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Spectroscopic Analysis of the Self-Magnetic Pinch Diode Used in Flash X-ray Radiography Research

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Abstract

Investigations are underway at Sandia National Laboratories' RITS-6 accelerator facility (10MV and 120kA) to study plasma formation and propagation in electron beam diodes used for flash x-ray radiography. In particular the Self Magnetic Pinch (SMP) Diode[1] has been studied using time and spatially resolved optical diagnostics to gain an understanding of the role of plasmas in diode performance. The SMP diode employs a hollow metal cathode and a thin aluminum foil anode in front of a high atomic number target to produce bremsstrahlung x-ray radiation. Results show plasma formation beginning during the second half of the (~70ns) x-ray radiation pulse. While plasma formation is observed on both the cathode and anode, it is predominantly the anode plasma which expands across the A-K gap region (~10mm). Data shows the presence of hydrocarbon and aluminum ion species with expansion velocities of a few 10's of cm/microsecond. Spectroscopic analysis is performed using time-dependent, collisional-radiative models to provide plasma density and temperature information. Diagnostics include optical imaging using gated, intensified CCD cameras, and gated/streaked spectra obtained using 1 meter Czerny-Turner monochromators. Recent results are presented.

1. J.E. Maenchen, et al., "Advances in Pulsed Power-Driven Radiography Systems," Proc. IEEE, Vol. 92, No. 7, pp. 1021-1042, 2004.

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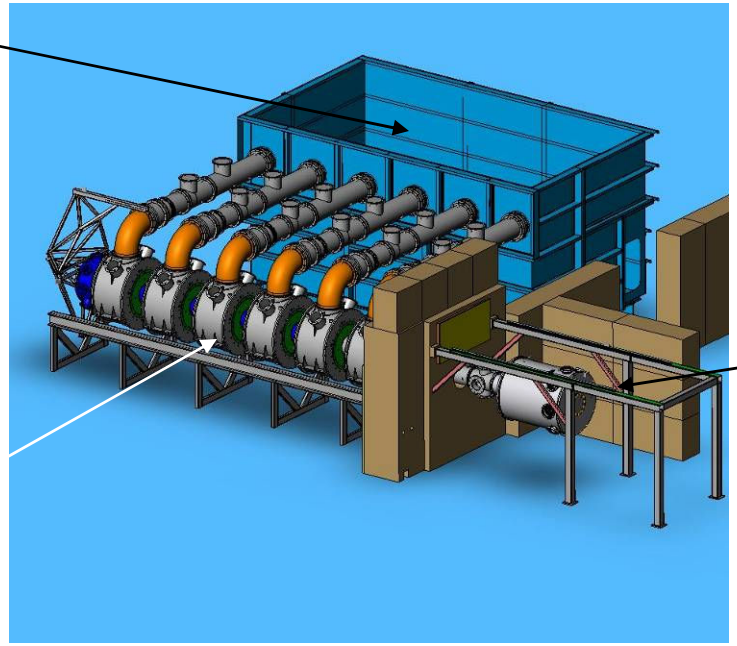
RITS-6 Accelerator at Sandia National Laboratories

RITS-6 is a 8-12 MV Marx driven six-stage Inductive Voltage Adder (IVA) capable of driving a variety of flash x-ray radiography diode configurations

