Development of a Spectroscopic Technique for Simultaneous Magnetic Field, Electron Density, and Temperature Measurements in ICF-Relevant Plasmas

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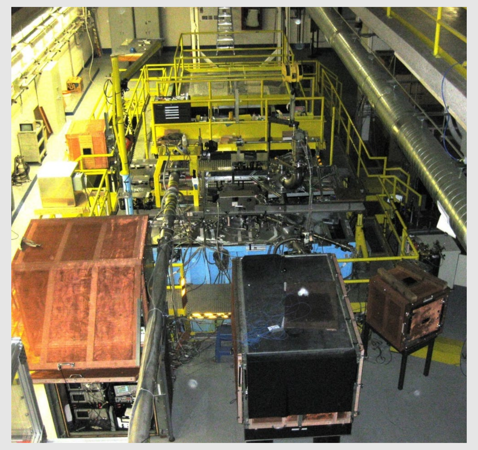
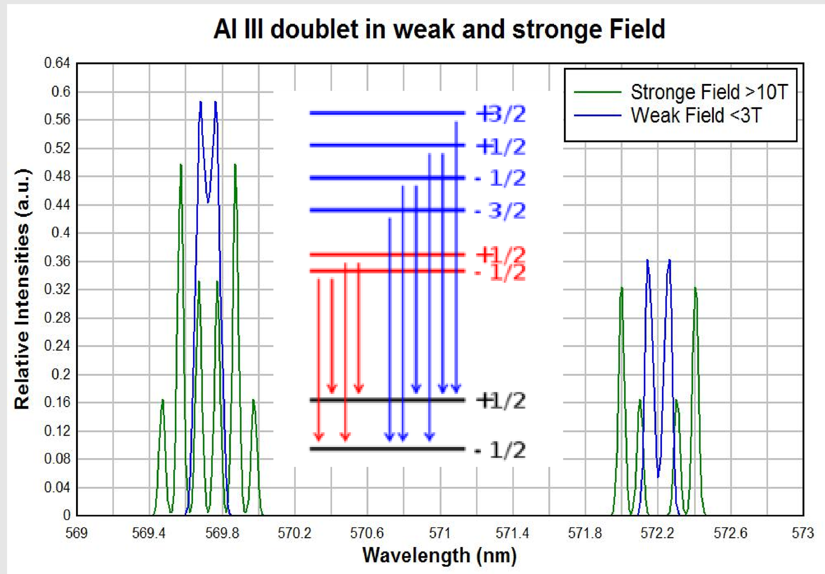
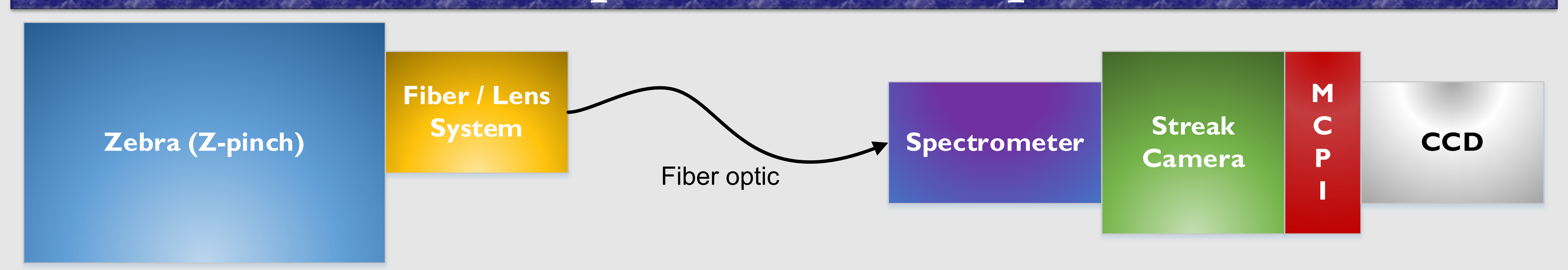
Introduction and Motivation



