Ion Temperature Measurements and Impurity Radiation in HSX

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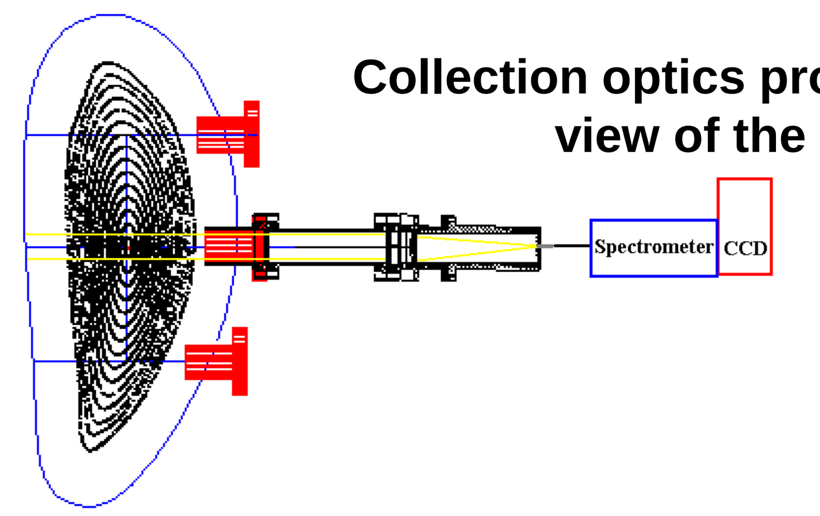
Overview

- Doppler spectroscopy is used to measure ion temperatures
- Data is shown for 1 Tesla Quasi-Helically Symmetry (QHS) and 10% Mirror a magnetic field configuration in which the symmetry is broken
- HSX plasmas are heated using up to 100kW of ECRH
- Carbon +4 temperatures in hydrogen plasmas are:
  - QHS: 50eV (100kW) and 35eV (50kW)
  - Mirror: 60eV (100kW) and 45eV(50kW)
- Carbon +4 temperatures in 100kW Mirror helium plasmas are 110eV
- Approximate radial location of ions is calculated using ADAS
- Ion temperature measurements are important for transport calculations
- Hot ions should drive HSX into the "ion root" where neoclassical transport should be drastically improved by quasi-helical symmetry

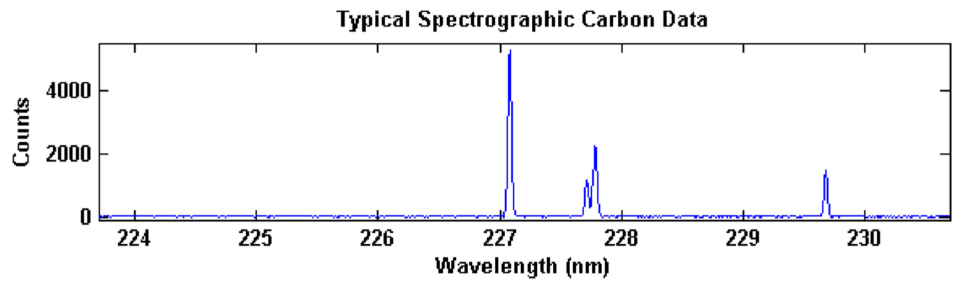
Diagnostic



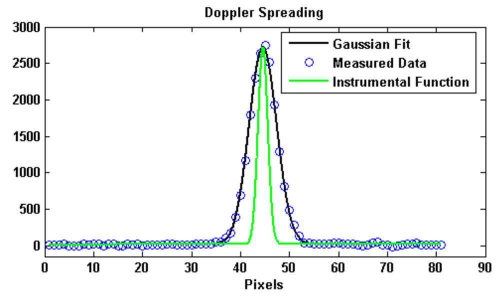
Collection optics provide an on-axis view of the plasma

- 1m Czerny-Turner spectrometer is used
  - 3600 groove per mm grating provides 0.25nm/mm dispersion (0.065nm per pixel)

