Suppression of GAE with new NBI sources on NSTX-U

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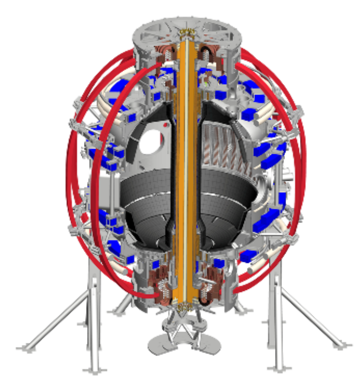
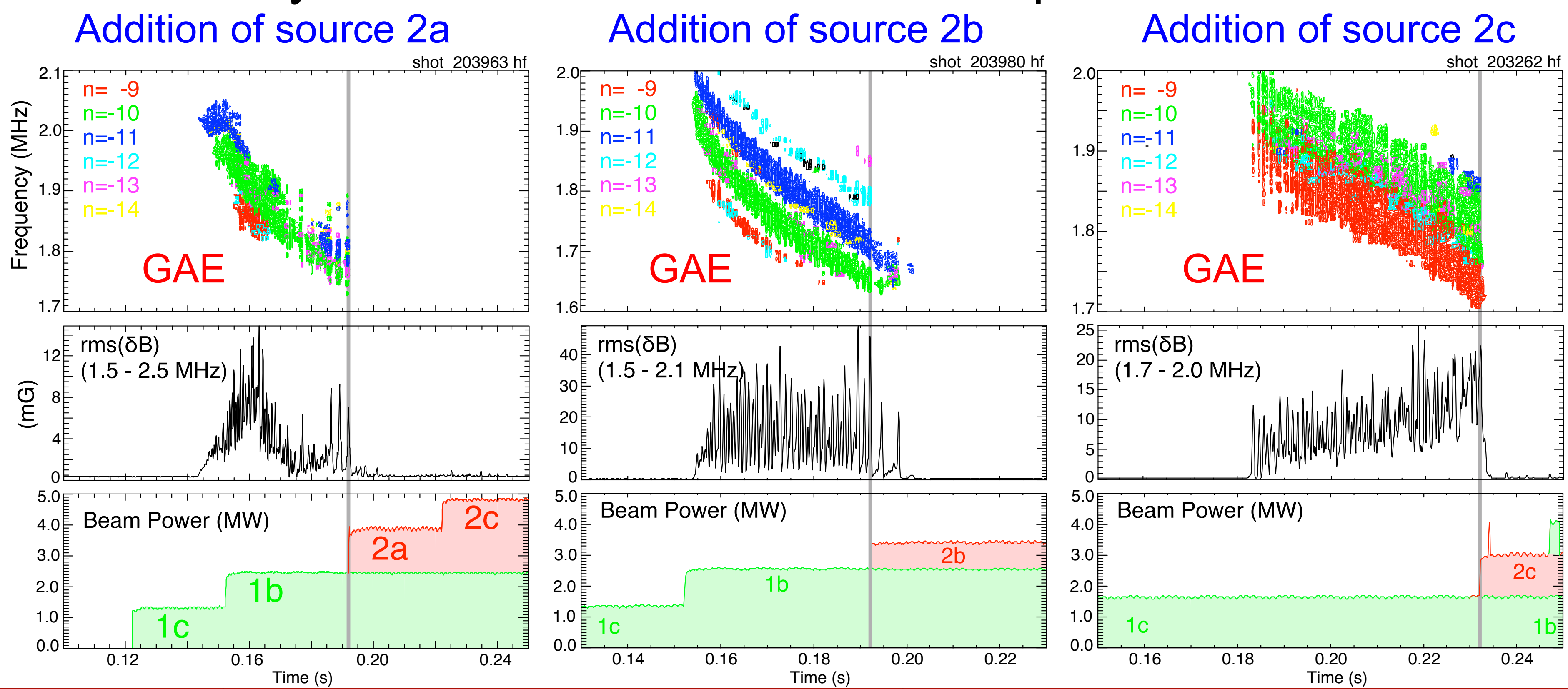


