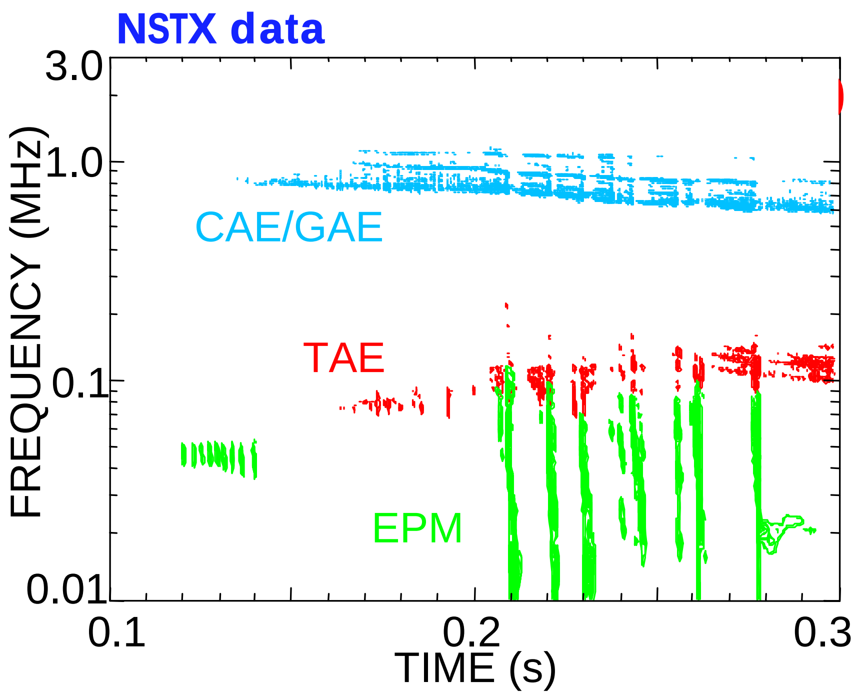
Effect of HHFW on Rapidly Chirping Modes



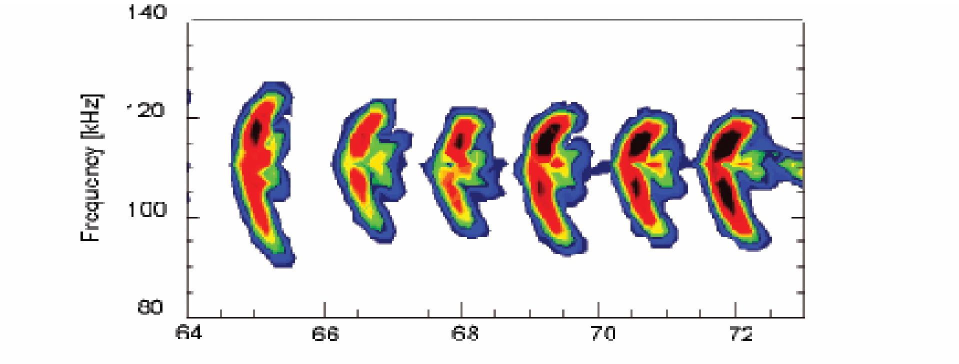
- Berk-Breizman model
- Plasma conditions
- Fishbones
- TAE-band
- Possible explanations

Bill Heidbrink, Herb Berk, Eric Fredrickson, Nikolai Gorelenkov, Sid Medley, Emil Ruskov with acknowledgments to many others

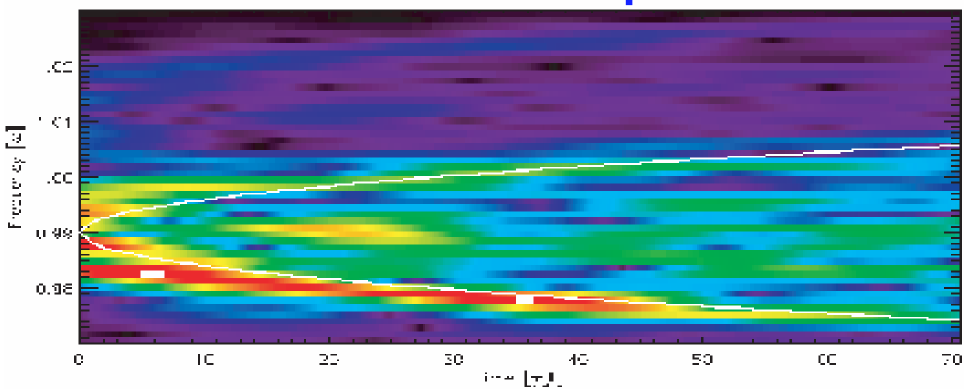
UCIrvine
University of California, Irvine

Rapid Frequency Chirping is Common

MAST data



Simulation of 1st MAST chirp

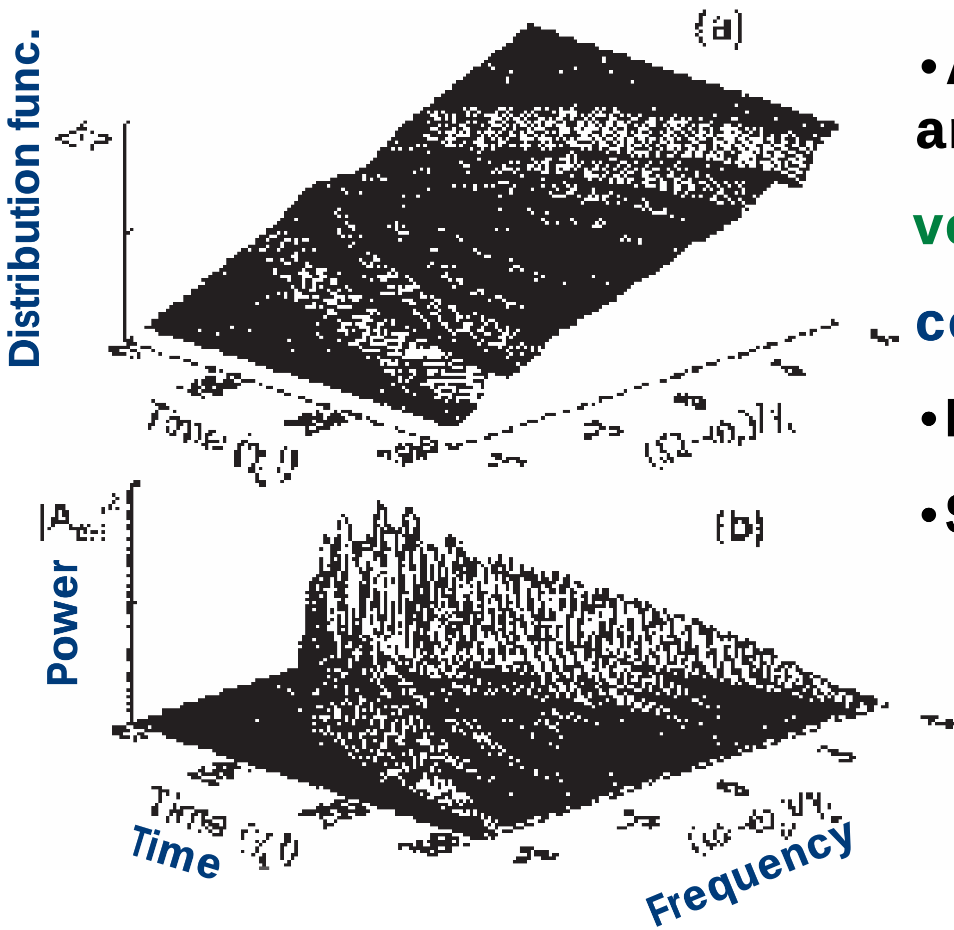


Pinches, PPCF 46 (2004) S47

- **PDX fishbones**
- **Chirping in TAE band in most toroidal devices**
- **Electron-driven instabilities in tokamaks**
- **Columbia Dipole experiment**

Is there a generic explanation?

