Laboratory Astrophysics: Using EBIT measurements to interpret high resolution spectra from celestial sources

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Abstract

Astrophysicists use radiation to investigate the physics controling a variety of celestial sources, including stellar atmospheres, black holes, and binary systems. By measuring the spectrum of the emitted radiation, astrophysicists can determine a source's temperature and composition. Accurate atomic data are needed for reliably interpreting these spectra. Here we present an overview of how LLNL's EBIT facility is used to put the atomic data on sound footing for use by the high energy astrophysics community.

Cygnus X-1 as a prime example of the demand for X-ray spectroscopy:

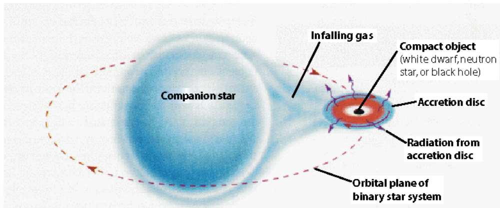


Figure 1: Illustration of a High Mass X-ray Binary. X-rays are produced by charged plasma from the companion star coming in contact with neutral material in the accretion disk

- Cyg X-1 is a High Mass X-ray Binary composed of a super-massive star and black hole
- Material of the stellar wind of the companion star accretes onto the black hole, resulting in X-ray radiation
- Doppler-shifted absorption lines provide information on the bulk motion and temperature of the source ions.
- Laboratory benchmarks provide zero-velocity line centers that can be used to determine the magnitude the doppler shift, and in turn the velocity of the ions.

Electron Beam Ion Trap: A Tool for providing high accuracy laboratory benchmarks

An EBIT is a device that creates and traps highly charged ions:

- Neutral material is injected into a high current density electron beam as a gas.
- The electron beam ionizes the neutral atoms, and traps them radially. A series of 3 electrodes (drift tubes), each at a different electric potential, trap the ions axially.
- By adjusting the beam energy, specific ion types can be created (up to bare nuclei) and excited.

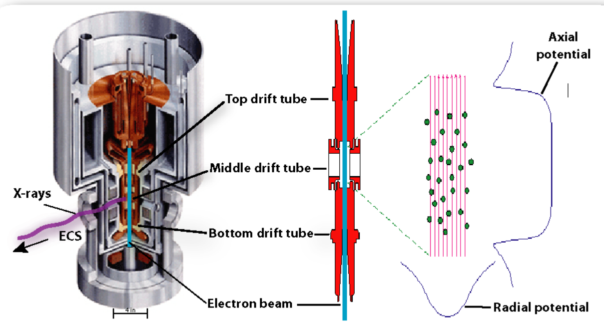
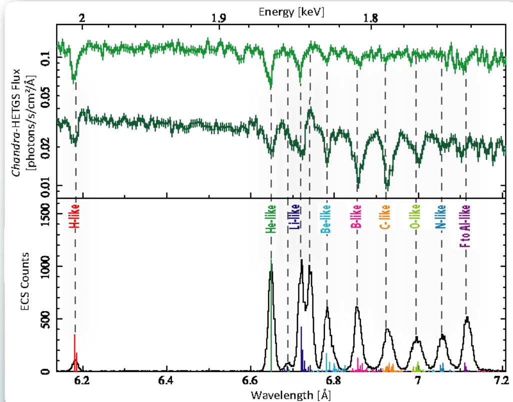


Figure 2: Diagram of the EBIT. Electrons are shown in blue

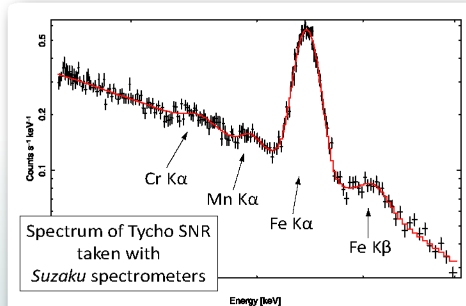
Si Kα Spectra: EBIT Generated Emission compared to Absorption in Cygnus X-1 Observed by *Chandra*



- Absorption lines of highly charged Si ions have been observed in the spectra from Cygnus X-1
- In order to determine if the measured absorption lines are doppler shifted, rest energy line centers are needed
- The lower panel shows the Kα transitions of several charge states of Si measured with the EBIT Calorimeter Spectrometer (ECS) at LLNL while the ions are at rest. Overlaid are the color coded theoretical calculations of these lines.
- Some Si ions are doppler shifted.

