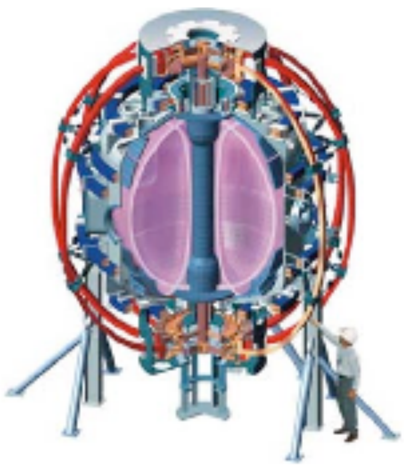
NSTX



Alfvén Cascade modes at high β_e in NSTX — structure and suppression

NA Crocker, ED Fredrickson, NN Gorelenkov

and many others …

NSTX Results and Theory Review

July, 2007

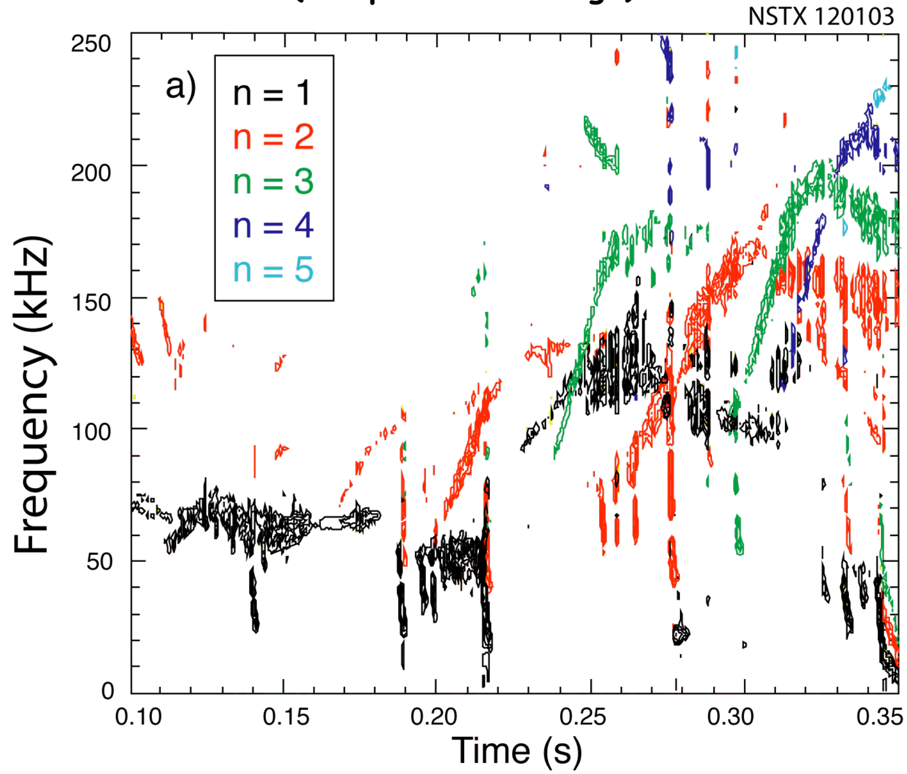
UCLA

XP 706: β_e scaling of Alfvén Cascade modes*

- excited by fast-ions (NB ions, fusion α's,…) in reversed-shear
- can transport fast-ions
- ITER plans reversed-shear operation
- Theory predicts suppression at high β_e
- NSTX reaches high β_e
  - Spherical tori have traditionally not seen ACs
  - β_e suppression first reported on NSTX

Alfvén Cascade modes at low β_e in NSTX

(δb spectrum at edge)