Berk-Breizman Model of Frequency Chirping: Propagating Holes & Clumps in Phase Space



- **Analogy between "bump-on-tail" and fast-ion modes:**

velocity-space gradient ←→

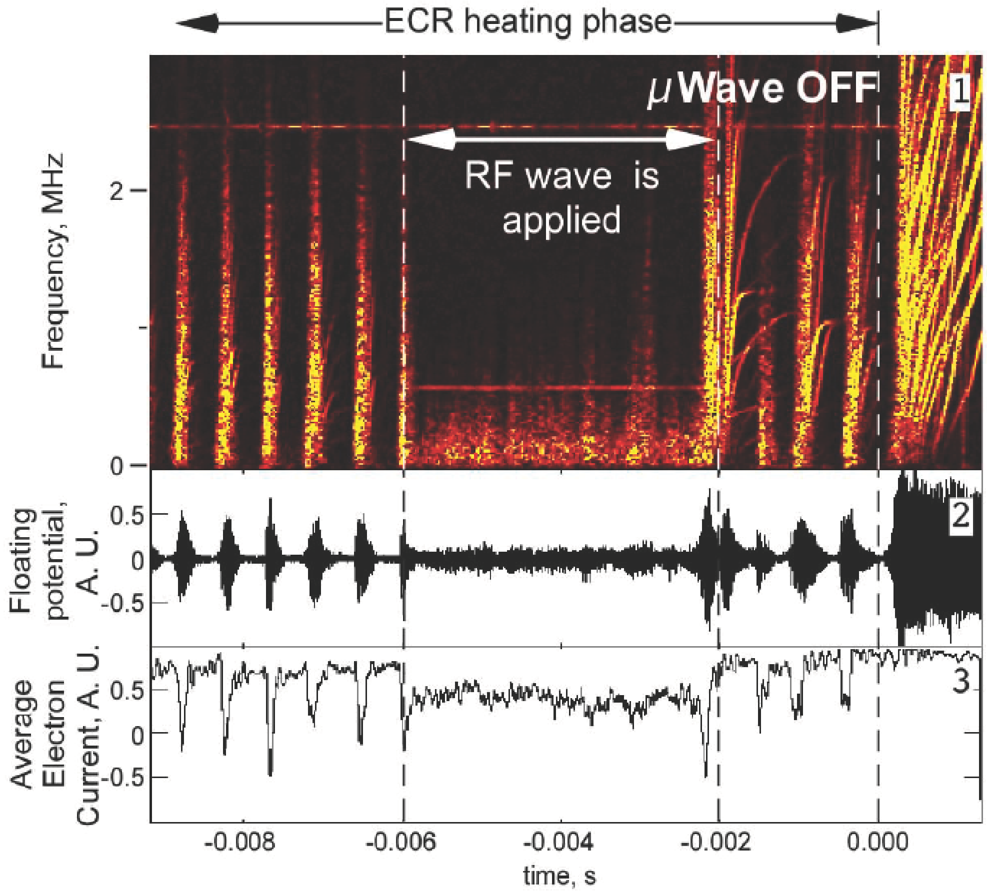
configuration-space gradient

- **Resonant ions get trapped in wave**
- **Structure propagate in time**

Berk, Phys. Pl. 6 (1999) 3102

50 W of ECH Suppressed Chirping

Columbia Dipole data

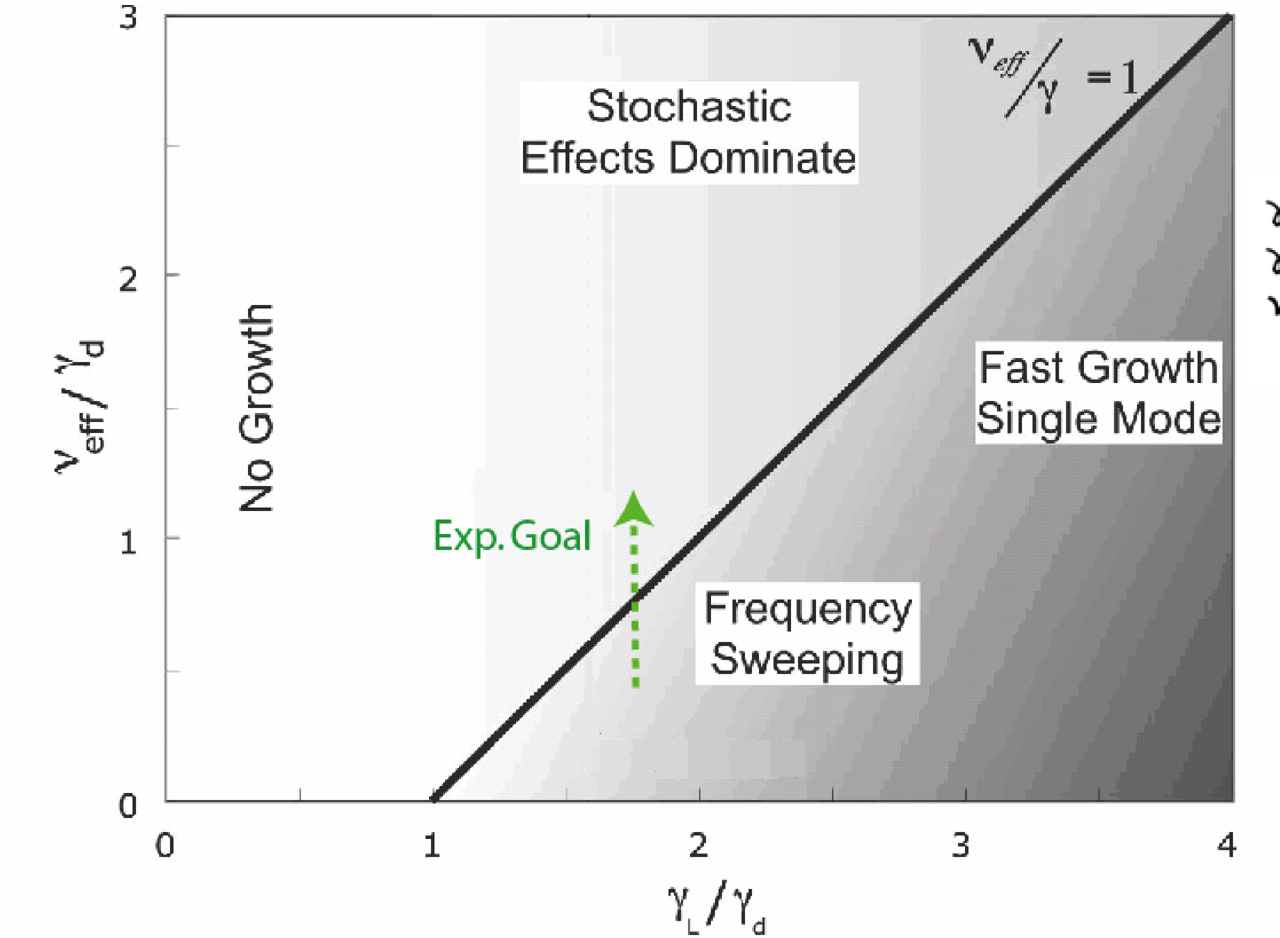


Maslovsky, Phys. Pl. 10 (2003) 1549

- **Phase space structures destroyed by RF acceleration → chirping stops**

- **Idea of NSTX XP: Use HHFW to suppress chirping**

Stochastic Acceleration destroys phase space "clumps" and "holes"



