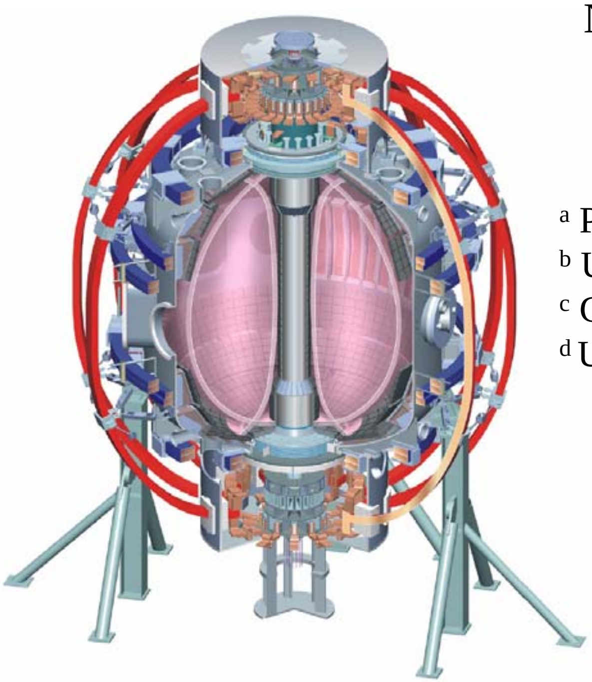
Supported by

Study of Aspect Ratio Effects on Kinetic MHD Instabilities in NSTX and DIII-D

E.D. Fredrickson,[a] W.W. Heidbrink,[b] C.Z. Cheng,[a] N.N. Gorelenkov,[a] E. Belova,[a] A.W. Hyatt,[c] G.J. Kramer,[a] J. Manickam,[a] J. Menard,[a] R. Nazikian,[a] T. L. Rhodes[d], E. Ruskov[b]

[a] Princeton Plasma Physics Laboratory, NJ
[b] University of California, Irvine, CA
[c] General Atomics, LaJolla, CA
[d] University of California, Los Angelos, CA

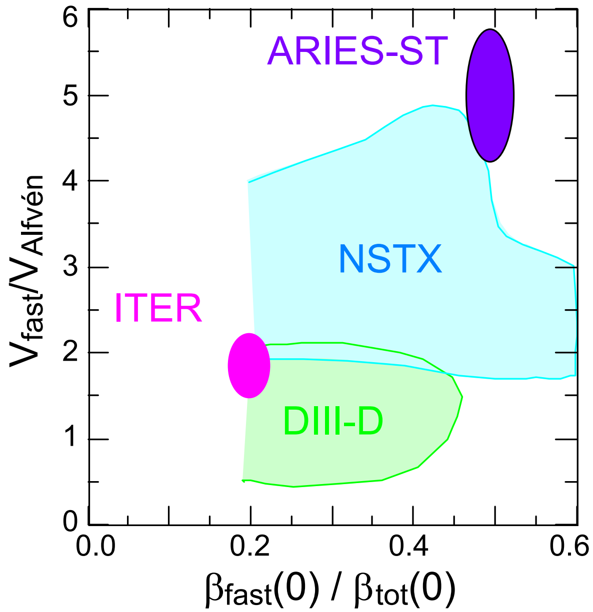


20th IAEA Fusion Energy Conference
1 – 6 November 2004
Vilamoura, Portugal

Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
NYU
ORNL
PPPL
PSI
SNL
UC Davis
UC Irvine
UCLA
UCSD
U Maryland
U Rochester
U Washington
U Wisconsin
Culham Sci Ctr
Hiroshima U
HIST
Kyushu Tokai U
Niigata U
Tsukuba U
U Tokyo
JAERI
Ioffe Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
U Quebec

