# Are they TAEs in NSTX?

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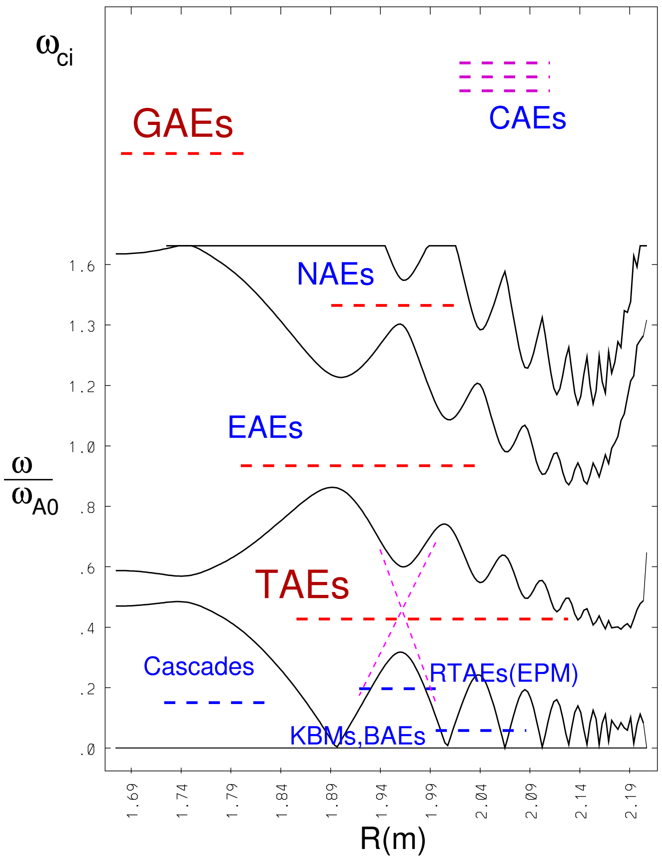
**NSTX seminar, May 30**

PRINCETON PLASMA PHYSICS LABORATORY

# What is TAE frequency?



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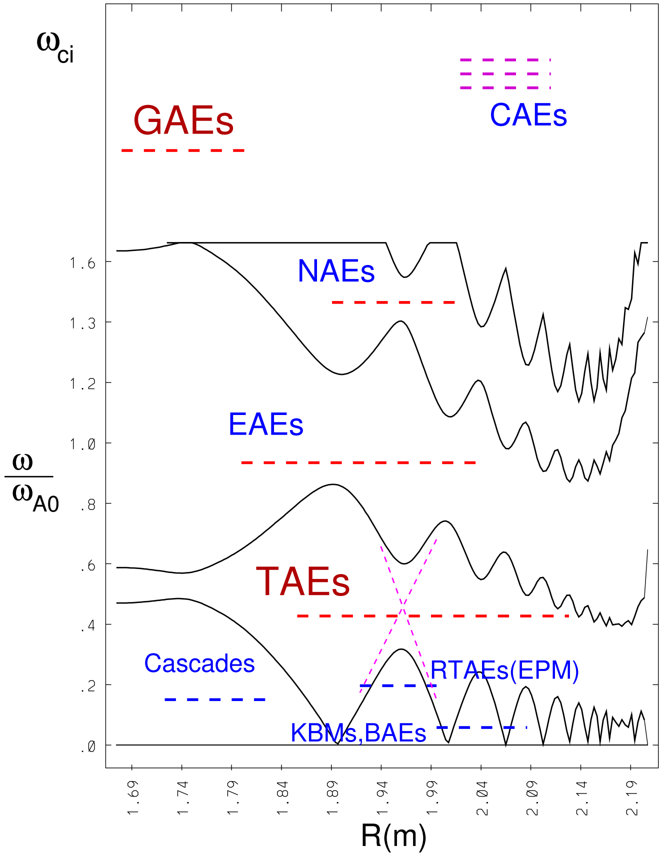


- Simple, commonly used estimate

$$\omega_{TAE} = \frac{v_A}{2qR} \Leftarrow k_{\parallel m} = -k_{\parallel m+1}$$