Visible spectroscopic techniques in the visible range are often used in plasma experiments to measure B-field induced Zeeman splitting, electron densities via Stark broadening, and temperatures from Doppler broadening. However, when electron densities and temperatures are sufficiently high, the broadening of the Stark and Doppler components can dominate the emission spectra and obscure the Zeeman component. In this research, we are developing a time-resolved multi-axial technique for measuring the Zeeman, Stark, and Doppler broadened line emission from dense magnetized plasmas in Z-pinch and Dense Plasma Focus (DPF) accelerators. The line profile is used to calculate the electron densities, temperatures, and B-fields. Experiments were conducted at the University of Nevada (Reno) Nevada Terawatt Facility (NTF) using the 1 MA Z-pinch (Zebra). The research explored the broadening and splitting of Al III doublet, 4p $^2P_{3/2}$ to 4s $^2S_{1/2}$ and 4p $^2P_{1/2}$ to 4s $^2S_{1/2}$ transitions. Optical light emitted from the pinch is fiber coupled to high-resolution spectrometers. The dual spectrometers are coupled to two high-speed visible streak cameras to capture time-resolved emission spectra from the experiment. The data reflects emission spectra from 100 ns before the current peak to 100 ns after the current peak, where the current peak is approximately the time at which the pinch occurs. The Al III doublet is used to measure Zeeman, Stark, and Doppler broadened emission. The line emission is then used to calculate the temperature, electron density, and B-fields. The measured quantities are used as initial parameters for the line shape code to simulate emission spectra and compare to experimental results. Future tests are planned to evaluate technique and modeling on other material wire array, gas puff, and DPF platforms.



Experimental Setup



- Wire arrays, gas puff, and ablation targets are used as "loads" in the 1MA class pulsar (Zebra). These "loads" spread across the anode cathode gap. Wire loads ohmically heated creating a coronal plasma. Plasma is then ablated from the wire cores by radiation and heat conduction and is driven by the j x B force toward the z-axis
  - Picture shows an inverse conical load (picture below), z-axis is centered l between the wires running between the anode and cathode (top to bottom)
- Light is collected from the stagnation region of the pinch through a Lens and fiber collimator. This is then routed through a fiber optical feed-through out of the Zebra chamber and coupled to spectrometer system where the input fiber is imaged onto the slit.
  - Slit width is set to 50 µm
- Spectra Pro Model 2750
  - 150 gr/mm, 1800 gr/mm, 2400 gr/ mm

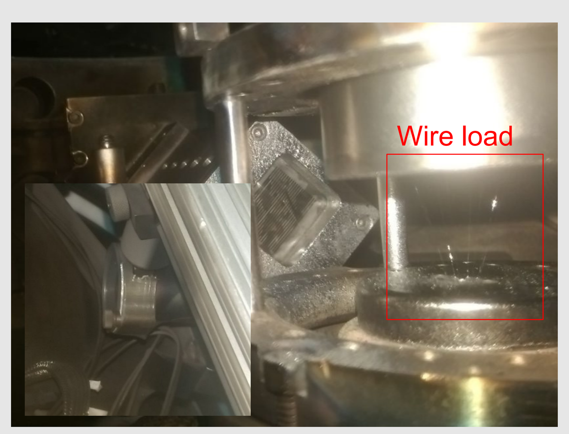
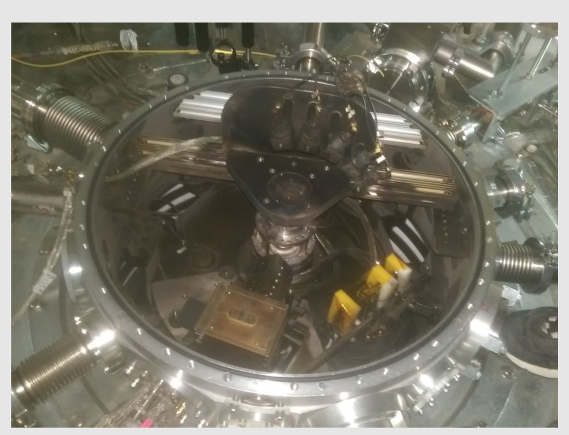
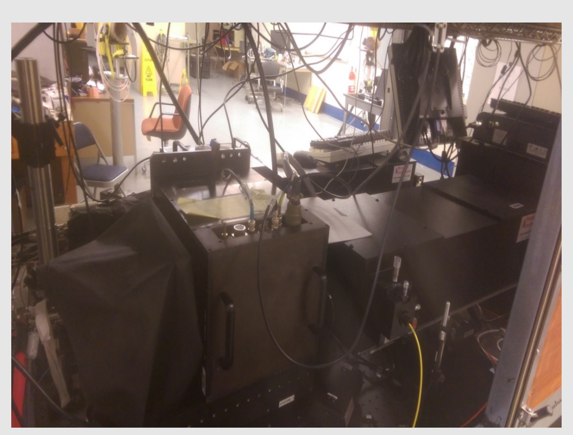


