Edge Impurity Ion Velocity and Temperature Measurements on NSTX

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Abstract

A new spectroscopic diagnostic on the National Spherical Torus Experiment (NSTX) measures the temperature and velocity of the plasma edge with both poloidal and toroidal views. The diagnostic is simultaneously sensitive to C \text{III}, C \text{IV}, and He \text{II} ambient emission light (between 4595 and 4705 Å) with 10 ms resolution, covering a radial region of 15 cm at the extreme edge of the outboard mid-plane with 7 toroidal and 6 poloidal sightlines. This measurement complements the toroidal rotation and C \text{VI} impurity temperature profiles, which are measured by the NSTX Charge-Exchange Recombination Spectroscopy (CHERS) diagnostic. Combined with the local pressure gradient and EFIT reconstructed magnetic field profile, the edge flow gives a measure of the local radial electric field. Preliminary results include measurements of: 1) rotation, temperature and radial electric field changes during H-mode, 2) an anisotropic ion temperature under the influence of high power RF heating in conjunction with velocity changes, 3) the location of the plasma edge as confirmed by EFIT, and 4) an increase in ion temperature outside of the separatrix.

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Outline

• Overview of the Edge Rotation Diagnostic
• Observations during NB plasmas
• Observations during RF plasmas
• Summary
Poloidal and Toroidal views are imaged through a single spectrometer onto a single detector.
Sample Shot 110077: NB heated, long H-mode

- From Dave Gates’ rtEFIT development XP on Feb. 10th, 2003
- Three source, NB heated, D\textsubscript{2} plasma
- Long H-mode period from \(~240\) ms to \(~460\) ms
- CHERS/ERD data integrated every 10 ms until 500 ms
  - 50 frames of ERD data over the discharge
Sample Shot 110077: raw ERD data

- The CCD is binned from 512x512 pixels to 512x47 in order to decrease the read-out time.

- Each time frame of the CCD contains:
  - 6 poloidal views
  - 7 toroidal views
  - 10 ms of integrated, dispersed light
    - X-axis: ~wavelength
    - Y-axis: ~radial location
      - Each fiber is spread over multiple pixels to avoid saturation
  - Color indicates light intensity
Sample Shot 110077: a sample spectrum

- The high dispersion, axial transmission grating used in the Kaiser-Spectrometer allows for very high throughput of light and fine spectral resolution.
  - ~22 photons/count from CCD
  - This data taken at f/11 (accepts f/1.8)
    - 97.3% of light thrown away to avoid detector saturation
Impurity Ion Dynamics from C III, C IV, and He II

C III triplet
47.88 eV ionization
3S to 3P0 transition
relatives amplitudes from theory
Can fit all 3 lines simultaneously to get very accurate v, T

He II
54.414 eV ionization

C IV doublet
64.489 eV ionization
2G to 2H0

The ERD relies on the intersection of the sightline with the intrinsic emission shell for localization. But each sightline measures aspects of different emission shells, which peak at different radii.
C Ⅲ Dynamics During Shot 110077

Key
- End of I_p ramp
- NB addition
- H-mode transition
- ELM-free period

• No change in v,T with additional NB power
• More negative velocity at H-mode transition
• Increase in T_i during ELM-free period
C III Profile Dynamics During Shot 110077

Signal Brightness
EFIT LCFS (red line) is in good agreement with ERD C III shell location.

ELM-free periods

H-mode

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C III Profile Dynamics During Shot 110077

Signal Brightness
EFIT LCFS (red line) is in good agreement with ERD C III shell location.

Temperature
Tor. And pol. Views show a minimum in Ti at the LCFS?

ELM-free periods

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C $\text{III}$ Profile Dynamics During Shot 110077

**Velocity**

ELM-free H-mode reduces the measured velocity

**Temperature**

Tor. and pol. Views show a minimum in Ti at the LCFS

**Signal Brightness**

EFIT LCFS (red line) is in good agreement with ERD C $\text{III}$ shell location.
Profiles Before and After H-mode Transition

**Toroidal View**

![Toroidal View Graph]

**Poloidal View**

![Poloidal View Graph]

**Velocity**

ELM-free H-mode reduces the measured velocity.

