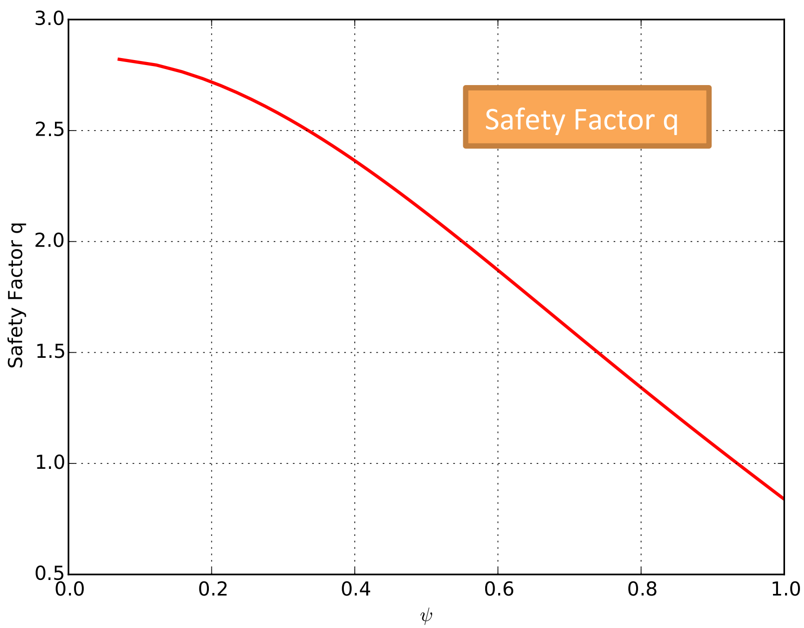
- The 5 slices locate at Φ=0, π/10, π/5, 3π/10 and 2π/5.
- The phase difference between vertically elongated slice and horizontally elongated slice is π/2.
- n=10 modes are dominant.

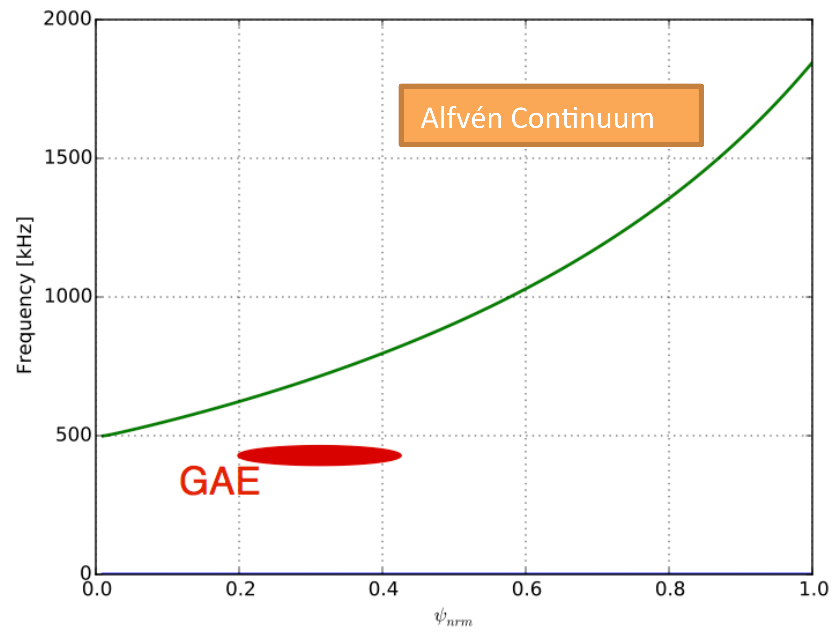
Spatial Profile of v_θ and δB_θ



- The poloidal flow is a combination of m/n=0/0 and 1/0 components.
- The m/n=1/0 component is dominant for the poloidal magnetic perturbation.
- The $v_\theta/v_A \sim \delta B_\theta/B_0$, where v_A is the Alfvén velocity, indicating an Alfvén eigenmode.

