AIAA Newsletter

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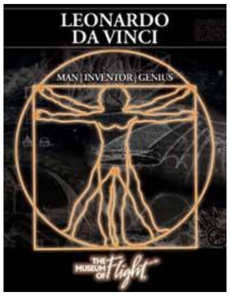

PNW AIAA 2006 –2007 Year

From the Left Seat

I'd like to welcome everyone to the 2007-2008 year for the PNW Section of AIAA. I have big shoes to fill, taking over the Chair position from Paul Kostek. Paul did an excellent job as the 2006-2007 Chair and has set a high bar for those that follow. I welcome the returning members of the Council, and look forward to new members we will be electing.

Each year we hold elections for council positions in the Spring/Summer. I encourage everyone to vote when you receive your ballots. I'd also like to encourage you to consider running for a council position in the future. Being active in the Section is a good way to be "connected." In my years on the Council, I have learned a lot about the aerospace industry in the Pacific Northwest.

Before I became active in the Section, I never put a moment's thought into the monthly dinner meetings. As a Council member, I made it a point to attend every one, when I was in town. I hadn't realized what I was missing. For example, last year, we had two AIAA Distinguished Lectures, learned about how moths fly, and learned about expensive Italian sports cars. We heard from a B-52 test pilot and learned about winglets. All of the lectures were educational and at a level everyone can enjoy. Plus, it is fun meeting friends and acquaintances on a regular basis. I would like to encourage all of you to mark your calendars and set aside the third Tuesday of each month for the AIAA PNW Section dinner meetings, starting in September (there may be exceptions to the day in some months).

I hope to see you at our first dinner meeting of the 2007-2008 Season in September!

Scott Eberhardt
2007-2008 PNW AIAA Chair

UW Student Branch Wins Award

Congratulations to the University of Washington AIAA student chapter for receiving the 2005-2006 Outstanding Student Branch award for the Western Region (VI) of AIAA. The student branch receives a $200 cash award along with a certificate that will be displayed in the department's renovated Guggenheim Hall.

ZaP Flow Z-Pinch Plasma Spectroscopy

The following paper by Genia Vogman was submitted at the April 2007 Region VI Student Research Conference.

Genia is an undergraduate research assistant in the Department of Aeronautics & Astronautics at the University of Washington. Professor Uri Shumlak was the advisor.

PNW AIAA Election

The 2007-2008 PNW AIAA elections will soon be taking place. Check the section website, www.pnwaiaa.org, which will soon contain information on candidates and voting instructions.

ZaP Flow Z-Pinch Plasma Spectroscopy

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The ZaP Flow Z-Pinch experiment is an innovative plasma confinement concept that uses a J×B force to compress and a sheared flow to stabilize an otherwise unstable column of plasma. The applications for a steady-state plasma configuration include fusion power production, high-energy space propulsion, and semiconductor photolithography. In order to study the characteristics and longevity of the pinch, the experiment utilizes an array of diagnostics including magnetic probes, holography, interferometry, photodiodes, and spectroscopy. Spectroscopy - the analysis of discreet light spectra emitted by the ions in a plasma - is a useful tool for checking measurement accuracy and analyzing overall plasma behavior. Oblique and radial-viewing telescopes are set up on the experiment in order to capture twenty chords of light data corresponding to twenty different locations along the one-centimeter diameter of the pinch. Investigating light intensity and wavelength in specific locations and times of the pinch lifetime yields qualitative and quantitative information regarding the impurities, temperature, and bulk velocity profile of a given plasma. The results of a recent 200 to 700 nanometer wavelength spectral survey effectively map impurities for the period in which a hydrogen plasma is stable. Examining the temporal behavior of plasma through this spectral data in ZaP will improve our understanding of plasma instabilities and ensure optimized methods of confinement.