- For NSTX #115731 with reversed $q$-profile, $q_{min} = 1.3$, we find

$$\omega_{TAE} \simeq 90kHz.$$

- Rotation is important factor in mode identification in NSTX

$$f_{pl} = f_{lab} - n f_{rot}$$

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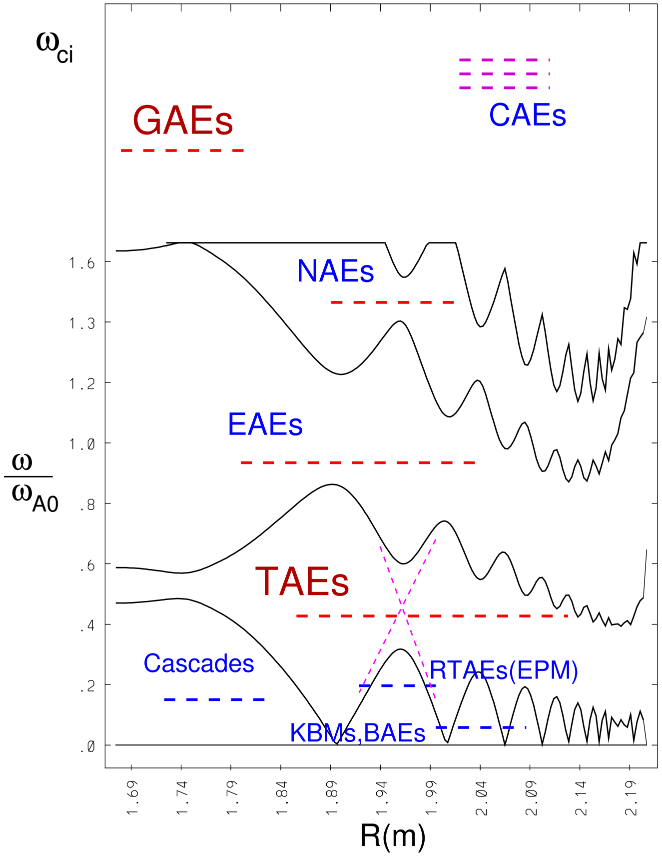


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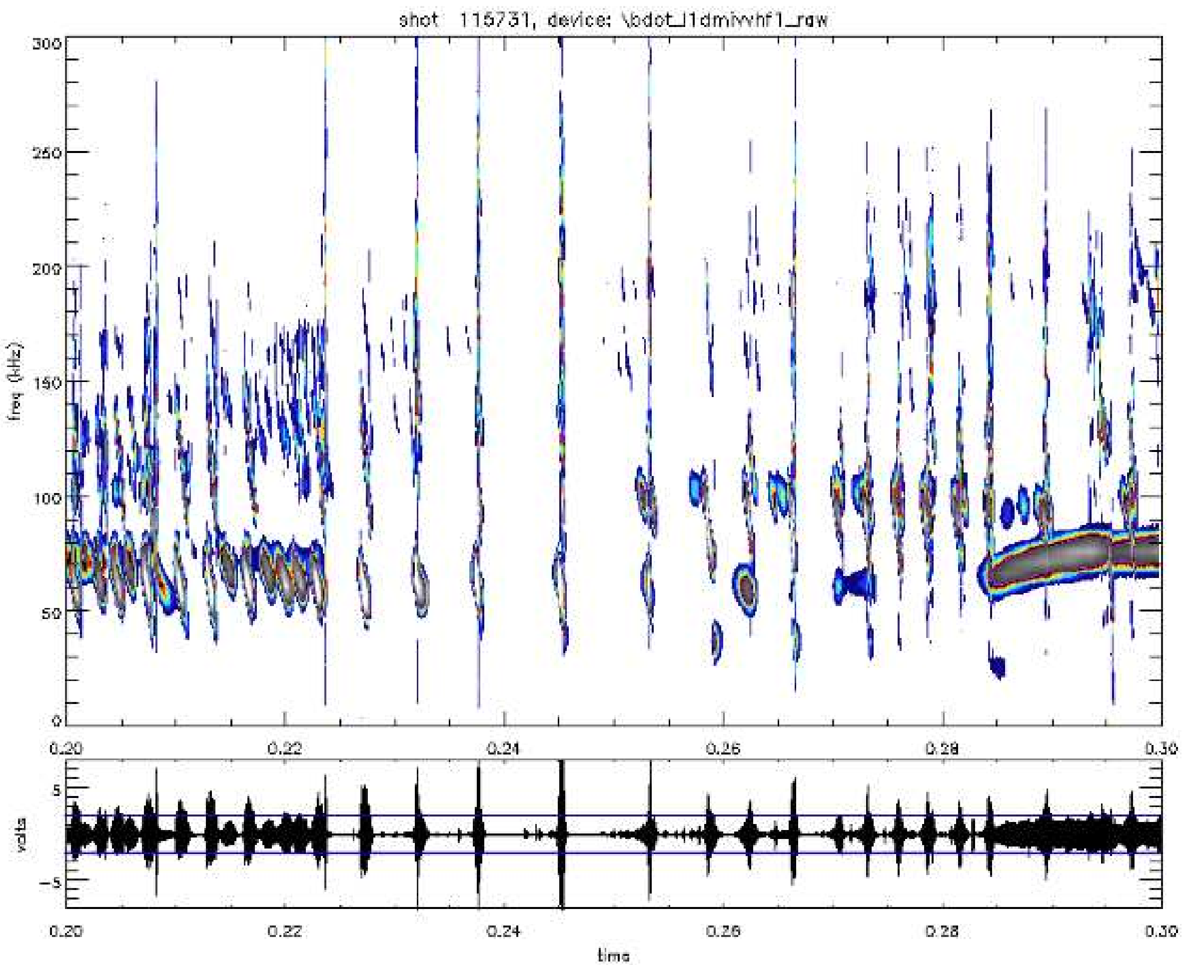
- In general low frequency modes are more effective in radial EP transport.