First NSTX-U campaign has yielded interesting observations in EP physics

- NSTX-U has higher toroidal field; lower $V_{beam}/V_{Alfvén}$.
- Three new beam sources (>750 NBI shots).
  - The new sources (2a,2b,2c) shift the distribution function towards higher pitch ($V_{||}/V$) and *can* make fast-ion distributions peaked off-axis.
- Experiments find that injection of any new source can suppress Global Alfvén eigenmodes (GAE).
  - Results are qualitatively consistent with analytic model of GAE stability [Gorelenkov, NF **43** (2003) 228].
  - Quantitative analysis with the HYM code finds both the unstable modes, and the suppression with source 2c.

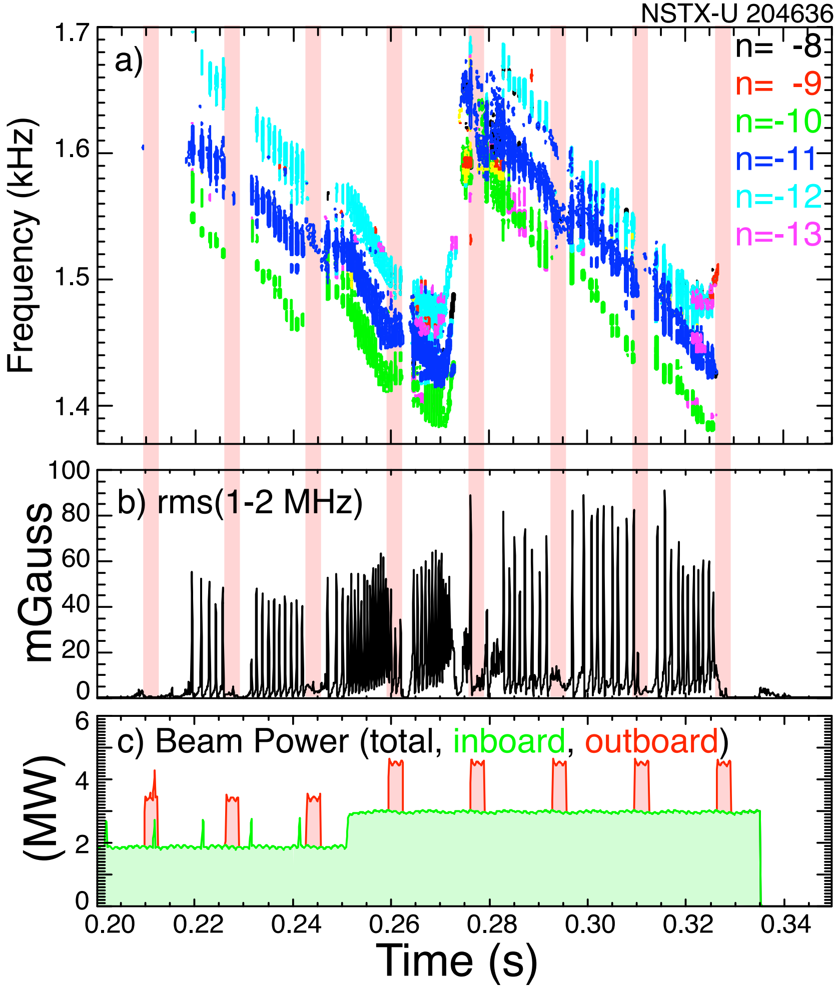
Outboard neutral beams suppress counter-propagating GAE

- GAE activity excited by one or two inboard sources can be suppressed by adding any one outboard source.
- Suppression can occur within milliseconds.
- Preliminary results from the HYM code explain this.



The suppression happens fast

- The fast-ion slowing down time is ≈100 ms;
  - complete suppression can be seen in much less than 3 ms.
  - fast-ion population doesn't reach equilibrium
- In this example, a string of 3 ms beam pulses was injected every ≈16 ms, on top of 1 or 2 inboard sources.
- Each outboard beam pulse results in suppression of the bursting GAE.

