Unmasking the Mysteries of High-Mass X-Ray Binaries (HMXBs): The Role of LLNL’s Electron Beam Ion Trap (EBIT)

Carey Baxter¹, Natalie Hell², Greg Brown³
¹California State University, Long Beach, CA  ²Remeis-Observatory/ECAP, University of Erlangen-Nuremberg, Germany  ³Lawrence Livermore National Laboratory, Livermore, CA

GOAL
• To analyze X-ray line spectra of excited, highly charged silicon (Si) produced by EBIT.

PURPOSE
• To use data as a point of reference for similar spectra measured by satellites Chandra and XMM-Newton.
• To calculate Doppler shift of X-ray lines and, in turn, ion velocity around HMXBs.

BACKGROUND
EBIT
• EBIT uses a narrow electron (~60μm) beam to excite and trap ions.
• X-ray emission from the excited ions is then diffracted using crystal spectrometers and analyzed.

WHY EBIT IS IMPORTANT
• High precision, high accuracy
• Provides spectral data that can’t be calculated
• Helps astronomers to better understand wind movement around HMXBs

CRYSTAL SPECTROMETERS DIFFRACT X-RAYS ACCORDING TO BRAGG’S LAW

\[ N \lambda = 2d \sin \theta \]

\( N \) – integer
\( \lambda \) – wavelength of incident wave
\( d \) – space between lines or atoms in target material
\( \theta \) – angle between incident ray and scattering planes

IN THE CLASSROOM

The Nature of Light: Diffraction and Interference
Can you explain this?
• **Diffraction** – the bending of waves around an object
• **Interference** – a phenomenon in which two waves superimpose to form a resultant wave of greater or lower amplitude

Wave Behavior: The Doppler Shift

\[ \Delta \lambda = \frac{v}{c} \]

\( \Delta \lambda \) = wavelength shift
\( \lambda_0 \) = wavelength of source not moving
\( v \) = velocity of source
\( c \) = speed of light

APPLICATION
• Monoenergetic electron beam allows for isolation of single charge state.
• Can probe different excitation mechanisms.
• Accuracy of better than ~5mÅ is achievable.
• Can calculate Doppler shifts of Si spectra and learn about wind around HMXBs’ accretion disks.

PROCEDURE
1. Injected Si (in the form of decamethyltetrasiloxane) into EBIT.
2. Used EBIT’s monoenergetic electron beam to produce and excite highly charged Si ions Si12+ to Si15+.
3. The strongest 2 to 1 transitions in each charge state were measured using a crystal spectrometer and an X-ray calorimeter.
4. The wavelength scale was calibrated using well-known wavelengths from hydrogenic and helium-like ions.

RESULTS
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 of 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.
- Overlaid are the color-coded theoretical calculations of these lines.
- Some Si ions are Doppler shifted. Ion velocities of ~200 km/s were determined.

Acknowledgements: The authors would like to thank Anthony Farrow, Ed Magee, David Layne, and Henry Chen for their help and guidance. This work was supported under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract #DE-AC52-07NA27344. This material is based upon work supported by the S.D. Bechtel, Jr. Foundation and by the National Science Foundation under Grant No. 07NA27344. This material is based upon work supported by the S.D. Bechtel, Jr. Foundation and by the National Science Foundation under Grant No. 0952013 and Grant No. 0934931 (East Bay Noyce Fellows only) and Grant No. 0833353 (check funding spreadsheet if needed). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the S.D. Bechtel, Jr. Foundation or the National Science Foundation.