Image to the left: Optical Probe
Image to the right: Conical wore array load

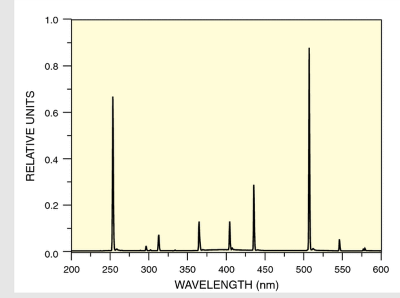


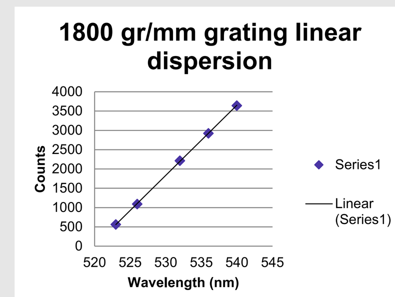
Zebra Chamber, load placed center of chamber

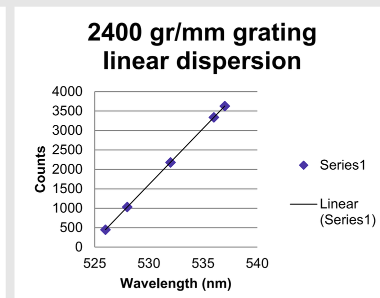


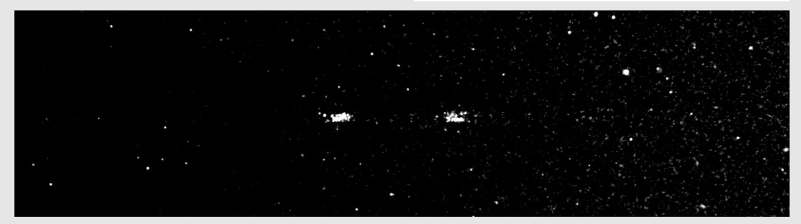
Streaked spectrometer system

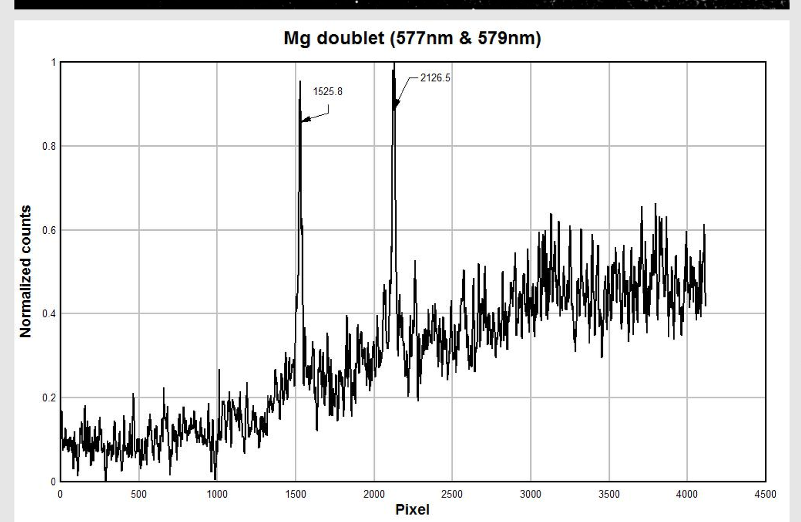
Streaked Spectrometer Characterization







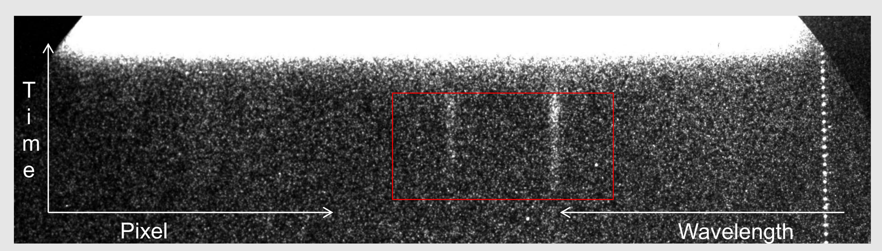


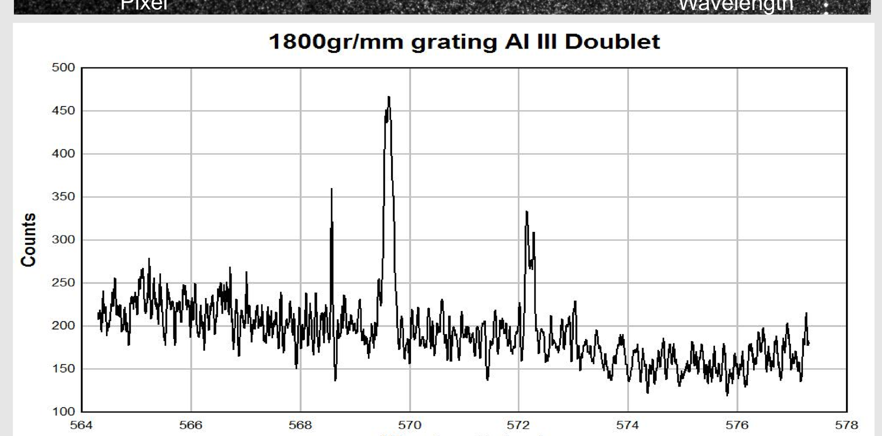


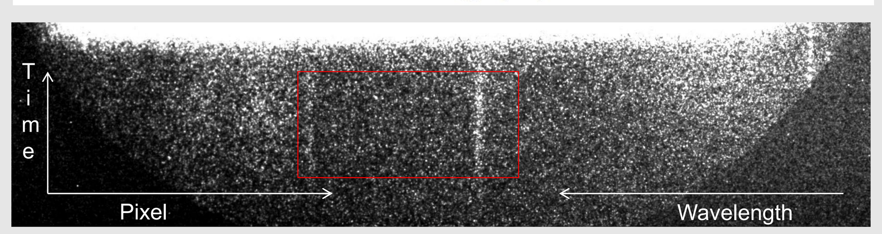
A Newport 6035 Hg (Ar) calibration lamp is used to characterize the streaked spectrometers linear dispersion for each grating (150gr/mm, 1800 gr/mm, and 2400gr/mm).

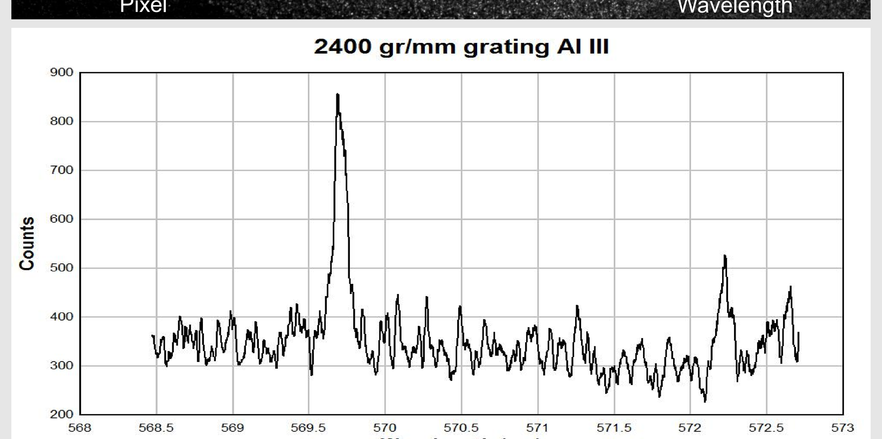
- For the 150 gr/mm grating multiple spectral lines from the calibration lamp is imaged across the slit. The spectral lines are located a specific pixels and the wavelength are known. Linear dispersion is then calculated
- For the 1800 gr/mm and 2400 gr/mm grating this single spectral line, 534.1 nm (Hg), is used to characterized the linear dispersions
  - 534.1nm is set to center wavelength on the spectrometer. This corresponded to a center pixel location on the streak camera system. Center wavelength on the spectrometer is varied, left and right across the slit. Pixel location and varied wavelength is record and used to determine linear dispersion across the slit.
- The resulting linear dispersion for the1800 gr/mm grating is 0.0054 nm/pix.
- The resulting linear dispersion for the 2400 gr/mm grating is 0.0032 nm/pix.
- Mg doublet (577 nm and 579 nm) is used to verify linear dispersion on both high resolution gratings.