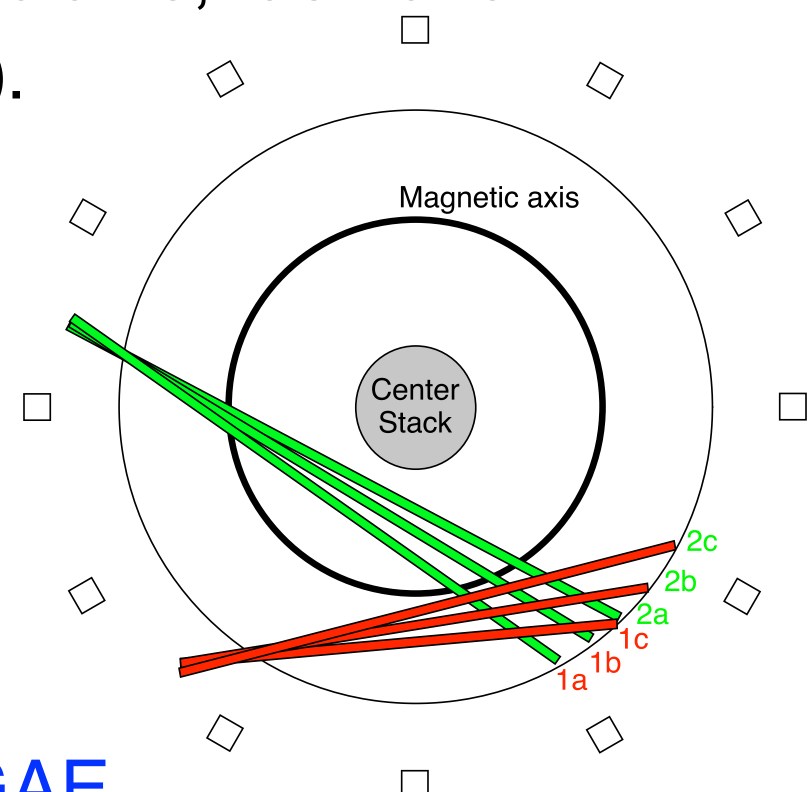


New beam sources on NSTX-U can tailor fast ion distribution to control instabilities

- New sources added to provide some current profile control (and more power).
- Tangency radii outside magnetic axis, fast ions deposited with high pitch ($V_{||}/V$).
- Robust suppression of GAE was seen with any new beam source.
- Analytic model* of GAE stability predicts:

