NSTX

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Linear coupling of Alfvén Cascade modes in NSTX

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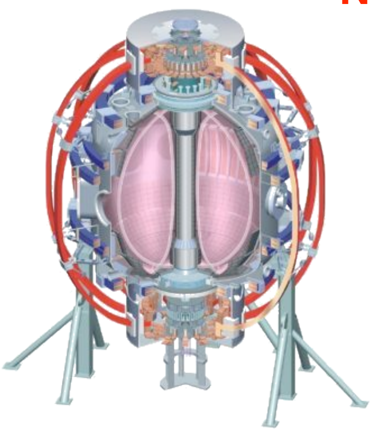


Recent NSTX results extend understanding of Alfvén Cascade (AC) mode* physics to high β and high ε

- Alfvén Cascade (AC) modes* unstable in reverse-shear (RS) plasmas
  - RS is advanced scenario for ITER & Component Test Facility –
- Understanding of AC physics desirable
  - ACs transport fast-ions (beam ions, ICRF accelerated ions and fusion alphas) – impact plasma performance
  - AC modes serve diagnostic function ["MHD spectroscopy" – measure $q_{min}(t)$]
- High β and high ε are relatively unexplored regimes for AC modes

***a.k.a. reverse-shear Alfvén eigenmodes**

Summary of Results

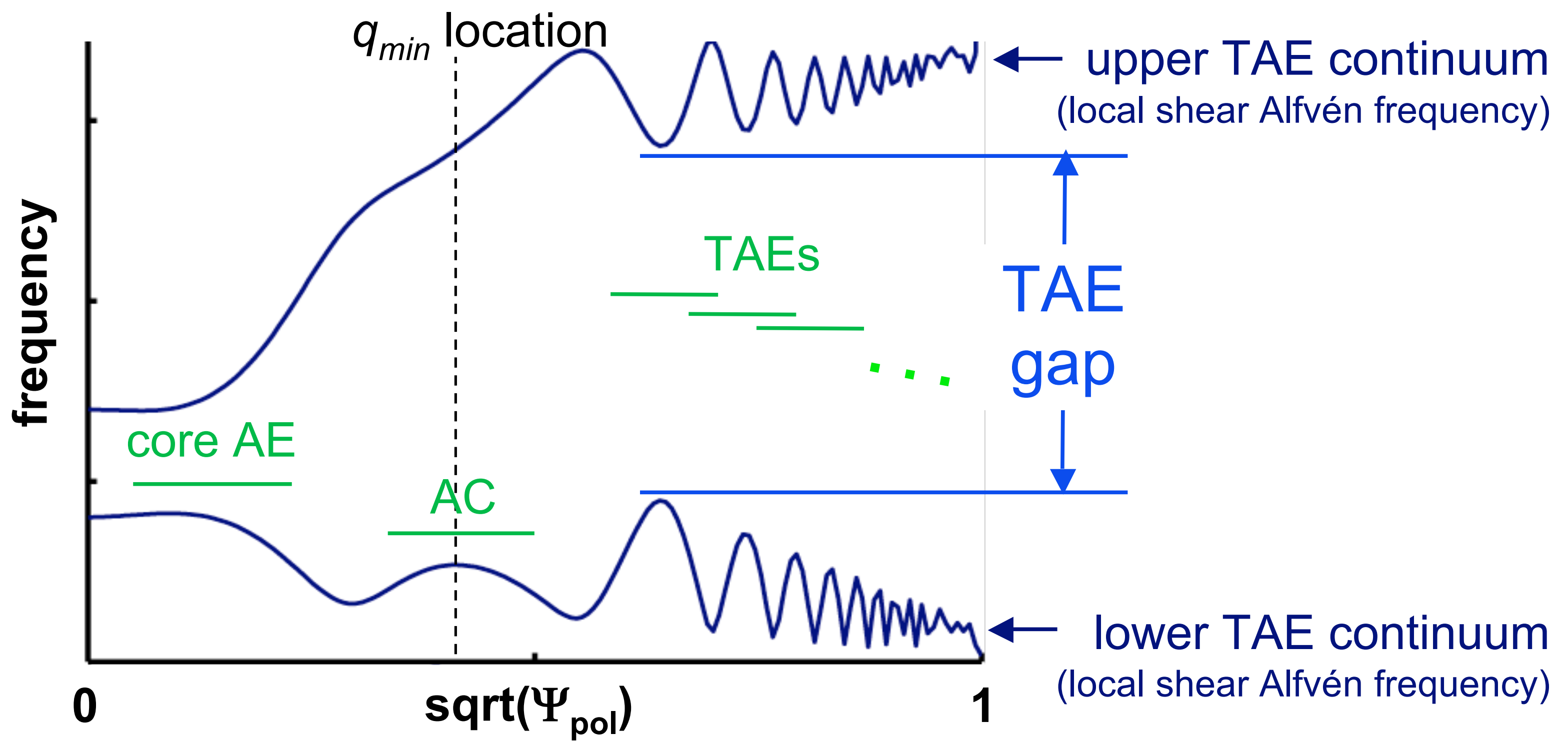
- NOVA-K linear stability code used to calculate shear Alfvén plasma eigenmode structure in NSTX reversed shear plasmas
  - extends study of Alfvén Cascade (AC) modes to high β (ratio of kinetic and magnetic pressures) and high ε (inverse aspect ratio, = a/R)
- Eigenmodes *not* "pure" AC modes – mode structure shows *linear coupling* of ACs with toroidicity-induced Alfvén eigenmodes (TAE)
- High β and high ε enhance linear coupling
- Coupling gives broad spectrum of poloidal components and radially extended structure
  - broad spectrum can lead to enhanced transport – multiple fast-ion resonances
  - extended structure enhances edge δB, so Mirnov coils see AC modes – coils relatively insensitive to ACs in conventional tokamaks

