NSTX-U

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Suppression of TAE and GAE with HHFW heating

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and the NSTX Research Team

presented by ***N. Bertelli***

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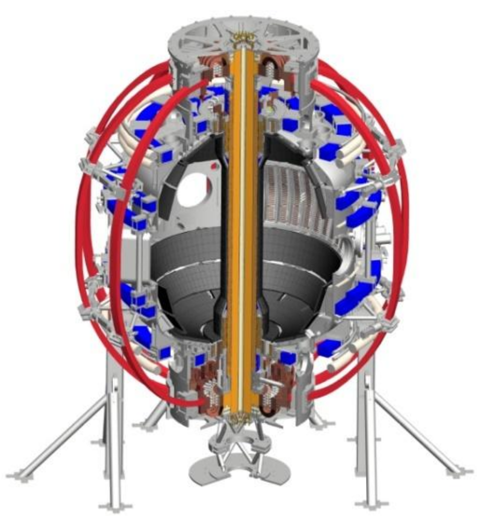

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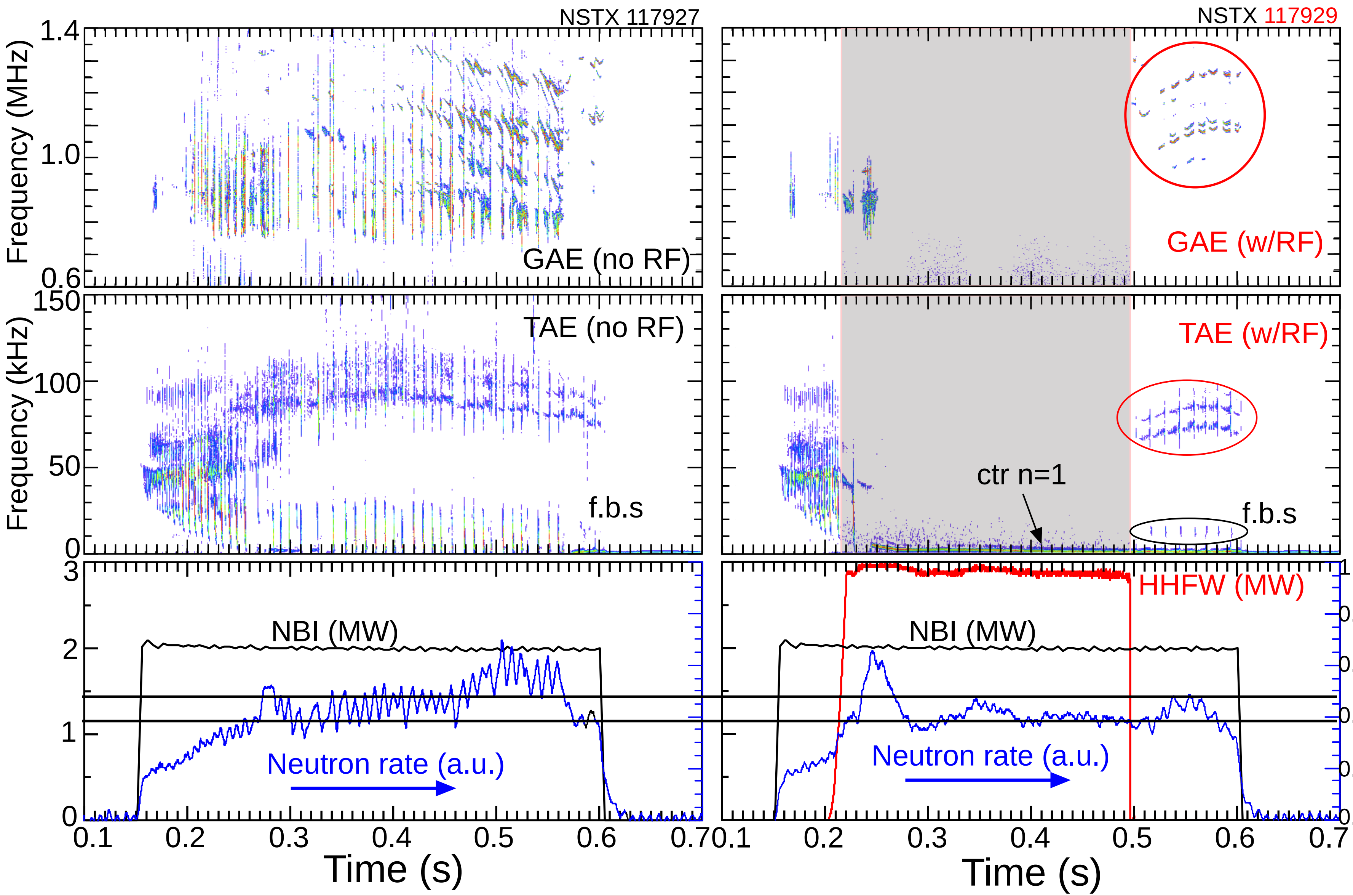
Introduction

