Observation of Global Alfvén Eigenmode Avalanche events on NSTX*

E. D. Fredrickson, N. Gorelenkov, E. Belova, N. A. Crocker, S. Kubota, B. LeBlanc, R. E. Bell, M. Podesta, H. Yuh, F. Levinton

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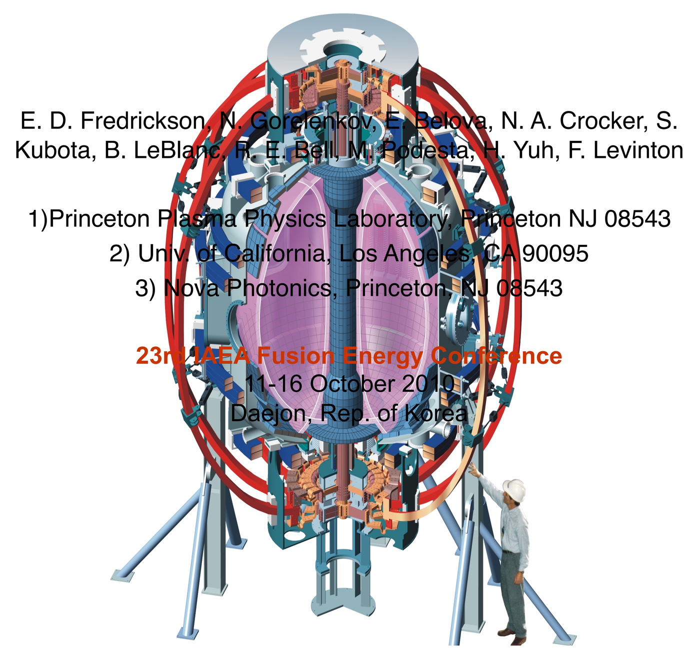
NSTX

Toroidal Alfvén Eigenmode Avalanches in NSTX



E. D. Fredrickson, N. Gorelenkov, E. Belova, N. A. Crocker, S. Kubota, B. LeBlanc, R. E. Bell, M. Podesta, H. Yuh, F. Levinton

1)Princeton Plasma Physics Laboratory, Princeton NJ 08543
2) Univ. of California, Los Angeles, CA 90095
3) Nova Photonics, Princeton NJ 08543

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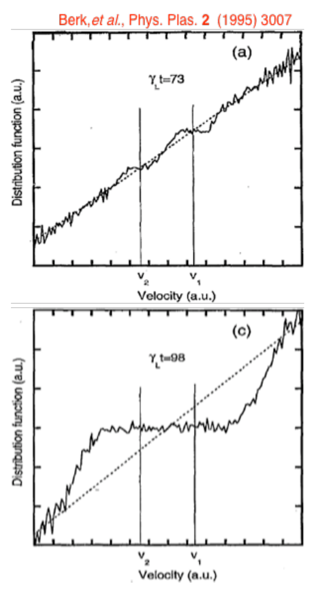
Multi-mode interaction of Alfvén Eignmodes can greatly enhance fast ion transport

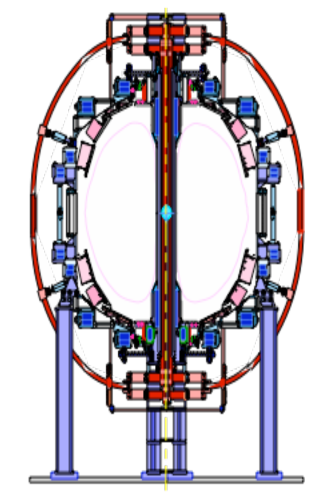


Berk, Briezman, et al., PoP **2** p3007

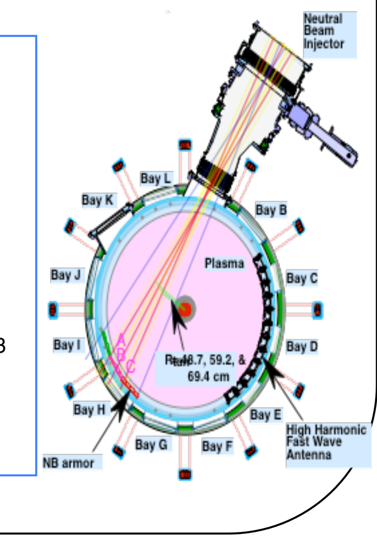
- Large amplitude modes overlap in fast-ion phase-space.
- Interaction accesses more free energy; resulting in stronger modes, destabilizes new modes; more fast ion transport.
- Interaction of multiple modes can also move ion further in phase-space, again enhancing losses.
- GAE avalanches would be indicated by strong mode bursts consisting of multiple modes.
- Although GAE have multiple resonances, more complex physics, this simple model captures the relevant physics.

