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CATALOGUING EMISSION LINE SPECTRA FROM FE VII–FE XXIV IN THE EXTREME ULTRAVIOLET

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RESUMEN

Se están realizando mediciones detalladas de laboratorio para producir tablas de espectros de líneas de emisión en la banda de longitudes de onda EUV de Fe VII – Fe XXIV. Se presenta una actualización de las listas de íneas del Fe XIII usadas en el Proyecto de Líneas de Emisión de *Chandra*.

ABSTRACT

Detailed laboratory astrophysics measurements are in progress to produce spectral tables for the Fe VII – Fe XXIV line emission in the EUV wavelength band. Results for Fe XIII are presented that update line lists used in the *Chandra* Emission Line Project.

Key Words: **ATOMIC DATA — LINE: IDENTIFICATION — ULTRAVIOLET: STARS — STARS: CORONAE**

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1. INTRODUCTION

The extreme ultraviolet wavelength band is particularly useful for studies of stellar coronae. This was first demonstrated by the superb spectra recorded with the *Extreme Ultraviolet Explorer* satellite and now with the recently launched *Chandra X-ray Observatory*.

Global fits of the short wavelength band spectra (80–140 Å) taken with the *Extreme Ultraviolet Explorer* have produced controversial results. In order to fit the high continuum, a bremsstrahlung emission component with an unreasonably high temperature on the order of 30×10^6 K had to be invoked (Mewe et al. 1995). Recent laboratory measurements have shown, however, that the line lists included in the global fitting models are seriously inadequate (Beiersdorfer et al. 1999). The measurement carried out at the Lawrence Livermore National Laboratory's Electron Beam Ion Trap (EBIT) showed that roughly 70% of the observed emission from Fe IX and Fe X were missing from global fitting models. To a lesser extent, this was also true for Fe VII and Fe VIII. A high density of unresolved lines was found in this spectral range. In addition, a number of well-resolved lines were comparable in strength to those included in the model calculations.

It is increasingly evident that the published atomic data used by astronomers are incomplete and inadequate to identify many if not most features in these spectra. Our goal is to use the unique spectral capabilities of the Livermore EBIT to compile a comprehensive catalogue of the line emission of astronomically relevant ions extending from Fe VII to Fe XXIV. In the following we present our measurement of Fe XIII and compare it to published spectral models.

2. EXPERIMENTAL TECHNIQUE

The Livermore EBIT is uniquely suited for this investigation because it can be operated at the very low electron beam voltages neccessary to produce the relatively low charge states of interest. For example, the ionization potentials of Fe XII, Fe XIII, and Fe XIV are 293 eV, 324 eV, and 358 eV, respectively. Different charge states are produced simply by changing the voltage of the electron beam. As the voltage increases, higher charge states appear when the ionization potential is exceeded and lower charge states decline and disappear

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as they "burn out." In theory, charge states appear one by one as the voltage increases. In practice, there is mixing because of recombination, and the next higher state is sometimes present because of a 30 eV spread in the beam energy, which is comparable to the separation in ionization potentials. The typical spectrum thus contains 3–5 charge states besides the dominant one. Figure 1 shows a spectrum produced at an electron beam energy of 330 eV, where Fe XIII is the dominant ion. The diagnostic peaks for Fe XIII are visible at 76–82 Å. Also visible are peaks for Fe XII at 82 Å and 84 Å, Fe XI at 71–73 Å and 89–93 Å, Fe X at 94–96 Å, and Fe IX at 103.5 Å.

By systematically recording spectra at different energies, we isolate the emission of a single charge state. Figure 2*a* compares the mixed Fe XIII spectrum with spectra taken at lower and higher beam energies dominated by Fe XII and Fe XIV, respectively. The upper panel of Figure 2*a* contrasts Fe XIII (open) with Fe XII (shaded), scaled to Fe XII's dominant peak at 82 Å. This provides a quick visual test of which features belong to lower charge states, indicated when the shaded peaks are equal to or greater than the open peaks. Likewise, the lower panel contrasts Fe XIII (open) with Fe XIV (shaded), scaled to Fe XIV's dominant peak at 76 Å. We isolate Fe XIII by sequentially subtracting lower and higher charge states from Fe IX to Fe XIV. The pure Fe XIII emission is shown in the upper panel of Figure 2*b*.

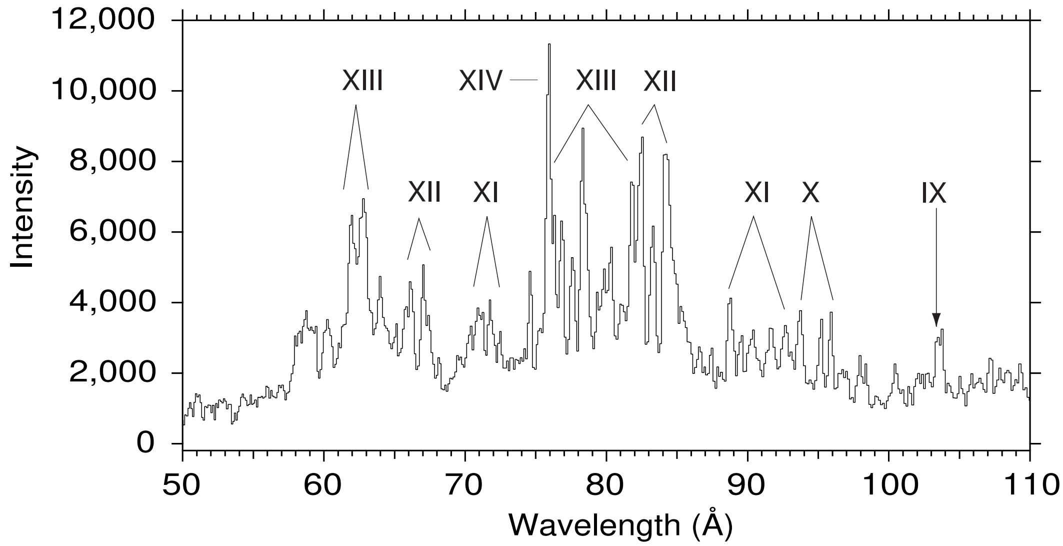

Fig. 1. Spectrum at beam energy of 330 eV. Fe XIII is dominant, but Fe IX – Fe XIV are also present.

