Evidence of Parametric Decay during HHFW Heating on NSTX

S. Diem, T. Biewer, B. LeBlanc, J. Hosea, M. Ono, C. Phillips, J. Wilson
(PPPL)

Abstract

In High Harmonic Fast Wave (HHFW) heating experiments on NSTX localized ion heating near the plasma edge has been observed. Excitation of parametric decay instabilities [M. Porkolab FE\&D 12 (1990) 93] during HHFW heating may cause this ion heating. A Langmuir probe whose output is coupled to a spectrum analyzer has been installed on NSTX to look for evidence of parametric decay in helium and deuterium target plasmas. Peaks in the spectrum are observed to be displaced from the 30 MHz HHFW frequency by $-n\Omega_i$, where $-1<n<3$ and Ω_i is the local ion cyclotron frequency. Upper sidebands with $+ \Omega_i$ have also been observed. In deuterium plasmas, the $+\Omega_\iota$ frequency has been observed for HHFW power >1 MW. The decay wave spectra for helium plasmas have the following characteristics: the $-\Omega_\iota$ peak rises from the 30 MHz HHFW peak at power levels > 0.9 MW, the $-2\ \Omega_\iota$ is visible for power levels > 0.65 MW, and the $-3\ \Omega_\iota$ for power >1.3 MW. The threshold HHFW power for parametric decay has been observed to decrease with edge density and increase with edge temperature in agreement with theory.

*This work supported by DOE Contract No. DE-AC02-76CH03073

Outline

- Motivation
- Parametric decay theory
- Evidence of parametric decay on NSTX
- Estimates of power lost to edge ions
- Conclusions
- Future work

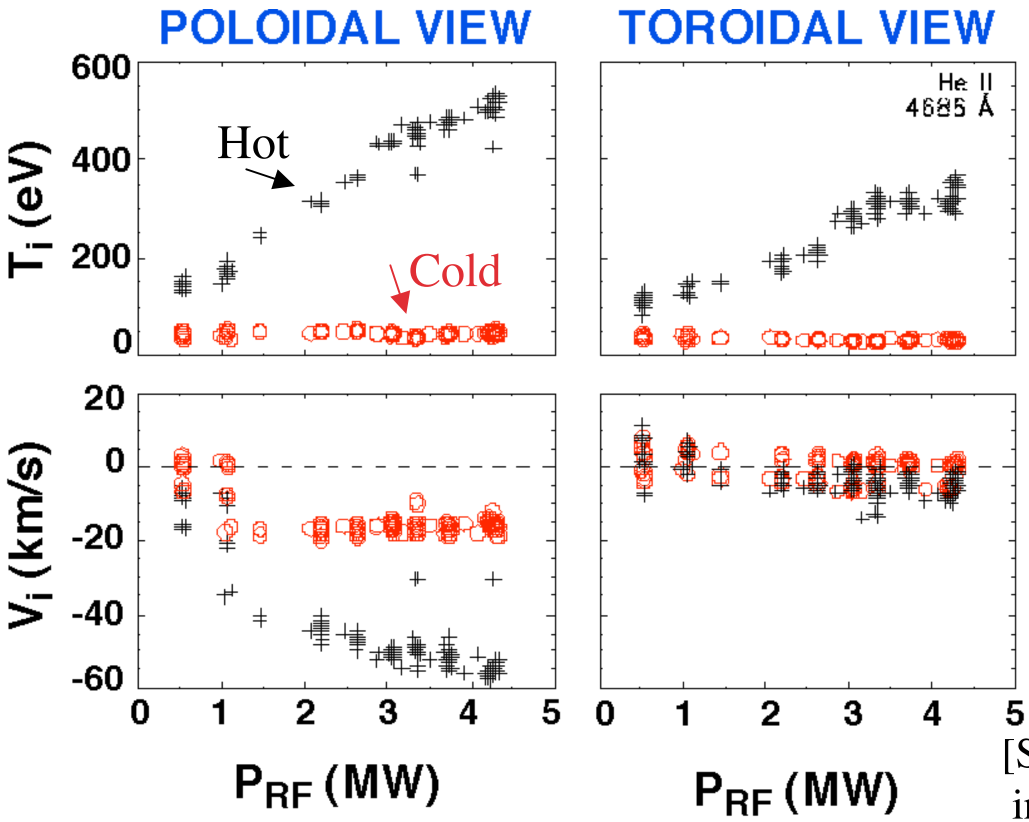
High Harmonic Fast Wave Heating has been successful on NSTX

- Efficient heating of electrons
  - Electron temperatures of 2-4 keV obtained
- Unidirectional currents have been driven
  - Up to 120 kA of Co current
  - Efficiencies comparable to those obtained on D-IIID seen

Unexpected behavior has been observed

- Edge rotation and impurity heating has been observed [Biewer RI1.001]
- Current drive efficiencies have sometimes been low [Ryan C03.013]
- Attempts to measure power deposition profile by power modulation have proven unsuccessful [Wilson CO3.012, Hosea JP1.012, LeBlanc JP1.009, Bernabei JP1.011]

More Power leads to more Edge Ion Heating



Negative poloidal velocity is upwards on the outboard midplane.

Negative toroidal velocity is opposite to the direction of I_p

[See Biewer RI1.001 for more information]

From NSTX Shot 110133 to 110145, the applied RF power was Increased. Empirically, T_i increases as $P_{RF}^{0.47}$.