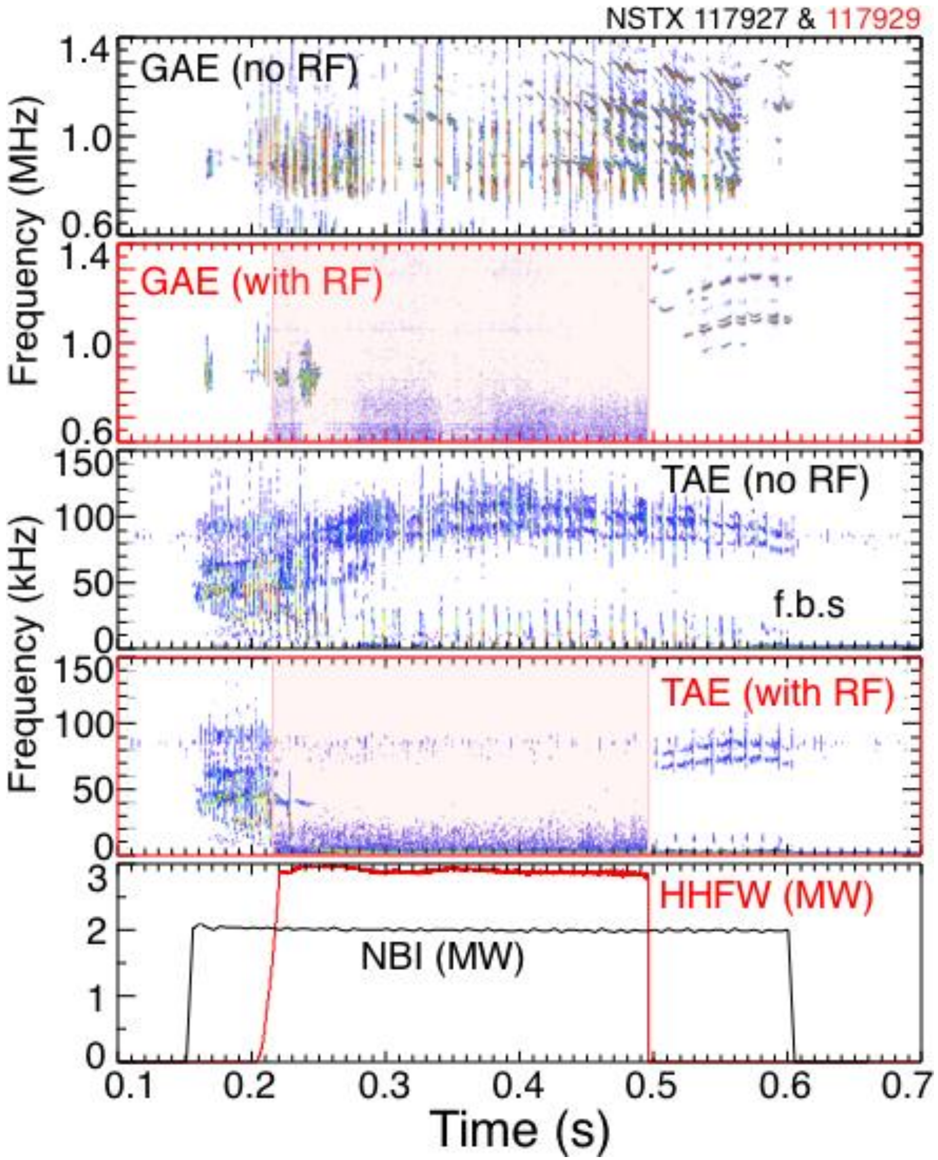
- This talk reports on observations made during a High Harmonic Fast Wave RF heating experiment to study power deposition and current drive using a 300 kA Helium plasma as target.
- There were 12 shots with 2MW of NBI plus up to 3MW of HHFW heating with various power, timing and phasing of the RF.
  - There is one NBI-only shot which is used as reference.
- Generally, the HHFW heating suppressed *all* fast-ion driven activity – fishbones, TAE, GAE.
- Neutron rate, NPA data show no indication of excessive fast ion losses with HHFW.
- Other, later experiments, were lower power, not as clear.

3(ish) MW of High-harmonic Fast Wave (HHFW) heating suppresses both TAE, CAE/GAE, & fishbone activity



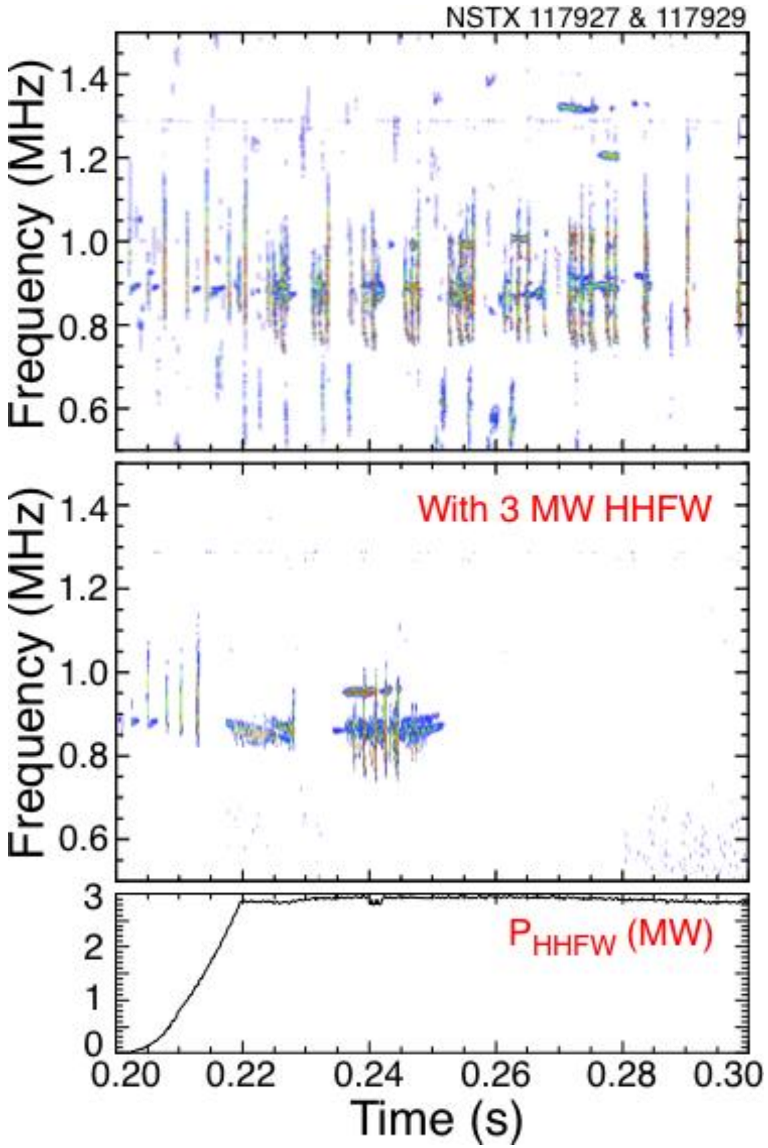
3(ish) MW of High-harmonic Fast Wave (HHFW) heating suppresses both TAE and GAE (fishbone) activity

- TAE and CAE/GAE excited with 2MW of NBI heating, but both TAE and GAE suppressed with HHFW.
- Both TAE and CAE/GAE reappear shortly after HHFW heating ends.
- HHFW, primarily for heating thermal electrons, also heats beam ions.
- RF-heating affect similar to energy diffusion – should suppress chirping.



