Spectroscopic Analysis of Wall Conditioning Methods in NSTX

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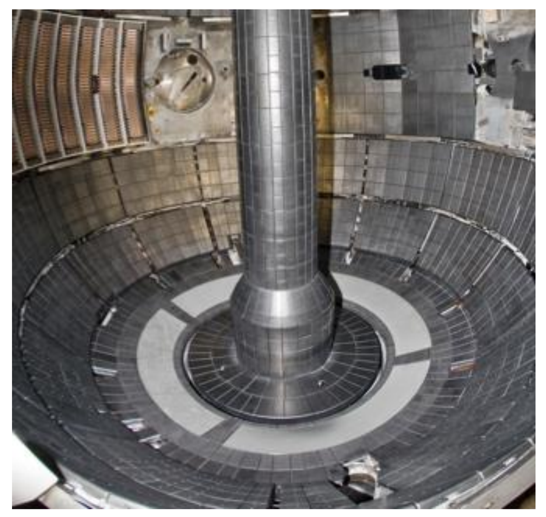
Wall conditioning improves plasma performance in NSTX

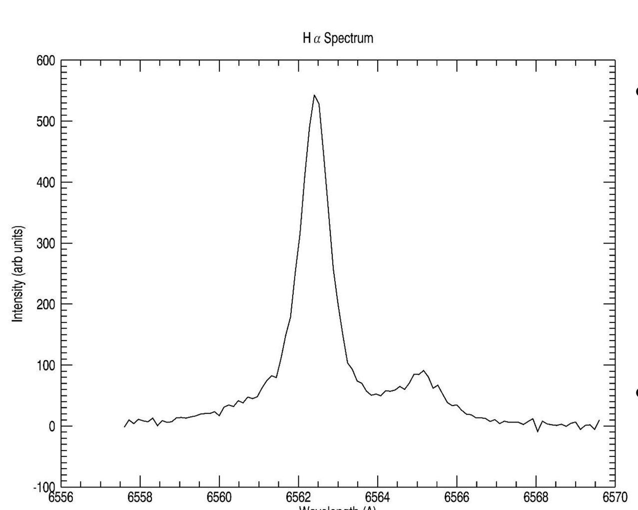
- In NSTX, plasma-facing components (PFCs) greatly affect plasma stability and performance
- Release of hydrogen-containing molecules from PFCs can increase radiative losses in the plasma
- Conditioning PFCs can reduce influx of hydrogenic atoms
- Techniques include boronization, lithium pellet injection (LPI), lithium evaporation
- Hydrogen to deuterium ratio (H/D) can indicate wall conditioning quality



NSTX divertor

Spectroscopy determines plasma properties from emitted photons

- Electrons in neutral atoms are excited by collisions in the plasma
- A photon is emitted when an electron transitions to lower energy state
- Each atom has a set of allowed energy level transitions which produce photons of specific wavelengths
- Spectrometers use diffraction gratings to observe wavelengths of interest



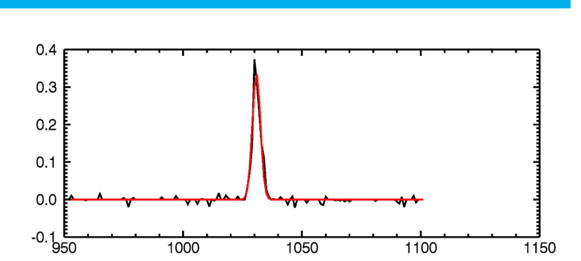
- Observed wavelength depends on the angle of incidence of the incoming light, number of grooves in the grating, and diffraction order.