NOVA-K* code explores high β, high ε AC physics

- Linear, ideal MHD, hybrid/kinetic code.
- Computes Alfvén eigenmode (AE) structure, frequency, growth rate
  - fast-ions treated perturbatively
  - "Chu" filtering scheme† eliminates acoustic singularities
  - geodesic curvature, β effects included
- Success demonstrated at predicting mode structure and frequency at low β and low ε
  - AC, TAE modes in DIII-D (Van Zeeland'06 APS), JET (Kramer'05 APS), TAE/GAEs in NSTX (Gorelenkov'03 APS)

*C. Z. Cheng et al, Phys. Reports (A Review Sec. of Phys. Letters.), **211**, 1 (1992)
†M. S. Chu et al., Phys. Fluids B **4**, 3713 (1992)

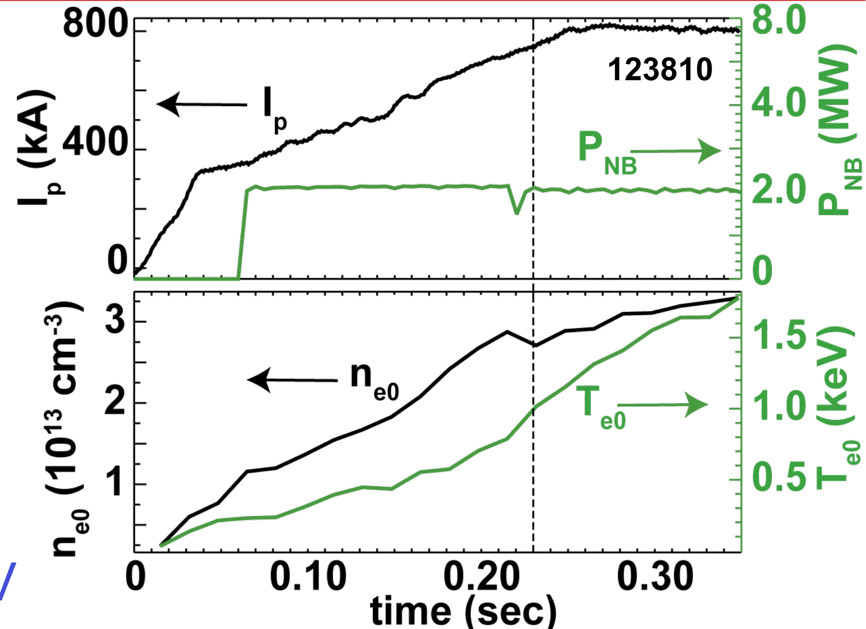
NOVA-K finds shear Alfvén plasma eigenmodes

