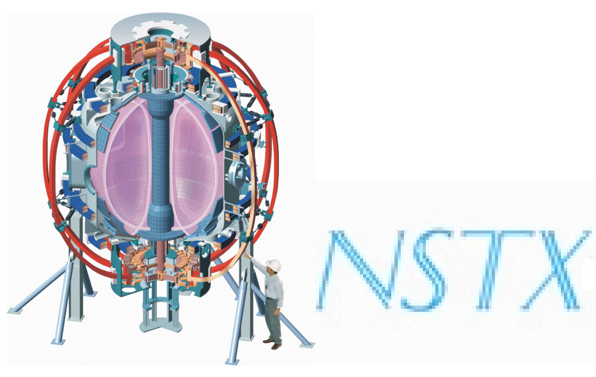
Observations of Anisotropic Ion Temperature in the NSTX Edge during RF Heating

T. M. Biewer[1], R. E. Bell[1], D. W. Johnson[1], P. M. Ryan[2], D. W. Swain[2], J. R. Wilson[1]

1. Princeton Plasma Physics Laboratory, Princeton, NJ 0854, USA

2. Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA



Abstract

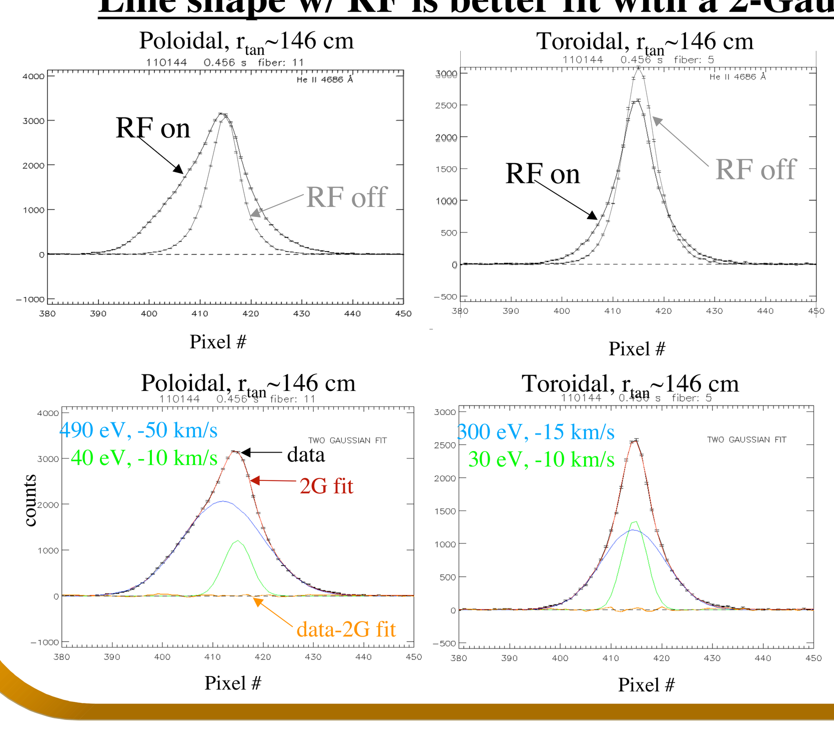
A new spectroscopic diagnostic on the National Spherical Torus Experiment (NSTX) measures the velocity distribution of ions in the plasma edge simultaneously along both poloidal and toroidal views. An anisotropic ion temperature is measured during high power High Harmonic Fast Wave (HHFW) Radio Frequency (RF) heating in helium plasmas, with the poloidal ion temperature roughly twice the toroidal ion temperature. Moreover, the measured spectral distribution suggests that two populations of ions are present and have temperatures of typically 500 eV and 50 eV with rotation velocities of -50 km/s and -10 km/s, respectively (predominantly perpendicular to the local magnetic field). This bi-modal distribution is observed in both the toroidal and poloidal views (for both He II and C III ions), and is well correlated with the period of RF power application to the plasma. The temperature of the hot component is observed to increase with the applied RF power, which was scanned between 0 and 4.3 MW. The 30 MHz HHFW launched by the NSTX antenna is expected and observed to heat core electrons, but plasma ions do not resonate with the launched wave, which is typically >25th harmonic of the ion cyclotron frequency in the region of observation. A likely ion heating mechanism is parametric decay of the launched HHFW into an Ion Bernstein Wave (IBW). IBW heating occurs in the perpendicular ion distribution, consistent with the toroidal and poloidal observations. Calculations of IBW propagation indicate that all of the IBW power created by a parametric decay process would be absorbed in the outer 10 cm of the plasma, predominantly on fully stripped ions. These predictions are in qualitative agreement with the observations. The presence of the IBW has been confirmed in RF heated NSTX plasmas with a Langmuir probe.