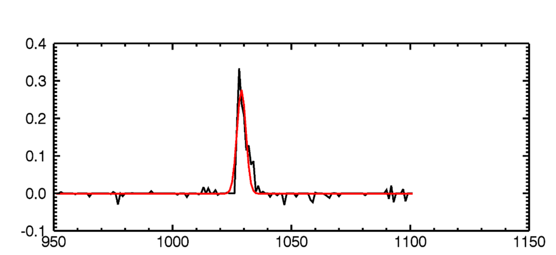
$$Gm\lambda = \sin(\alpha) + \sin(\beta)$$

- Spectral lines appear as Gaussian (right) if temperature follows a Maxwellian distribution

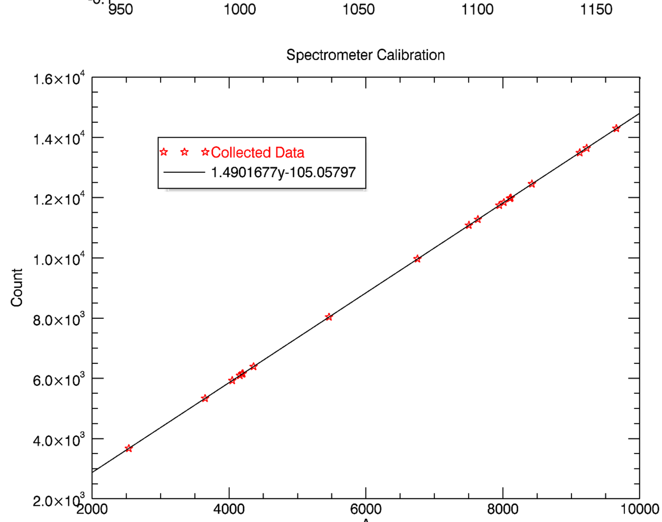
Wavelength calibration and focusing of a spectrometer

- An LC100 linear charge-coupled device (CCD) was installed on an HR-320 spectrometer
- Hydrogen spectra recorded at varying distances from CCD, fitted with Gaussians
- Focal point occurs when the full-width half-max (FWHM) is minimized.
- Right: Image of a focused (top) and unfocused (middle) spectrum.



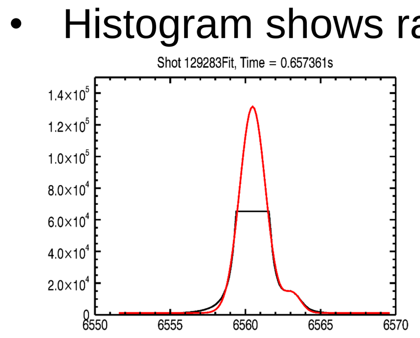


- Mercury and argon lamps used for wavelength calibration
- Right: observed wavelengths plotted with spectrometer counts, fitted with linear regression

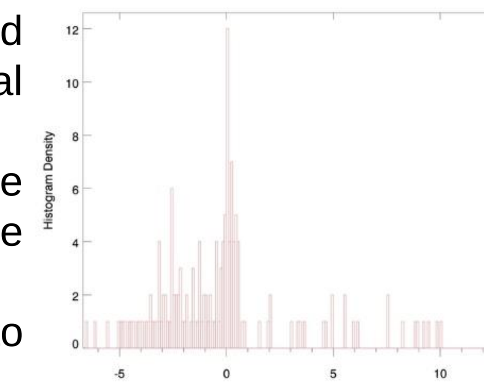


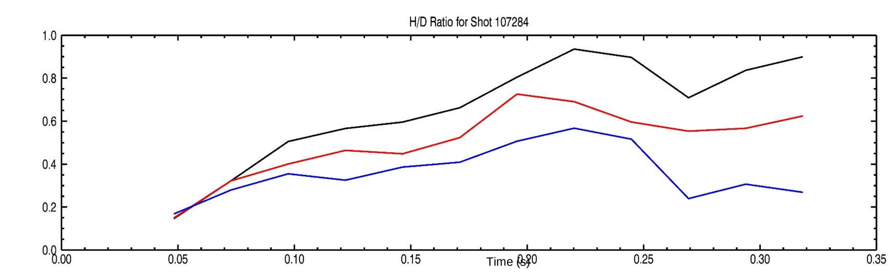
H/D ratio is determined with a curve fitting code

- Recorded spectra are assumed to be modeled by Gaussian sum and third-order polynomial background
- Interactive Data Language (IDL) procedure MPFITFUN used to find least squares fit of the model to the spectrum and output intensities.
- Saturated pixels are discounted from the data to produce better fits (bottom left)