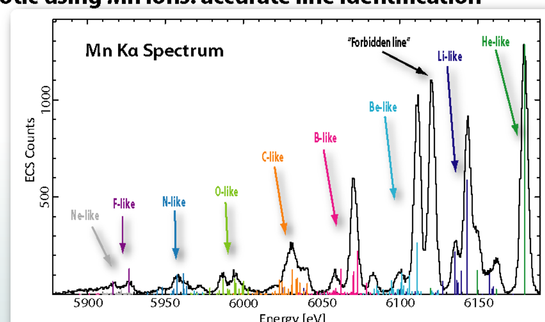
The Motivation to Measure Mn

- High sensitivity, high resolution measurements with Astro-H, will open the door to diagnostics using Mn ions in a variety of soruces.
- Both Mn and Cr have been measured in Supernova remnants (SNR) using low resolution instruments currently in orbit.
- The emission from Mn and Cr can be used to better determine the age of the star before it went Supernova.
- Future X-ray observatories (like ASTRO-H) will benefit from the new atomic data



First step towards a reliable diagnsotic using Mn ions: accurate line identification

- Mn spectrum measured by EBIT (solid black line)
- Theoretical spectrum of K-α transitions (colored histogram)
- The $1s2s \rightarrow 1s^2$ "forbidden line" transition in He-like ions is usually weak, however, it is strong here owing to innershell ionization of Li-like Mn.
- Theory assists in the identification of measured lines.



Astro-H X-ray Observatory

- Astro-H, to be launched in 2014, will make it possible to measure Si and Mn line emission in high resolution for extended sources.
- Astro-H will also carry an X-ray microcalorimeter very similar to the ECS used at LLNL.

World-firsts with Astro-H

1. *Imaging and spectroscopic observatons in both soft and hard X-rays.*
2. *Spectroscopc observations with a micro calorimeter, giving the highest energy resolution to date for extendsed sources.*
3. *The most sensitive observations over a wide energy range, from soft X-rays to gamma rays (0.3-600 keV)*

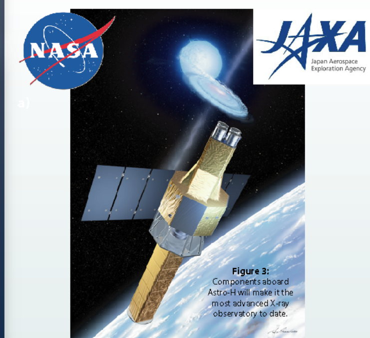


Figure 3: Components aboard Astro-H will make it the most advanced X-ray observatory to date.

Featured Instruments:

Soft X-ray Telescope (SXT)
Hard X-ray Telescope (HXT)
Soft X-ray Imager (SXI)
Hard X-ray Imager (HXI)
Soft X-ray Spectrometer (SXS)
Soft Gamma-ray Detector (SGD)

Other Applications

LLNL's EBIT also plays a strong role in interpreting spectra measured at several other facilities including :

- **SLAC's LCLS Free Electron Laser**
- **The National Ingition Facility (NIF)**
- **The National Spherical Torus Experiment at Princeton Plasma**

References
Figure 1: http://science.nasa.gov/
Figure 2: https://ebit.llnl.gov/
Figure 3: http://www.jaxa.jp
Chandra Data: http://www.sron.nl/files/HEA/XRAY2010/posters/6/609_miskovicova.pdf

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