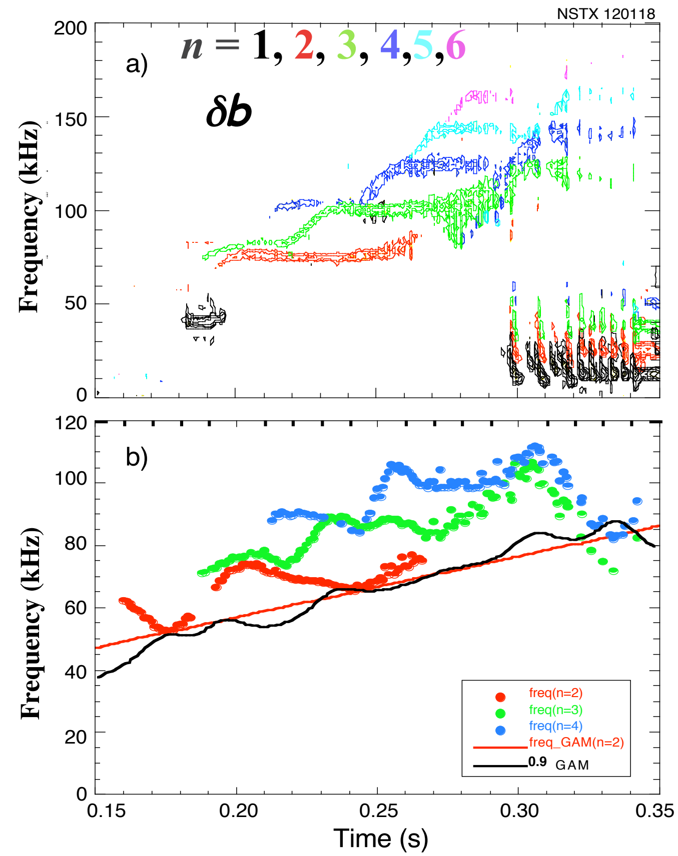


Alfvén Cascade modes observed in NSTX

- Series of upward frequency sweeps observed (top right)
  - increasing toroidal mode numbers
- Doppler corrected *f* (bottom right) shows up-sweep followed by down-sweep
  - Doppler shift resulting from plasma rotation measured at the assumed mode location near q_{min}, R = 1.25 m
  - Down sweep theoretically more strongly damped
- Up-sweep consistent with Alfvén Cascade (AC) mode: ACs sweep up from f_{min} as q_{min} falls (bottom right).
  - Predicted AC chirp start frequency* is f_{GAM}; due to coupling with GAMs

$$f_{GAM}^2 = \frac{1}{(2\pi)^2}\frac{2C_S^2}{R^2}\left(1+\frac{7}{4}\frac{T_i}{T_e}\right)$$

  - The red curve is the interpolated n = 2 f_{GAM} evolution
  - the black is the local f_{GAM} scaled by 0.9 to match the data



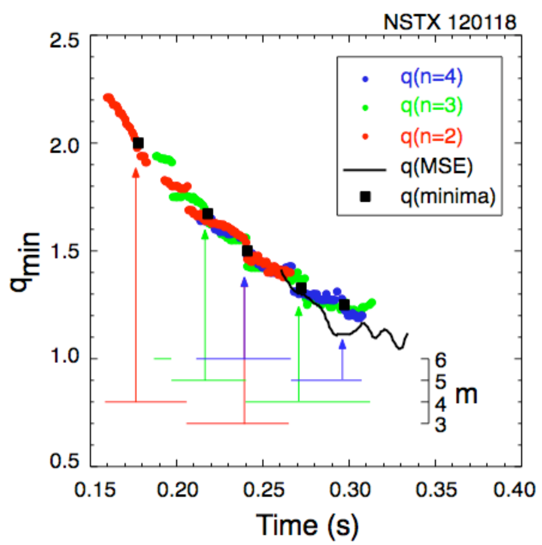
*Breizman, *et al*. [*Phys. Plasmas 12 (2005) 112506*]

AC frequency depends on $q_{min}(t)$

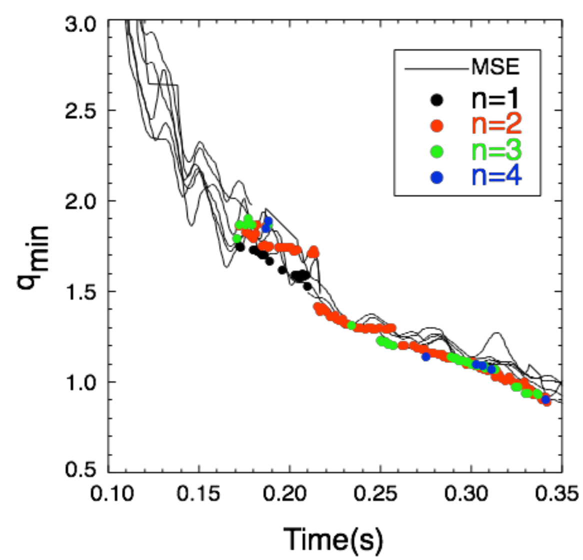
- Using measured *n* and reasonable *m*, $q_{min}(t)$ inferred from AC frequency
  - choice of m for multiple modes must yield consistent $q_{min}(t)$
  - consistent $q_{min}(t)$ given by (m,n) = (5,2), (4,2)+(2,1), (5,3), (3,2), (4,3), (5,4)
  - times of mode frequency minima (sweep start) marked with black squares

