Suppression of Frequency Chirping in NTSX by HHFW heating of Beam Ions

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Abstract

Injection of over 2 MW of deuterium neutral beams into a helium L-mode plasma produced instabilities with rapid frequency sweeps or ``chirping.'' Some instabilities with steady ~100 kHz frequencies were also produced. In the Berk-Breizman model of frequency chirping, resonant fast ions form holes and clumps in phase space [1]. Increased collisionality of the fast ions can scatter resonant ions from the potential well, suppressing the chirping.

To test this idea, 2-3 MW of high-harmonic fast wave radio-frequency (HHFW) heating was applied in 30ms pulses during strong chirping. Although neutral-particle measurements indicate effective perpendicular heating of the fast ions, the chirping behavior was hardly affected. In contrast, RF heating altered the frequency and amplitude of the constant-frequency modes in ~10 ms, which is the timescale for modification of the entire fast-ion distribution function by the RF. The effect on the constant-frequency modes was most pronounced for more perpendicular angles of beam injection.

[1] H.L. Berk et al., Phys. Plasmas 6 (1999) 3102.

Motivation

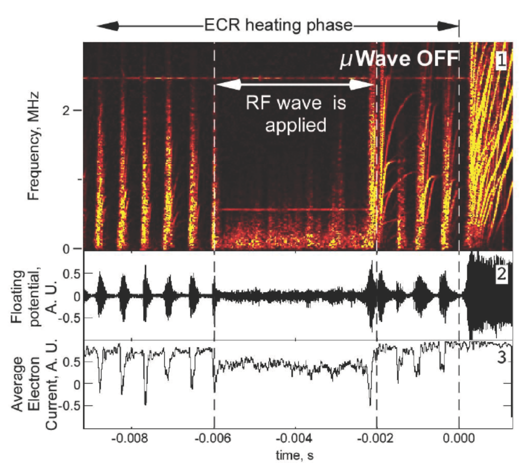
1. **The nonlinear saturation of fast-ion instabilities:**
   - **determines their ultimate impact on fast-ion transport**
   - **must be understood in order to predict the effect of alpha driven instabilities in ITER and other burning plasmas**

2. **Despite many similarities between existing devices, frequency chirping in the sub TAE frequency range is not universal** *(common in NSTX,MAST and START, but rare in DIII-D)*.

3. **The Berk-Breizman theory successfully explained the suppression of fast electron chirping modes with RF power in the Collisionless Terrella Experiment (CTX).**

   Does it apply to beam-ions in NSTX?

Increased Collisions Suppress Chirping in a Dipole Experiment



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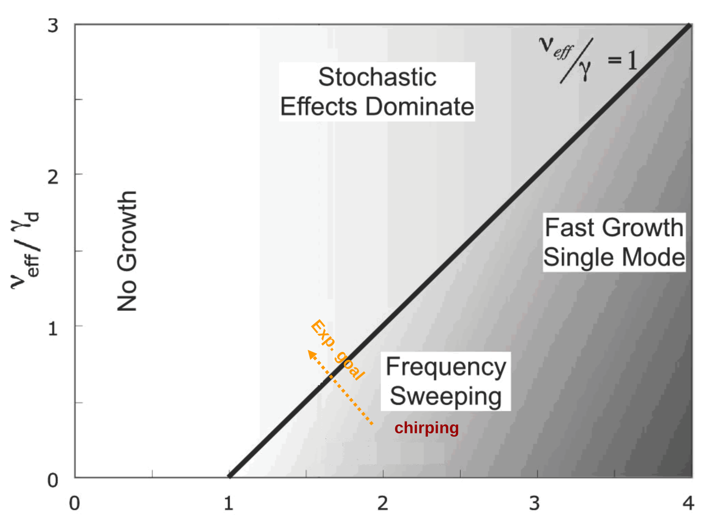
- **Interchange instabilities driven by *energetic electrons* trapped by a magnetic dipole produced frequency sweeping modes.**
- **This chirping was suppressed with low-power RF fields.**
- **A self-consistent nonlinear simulation reproduced the chirping and identified phase-space holes as predicted by the Berk-Breizman theory.**

