Modeling X-Ray Photoionization Experiments

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Introduction

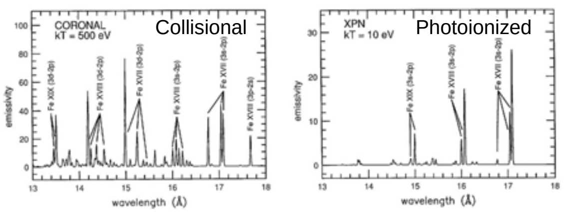
In order to reliably determine the temperature, density, and ionization of an astrophysical plasma, an accurate model of its spectrum is required. The modeling work described here, in conjunction with laboratory experiments, seeks to benchmark codes used to analyze spectra of accretion-powered objects.

Plasma Basics

Plasma is a state of matter consisting of a fluid of ions and free electrons. Electrons become detached from their atoms by acquiring energy in one of two processes.

- **Collisional:** Atoms are struck by free electrons
- **Photoionized:** Atoms absorb high-energy photons

The spectra of different types of plasma are radically different. Note how different lines belonging to the same iron ions appear in one spectrum but not the other (below).



The spectra of x-ray photoionized nebulae (XPN) are not as well documented as those of collisional (coronal) plasmas. The goal of the present research is to rectify this situation.

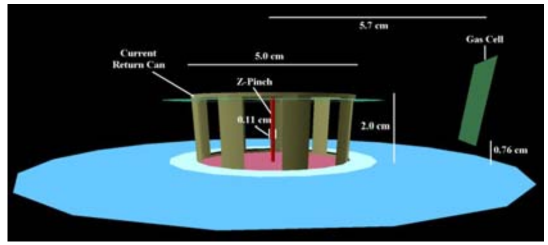
Astrophysical Applications

Photoionized plasmas feature prominently in many exotic astrophysical environments, such as around **x-ray binaries** (XRBs) and **active galactic nuclei** (AGNs). In both of these cases, material accretes onto a massive body, converting its gravitational potential energy to thermal energy. Ultimately, this energy is released in the form of x-rays, which radiate into the surrounding gas and produce photoionized plasma.

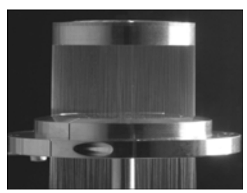
An artist's conception of an x-ray binary is on the left, with an x-ray telescope image of the active galaxy M82 on the right.

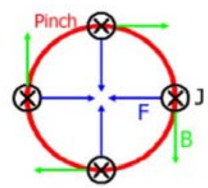
Laboratory Experiments

Experiments on the Z Machine at Sandia National Laboratory have been designed to mimic the phenomena in these astrophysical objects. A collapsing column of plasma known as a **z-pinch** serves as the x-ray source, with a small neon gas cell receiving the radiation (below). Properly scaling the gas density and its distance to the source, the **ionization parameter**, a measure of photoionization in the plasma, approaches astrophysically relevant values.



Electrical energy stored in capacitors is discharged into a cylindrical array of tungsten wires (left). Current J vaporizes the wires into a plasma and creates a magnetic field B in the clockwise direction. The resulting Lorentz force (F = JxB) implodes or "pinches" the plasma onto the z-axis (right).





As the z-pinch plasma stagnates on its axis, kinetic energy is converted to thermal energy, which is radiated away as x-rays. Radiation penetrates the neon gas cell, converting it into a plasma through a combination of photoionization and collisional processes. Using the pinch as a backlighter, an absorption spectrum of the plasma is taken.

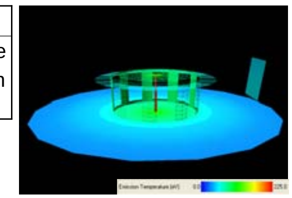
Environment	Astrophysical	Laboratory
Energy Source	Gravitational Potential Energy	Electrostatic Potential Energy
X-Ray Generator	Accretion	Z-pinch
Photoionized Matter	Circumstellar gas	Neon gas cell
Density	~10^{14} ions/cm^3	~10^{18} ions/cm^3
Distance Scale	AU to light years	Centimeters
Ionization Parameter	10-100 erg*cm/s	5-10 erg*cm/s

Modeling Studies

The following suite of modeling programs has been employed to simulate laboratory conditions in the neon gas cell experiment. By reproducing the neon absorption spectrum and comparing it to the spectrum obtained in the experiment, it is possible to determine the conditions in the plasma that will produce specific spectral features.

VisRad: A "viewfactor" code that calculates the radiation flux everywhere in a simulated experimental environment.

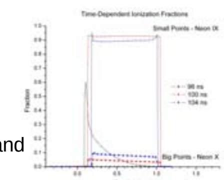
Inputs	Outputs
Pinch power	Temperature
Surface albedos	Spectrum on
Exp. geometry	the gas cell



A snapshot showing the temperature on each surface as the pinch implodes.

Helios: A hydrodynamics code that calculates physical conditions inside the neon plasma.

Inputs	Outputs
Equations of state	Temperature
Atomic models	Density
Incident spectrum	Ionization

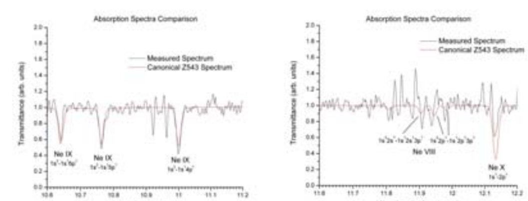


The ionization fractions of Ne IX and Ne X, two charge states of neon.

Spect3D: A spectral synthesis code that calculates atomic level populations and transition probabilities for given lines.

Inputs	Outputs
Plasma conditions	Absorption
Incident spectrum	and emission
Atomic models	spectra

In comparison to the data, our model shows slight overionization, with an overabundance of Ne X and too little Ne VIII.



Future work will focus on utilizing quantitative gauges of line strengths and diagnosing shortcomings in the atomic models.

Acknowledgements

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