  $k_\perp \rho < 1.9$ stabilizing,

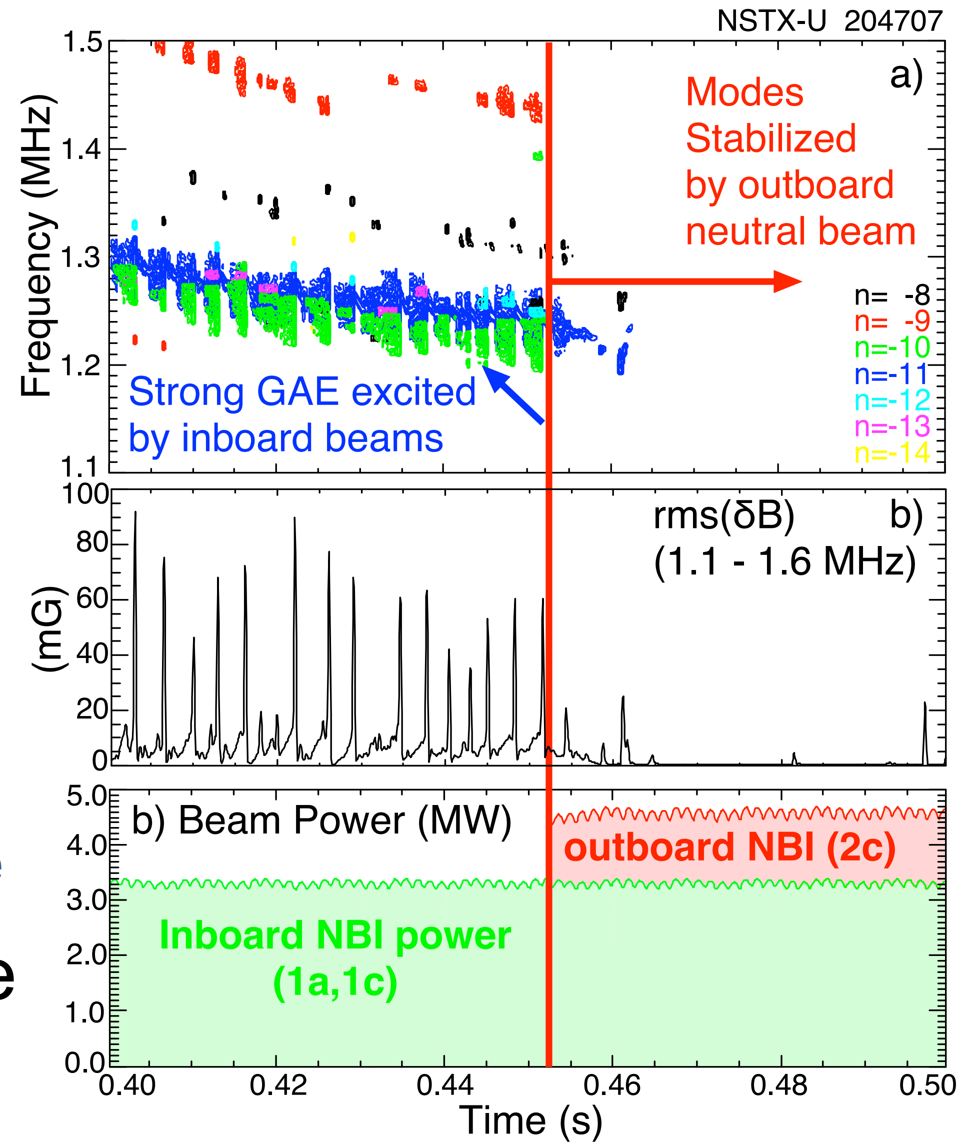
  $1.9 > k_\perp \rho > 3.9$ destabilize GAE



*Gorelenkov, *et al.*, NF **43** (2003) 228.

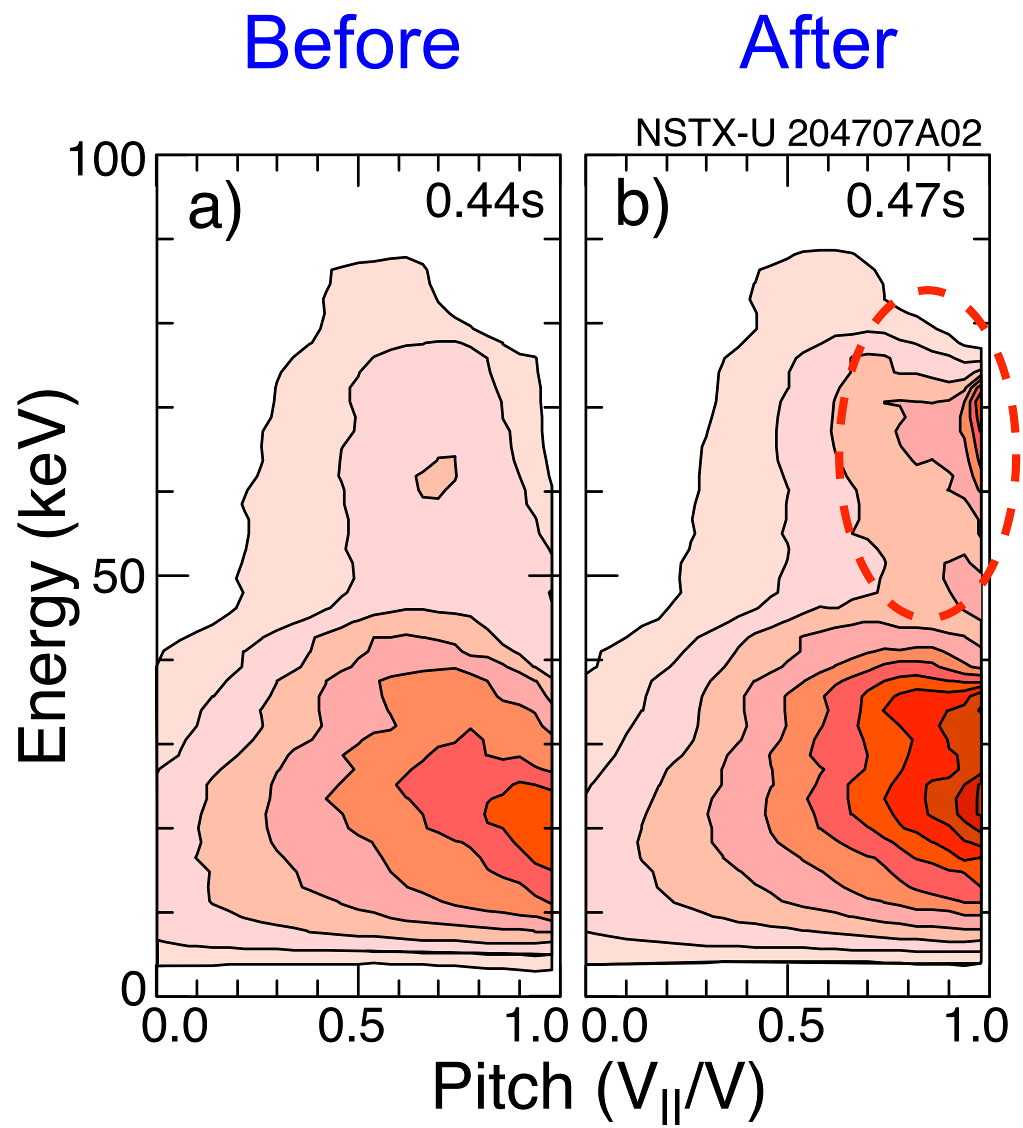
TRANSP and then HYM are used to model GAE suppression