Pictorial view of the Berk-Breizman theory



γ_L = linear growth rate
γ_d = nonresonant dissipation
ν_{eff} = collisionality parameter
$\gamma = \gamma_L - \gamma_d$

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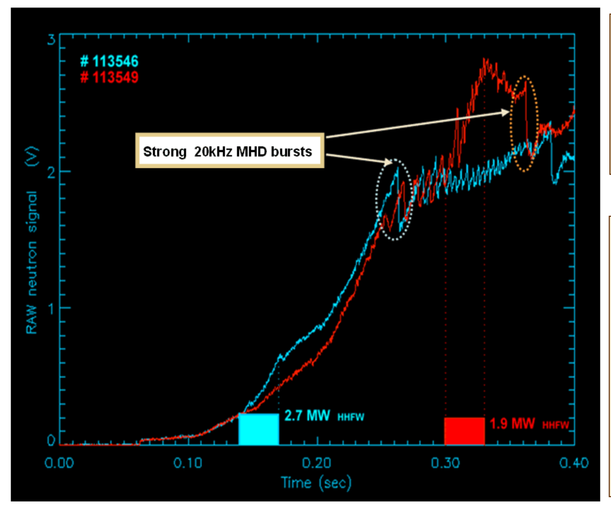
In NSTX HHFW increases the neutron rate
Chirping causes 10-20kHz MHD bursts cause rapid, sawteeth-like drops



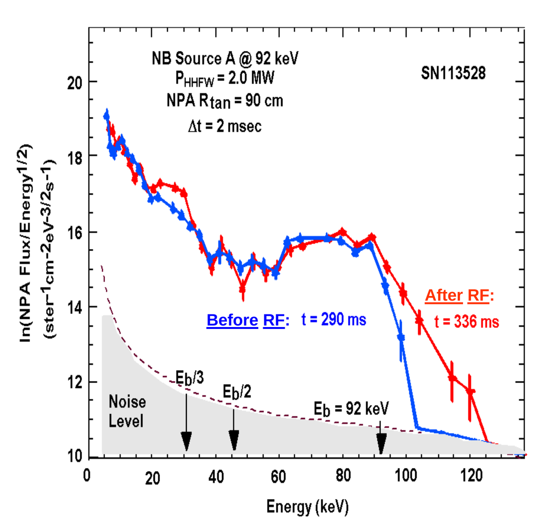
Q: How do we get the HHFW to detrap the resonant ions?

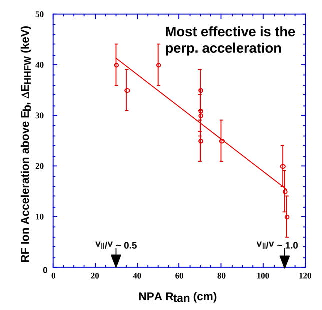
A: Select an operating regime where:

Chirping causes drops, and HHFW causes increases in the neutron rate

- **We used HHFW in helium L-mode plasma to accelerate beam ions and produced a rich set of fast-ion driven instabilities.**
- **Early chirping** *(during current ramp-up)* **seen only for the most tangential full energy beam injection (source A, 2MW / 90 keV).**
- **Late chirping seen in all shots.**

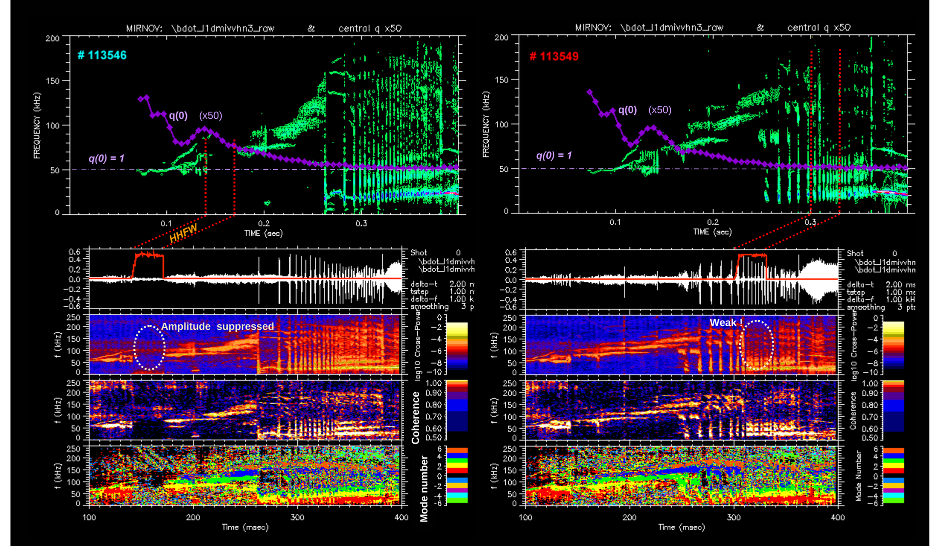
NPA data proves that HHFW accelerates beam ions