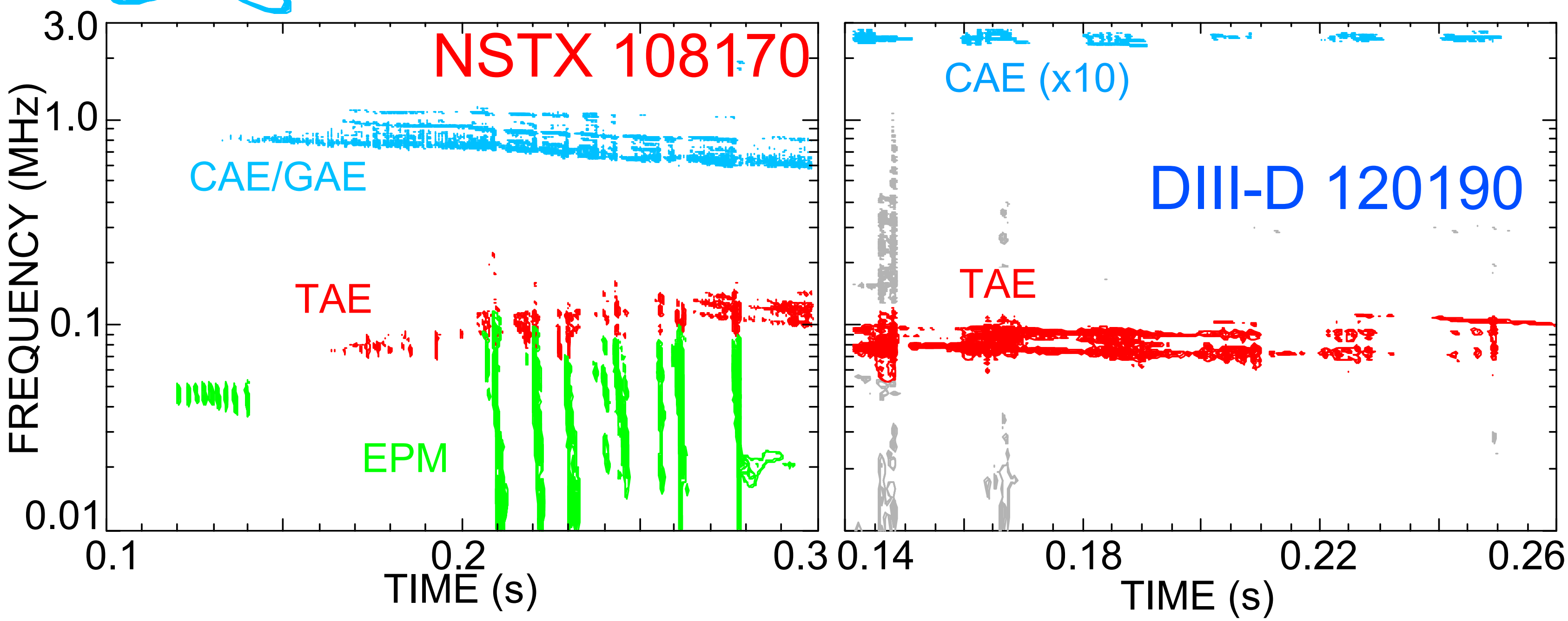
Kinetic instabilities are an important issue for Spherical Tori

- Low field, high density, high $\beta_{fast\ ion}$; $V_{fast\ ion} / V_{alfvén} > 1$:
  - Strong drive for EPM and Alfvénic modes.
- Compact device, large fast ion orbit:
  - Long wavelength Alfvén modes
  - Enhanced fast ion transport
- NSTX, DIII-D are complementary for benchmarking codes (M3D,HYM,NOVA).



- Compressional and Toroidal Alfvén Eigenmodes (**CAE**/**TAE**), as well as Energetic Particle Modes (**EPM**) are all expected.
- Low aspect ratio more stable for ballooning modes (**KBM**).