→One possible explanation is Parametric Decay

A Possible Specific RF Effect is Parametric Decay

- Parametric decay has been observed in many rf heating experiments (CMOD, ASDEX, DIIID, JET)
- Not usually sufficiently strong to play a major role in energy balance:

Exception: Lower Hybrid current drive where it is responsible for density limit

Characteristics of Parametric Decay

- Review of Parametric Decay for the edge plasma in the ICRF Regime has been given by Porkolab *Eng. Fusion and Design* **12** (1990) pg. 93
- Nonlinear three wave coupling process with selection rules:
    - Conservation of Energy

HHFW ~ 30 MHz

$$\omega_0 = \omega_1 + \omega_2$$

ICQM ~ 2 MHz

IBW ~ 28 MHz

    - Conservation of Momentum

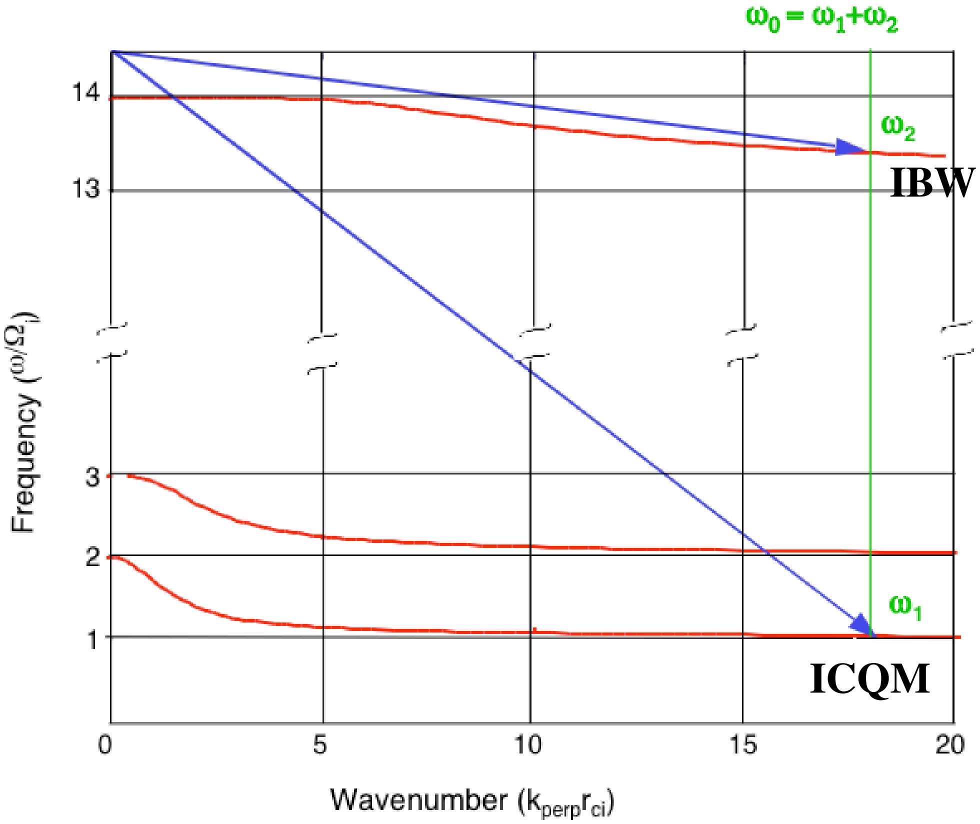
$$\mathbf{k}_o = \mathbf{k}_1 + \mathbf{k}_2$$

- Since the “pump” fast wave has a long perpendicular wavelength and the “daughter” waves are expected to have short wavelengths, the latter condition can be taken as:

$$\mathbf{k}_1 = - \mathbf{k}_2$$

Characteristics of Parametric Decay (continued)

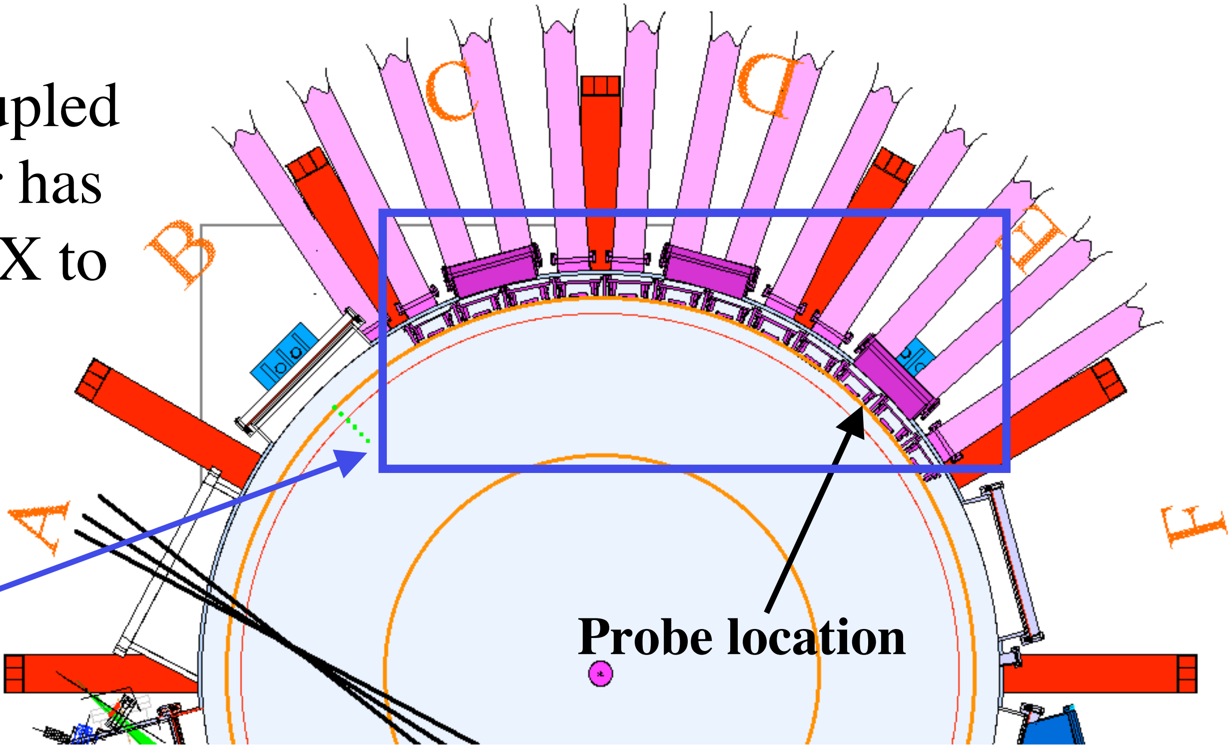
- Pump wave will decay into an ion Bernstein wave and either another ion Bernstein wave (IBW), an ion quasi-mode (ICQM non-propagating) or an electron quasi-mode