Nomenclature

a	Z-pinch diameter
k	wavenumber
λ	wavelength
T	Temperature
w	Gaussian full-width half max
V_A	Alfven velocity
v_z	Plasma flow velocity, cm/μs

I. Introduction

Plasma is a highly-energized and dense ionized gas that has extensive applications in propulsion, fusion, and electronics. Unfortunately, the same properties that make it useful - extreme conductivity and high temperatures - also tend to make it susceptible to instabilities which cause it to be short-lived and hence difficult to work with. Currently a variety of geometries are being used to explore ways to confine plasma for extended periods of time. These geometries range from toroidal to columnar setups and are investigated for their stabilizing effects. The ZaP Flow Z-pinch is one such confinement mechanism. The use of spectroscopy as a diagnostic tool in the experiment yields important information regarding plasma characteristics and offers a way to assess the hardware in the experiment.

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II. Plasma Confinement and the Zap Flow Z-Pinch Experiment

The ZaP Flow Z-pinch uses a simple design to create a plasma column that is confined by its own magnetic field. A Z-pinch generates a column of plasma with an axial current flowing from an inner electrode to an outer electrode (see Fig. 1).

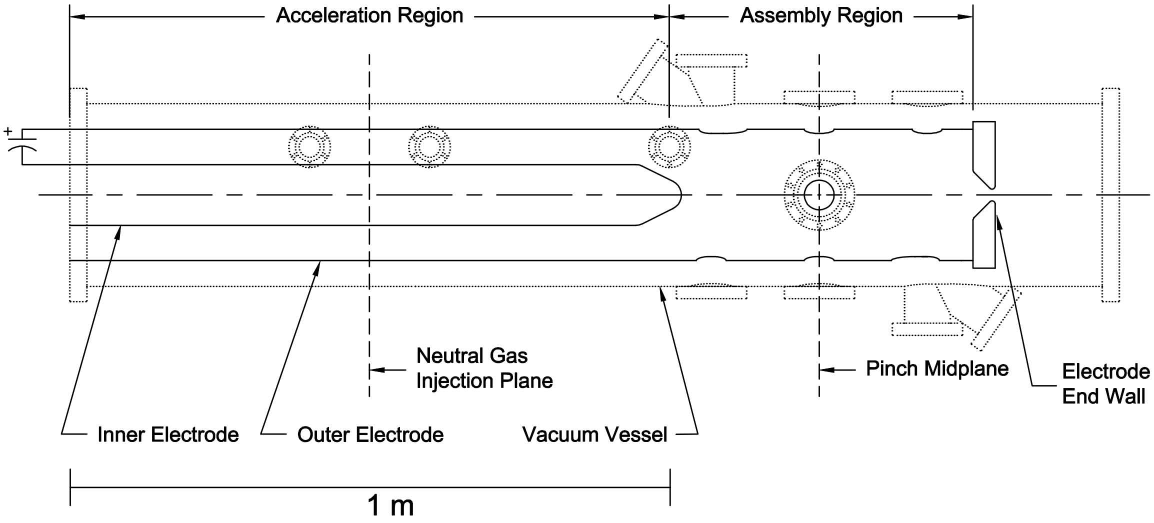

Figure 1. Side view of the ZaP Flow Z-Pinch experiment apparatus: The outer vacuum chamber contains an inner and outer electrode.

In order to create a plasma, a neutral gas is puffed between the two electrodes whose potential difference causes the gas to separate into its ion and electron components thereby forming a plasma. The plasma is then axially accelerated into the assembly region by the current that flows through it from the inner to the outer electrode. The resulting azimuthal magnetic fields (see Fig. 2) confine and compress the column producing a hot, dense, and stable plasma. The ZaP Flow Z-Pinch experiment at the University of Washington investigates sheared flow as a way to mitigate plasma instabilities and create a stable pinch. Experimental trials have confirmed that quiescent, or stable, periods correspond to times when velocity shear exists in the pinch. A stable plasma column results when a shear of $v_z/a \geq 0.1$ kV_A is achieved.

