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

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Abstract. A new spectroscopic diagnostic on the National Spherical Torus Experiment (NSTX) measures the velocity distribution of ions in the plasma edge with both poloidal and toroidal views. An anisotropic ion temperature is measured during the presence of high power HHFW RF heating in He plasmas, with the poloidal T_i roughly twice the toroidal T_i. Moreover, the measured spectral distribution suggests that two populations have temperatures of 500 eV and 50 eV with rotation velocities of -50 km/s and -10 km/s, respectively. This bi-modal distribution is observed in both the toroidal and poloidal views (in 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 edge ions is observed to increase with the applied RF power, which was scanned between 0 and 4.3 MW. The ion heating mechanism from HHFW RF power has not yet been identified.

INTRODUCTION

A new spectroscopic diagnostic with both toroidal and poloidal views has been implemented in the edge of NSTX plasmas. This edge rotation diagnostic (ERD) was designed to measure the velocity and temperature of ions in the edge of NSTX. Correlated with HHFW, a strong heating of He II and C III ions is observed. The apparent temperature is anisotropic; the T_i viewing poloidally is roughly twice the T_i measured with the toroidal view. Moreover, a bi-modal distribution of these ions is observed. The presence of two distributions of ions is consistent with calculated ionization and thermalization times for He II. No direct method of edge RF ion heating has yet been identified.

OBSERVATIONS

The edge rotation diagnostic (ERD)[1] measures the intrinsic emission of light from the plasma edge. There are 7 toroidally directed views and 6 poloidally directed views of the outboard plasma edge. The poloidal views are $\sim$ 20 cm (toroidally) from the RF antenna, and the toroidal views are $\sim$ 2 m away. The intersection of the diagnostic sightline with the intrinsic emission shell provides the localization of the measurement. The sightlines are nearly tangent to the flux surfaces. The C III triplet near 4651 Å and the He II line at 4685 Å are measured. In the results presented here, Helium is the bulk "working" ion of the discharge.

The National Spherical Torus Experiment (NSTX)[2] is a large spherical tokamak[3] with a major radius of 0.85 m and a minor radius of 0.65 m. Pulse lengths for these

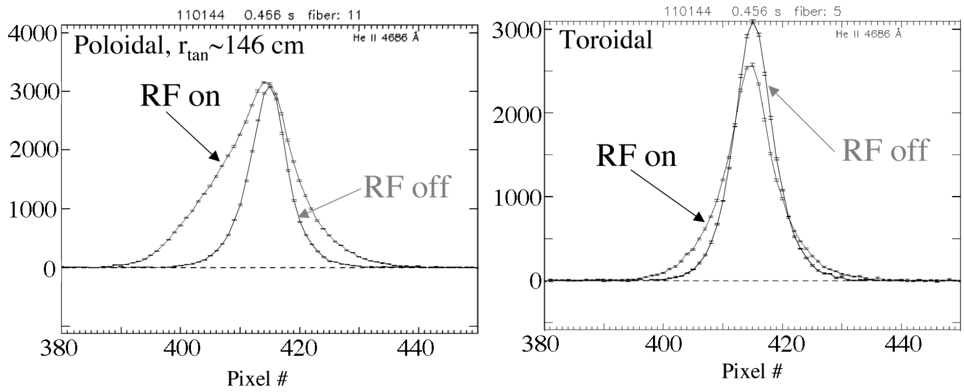

FIGURE 1. The He II spectrum from Shot 110144 during adjacent 10 ms time slices (centered on 455 and 465 ms), showing the difference in the poloidal view and toroidal view when HHFW RF heating is applied to the plasma. RF heating (4.3 MW) ends at 460 ms. Both views are tangent to the flux surface at $\sim$ 146 cm. Error bars indicate statistical uncertainty.