Broad Spectrum of kinetic instabilities in both NSTX and DIII-D at low field



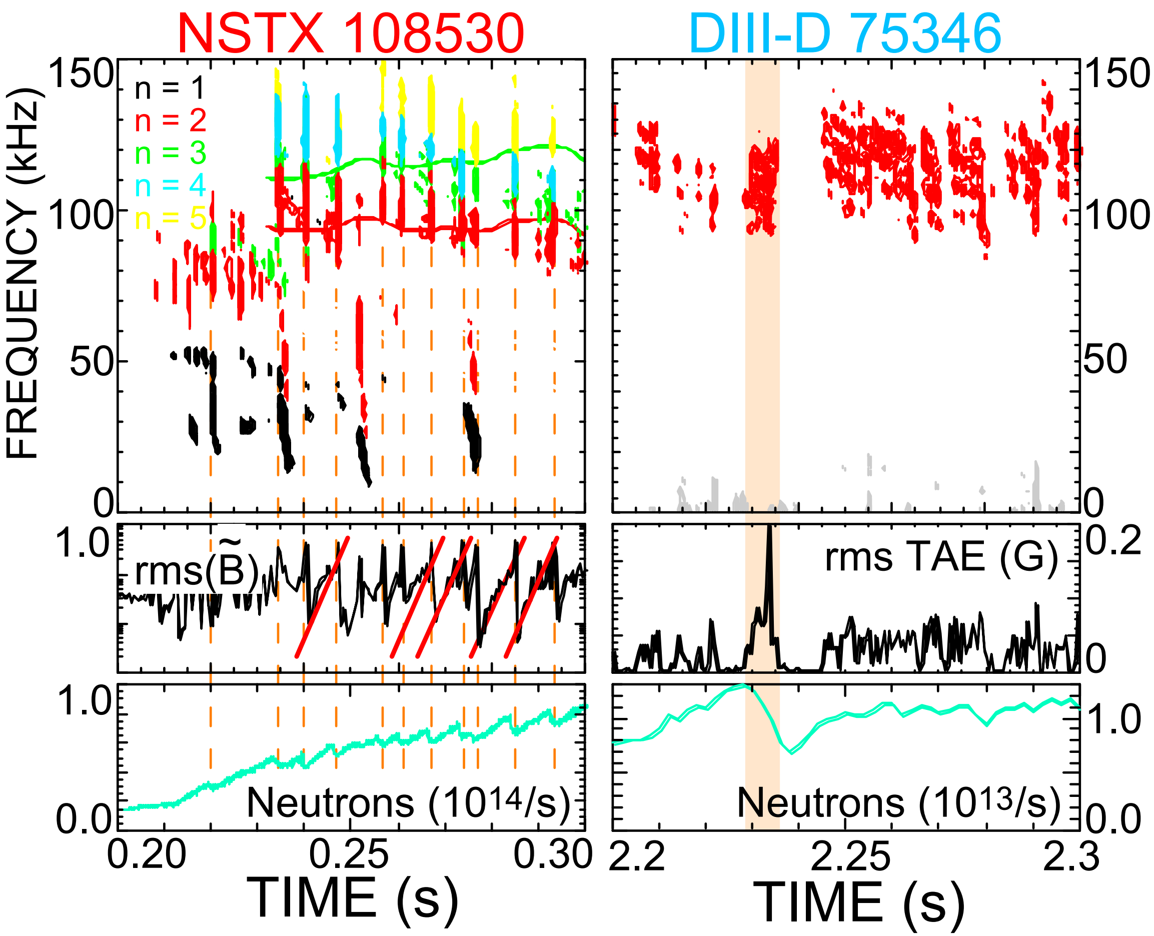
- EPMs, TAE and CAE seen on both NSTX and DIII-D.
- EPM and TAE induce significant fast ion losses.
- Modes seen where fast-ion β is high.
- What are controlling parameters: V_f/V_A, β_f/β_{tot}, ρ^*, R/a?

TAE can cause significant losses at both low and high aspect ratio,

- Largest losses occur with multiple unstable modes.

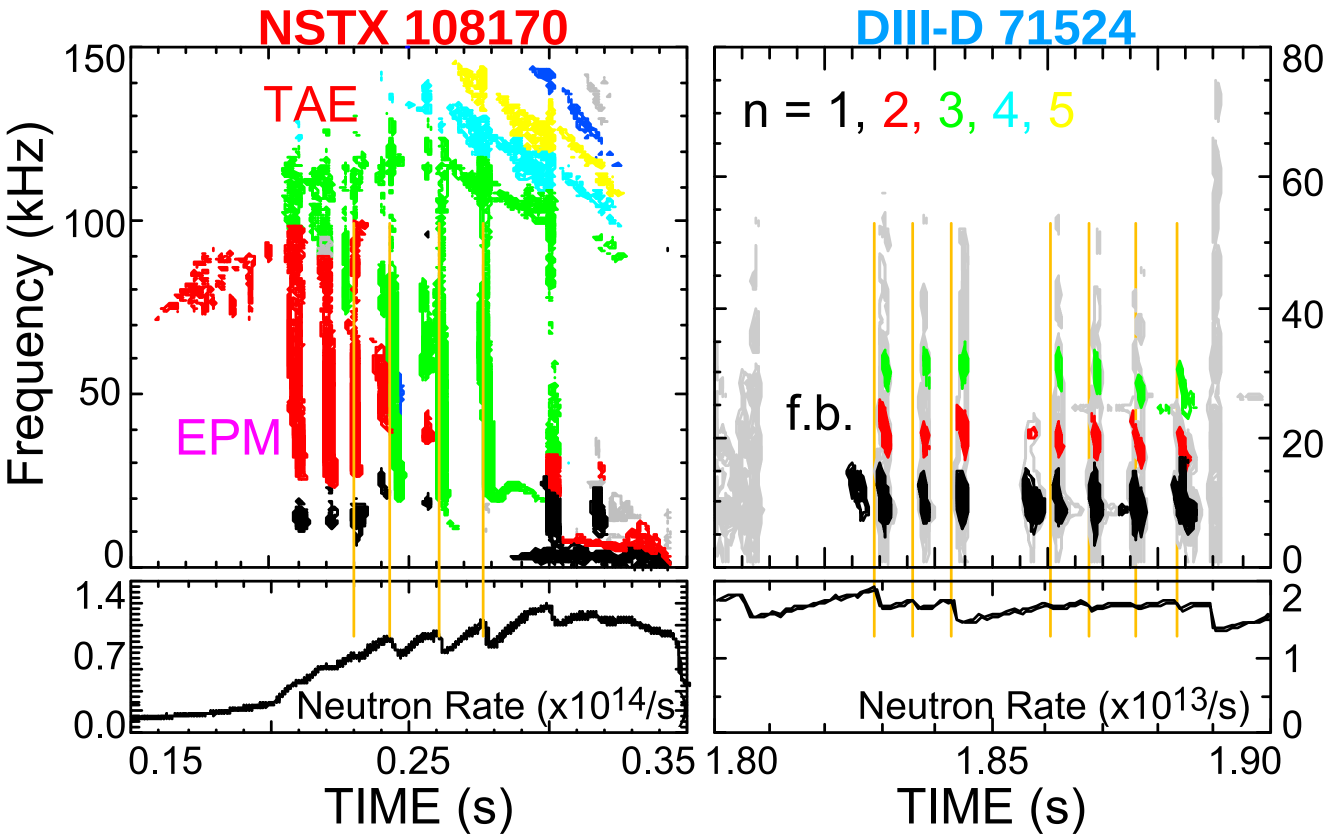
On NSTX:

- TAEs most virulent in low-shear, q(0) ≈ 2 regime*.
  - TAE seen at toroidal β's greater than 20%.
  - Observed growth rates in good agreement with NOVA estimates.
  - Up to 15% drops in DD neutron rate from TAE.
- With higher shear, TAE not bursting
  - no enhanced fast ion loss



*N.N. Gorelenkov, et al., Phys.Plasmas **7** (2000) 1433.

EPM bursts cause fast ion loss similar to fishbones



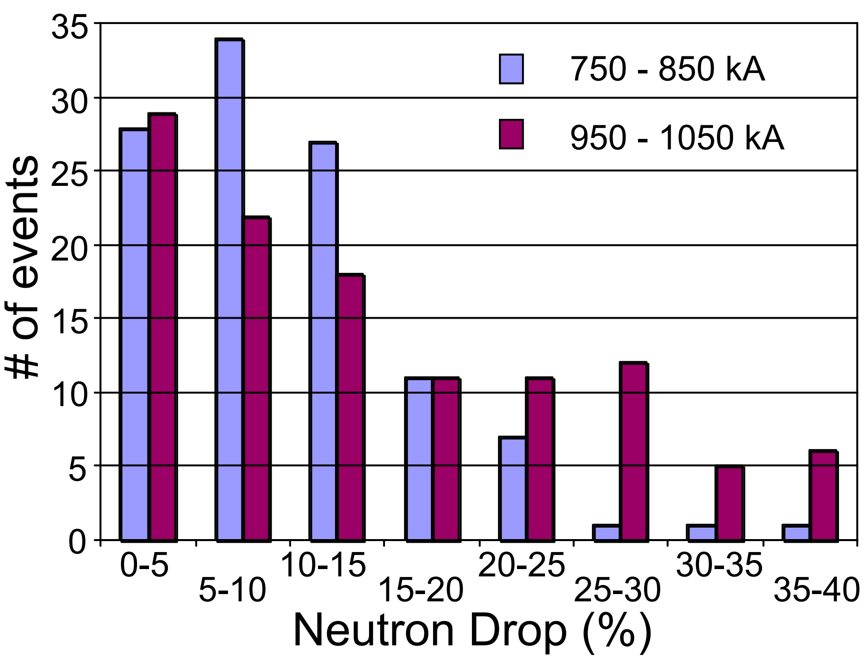
- On NSTX, bursting, chirping EPMs correlate with large fast ion losses
  - Losses up to 40%
    - like fishbones
  - Typically q(0), n > 1,
    - not like fishbones
  - Driven through a bounce-resonance
- Some fishbones are seen in NSTX
  - n=1, q(0)=1
  - and at precession drift frequency