- $T_{Electron}$ (≈1.7keV), density ($3.2x10^{19}/m^3$) measured with Thomson scattering.
- T_{ion} (≈1.7keV), toroidal rotation (≈28kHz) measured with CHERS.
- Equilibrium reconstruction with EFIT,
  – no MSE to constrain q profile
- TRANSP used to calculate fast-ion distribution.



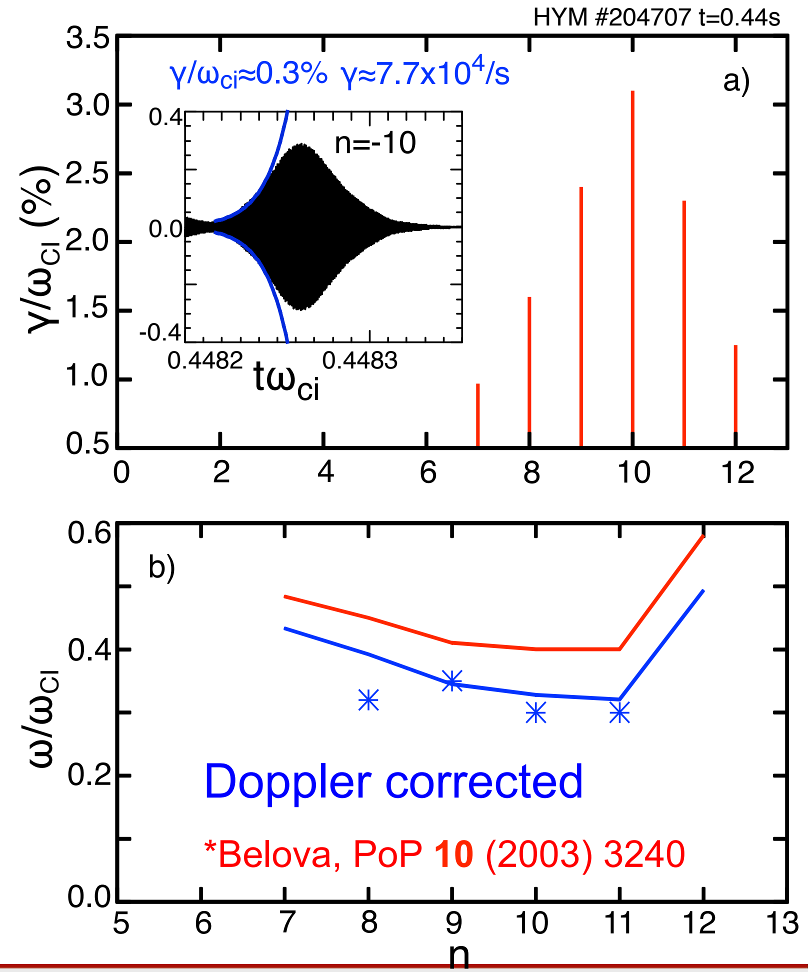
TRANSP finds that new source fills in high pitch region, reverses gradient