- 60 ns FWHM pulse width
- >400 R x-ray doses at 1meter



Diode Region

- Commissioned Fall 2005
- Optical Diagnostics Initiated Fall 2006

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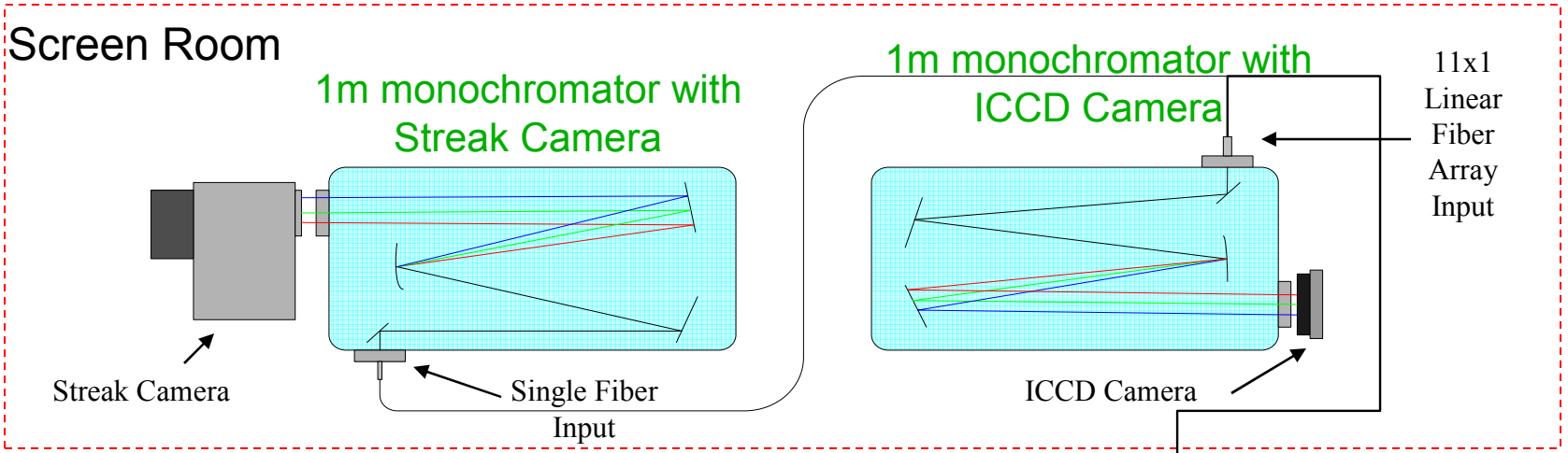
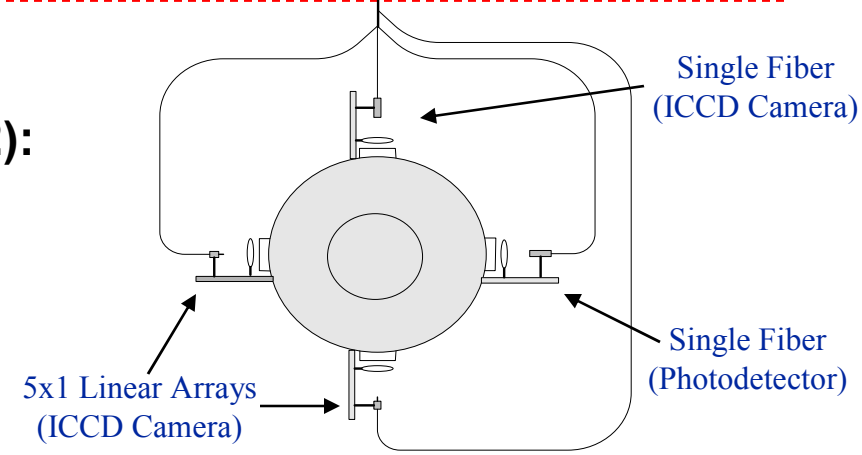
Experimental Setup for Spectroscopy Diagnostics on RITS-6



- **McPherson Model 2061 Monochromator (2):**
  - **1 meter instruments with L-CA-24 Streak Camera and PI-Max ICCD Output Detectors**
- **Photek Nanosecond Gated Camera (2)**
- **Silicon PIN Photodetector (8)**