NSTX has low field, high density and current; perfect for study of fast ion-driven modes

- Low field, high density $V_{Alfvén} \approx 0.5$ - 2.7×10^6 m/s.
- Typical beam injection energy 60 - 100 kV, $V_{fast} \approx 2.6$ - 3.1×10^6 m/s
- Reactors would have higher field, fusion α's and $V_{fast}/V_{Alfvén} > 1$

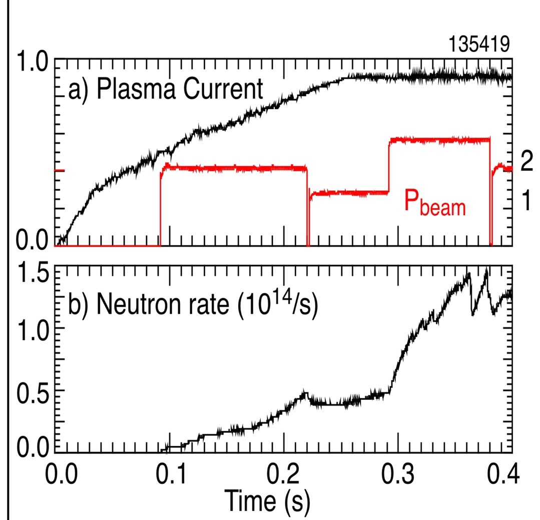


- R_0 = 0.86 m
- a = 0.68 m
- B_0 = 0.3-0.55 T
- I_p ≤ 1.2 MA
- β_{tor} ≤ 40%
- n_e ≤ $10 \times 10^{19}/m^3$

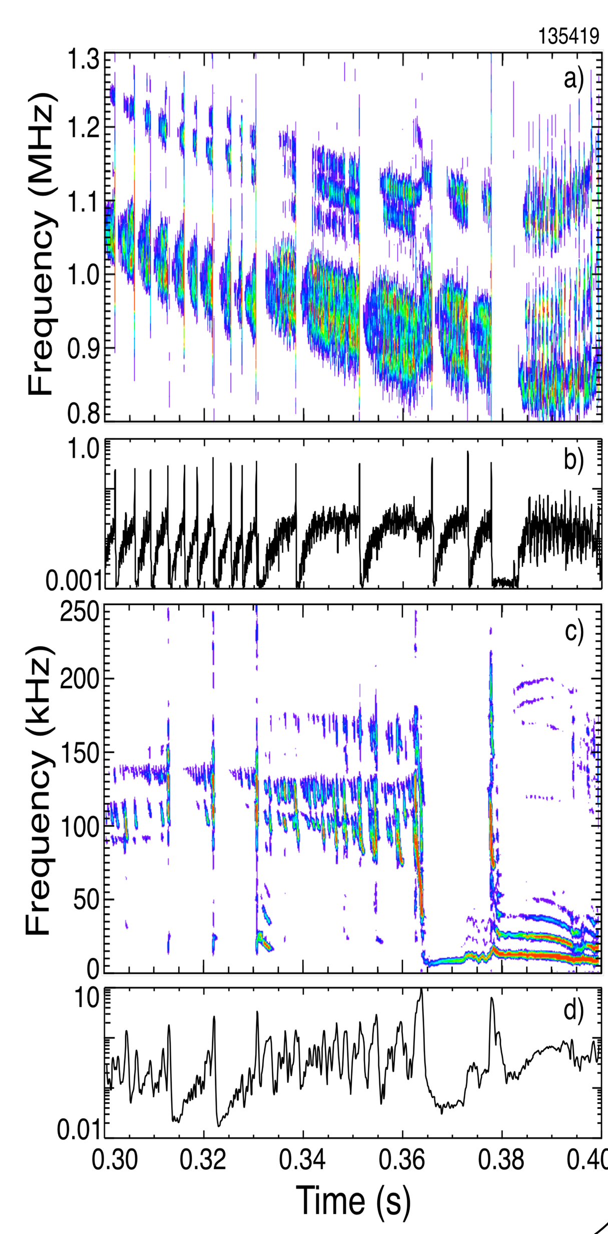


GAE Avalanches studied under plasma conditions optimized for diagnosis TAE avalanches

- Plasma conditions developed to study TAE avalanches also often have GAE avalanches.
- Source A injected early and late for MSE diagnostic, two lower voltage sources used to excite avalanches.