## *MHD activity @ reversed shear* #115731 *($f_{TAE} \simeq 90kHz$)*




At $t = 0.262 sec$, $n = 2$ 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.

## *A little bit of theory in low-β large aspect ratio equilibrium*

Simplified shear Alfvén and acoustic equations (from Cheng, Chance '86):

$$\begin{array}{llll} \Omega^2\hat{\xi}_s & -\hat{k}_{\|}^2\hat{\xi}_s & -q^2\gamma\beta\sin\theta\nabla\cdot\xi & =0 \\ -2\sin\theta\hat{\xi}_s\Omega^2 & +\Omega^2\nabla\cdot\xi & -\frac{\gamma\beta}{2}\hat{k}_{\|}^2\nabla\cdot\xi & =0, \end{array}$$

where $\Omega=\omega qR/v_A$, $\hat{\xi}_s\simeq\xi\cdot\vec{e}_\theta/R$, $\hat{k}_{\|}\equiv i\partial/\partial\theta$.

- Pure Alfvénic branch $\Omega^2=k_{\|}^2+\gamma\beta q^2\left(1+1/2q^2\right)$ (Chu'92, Breizman'05, Berk'06, Turnbull '92).
- Pure acoustic mode (AM) $\Omega^2=\frac{1}{2}\gamma\beta k_{\|}^2$.
- GAMs: $\Omega^2=\gamma\beta q^2\left(1+1/2q^2\right)\text{(Winsor'68, Breizman'05, Berk'06)}$.
- Toroidal AM: $\Omega^2\ll\gamma\beta q^2$ is new (preliminary): $-\hat{k}_{\|}^2\hat{\xi}_s\sim q^2\gamma\beta\sin\theta\nabla\cdot\xi$ (AM) at $k_{\|}=0$. One can show that $\Omega^2\sim\varepsilon\beta^2$ due to poloidal variation of the Jacobian induced by toroidicity (in progress).

## *Consider high aspect ratio low-β tokamak - "nonspherical torus"*

$R_0 = 0.806m$, but with the aspect ratio $A = 10$, $a = 0.081m$,
$\beta \equiv 2p/B_0^2 = 0.3\%$, $q_a = 11.3$, $q(0) = 2.16$, $q_{min} = 1.3$,
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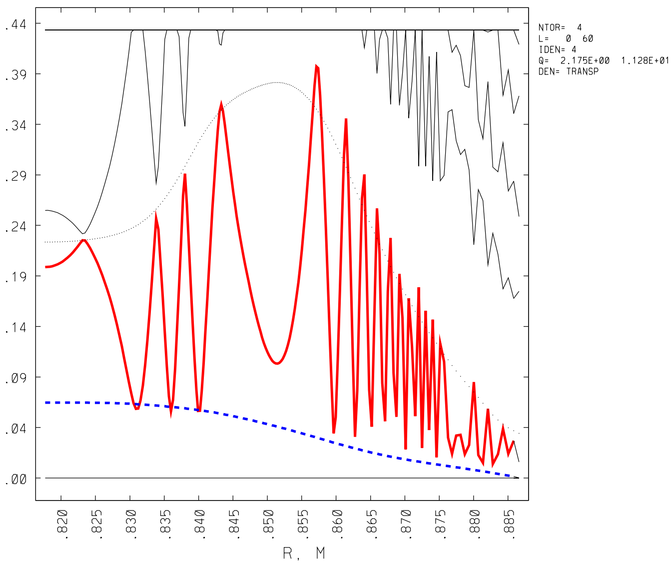
Acoustic filtered continuum (Chu’92) vs