- Require both frequency and wave-number matching simultaneously for two resonant waves
  - The quasi-mode (ICQM - non propagating) has no k_{perp} dependence so simultaneous matching of frequency and wave number is easily achieved

Looking for Evidence of Parametric Decay on NSTX

A Langmuir probe coupled to a spectrum analyzer has been installed on NSTX to look for evidence of Parametric Decay



HHFW RF antenna

- ICQM cannot be detected because of equipment limitations - frequency is too low to be detected
- Look for characteristic IBW peaks:

$$f = f_0 - n\Omega_i$$

IBW

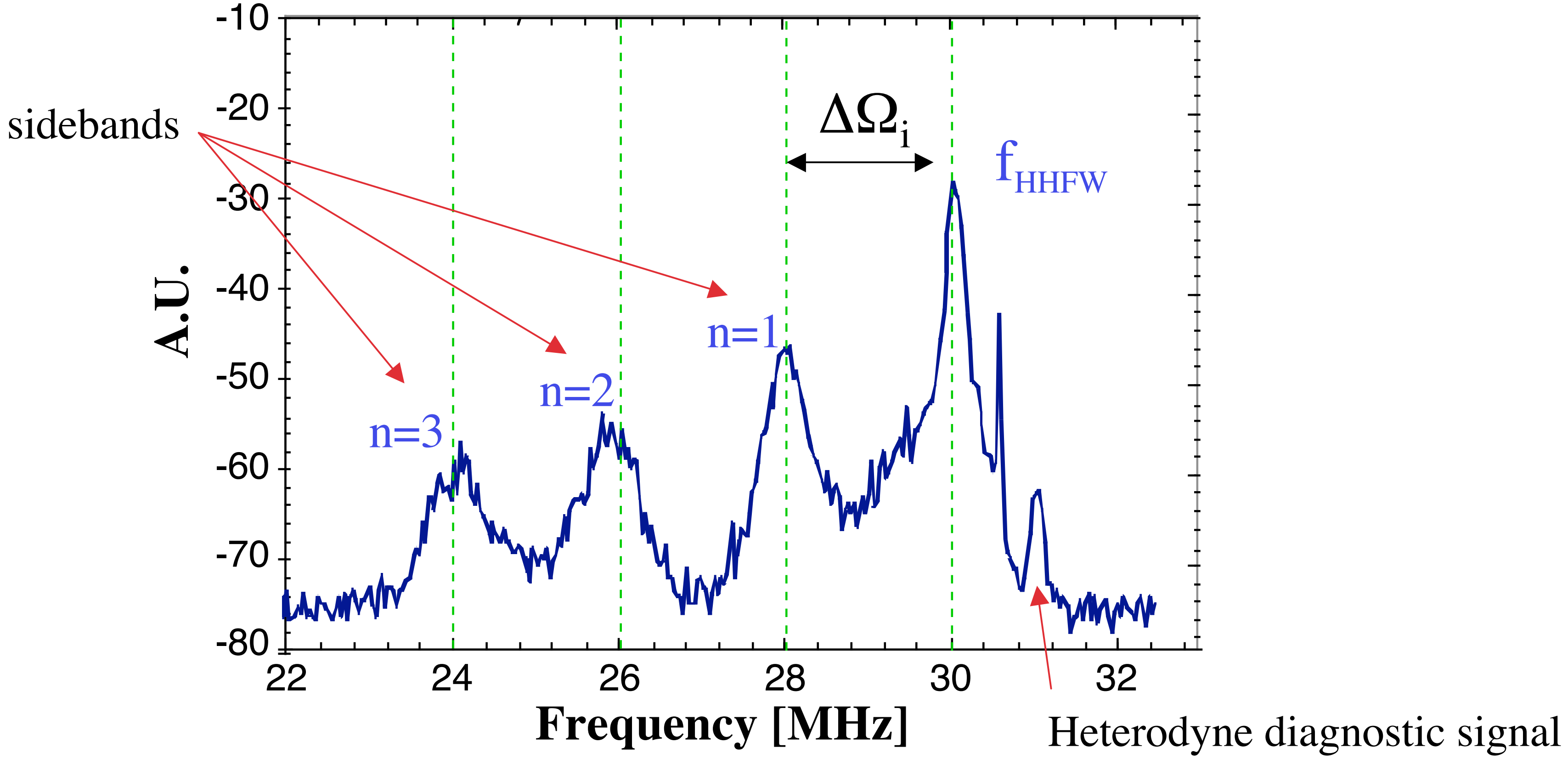
HHFW

Harmonics of Ω_ι

Characteristic Peaks Observed

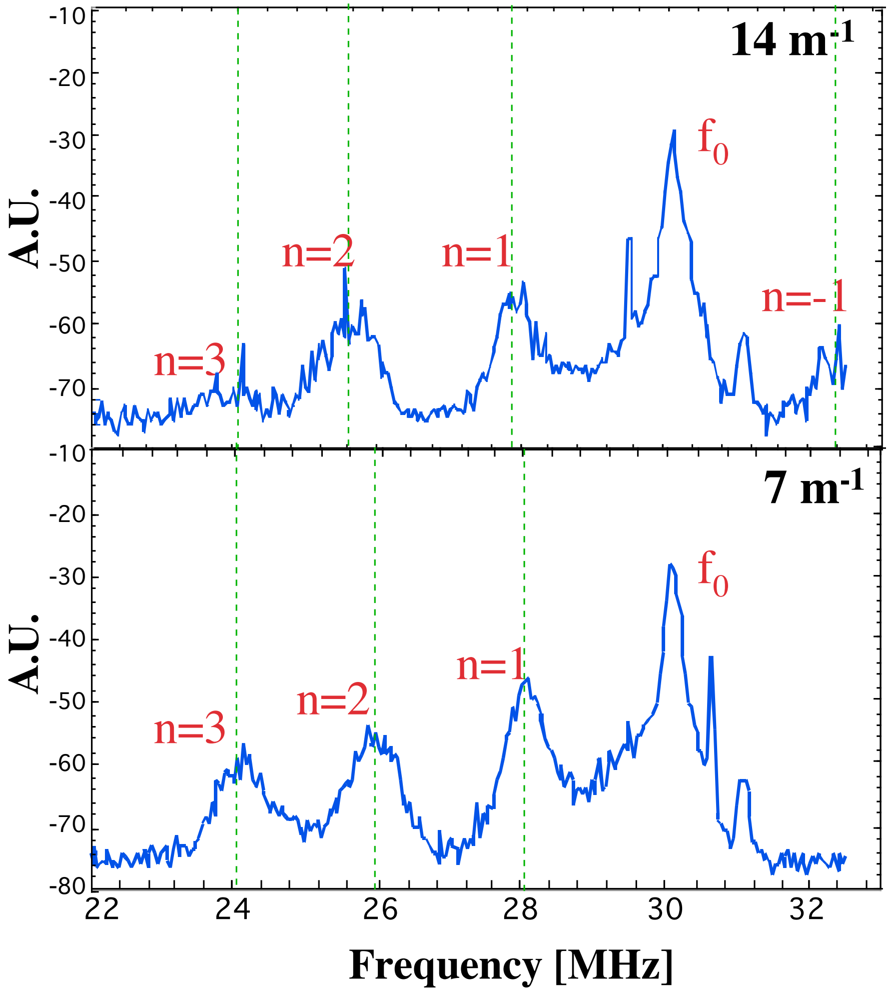
- Both upper and lower sidebands were observed