γ_L – linear growth rate

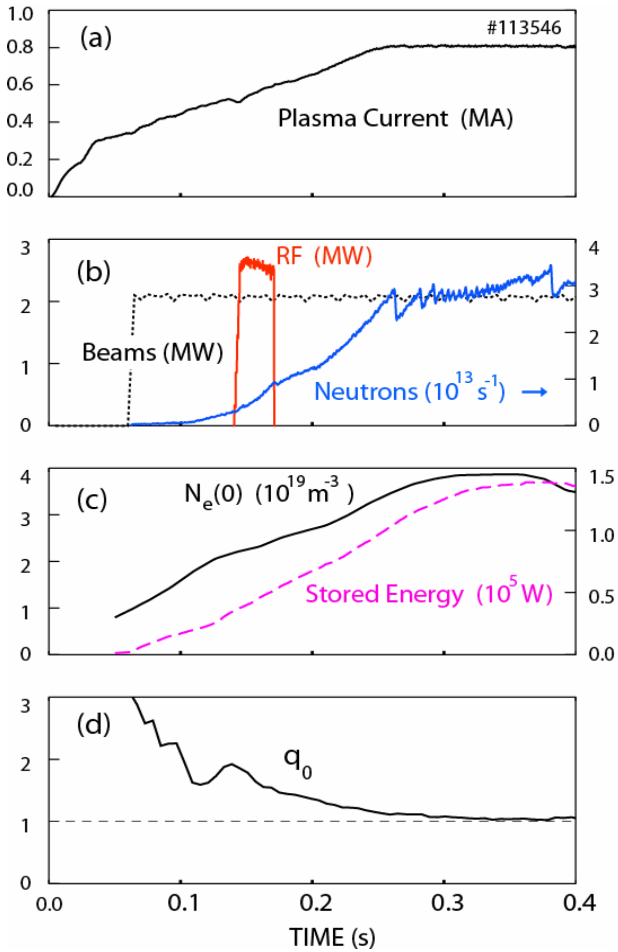
γ_d – nonresonant dissipation

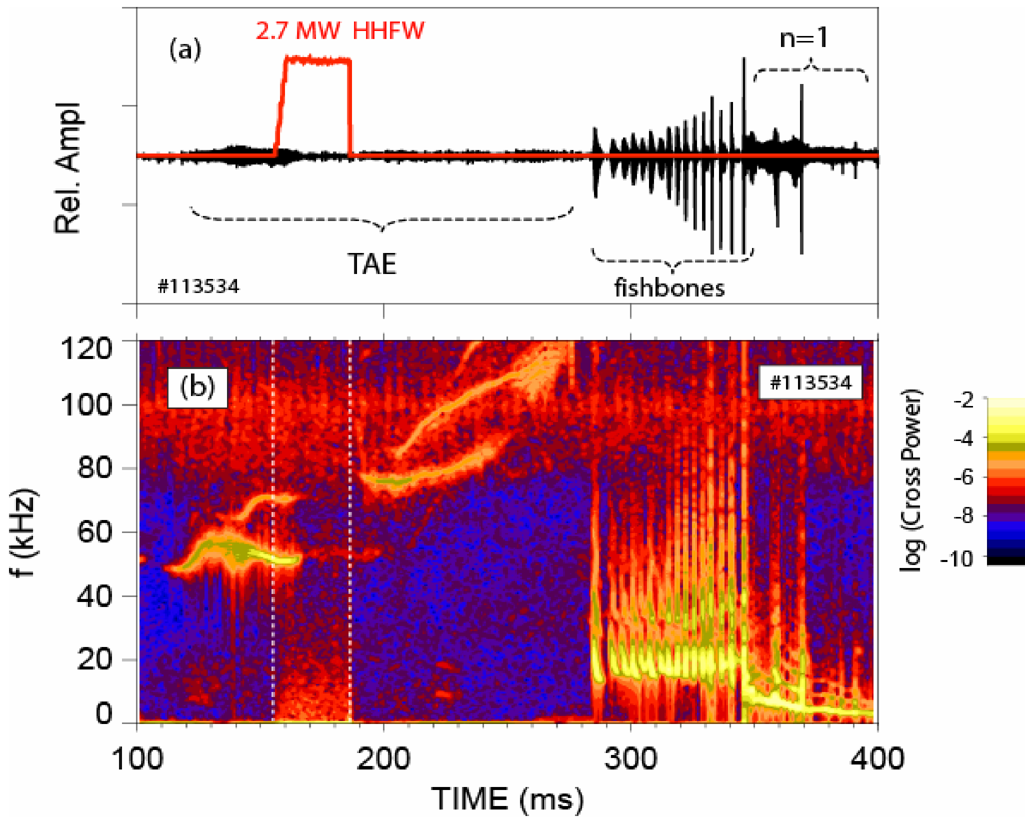
ν_{eff} – collisionality parameter

$\gamma = \gamma_L - \gamma_d$

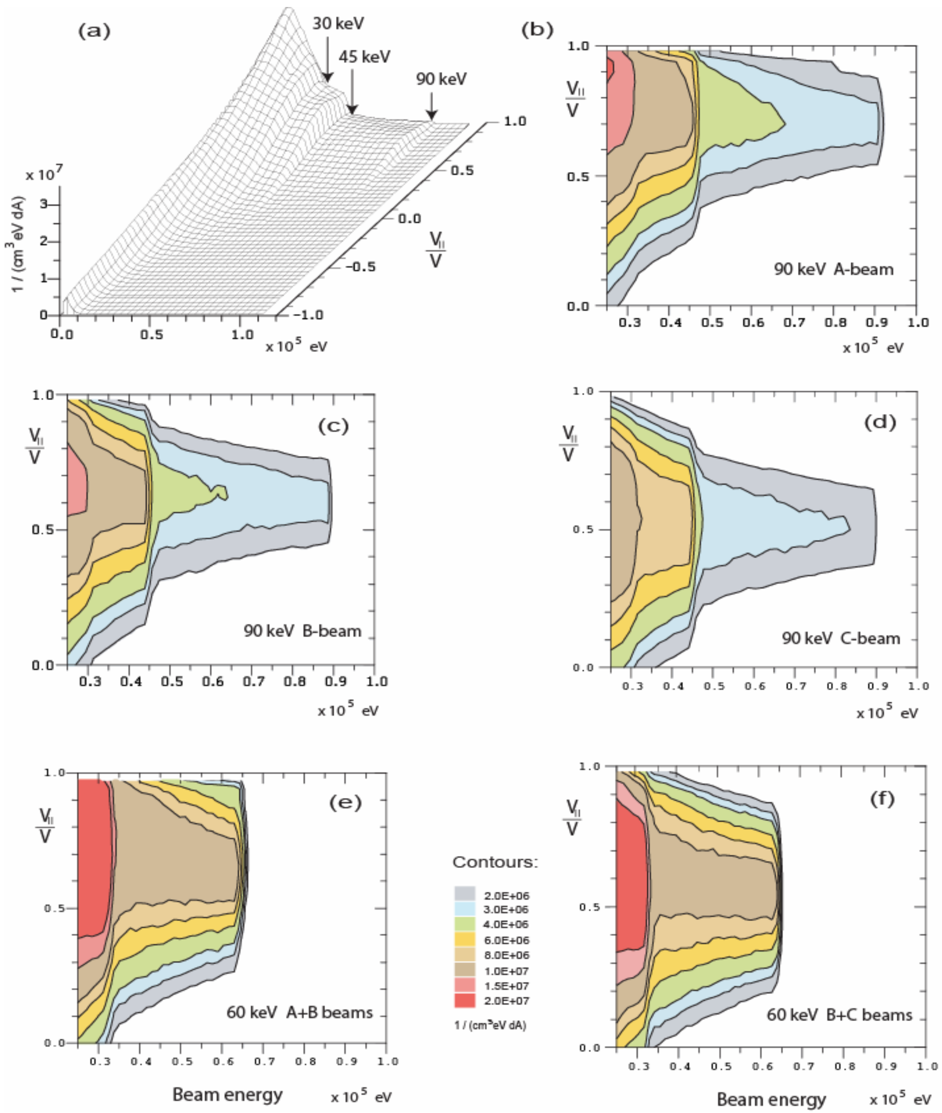
D.Maslovsky *et al.*, Phys.Plasmas **10** (2003) 1549