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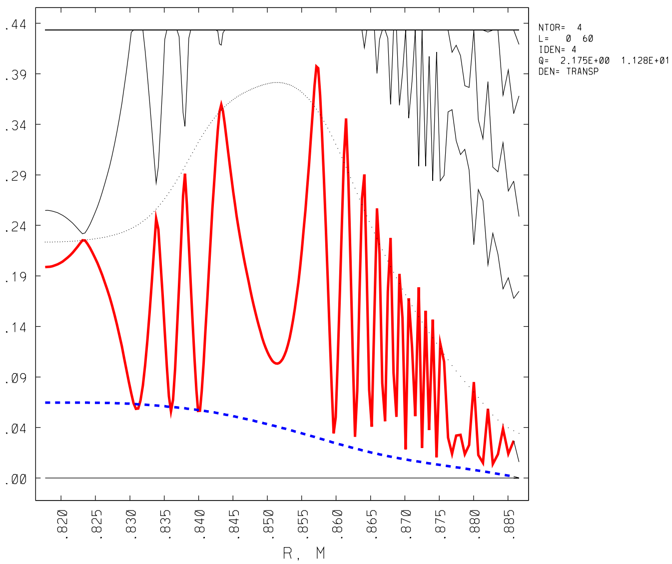
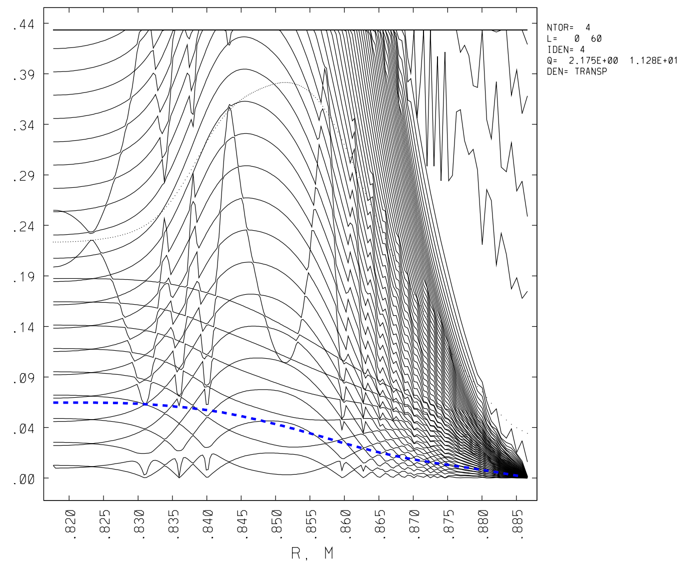


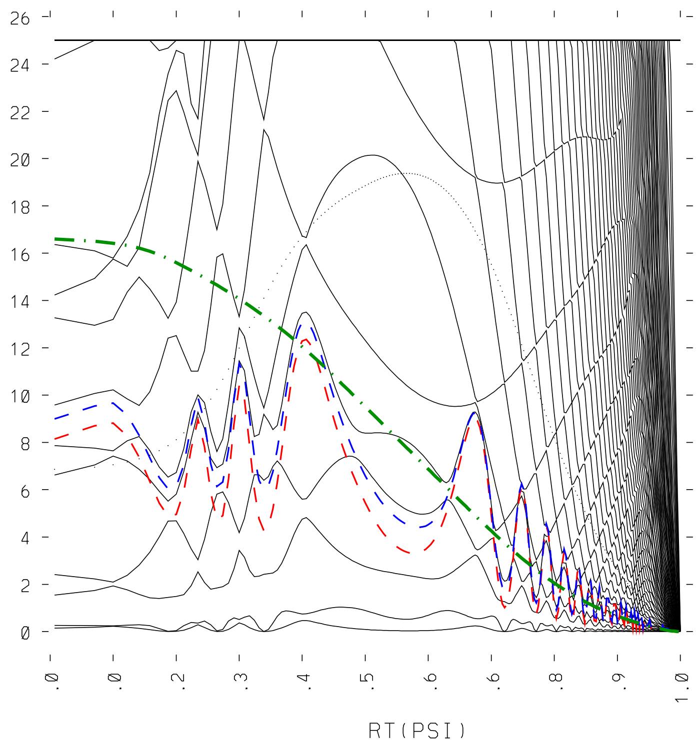

Full MHD continuum




Numerical analysis is very much simplified with filtering.

