Z_{eff} Profiles Using Charge Exchange Recombination Spectroscopy on NSTX

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Abstract

Radial carbon ion density profiles are measured in NSTX plasmas using charge exchange recombination spectroscopy (CHERS). Determination of the carbon ion density requires knowledge of the neutral beam parameters and geometry, a neutral beam attenuation calculation, electron density and temperature measurements from Thomson scattering, an absolute intensity calibration, and a calculation of the effective emission rate for charge exchange. Profiles of the effective charge, Z_{eff}, are then calculated assuming carbon is the dominant impurity in the core plasma. A comparison of the expected visible bremsstrahlung emission based on the inferred Z_{eff} profiles is consistent with measured values from CHERS spectra in the core plasma; excessive emission is observed for edge sightlines. Z_{eff} profiles are typically flat for L-mode plasmas and evolve to hollow profiles during H mode in NSTX. The characteristic "ears" in the electron density during H mode seems to be the result of increased carbon ion density in the region of the edge density gradient.

Carbon Density and Z_{eff} using Charge Exchange Recombination Spectroscopy

The charge exchange recombination spectroscopy (CHERS) diagnostic observes the C VI line at 5290.5 Å. The emission due to charge exchange is given by

$$E^{CX} = n_c n_b \langle \sigma^{CX} v \rangle^{eff},$$

where n_c is the carbon density, n_b is the beam neutral density determined from a neutral beam attenuation calculation, and $\langle \sigma^{CX} v \rangle^{eff}$ is the effective emission rate due to charge exchange integrated over all beam components. An effective emission rate is determined using a collisional radiative model

The carbon density can be determined from the measured brightness,

$$n_C = \frac{B^{CX}}{\frac{1}{4\pi}\int n_b \langle \sigma^{CX} v \rangle^{eff} \, d\ell},$$

where B^{CX} is the measured brightness with the line integral along the intersection of the line of sight with the neutral beam.

The effective charge is defined as

$$Z_{eff} = \frac{1}{n_e}\sum_i n_i Z_i^2 .$$

Assuming carbon is the dominant impurity in NSTX,

$$Z_{eff} = 1 + \frac{n_c}{n_e}(Z_c^2 - Z_c) = 1 + 30\frac{n_c}{n_e}.$$

Z_{eff} using Visible Bremsstrahlung

Visible bremmstrahlung emission due to electron-ion collisions is a function of the electron density, electron temperature, and effective charge:

$$E^{VB} = 7.63 \times 10^{-15} \frac{n_e^2 Z_{eff} \bar{g}_{ff}}{T_e^{\frac{1}{2}} \lambda} \left[\frac{photons}{s\ \mathrm{cm}^3\ \mathrm{sr}\ \mathrm{Å}} \right],$$

where n_e (cm^{-3}) is the electron density, T_e (eV) is the electron temperature, λ $(Å)$ is the wavelength, and $\bar{g}_{ff}(\lambda, T_e, Z_{eff})$ is the temperature averaged Gaunt factor.

The measured bremsstralung signal is a chord averaged measurement,

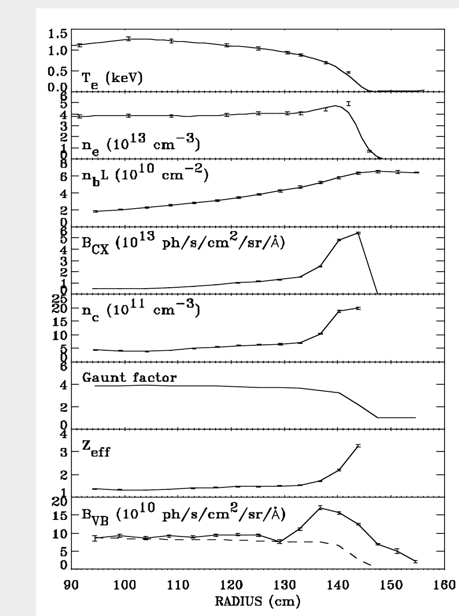
$$B_i^{VB} = \sum_j L_{ij} E_j^{VB} \quad ,$$

where L_{ij} is a length matrix and B_i^{VB}a is the brightness through chord i. To obtain Z_{eff} profiles from a visible bremsstrahlung measurement, independent measurements of electron temperature and density and an Abel inversion are required. The plasma edge is troublesome to visible bremmstrahlung measurements: even with a region of the visible spectrum free of line radiation, other pollutant emission due to molecular emission is present in the visible.

