First Absolutely Calibrated Measurements of Localized Ion Velocity in the MST in Locked and Unlocked Plasmas

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Abstract
The MST operates the Ion Doppler Spectrometer (IDS) for high time-resolution passive and active measurements of impurity ion emission. Absolutely calibrated measurements of flow are difficult because the spectrometer records data within 0.3 nm of the C²⁺ line of interest, and commercial calibration lamps do not produce lines in this narrow range. A novel optical system was designed to absolutely calibrate the IDS II. The device uses an UV LED to produce a broad emission curve in the desired region. A Fabry-Perot etalon filters this light, cutting transmission peaks into the pattern of the LED emission. An optical train of fused silica lenses focuses the light into the IDS with f/4. A holographic diffuser blurs the light cone to increase homogeneity. Using this light source, the absolute Doppler shift of ion emissions can be measured in MST plasmas. In combination with CHERS, localized ion velocities can now be measured. Currently, a time-averaged measurement along the chord bisecting the poloidal plane is used to calibrate the MST; the quality of these central chord calibrations can be characterized with our absolute calibration. Calibration errors may also be quantified and minimized by optimizing the curve-fitting process. Preliminary measurements of toroidal velocity in locked and unlocked plasmas will be shown. This work has been supported by US DOE.

Motivation
- Minimize the flow uncertainty due to calibration of the spectrometer
- Obtain an overall spectrometer calibration that contributes less than 1 km/s uncertainty to flow measurements
- Make localized measurements of ion flow in the MST

Design of Wavelength Source With Narrow Peak Near 343 nm
The Ion Doppler Spectrometer version II (IDS II) has a spectral range of a few Angstroms and commercial calibration lamps cannot provide a wavelength calibration at a C²⁺ line of interest (~343 nm). A light source was desired that can calibrate the IDS II at this wavelength.

Ultraviolet LED
- 0.3 mW LED with maximum output at 340 nm

Fabry-Perot Etalon
- SLS Optics ar-gapped etalon with mirror separation d = 0.0098 mm
- Wavelengths with an integer number of periods in 2d are transmitted; the others interfere destructively

Optical Train
- Fused silica lenses
- Magnification of 3 and light cone of f/4 to fill IDS II optics
- Holographic diffuser homogenizes the light cone and smooths structure of LED emission

Localized Measurements of Ion Flow in Locked and Unlocked Plasmas Using CHERS

The IDSII Spectrometer
- The Ion Doppler Spectrometer version II (IDS II) makes high time resolution measurement of a single emission line
- Localized flow measurements are made using CHERS, which finds the Doppler shift of the charge-exchange peak caused by interaction with a neutral hydrogen beam

Below: Toroidal view of MST. Purple is beam of neutral H and blue is view of fibers.

Flow Measurements
- In locked plasmas, the ion flow in the center of the torus decreases when the plasma locks
- Compare light source calibration to chord 7 calibration

Future Work
- Compare light source calibration to chord 7 calibration

Abstract
The wavelength of the light source must be determined to calibrate the Ion Doppler Spectrometer and measure flow. Right are the neon and etalon spectra. The two nearest neon peaks are used to determine the wavelength at the etalon peak of interest.

Value to determine Complications with Standard Calibration Optimized Curve-Fitting Method Contribution to Flow Uncertainty

Location of Neon Lines (pixel) Fit Gaussian and find centroid location Spline cubic interpolation
- Neon line is asymmetric due to spectrometer optics; so the centroid depends on the number of pixels fit Several CID images were averaged and a Carle method was used to find uncertainty for neon and etalon lines 0.5 km/s

Centroid of Desired Etalon Line (pixel) Fit Airy function and find transmission maximum Spline cubic interpolation
- Airy function model is unreliable as it is extremely sensitive to initial guesses for parameters The etalon peak is broader and more flat, causing the uncertainty in position to be greater 0.9 km/s

Wavelength at Etalon Line (nm) Parabolic best fit to neon peaks Two nearest neon lines to find straight line
- Spectrometer calibration curve is biased to match well at larger wavelengths because there are few neon lines smaller than 343 nm

Curvature of image on CCD
- Makes neon lines asymmetric (non-Gaussian)
- Nonuniform illumination of input fiber can lead to apparent shifts in line location
- Effect can be counteracted by using middle portion of image where there is less distortion

Right: Exaggeration of curvature of image on CCD camera. Emissions are non-Gaussian due to this distortion. This lineshape will be affected less by using only the shaded region of the image

Random and Systematic Uncertainty
- Monte Carlo fitting predicts 1 km/s random uncertainty on the wavelength of the etalon line
- Comparing two sets of images, the Monte Carlo predictions were within 0.3 km/s
- Using calibration, the wavelength of a nearby neon line was predicted. The prediction was within 0.02 A of the published wavelength, implying a systematic uncertainty of 1.6 km/s
- Systematic uncertainty could be reduced by instead using three lines for a parabolic fit near the line of interest

Future Work
- Quantify systematic error introduced because the IDS II and CCG spectrometer have different instrument functions
- Confirm systematic error in etalon peak calibration by calibrating the IDS II for a neon line with known wavelength rather than the C²⁺ line

Conclusions
- Standard calibration procedures are complicated by the asymmetry of lineshapes introduced by spectrometer optics.
- Random uncertainty in a spectrometer calibration was reduced to 1 km/s by using cubic interpolations to find line maxima and a Monte Carlo method to determine uncertainty.
- Localized toroidal flow data respond to plasma locking, and a central chord calibration should be able to absolutely calibrate these measurements.

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