- Source 2c, R_{tan} = 1.1 m, was added at 0.45s.
- New fast ions have mostly 0.8<$V_{||}/V$<1.
- Fast ions in this pitch range have smaller larmor radius – might be stabilizing.
- Gradient of fast-ion distribution in pitch reverses in this region.



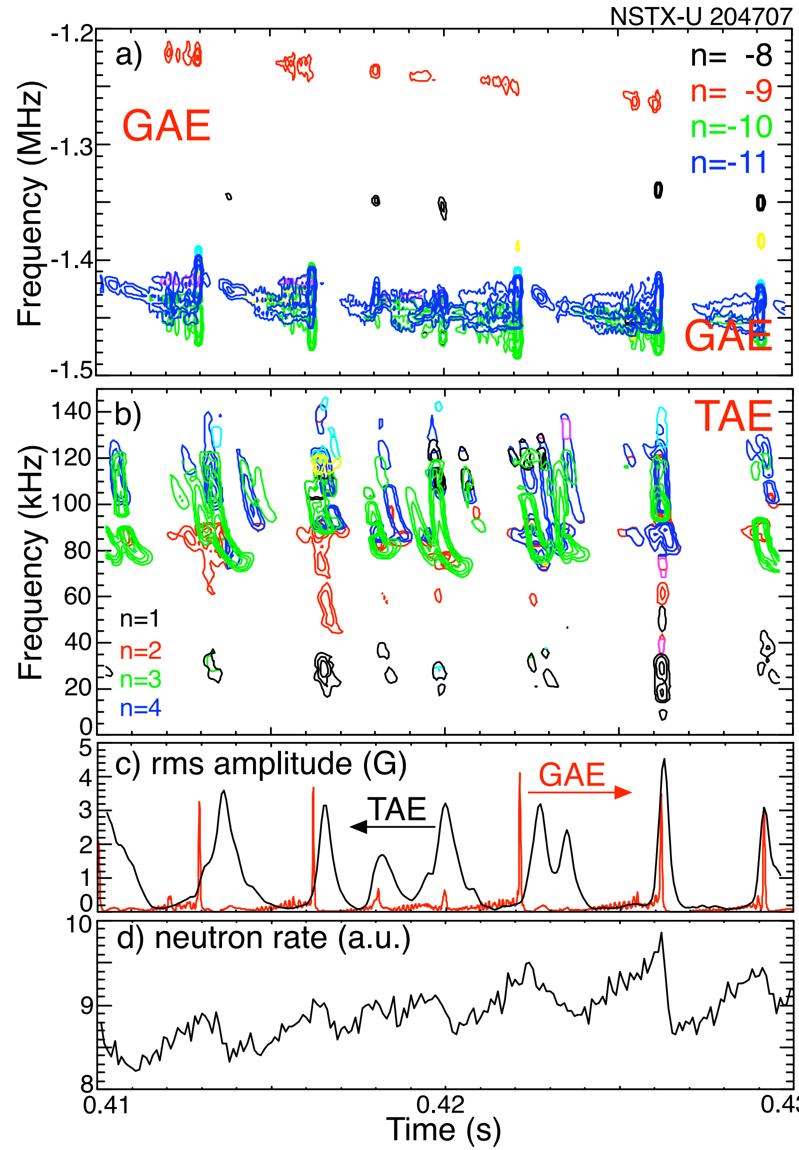
Most unstable modes in HYM* are n=9-11, agrees with experimental measurements

- Modes are identified as Global Alfvén eigenmodes from the polarization of the magnetic fluctuations.
- Doppler-corrected mode frequencies are in good agreement with experimental frequencies, ≈0.35 ω_{ci}.
- Experimental "growth rate" is smaller, γ/ω_{ci} ≈ 0.3% *vs*. 3%.
- But, fast ion distribution in experiment is perturbed,
  - either due to TAE avalanches or the GAE bursts themselves.