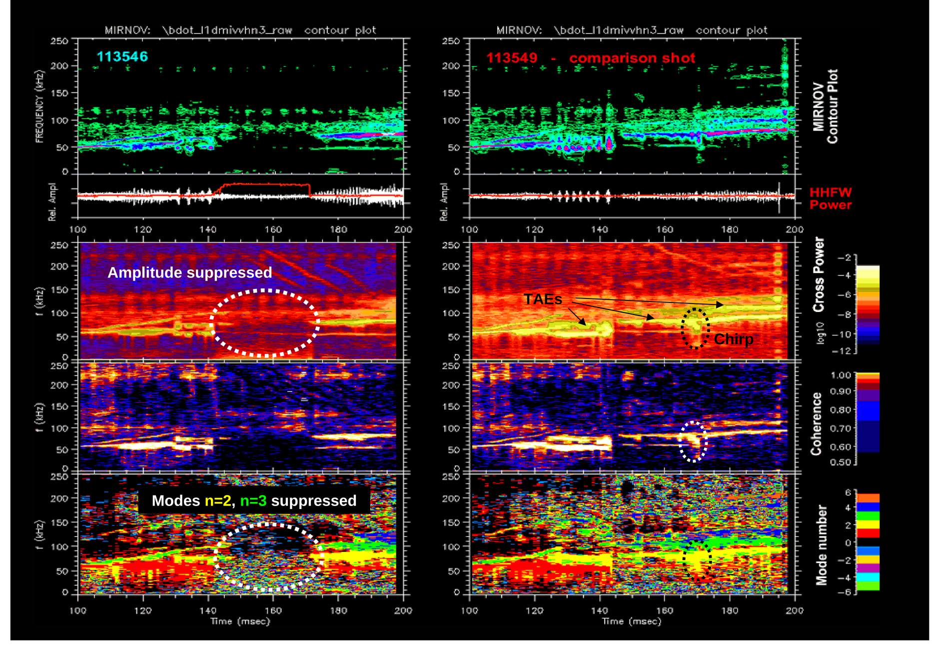
- **Comparable RF acceleration of neutral beam ions observed at E_b ~ 65 keV and E_b ~ 90 keV for all NB sources.**
- **The energetic ion tails form in less than 15 ms for P_{HHFW} ~ 2 MW.**
- **Tail decay time ~ 12 ms**

HHFW suppresses MHD modes: early TAEs and … … chirping, but weakly, most often barely