Helium L-Mode w/ Early TAES and Late Fishbones

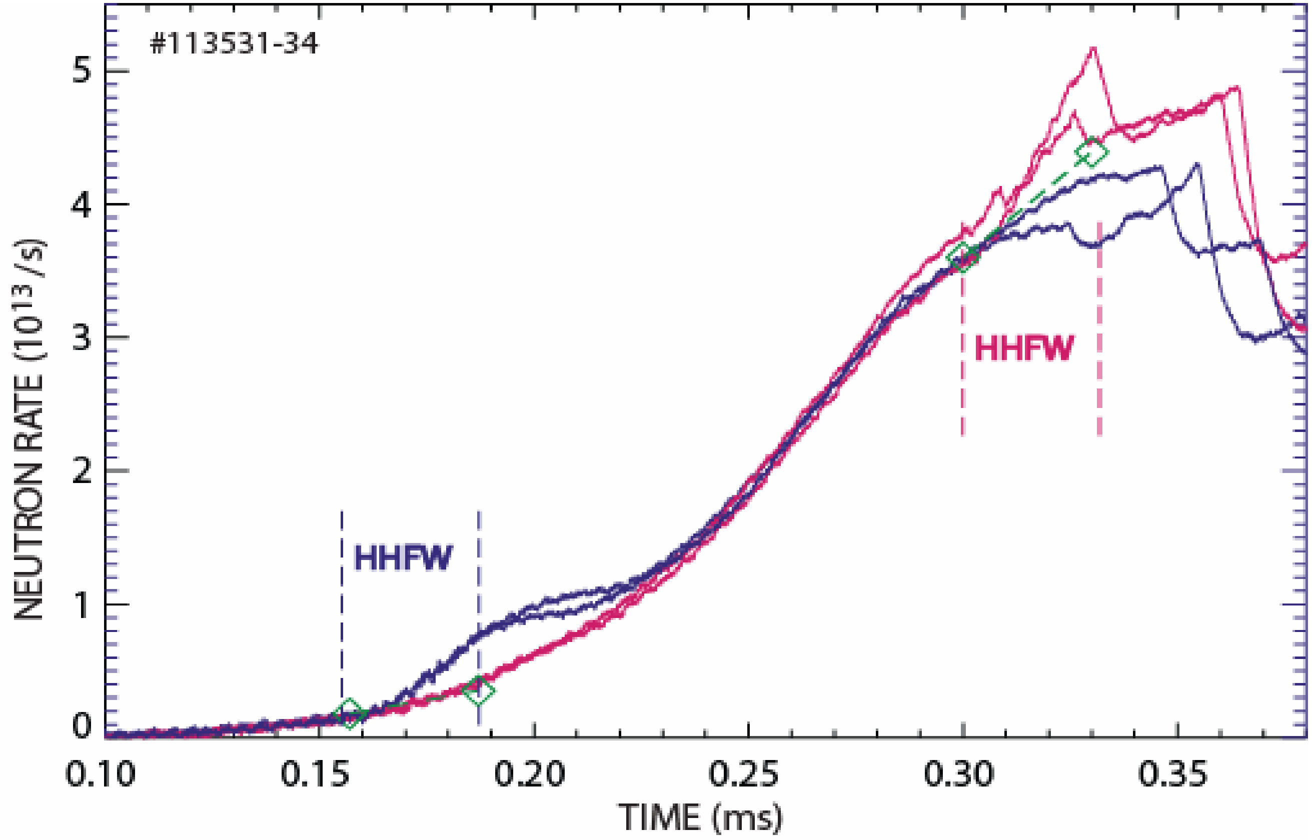




Five Beam Configurations in Nominally Identical Plasmas

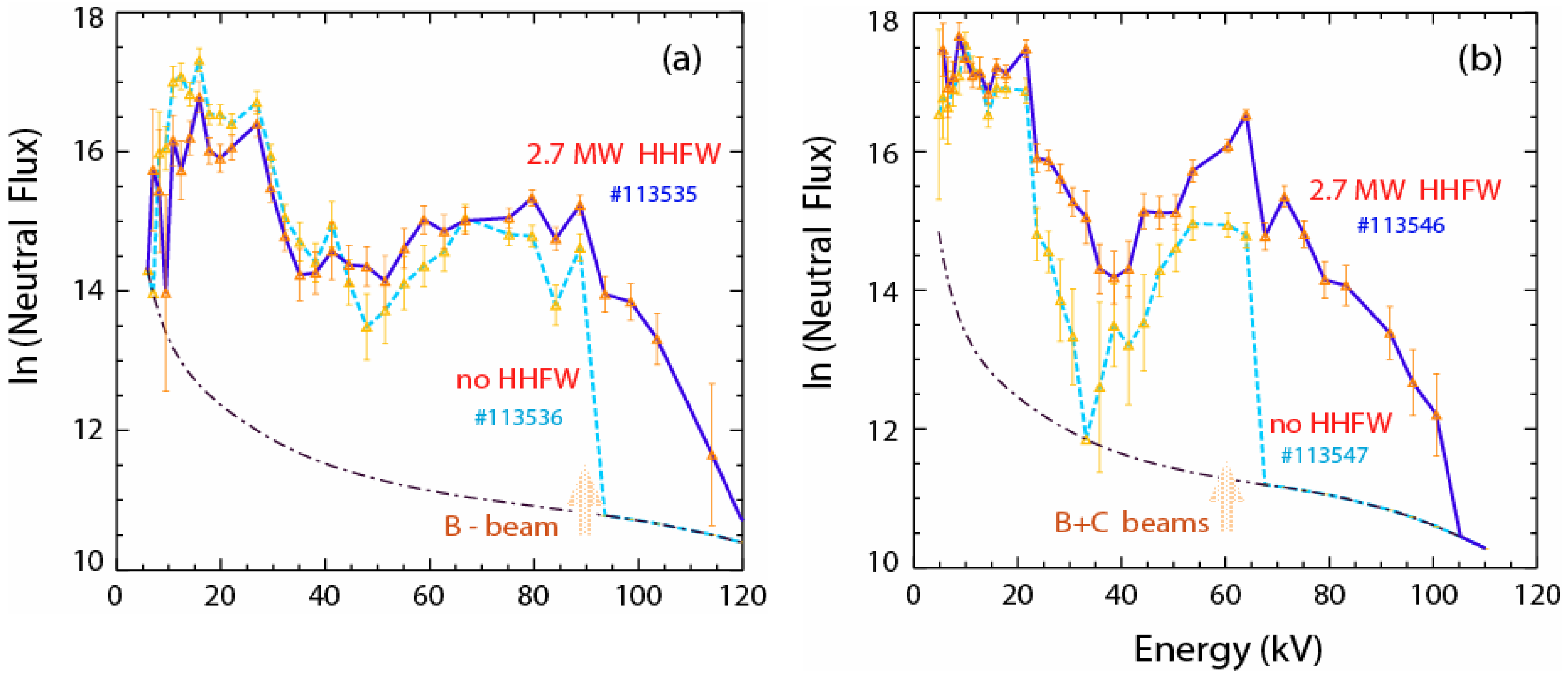