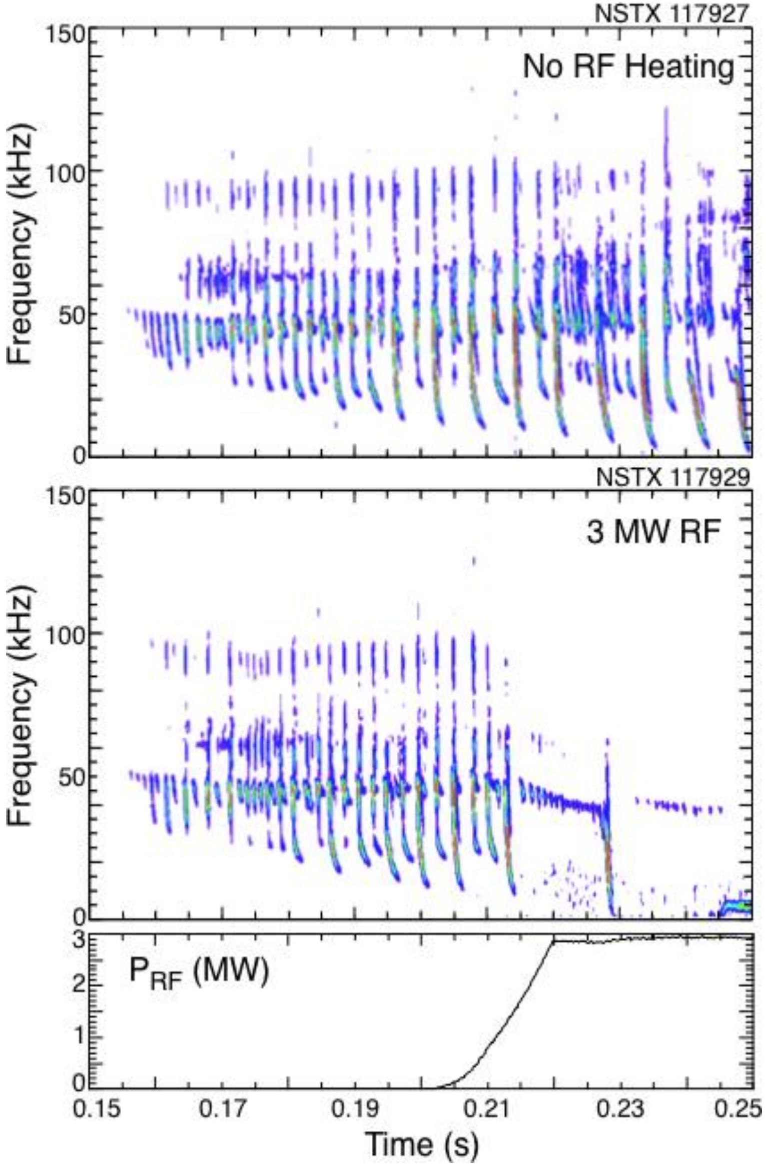
GAE not suppressed immediately, but question is why!

- Significant fast ion pump-out with HHFW? But no neutron rate, stored energy drop?
- Phase-space redistribution by HHFW? But, for TAE/hfAE/f.b.?
- Direct suppression? No existing models.
- Equilibrium changes (not in what is measured).
- What can we look at to answer these questions?



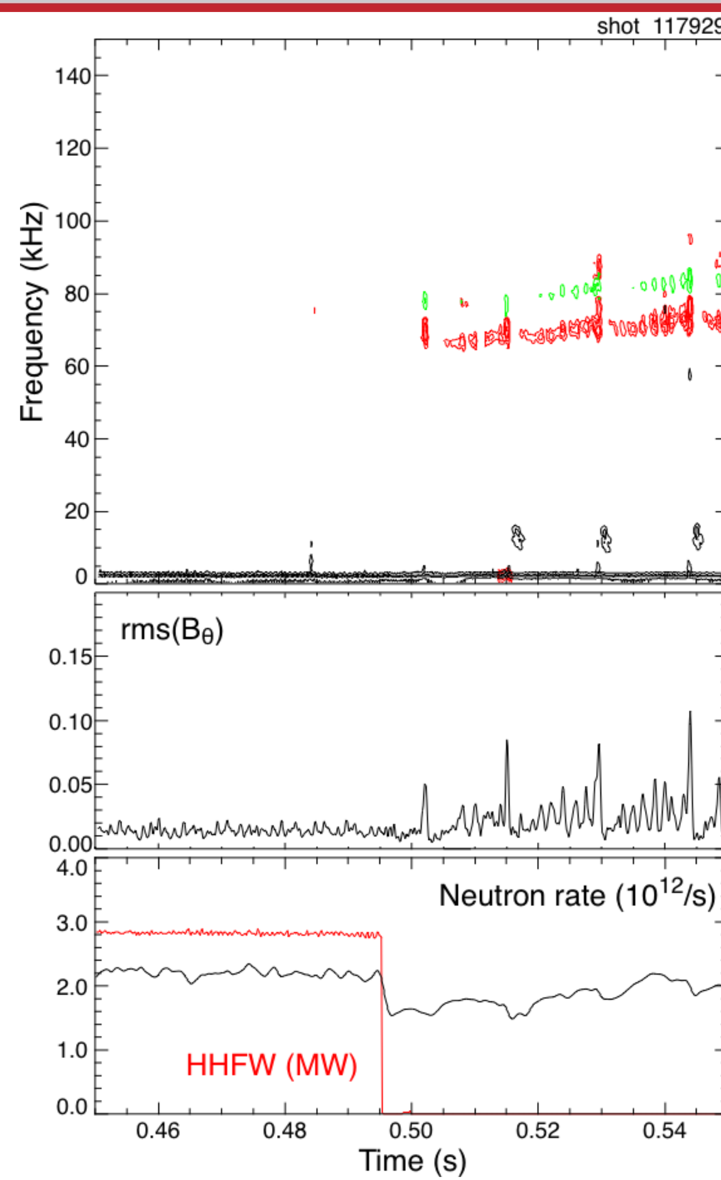
Similar suppression of chirping, then complete suppression of modes also seen for TAE

- Long frequency chirps are mostly suppressed in the first 20 ms of HHFW.
- Mode amplitude is also reduced.
- Mechanism for suppression of modes after 0.25s not clear, TAE should be excited by a broad range of fast ions.
- However, changes to equilibrium parameters (T_e, n_e, T_i and rotation) relatively small.
- Possibly related to same mechanism as ECH stabilization of rsAE seen on DIII-D.