Data Analysis



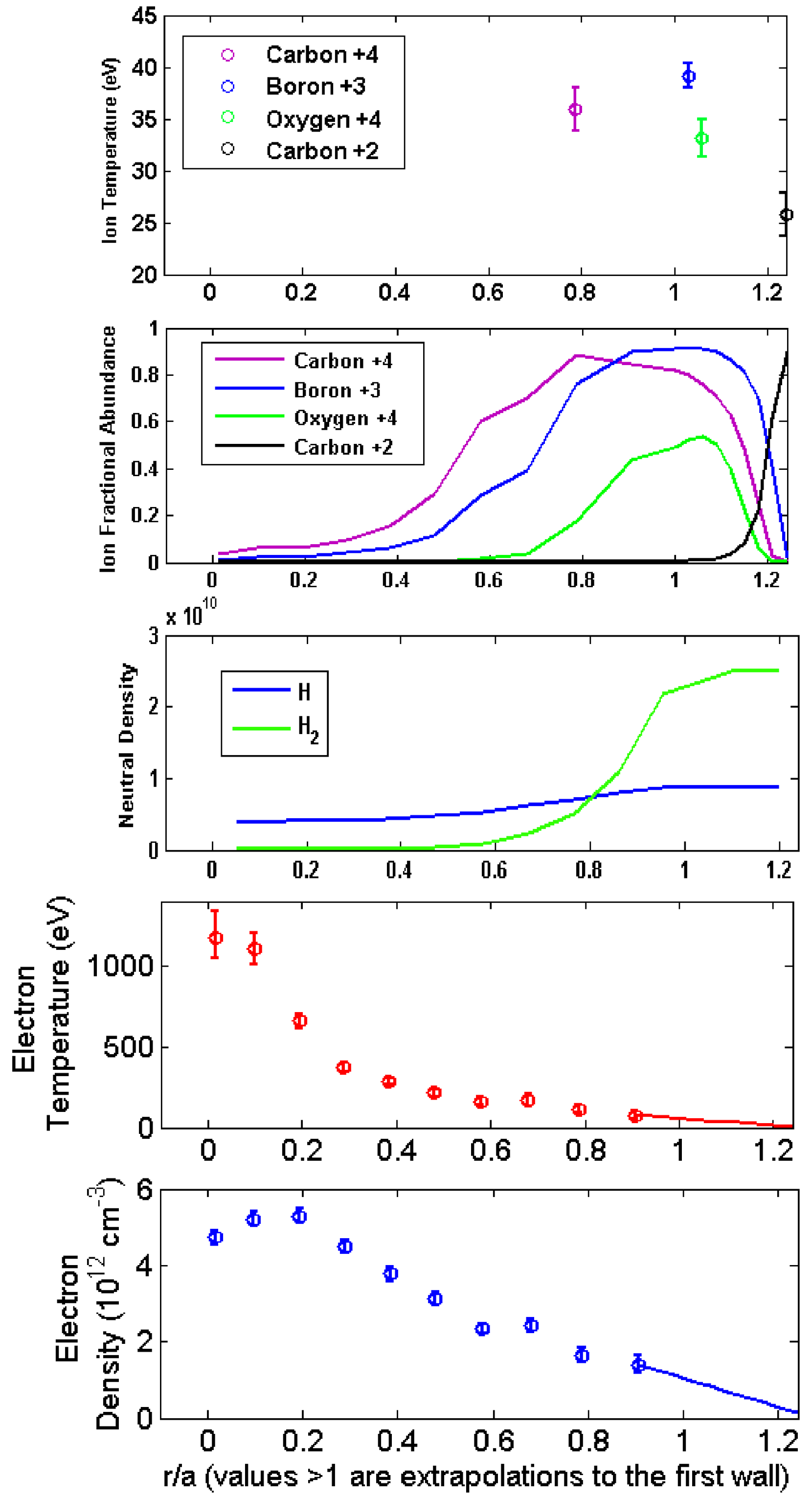
- •Four carbon lines can be observed simultaneously
- •The three lines on the left are all emitted by C+4 ions and typically produce the same measured temperature
- •The line on the far right is produce by C+2 and consistently shows a lower temperature than the other lines



- •The instrumental function is measured using a mercury calibration lamp
- •Data is fit with a Gaussian function
- •The difference between the instrumental function and the fitted Gaussian gives the Doppler broadening and temperature