HHFW Accelerated Fast Ions

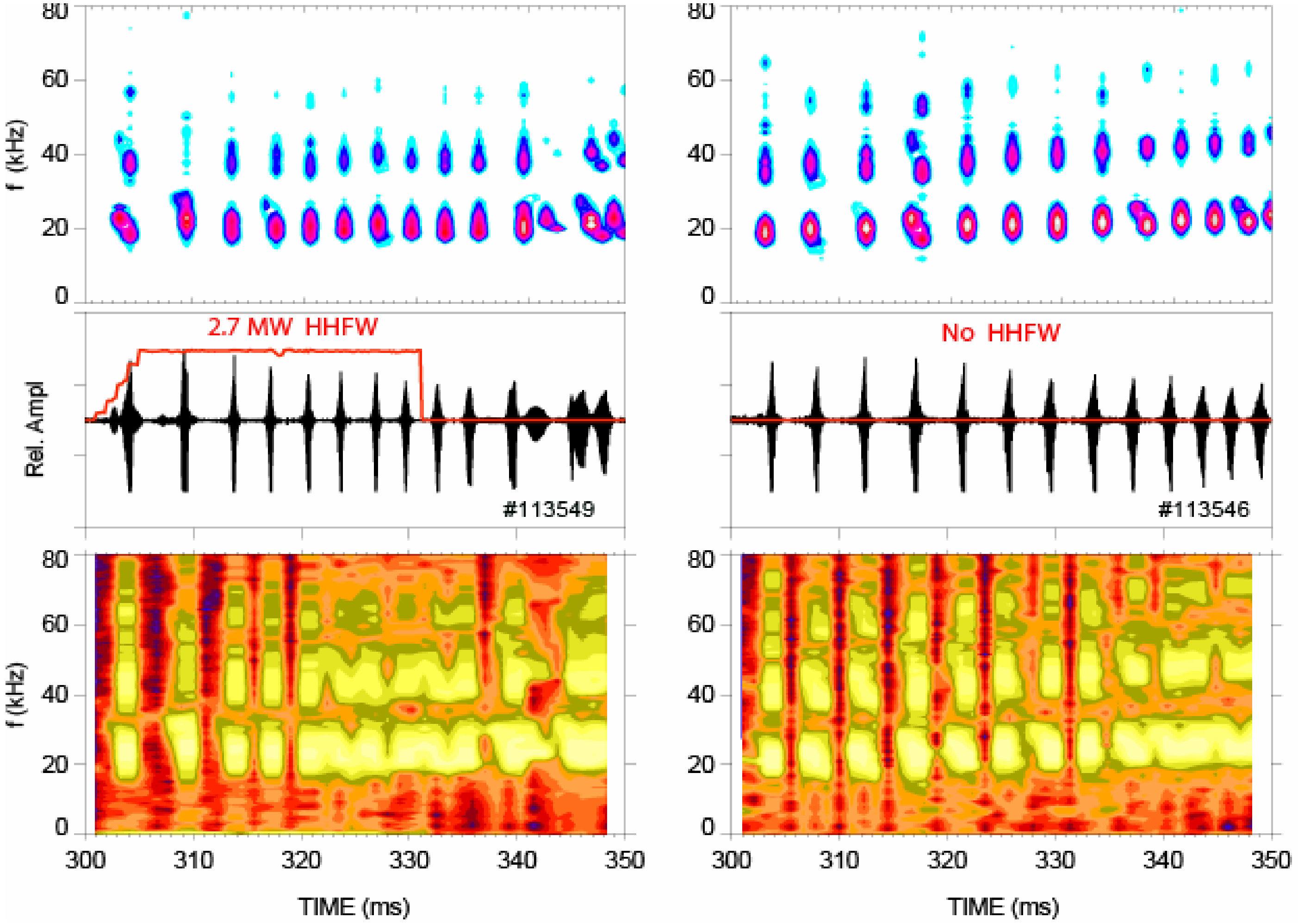


- 14 m^{-1}
- 2-3 MW

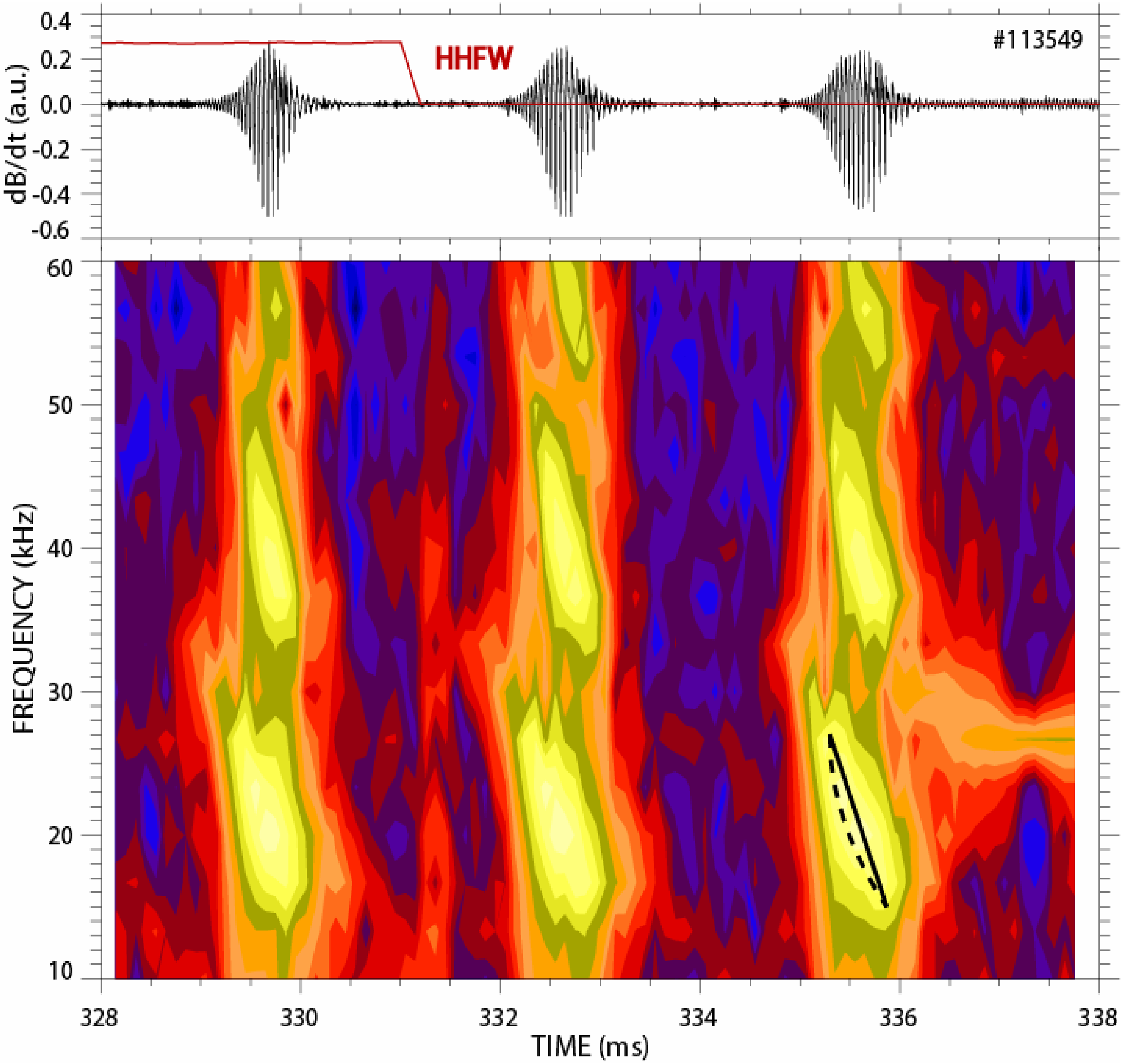
HHFW Accelerated Fast Ions for All Distribution Functions