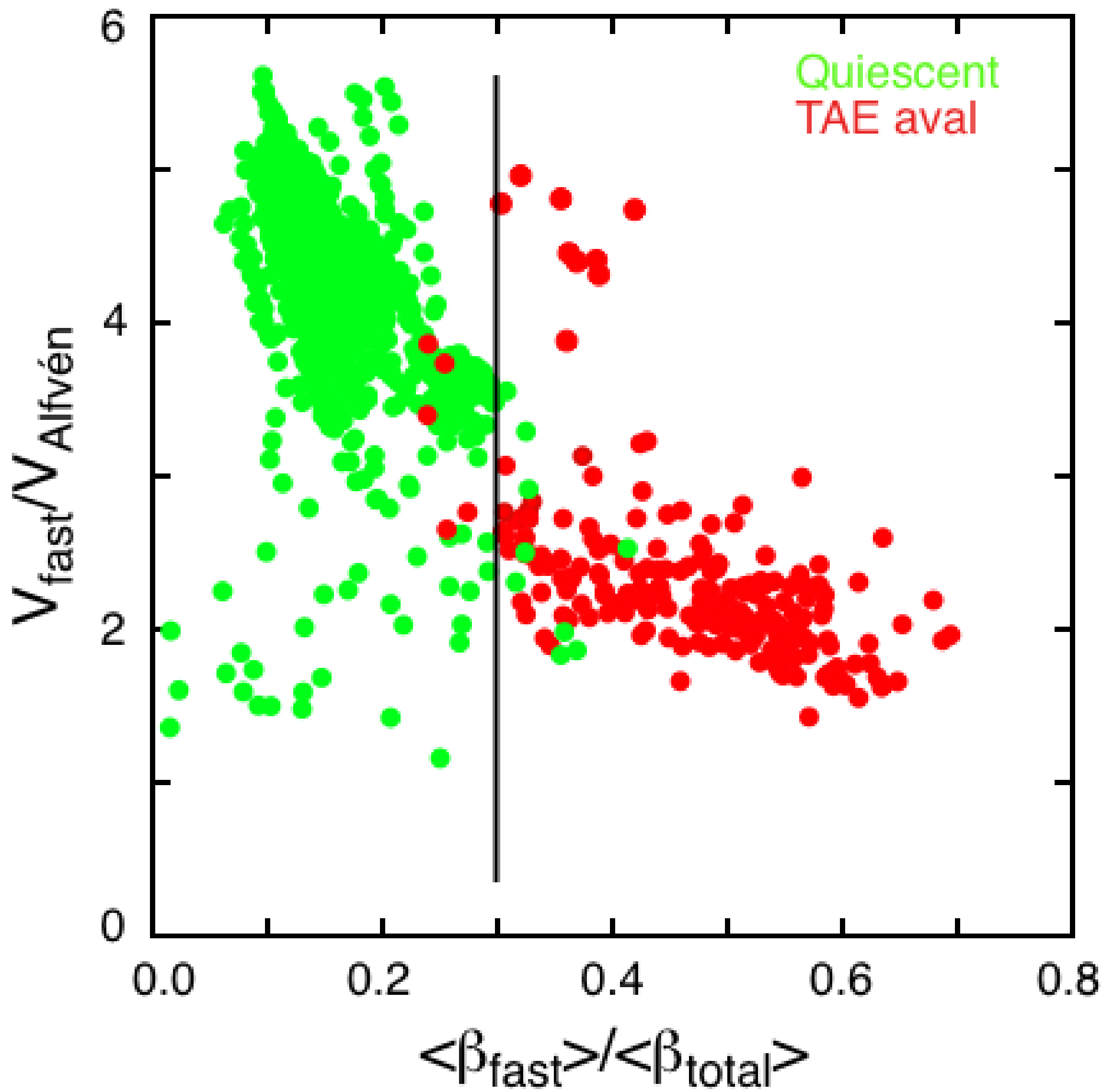
TAE + fishbones reappear after HHFW ends

- Also, n=1 TAE mostly gone, but a little more n=4 TAE.
- Strong TAE chirping is also mostly absent – chirping correlated with elevated q(0)?
- TAE peak amplitude is also lower and without strong frequency chirps.
- TAE reappear after HHFW ends, but not immediately.
- Peak mode amplitude doesn't quite recover to no-RF case, and fishbones are more feeble.



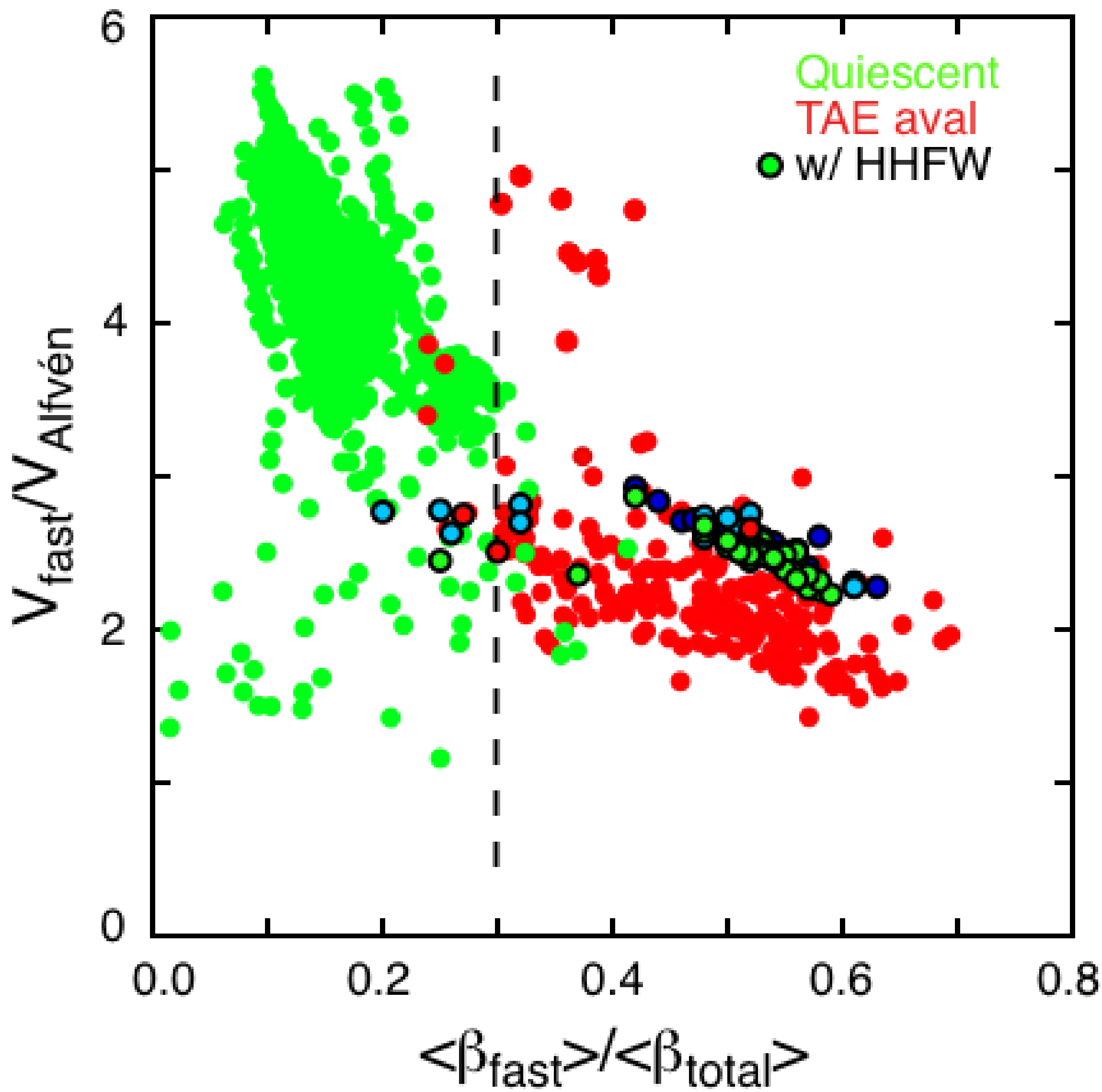
TAE avalanches rare for $<\beta_{fast}>/<\beta_{total}> < 0.3$, Quiescent plasmas are rare above this line

- TAE-quiesence seen for $\beta_{fast}/\beta_{tot} < 0.3$.