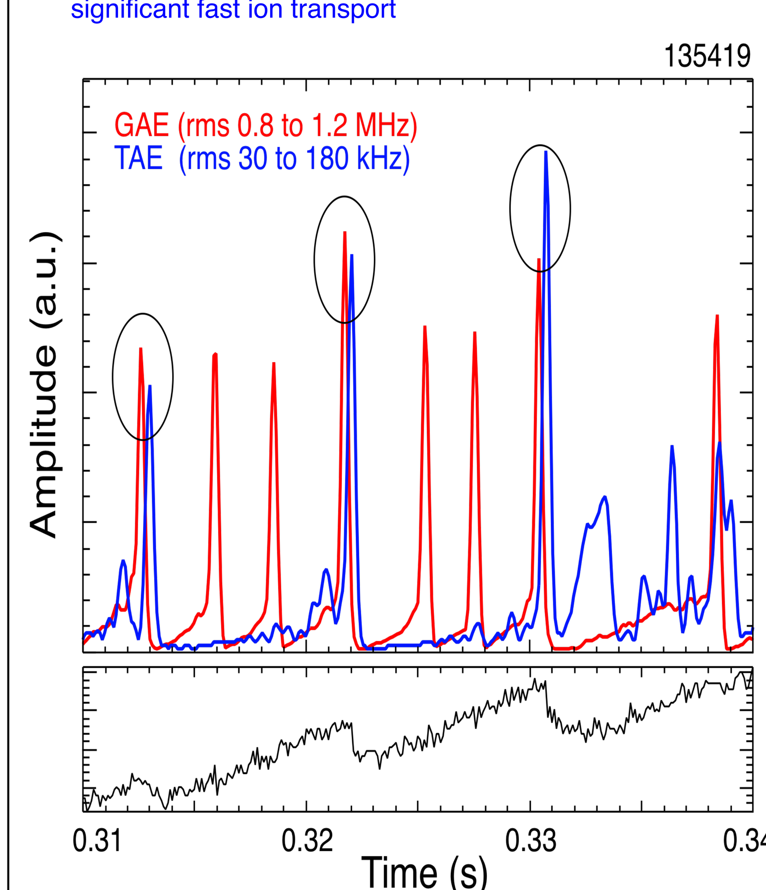


- spectrogram showing multiple bursting & chirping GAE ($7 \le n \le 10$).
- rms magnetic fluctuations over frequency range 0.8MHz to 1.3MHz show slow linear growth, culiminating in explosive burst, followed by quiet period.
- TAE avalanches show up in same time period, with similar behavior in rms magnetic fluctuations over frequency range from 30kHz to 200kHz.