HHFW has no effect on Fishbones

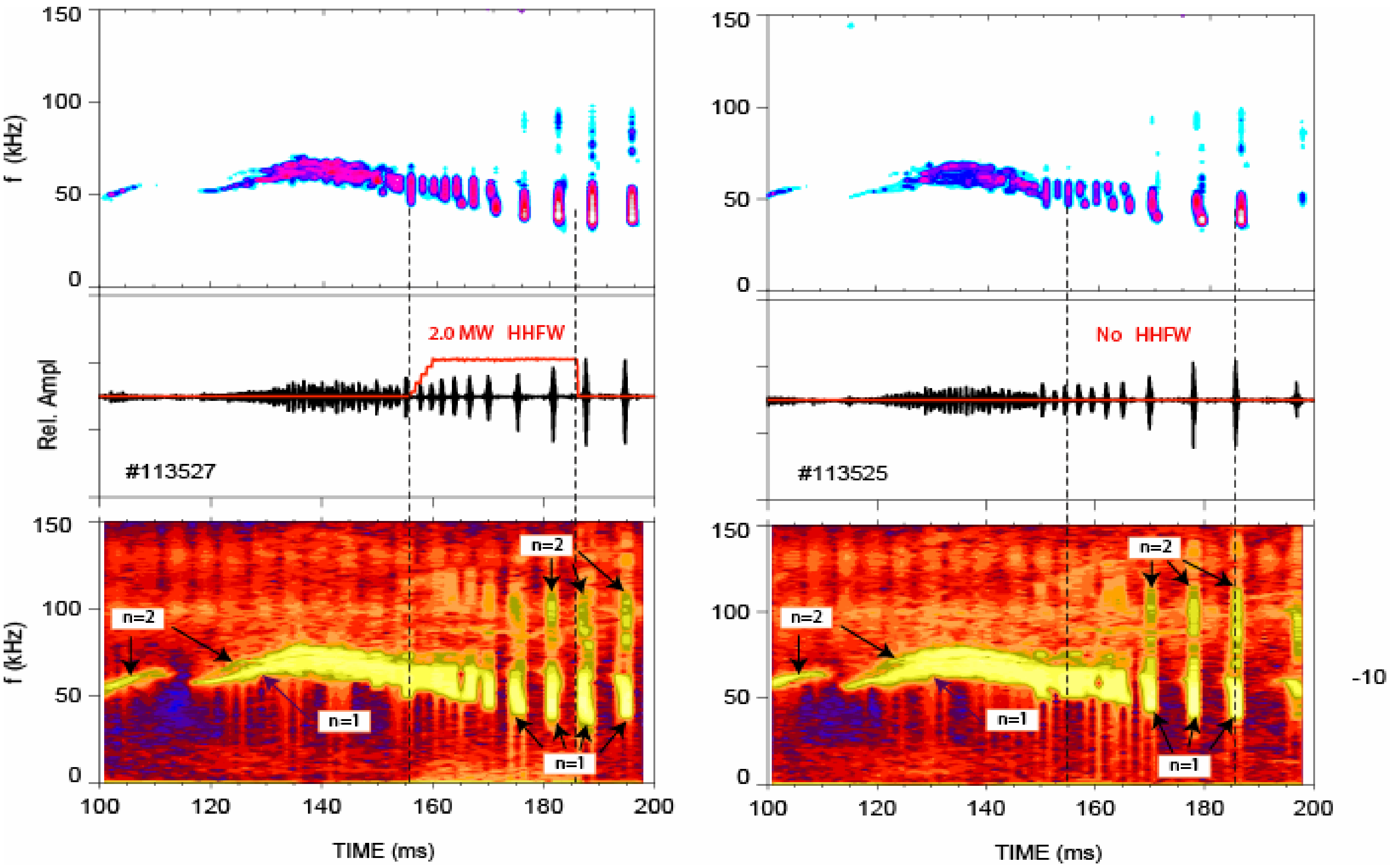


HHFW has no effect on Fishbones

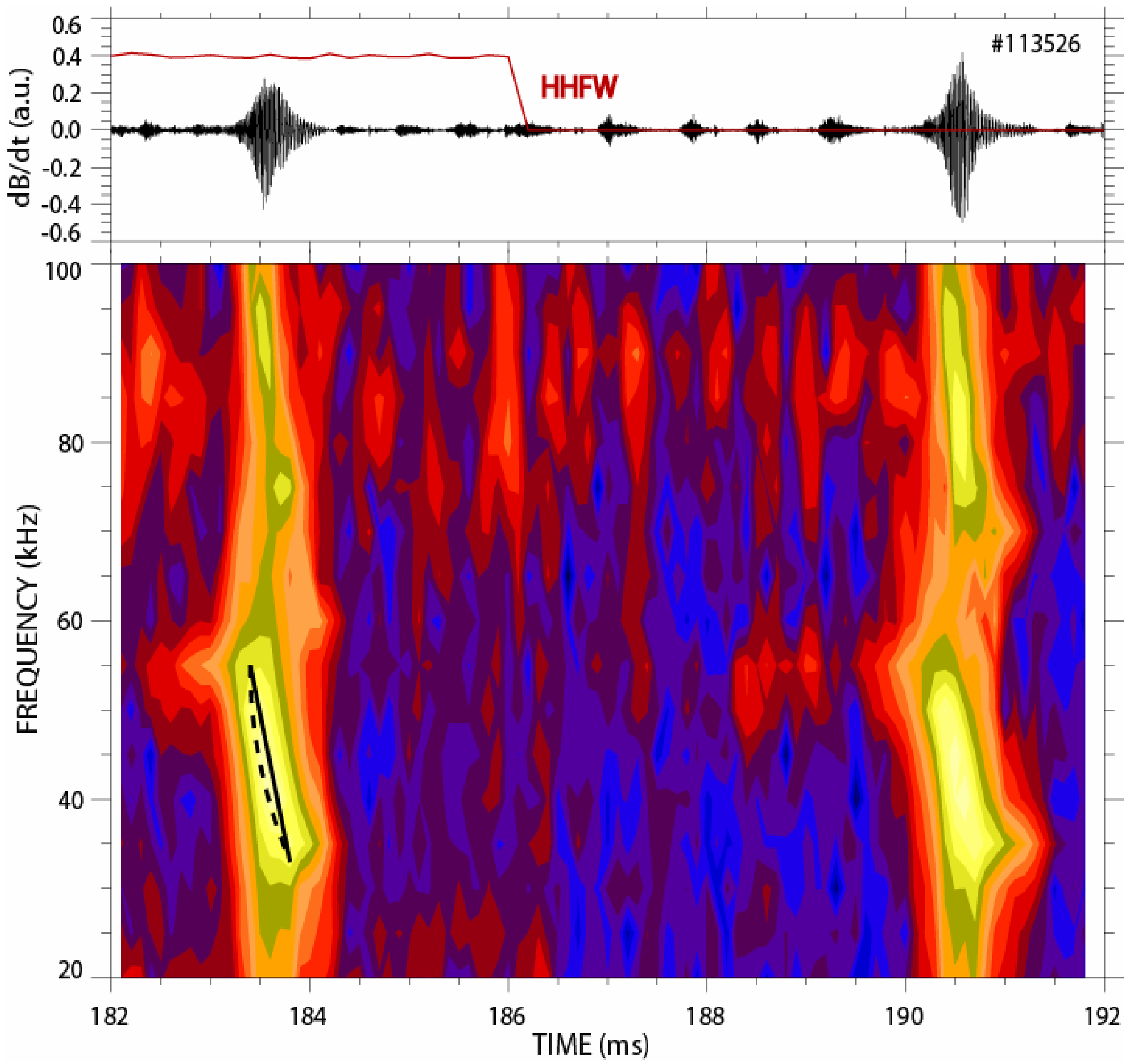


- Perturbative BB theory predicts $\delta f \sim t^{1/2}$
- Recent strongly driven simulations predict $\delta f \sim t$
- Fishbone chirp is linear in time