Optical Fiber Arrangement around RITS chamber

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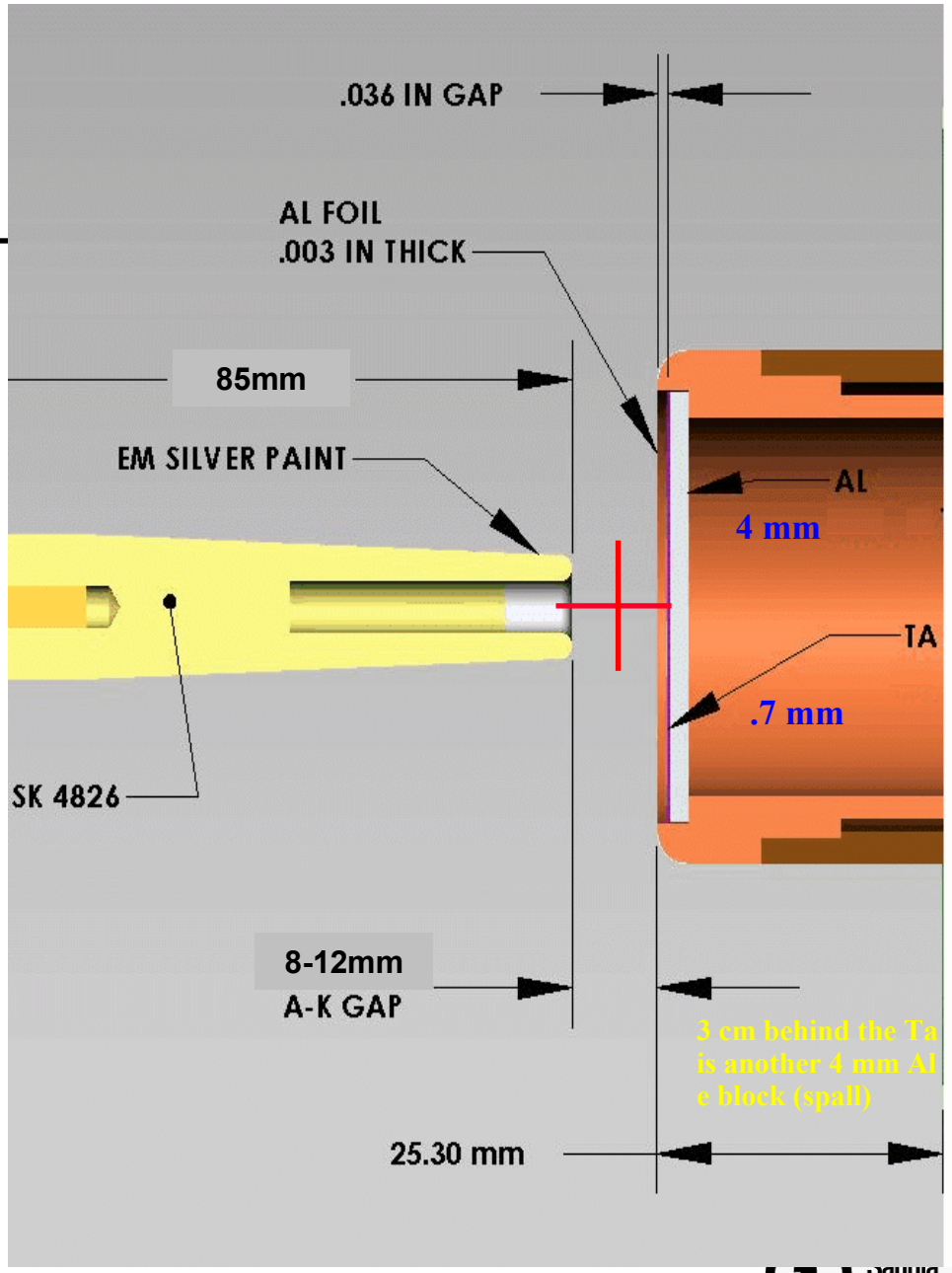
SMP Diode Configuration

For the SMP diode, the cathode is aluminum with colloidal silver on the tip. The A-K gap is variable between 8.0-12.0mm, and the target is 2” diameter Ta behind a thin Al foil. Fiber array #1 looks across the A-K gap at the centerline, and Fiber array #2 looks perpendicular to the beam in front of the cathode in the A-K gap.



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Purpose of Plasma Spectroscopy Experiments

- Identify plasma species in space and time.
- Obtain plasma information including charge states, electron and ion temperatures, and densities.
- Study the effects of plasma formation on diode impedance.
- Provide experimental validation for plasma physics modeling.