This research was supported by the U.S. D.O.E. under contract: DE-AC02-76CH03073

Summary

- Launched HHFW leads to core electron and unexpected edge ion heating in NSTX.
- Applying power to the RF antenna coincides with large amounts of carbon influx.
- This carbon is useful as a charge exchange diagnostic.
- Anisotropic edge ion temperatures are measured, consistent with an enhanced perpendicular energy content.
- The launched HHFW undergoes parametric decay into an IBW and an ICQM, which damp in the outer 10 cm of the plasma.
- IBW's are confirmed in these plasmas by swept Langmuir probe measurements.
- Edge ion heating is observed in all HHFW plasmas.

1. Line shape w/ RF is better fit with a 2-Gaussian distribution.

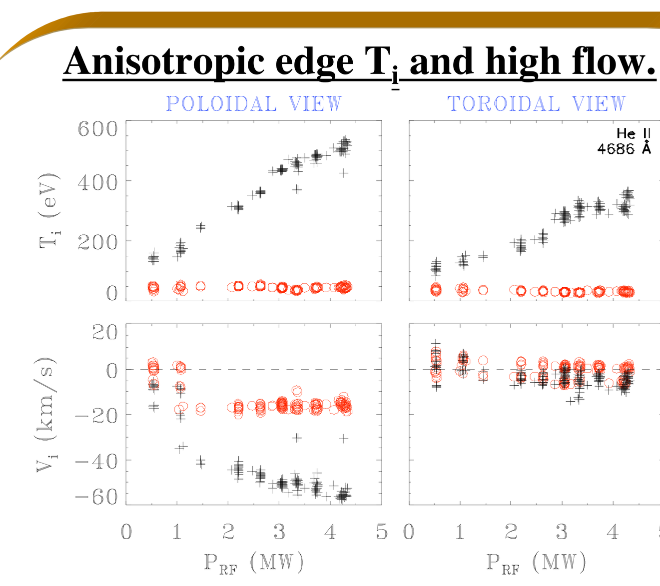


When HHFW RF power is applied to NSTX plasmas, the measured He II and C III spectra (edge light) become distorted.

Fitting with 2 Gaussians accurately represents the data and reveals a bi-modal distribution function of "hot" and "cold" ions at the same radial location in the edge of the plasma.

The poloidally measured distribution has a systematically higher temperature than the toroidally measured distribution, for a given RF input power.

4. Anisotropic edge T_i and high flow.



Negative poloidal velocity is upwards on the outboard midplane.
Negative toroidal velocity is opposite to the direction of I_p.

At a given RF power, the poloidally measured temperature is hotter than the toroidally measured temperature, by approximately the tangent of the magnetic pitch angle.

This implies an anisotropic temperature, with the perpendicular distribution heated primarily, consistent with IBW absorption.