D_2 Frequency spectrum from Langmuir probe



Deuterium Plasma Characteristics

- Probe data for 14 m^{-1} for power levels $P_{HHFW} = 0.6 - 2$ MW was obtained
- Only one plasma for 7 m^{-1}



14 m^{-1}

- Upper sideband, $+\Omega_i$ visible for $P_{HHFW} > 1$ MW

7 m^{-1}

- Only have data for $P_{HHFW} = 1$ MW
- Peaks have greater amplitude than those for 14 m^{-1} at same power level

Spectra Differed Between He and D_2 Plasmas

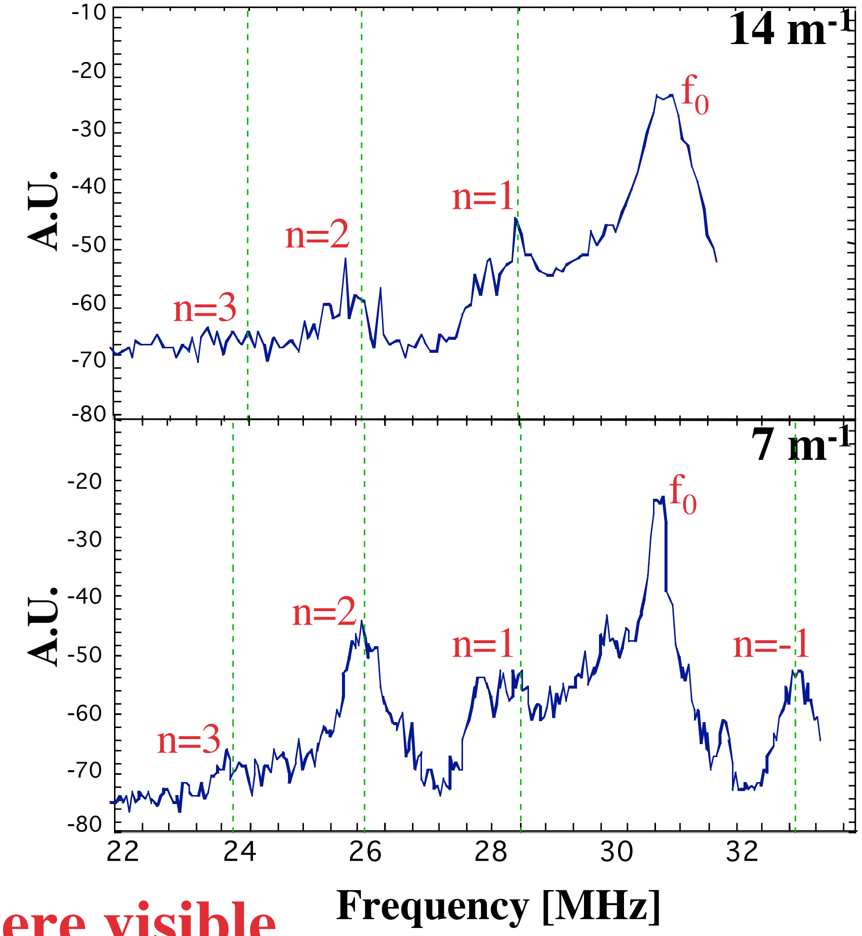
- Probe data from both 14 m^{-1} and 7 m^{-1} was obtained for $P_{HHFW} = 0.4 - 2$ MW and the following trends were observed:

14 m^{-1}

- $-2\Omega_i$ visible for $P_{HHFW} > 0.65$MW
- $-3\Omega_i$ visible for $P_{HHFW} >1.3$MW

7 m^{-1}

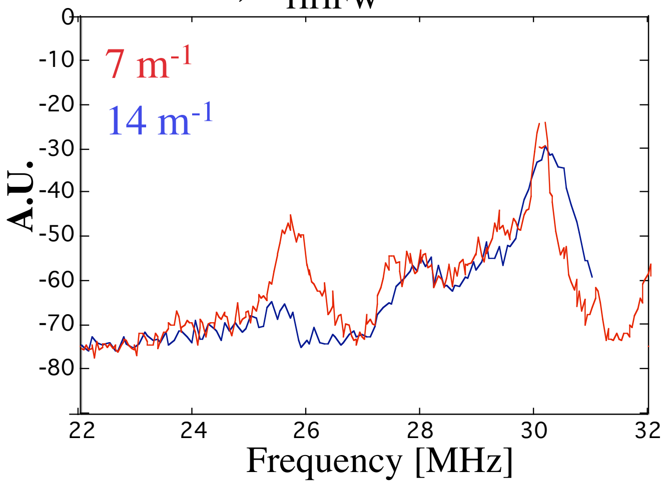
- n= -1, 1, and 2 peaks were visible
- Very small $-3\Omega_\iota$ observed for $P_{HHFW}>1.6$ MW