3. DISCUSSION

Spectral models in the extreme ultraviolet are highly incomplete, partly because calculations are complex and time-consuming, given the wealth of possible transitions. In addition, it was thought that these "minor" transitions were unlikely to make a significant contribution to the overall flux used for global-fit models. As a result, the CHIANTI code, for example, which claims to be "essentially complete" for wavelengths above 50 Å (Dere et al. 1997) was found to be seriously deficient in describing the spectral flux observed with EBIT for Fe VII – Fe X (Beiersdorfer et al. 1999) in this wavelength.

We find that this pattern holds through Fe XIII. Figure 2*b* compares the Fe XIII spectrum produced on EBIT with calculations utilizing the MeKa database (Kaastra & Mewe 1993). The MeKa code fails, omitting most of the lines we found. Moreover, the intensities of the eight lines in this spectral range do not match the measurements. CHIANTI performs even worse: just four lines are listed for this spectral range, and no intensities are predicted.

A complete spectral listing of Fe XIII, including lines from Fe VII – Fe XII, based on our measurements is now nearly complete and will be released shortly.

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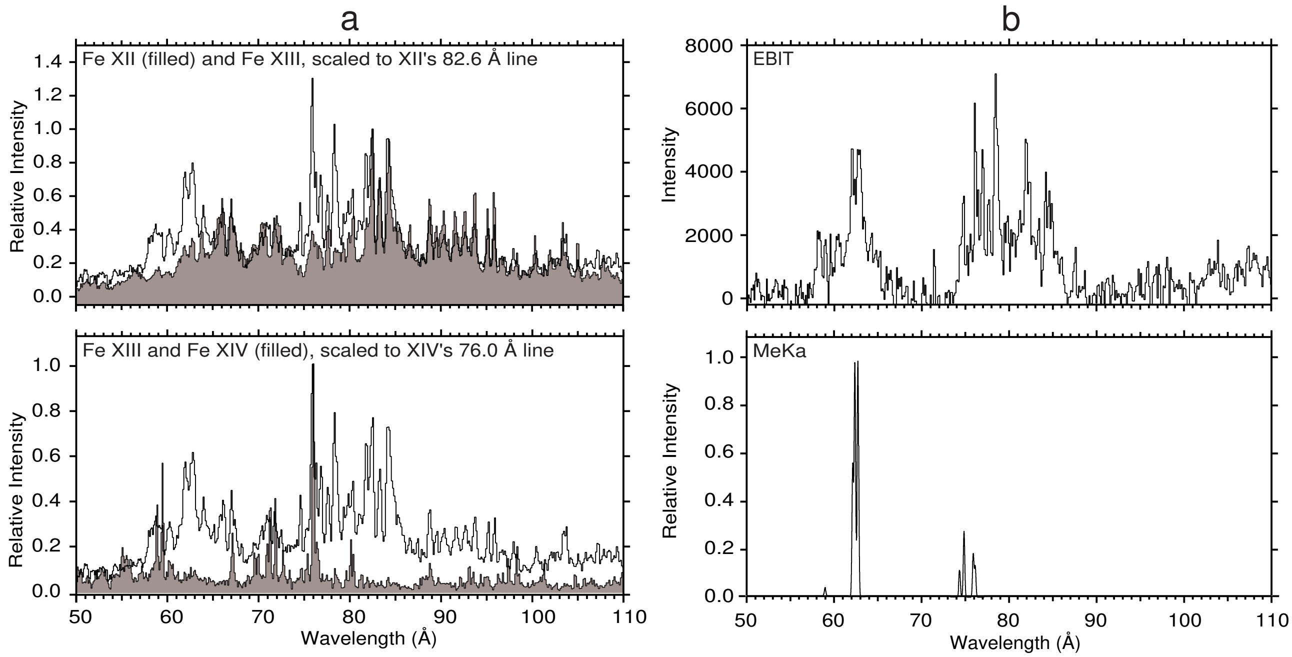

Fig. 2. *(a)* Mixed Fe XIII compared with spectra of lower (top) and higher (bottom) beam energies. *(b)* Pure Fe XIII from EBIT compared calculations from the MeKa database (Kaastra & Mewe 1993).

In summary, published atomic modeling codes do not adequately reproduce the wealth of extreme ultraviolet lines seen in Fe VII through Fe XIII. The fact that the inadequacies extend from the lower charge states to Fe XIII may have important implications not only for cool stars such as α Cen, but also for hotter stars such as Capella. Such shortfalls likely also exist for other astronomically relevant elements, such as neon, magnesium, silicon, and nickel, as will undoubtedly become evident in analyses of future *Chandra* data. Plans are in progess to extend our measurements to the emission from these ions and to shorter wavelengths.

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