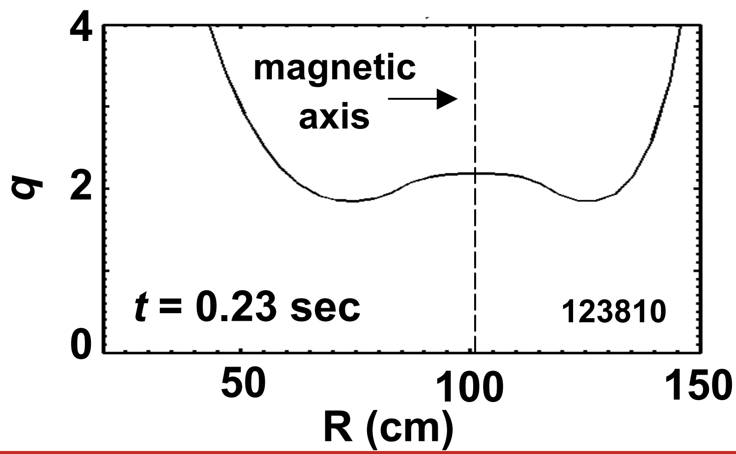


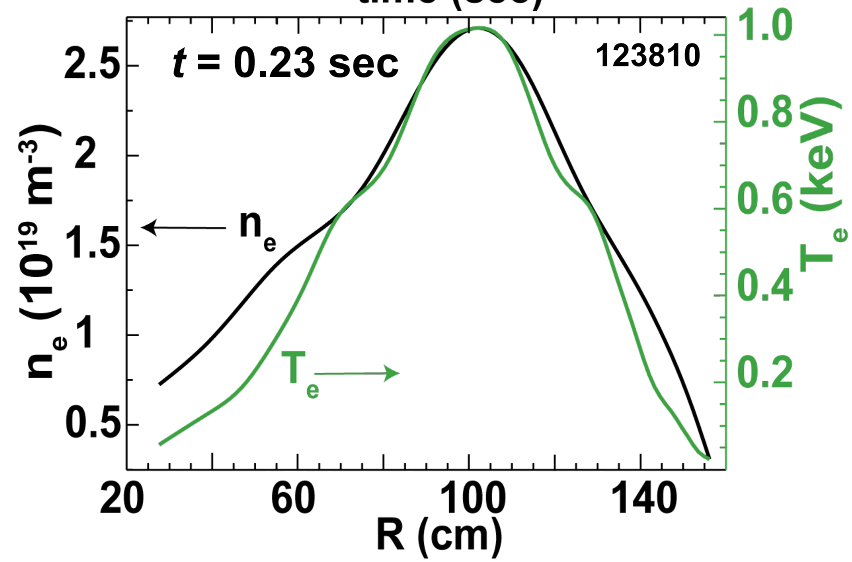
- Toroidal coupling of poloidal component opens “TAE gap” ⇒ TAEs live in gap
- AC mode lives above continuum at q_{min} (region of weak shear)
- Weak shear at axis makes core AE AC-like

NOVA-K used to study AC modes over range of β in He L-mode NSTX plasmas

- Reverse shear, lower single null
- B_{TOR} = 0.45 T, I_p = 0.8 MA
- 2 MW Neutral beam heating
  - –90 keV, Deuterium
- β_{tor} at q_{min} up to 11% (including fast ions)
  - –n_{e0} ~ 1 – 3.5x10^{19} m^{-3}, T_{e0} ~ 0.5 – 1 keV
- n_e and T_e strongly peaked



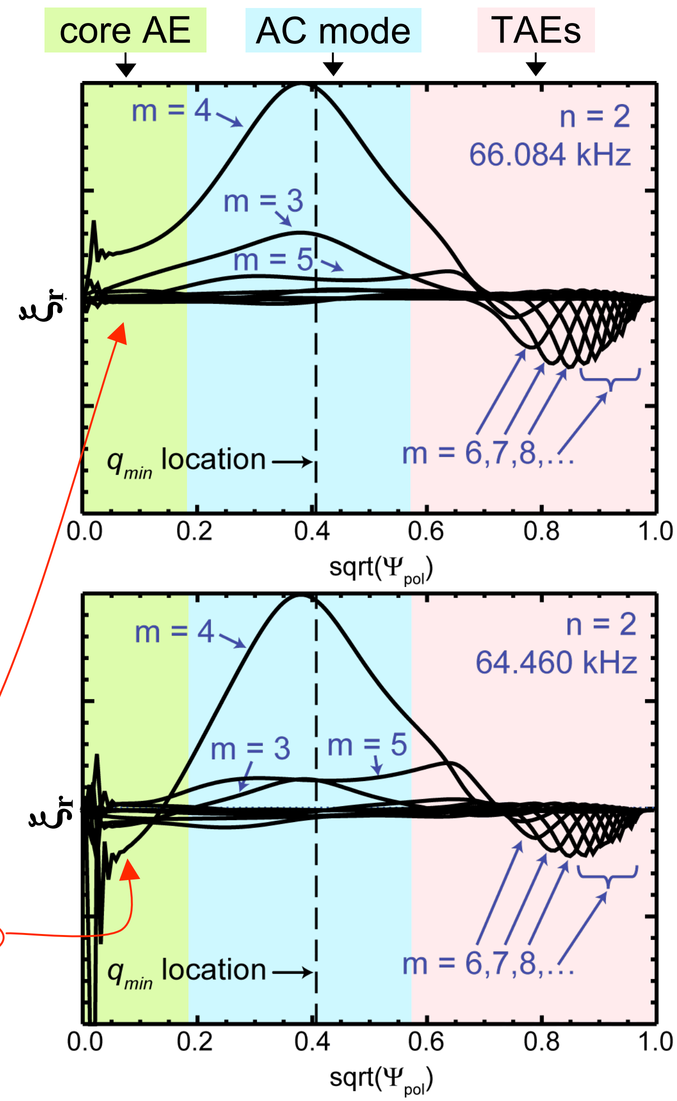




NOVA-K shows NSTX eigenmodes *not* purely TAEs or ACs*: Eigenmodes formed by linear coupling of AC with TAEs