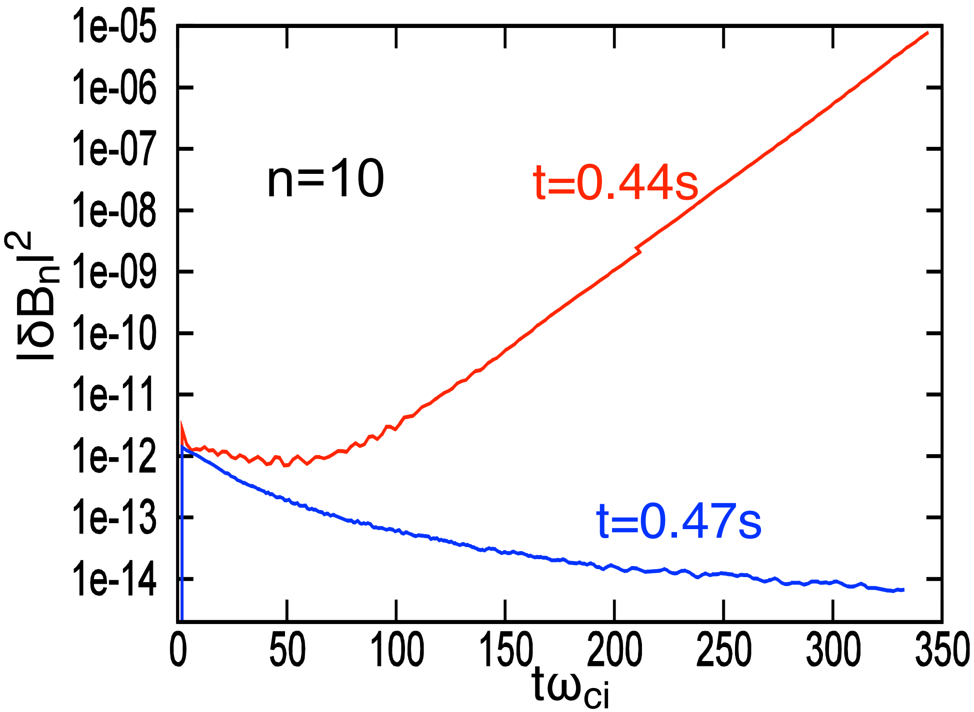
GAE cause some fast ion transport, and possibly affect thermal electron transport

- This example, with strong GAE bursts, provides indirect evidence for fast-ion redistribution.
- Commonly, strong GAE bursts are immediately followed by TAE avalanches.
- Suggests fast ion redistribution just enough to trigger TAE.
- TAE probably responsible for neutron drops.



HYM finds modes stabilized by 3rd source

- Simulations with the HYM code at 0.47s, 20ms after 3rd source is injected, find all modes stable.
- Simulation used equilibrium data from 0.47s and new fast-ion distribution.



- Results are still being analyzed, but suppression may come from change in fast-ion gradient, or from population of near-tangential fast ions.
- Future experiments will explore energy dependence.

GAE suppression seen with added NBI power, reproduced with HYM simulations

- ctr-propagating GAE have been correlated with flattening of the core electron temperature profile, possibly through enhanced electron thermal transport, or through some form of energy channeling.
- Experiments on NSTX-U with new neutral beam sources have found that the ctr-GAE can be completely suppressed with ≈25% of the beam power supplied by one of the new beam sources.
- Suppression may come from the population of nearly tangential fast ions, or through modifications of the gradients in the fast-ion distribution.