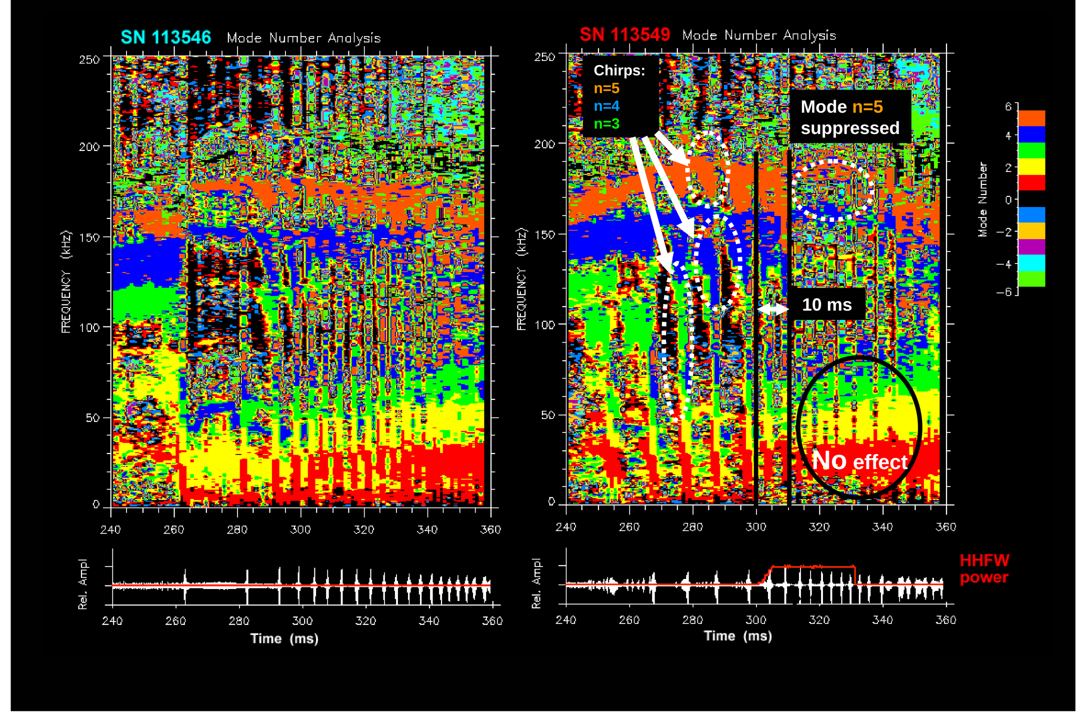


Note: These two shots use beams B and C with 2MW / 60keV and have nearly identical plasma parameters.

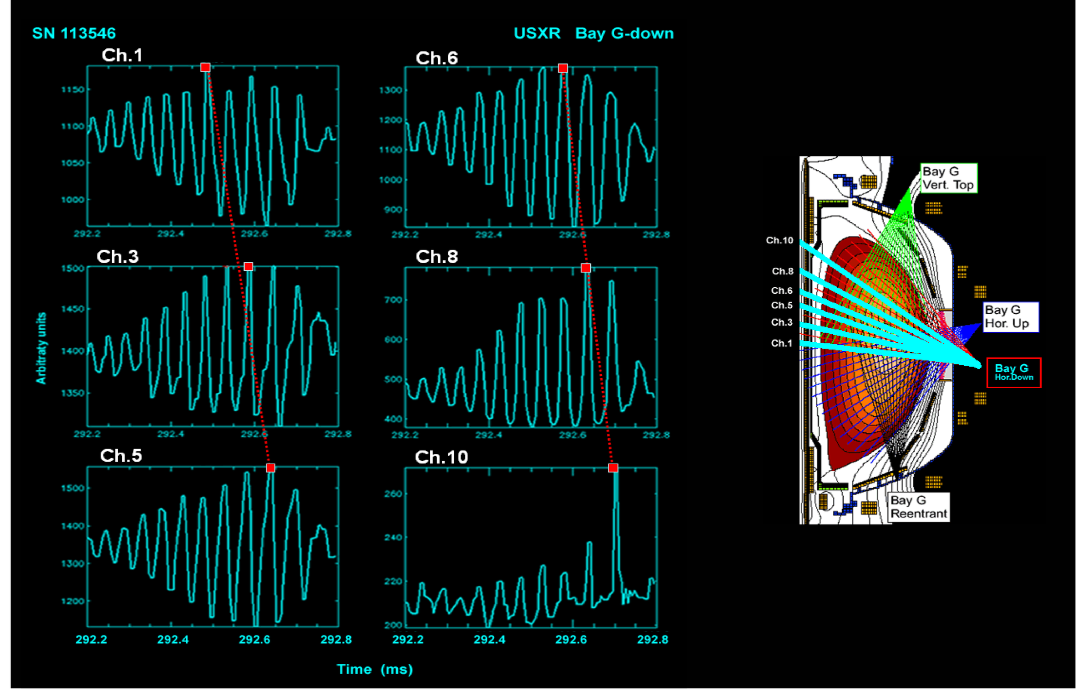
HHFW suppresses early TAE modes and chirps: close-up