HHFW has no effect on TAE-band chirping

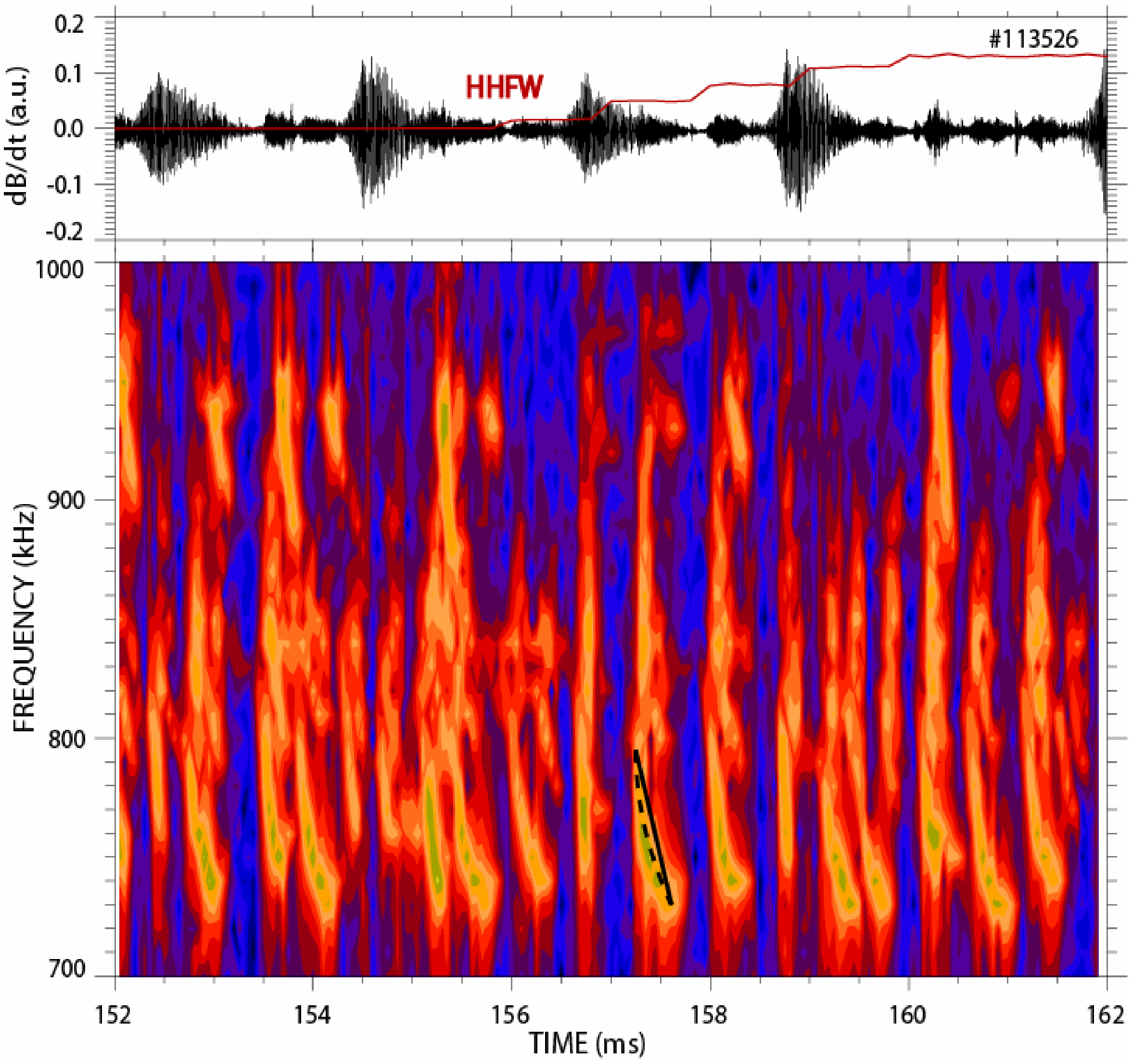


HHFW has no effect on TAE-band chirping



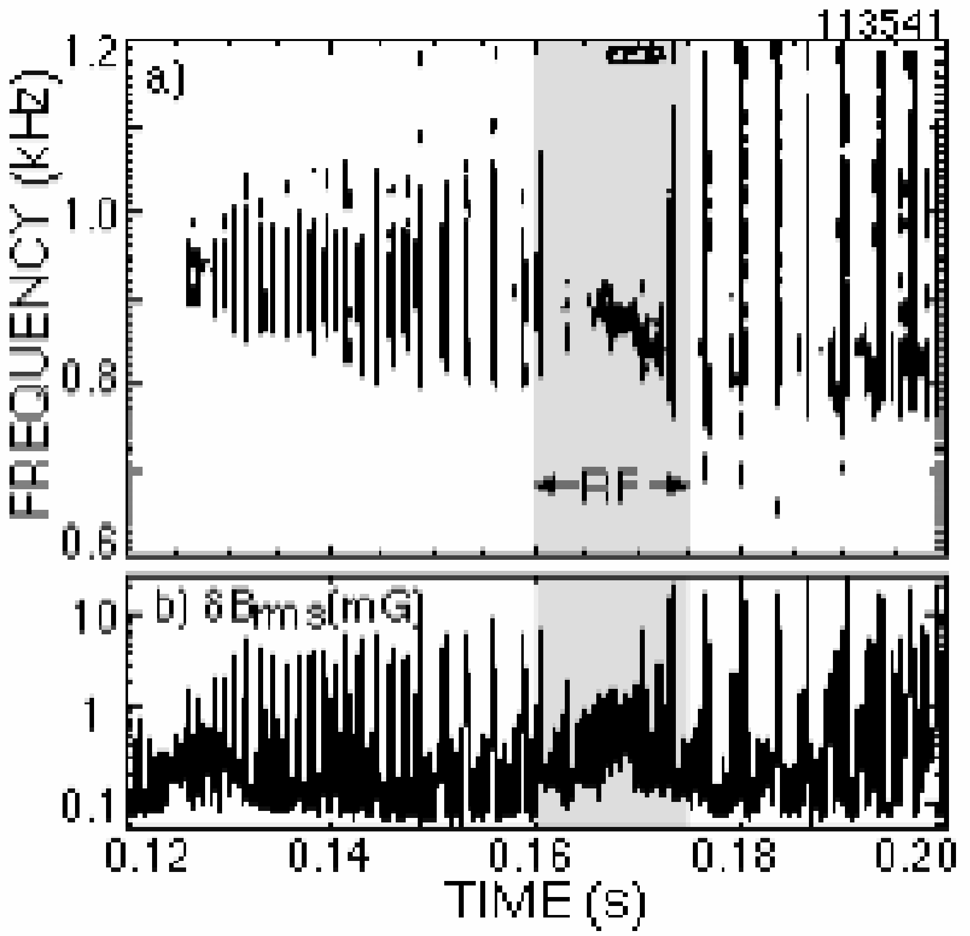
- Chirp is linear in time

Possible effect on MHz-band chirping



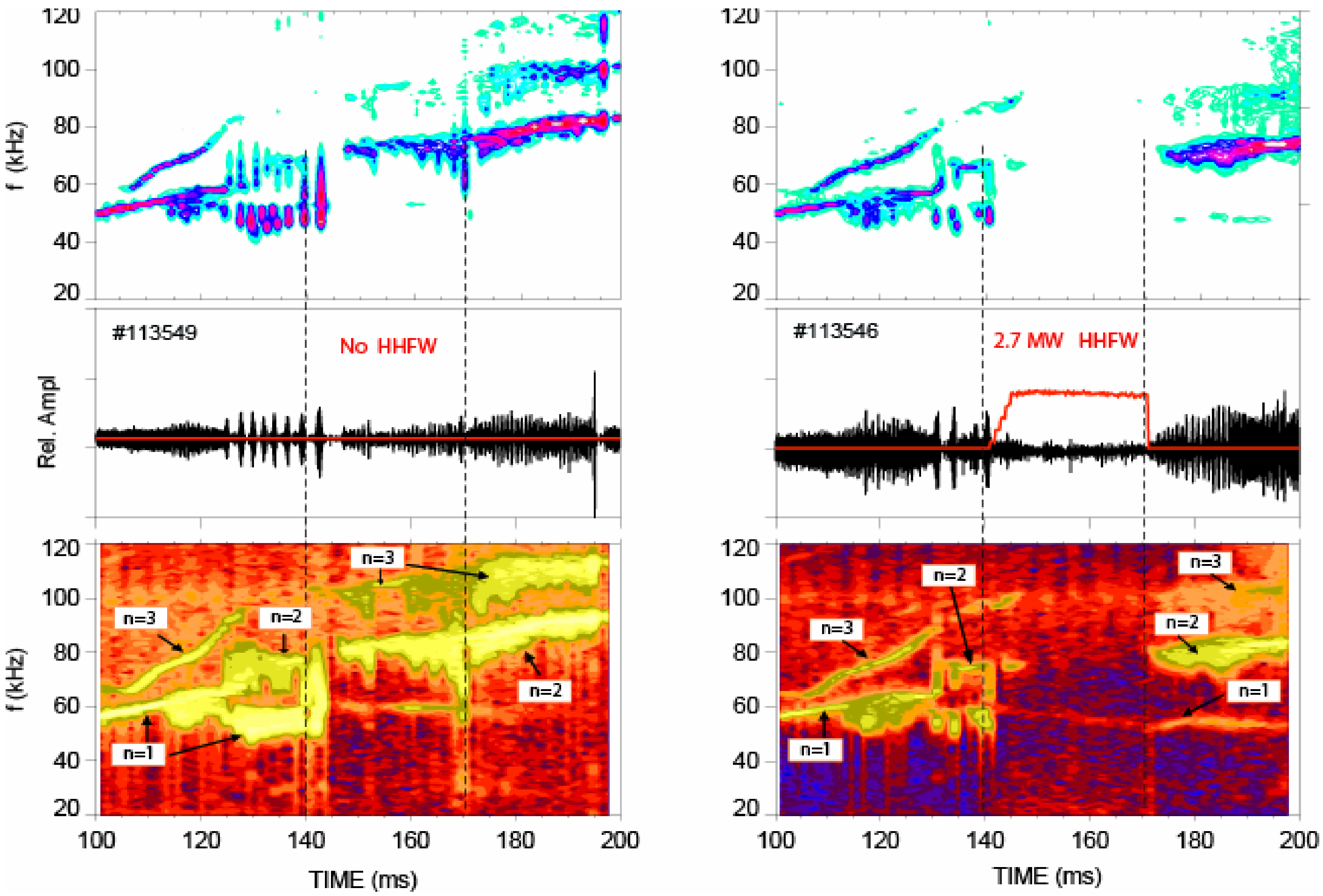
- **No effect in this case.**
- **Chirp follows $t^{1/2}$ perturbative BB scaling**

