

**REMOVING SPECTRAL DIAGNOSTICS OF GALACTIC AND STELLAR  
X-RAY EMISSION FROM CHARGED EXCHANGE RECOMBINATION**

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Our research uses the electron beam ion trap (EBIT) at the Lawrence Livermore National Laboratory to study X-ray emission from the charge exchange (CX) of highly charged ions with neutral gases. The resulting data help to fill a void in existing experimental and theoretical understanding of this atomic physics process, and are needed to explain all or part of the observed X-ray emission from the soft X-ray background, stellar winds, the Galactic Center and Galactic Ridge, supernova ejecta, and photoionized nebulae. Appreciation of the astrophysical relevance of our work continues to grow with the publication of roughly a dozen papers in the past four years describing Chandra and XMM observations of geocoronal and heliospheric CX emission, the temporal variation of such emission and correlation with X-ray emission enhancements observed by ROSAT, the theoretical spatial distribution of that emission, and CX emission around other stars. A similar number of papers were also published during that time describing CX emission from planets and comets. We expect that the launch of ASTRO-E2, with its second-generation XRS microcalorimeter (with 6-eV resolution), will reveal even more clearly the contributions of CX to astrophysical emission.

In our EBIT work, we collected CX spectra from such ions as H-like and He-like Ne, Ar, and Fe. Our early measurements were made with a high-purity Ge detector, but during the second year we began operation of the first-generation XRS microcalorimeter (a twin of the XRS on ASTRO-E) and greatly improved the resolution of our measurements from roughly 150 eV (FWHM) with the Ge detectors to 10 eV with the XRS. We found that saturation of the XRS counting apparatus, which we described in our proposal as a potential concern, is not a problem for studying CX.

During the course of our research, we expanded the number of injection gases permitted by the LLNL safety team, purchased and eventually operated an atomic H source, and clearly demonstrated the feasibility of our longer-range plan. For example, we successfully injected He into EBIT (not a small feat because of the difficulty of maintaining a good vacuum with He and avoiding electrical breakdown) to collect a H-like oxygen CX spectrum. The highest energy CX spectrum recorded with the XRS to date is that of the Ar K-shell emission. These measurements provided the first observation of the relative intensity ratios of resolved He-like singlet and triplet  $n=2 \rightarrow 1$  lines. We also carried out measurements of He-like Ne as a function of collision energy (i.e., ion temperature). Significant differences in the resulting x-ray spectra were noted. In all cases, the intensity of high- $n$  H-like Lyman lines is significantly higher than current theoretical CX models predict.

Some of those results have yet to be published, but a list of papers derived from our SARA-grant work includes:

"Charge Exchange Spectra of Hydrogenic and He-like Iron," B.J. Wargelin, et al. (to be submitted Dec 2004)

"New Results in Laboratory Astrophysics," P. Beiersdorfer, et al., Proc. Astro. Soc. Pacific (in press)

"Laboratory X-Ray Astrophysics," P. Beiersdorfer, Ann. Rev. A&A, 41, 343 (2003).

"Overview of the Livermore Electron Beam Ion Trap Project," P. Beiersdorfer, et al., Nucl. Instrum. Methods B, 205, 173 (2003).