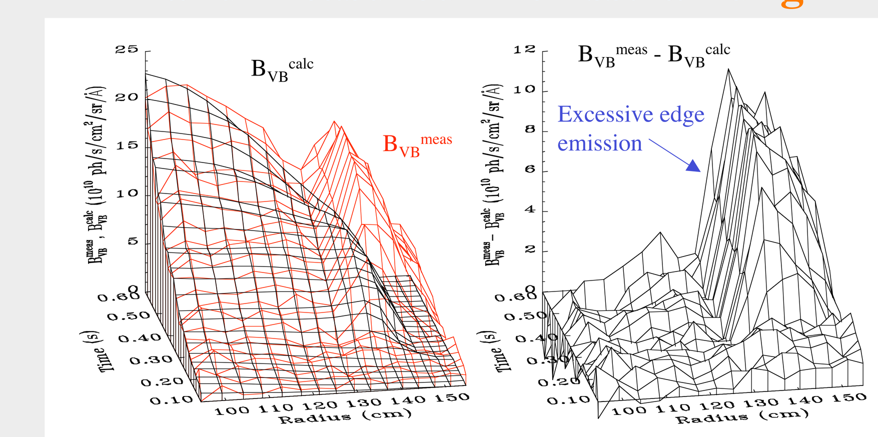
Here we attempt to find a line-free region of the CHERS spectrum to measure the visible bremsstrahlung brightness along our sightlines. Comparing that measured value to a calculated value based on Zeff assuming carbon is the only impurity, we can get some confidence in the carbon density from charge exchange spectroscopy.

Steps to Determine Z_{eff} and B_{VB}

- T_e, n_e from Thomson scattering
- n_b from beam attenuation calculation
- $<\sigma^{cx}v>^{eff}$ from integrating CX cross sections
- B^{cx} from fit
- $n_c(B^{cx}, n_b, <\sigma^{cx}v>^{eff})$ from fit
- Z_{eff} assuming carbon is sole impurity
- $g_{ff}(\lambda, T_e, Z_{eff})$ computed
- $B_{VB}{}^{calc}$ from Z_{eff} (dashed line)
- B_{VB} measured from CHERS spectra at λ_{VB} (solid line)



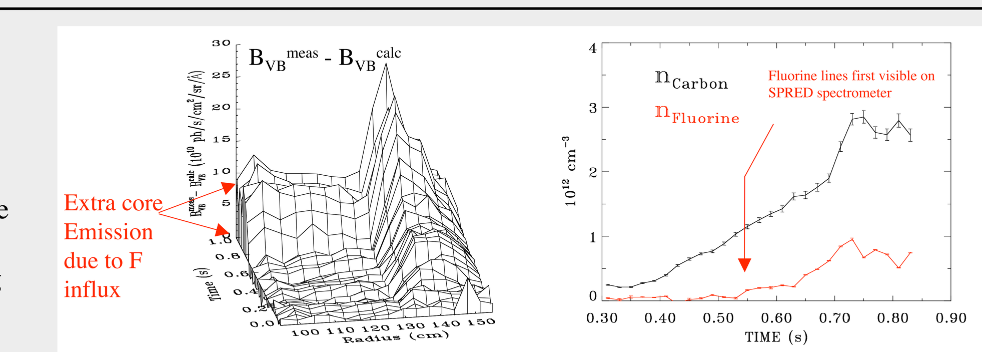
Comparison of Calculated (from CX Z_{eff}) and Measured Bremsstrahlung



- Calculated bremsstrahlung using CX data agrees well with measured bremsstrahlung in core
- Measured bremsstrahlung shows excessive emission near edge
  - unresolved line emission, molecular band emission, recombination continuum