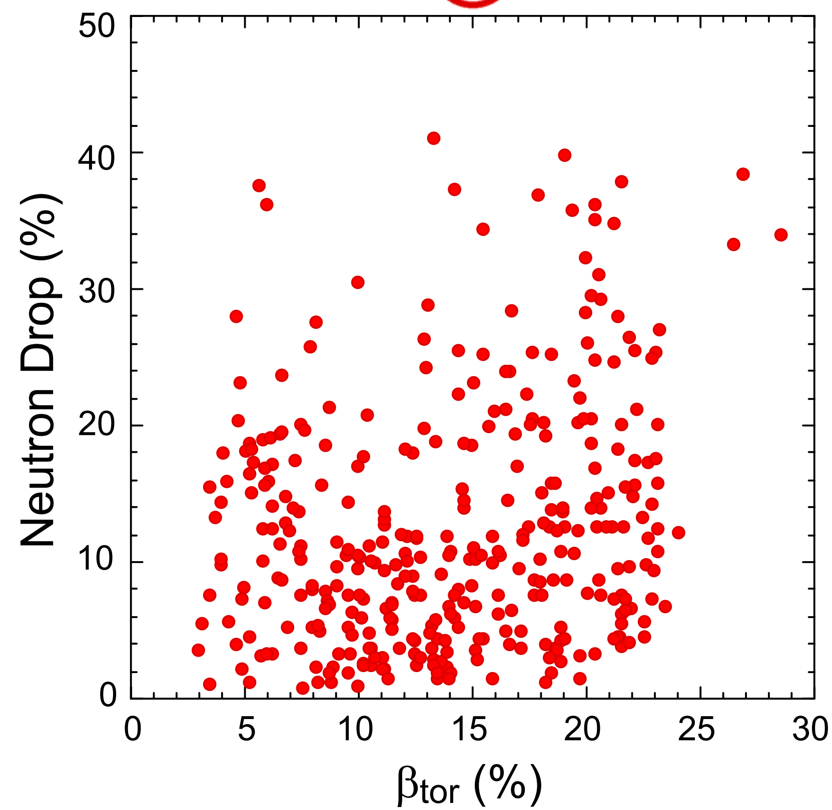
- On DIII-D, fishbones are more common than EPMs.
- Higher frequency DIII-D chirping modes* resemble NSTX EPMs

*Heidbrink, PPCF **37** (1995) 937.

Bursting modes can lead to fast ion loss events

- Losses from EPM and TAE.
  - Neutron drop most sensitive to loss of most energetic beam ions.
- Higher current (smaller ion orbit) has no effect on losses.