Reprint Request

PDF of this poster is available online at:
http://w3.pppl.gov/~tbiewer/EPS04poster.pdf
Or sign up below for an emailed copy:

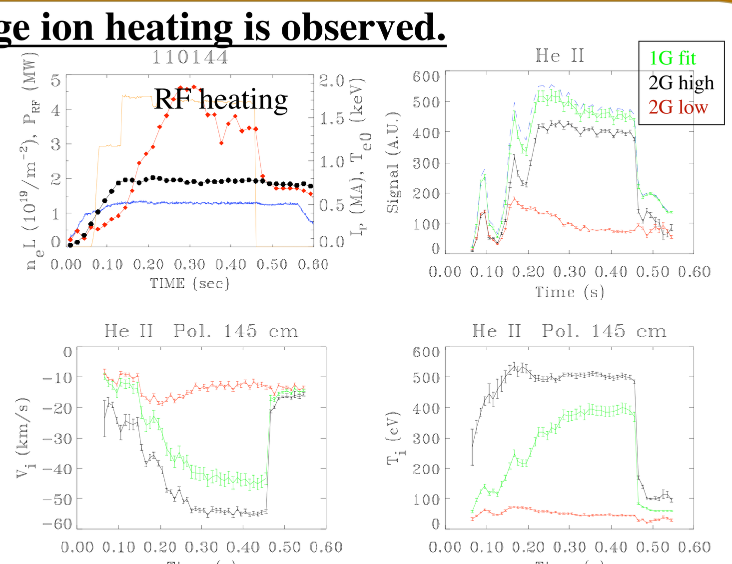
2. Core electron and edge ion heating is observed.

Electron heating from HHFW is expected and observed.

Edge ions are resonant at 27th (He) and 41st (C) sub-harmonic of the HHFW, and should not be affected by the launched wave, but are!

The period over which this edge ion heating is observed correlates very well with the period of RF power application to the plasma.

A new rotational and thermal equilibrium is established.



5. Langmuir probe measurements confirm the presence of IBW's.

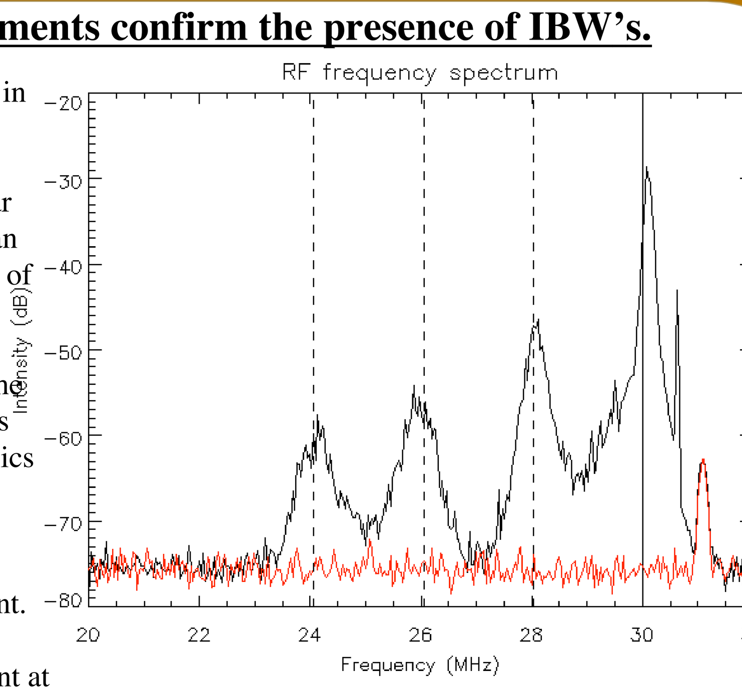
The 30 MHz launched HHFW is attenuated in this spectrum with a 40 dB notch filter.

A portion of the HHFW undergoes nonlinear parametric decay into a daughter IBW and an ICQM, which both damp in the outer 10 cm of plasma.