Results

Temperatures and Approximate Radial Locations of Various Ions

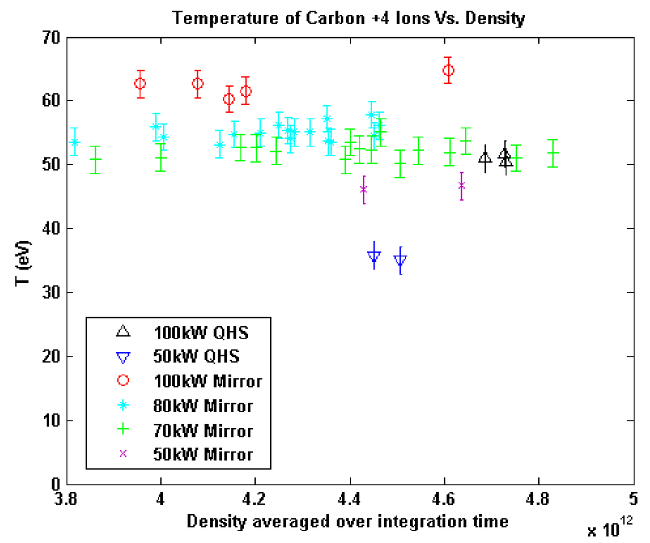


- ADAS is used to calculate the approximate radial location of various ions based on measured profiles
  - -Electron temperature and density profiles are measured with Thomson Scattering
  - -Neutral hydrogen profiles are found using measurements from H_α detectors and DEGAS simulations done by J. Lore

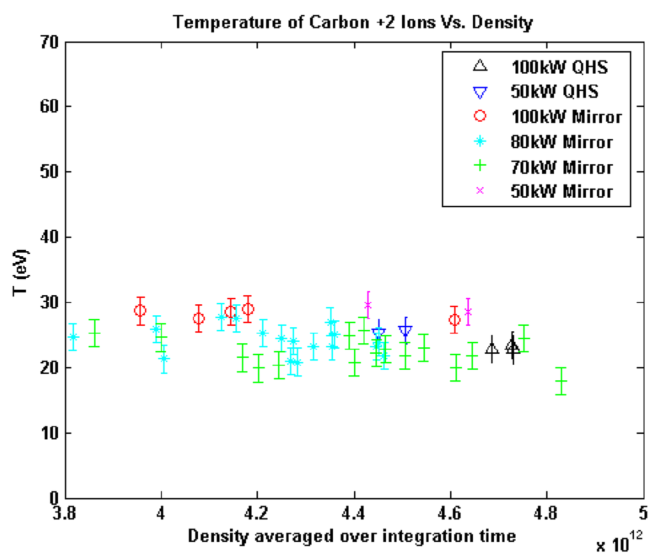
Wavelengths Used

- •Boron +3 λ=282.168nm
- •Carbon +2 λ=229.687nm
- •Carbon +4 λ=227.091, 227.725 and 227.792nm
- •Oxygen +4 λ=278.101nm

QHS and Mirror Carbon Data Comparison

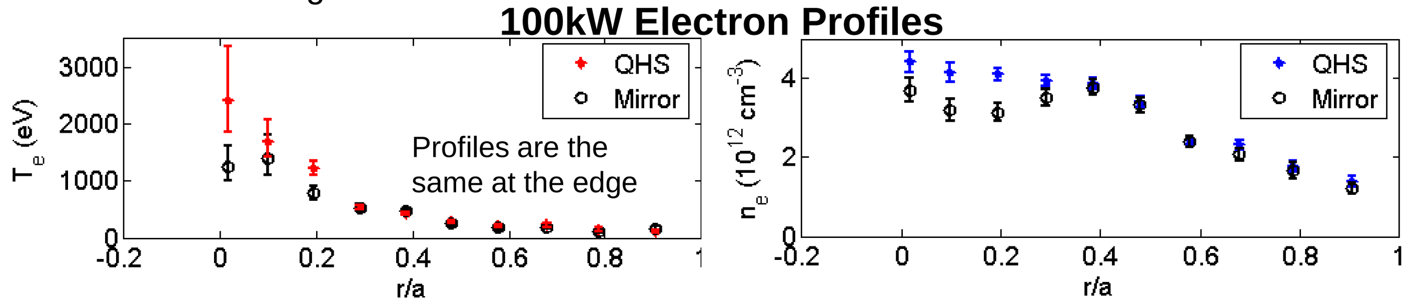


- For the same electron heating power ions are hotter in Mirror than in QHS
- Temperatures increase for increased electron heating



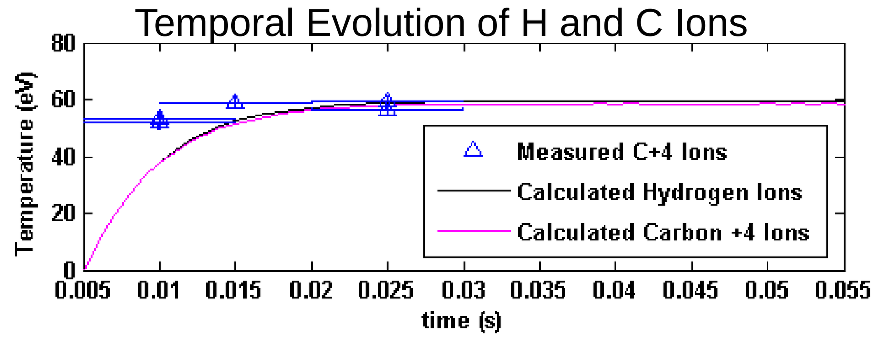
- Carbon +2 temperatures are about 25eV for all configurations