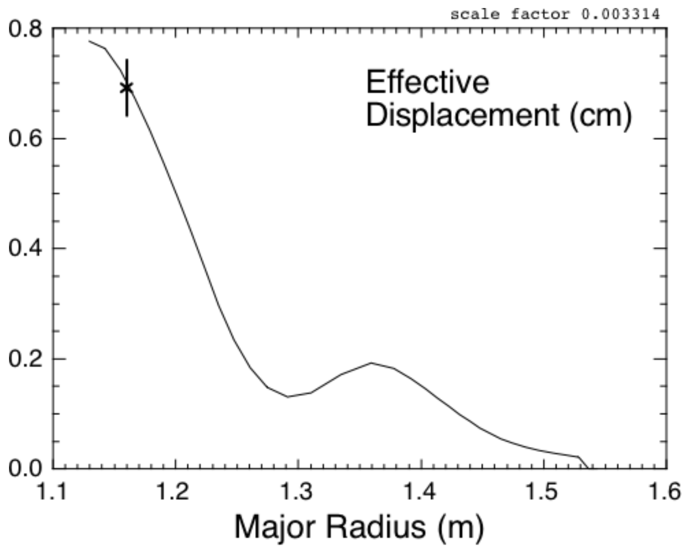
Parameters for these HHFW-stabilized shots similar to other avalanching NSTX plasmas

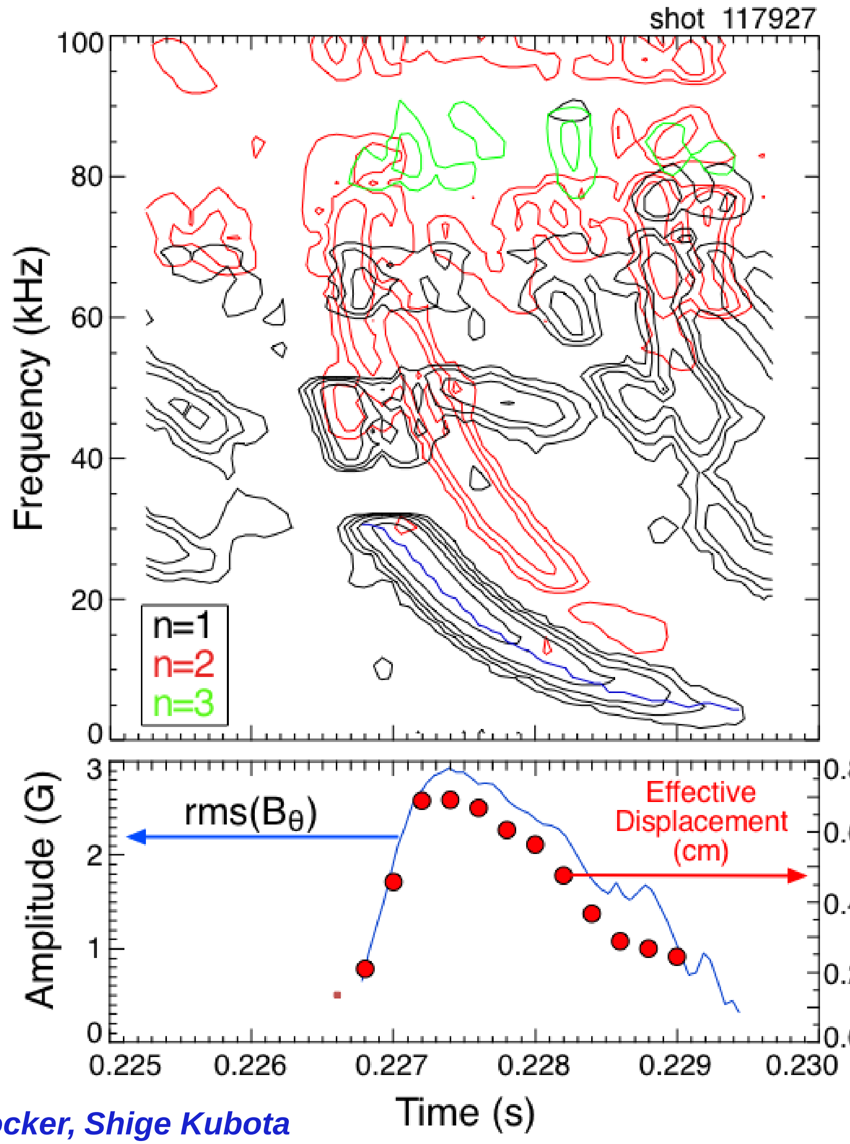
- TAE-quiesence seen for $\beta_{fast}/\beta_{tot} < 0.3$.
- Green-bordered-in-black points are HHFW-stabilized.
- Blue-in-black, red-in-black are beam-only periods.
- Cyan-in-black are transition points, that is shortly after HHFW is applied.



NOVA and ORBIT were used to model fast-ion redistribution through an early TAE burst

- Absolute mode amplitude evolution provided by a single reflectometer channel – no check of mode structure.
- Only dominant n=1 and much weaker n=2 used in ORBIT simulation.