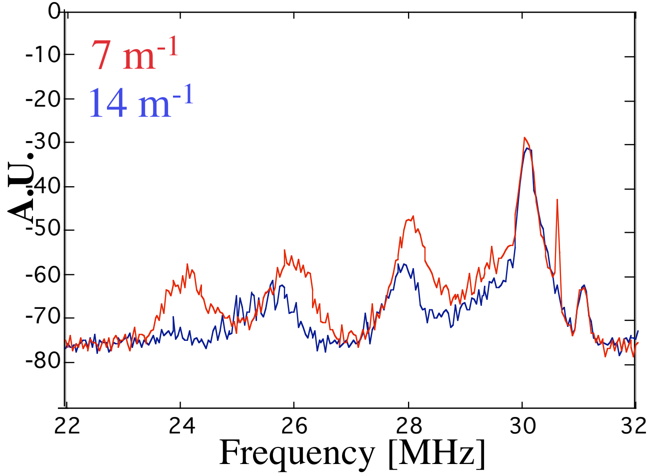


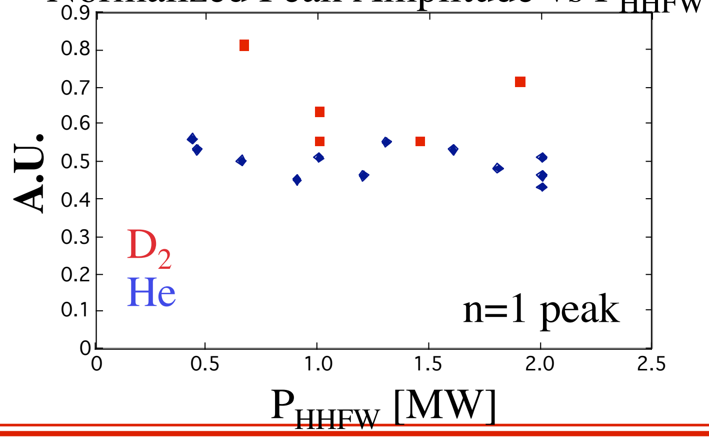
At higher P_{HHFW} more sidebands were visible

At Same Power Level, 7 m^{-1} Peaks Larger than 14 m^{-1} Peaks

- At same power level, 7 m^{-1} peaks bigger than 14 m^{-1} peaks


He, P_{HHFW} ~1MW

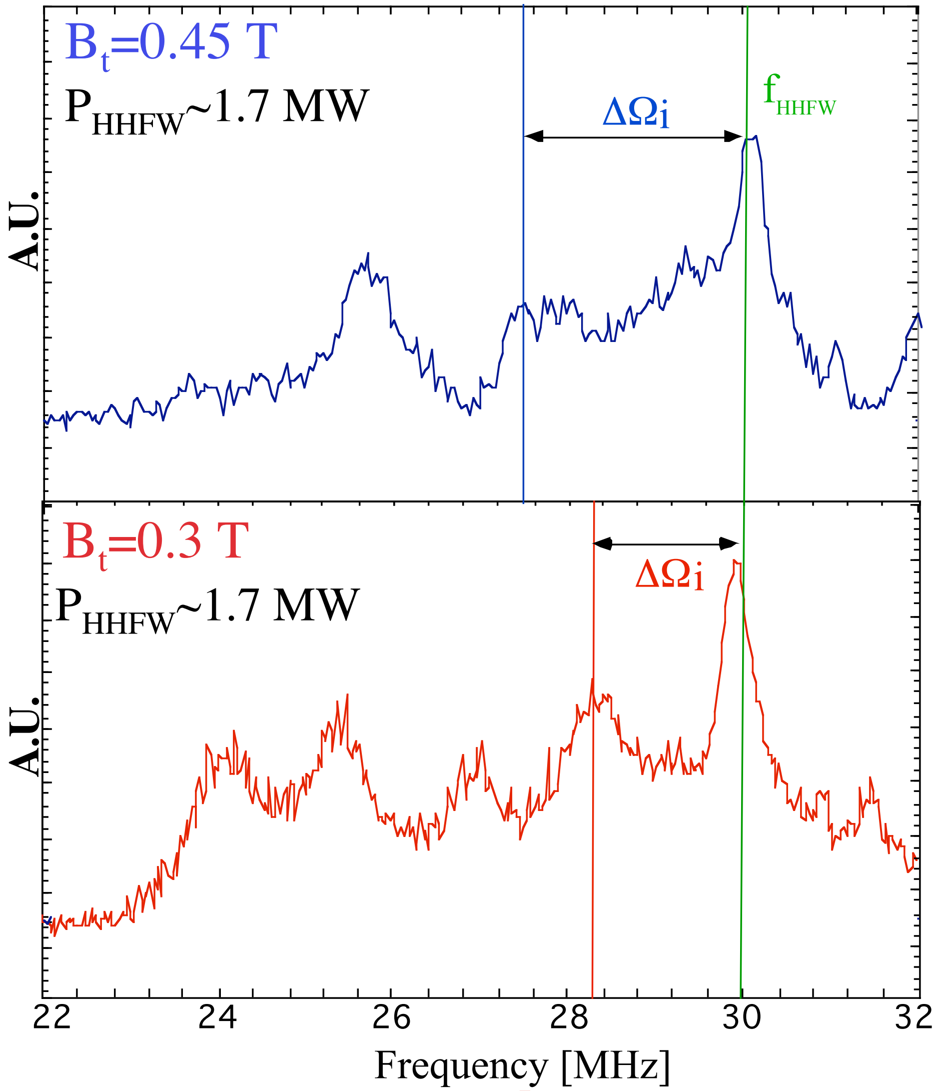

D_2, P_{HHFW}~2MW


Normalized Peak Amplitude vs P_{HHFW}

- D_2 peaks were also greater than He peaks

TF Lowered to B_T=0.3 T; Sidebands Moved Closer Together

- Data from previous shots had B_T= 0.45 T
  - For B_T = 0.45 T, sidebands were spaced 2.5 MHz apart
  - For B_T = 0.3 T, sidebands were spaced 1.5 MHz apart



