New beam driven modes below geodesic acoustic frequency in NSTX

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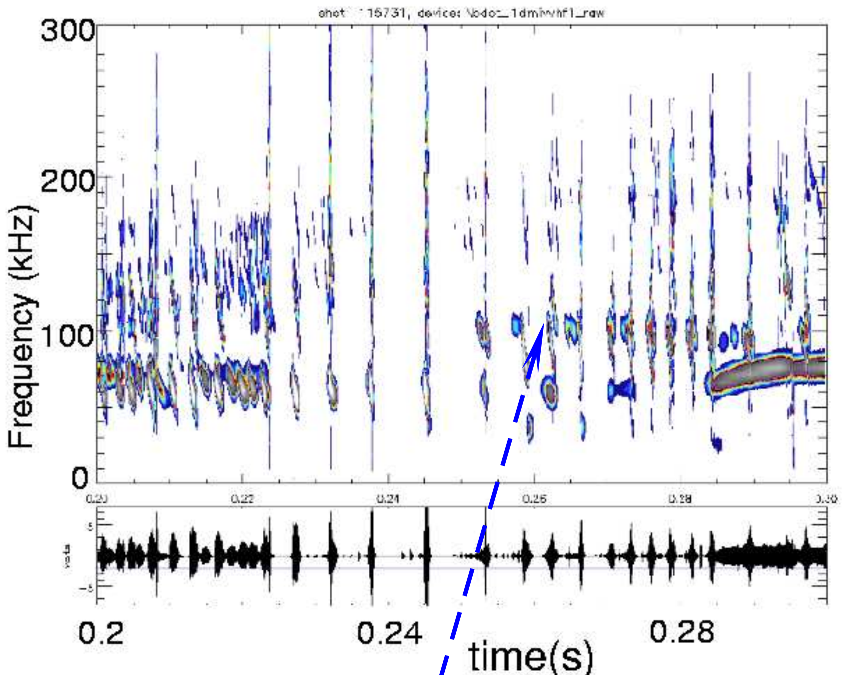
Multiple MHD instabilities are routinely observed in NSTX

Mirnov activity @ reversed shear #115731 ($f_{TAE} = v_A/2qR \simeq 90kHz$)



At $t = 0.262sec$, $n = 2$ mode frequency $f_{lab} \simeq 103\,kHz$,
$f_{pl} \simeq f_{lab} - n \times 30 = 43\,kHz$, $\Rightarrow$ too low for TAE for all observed modes.

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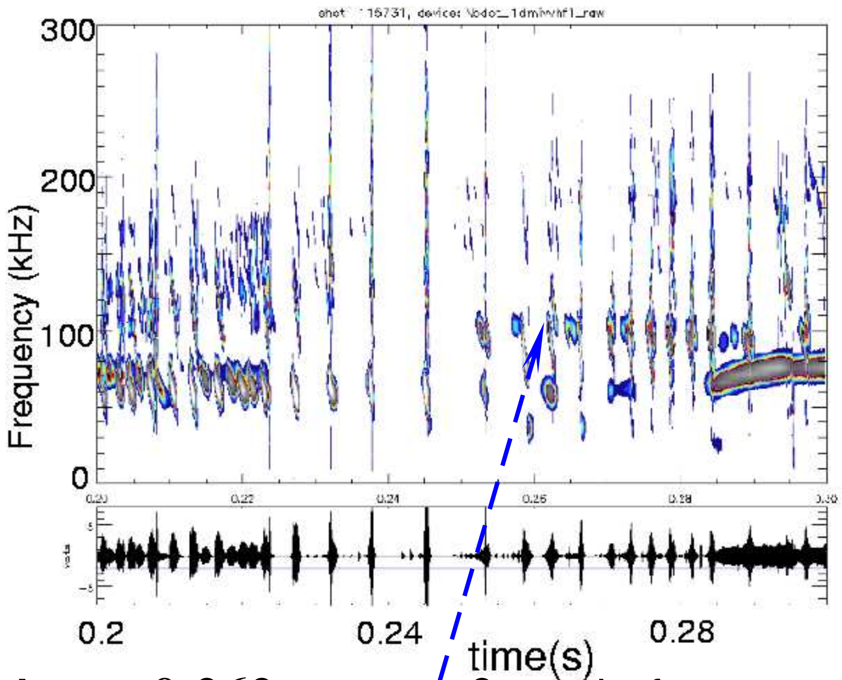

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What are these modes: EPMs, fishbones, KBM, TAEs?