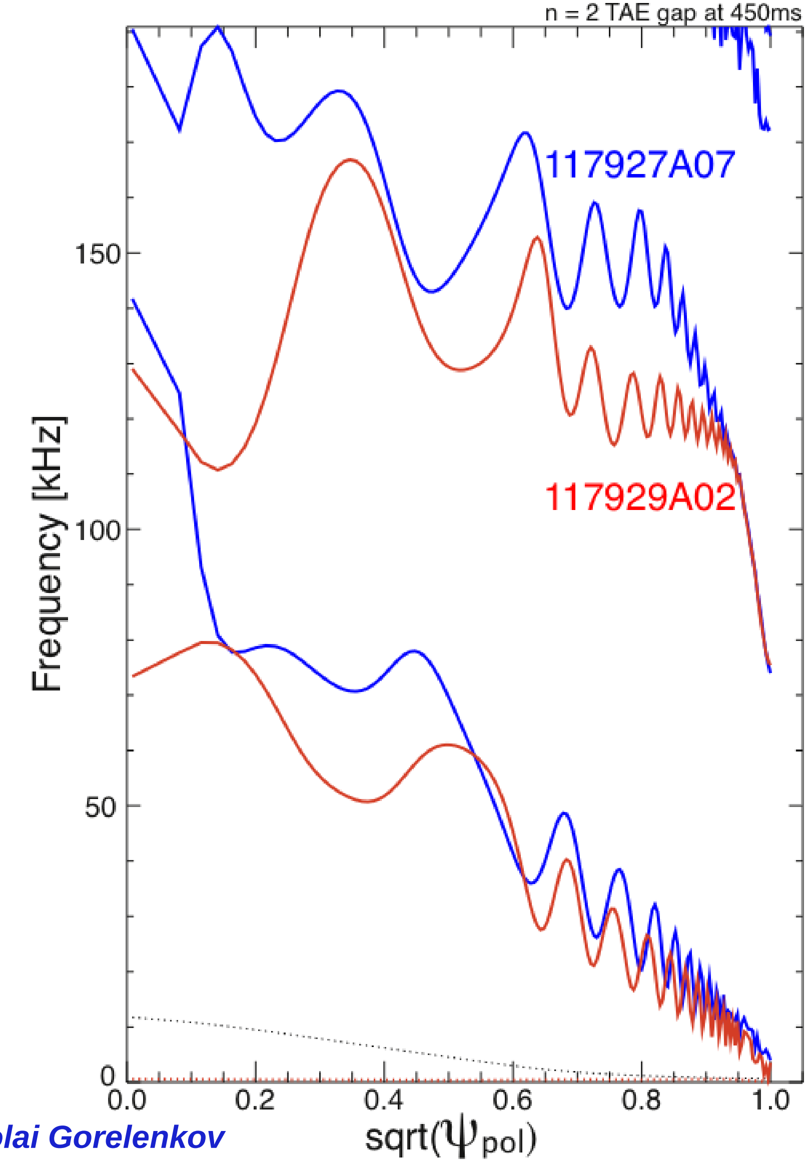




Neal Crocker, Shige Kubota

No obvious explanation in NOVA analysis, although detailed stability calculations still remain to be done

- Low rotation rate means NOVA fast-ion drive calculations should be reasonable.
  - for normal NSTX plasmas, the high rotation is not folded into the resonance calculations.
- Non-RF shot (blue) has 'closed' continuum near axis, but q(0) is relatively uncertain.

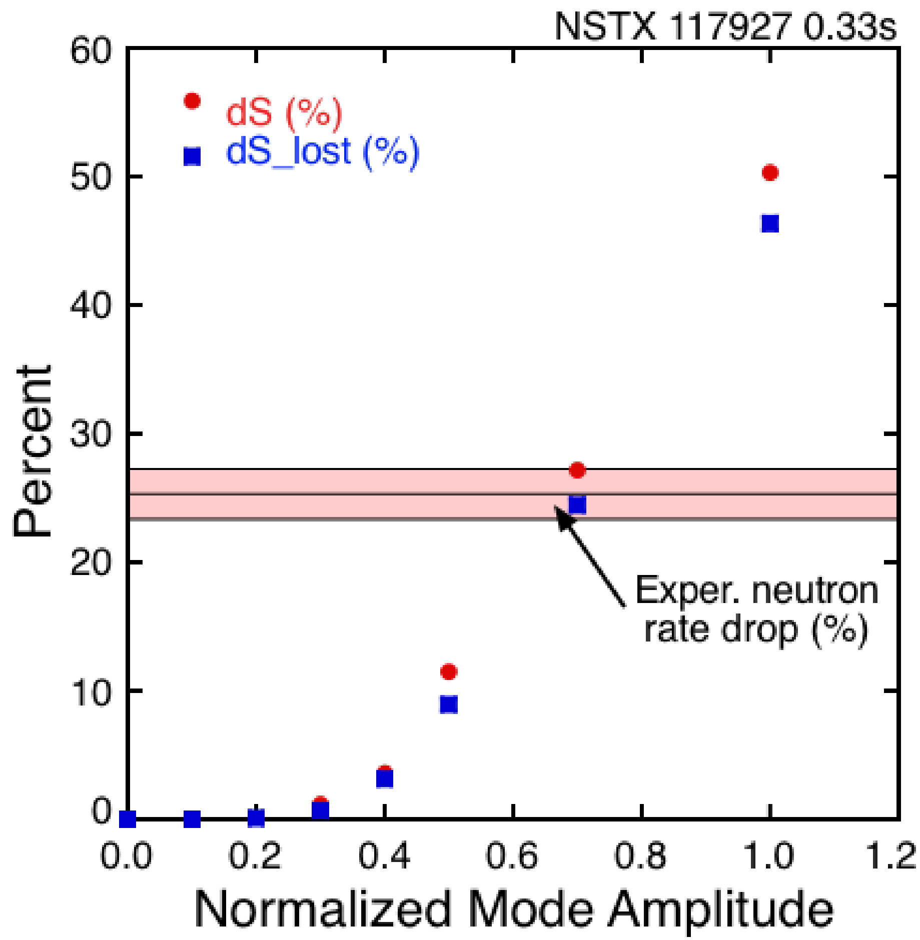


NOVA – Gerrit Kramer, Nikolai Gorelenkov

As found previously, reasonable agreement between measured mode amplitude and neutron rate drop

- In this case, neutron rate drop mostly from lost fast ions.
- Mode amplitude 70% of measured amplitude gives best agreement with neutron rate drop measurement.
- Agreement gives some confidence in NOVA/ORBIT modeling.
- Constraint on mode amplitude is pretty weak – meaning large uncertainty.

