Laboratory Astrophysics at the LLNL Electron Beam Ion Traps

EBIT-I & EBIT-II

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Abstract

In order to provide a complete, accurate set of atomic data for interpreting spectra provided by missions such as *XMM-Newton*, the *Chandra X-Ray Observatory*, and *Astro-E2*, we have harnessed the Lawrence Livermore National Laboratory's electron beam ion traps EBIT-I, EBIT- II, and Super-EBIT for laboratory astrophysics. In support of this work we have developed a number of unique techniques, including the ability to experimentally simulate a Maxwellian distribution of electron energies and measuring low-energy charge exchange cross sections using the "magnetic trapping mode". We have also built and operated a full suite of spectrometers spanning the 1–7000 Å wavelength band, the most recent being a spectrometer based on a spare Astro-E 6 X 6 microcalorimeter array. Results of our efforts include a complete list of wavelengths of the Fe L-shell transitions, measurements of absolute and relative cross sections for direct impact, dielectronic, and resonance excitation, and measurements of low energy charge transfer reactions. A brief overview of the LLNL ebit facility, its capabilities, and some results will be discussed.

1. Introduction

Invented at the Lawrence Livermore National Laboratory (LLNL), the electron beam ion trap; EBIT (Levine *et al.* 1988) has proven to be a useful tool for laboratory astrophysics. The success of the LLNL EBIT, EBIT-I, lead to the second EBIT, EBIT-II, completed at LLNL in 1990. EBIT-I was then modified to operate at higher electron beam energies and was renamed Super-EBIT. Later, several other EBITs were built (Silver *et al.* 1994; Gillaspy 1997; Biedermann *et al.* 1997; Curell *et al.* 1996; López-Urrutia *et al.* 2001). All of these EBITs are based on the Livermore EBIT-I design, but none is an exact replica, making the operating parameters and capabilities of each device distinct.

Over the last decade the LLNL EBITs have been harnessed as tools for laboratory astrophysics in support of the *Chandra*, *XMM-Newton*, and *Astro-E2* X-ray observatories. During this time several collaborations have been developed with astrophysical science programs, such as the Columbia Astrophysics Laboratory and the NASA/Goddard Space Flight Center. Our program has included the development of a plethora of instruments and methods for investigating astrophysically relevant problems.

2. Operating Parameters and Results

EBIT-I is the current electron beam ion trap operating at LLNL. A detailed description can be found in (Beiersdorfer *et al.* 2000). EBIT-I operates at an electron density of $\sim 5 \times 10^{11}$ cm^{-3} and has a mono-energetic electron beam energy that can be adjusted from $\sim$ 100 eV to 100,000 eV for a given experiment. It has five ports that observe the trap directly. For these ports we choose from over 20 spectrometers covering a range of 1–7000 Å. Typically, an experiment consists of a set of vacuum crystal spectrometers (occupying two ports) covering the 10–18 Å region continuously with 1 eV resolution; a flat-field grating spectrometer that covers the 10–50 Å region; a curved-crystal spectrometer for K-shell measurements, for example, of Fe XXV; and, the NASA/GSFC spare Astro-E spectrometer, the XRS. The XRS is a 6 X 6 square microcalorimeter array consisting of 32 active channels with an area of $\sim$ 13 mm^2 (Porter *et al.* 2001). Because of the high gain stability of all 32 active channels, we are able to accumulate data continuously without significant gain drift for over 12 hours.

In order to address problems encountered in the analysis of astrophysical spectra, we have developed several advanced operating techniques for EBIT- I. For example, to measure contributions from processes such as dielectronic recombination and resonance excitation, the e$^-$ beam is swept linearly from below excitation threshold to above threshold while the spectrum is recorded as a function of beam energy. An example of one of these experiments is given in figure 1. With the addition of the NASA/GSFC XRS, we can provide absolute excitation cross sections by normalizing to radiative recombination (Chen *et al.* 2002) (figure 2). Other results and measuring techniques include the development of a Maxwellian temperature simulator making it possible to measure spectra in thermal plasmas at different temperatures; we measured the wavelengths and identified all the Fe L-shell X-ray emission from Fe XVII–XXIV (Brown *et al.* 2002, 1998); we resolved a long standing problem with relative line intensities (Brown *et al.* 2001). Using the magnetic trapping mode (Beiersdorfer *et al.* 1994), where the electron beam is off and the ions are trapped by the magnetic field of EBIT-I, we are able to measure charge exchange recombination cross sections (see Beiersdorfer *et al.* these proceedings). The complete list of results is too numerous to list here[1].

In support of present and future X-ray missions we will continue to study astrophysically relevant radiation processes and to develop new methods and instrumentation. This includes building and installing a new dedicated EBIT Calorimeter Spectrometer (ECS). The cryogenic and refrigerator lifetime of the ECS will see a dramatic improvement, increasing the data acquisition - cryogenic Dewar refill cycle. The ECS, in addition to the regular upgrades to our spectroscopic equipment, will improve our ability to address astrophysically relevant problems.