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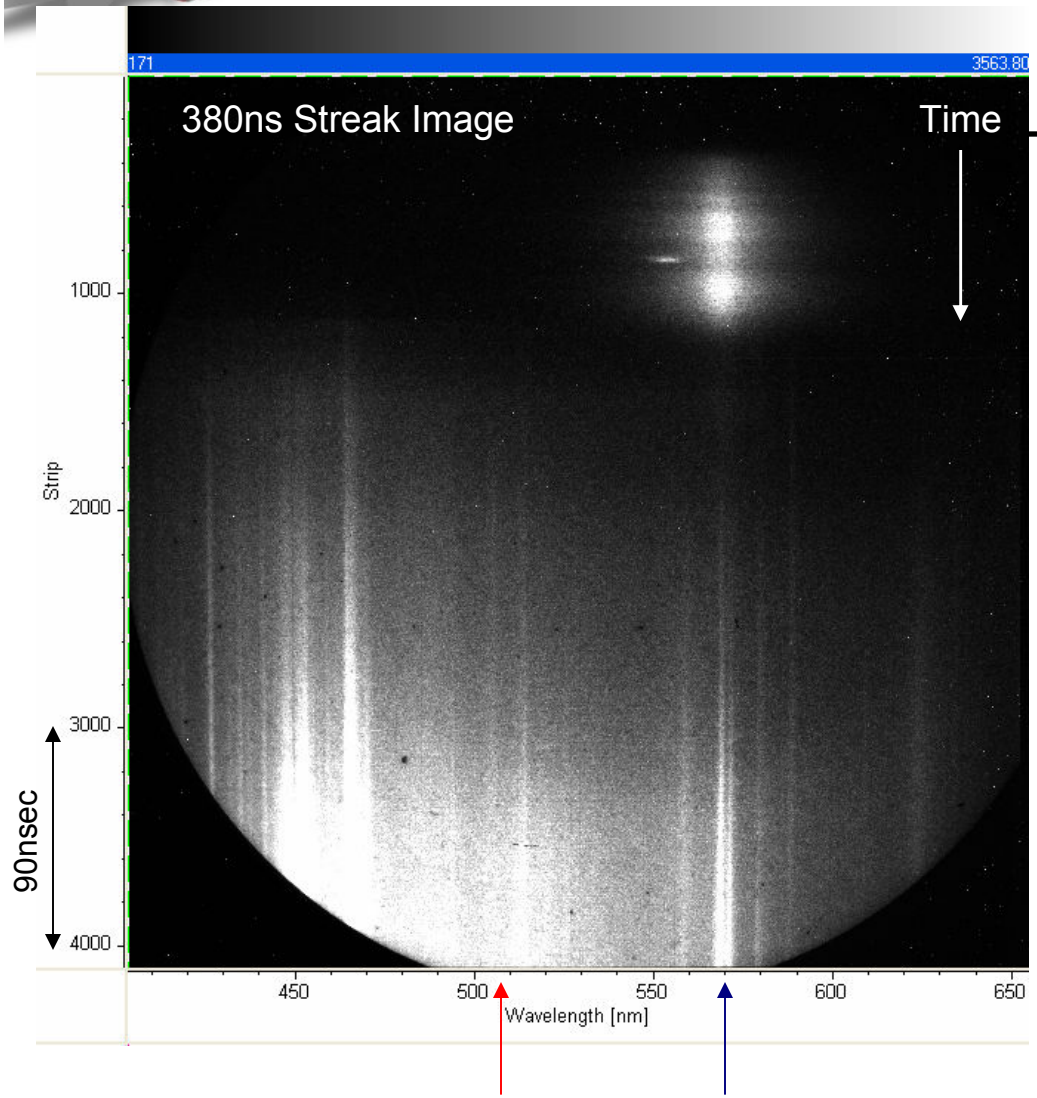
