

Iron emission lines in solar and laboratory plasmas

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Abstract. We present a spectrum of the Sun taken by the *Cosmic Hot Interstellar Plasma Spectrometer (CHIPS)* covering 150 to 275 Å. This spectrum is dominated in the 200 Å region by emission lines from intermediate charge states of iron (Fe VIII – Fe XVI). We also made laboratory measurements of iron emission at temperatures relevant to solar emission on the EBIT-II electron beam ion trap and the Large Helical Device stellerator. We used our laboratory measurements to identify lines and check the CHIANTI database and then used CHIANTI to validate line identifications in the *CHIPS* spectrum.

1. Introduction

Iron plays an important role in virtually every plasma, both in man-made plasmas, such as for fusion, and in astrophysical plasmas, such as the Sun. The solar spectrum is dominated by emission lines from intermediate to high charge states of iron and is currently being observed in high resolution in the 180 to 204 Å and 250 to 290 Å range by the *EUV Imaging Spectrometer on Hinode (Astro-B)* and at lower resolution in the 90 to 270 Å range by the *Cosmic Hot Interstellar Plasma Spectrometer (CHIPS)*. In addition, the *Solar EUV Rocket Telescope and Spectrograph (SERTS)* observed this region during its 10 flights. EUV emission lines of iron have well known and valuable diagnostics utility for such parameters as temperature and density. In particular, much attention has been directed to the spectrum of Fe XIII near 200 Å as a density diagnostic in the range typical of solar plasmas because it is believed to be relatively free of atomic physics problems. These lines have been observed, for example, in the solar spectrum by *SERTS* and in spectra of Procyon and ϵ Eridani by the *Extreme Ultraviolet Explorer (EUVE)* [1, 2, 4, 3].

2. Spectroscopic measurements

EBIT-II is an electron beam ion trap at Lawrence Livermore National Laboratory in Livermore, California [5], that has been optimized for laboratory astrophysics measurements [6, 7, 8]. Measurements on EBIT-II utilized similar techniques as those described in earlier measurements of the iron emission [9, 10, 11, 12]. Iron was injected into the trap in the form of iron pentacarbonyl via a gas injector. The electron beam energy ranged from 363 to 513 eV. The higher energy is sufficient to produce charge states as high as Fe XVI. The spectra were recorded

with the grazing-incidence spectrometer described by Beiersdorfer et al [13], which employs a 1200 line/mm flat-field grating developed by Harada & Kita [14] with a 3° angle of incidence. Readouts were taken with a back-illuminated, liquid nitrogen-cooled CCD camera with a one inch square array of 1024×1024 pixels. The resolving power is ~ 600 at 200 Å. A foil comprised of a 2000 Å thick aluminum layer on top of 1000 Å of paralene was placed in front of the grating in order to screen out emission from lines with wavelengths below 170 Å. The wavelength scale was established using the well known K-shell emission lines of nitrogen, in particular the N VII Lyman- α line and the N VI resonance line commonly referred to as w , as described by Beiersdorfer et al [13], observed in higher (7th through 10th) orders. The wavelengths of the iron emission lines in this wavelength region are well known, and we have not attempted to improve upon those data. Spectra were also taken without an active trap, i.e., without a potential applied to the trap electrodes. These spectra enabled us to determine the level of background emission (including visible light from the electron-gun filament, to which the CCD camera is sensitive), which was then subtracted from the iron to yield background-corrected spectra.

The Large Helical Device (LHD) is a steady-state stellarator at the National Institute for Fusion Science in Toki, Japan [15, 16]. Measurements on the LHD were made with the SOXMOS EUV grazing-incidence spectrometer [17] covering the wavelength range from 158 to 214 Å. The instrument utilized a 600 lines/mm grating. It was operated with a 10 μm slit, which provided a resolving power of ~ 780 throughout the wavelength range of interest. The iron concentration in the LHD was increased by injection of plastic pellets with an iron core known as TESPEL [18]. Iron then dominates the emission, and essentially no lines from other elements are seen. The discharge in this shot lasted about 4.5 s and the temperature reached to (2 to 3) keV during the main part of the discharge; this temperature is, however, greatly reduced during the plasma decay phase after the end of the heating by neutral beam injection. By recording spectra throughout the discharge every 0.1 s, spectra with different ionization balances are obtained. For example, while the emission from Fe XXIV dominates the spectral region near 200 Å during the main part of the discharge, after the end of the plasma heating the temperature is sufficiently low to see emission from Fe VIII through Fe XIII, similar to the measurements made on EBIT-II [16]. The wavelength scale was determined using 15 strong Fe lines between 171.07 Å and 211.33 Å, as the wavelengths of the iron emission lines in this region are well known.