TAE avalanches often immediately preceded by GAE avalanche

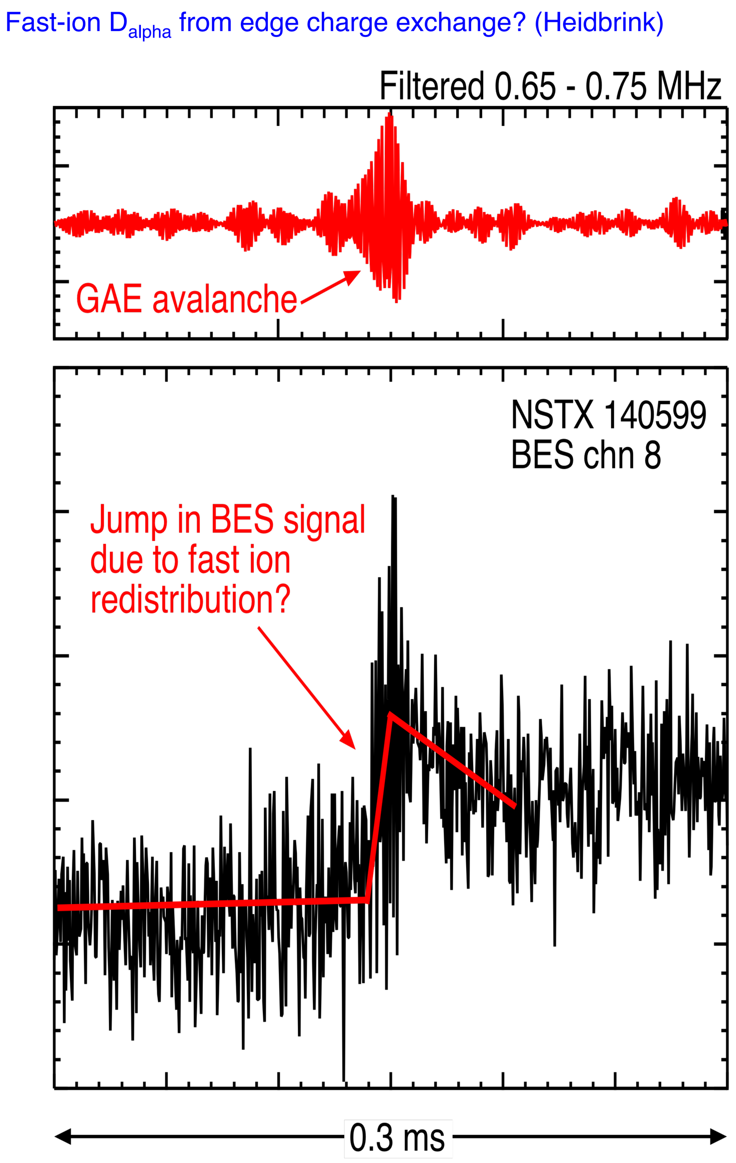
- No direct evidence (?) for fast ion redistribution seen; no neutron rate drops, no losses measured with the Fast Lost Ion Probe (FLIP), no losses seen on the scanning NPA.
- Correlation with TAE avalanches best indication of significant fast ion transport



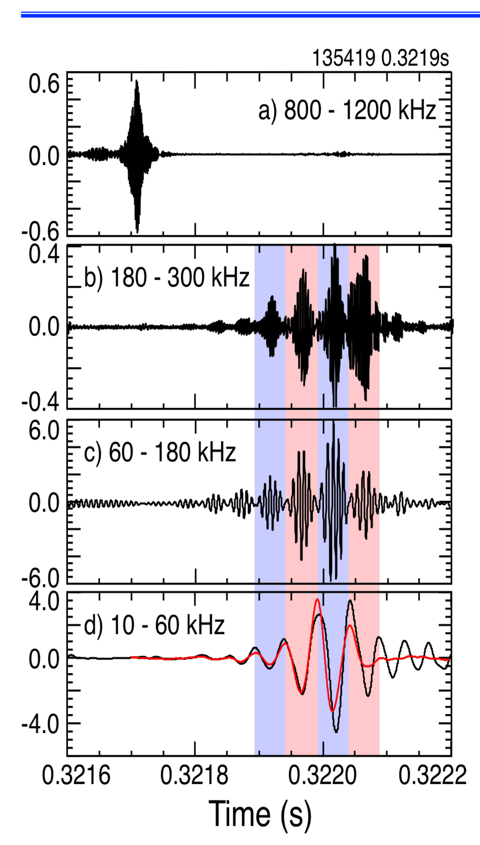
- Quiescent period following avalanche also indicates fast ion redistribution, but not extent.
- GAE burst is very short; rms plot broadens the spike in time and reduces the height.