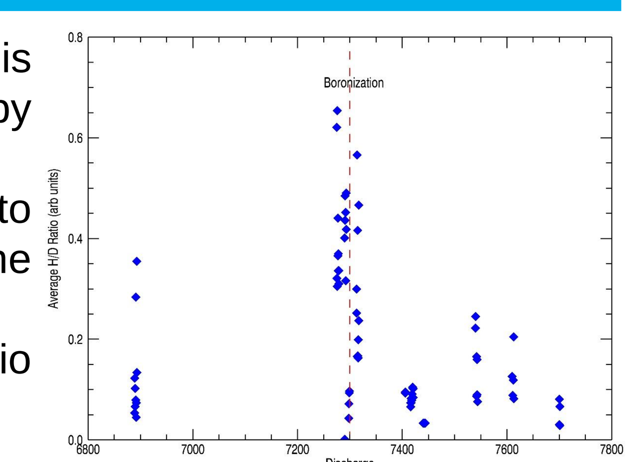
- Time-resolved H/D is produced by analyzing a series of spectrometer frames (bottom right)
- Histogram shows randomly distributed fitting error (top right)

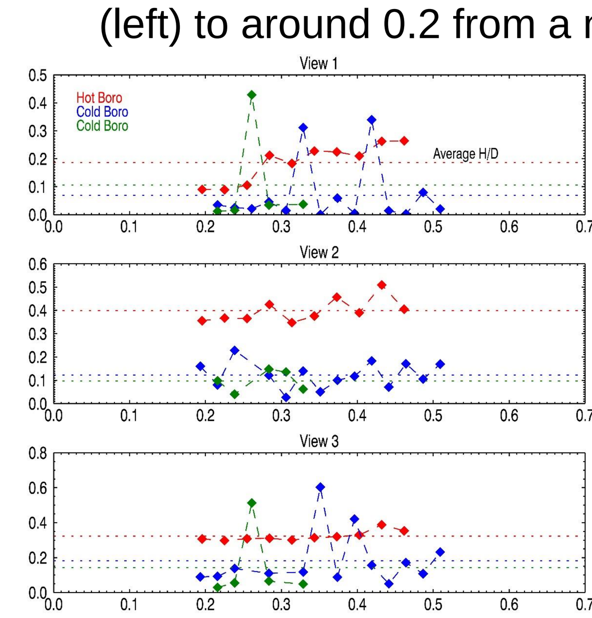




Wall conditioning methods are shown to reduce the H/D ratio

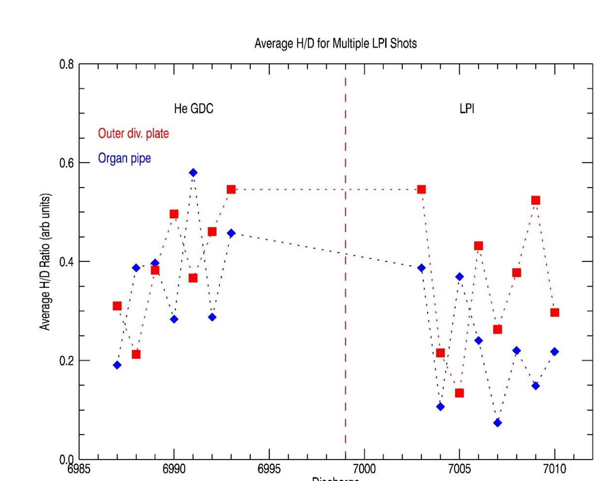
- Helium glow discharge cleaning (GDC) is used to clean PFCs of hydrogenic atoms by inducing sputtering and desorption
- Deuterated trimethylboron (TMB) is added to He GDC to deposit a thin layer of boron on the PFCs
- Boronization is shown to reduce H/D ratio (left) to around 0.2 from a max of 0.5