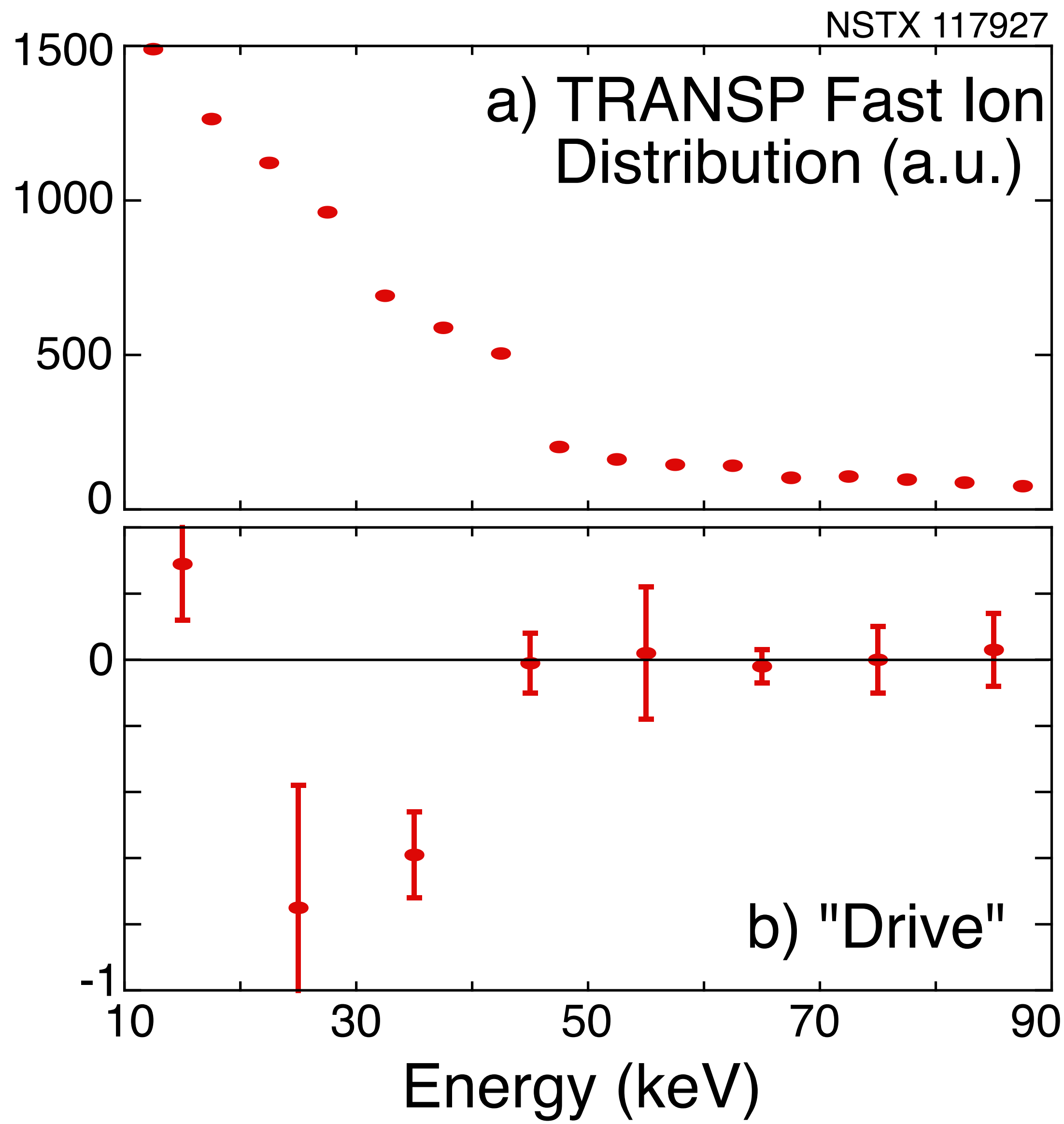
ORBIT – R. White



Large $V_{fast}/V_{Alfvén}$ means most of distribution can resonantly interact with TAE

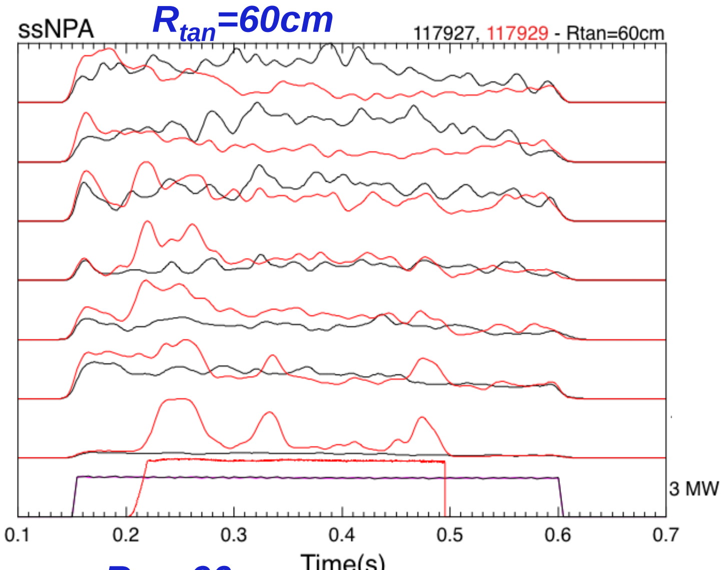
- ORBIT simulations predict most of drive for TAE comes from lower energy beam ions.

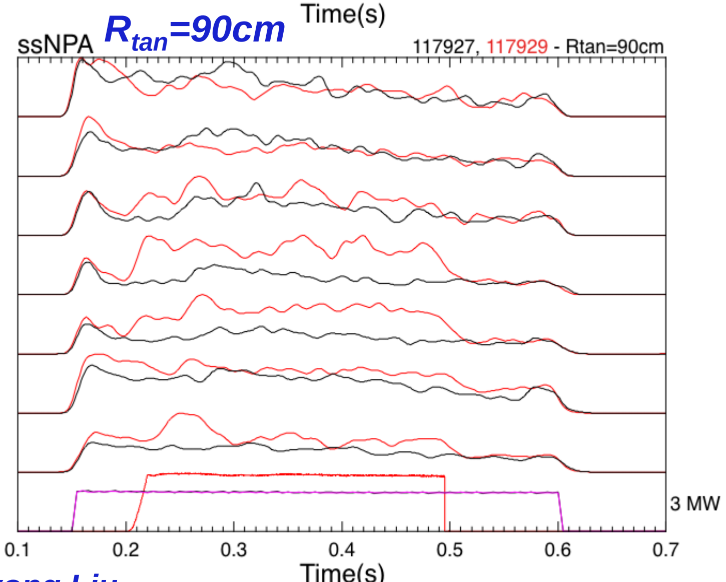
- Higher energy beam ions can strongly interact, but *net* drive is small.



NPA data suggests some phase-space redistribution of beam ions with HHFW heating

- Some deficit in higher energies between beam-only (black) and beam+HHFW (red) at R_{tan}=60cm.
- Possibly an increment with HHFW in intermediate energy range for R_{tan}=90cm.
- Changes smaller for R_{tan}=100cm and R_{tan}=120cm.
- More work is needed to interpret these observations.
- Lowest NPA energy range higher than 45 keV.