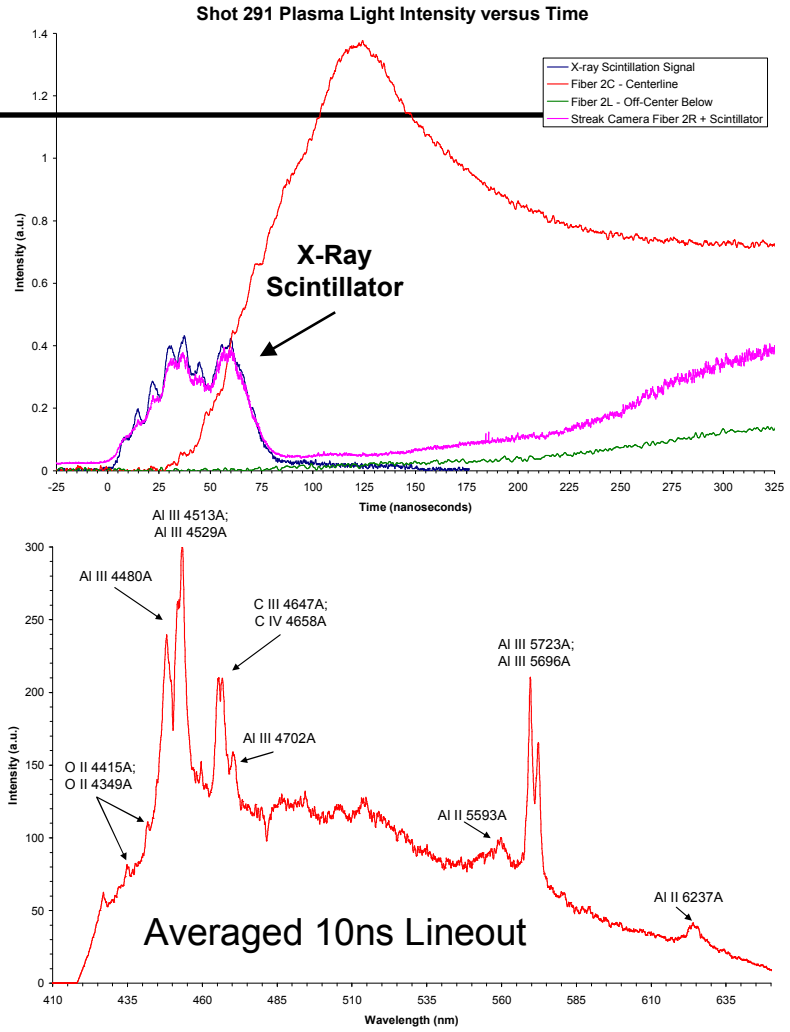
Streak Camera Spectra: SMP Diode