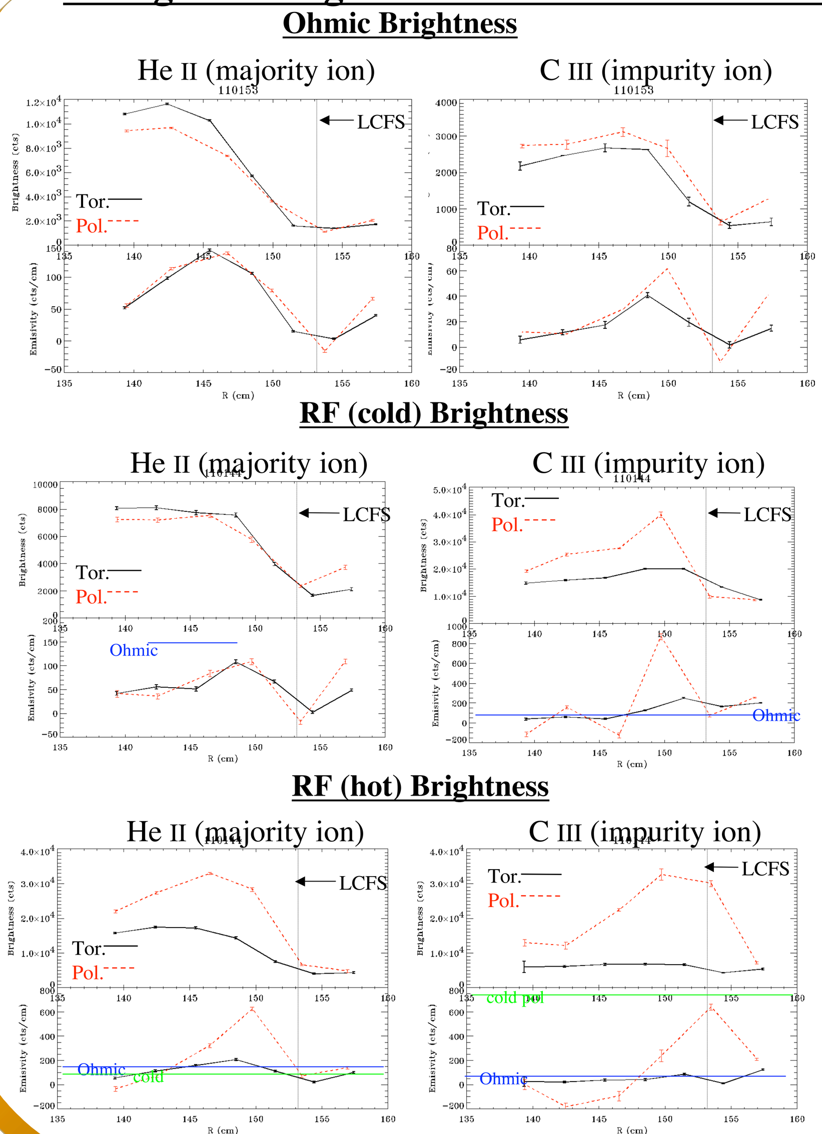
IBW's are observed as lower sidebands of the launched HHFW at the expected frequencies (dashed vertical lines) for the first 3 harmonics of the ion cyclotron quasi-mode.

An Ohmic shot (no RF) is shown (in red), indicating the noise-floor of the measurement.

Pick-up from a heterodyne network is present at 31 MHz in both spectra.