Estimate of Parasitic Power Going into Edge Ions

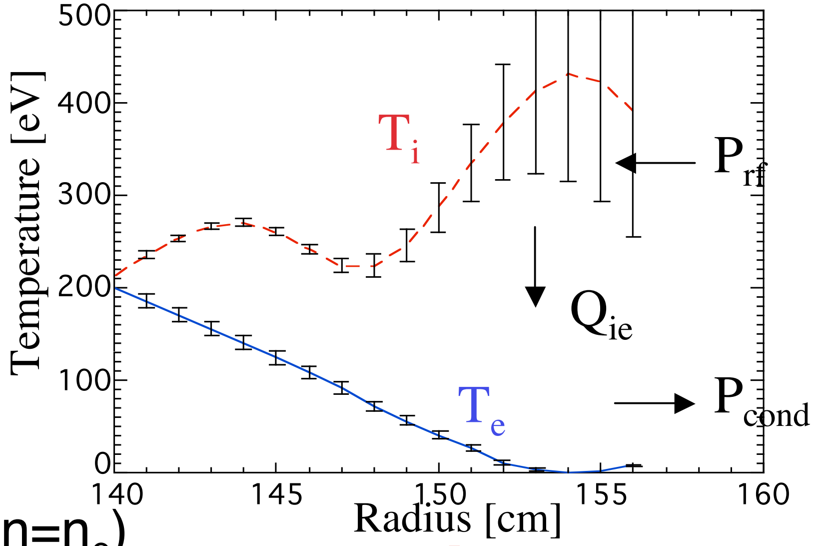
- Cannot measure power from Langmuir probe
- Estimate amount of power needed if collisional heating was the process
  - This gives a lower bound

$$Q_i = \frac{3m_e}{m_i}\frac{nk}{\tau_e}\left(T_e - T_i\right)$$

Where:

$$\tau_e = \frac{3\sqrt{m_e}\left(kT_e\right)^{3/2}}{4\sqrt{2\pi}\,n\lambda e^4}$$

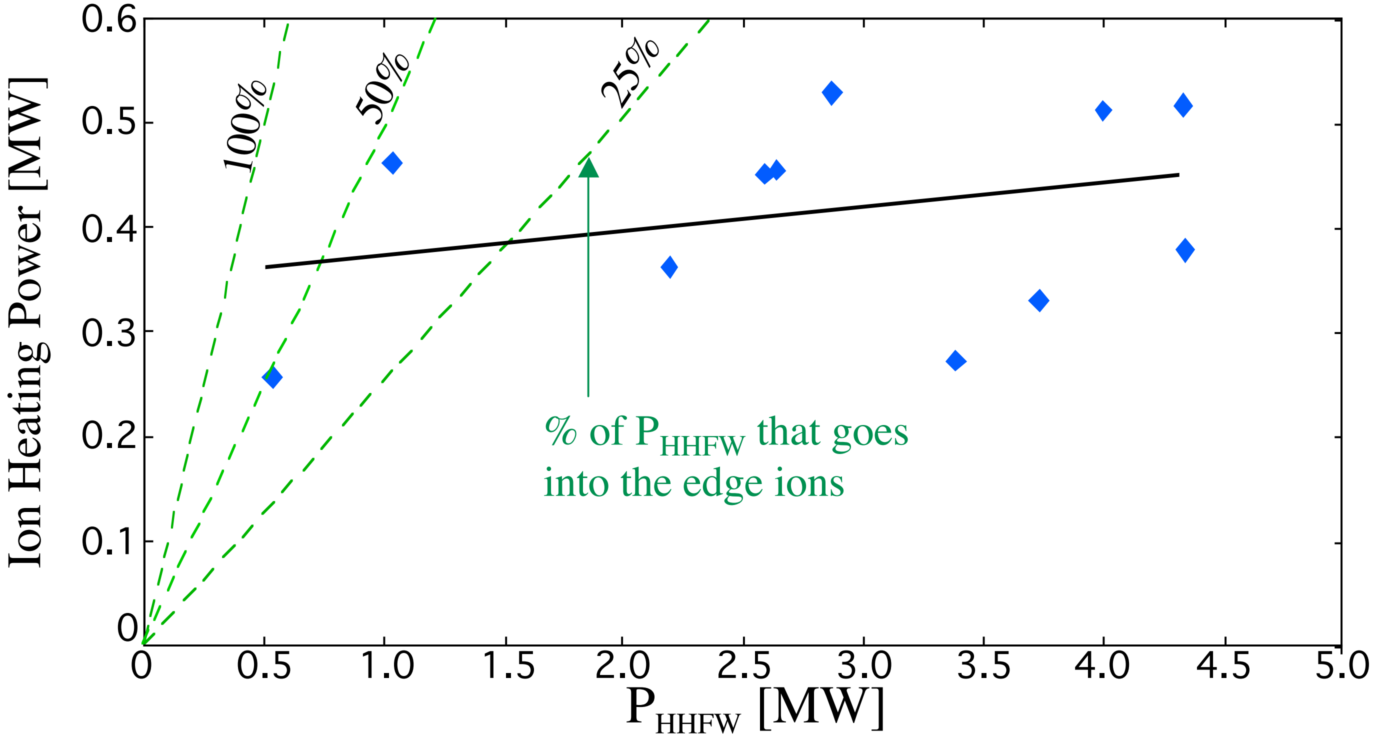
- Basic assumptions used
  - Poloidal symmetry
  - Cylindrical geometry
  - Edge Ion heating occurs only in region from R=140-156 cm
  - Assume all ions participate ($n=n_e$)



At Lower P_{HHFW} Levels - More Energy Goes To Edge Ions for 7 m^{-1}

- RF power scanned with other conditions held constant
- Around 0.5-1.0 MW of HHFW, about 50% of the power goes into the edge ions