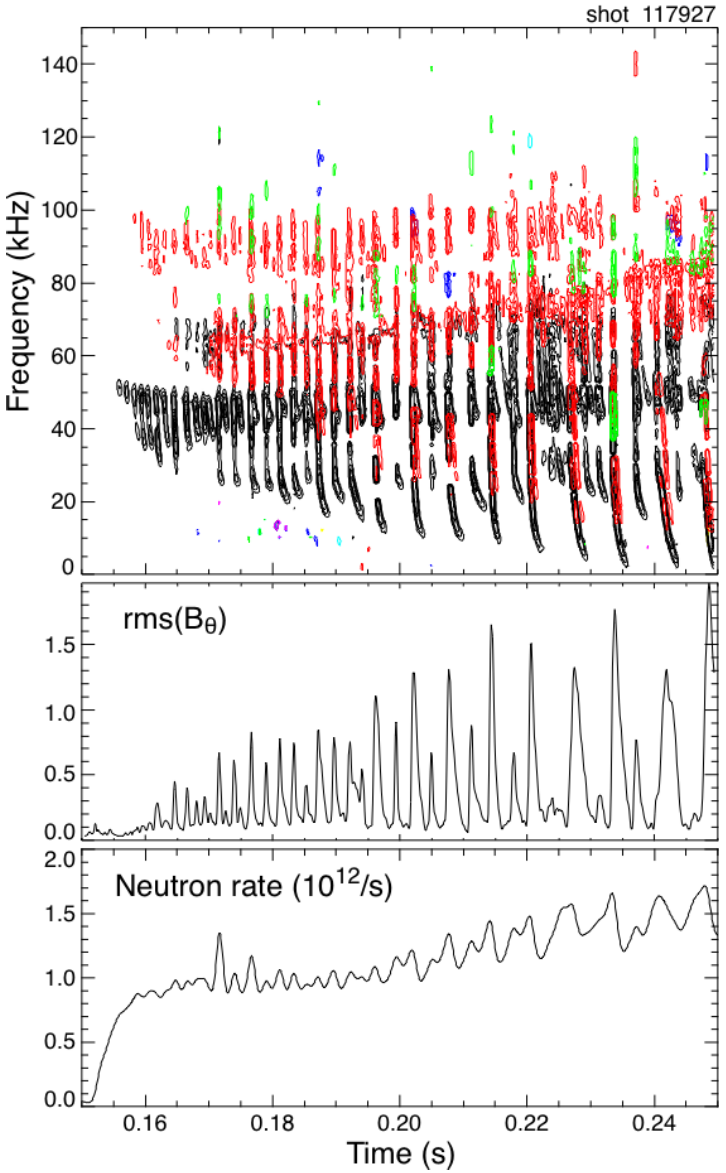
ssNPA - Deyong Liu

Summary – effective TAE suppression technique discovered?

- ≈3 MW of HHFW heating is seen to suppress *all* fast-ion driven activity – fishbones, TAE, GAE.
- The suppression is not immediate, but takes some 10's of ms, suggesting that the HHFW is modifying the distribution of fast ions.
- Neutron rate and NPA data show no indication of excessive fast ion losses with HHFW, although NPA data suggests some redistribution is happening.
- There is some suggestion that the frequency chirping is initially suppressed, followed by stabilization of the modes.
- The target plasma was not typical, future work will explore extending this suppression technique to more typical conditions.

TAE are mostly low toroidal mode number, n=1 up to n=3

- Target plasma was Helium with plasma current of about 300 kA.
- One neutral beam source was injected at 90 keV.
- The low measured neutron rate is comparable to the beam-beam neutron rate modeled with TRANSP.
- Neutron rate drops, of order 25%, seen with each burst.



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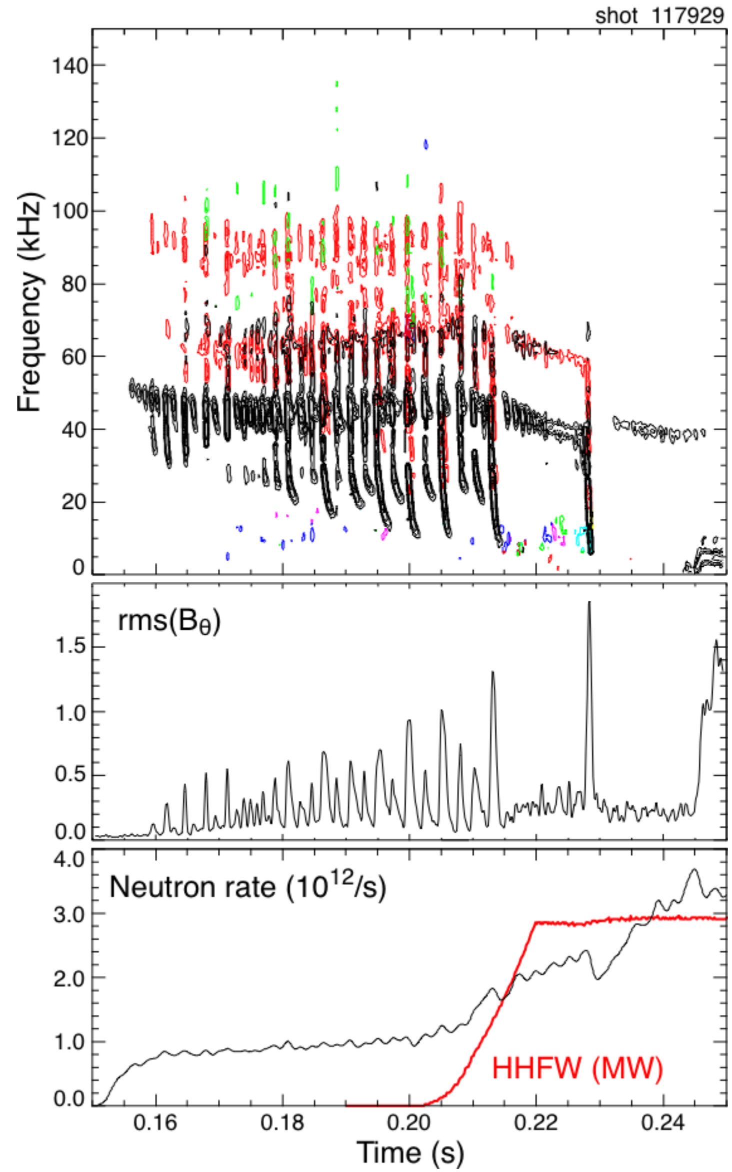
- One neutral beam source was injected at 90 keV.
- The low measured neutron rate is comparable to the beam-beam neutron rate modeled with TRANSP.
- Neutron rate drops, of order 25%, seen with each burst.
- Neutron rate increase with HHFW is, at least partly, due to pick-up.



TAE transition from strong chirping to weak, or no chirping