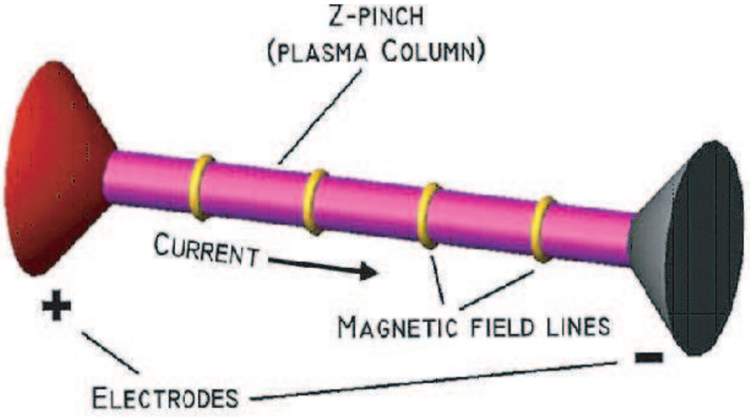

Figure 2. The J×B force that results from the ZaP Flow Z-Pinch experiment geometry generates a columnar plasma pinch. As a result the plasma is essentially confined by its own magnetic field.

III. Spectroscopy as a Diagnostic Tool in the ZaP Experiment

Because of the extreme temperatures associated with plasma, certain measurements in the ZaP experiment must be carried out through passive means such as spectroscopy. Spectroscopy provides a means of collecting and analyzing the light emitted by a given plasma and consequently offers a way to examine its temporal and spatial characteristics as well as its temperature. Spectroscopy separates the light emitted by a plasma into discrete lines each of which represents a particular ion at a distinct energy level (see Fig. 3). The energy level configuration in a given ion depends on the element and how many electrons it has. The larger the difference in energy levels, the more energy released by the electron, the smaller the wavelength of light emitted. Some ions will emit light at wavelengths within 0.001 nanometers of each other, but can still be distinguished based on the presence of other emission lines. For instance C III and Hg IIX lines may lie very close to each other in the region of 228 nanometers, but the appearance of other C III lines at other wavelengths (for instance at the 416 nanometer region) and the absense of other Hg lines would indicate that C III is the ion being observed. Therefore every ion can be identified on the basis of its energy level configuration, and its signature set of spectral lines.

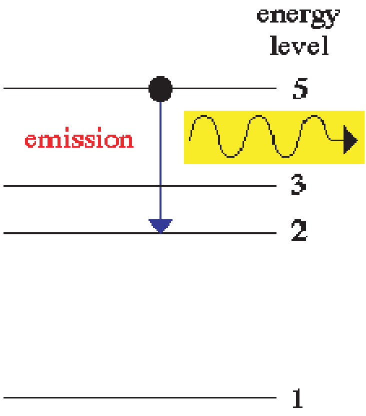

Figure 3. When an electron drops from a high energy level to a lower energy level it emits a distinct wavelength of light.

Hydrogen plasmas, which are used for spectroscopy measurements, are unique in that they are composed of ions that are fully stripped and do not emit line radiation. However, impurity ions, which inevitably exist in the experiment, are of great interest in that they provide qualitative information regarding the temperature of a given plasma. Hence the identification of these impurities through spectroscopy allows for a mapping of temperature with respect to time and position, and therefore a characterization of the plasma dynamics in the experiment.