Zebra Streaked Spectroscopy Data



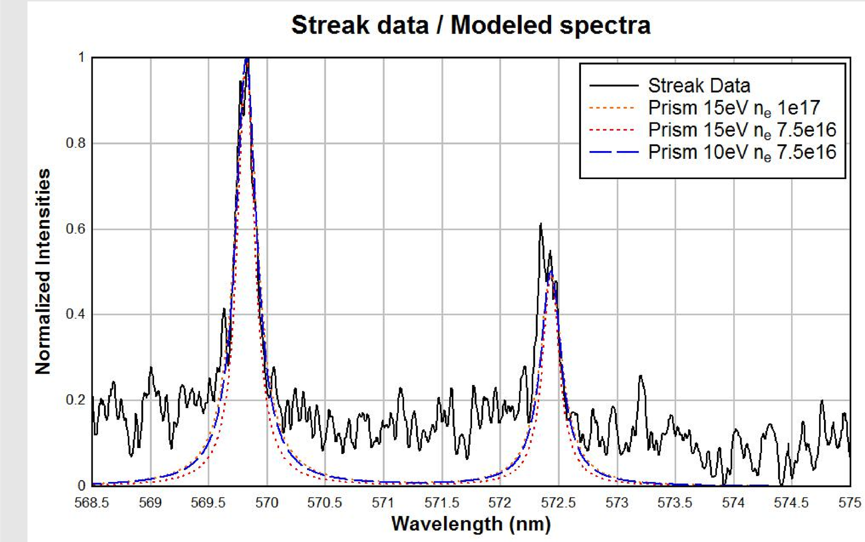


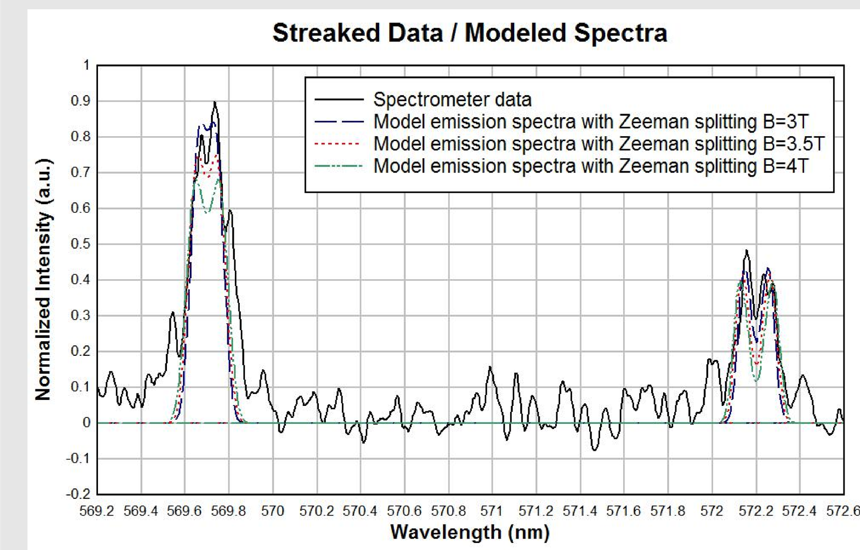




- Cylinder, conical, and X wire array loads are used in the Zebra machine.
- Initial probing experiments used grating #1 (150 gr/mm) to identify Al III doublet and to identify emission time frame
- Time resolved spectral data is obtained using grating # 2 (1800 gr/mm) centered around the Al III doublet (570nm).
  - Spectral line emission occurs 100 ns before current peak due to ohmic heating for the wire arrays
    - Line emission duration approximately 80 ns
  - Lineout taken 40 ns in to line emission, averaged over 20 ns
- Results obtained with Grating # 3 (2400 gr/mm)
  - The spectral line emission occurs 100 ns before current peak
    - The line emission duration was measured to be approximately 80 ns
  - The lineout taken 40 ns in to line emission and averaged over 20 ns

Analysis





Analysis of streaked spectra using grating #3 (high resolution grating)

- Lineout of Al III doublet is taken from streaked image, 100ns before current peak, averaged over 20ns
- Modeled spectra of the Al III doublet, is plotted with the streaked data of the Al III doublet
  - Line intensity for Al III doublet is used to bound temperature ~5-15 eV
  - Stark broadening/pressure broadening parameters are varied in the model until an approximate fit is achieved n_e~1e16-7.5e16
- Modeled spectra from PrismSpec is used as an input parameter in Zeeman Splitting code
  - Modeled line emission spectra, including Zeeman splitting due to Magnetic fields are modeled, plotted and compared to data
- Process is iterated to find best fit
  - Results from modeled spectra estimates B-fields ~3-4T

Conclusion and Future Work

- Streaked spectra of Al III doublet can be captured from Aluminum wire array loads used for Z-pinch plasmas
- Spectra can be used to measure electron density, temperature, and magnetic fields.
  - Al III doublet can be used for low temperature > 20 eV.
- Future work should look at other material or dopants for loads.
  - Na can be used for temperatures >100 eV.
- Explore laser ablation Z-pinch targets.
- Explore gas puff experiments.
- Expand approach to other machines, specifically dense plasma focus.

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Poster Information

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