$$q_{min} = \frac{mV_{Alfvén}}{nV_{Alfvén} + R(\omega_{mode}^2 - \omega_{min}^2)^{1/2}}$$

ω_{min} from observation ($\sim 2\pi f_{GAM}$)



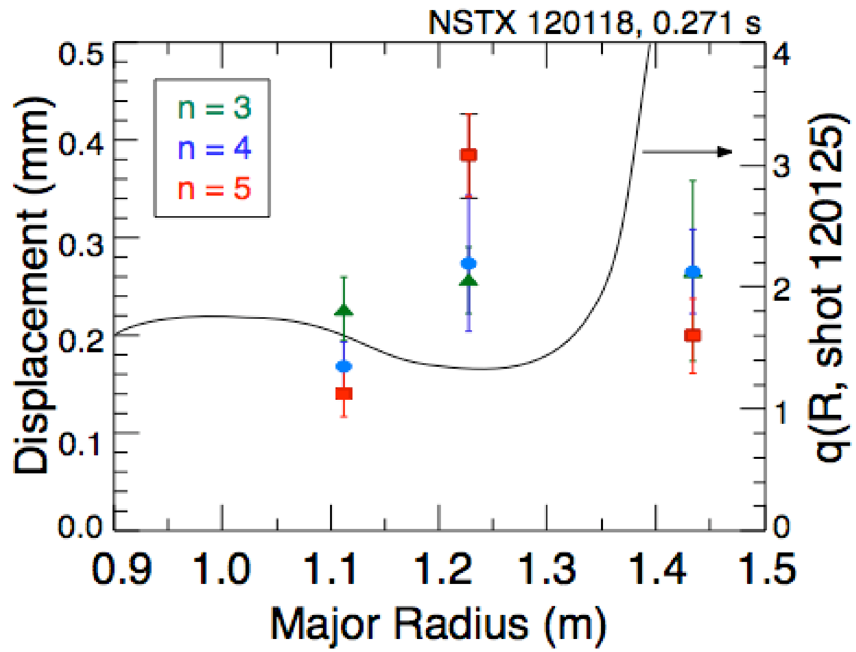
higher density case



lower density case

- Inferred $q_{min}(t)$ compares well with $q_{min}(t)$ from MSE (from same and similar shots)

ACs seem to peak near q_{min} as expected



- Internal structure of modes measured with reflectometers
- q profile from similar shows minimum at R ~ 1.25 m.
- Structure consistent with localization at q_{min}
  - Strong localization for highest *n* mode, as expected from theory

ACs suppression observed at high β_e

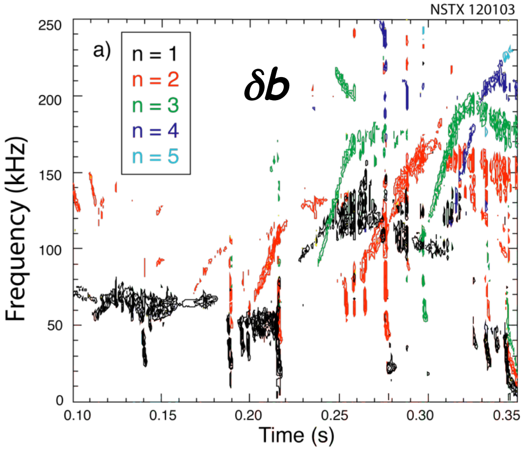
- Theory* predicts AC frequency sweeps from f_{min} (=f_{GAM}) to f_{TAE}; can derive critical β_e for suppression by setting f_{GAM} = f_{TAE}

$$\frac{\omega_{\min}^2}{\omega_{TAE}^2} = \frac{4q^2R^2}{V_A^2}\frac{2C_S^2}{R^2}\left(1+\frac{7}{4}\frac{T_i}{T_e}\right) = 4q^2\beta_{e,crit}\left(1+\frac{7}{4}\frac{T_i}{T_e}\right) \approx 1$$