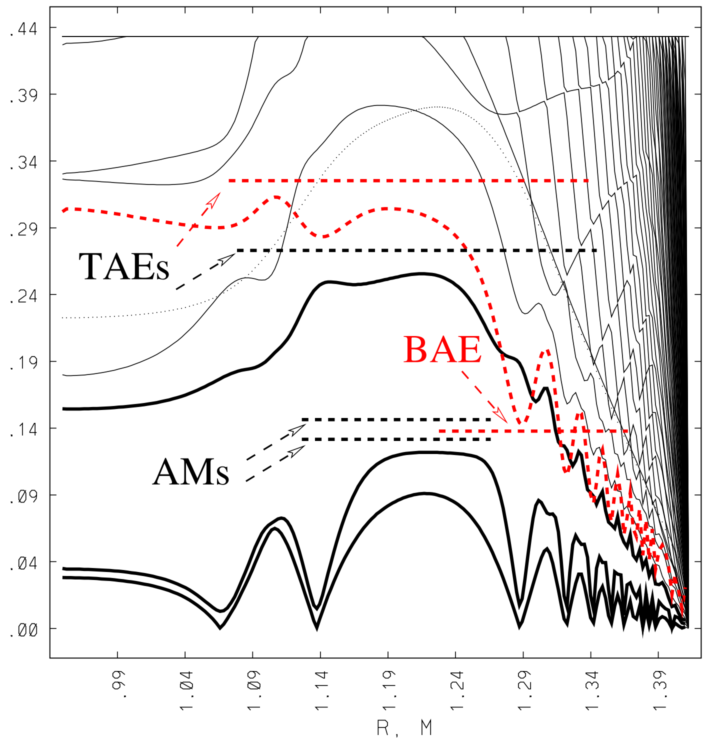
BAE and TAE gaps are well reproduced with the filtering technique.

# NSTX medium $\beta = 5\%$ equilibrium from TRANSP @q MSE




- Overlaid red is for acoustic mode filtering scheme (Chu'92)
- Overlaid blue continuum includes $q$ correction $\left(1+1/2q^2\right)$.
- Black is for full ideal MHD NOVA continuum. Influens on gaps from the acoustic modes.
- Global AMs are more likely at high $\beta$ since frequency spacing for the acoustic continuum is $\Delta\Omega \sim \sqrt{\gamma\beta/2}$.
- Hard to find the mode at lower to medium beta due to strong interaction with the continuum !!

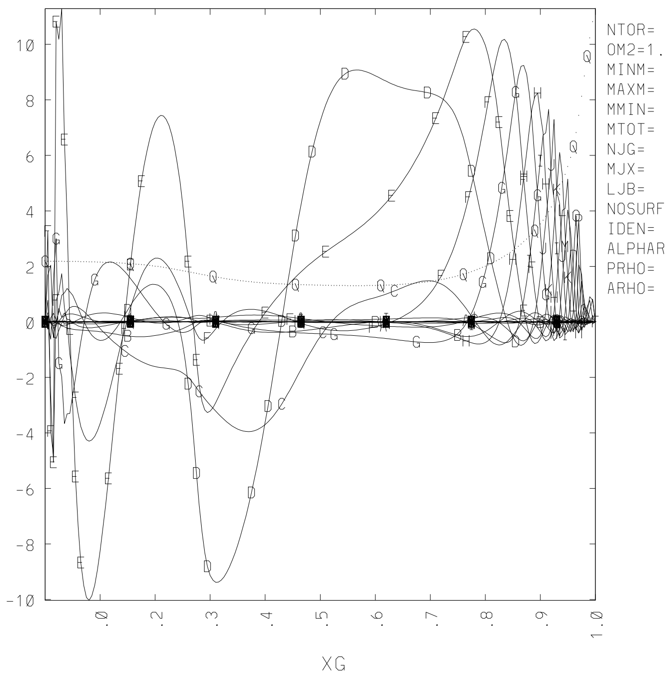
# *TRANSP high $\beta = 21\%$ equilibrium case*