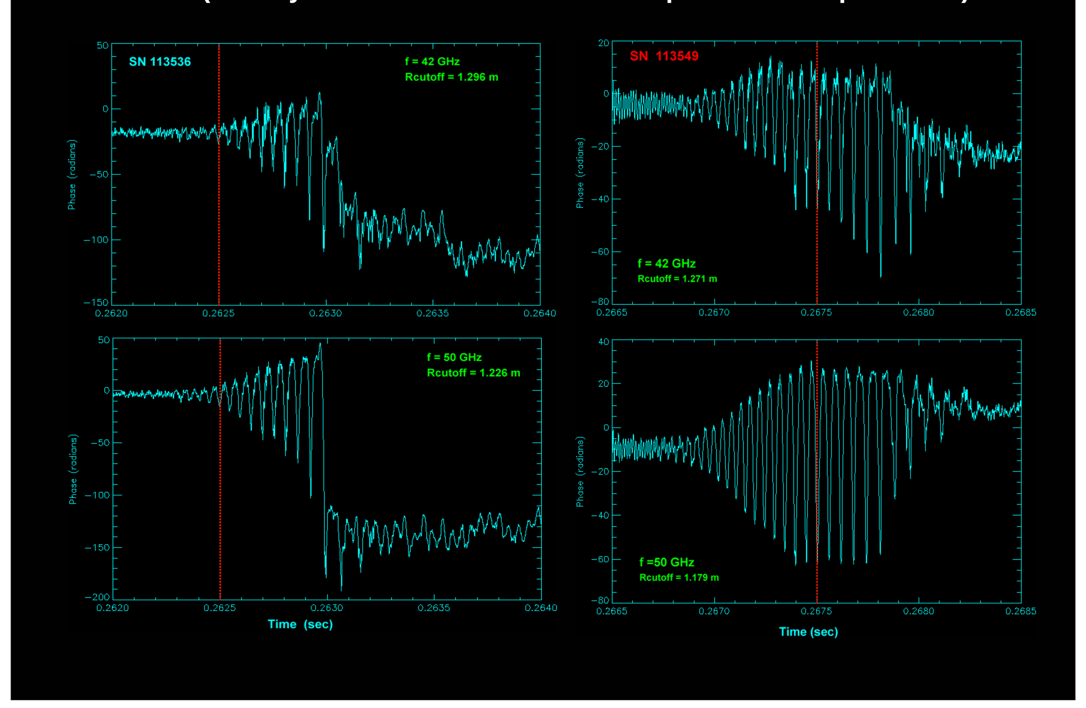
HHFW weakly suppresses late high-n TAE modes and chirps: close-up



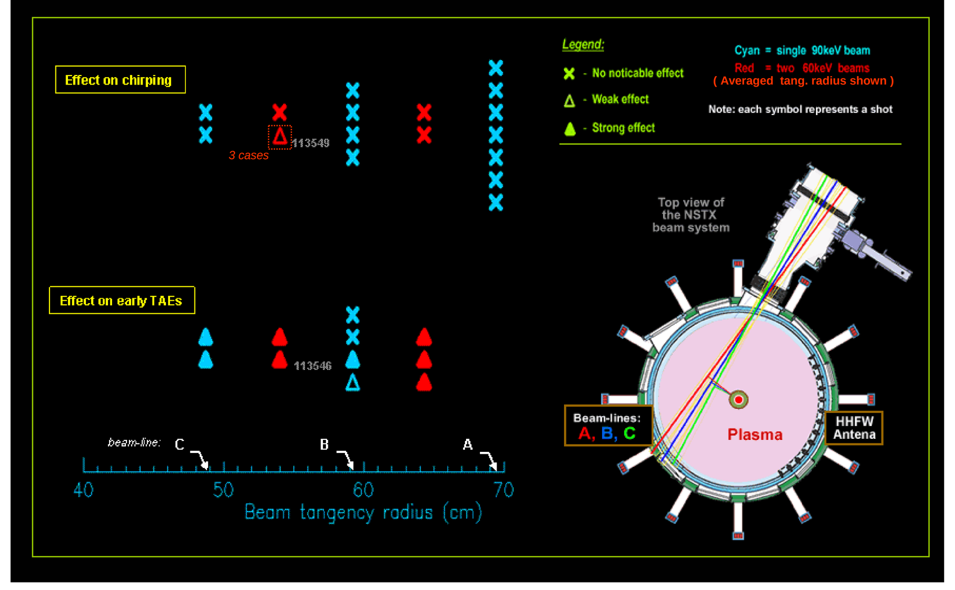
Soft X-ray data exists
(core localized 20kHz MHD bursts propagating outwards shown)