New NB geometry, higher field lead to unexpected EP physics results

- New neutral beam sources provide flexibility to control fast-ion distribution function.
- Higher field operation may help decouple TAE from fishbones, inextricably linked on NSTX.
- Mirnov array extended for better mode number resolution and bandwidth extended to ≈ 4 MHz.
- Three surprising observations in first campaign:
  - Adding beam power can suppress GAE
  - Counter-propagating TAE
  - ICE (not seen on NSTX)
- New and improved diagnostics are coming.

An analytic model for GAE drive/damping suggests an interpretation of observations

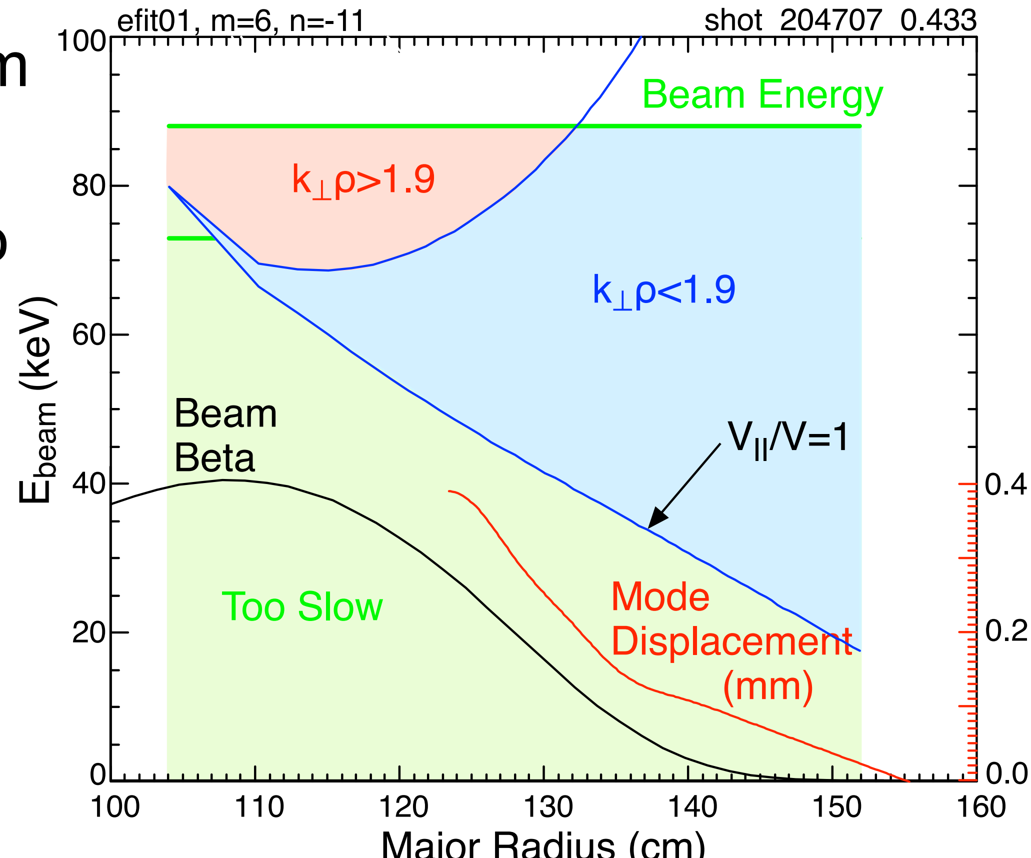
- One possible suppression mechanism is that outboard beam ions have smaller $k_\perp \rho$ [Gorelenkov, *et al.*, NF **43** (2003) 228].

  $k_\perp \rho < 1.9$ stabilizing, $k_\perp \rho > 1.9$ driving

- Can estimate $k_{||}$ and $k_\perp$ from dispersion relation.
- Green region shows ions too slow to match resonance condition:

  $\omega_{mode} + k_{||} V_{b||} \pm V_{b||}/qR = \omega_{ci}$

- Blue region, ions can be resonant, but stabilizing.
- Red region, ions can be resonant and destabilizing.



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