Fast-ion D_{alpha} level jumps during GAE avalanche, fast-ion redistribution

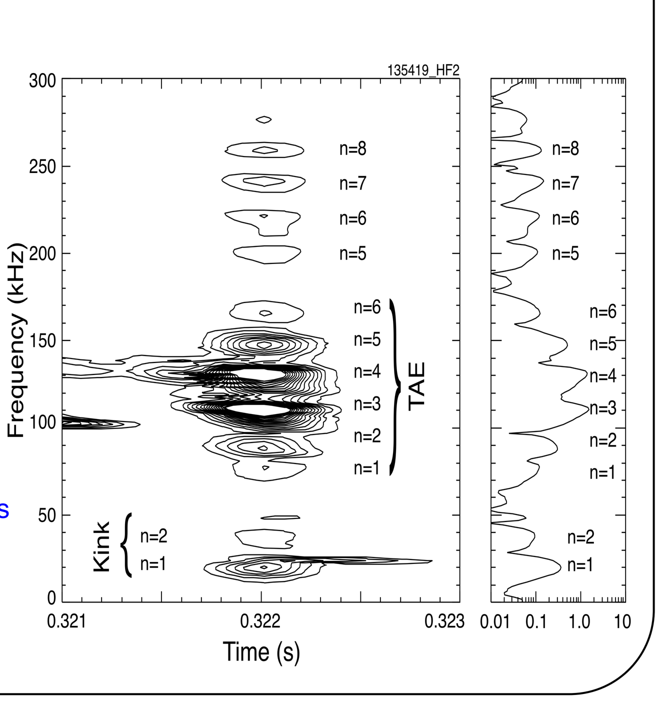
- GAE seen with BES, but interpretation of eigenfunction becomes suspect.
- Fast-ion D_{alpha} from edge charge exchange? (Heidbrink)



GAE avalanche precedes onset of TAE avalanche

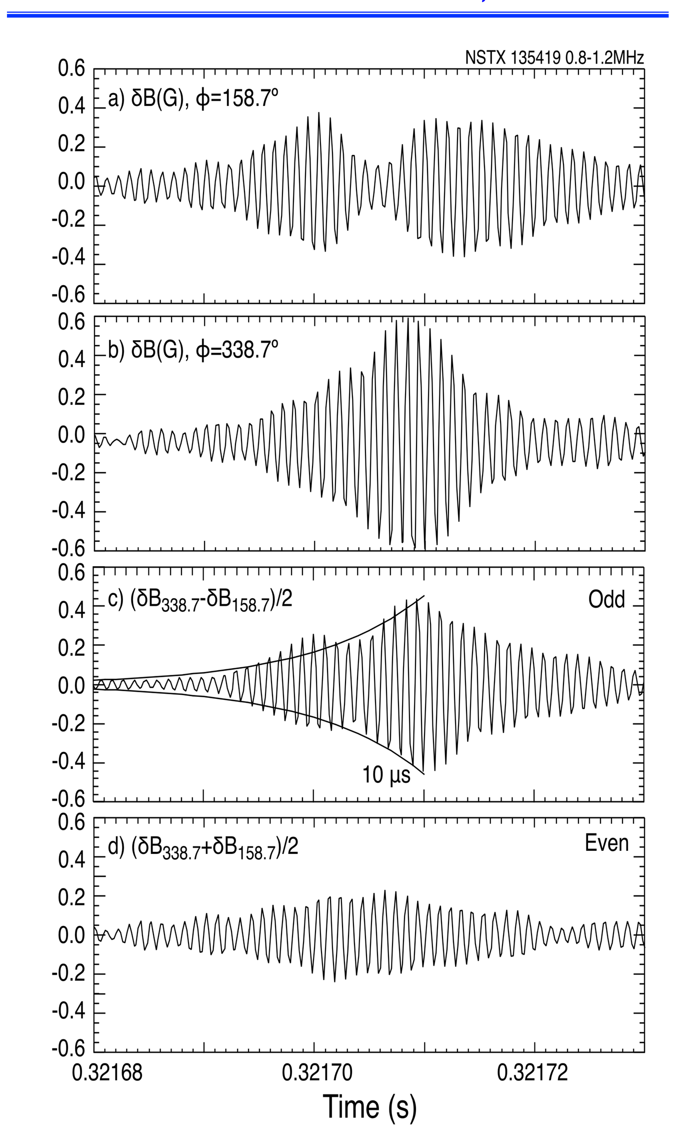


- Non-linear mode coupling apparent in TAE avalanches.
- Both sum and difference frequency modes seen, satisfying frequency and wavelength constraints.
- No evidence of 3-wave coupling for GAE avalanches.