Possible effect on MHz-band chirping



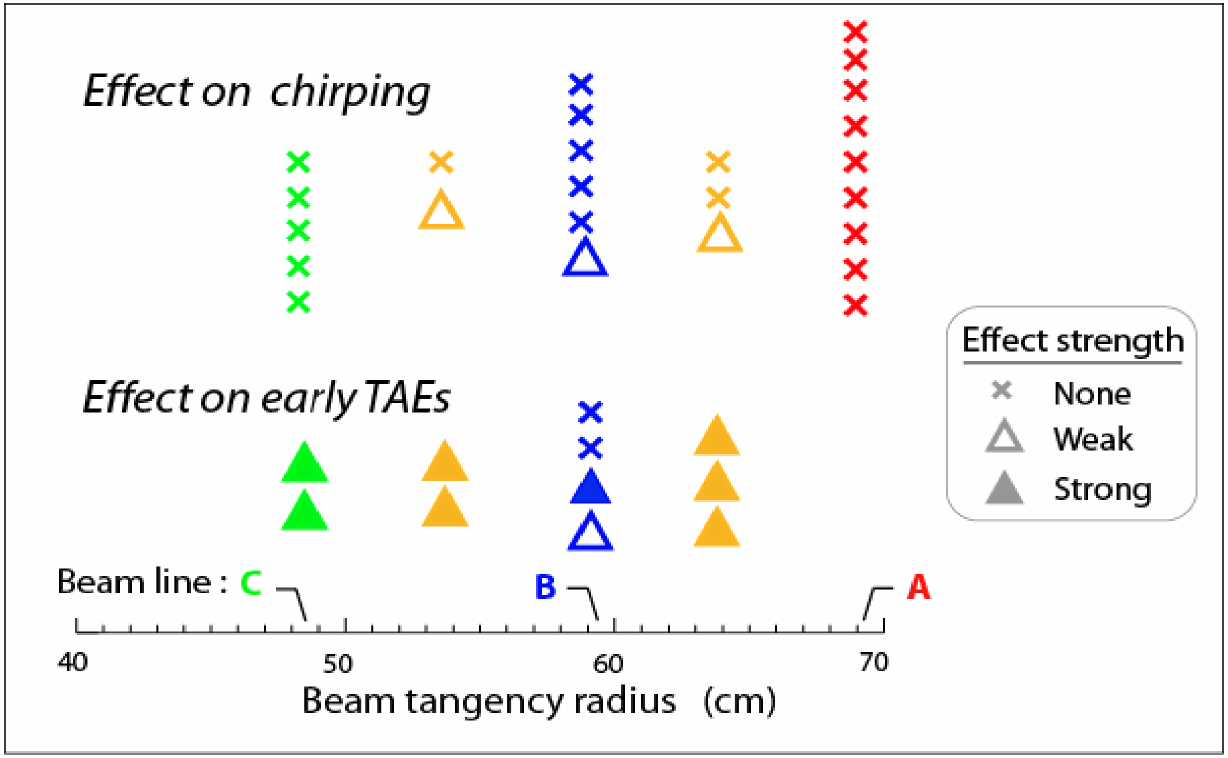
- An effect in this case but one large chirp near end of pulse
- Comparison shots are different

HHFW alters steady-frequency TAEs



- **Change occurs in ~ 5 ms**

Summary of Observations



- **Fishbones w/ all beam combinations**
  No effect of HHFW
- **TAE chirping strongest with 90 keV source A**
  No effect of HHFW
- **Steady frequency TAEs w/ source C and 65 keV**
  HHFW stabilizes in 1-10 ms
- **CAE/GAE w/ all beams**
  Ambiguous HHFW effect on chirping

Empirical Explanation in terms of Trapped/Passing Populations

- HHFW adds perpendicular energy → more trapped particles
- Strong chirping occurs when modes are more strongly driven
- TAEs are driven by passing particles
- HHFW suppresses steady TAEs on collisional timescale by reducing passing population
- Chirping TAEs are too strong to be altered
- More trapped particles just drives fishbones harder

- Fishbones w/ all beam combinations
  No effect of HHFW
- TAE chirping strongest with 90 keV source A
  No effect of HHFW
- Steady frequency TAEs w/ source C and 65 keV
  HHFW stabilizes in 1-10 ms
- CAE/GAE w/ all beams
  Ambiguous HHFW effect on chirping

Calculations indicate the HHFW was marginal

To alter the chirp, need

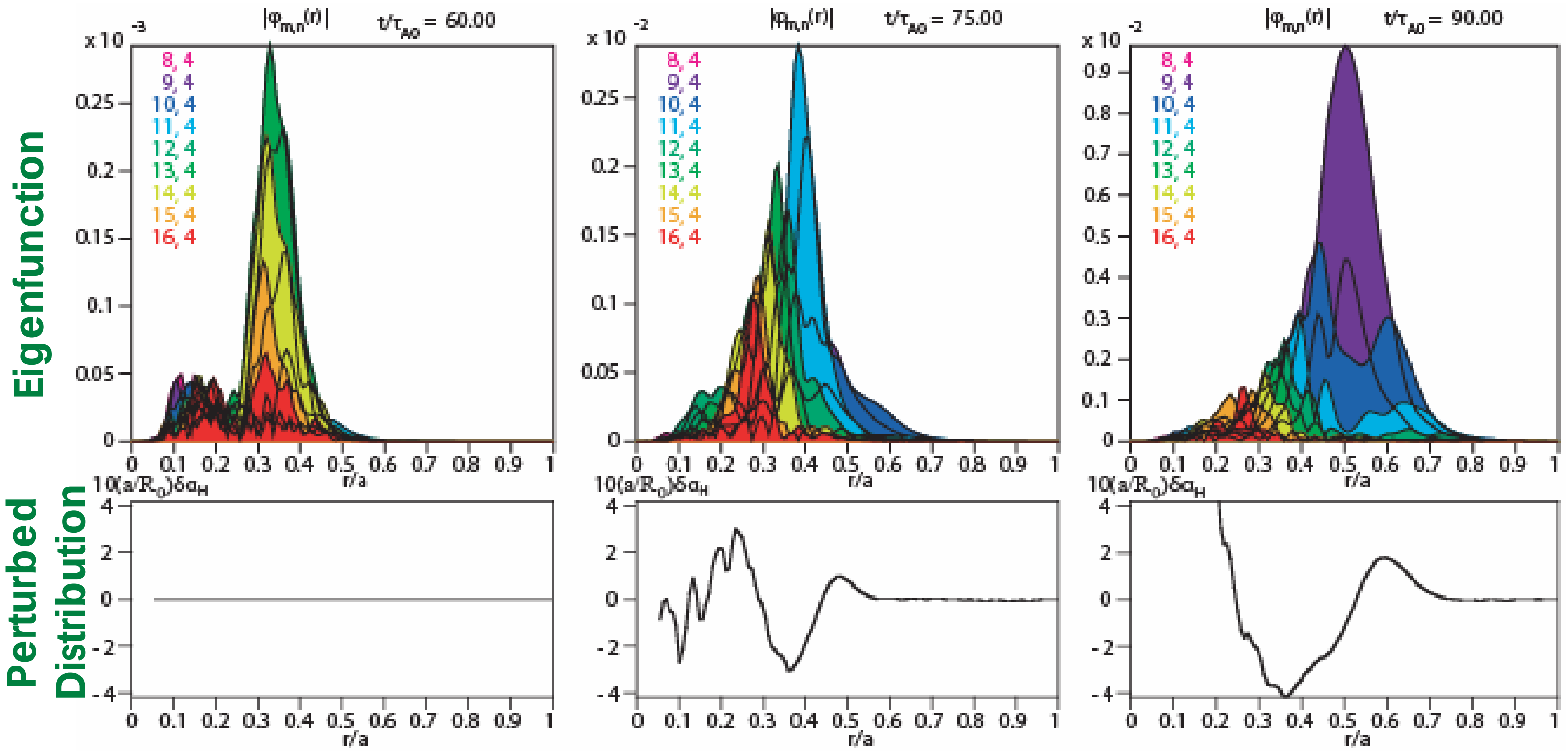
$$(\delta E/E_r)^2 \gtrsim (\omega_b/\omega)^2.$$

- δE stochastic diffusion during chirp [from $(\delta E)^2 \sim D_E t$ with D_E from NPA data and t from chirp duration]
- E_r energy of resonant fast ions ($\sim$ 50 keV)
- ω_b trapping frequency (from measured mode amplitude of $\delta n/n \sim 0.01$ and NOVA-K calculation)
- ω is the mode frequency (measured)

Find LHS and RHS are both $O(0.01)$.

Alternative chirping model: "Avalanche"

Simulation of JET reversed-shear case



Zonca, NF 45 (2005) 477

Conclusions

- HHFW did not suppress chirping of fishbones or TAEs
- Was not a definitive test of Berk-Breizman model. Used a blunderbuss instead of a scalpel
- Need better insight into a) part of phase space that drives instabilities & b) effect of HHFW in phase space → Better fast-ion diagnostics