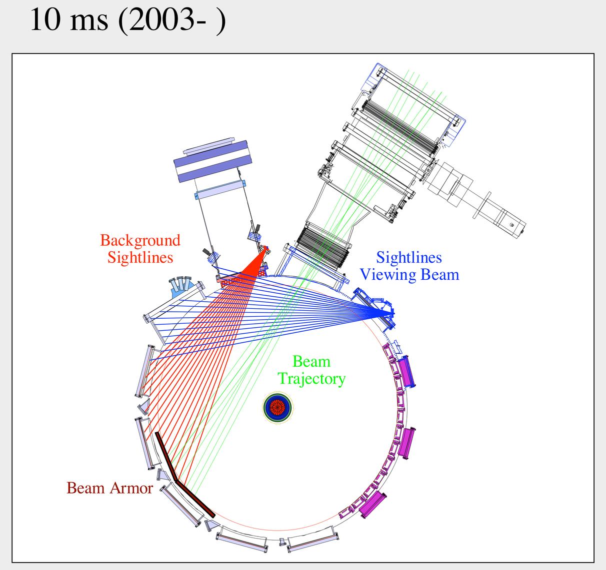
Fluorine Influx

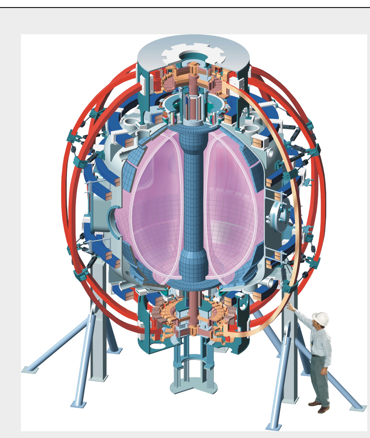
- Discrepancy between bremsstrahlung calculated using carbon density and measured bremsstrahlung for shot #109079 indicates that non-carbon emission was present
- Spectra from SPRED spectrometer show strong line emission from fluorine late in this discharge
- Fluorine density in core can be calculated based on "extra" bremsstrahlung emission using $Z_F = 9$.



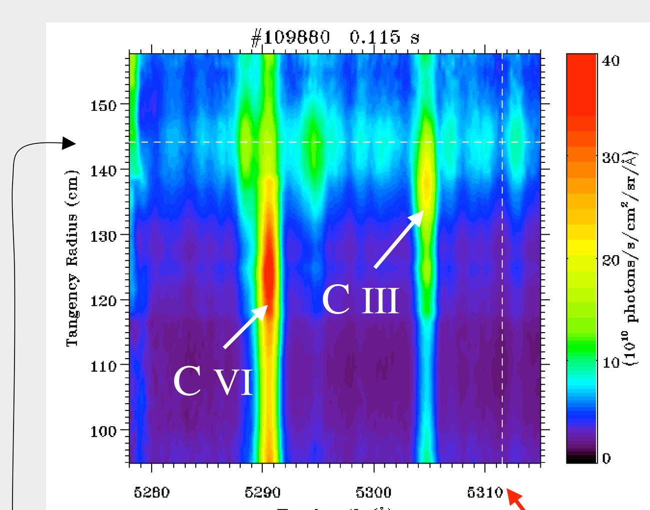
CHERS Viewing Geometry

- Active view across neutral beam give good radial localization
- Passive view measures background emission
- Time resolution 20 ms (1999-2002), 10 ms (2003-)