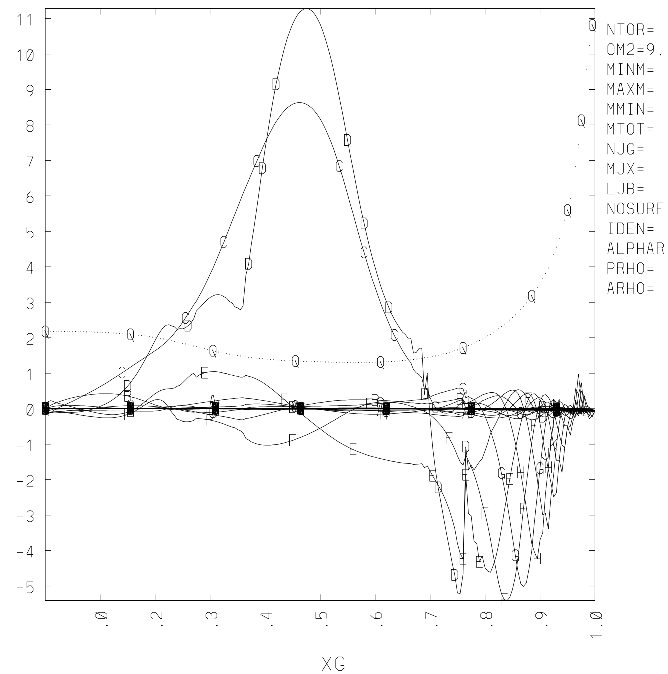

- Red is for acoustic mode filtering scheme (Chu'92): TAE and BAE (Turnbull '93) modes are recovered.
- Black is for full ideal MHD NOVA continuum.
- Global AMs are more likely to exist at high $\beta$ since frequency spacing for the acoustic continuum is $\Delta\Omega \sim \sqrt{\gamma\beta/2}$.
- Two AM branches are found. GAM is interacting strongly with the Alfvén branch.
- TAM forms global eigenmodes above acoustic continuum.