100kW Electron Profiles



Impurity and Majority Ion Temperatures

- •The evolution of hydrogen ion temperatures and impurity ion temperatures has been calculated using energy loss collision rates
- •Charge exchange is the dominant energy loss term for hydrogen ions
- •Ion confinement time was adjusted to help match calculated and measured temperatures
- •Calculations show good agreement between impurity and majority ion temperatures at all times



horizontal error bars indicate integration time

$$\frac{3}{2}n_i\frac{dT_i}{dt}=-\nu_\varepsilon^{i/e}n_i(T_i-T_e)-\nu_\varepsilon^{i/p}n_i(T_i-T_p)-\frac{3n_pT_pn_n}{2\tau_{imp}}$$

$$\frac{3}{2}n_p\frac{dT_p}{dt}=-\nu_\varepsilon^{p/e}n_p(T_p-T_e)-\nu_\varepsilon^{p/i}n_p(T_p-T_i)-\frac{3}{2}n_pT_pn_n\langle\sigma_{cx}v\rangle$$

$$\nu_\varepsilon^{s/s'}=\frac{n_{s'}q_s^2q_{s'}^2\ln\Lambda_{ss'}}{\pi^{3/2}\varepsilon_o m_s m_{s'}\mathbf{v}_{Tss'}^3}\qquad \mathbf{v}_{Tss'}=\sqrt{\mathbf{v}_{Ts}^2+\mathbf{v}_{Ts'}^2}$$

$\tau_\varepsilon^{i/e}$=9.1ms $\tau_\varepsilon^{i/p}$=0.039ms $\tau_\varepsilon^{p/e}$=12ms $\tau_\varepsilon^{p/i}$=14ms $\tau_{cx}^{p/n}=7.8\text{ms}=\frac{1}{n_n\langle\sigma_{cx}v\rangle}$

Parameters Used:

From r/a=.6 in

1 Tesla Mirror

100kW ECRH heating

Te=300eV

$n_e=3.2*10^{12}$ cm^{-3}

$n_c=10^{10}$ cm^{-3}

$n_{H\ neutral}=10^{10}$ cm^{-3}

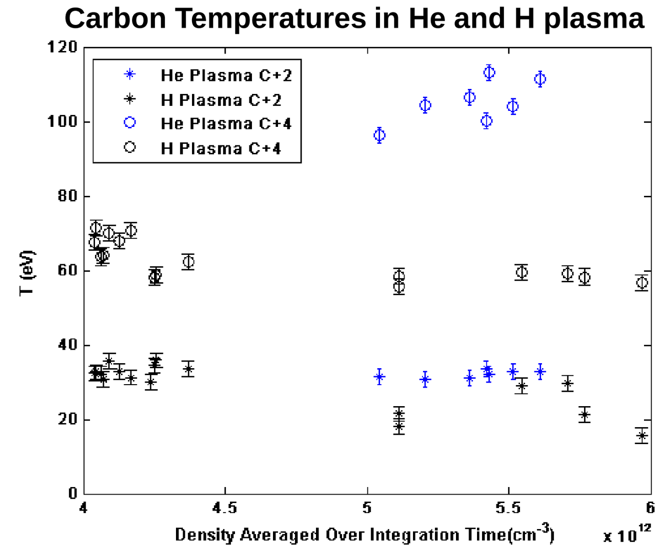
τ_{imp}=2 ms

High Power He and H Plasmas

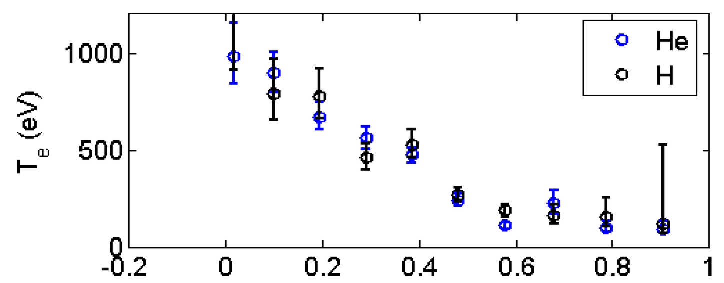
Ion Temperatures in Helium and Hydrogen 100kW Mirror Plasma