Theory of Alfvén/acoustic continuum

Simplified shear Alfvén and acoustic coupled equations in low-β, large aspect ratio plasma (Cheng, Chance '86):

$$\Omega^2 y + \partial_\parallel^2 y \quad + \gamma\beta \sin\theta\, z \quad = 0 \qquad (1)$$

$$\Omega^2 \left(1 + \frac{\gamma\beta}{2}\right) z + \frac{\gamma\beta}{2} \partial_\parallel^2 z \quad + 2\Omega^2 \sin\theta\, y \quad = 0, \qquad (2)$$

where $\Omega \equiv \omega R_0 / v_A$, $y \equiv \xi_s \varepsilon / q$, $\xi_s \equiv \vec{\xi} \cdot \frac{[\mathbf{B} \times \nabla\psi]}{|\nabla\psi|^2}$ and $z \equiv \nabla \cdot \vec{\xi}$, $\hat{k}_\parallel \equiv i\partial_\parallel$.

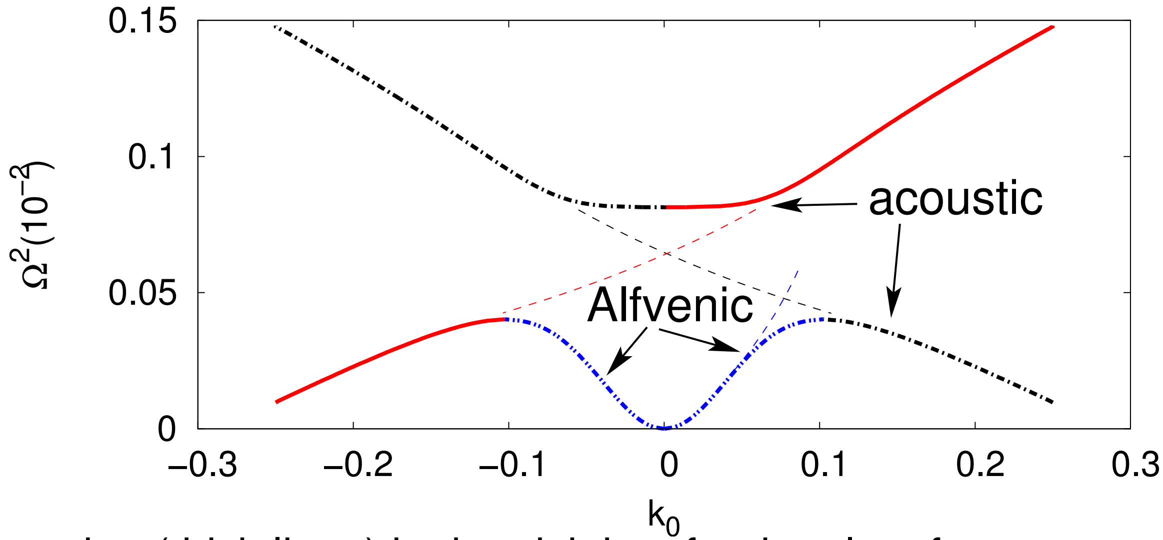
Coupling is due to geodesic curvature

Various solutions follows:

- Pure Alfvénic branch $\Omega^2 = k_\parallel^2 + \gamma\beta\left(1 + 1/2q^2\right)$ (Chu'92, Breizman'05, Berk'06, Turnbull '92).
- Pure acoustic modes (AMs) $\Omega^2 = \frac{1}{2}\gamma\beta k_\parallel^2$. (Goedbloed'75)
- GAMs: $\Omega^2 = \gamma\beta\left(1 + 1/2q^2\right)$ (Winsor'68, Breizman'05, Berk'06) in the assumption of $\Omega^2 \geq \gamma\beta$.
- Modified shear Alfvén branch exist for $\Omega^2 \ll \gamma\beta$.