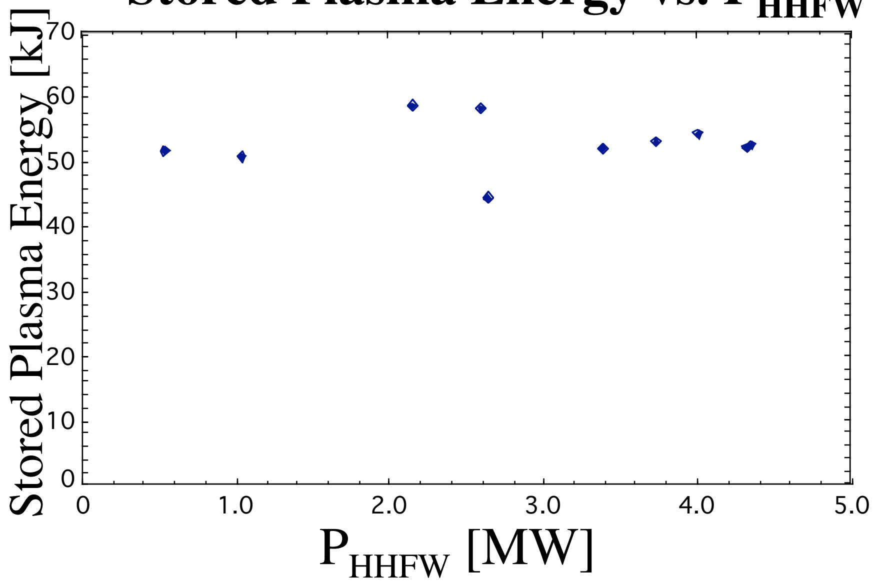
Time-averaged Ion Heating Power vs. P_{HHFW}



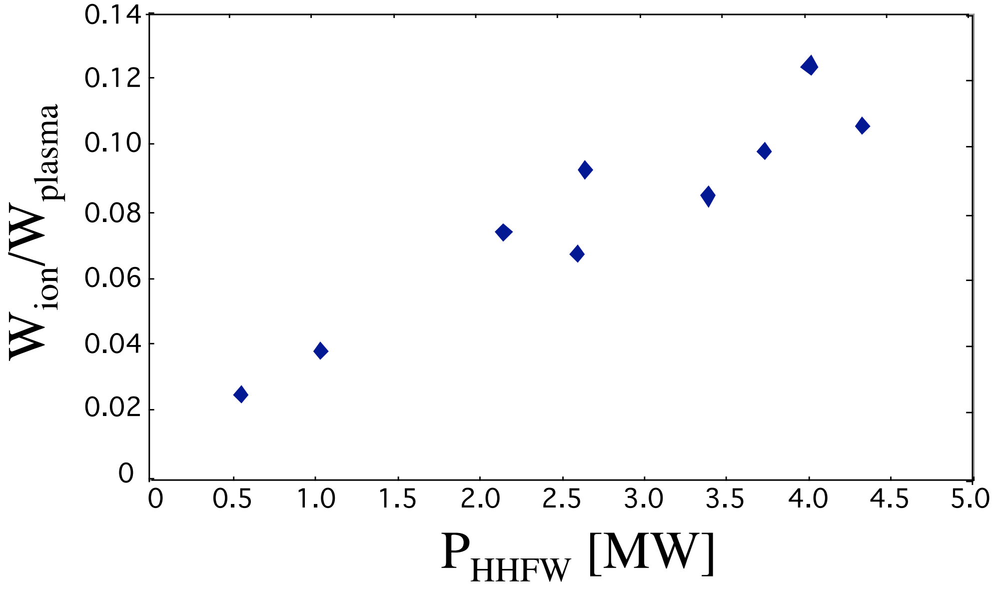
Edge Stored Ion Energy Increases with HHFW for 7 m^{-1} Phasing

- While stored plasma energy remained constant, the stored ion energy increased with P_{HHFW}

Stored Plasma Energy vs. P_{HHFW}



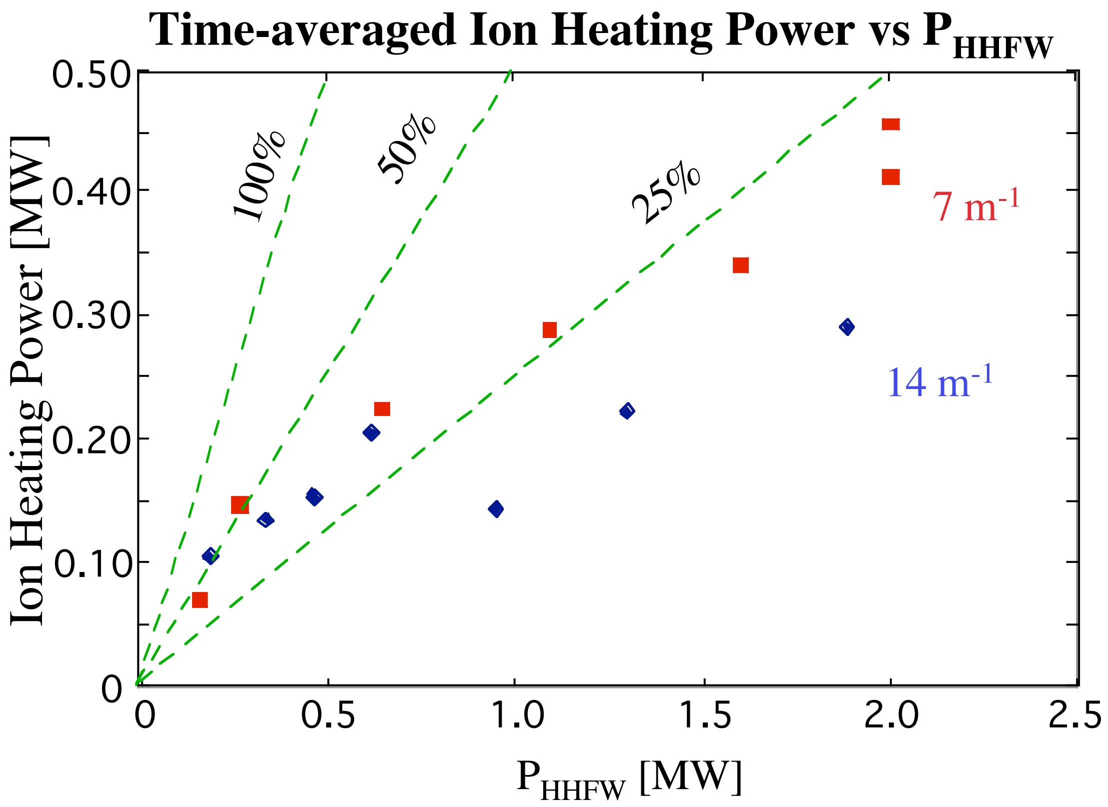
$\frac{\text{Stored Ion Energy}}{\text{Stored Plasma Energy}}$ vs. P_{HHFW}