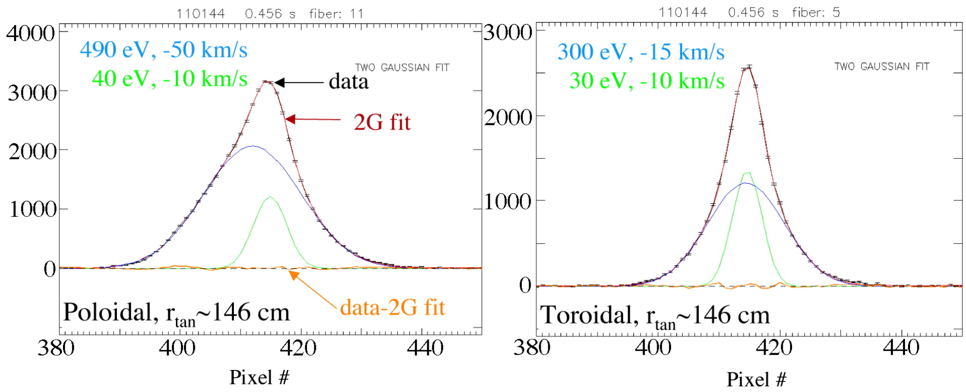

FIGURE 2. The He II spectrum under the influence of RF heating, fit with two Gaussians.

NSTX discharges are $\simeq$ 600 ms, with an on-axis toroidal magnetic field of $\sim$ 0.3 T. The plasma current is 500 kA. The on-axis electron temperature and density are $\leq$ 2 keV and $\sim 2 \times 10^{19}$ m^{-3}, respectively with $\leq$ 4.3 MW of HHFW RF auxiliary heating[4].

During the application of 30 MHz RF heating, phased to drive current, a distortion to the spectrum of both He II (as shown in Fig. 1) and C III is observed. The distortion is more pronounced in the poloidal view, but it is also present in the toroidal view. Under the influence of RF power, the spectrum is clearly non-Maxwellian. However, fitting the spectrum with two Gaussians yields a very accurate representation of the measured data, as shown in Fig. 2, suggesting "hot" and "cold" components are present.

Fig. 3 shows the time evolution of NSTX Shot 110144. HHFW heating is applied from 60 to 460 ms. The effect of the RF heating is apparent in the edge measured brightness, velocity, and rotation. After the RF is applied, $\sim$ 100 ms are needed to establish a new equilibrium rotation, as indicated by the velocity trace. Once an equilibrium is established, however, the plasma is very robust, as indicated by the near constant level of velocity and temperature. When the RF heating is terminated, the hot component

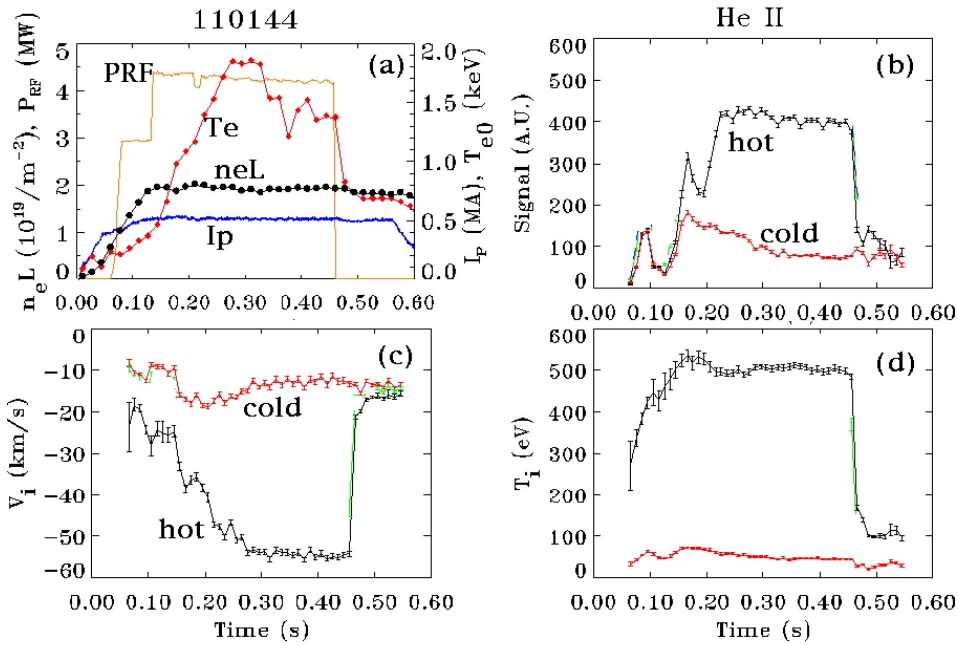

FIGURE 3. Time evolution of NSTX Shot 110144, showing (a) I_p, T_e, n_e, and P_{RF} and the hot and cold components of poloidally measured He II (b) brightness, (c) velocity, and (d) temperature at a tangency radius of 146 cm.