3. Charge exchange with RF antenna sourced carbon impurities reveals hot edge ion dynamics.

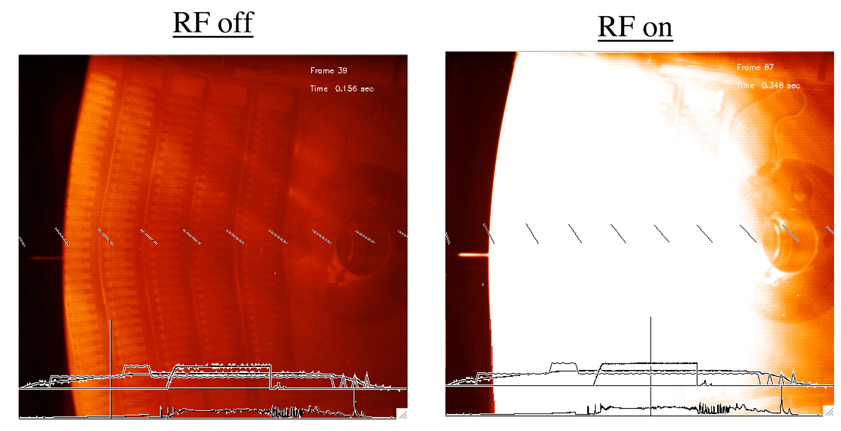


The powered RF antenna acts as a source of neutral particles at the edge of the plasma.

In the poloidal view (~20 cm from the RF antenna toroidally) the brightness of C III increases by a factor of 10.

In the toroidal view (~2 m from RF antenna toroidally) the brightness of C III increases by a factor of 3.

Visible camera images of the plasma confirm the increase in plasma brightness adjacent to the RF antenna.



Charge exchange with these antenna sourced neutrals allows the formerly fully-stripped, hot helium ions to be seen by the ERD.

"Hot" component represent He^{2+} dynamics.

"Cold" component represent He^{+} dynamics.

Time scales allow two populations to exist simultaneously in non-equilibrium:

Emission: ~1 ns.

Ionization of hot He^{+}: ~100 μs.

Thermalization between hot and cold helium: ~10 ms.

6. Edge ion heating observed in many plasmas.

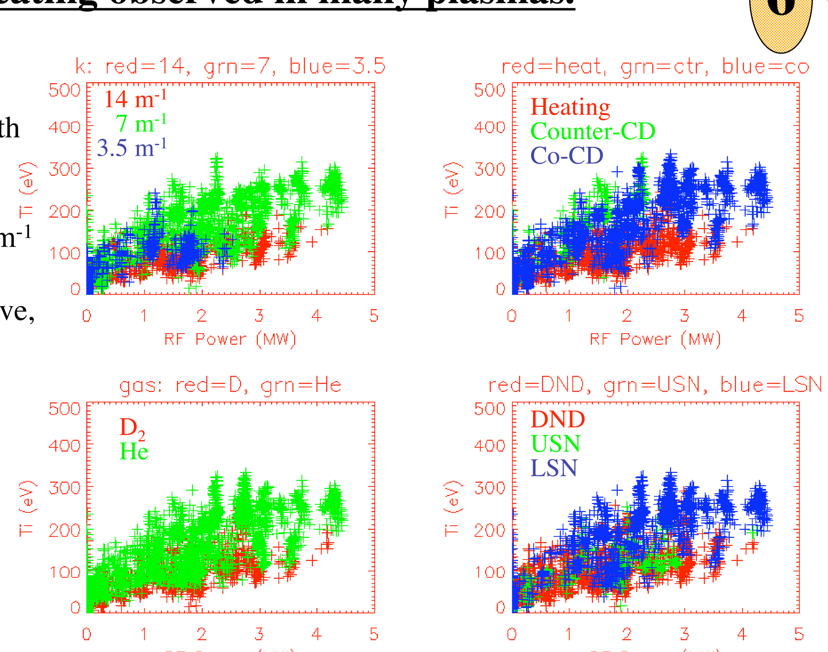
Parametric heating of edge ions is observed in all NSTX plasmas with applied HHFW power.

