Modeling Studies of Photoionization Experiments Driven by Z-pinch X-rays

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ABSTRACT

We have conducted modeling studies of several gas cell shots on the Z accelerator at Sandia National Laboratories in order to study the effects of the irradiance of a low-density gas by a strong x-ray source. Thus far, we have successfully matched a synthesized absorption spectrum to an experimental spectrum obtained from one of the shots, with especially good agreement for many of the absorption lines. Our results have demonstrated we can successfully model the photoionization experiments being conducted at Sandia, and can be used to design new experiments for future shots at Sandia. Our analysis of the excitation/ionization kinematics and physical conditions of the photoionized plasma has also helped benchmark the atomic kinetics models for these plasmas, thereby allowing for better interpretation of measured spectra from plasmas photoionized by cosmic sources.

1. Introduction

1.1. What type of astrophysical objects?

[Figure: Artist Conception of an X-ray Binary]

[Figure: Artist Renderings of Chandra and XMM Newton Space Telescopes]

What kinds of x-ray sources produce photoionized plasmas?

Why are these sources interesting?

Why is this coming to our attention now, and why is it important? (Motivate the research)

1.2. Differences between photoionized spectrum and coronal spectrum.

[Figure: High-Resolution X-ray Spectrum of a Photoionized Plasma]

[Figure: Iron Model Emission Rate Spectra for Coronal and Photoionized Plasmas from Liedahl et al. 1990]

Describe the spectral signatures of photoionized plasmas, and how they differ from coronal plasmas.

1.3. What's the point of doing experiments in the lab?

Motivation for laboratory astrophysics.

More efficient method for testing models (can easily change parameters of the experiment).

1.4. Brief description of gas cell experiments.

[Figure: Photograph(s) of Experimental Setup]

[Figure: Image of 3-D Model of Experimental Setup, with LOS shown]

How do these experiments relate to the cosmic situations?

Describe the material properties, geometries, and relative positions of all objects in the experiment.

1.5. Describe Z-pinch and Z-machine

[Figure: Photograph of the Z accelerator at Sandia National Laboratories]

[Figure: Schematic J X B force diagram for the Z pinch]

Describe how the Z acclerator works (i.e. how it produces such a large x-ray flux over a small time interval) and give numbers for the magnitude of the x-ray flux and pulse length.

1.6. Ionization Parameter

[Figure: Contours of constant ionization paramter for HMXRB Vela X-1 from Sako et al. 1999]

A brief derivation and discussion of why the ionization parameter describes the degree of relative importance of photoionization processes and collisional processes.

Calculation of the ionization parameter for one of the Z-pinch shots. Compare to a typical ionization parameter for a cosmic photoionized nebula.

1.7. What's the scope of the thesis

Step 1: Use modeling procedure to model a shot that has already been conducted, and compare the synthesized spectrum to the measured absorption spectrum from the shot.

Step 2: Use same modeling procedure to design new experiments using different gas fills, different gas cell geometries, and different gas cell positions.

2. Modeling

[Figure: Flow chart of modeling procedure]

Give a rough layout of the different steps of the modeling procedure, to be described in detail in the following sections.

2.1. VisRad

[Figure: Contributions to Incident Spectrum on Center of Gas Cell at t = 100 ns]

Why do we need to use a 3-D viewfactor code to calculate the incident flux on the gas cell?

Couldn't we just use the inverse square law?

2.1.1. Constructing a Workspace

[Figure: Screenshot(s) of workspace showing the pinch, current return can, and gas cell]

[Table: VisRad Simulation Parameters]

Describe the procedure for creating a 3-D model of the experimental setup, including all of the necessary input parameters.

2.1.2. Input Parameters of the Experiment

[Figure: Pinch Radius vs. Time]

[Figure: Albedo Model]

[Figure: Pinch Power vs. Time]

[Figure: Pinch Emission Temperature vs. Time]

How do we measure the time-dependent pinch radius and power?

How do we infer the albedo models for the surfaces in the experiment?

How can we use the pinch radial and power data to approximate its emission temperature as a function of time?

2.1.3. How does the code work?

[Figure: Screenshot of workspace, showing the region of the gas cell highlighted where we measure the incident flux]

[Figure: Slides from animation of simulation for several time steps.]

[Figure: Time-dependent incident flux at the center of the face of the gas cell]

Brief description of how VisRad computes the viewfactors and then computes the incident flux on the face of the gas cell.

2.1.4. Spatial variation of incident flux on the face of the gas cell

[Figure: Screenshots of views of the pinch from different locations on the face of the gas cell]

[Figure: Spatially-dependent incident flux on the face of the gas cell]

Why does the flux differ at different locations on the face of the gas cell?

2.2. Helios

[Table: Input parameters for Helios simulation]

Give a brief description of how Helios works, and what its objective is.

2.2.1. Propaceos

[Figure: Opacity models for mylar vs. plastic]

Describe how this opacity model is used and when it is used in the hydro simulations.

2.2.2. Ion Temperature and Mass Density Output

[Figure: Example plots of ion temperature and mass density versus position]

Explain what is going on in these plots, and why they are useful (and necessary) for synthesizing a spectrum.

2.2.3. Non-LTE vs. LTE

[Figure: Ion Temperature vs. Position for Non-LTE and LTE simulations]

[Figure: Mass Density vs. Position for Non-LTE and LTE simulations]

Give a brief description of Non-LTE and LTE, and describe why Non-LTE is more appropriate for these experiments.

2.3. Spect3D

[Table: Input paramters for Spect3D simulations]

Give a brief description of how Spect3D works, and motivate its utility by mentioning how other modeling suites often do not include a spectral synthesizer.

2.3.1. Atomic Model Builder

Explain what this program does and how the file it creates largely determines which features we can see in the final synthesized spectrum.

2.3.2. Absorption and Emission Spectra

[Figure: Spect3D Synthesized Absorption and Emission Spectra]

Describe how one synthesizes an absorption or emission spectrum, and how these would be measured in the experimental setup.

3. Modeling of Shot Z543

[Figure: Incident flux at the center of the gas cell as a function of time]

[Figure: Time-Dependent Ion Temperature vs. Position]

[Figure: 3-D Plot of Time-Dependent Ion Temperature vs. Position]

[Figure: Time-Dependent Mass Density vs. Position]

[Figure: Synthesized Absorption Spectrum compared to measured spectrum]

Discuss the agreement of the synthesized spectrum and the absorption spectrum, and explain what we can glean from the time-dependent ion temperature and mass density plots.

4. Scaling Studies

I cannot fully outline this section yet because I am not yet certain of the breadth of the scaling studies I will be conducting. I have begun a scaling study for the density of the gas fill in the cell, but that is all I have done thus far.

5. Conclusion

Is this modeling procedure effective for modeling the gas cell experiments conducted at Sandia National Laboratories?

How has this work benchmarked the atomic kinetics models for photoionized plasmas?

How has this work helped to ensure that our interpretation of measured spectra from cosmic photoionized plasmas is correct?