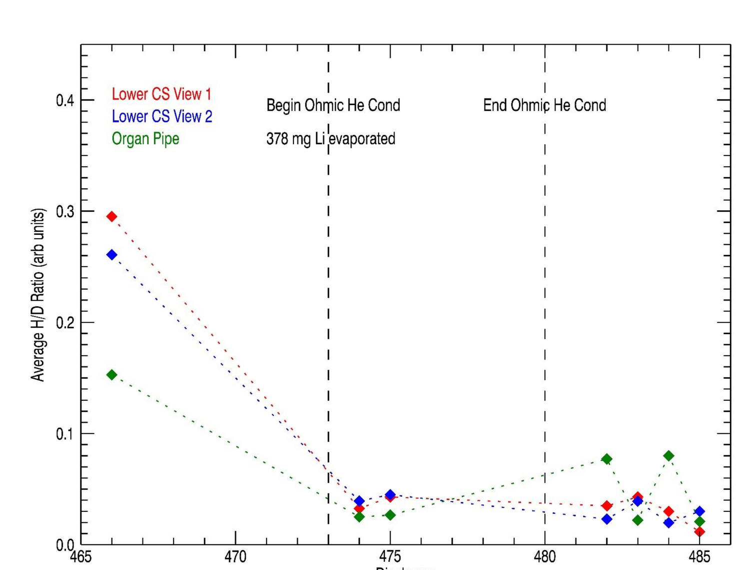




- Boronization also shown to reduce brightness of other impurities (e.g. oxygen and carbon)
- Hot boronization applied to 350 ℃ PFCs, cold boronization at room temperature
- This analysis found an increase in H brightness after hot boronization (left, red) over cold (green, blue), possibly due to thermal desorption.

- LPI launched small lithium pellets into the edge plasma to introduce a Li coating on the divertor PFCs
- This analysis did not show LPI to have a significant effect on H/D ratio.





- Lithium evaporation uses an Li evaporator (LITER) to deposit evaporated Li on the divertor.
- Li chemically sequesters deuterium and hydrogen and prevents recycling
- In conjunction with He GDC, this analysis has shown Li evaporation to significantly reduce H/D from greater than 0.25 to less than 0.1 (left).

Resolving H/D mass ratio with the HR-320

- Spectrometer calibration was used to calculate the hydrogen to deuterium mass ratio by relating mass to wavelength

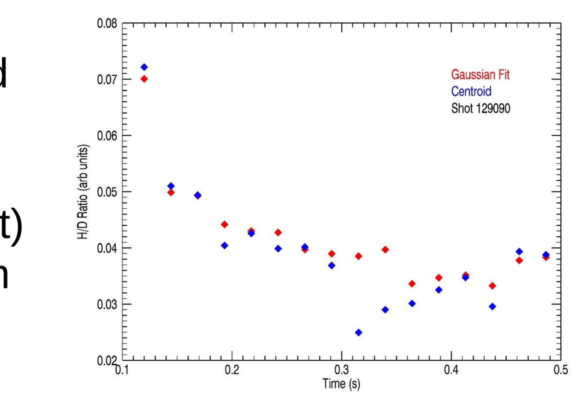
$$\frac{\lambda_H - \lambda_D}{\lambda_H} = \frac{1 - M_H/M_D}{1 + M_H/m_e}$$

- Mass ratio was calculated at 0.511 (accepted 0.500), but with an error of $\pm$ 0.3, due to human error in reading the count displayed by the spectrometer
- Mass ratio was recalculated using the linear dispersion to determine wavelength (equation follows) at 0.53 with an error of 0.03

$$r' \frac{\delta\beta}{\delta\lambda} = Gm\sec(\beta)$$

Comparison with past H/D fitting techniques

- Prior methods found the area-weighted centroid of the spectrum to resolve H/D
- The new method is found to track well with the values determined by the centroid method (right)
- The centroid method occasionally deviates from the Gaussian fit, as seen near t=0.3 s



Conclusions

- The developed code is shown to be a reliable method for determining H/D ratio
- Both boronization and Li evaporation are shown to reduce observed H/D ratio
- H/D ratio revealed no substantial correlation between LPI and decreased H brightness

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