# *TAE structure with and without filtering*

Filtered continuum opens the gap




Full continuum limits TAE localization

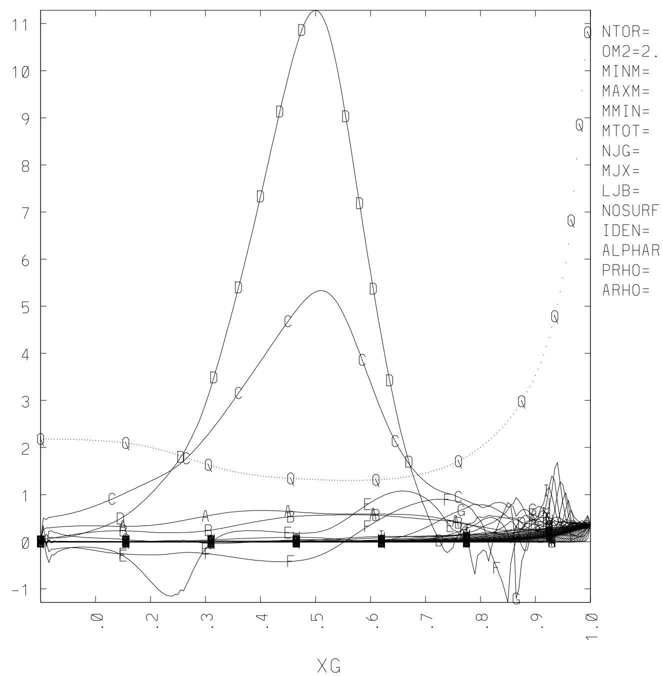



Mode structure is notably different in two models

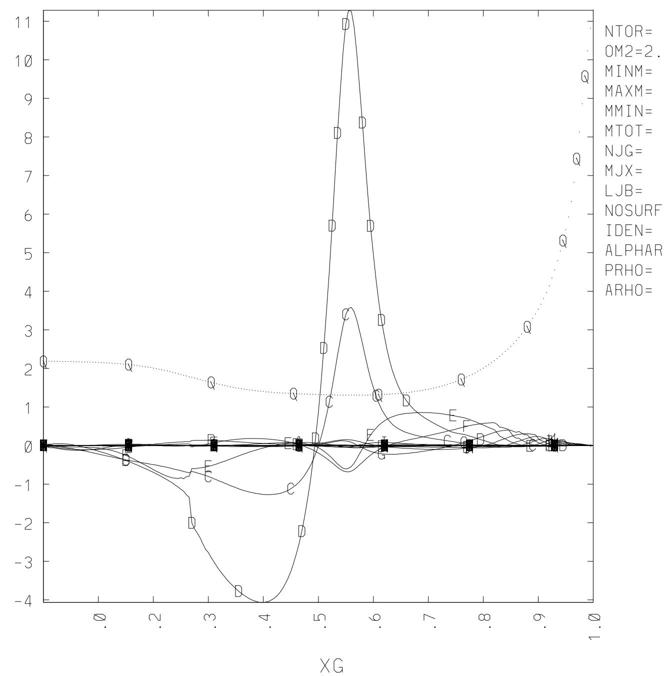
Interaction with the continuum is stronger without filtering. Is continuum damping proportional to $\beta$ (MAST results)?

# Global Acoustic mode structure and frequency

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

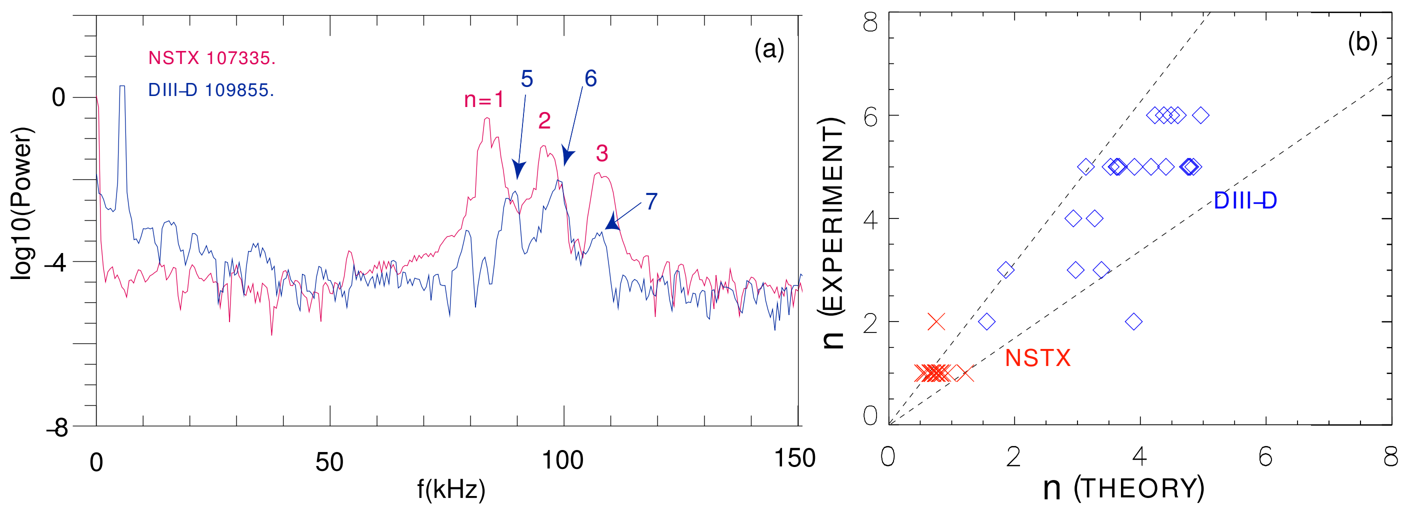



Second radial TAM $f = 33.8kHz$




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

# *TAEs are observed in NSTX at higher frequency*




- Most unstable mode numbers (larger amplitude at the edge) scale with $a/q^2$ (Heidbrink '02, Gorelenkov '03).

# *SUMMARY*

- Preliminary analysis show the existence of low-n global Toroidicity modified Acoustic eigen-Modes (TAM) in NSTX.
- The $n = 2$ TAM frequency computed by NOVA, $35kHz$, is very close to the observed frequency $43kHz$ after deducting the toroidal rotation Doppler shift for #$115731$ shot.
- TAMs can exist in high beta plasma with wider BAE gap.
- TAEs are pushed higher in frequency due to beta effect.
- Kinetic modification of MHD theory is important issue for new class of modes (parallel phase velocity is on the order of the sound speed).