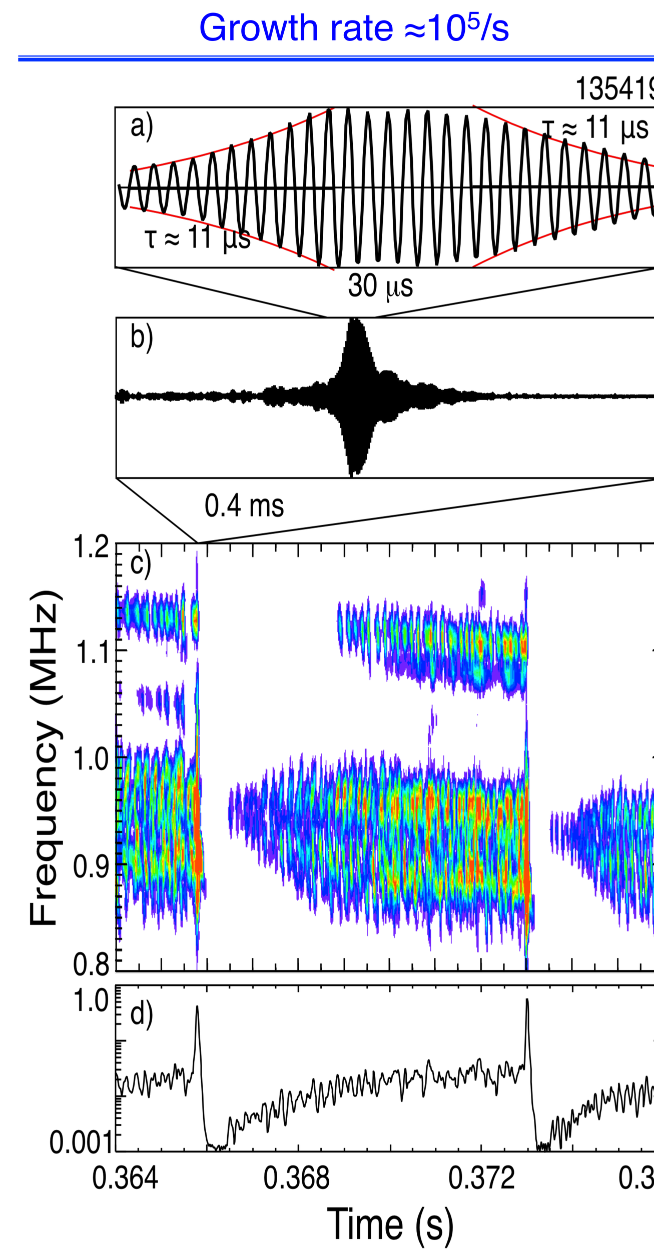
- GAE fast ion redistribution triggers TAE avalanche.
- Seen in many cases, but not always.

GAE burst contains even, odd n's



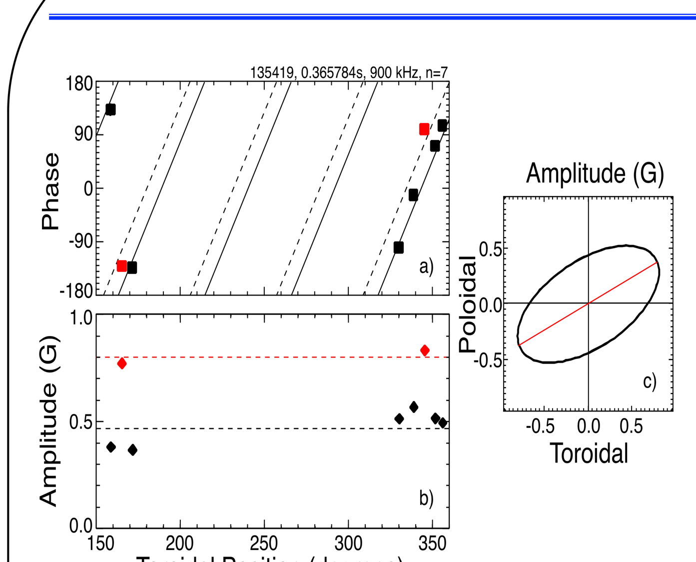
- Even-odd components separated by coil pairs 180° apart
- Modulation of 'odd' component suggest multiple 'odd' modes.