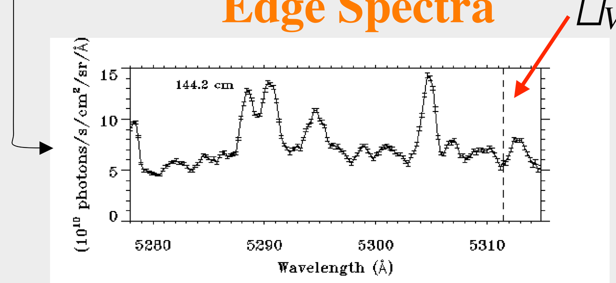




CHERS Background Spectra

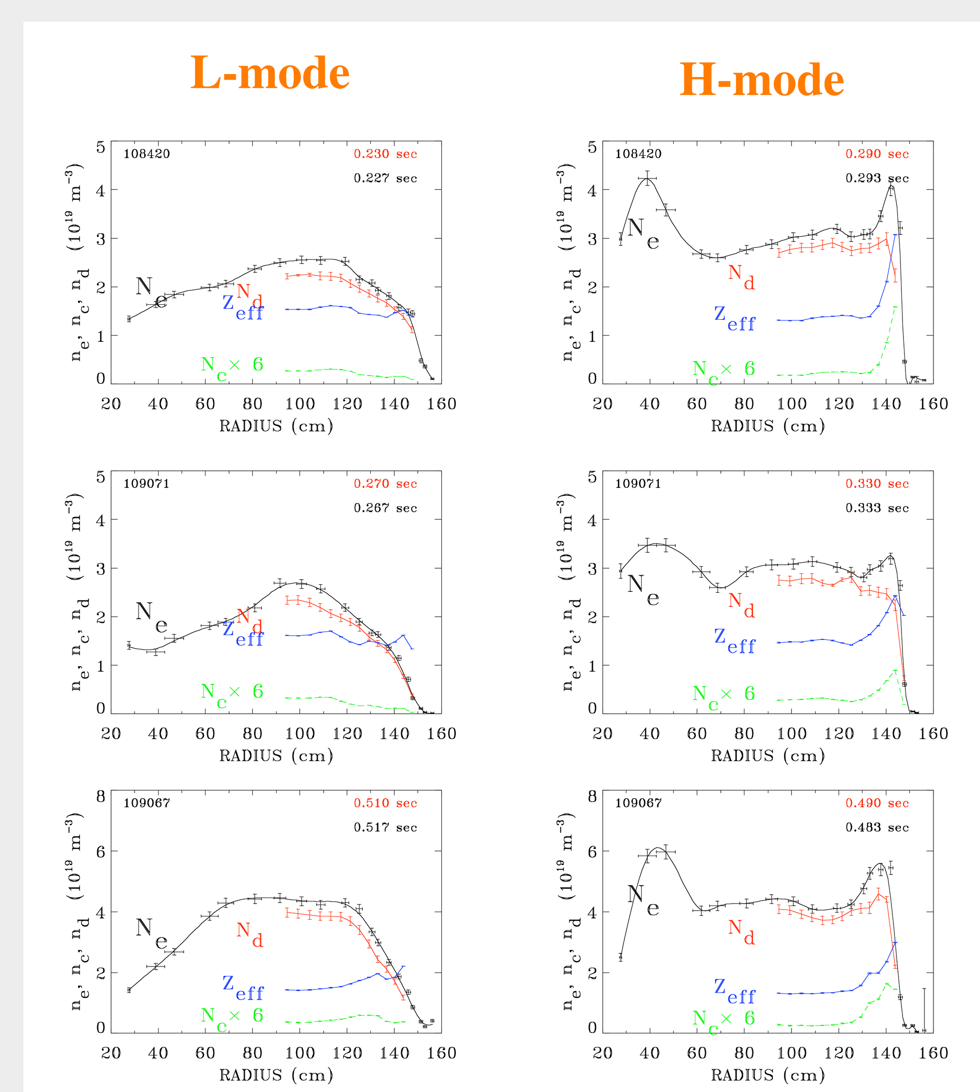


Edge Spectra

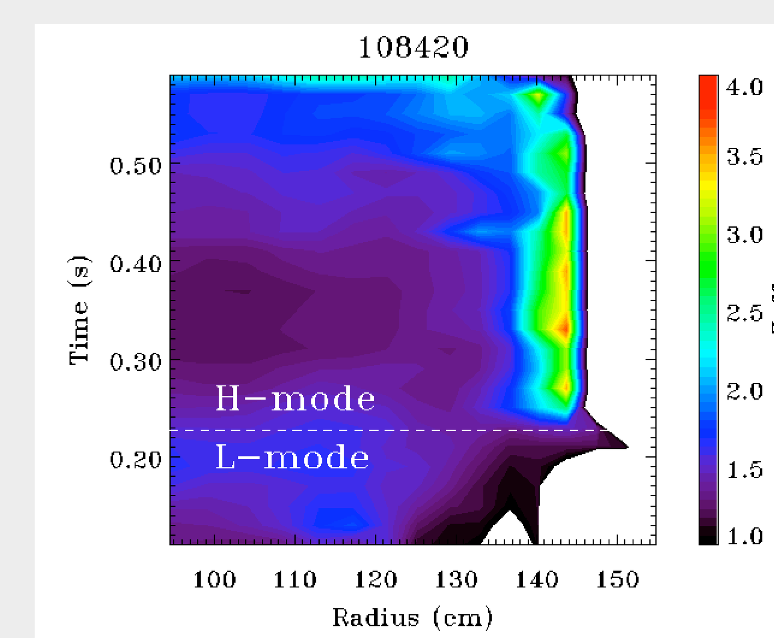


- CHERS spectra absolutely calibrated
- CHERS edge spectra shows line emission of low ionization states (mostly carbon)
- Visible bremsstrahlung signal is extracted at wavelength λ_{VB} from CHERS spectra

Z_{eff} and Density Profiles



Z_{eff} Evolution



- Z_{eff} typically flat during L-mode
- Carbon density profile peaks near edge after H-mode transition
- Z_{eff} drops in core, increases at edge after H-mode transition
- Typical values Z_{eff} ~1.2-1.5 in core, Z_{eff} ~3-3.5 at edge during H-mode
- "Ear" in electron density during H mode due to carbon density peaking at edge

Summary

- Carbon density profiles measured using charge exchange recombination spectroscopy
- Carbon is the dominant impurity in NSTX
- Z_{eff} profiles obtained using CHERS carbon density
  - typically flat during L-mode
  - hollow during H mode due to accumulation of carbon near plasma edge
- Particle transport barrier at edge

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