IV. Spectrometer Diagnostic Converts Light into Electric Signals

In order to obtain discrete spectra, the light emitted by the plasma must be collected and then separated into its components. A radial-viewing telescope which is situated perpendicular to the pinch collects the light and a twenty-chord fiber-optic cable then transports it from the telescope to the spectrometer. The cable transmits chord-integrated light in such a way so as to have each fiber correspond to a distinct chord through the one-centimeter diameter of the pinch. The spectrometer diffracts the light into its components which enter an intensified charge-coupled device (ICCD). The ICCD then translates the light spectra into electric signals which can be read by computer software such as WinSpec (see Fig.4). The spectrometers resolution and signal yield can be adjusted by changing the diffraction grating among three settings; 150, 2400, and 3600 grooves per millimeter. The higher the groove count, the higher the resolution of a given spectral line, the smaller the range of wavelengths that can be viewed by the instrument. Its important to use more than one grating setting in plotting impurities so that the spectral line location relative to other lines can be analyzed with accuracy.

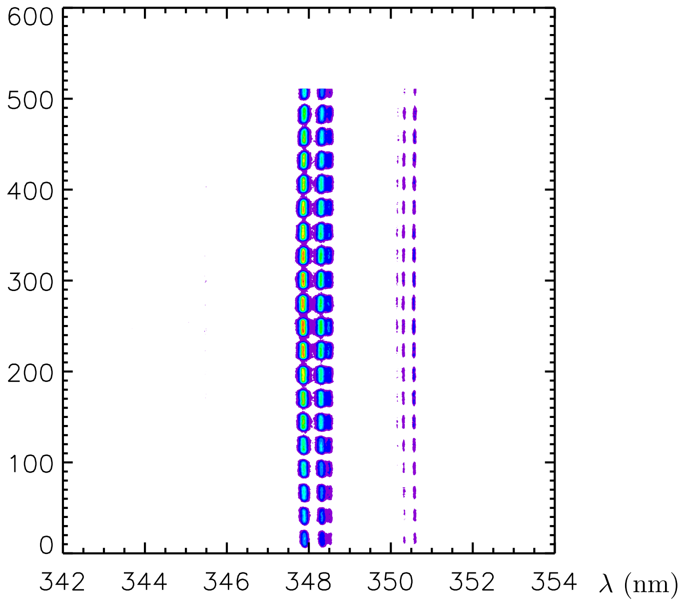

Figure 4. Nitrogen IV line emissions around 348 nm with 20 chords corresponding to 20 positions along the diameter of the pinch. The outermost chords, denoted by 512 and 0 pixels, correspond to the outer edges of the pinch and tend to exhibit smaller intensities.

V. Calibrating Spectroscopy Instruments

In order to ensure accuracy in the 20-chord output signal,[2] it is necessary to calibrate and normalize each chords intensity of response to the same signal. To do so, cadmium, mercury, and neon calibration lamps are used. Each lamp emits specified wavelengths of light and is passed over each of the twenty chords of the fiber-optic detector one by one. It is necessary to use lamps with emission wavelengths within the spectrum of interest so that the instrument can be calibrated to measure the wavelengths of the ions seen in the experiment. The peak intensity of each chord is measured using a photodiode light detector that measures intensity. The photodiode outputs a reading of the broadband intensity of the calibration lamp light, which is used to generate a calibration factor for each chord so as to normalize the output of the signal. This factor is then used as an input into the data analysis code and characterizes the adjustments that need to be made on the spectrometer and fiber-optics.

VI. Line Emission at the Atomic Level

Every impurity ion in the plasma emits a set of distinct spectral lines that can be used to identify both the element and its ionization state. Higher ionization states indicate higher temperatures. The ionization state corresponds to the number of electrons that have been stripped off of an atom as a result of plasma temperature. The higher the temperature, the more electrons are stripped off, and therefore the higher the ionization state. A given ions spectral line can only be observed while the bulk temperature of the plasma is at or near the ions energy level. Therefore a particular ion will only emit light as long as its ionization state falls within the Z-pinch plasma temperature range.