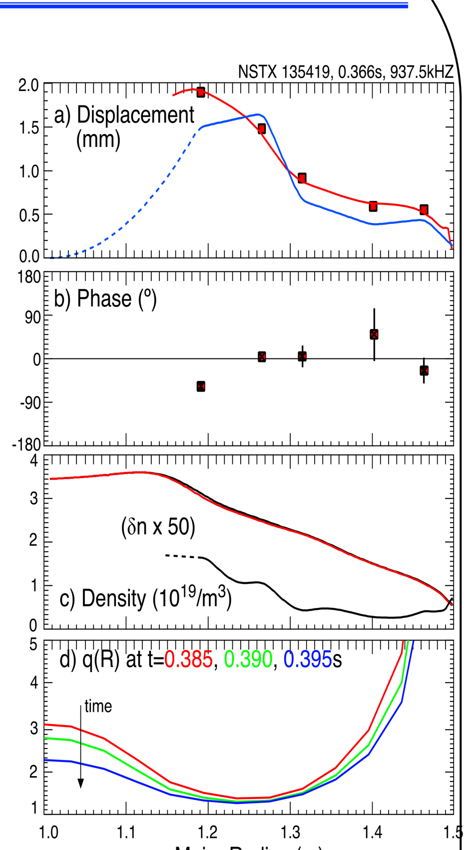
Growth rate ≈10^5/s



- Inter-avalanche period consists of multiple, bursting chirping modes at roughly 10% of peak avalanche amplitude.

Mode structure consistent with GAE

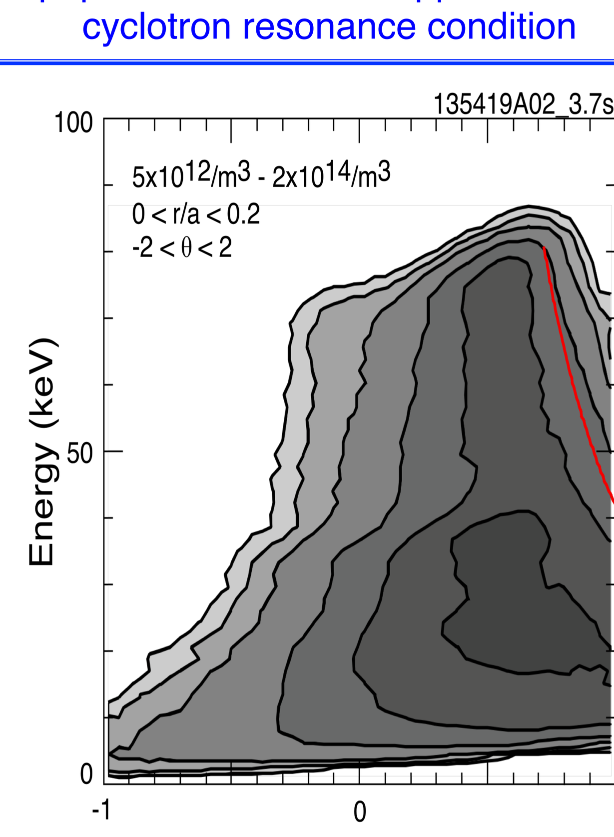




- Reflectometer measurements indicate mode peaks towards magnetic axis.
- Phase data suggests lowest order radial eigenmode structure.
- Mode amplitude reaches $\delta n/n \approx 1\%$

- Pitch of magnetic fluctuations is measured with an array of coils.
- Within uncertainty, phase/amplitude relation of poloidal and toroidal fluctuations indicate polarization of mode at plasma edge is compressional (GAE are shear Alfvén modes).
- Consistent with simulations of GAE for similar conditions which show coupling to compressional component towards plasma edge..

Fast ion distribution predicts fast ion population satisfies Doppler-shifted cyclotron resonance condition



- Resonance sits on perpendicular bump-on-tail.

Avalanching of both TAE and GAE is now seen on NSTX

- Alfvénic modes in the frequency range 0.5MHz to 1.5MHz are commonly seen in NSTX beam heated plasmas.
- They exhibit broad range of behavior, including bursting, chirping, and, as described here, avalanching.
- Modes are identified as GAE based on radial mode amplitude profile from reflectometer array data, and recently from the BES diagnostic.
- Peak mode amplitudes reach $\delta n/n \approx 1\%$
- Modes propagate counter to the injected neutral beams, satisfying a Doppler-shifted cyclotron resonance.
- Toroidal mode numbers in range from n=6 to n=11.
- GAE avalanches are seen to trigger TAE avalanches, demonstrating that fast ion redistribution from these modes is important to other fast ion driven instabilities.
- The BES diagnostic gives further evidence of measureable fast ion redistribution, acting as a passive FIDA instrument, so that an increase in the BES baseline signal is interpreted as evidence of fast ion redistribution.