Antenna phased at 14, 7, and 3.5 m^{-1}

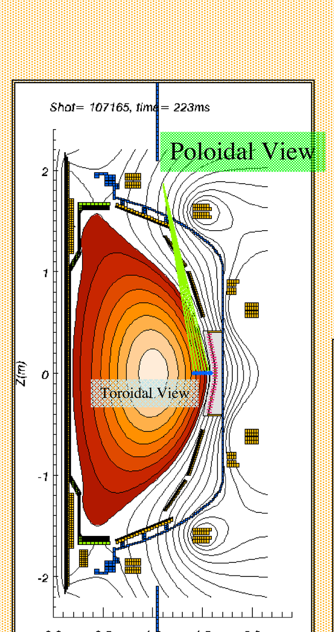
Antenna phased for co-current drive, counter-current drive, and heating

He and D_2 fuelled discharges Upper-single null, Lower-single null, and Double-null

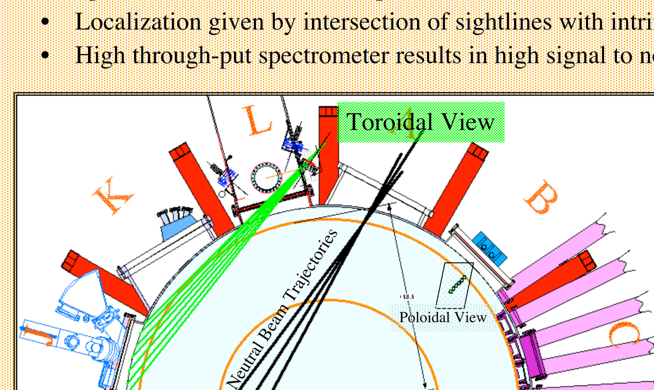
Various I_p, n_e, and B_t values



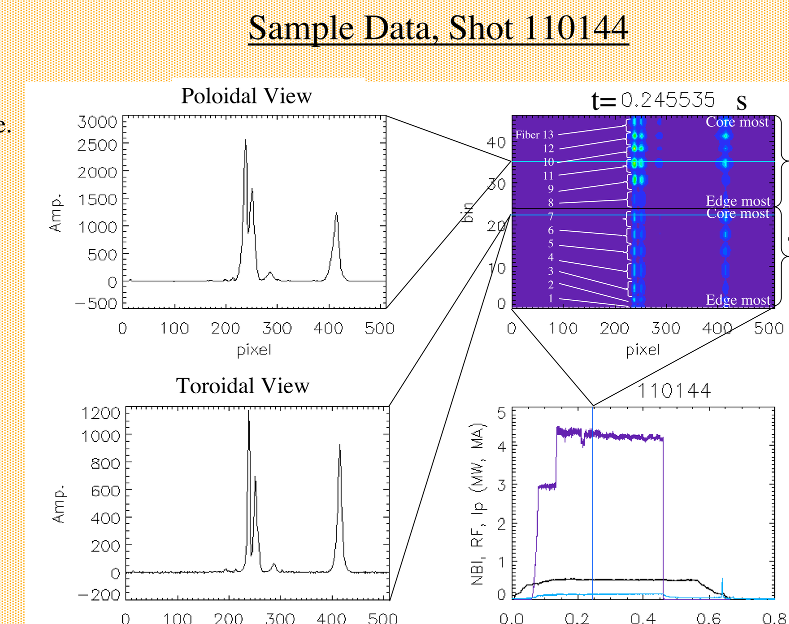
Overview of the Edge Rotation Diagnostic (ERD)



- Detailed description available at http://w3.pppl.gov/~tbiewer/RSI_ERD.pdf
  - T. M. Biewer, R. E. Bell, R. Feder, D.W. Johnson, R. Palladino, RSI **75** (3), p 650
- 10 ms time resolution
- 7 toroidal and 6 poloidal sightlines cover 140 to 160 cm at the outboard midplane.
- Sensitive to intrinsic emission light of C III, C IV, and He II.
- Measures velocity, temperature, and brightness of edge ions.
- Spectral resolution of 0.22 Å/pixel with 75 μm slits.
- Localization given by intersection of sightlines with intrinsic emission shells.
- High through-put spectrometer results in high signal to noise ratio.



Sample Data, Shot 110144



Ion dynamics from C III, C IV, and He II are studied.