Even though every ion has a unique wavelength identity, the spectral lines actually appear as Gaussian distributions (see Fig.5) as a result of velocity differences among particles. This Gaussian distribution is a result of Doppler Effect. Because ion particles within the plasma move in random directions as they emit light, the characteristic wavelength in effect becomes the mode, or peak of the Gaussian curve. Consequently the width of the Gaussian is indicative of the range of the random velocity of the particles and in effect their kinetic energy and temperature (see Eq. 1), both of which can be determined with spectroscopy data.

$$T \propto w^2 \tag{1}$$

In terms of temporal evolution, if an ion with a given ionization state disappears and lower ionization states appear it can be concluded that the plasma cooled. Likewise, the appearance of higher ionization

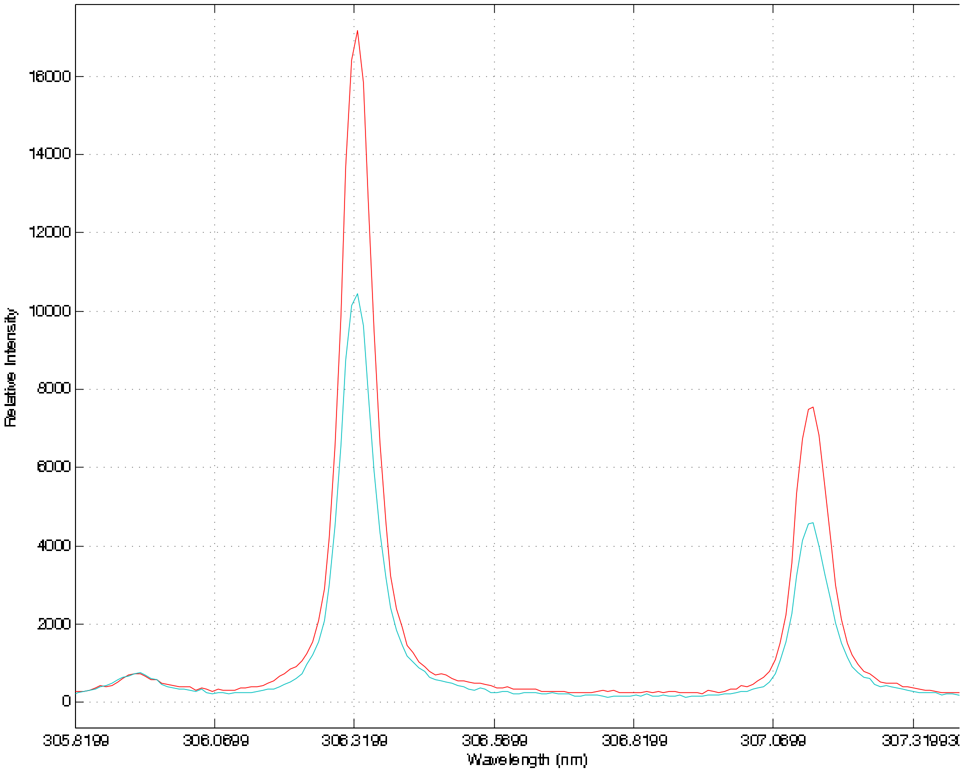

Figure 5. Oxygen IV emission spectra are seen as Gaussian-shaped due to the Doppler Effect associated with random-direction particle velocities.

states over time is indicative of a hotter plasma. The effect is commonly identified as the burn-through of a particular ion; for instance if oxygen III lines are visible at one point, and oxygen V lines become prevalent at a latter point in time, the plasma has in effect burned through oxygen III. Because the temperature of the plasma depends on capacitor bank voltage, investigating multiple ion species allows for better accuracy and applicability of the temperature profiles.

VII. Identifying Line Spectra

The spectral range that corresponds with the bulk of the ion impurity data is the 200 to 700 nanometer range. A survey of this range at the quiescent period of a hydrogen plasma has been taken in efforts to map ion impurities across the spectrum. Hydrogen ions, due to the absence of electrons, emit no spectral lines, which allows for identification of ion impurities with minimal emissive contribution from the plasma itself.