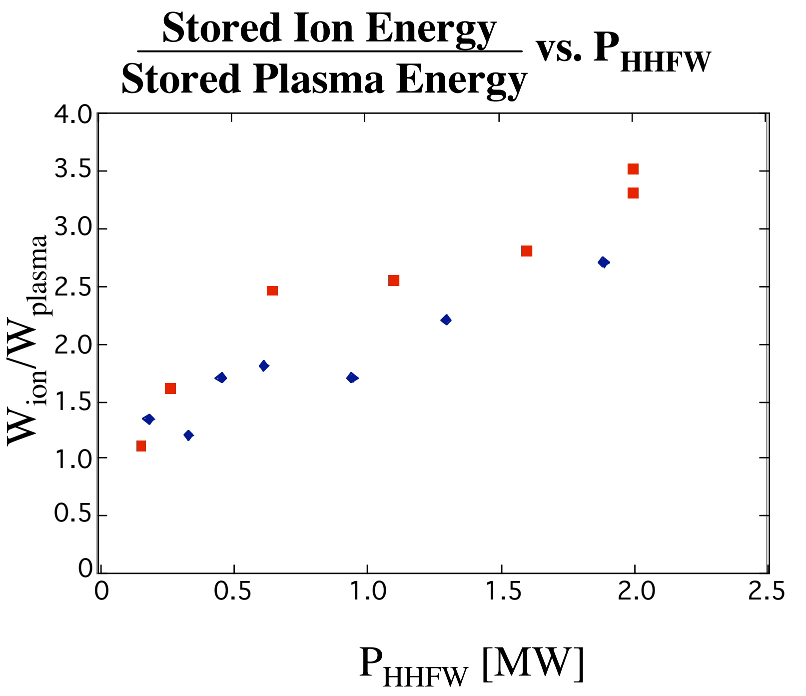


[See Hosea JP1.012]

Lower $k_{||}$ Leads to ~ 20% Parasitic Power Loss

- Ion heating power and stored ion energy is higher for 7 m^{-1} than for 14 m^{-1}
- 14 m^{-1} phasing, ~18% of the RF power is absorbed by the edge ions
- 7 m^{-1} phasing, ~ 23% of the RF power is absorbed by the edge ions

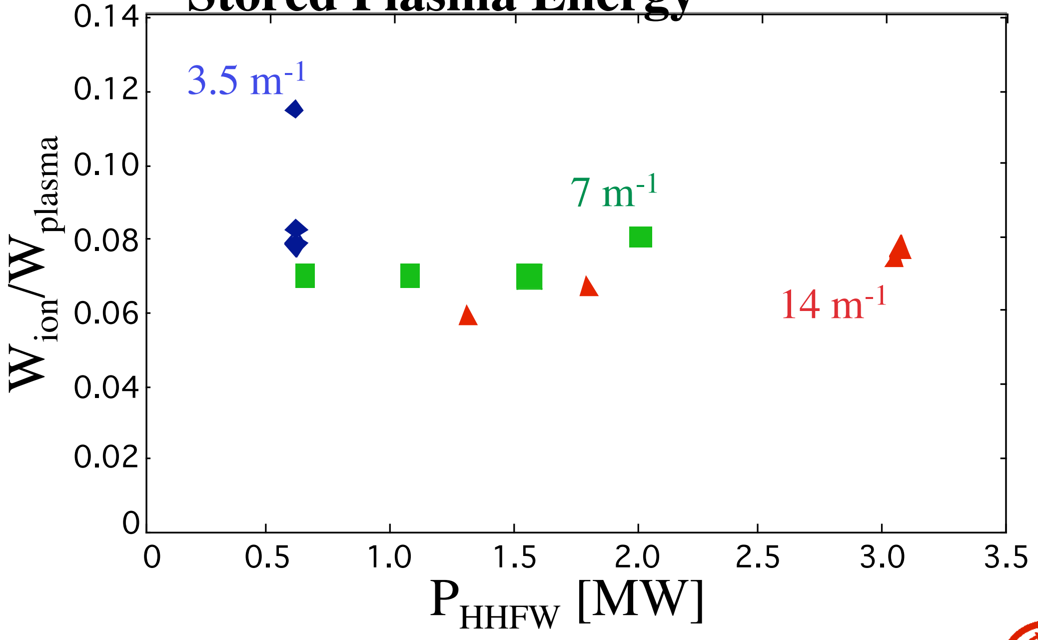




$3.5\ m^{-1}$ Phasing Results in Greater Edge Ion Heating

- Plasma current and toroidal field were kept constant for these He plasmas
- This is consistent with the observation that higher wavelengths result in greater edge ion energy absorption

$$\frac{\textbf{Stored Ion Energy}}{\textbf{Stored Plasma Energy}}\ \textbf{vs. } \mathbf{P_{HHFW}}$$



Conclusions

- New observations show edge ion heating during HHFW operation
- Theory states that the HHFW should parametrically decay into an ICQM & IBW
- Evidence of parametric decay seen in NSTX He and D plasmas - probe data is consistent with IBW excitation
- An increase in power yields more decay sidebands
- Parametric decay results in $\geq$20% P_{HHFW} loss to edge ion heating

Future Work

- More robust probe will be used to get measurements closer to the plasma edge
- Examine spectrum to account for peak shape and height
- Future run campaign to vary edge temperature and density planned to compare with theoretical predictions
  - Parametric decay threshold should increase with increase in temperature and decrease with increase in density
- Get a better understanding of HHFW power flow to edge ions