- Predicted $\beta_{e,crit} \approx (20\% - 25\%)/q^2$ matches observation
  - Prediction includes small empirical correction factors for $\omega_{\min}$ and ω_{TAE} from experimental spectra

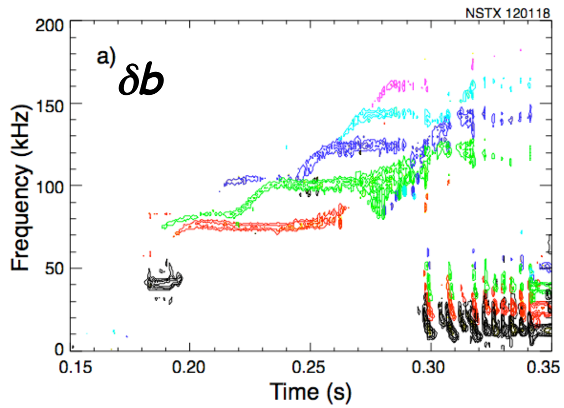
low β_e: large f sweep

$\beta_e/\beta_{e,crit} \approx 0.06 - 0.2$



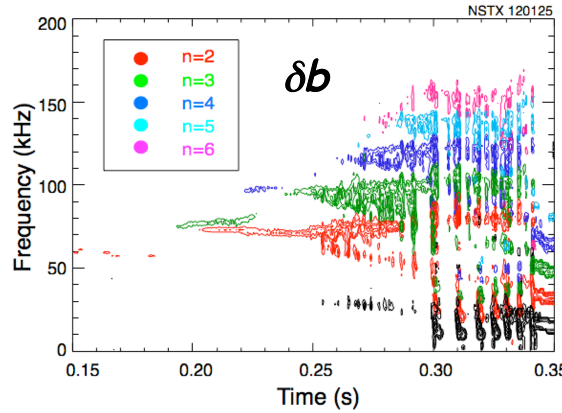
medium β_e: small f sweep

$\beta_e/\beta_{e,crit} \approx 0.5 - 0.7$



high β_e: no f sweep

$\beta_e/\beta_{e,crit} \approx 1$