Impurity ions contributing to the emitted light will often include air molecule ions as well as metal ions from the walls of the containment device. A total of 208 lines were identified with the help of the NIST Online Database. Oxygen, nitrogen, carbon, tungsten, and boron were found to be the prominent light-emitting ions within the plasma. Figure 6 The locations of each ion within the 500 nanometer scope are important in observing temperature patterns in the plasma. If a specific ion with a certain ionization state no longer shows at one wavelength, its presence can be checked at other wavelengths to confirm whether the temperature really increased or decreased by a significant amount. As expected C I was only seen at lower voltages, while the presence of C IV at higher voltages was indicative of a temperature change of at least eight electron-volts, or about 93000 Kelvin, the temperature increase necessary to burn through C III.[1] The minimum temperature change is accurate for steady-state plasma, while for dynamic burn-through, much higher temperatures are required.

As expected, the majority of spectral lines are the product of non-metal ions emitting radiation (see Fig. 3). Most of these ions exhibited higher intensities toward the center of the plasma, around chord 10 (see Fig 7), where the plasma temperature is notably higher. The low-ionization-state tungsten ions, on the other hand, were observed to be near the low-temperature edges of the plasma. This is consistent with

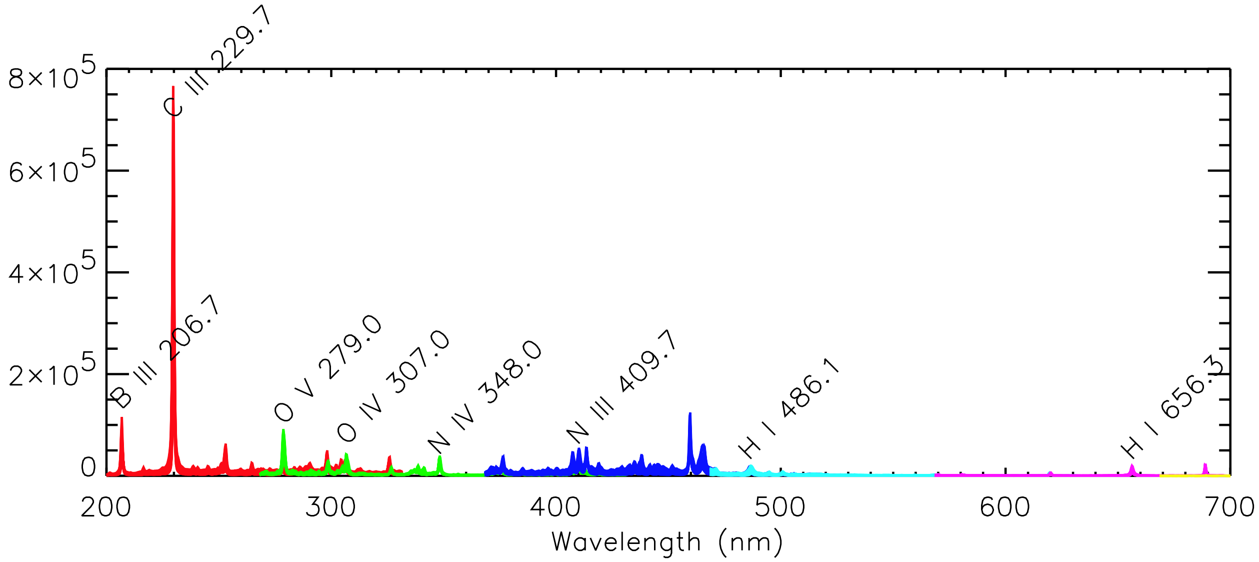

Figure 6. The identification of some of the major ion spectra seen in ZaP plasmas.[3]