Analytic solution for Alfvén/acoustic continuum gap is found

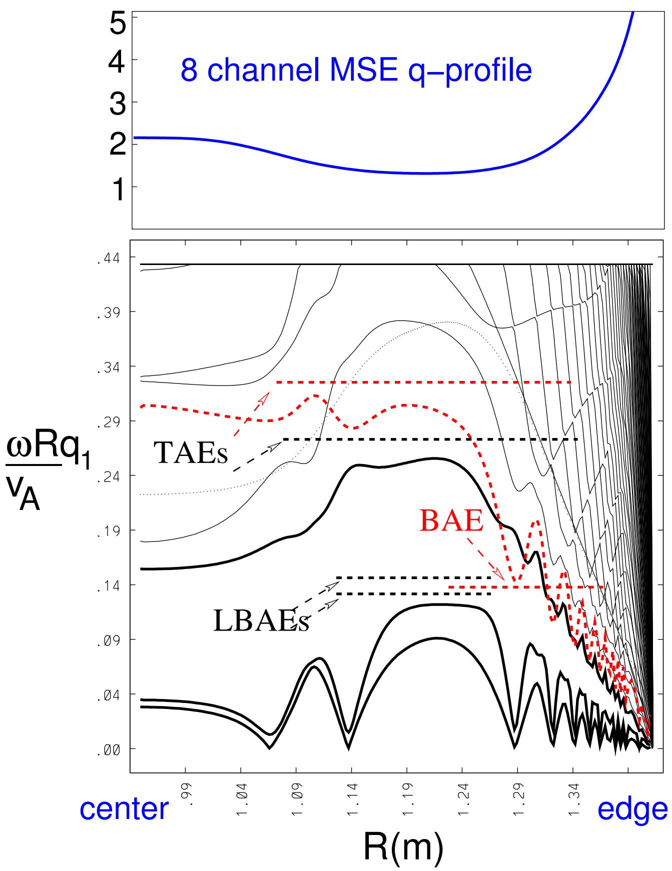
- Alfvén-like continuum branch emerges at low frequency: $\Omega^2 = k_0^2/\left(1+2q^2\right)$, (Mikhailovskii,'75,'98, also Smolyakov private communication).
- Geodesic curvature couples it with two acoustic sidebands at $\Omega^2 = \gamma\beta k_{\pm1}^2/2\,(1+\delta)$ and creates a new gap.



Analytic dispersion (thick lines) in the vicinity of rational surface at $q = 1.75$, $\beta = 0.3\%$.

See more today in NSTX poster session (N.N.Gorelenkov et.al.)

New global LBAE modes emerge due to coupling of Alfvén and acoustic waves at high β

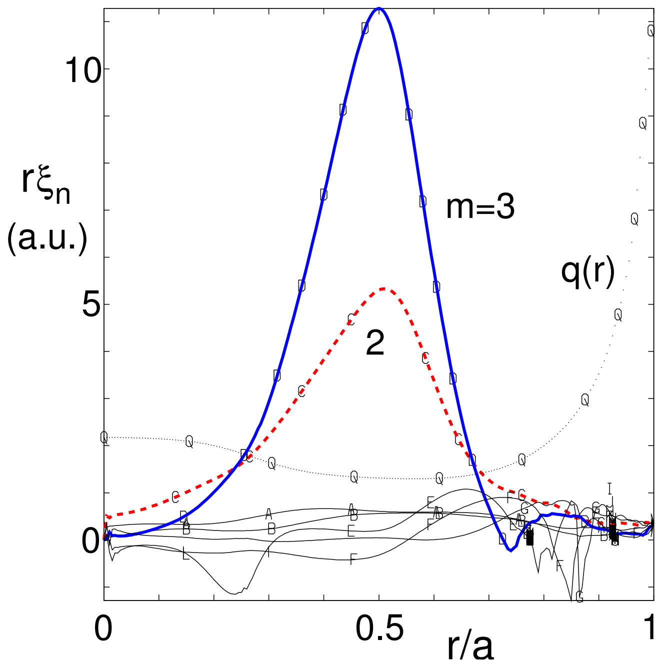


MSE measured q-profile is used in NOVA modeling
Two models are applied:

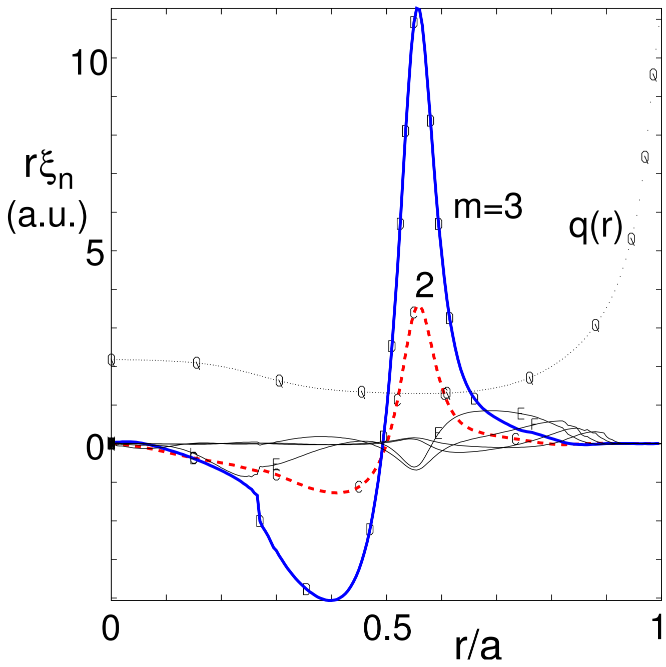
- Red is for acoustic mode filtering out scheme (Chu'92): TAE and BAE (Turnbull '93, Hausmans'95) are found.
  BAE is damped on continuum
- Black: full ideal MHD continuum (NOVA).
- Global modes are more likely to exist at high β since frequency spacing for the acoustic continuum is $\Delta\Omega \sim (\gamma\beta)^{3/4}/q$.
- Two Alfvén/acoustic continuum branches are found with $\Omega^2 < \gamma\beta$.
- New global modes, Low shear Beta-induced Alfvén Eigenmodes (LBAE), are formed above the continuum.

Global LBAE structure and frequency at $n = 2$

First radial LBAE (higher $f = 35kHz$)



Second radial LBAE $f = 33.8kHz$



Two dominant harmonics, $m = 2, 3$, are present due to $nq_{min} = 2.6$.