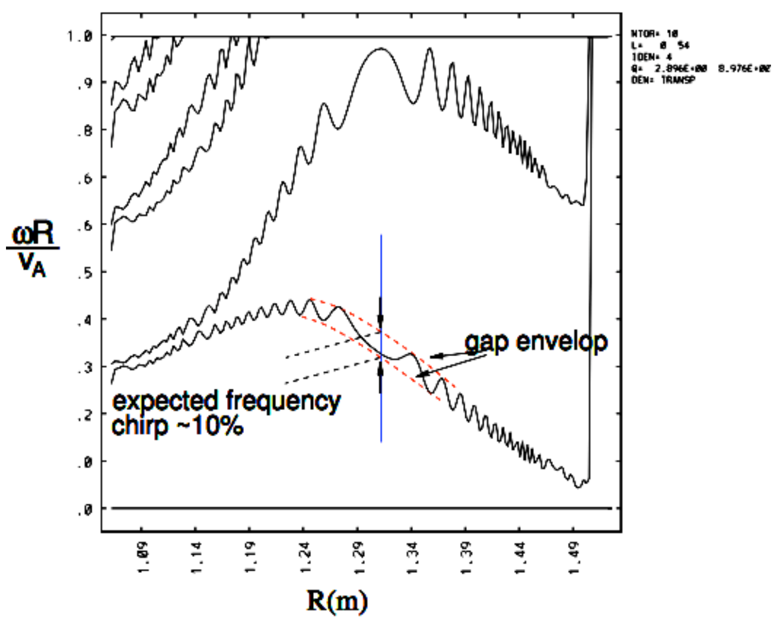


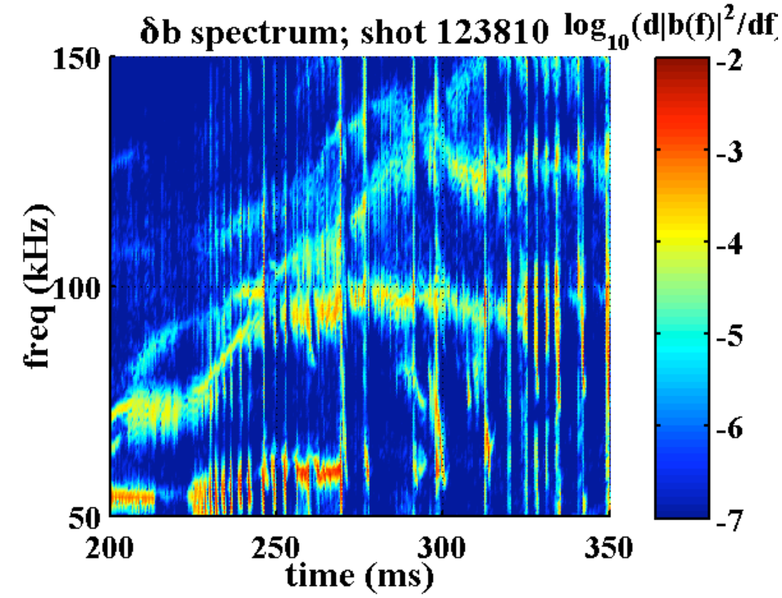
*Breizman, *et al.* [*Phys. Plasmas 12 (2005) 112506*]

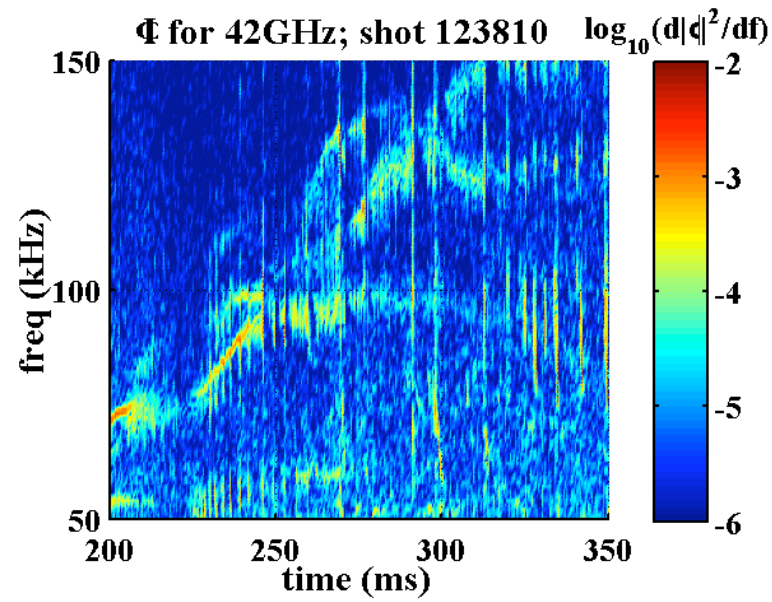
Structure measurements will be compared with NOVA-K calculation

- Three fixed-frequency reflectometers measure radial structure of mode (low field side)
  - All three reflectometers use same antennae: no geometrical phase shifts
- NOVA-K includes GAM coupling
  - calculates AC structure and frequency