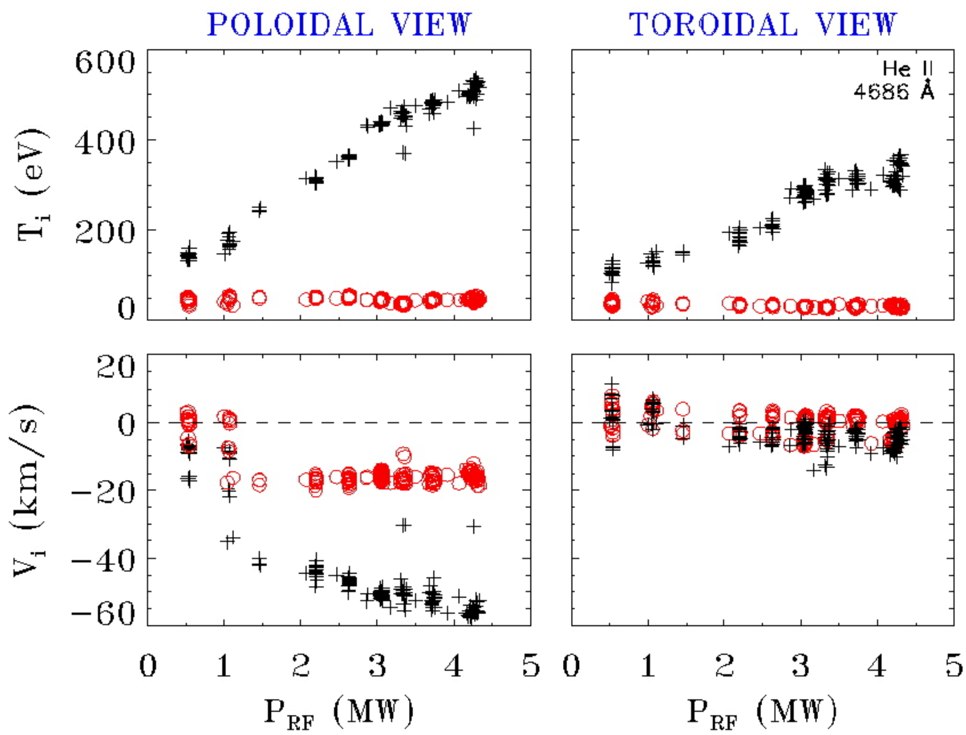

FIGURE 4. The temperature of the "hot" component scales with P_{RF}, whereas the temperature of the "cold" component is not effected by the amount of RF power applied to the plasma. He II data from Shots 110133-110145 are shown.

disappears promptly from the plasma. Fig. 4 shows how T_i and v of the hot and cold components vary with the amount of RF power that is applied to the plasma.

DISCUSSION

The observed anisotropic temperature is consistent with ions having a large perpendicular energy content. One interpretation of the observed bi-modal distribution, is that there are two populations of He ions in the plasma. In this scenario, the RF creates (by some unidentified mechanism) a high-temperature population of He II ions. The emission time scale is ~ 1 ns, implying that light from both populations (hot and cold) would be readily observed, since the time scale for thermalization between two populations of He ions is ~ 10 ms. However, the time scale for ionization is $\sim 100\ \mu$s. Hence, thermalization between the hot and cold populations would not be observed before ionization occurs. Presumably, thermalization occurs among fully stripped He III ions, which do not emit.

Key to this interpretation of the observed bi-modal distribution is the heating mechanism of the RF which creates the hot component of He ions. The HHFW launched by the NSTX antenna is not expected to heat edge ions[5], but core electron heating is expected and observed. Resonant heating at the ion cyclotron frequency (27^{th} sub-harmonic for He, and 41^{st} for C) is unlikely. One possibility for ion heating is parametric decay of the launched HHFW into a daughter HHFW and an ion quasi-mode at the fundamental ion cyclotron resonance. Ion heating could then occur either directly at the fundamental cyclotron frequency or by stochastic heating. In the near-field of the antenna, a compressional wave could be generated which may stochastically heat He (and C) ions[6]. Attempts to invert the poloidal brightness assuming constant emissivity on a flux surface fail, i.e. negative emissivities are obtained. Localized emission near the midplane can explain the observed brightness profile. Single particle simulations suggest that hot, trapped ions with high perpendicular energies have banana-orbits which are primarily localized to the midplane, increasing emission there.

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