- •Carbon +4 ions show higher temperatures in helium plasmas than in hydrogen plasma
- •Carbon temperatures are independent of line averaged electron density in the observed range
- •Differences in C+4 temperature suggests improved ion confinement during He discharges, which is likely a result of decreased charge exchange power loss

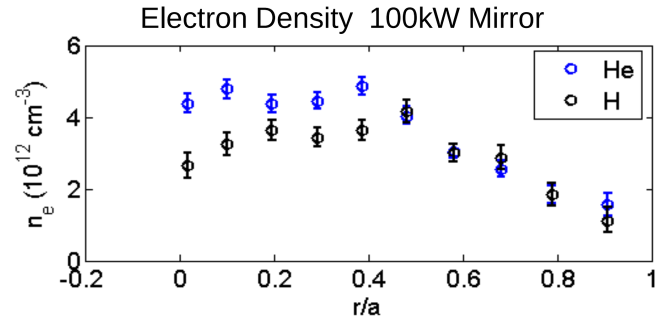
Carbon Temperatures in He and H plasma



Electron Temperatures 100kW Mirror

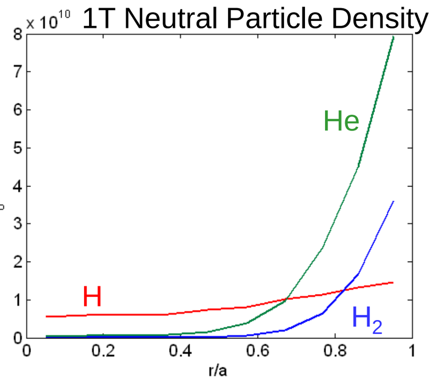


Electron Density 100kW Mirror

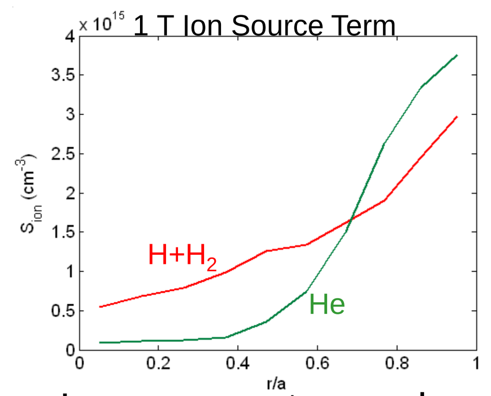


DEGAS Calculations for He and H

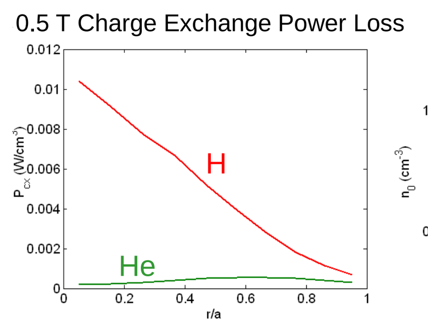
The following DEGAS calculations were performed by J. Canik

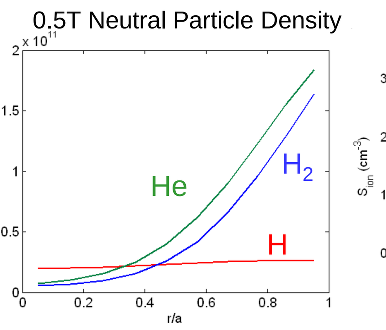


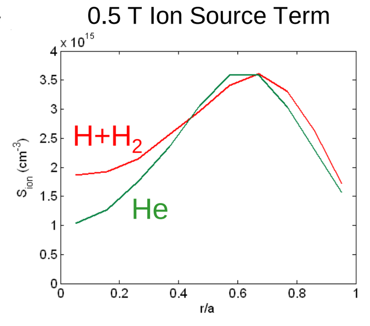
Total neutral density will be lower in the core for helium plasmas



Ion source rates are lower in the core for helium plasmas







Power lost through charge exchange is reduced through the entire plasma even when the total neutral densities are comparable because the charge exchange cross section is much smaller for helium than for hydrogen

Summary

- Measurements made using passive spectroscopy in HSX show that Carbon+4 temperatures:
  - increase with increased electron heating
  - are higher in shots with the helical symmetry broken
  - are higher in helium plasmas than hydrogen plasmas because of reduced charge exchange power loss
- Impurity ion temperatures can be used as an indicator of primary ion temperatures

Future Work

- Further study of ion transport is needed to fully explain the mechanism for the observed temperature differences
- A ChERS (Charge Exchange Recombination Spectroscopy) system is currently being developed. This will allow spatially localized temperature measurements of the entire plasma.

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