NOVA-K: Alfvén Continuum
with GAM coupling

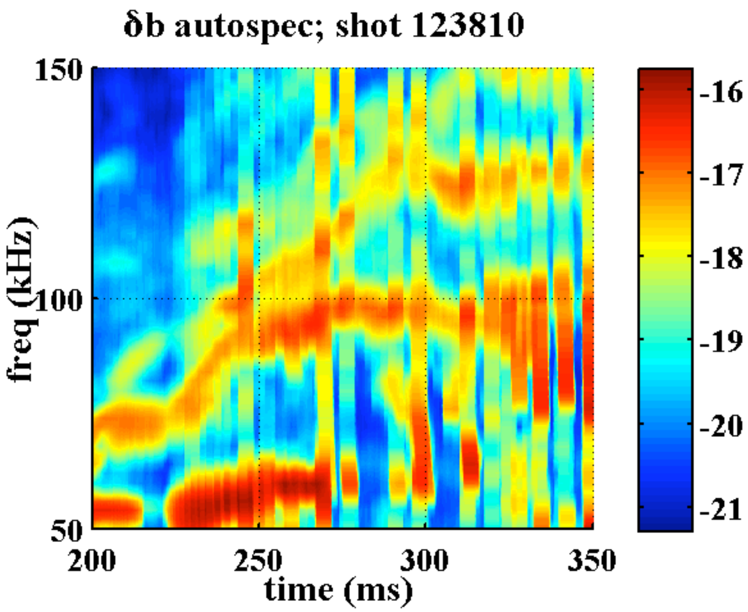


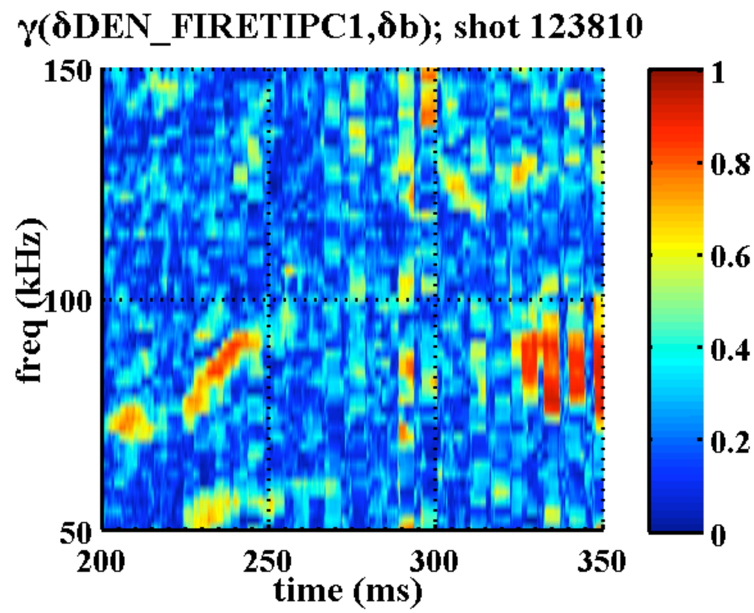




FIReTIP Tangential Interferometers Sensitive to ACs - Contribute to NOVA-K comparison

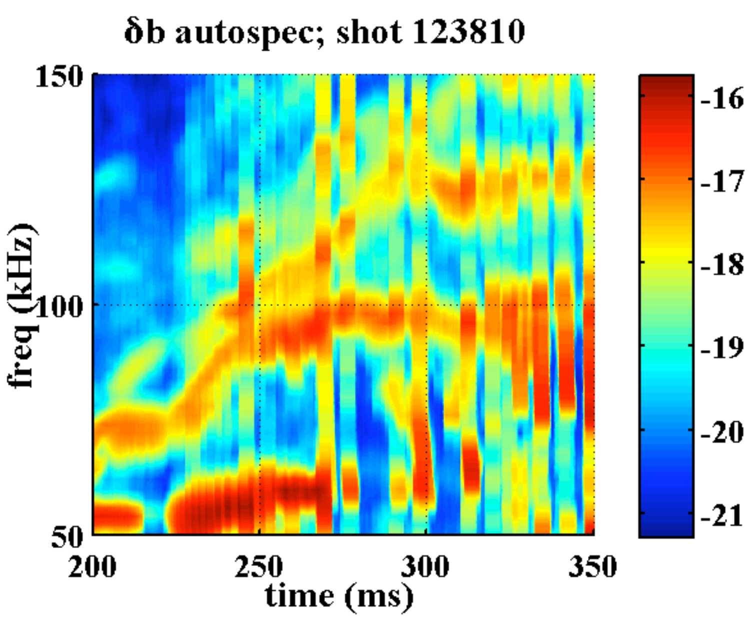
- Tangential FIR interferometers measure density perturbation across plasma
  - constrain comparison of measurement with calculated structure
- Three chords show significant coherence in 123810 (chords with R_{tan} < 1m)