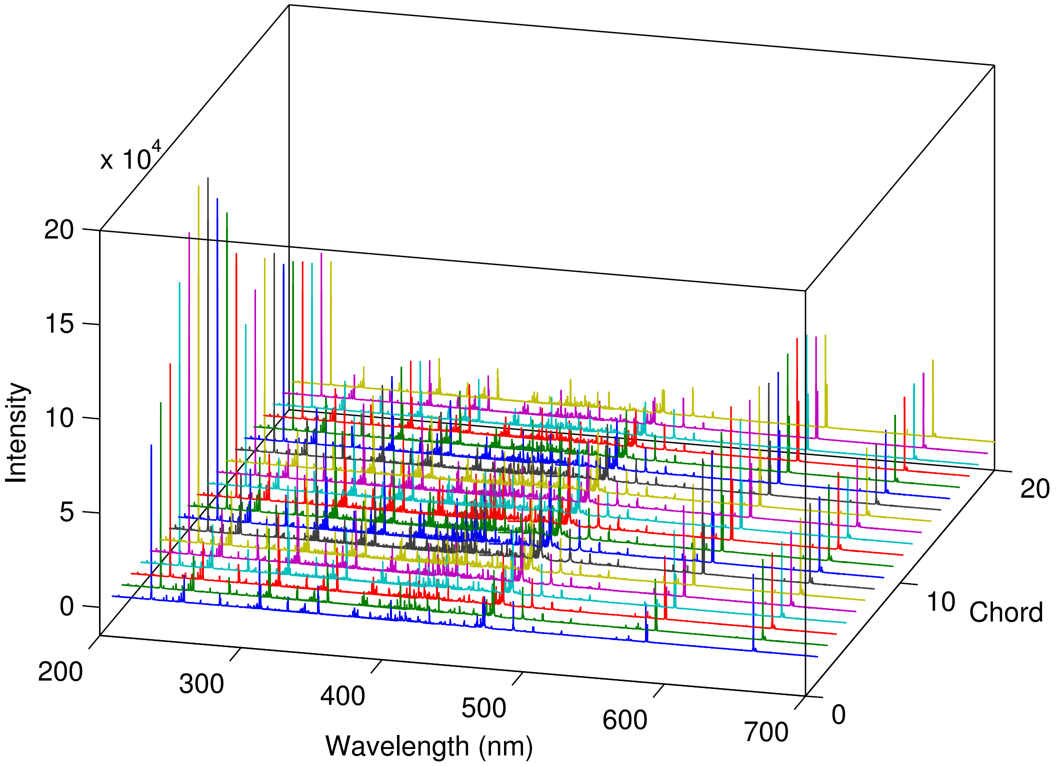

Figure 7. A mapping of ion impurities exhibits a distribution where higher intensities are seen toward the center of the Z-pinch plasma column.

burn-through trends; ions will be most prevalent, and thereby exhibit higher intensities, at the temperature range of their specific ionization state.

VIII. Conclusion

Ultimately spectroscopy serves many purposes in the ZaP experiment including quantitative temperature analysis with regard to position and time. Independent of both of these variables, however, the data is still useful in that it provides a way to check instrumentation and data collection process for accuracy and ensures consistency in measurement. Even though the impurity identification and resulting temperature patterns described are strictly qualitative, they are useful in that they provide a means of validating experimental results. Furthermore spectral identification of impurities offers insight into the state of the vacuum system and the experimental hardware it contains, both of which can be evaluated based on the amount and type of ions present in the plasma.

Investigating the properties and behaviors of plasmas in the Z-pinch configuration allows for greater understanding of plasma instabilities and offers insight into ways of extending the confinement period - the ultimate goal of plasma containment studies. Thus through the use of spectroscopy and impurity ion identification, the state of the plasma can be characterized and instrumentation can be adjusted for improved measurement accuracy.

Acknowledgments

The authors wish to thank Raymond Golingo, Brian Nelson, Sean Knecht, Keith Munson, and Colin Adams for the assistance and advice, along with the entire ZaP team for their support. The authors also wish to acknowledge the Department of Energy for its sponsorship of the ZaP Experiment.

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