Emission Line Spectra in the Soft X-ray Region 20 – 75 Å

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Abstract

As part of a project to complete a comprehensive catalogue of astrophysically relevant emission lines in support of new-generation X-ray observatories using the Lawrence Livermore electron beam ion traps EBIT-I and EBIT-II, emission lines of argon and sulfur in the soft X-ray and extreme ultraviolet region were studied. Observations of Ar IX through Ar XVI and S VII through S XIV between 20 and 75 Å are presented to illustrate our work.

1. Introduction

Satellite observations in the soft X-ray and extreme ultraviolet region provide important diagnostic opportunities for astronomers. The region between 20 and 80 Å has received scant attention, however, even in solar measurements. Observations in the soft x-ray region by the *Chandra X-ray Observatory* and *XMM-Newton* are now providing high-resolution measurements, which have far outpaced available databases. There are many more lines in these spectra than can be currently identified, as is illustrated by Chandra spectra of Capella (Brinkman 2000) and Procyon (Raassen *et al.* 2002).

Long-term exposures of HR 1099 have shown a wealth of weak lines that cannot be identified with available databases. These weak lines raise the "background" level for the brighter, known lines and add uncertainty to their interpretation. Contributions to these unidentified lines are thought to come from argon, sulfur, silicon, magnesium, calcium, iron, and nickel. Calculations are helpful to predict emissions from these elements. However, a major problem is that the wavelengths are frequently unreliable, given the high density of unidentified lines in this region. This is because the structure of the intermediate ionization stages of all high-Z ions of astrophysical interest are significantly affected by electron-electron interactions, and these ionization stages must be calculated in intermediate coupling. Wavelength errors of a few percent are not uncommon, and no *ab initio* code can calculate wavelengths to better than a quarter percent for mid-Z L-shell or M-shell ions.

Laboratory measurements are thus essential to locate the lines and to correlate them with the proper charge state. We are undertaking a concerted effort to identify all important lines from all relevant elements and ionization stages in this wavelength region (e.g, Lepson *et al.* 2000, 2002). Here we present spectroscopic measurements of argon and sulfur. These measurements were taken on the Lawrence Livermore electron beam ion trap EBIT-II. We also have performed new calcululations using of the Hebrew University - Lawrence Livermore Atomic Code HULLAC, which were used for comparison.

2. Spectroscopic measurements

EBIT-II has been operating since January 1990. It is the second electron beam ion trap to be put into operation, following the device's development at the Lawrence Livermore National Laboratory in 1986. It is particularly well- suited for spectral investigations because it can be operated at the low voltages (100–1,000 eV) necessary to produce the appropriate charge states. Moreover, different charge states can be produced simply by changing the voltage of the electron beam. As the voltage increases, higher charge states appear when their ionization potentials are exceeded; by systematically recording spectra at different energies and observing the rise and relative decline of different charge states, it is possible to determine which emission lines belong to which charge state.

Spectra were measured with a grazing-incidence spectrometer (Utter *et al.* 1999). Readouts were taken with a back-illuminated, liquid nitrogen-cooled CCD camera with a one inch square array of 1,024 $\times$ 1,024 pixels. Figure 1 shows a representative spectrum of argon taken on EBIT-II at a beam energy of 900 eV, with the strongest argon lines labeled by charge state. Note that charge states from Ar IX through Ar XVI are present. The charge states were identified by comparing spectra taken at different beam energies (cf. Lepson *et al.* 2000). This spectrum was chosen to show all the charge states we investigated; lower energy spectra have fewer charge states present. Figure 2 shows a spectrum of sulfur taken at a beam energy of 600 eV. Emission lines from charge states S VII through S XIV are identified. We also constructed synthetic spectra derived from our HULLAC calculations. A sample synthetic spectrum is shown in Fig. 3; this spectrum has been made to emulate Fig. 2, and includes S VII through S XIV. The synthetic HULLAC spectra were intensity corrected for our detector response to be directly comparable with our measurements and to assist in line identification.

3. Summary

Our work is an ongoing effort to catalogue all astrophysically relevant lines in the soft X-ray and extreme ultraviolet region (25 – 140 Å). Our laboratory measurements and spectral modeling represent a synergistic approach to build up such a catalogue. In this setting, most strong lines and some weaker lines can be identified with confidence. We will continue these studies until all important lines are identified. The L-shell spectra of silicon, for example, are currently being measured, and results will be available in the near future.