Both measured and simulated LBAE polarization contain $\delta B_{\|}$

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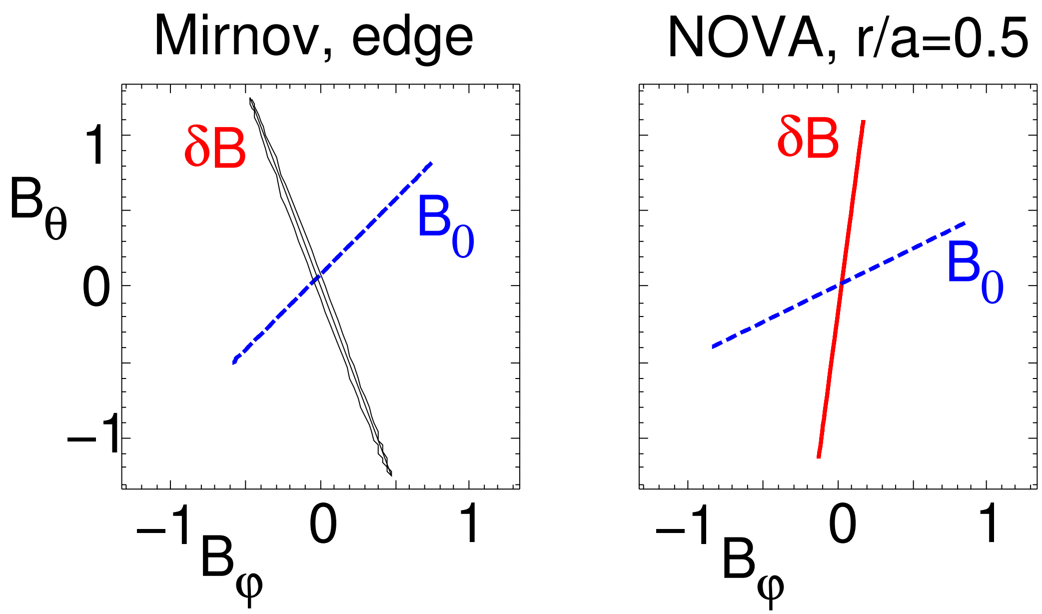
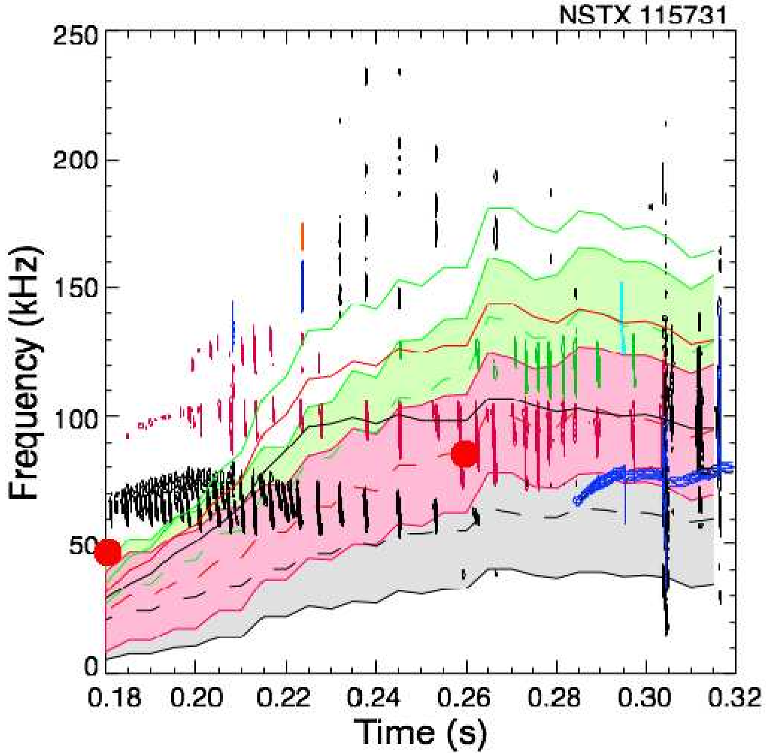


NOVA model can not be used for polarization simulation at the edge due to multiple singularities resonances.

Significant $\delta B_{\|}$ is measured and computed.

LBAE frequency agrees with measurements at high beta



- Black, red, green shaded areas are for theoretical scaling of LBAE gap with rotation and $n = 1, 2, 3$.
- Upper black, red and green are core n=1,2 and 3 TAE frequencies.
- Red dots are predictions by NOVA for $n = 2$: frequency (accumulation point) and polarization are consistent with observations.
- Discrepancy for initial phase of the discharge is due to strong sheared rotation $f_{rot} \simeq 30kHz$ at $t = 0.26sec$.
- Possible causes of the discrepancy:
  - toroidal rotation is strongly sheared and may affect the mode localization
  - EPM effects push TAE frequency (accumulation point) down to merge into LBAE solution (accumulation point). r-TAE to r-KBM transition like effect (Cheng '95, Gorelenkov '03).

SUMMARY

- Theoretical analysis shows:
  - the existence of geodesic curvature induced gaps in the Alfvén/acoustic continuum below GAM frequency.
  - low-n global toroidicity-induced Alfvén/acoustic eigenmodes, which we call Low shear BAE (LBAE)
  - LBAE exist in non-zero beta plasma within wider BAE gap.
- LBAEs are different from BAE of Heidbrink-Turnbull-Chu-Hausmans interpretation as they require compressibility effect, i.e. sound wave coupling and low magnetic shear.
- TAE frequency is pushed higher due to beta (GAM) effect.
- The $n = 2$ LBAE frequency computed by NOVA, $35kHz$, is very close to the observed frequency $43kHz$ after deducting the toroidal rotation for $\#115731$ shot.
- Kinetic modification of MHD theory may be important issue for new class of modes. But LBAE parallel phase velocity is close to the Alfvén speed and avoidance of strong Landau damping is likely.