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

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GOAL
• To use 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’ accretion disks

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

\[ N \lambda = 2dsin\theta \]

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

Bragg diffraction occurs when electromagnetic waves (like X-rays) encounter obstacles (like atoms in a crystal) whose spacing is comparable to the wavelength.

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.

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

- Challenge: Use these concepts to:
  • Find track spacing of CD and DVD
  • Find diameter of lycopodium spore

IN THE CLASSROOM
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

- 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.

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

- HETGS Flux
- ECS Counts

Measured EBIT Calorimeter Spectrum

The high-resolution crystal spectrum of Si resolves blends in Calorimeter and Chandra spectra.

- Measured High-Resolution Crystal Spectrum of Si Kα

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