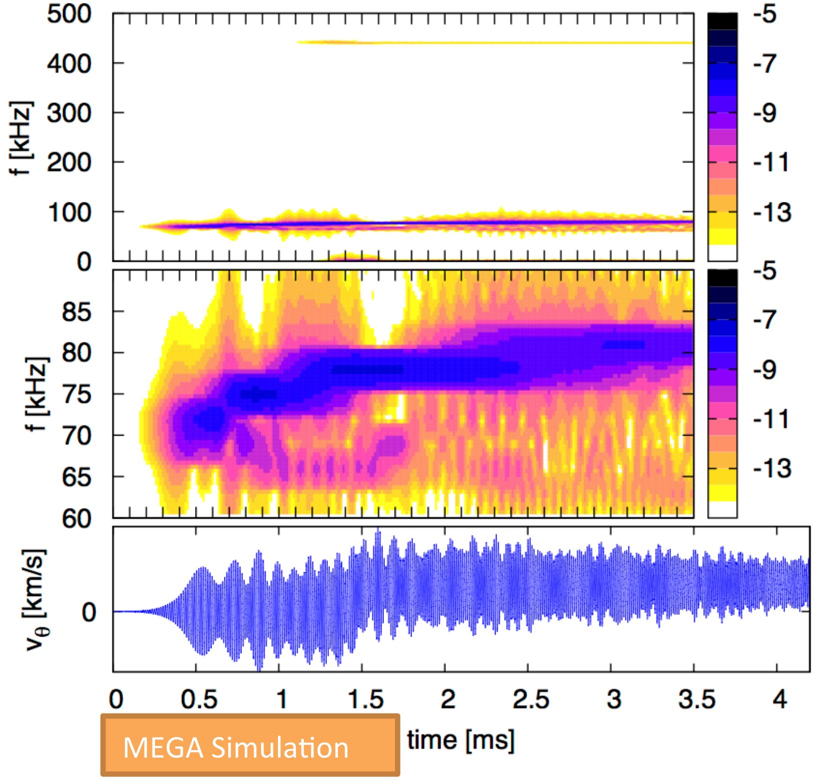
The q-Profile and GAE Continuum

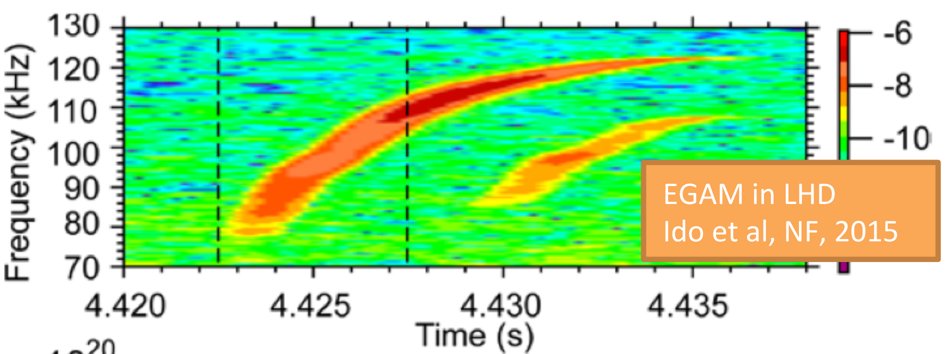




- The frequency f~460kHz is consistent with the n=0 GAE frequency given by $mv_A/(2\pi q_0 R)$ for m=1.

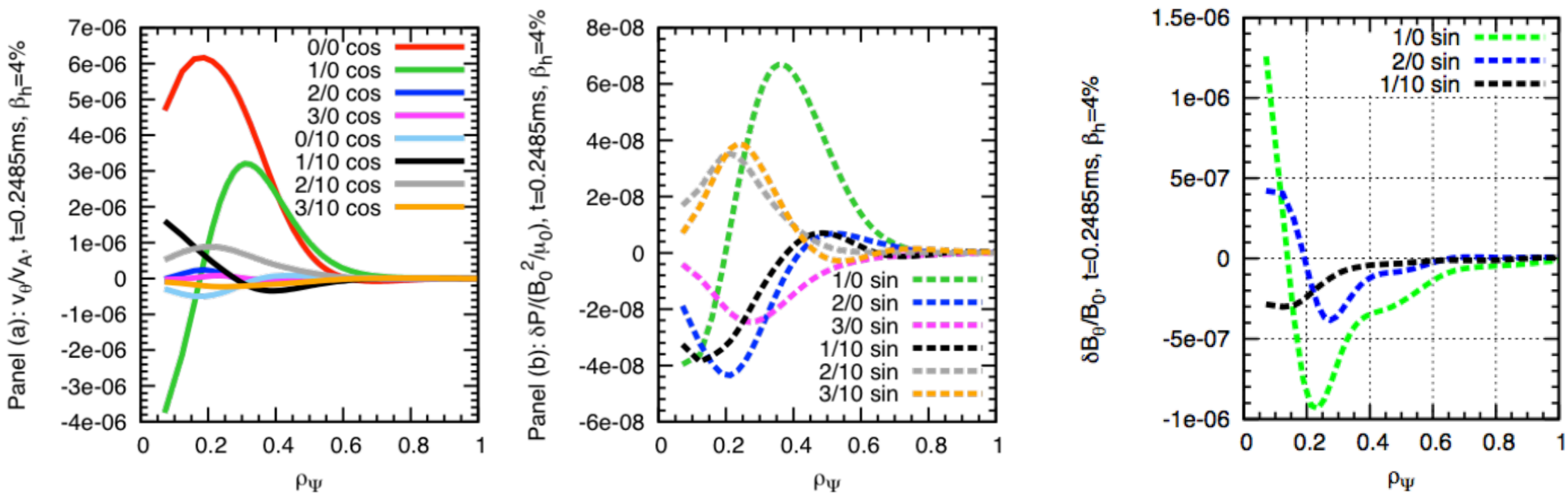
Time Evolution of EGAM (β_h=4%)