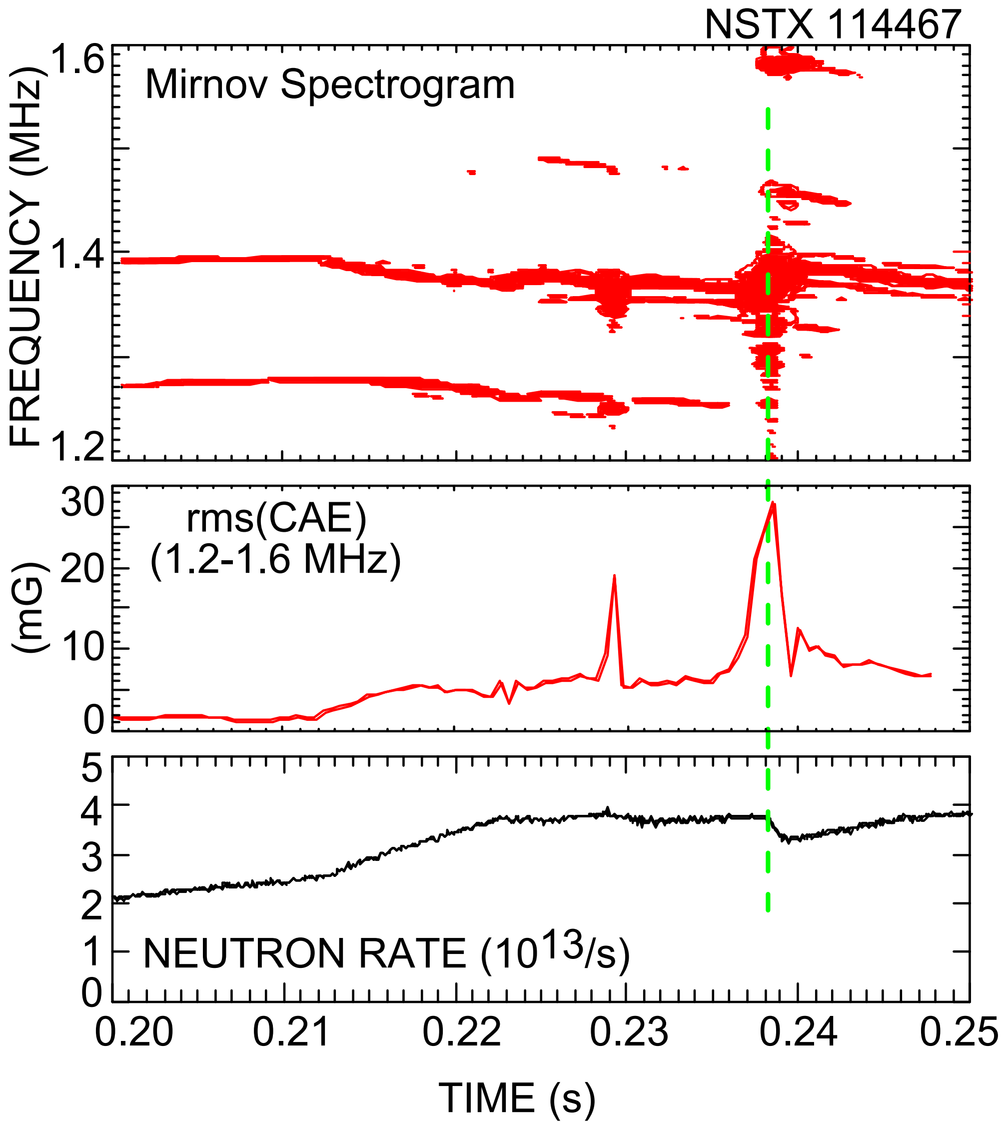




- TAE/EPM seen at β greater than 20%, as predicted;
  - EPMs persist despite precession drift reversal (through bounce resonance).

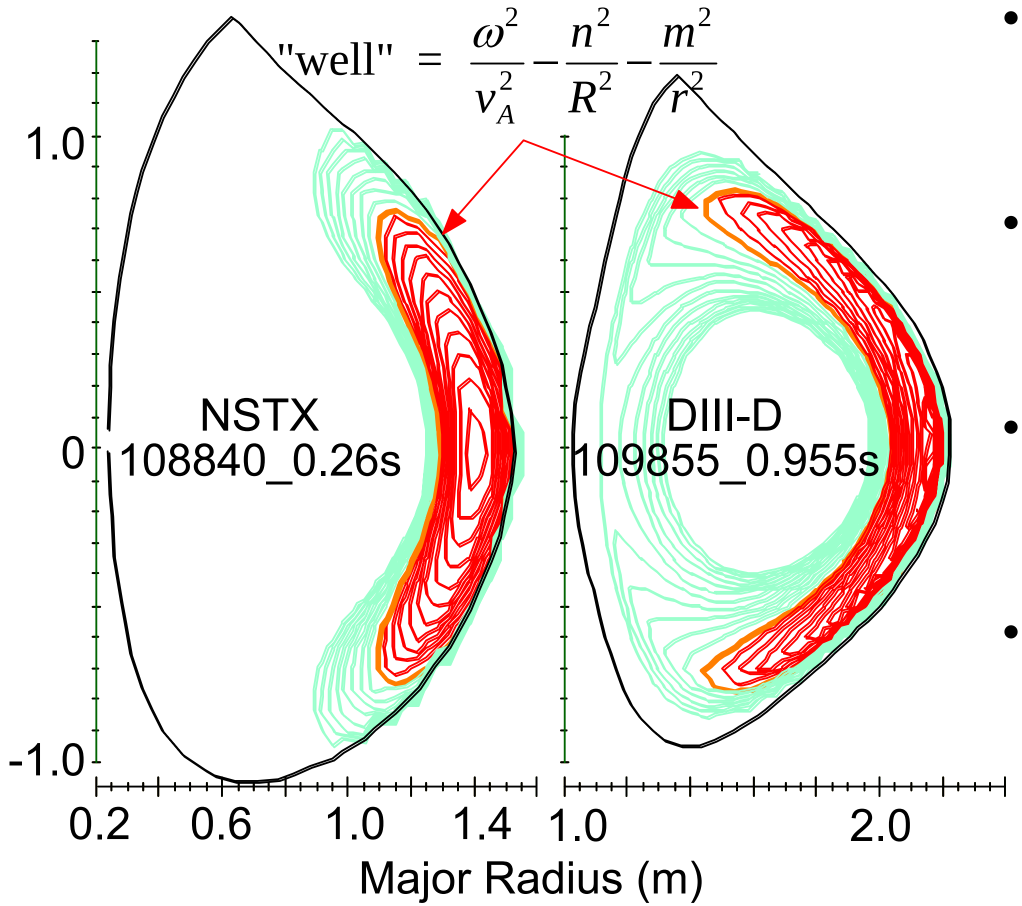
Do CAEs also drive fast ion transport?

- Correlation of neutron drop with large CAE burst has been observed.
- CAE bursts coincident with EPM onset suggest CAE-induced fast ion transport.
- CAE amplitude typically reduced by EPM-induced fast ion loss.
- Three-way interaction of fast ions with EPMs, TAE and CAE difficult to model.