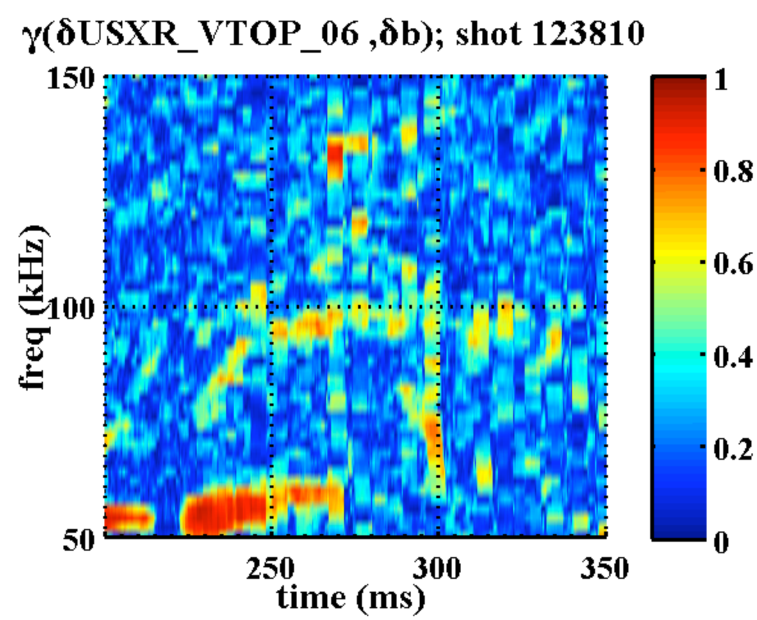




Multiple soft X-ray chords also see ACs

- Multiple soft x-ray chords highly coherent with edge magnetics (δb)
- Possible uses:
  - unfold δT_e (w/modeling, δn_e measurement and NOVA-K calculation)
  - cross-check of γ (ratio of specific heats); ACs dispersion relation sensitive to γ (coupling to GAM)

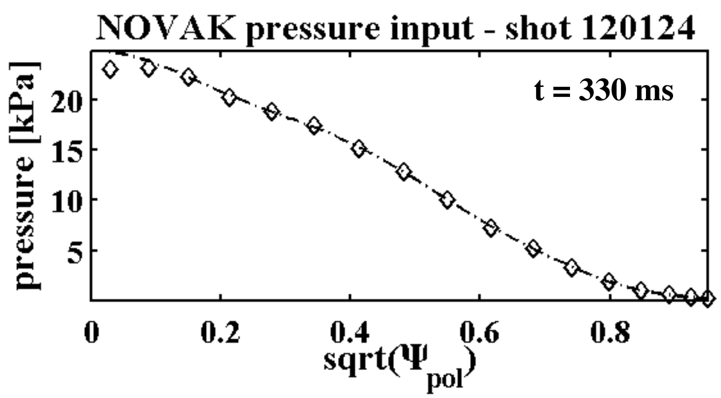


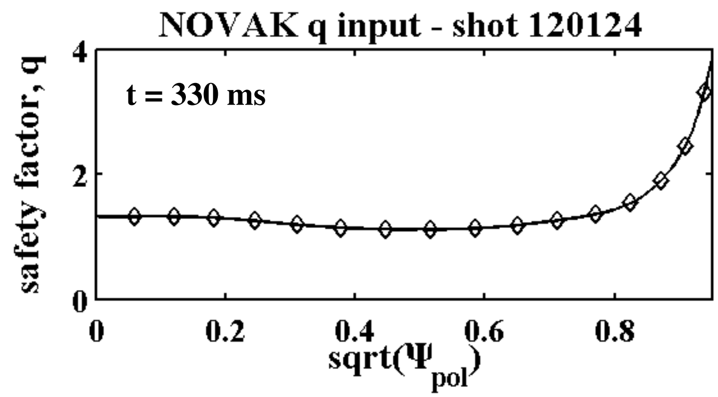


Conclusions

- **Alfvén Cascade modes observed and verified in NSTX**
  - mode frequencies sweep from ~ f_{GAM} to ~ f_{TAE}
  - $q_{min}(t)$ determined from frequency sweep agrees with MSE
  - localized near q_{min}
  - suppression observed near predicted β_e (where f_{GAM} ~ f_{TAE})
- **Multiple internal measurements of AC structure obtained**
  - local density fluctuations: three reflectometers measure
  - chord integrated density fluctuations: three tangential interferometers
  - SXR emission: temperature fluctuations (?)
- **Calculated mode structure (NOVA-K) will be compared with measurements**
  - NOVA-K inlcudes GAM coupling:
  - calculates frequency
  - predicts suppression at high β_e