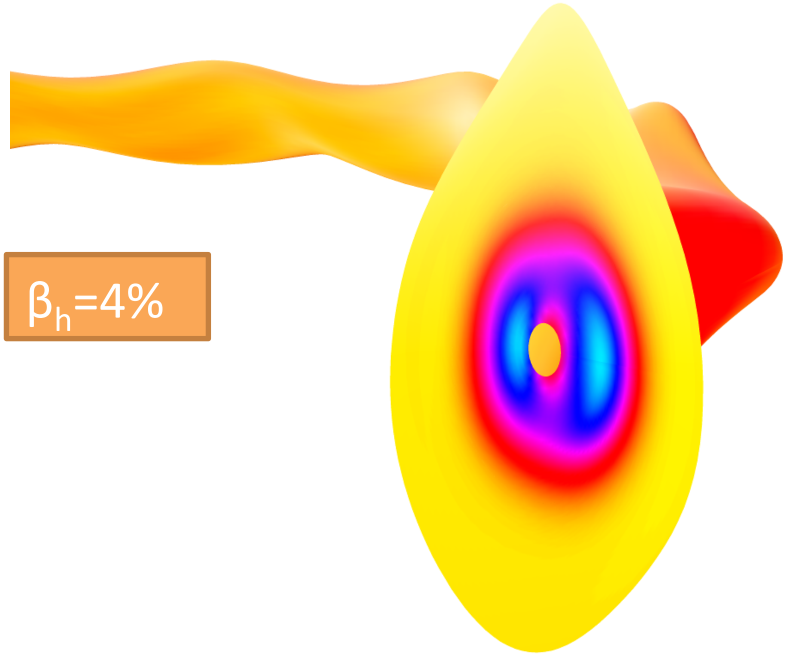
- The EGAM with f~70kHz is dominant, and the GAE with frequency f~450kHz also appears with very weak amplitude.
- The frequency and the frequency chirping of the EGAM are similar to the experimental observation.
- The average of the poloidal flow takes a positive value, which indicates the generation of the negative radial electric field due to the redistribution of energetic ions.

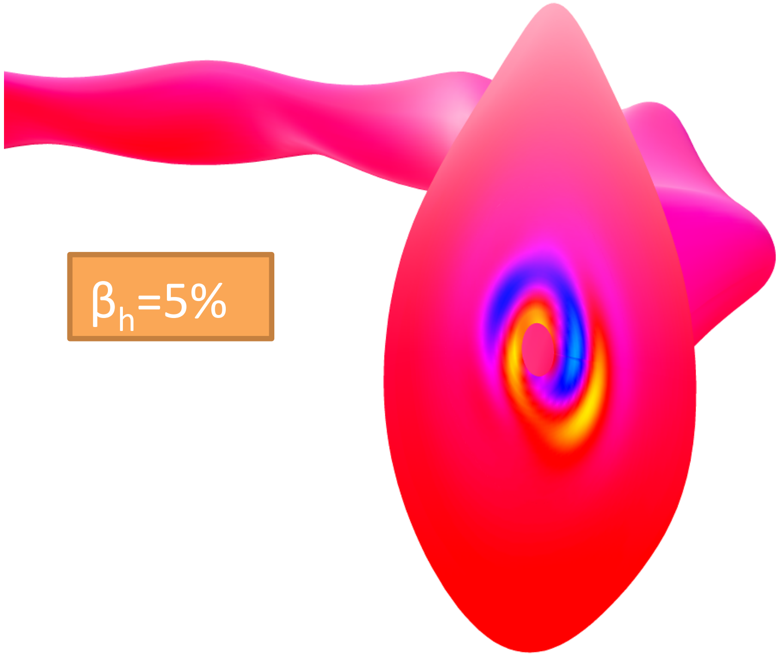
Spatial Profile of v_θ, δP and δB_θ



- The poloidal flow is a combination of m/n=0/0 and 1/0 components, but 0/0 component is dominant.
- For the pressure perturbation, the n=10 harmonics are comparable to the n=0 harmonics.
- The m/n=1/0 component is dominant for the poloidal magnetic perturbation.
- The $v_\theta/v_A \gg \delta B_\theta/B_0$ indicating an electrostatic mode.

The 3D Mode Profile of v_θ For Both The 2 Cases





The m/n=0/0 component is dominant for the EGAM (left), while the m/n=1/0 component is dominant for the GAE (right).

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Summary

- The first simulation results of energetic particle driven geodesic acoustic mode (EGAM) in 3-dimensional LHD equilibrium are presented.
- The n=10 harmonics of the 3-dimensional LHD equilibrium brings about the coupling between the n=0 and 10 harmonics for the spatial profile of the EGAM.
- In addition to the EGAM with frequency ~ 75kHz, a GAE with n=0 and frequency~460kHz is discovered in the simulation.
- The frequency chirping, which is observed in LHD experiments, takes place for both the EGAM and GAE.
- In the nonlinear evolution, the average of the poloidal flow takes a positive value, which indicates the generation of the negative radial electric field due to the redistribution of energetic ions.

Thanks for your attention!