Similarity study of CAE shows aspect-ratio dependence

CAE “wells” for “m = 3”, n=5 mode



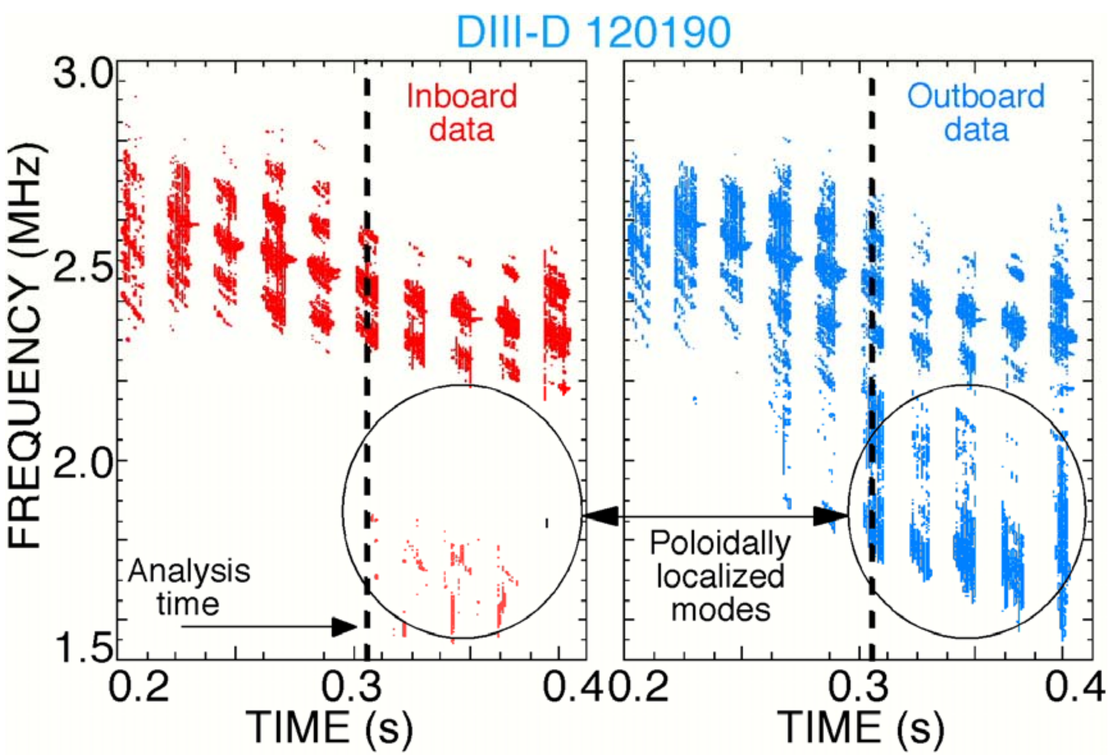
- Modes evanescent on inboard side.

- DIII-D, NSTX can match parameters, excepting major radius.
- CAE driven through Doppler-shifted ion cylotron resonance on both machines.
- Greater poloidal localization of CAE is expected at low aspect ratio.
- Graph of "well" from wave equation qualitatively illustrates behavior:

$$\left\{\frac{1}{r}\frac{\partial}{\partial r}r\frac{\partial}{\partial r} + \frac{\omega^2}{V_{Alfvén}^2} - \frac{m^2}{r^2} - \frac{n^2}{R^2}\right\} f = 0$$

Poloidally symmetric CAE seen in DIII-D

- Sensors on inboard/outboard midplane detect CAE on DIII-D.
- Waves above ≈2.2 MHz are "symmetric".
- Lower frequency waves poloidally localized to outboard side.
- Similar measurements not yet available on NSTX.