**Temperature**

Tor. and pol. Views show a minimum in Ti near the LCFS.

**Signal Brightness**

Outward shift and narrowing in the peak brightness during H-mode consistent with generally hotter edge and steeper $T_e$ gradient.

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$E_r \sim v_x B$ suggest improved $e^-$ confinement

Before H-mode transition
After H-mode transition
Sample Shot 110144: RF Heating, He plasma

• From Phil Ryan’s HHFW CD XP-312 on Feb. 12th, 2003
• He plasma
• 4.3 MW of RF power @ 30 MHz
Sample Shot 110144: RF Heating, He plasma

Poloidal View

Toroidal View

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He II spectra during Shot 110144

Two successive time frames clearly show the spectral consequences of RF heating in the edge plasma.
A single Gaussian fit of He II does not capture the dynamics.
Two thermal populations of He II ions are present during RF.

Fitting the data with two Gaussians gives a much better representation of the data.

![Graph showing two thermal populations of He II ions during RF with data fitting and parameters given.]
He II Dynamics During Shot 110144: Poloidal

r_{tan} \approx 146 \text{ cm}

Key
1G fit
2G high
2G low

He II ion. pot. 54 eV

\[\text{He II Pol.11}\]

\[\text{velocity (km/s)}\]
\[\text{t (s)}\]
\[
\begin{array}{c}
0 \\
10 \\
20 \\
30 \\
40 \\
50 \\
60 \\
\end{array}
\]

\[
\begin{array}{c}
0 \\
10 \\
20 \\
30 \\
40 \\
50 \\
60 \\
\end{array}
\]

\[\text{~300 ms to estab. pop.}\]

\[\text{~30 ms to remove pop.}\]

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He II Dynamics During Shot 110144: Toroidal

He II Tor.146

r_{\text{tan}} \sim 146 \text{ cm}

Key
1G fit
2G high
2G low

He II ion.
pot. 54 eV

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He II Low v. High populations (Pol.)

He Brightness 110144 (Low)

He Brightness 110144 (High)

Poloidal $T_i$ (Low)

Poloidal $T_i$ (High)

Poloidal Velocity (Low)

Poloidal Velocity (High)

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He II Low v. High populations (Tor.)

He Brightness 110144 (Low)

He Brightness 110144 (High)

Toroidal T_i (Low)

Toroidal T_i (High)

Toroidal Velocity (Low)

Toroidal Velocity (High)
Single Gaussian C III $T_i$ increases with $P_{RF}$

Each color is a different shot [110133-110145] (co-CD), multiple time points are plotted for each shot.

TS int. $T_e (r=146 \text{ cm})$

C III ionization potential (47 eV)

NB heated plasma equivalent $T_i$ (~30 eV)
Single Gaussian C III $T_i$ increases with $P_{RF}$

Each color is a different shot [110133-110145] (co-CD), multiple time points are plotted for each shot

$C_{III}$ ionization potential (47 eV)

NB heated plasma equivalent $T_i$ (~30 eV)

TS int. $T_e$ (r=146 cm)
On-axis $T_e$ also increases with $P_{RF}$.
C \text{III} (SG) velocity
Summary

• New measurements from the ERD are emerging
  – Dynamics of C III, He II, and C IV

• NB heated plasmas
  – C III shell is inside the LCFS (EFIT)
  – Apparent minimum in $T_i$ at LCFS
  – No large edge $v$ or $T_i$ changes as NB power increases
  – ELM-free H-mode corresponds with larger $v_B$

• RF heated plasmas
  – RF influence seems to favor two populations of He II ions in the edge
  – Anisotropy in toroidal v. poloidal view may indicate anisotropy in parallel v. perp. dist. func.
  – ~300 ms are needed to establish the “hot” component of the dist. Func, but it is lost in ~30 ms or less
  – “perp.” temperature grows like $\sqrt{P_{RF}}$

• Much future work remains
Reprints

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