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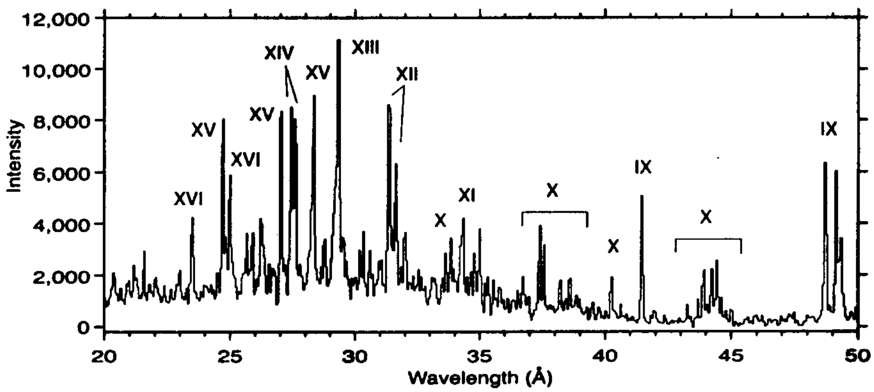

Fig. 1.— Spectrum of argon taken on EBIT-II at a beam energy of 900 eV, with Ar IX through Ar XVI present. Major peaks are labelled for each charge state.

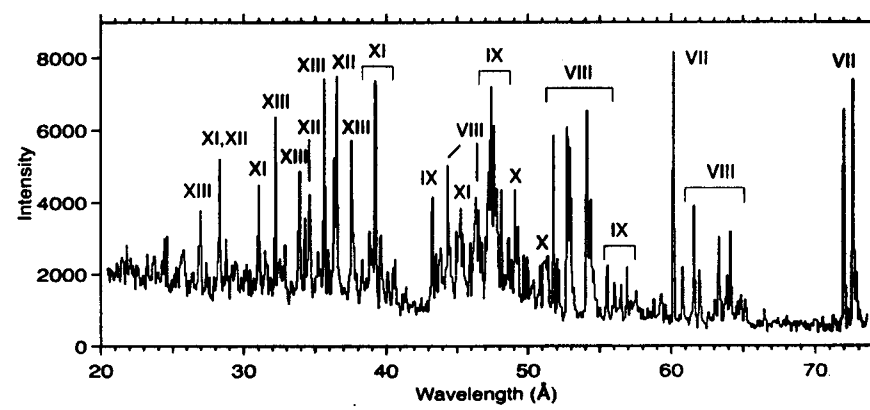

Fig. 2. Spectrum of sulfur taken on EBIT-II at a beam energy of 600 eV, with S VII through S XIV present. Major peaks are labelled for each charge state.

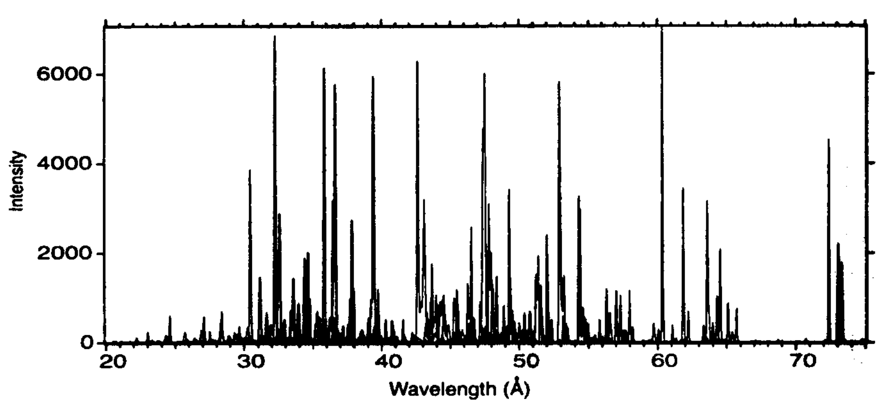

Fig. 3.— Synthetic spectrum of sulfur calculated with HULLAC. Spectrum includes S VII through S XIV, and has been intensity corrected for the detector response to be directly comparable to the EBIT-II data. Relative peak sizes were adjusted between data and calculations to match for the highest peak in each charge state.