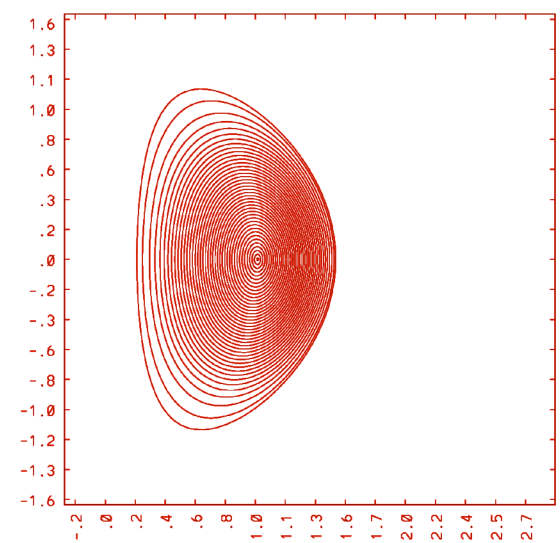
NOVA-K solves linear ideal MHD stability equation





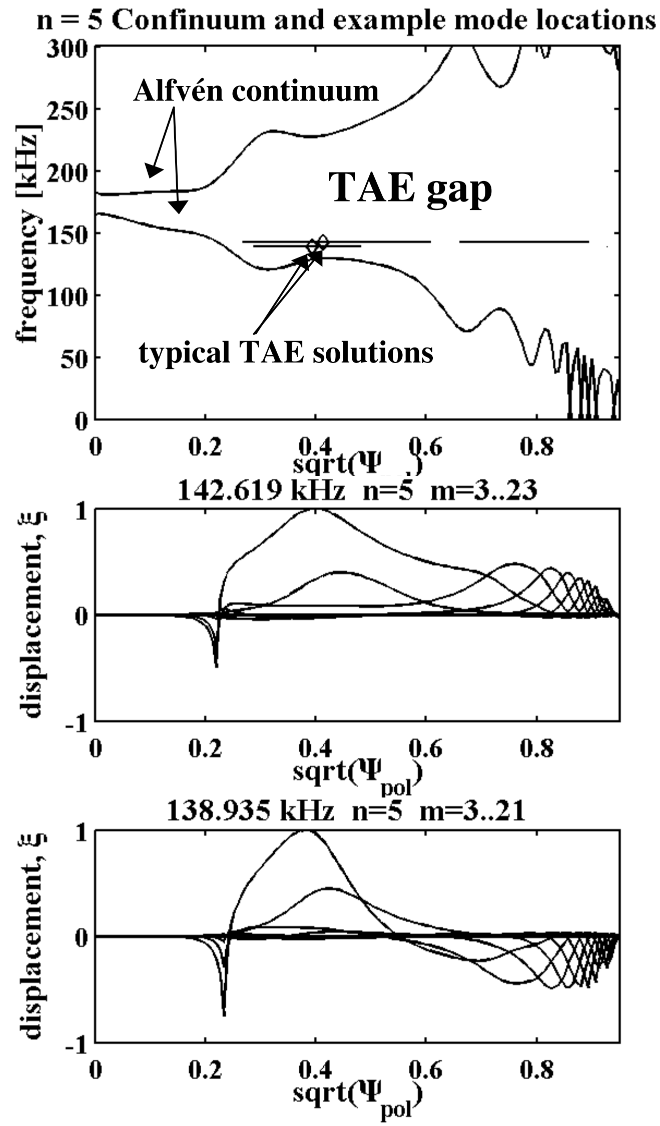
- **Solves in "perturbative" limit**
  - fast ions affect growth rate, not mode structure and frequency
- **Equilibrium taken from experiment:**
  - plasma geometry
  - pressure profile
  - q profile
- **Essumes no rotation**
  - must account for rotation in experiment – typically, mode considered Doppler-shifted by rotation at mode peak
- **γ (ratio of specific heats) is free parameter**

NOVA-K input geometry - shot 120124



NOVA-K calculates frequency and structure of Alfvén eigenmodes

- Typical solutions (middle right) peak near region of q_{min}, in agreement with reflectometer measurements



AC mode structure probed by internal fluctuation diagnostics

- **Multiple reflectometers measure local density perturbation (bottom left)**
  - radial structure of mode (low field side)
- **Tangential FIR interferometers density perturbation across plasma (bottom left)**
  - constraint on comparison with predicted structure
- **Multi-chord Soft X-ray arrays (bottom right)**
  - Possible temperature fluctuations