[1] Visit http://www-phys.llnl.gov/Research/EBIT/ and http://homepage.mac.com/ebit for a more complete list of measurements conducted at the LLNL EBIT facility

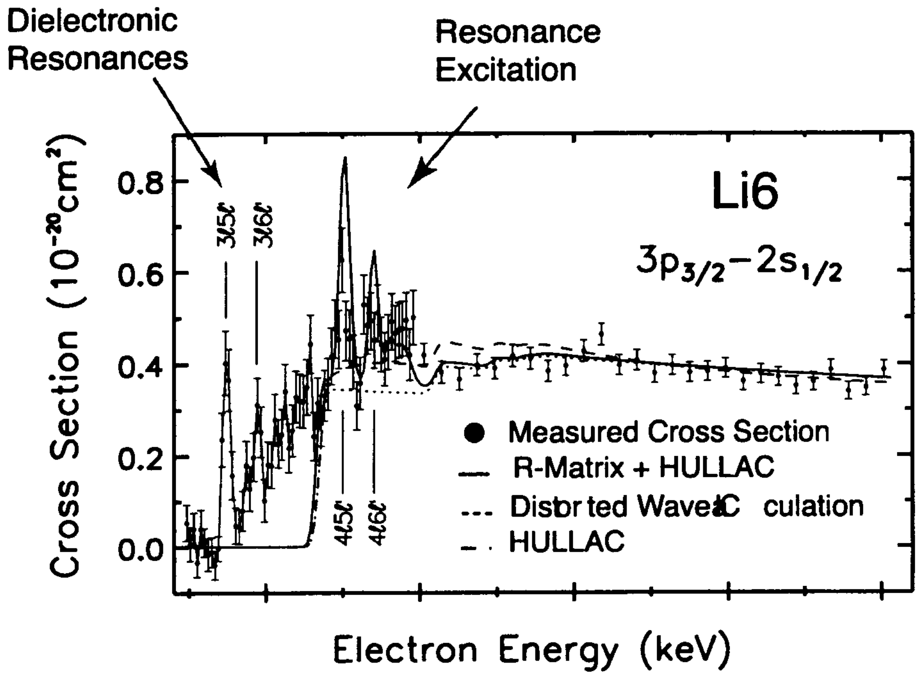

Fig. 1.— Measured cross section as a function of electron impact energy for the $3p_{3/2} \rightarrow 2s_{1/2}$ Fe XXIV line at 10.6 Å (Gu *et al.* 1999) labeled Li6. Notice the contribution below threshold from dielectronic recombination and the enhancement near threshold from resonance excitation.

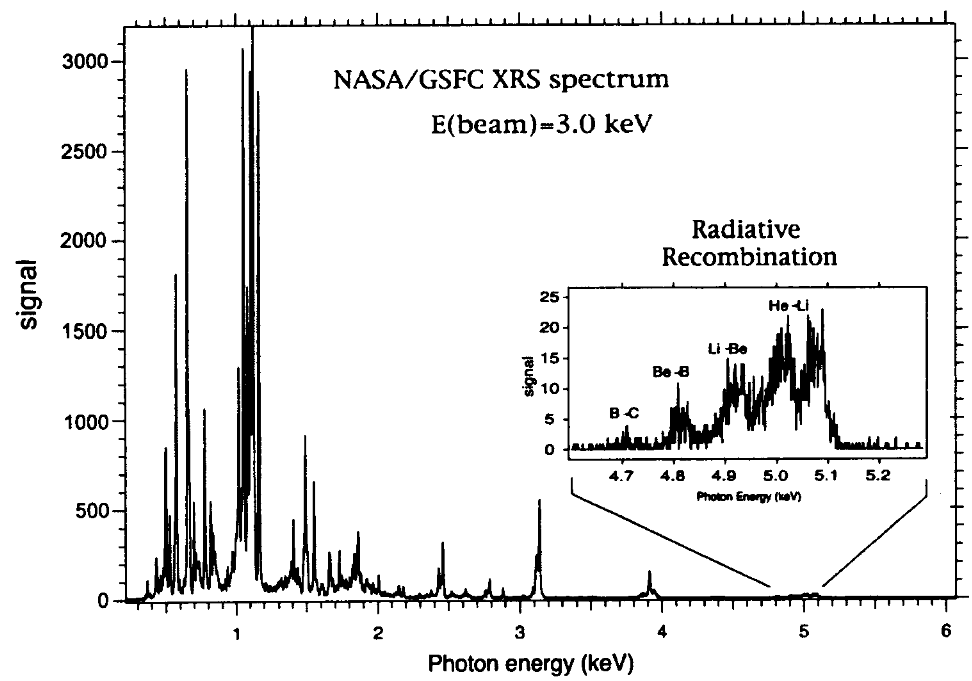

Fig. 2.— A spectrum recorded by the NASA/GSFC microcalorimeter array. This spectrum includes the weak emission from radiative recombination (RR). The measurement or the RR emission, even with a 32 pixel array, requires long integration times.

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