- Eigenmodes have coupled parts with AC-like or TAE-like structure
  - AC: dominant component (m,n) at minimum q, with weak sidebands (m±1,n)
  - TAE: two dominant components, (m-1,n) at q = (m-1)/n and (m,n) at q = m/n
  - Core AE: similar to AC (caused by weak shear at magnetic axis)
- NOVA-K finds multiple eigenmodes with AC-like structure
  - closely spaced frequencies
  - structures differ due to parity of coupled parts
    - e.g. core AE couples with positive or negative parity to rest of eigenmode (*see right*)

Radial structure of eigenmode

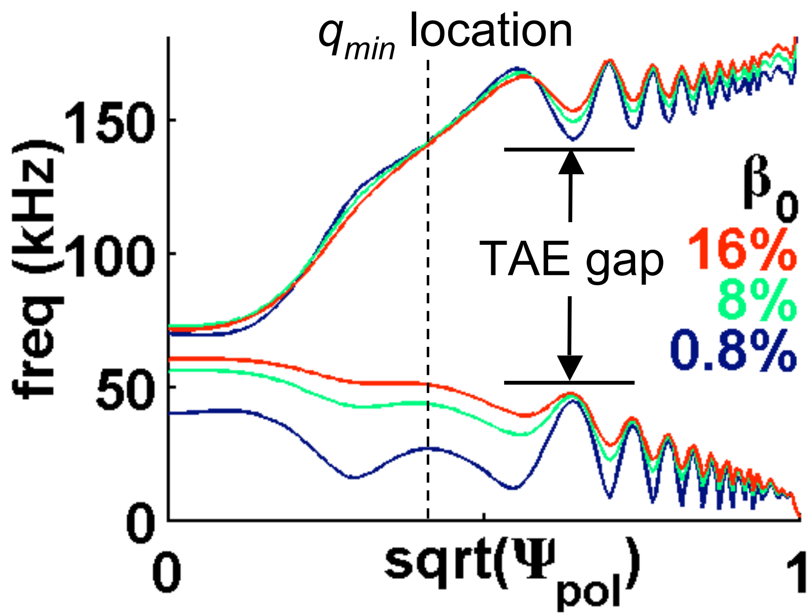


*see also M. A. Van Zeeland et al, Phys. Plasmas **14**, 056102 (2007)

High ε enhances linear coupling of ACs to TAEs in NSTX

- Higher ε gives stronger *toroidicity-induced coupling* $\Rightarrow$ NSTX has stronger coupling than conventional tokamaks
- Linear coupling requires AC to have natural frequency similar to TAEs
- Higher ε widens TAE gap $\Rightarrow$ natural AC and TAE frequencies likelier to be similar

High β of NSTX enhances coupling of AC mode to TAEs



- β scan shows β increase elevates continuum near q_{min}– raises AC frequency into TAE gap
  - –AC "lives" above continuum (AC frequency depends on continuum frequency)
- Elevation into TAE gap ⇒ AC couples with TAEs
  - –Linear coupling requires AC to have natural frequencies similar to TAEs

Effect of linear coupling on eigenmode structure impacts fast-ion transport and experimental detection of AC modes

- Coupled eigenmodes have broader poloidal spectrum
  - Each poloidal harmonic has fast-ion phase space resonance
  - resonances can overlap at large amplitude, leading to fast-ion transport
  - many harmonics can lead to enhanced transport
- Coupled eigenmodes have increased radial extent
  - enhances edge $\delta B \Rightarrow$ edge Mirnov coils see AC modes*
    - Mirnov coils relatively *insensitive* to ACs in *conventional tokamak*
  - eigenmode can perturb fast-ion orbits across large radial region, enhancing fast-ion transport

*see also M. A. Van Zeeland et al, Phys. Plasmas **14**, 056102 (2007)

Conclusions

- NOVA-K linear stability code used to calculate shear Alfvén plasma eigenmode structure in NSTX reversed shear plasmas
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Future work

- Use ORBIT calculation to assess effectiveness of coupled eigenmodes for causing resonance overlap transport
- Experimentally test effect of coupling on transport: coupling experimentally modifiable by changing AC and TAE natural frequencies:
  - Vary magnetic shear: edge TAE frequency sensitive to edge q; AC frequency sensitive to q_{min}
  - Vary toroidal rotation shear: gives relative Doppler shift between TAE in edge and AC in core
  - Vary β: controls elevation of AC into TAE gap
- Test ε dependence of coupling with multi-machine "aspect ratio scan"