85mm long, 12.5mm diameter, Al cathode w/ silver tip, and 12mm A-K gap

Fiber 2R 7.5mm Off-Center
9.0mm From Cathode Tip

Shot 291

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CR Modeling of SMP Diode Plasmas

- Time dependent collisional-radiative modeling of plasma parameters[1].
- Determinations of electron densities, percent ionizations, intensities, and opacities.
- Calculations of aluminum and carbon line shapes, which include quasistatic ion, electron impact, and ion dynamic effects.
- Self-consistent calculations of line shapes, including Stark, Doppler, and opacity effects.

1. E. Stambulchik and Y. Maron, "A Study of Ion-Dynamics and Correlation Effects for Spectral Line Broadening in Plasma: K-shell Lines," Journal of Quantitative Spectroscopy and Radiative Transfer, Vol. 99, pp. 730-749, 2006.

Analysis of SMP Spectral Data

- Line shapes (Stark broadened) give plasma electron density (N_e).
- Line ratios give electron temperature (T_e).
- Absolute line intensities give non-protonic ion densities (N_i).
- Absolute continuum intensity gives electron density (N_e).
- Proton density (N_p) determined from electron and non-protonic ion densities.

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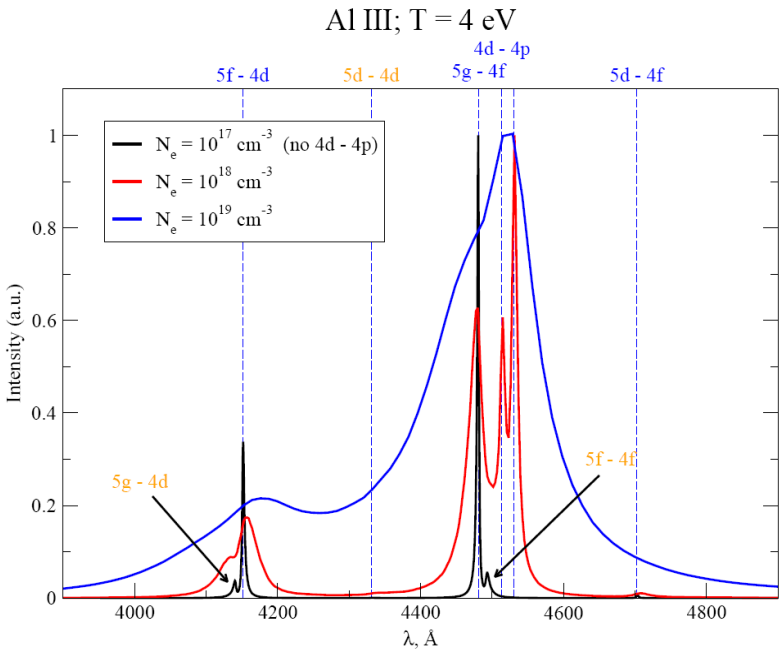
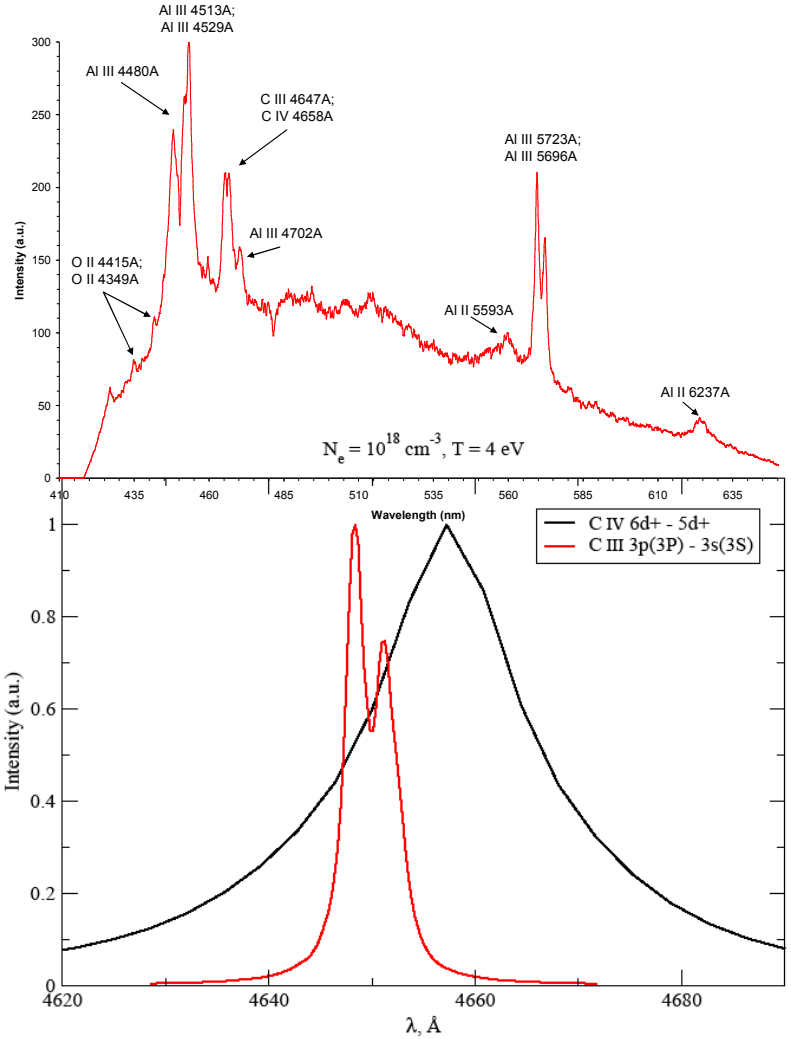
Spectroscopic Analysis

- **Electron Density: 5×10^{17} cm^{-3}**
- **Electron Temperature: 4eV**
- **Aluminum Ion Density: 3×10^{14} cm^{-3}**
- **Carbon Ion Density: 6×10^{14} cm^{-3}**



Calculated Al III Lineshapes



Calculated C III and C IV Lineshapes

Summary and Conclusions

- Optical spectroscopy diagnostics were fielded on the SMP diode on RITS-6.
- Time and spatially resolved spectra were collected.
- Spectra were analyzed by comparing experimental carbon and aluminum lineshapes to those calculated from a two-species, time-dependant, collisional-radiative model.
- Electron temperatures and densities were determined, and the ratio of line intensities to continuum provided absolute ion species densities.
- Since the absolute species densities were determined to be much lower than the electron densities, it is determined that the plasma is composed primarily of protons.

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