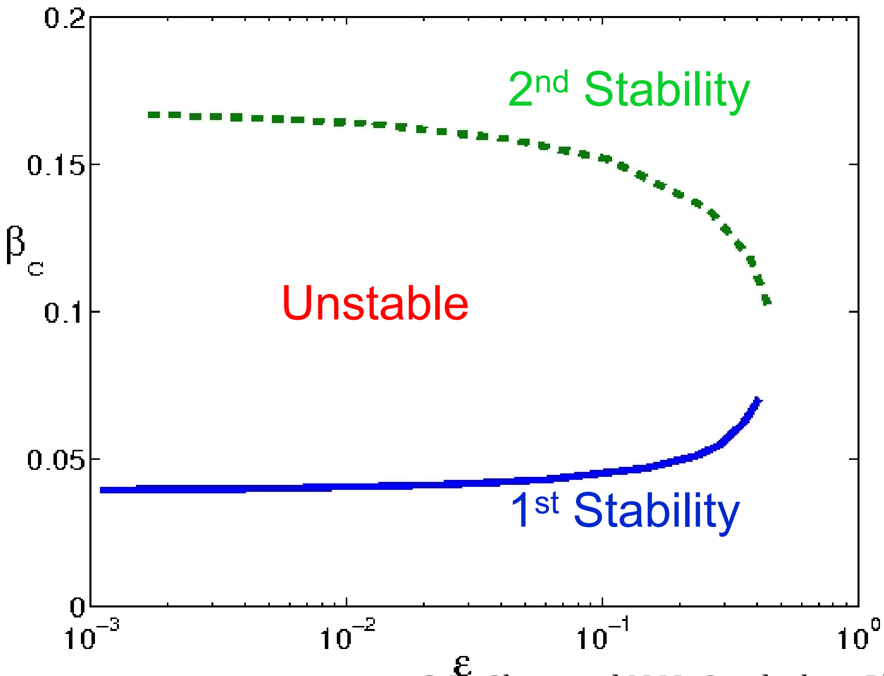


- Simple model predicts mode wells below 2.2 MHz are poloidally localized
- Above 2.2 MHz the wells become more symmetric, consistent with observations.

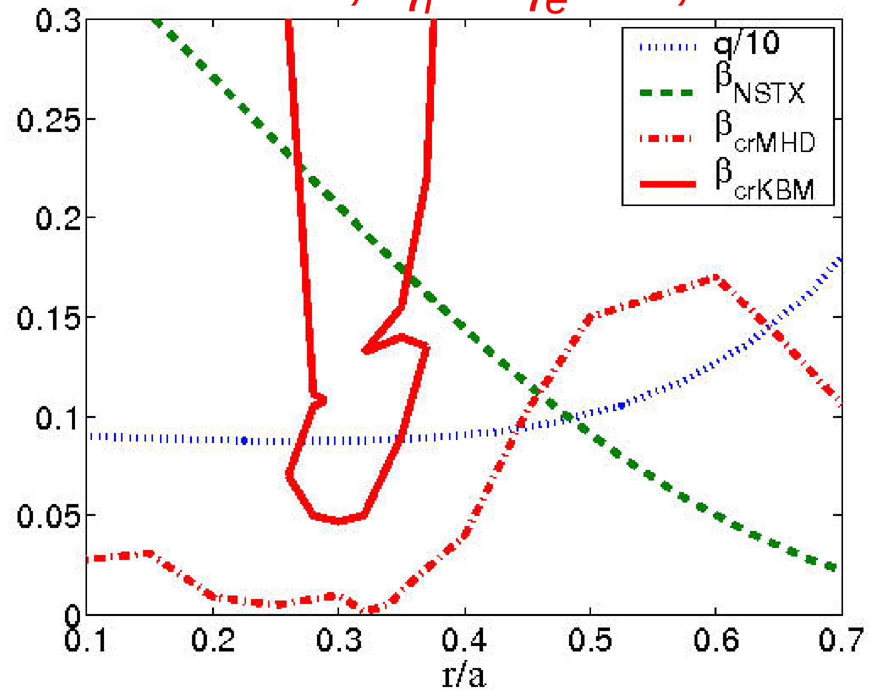
Low aspect ratio predicted to enhance FLR stabilization of ballooning modes

- The enhanced stability results from a larger trapped-electron fraction.
- Ideal MHD finds the region r/a<0.44 to be unstable; which shrinks to 0.27<r/a<0.36 with FLR effects (at an aspect ratio of 1.27).
- Experiments on NSTX and DIII-D can study this prediction.

ε = r/R, $k_\theta \rho_i$ = 0.45, s = 0.5



R/a = 1.27, $\eta_i = \eta_e$ = 1, n=12



C.Z. Cheng and N.N. Gorelenkov, Phys. Plasmas, to appear in Phys. Plasmas (2004).

ST's in new regime of kinetic instabilities

- A wide variety of kinetic instabilities has already been seen in NSTX (and START, MAST); only the most common discussed here.
- Kinetic instabilities not expected to be, nor are they, benign; need capability to predict and scale.
- ST geometry is a challenge for many existing MHD codes; we need to modify, or develop new, codes.
  - Good progress is being made on theory of EPM's, TAE, CAE, KBM.
  - As in conventional tokamaks, operation in advanced regimes likely to introduce many new varieties of kinetic modes.
- NSTX and DIII-D provide excellent test beds for validating theoretical models used to predict reactor (ITER, ARIES-ST) stability to kinetic instabilities.