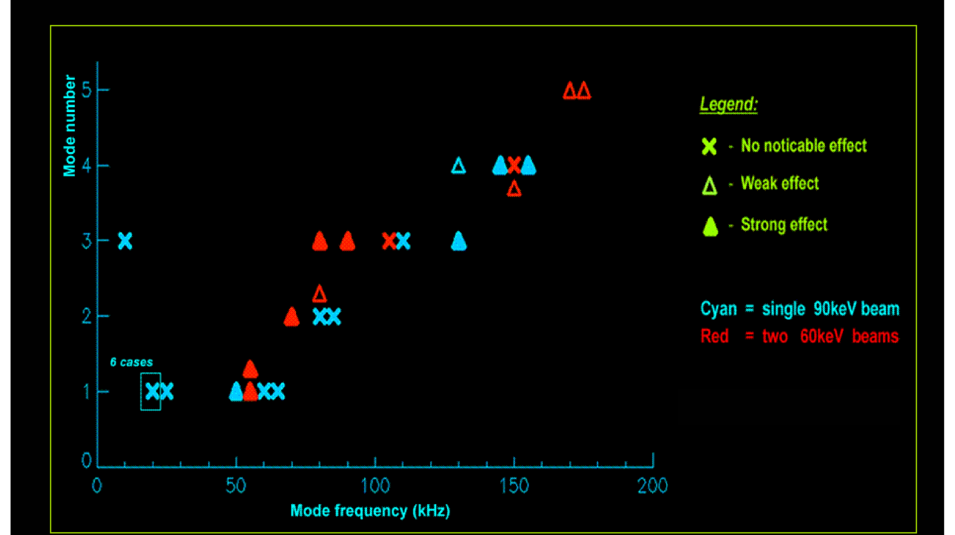
Reflectometry data exists
(density fluctuations at times of sharp neutron drops shown)



Experimental summary of suppression of beam-ion driven instabilities by HHFW heating: beam sources view



Experimental summary of suppression of beam-ion driven instabilities by HHFW heating: mode-frequency view



Conclusions

- **We successfully achieved regimes with strong instabilities and effective HHFW acceleration of beam ions.**
- **Early, "steady" TAE-like modes are most strongly suppressed in L-mode plasmas heated with low energy (60keV) beams with large perpendicular component.**
- **The suppression of chirping instabilities with applied HHFW heating *is weak* and is seen for higher-n mode numbers (n>=3) in plasmas heated with 60keV beams with large perpendicular component.**
- **The strong 10-20 kHz n=1 MHD bursts are not affected at all.**

Preliminary hypothesis:

The early instabilities (during current ramp-up) are not that strong, thus modest changes in the beam distribution function by HHFW alter their nonlinear saturation. This is not the case with the later, stronger chirping instabilities which are harder to suppress.

- **TAEs are driven by passing particles: by moving some of the passing particle into trapped orbits, the perpendicular heating reduces the fast ion drive.**
- **Chirping modes are driven by trapped beam ions, so perpendicular heating enhances the drive instead of suppressing it.**

Outstanding question:

Does the beam distribution function affect the mode structure?

- **Does the mode structure move outwards during the chirping event?**
- **Does the mode structure change with changing beam sources?**

To do list

- As CHERS data becomes available, prepare TRANSP runs for all shots of interest and get the beam-distribution (without HHFW) from TRANSP.
- Analyze NPA data and model the distribution function with applied HHFW heating.
- Continue the analysis of soft X-ray and reflectometer data to identify the modes.
- Calculate the linear TAE growth rate for the beam-distribution function with and without HHFW and check whether their difference can explain the early suppression of TAE-like modes.
- Develop quantitative estimate of the instability growth rates, and the collisionality, and relate them to the Berk-Breizman theoretical model.