Measurements on *CHIPS* were made possible by a fortuitous low-throughput light leak, since the instrument is too sensitive to directly observe the Sun. Normal operation employs a mirror inside a slit to reflect photons to the detector. However, when pointed at the “correct” angle relative to the Sun, photons scattered off a baffle bypass the mirror to directly hit the detector. The resolving power is ~ 150 at 200 Å, and the spectrum presented here was obtained through a 1000 Å thick aluminum filter. For further details of the instrument and spacecraft, see [19, 20, 21]. A detailed analysis of the *CHIPS* solar spectra is presented in [22].

3. The spectra

Figure 1 shows the iron spectrum from EBIT-II in the range from 170 to 285 Å. The spectrum represents the sum of about 20 spectra after background subtraction. The spectrum includes lines from charge states between Fe VIII and Fe XV. Figure 2 shows the iron spectrum from the LHD in the range from 170 to 214 Å, and includes lines from charge states between Fe VIII and Fe XIV. Figure 3 shows a spectrum from *CHIPS* in the range from 150 to 275 Å. The spectrum includes iron from charge states between Fe VIII and Fe XV, and also includes a few lines from elements other than iron. In contrast, the laboratory spectra only include iron. Essentially all lines in the spectra have been identified and are labelled. For identification we relied on the atomic data provided by the CHIANTI spectral model [23, 24], as we found that the CHIANTI database did a very good job at reproducing the iron spectra from the EBIT-II and the LHD [16].

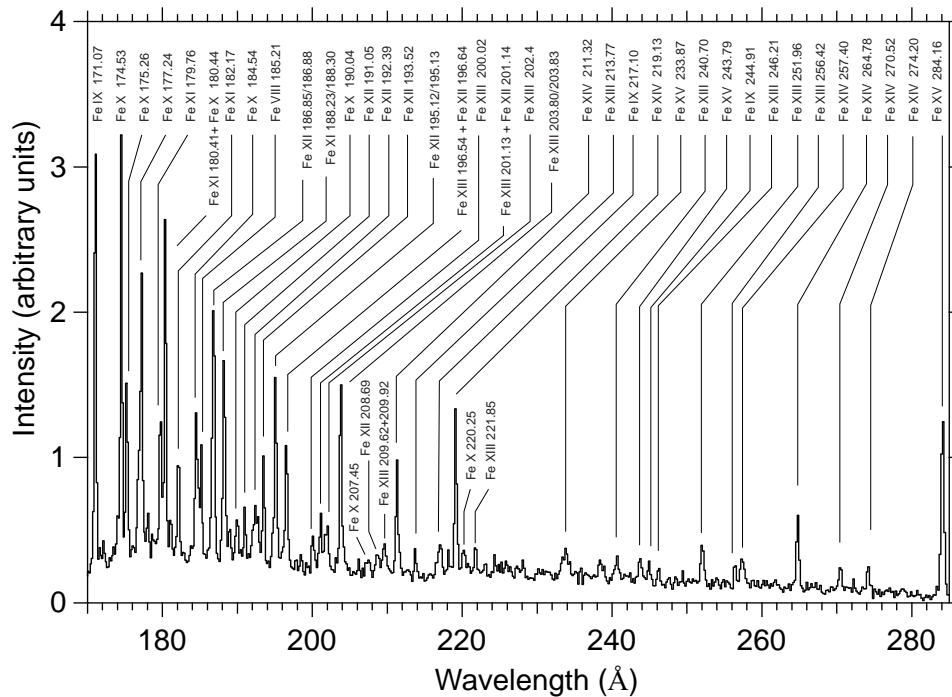


Figure 1. Iron spectrum taken on the electron beam ion trap EBIT-II, covering the range 170 to 285 Å. Charge states from Fe VIII through Fe XV are seen. The wavelengths for all figures are those given by CHIANTI [23, 24].

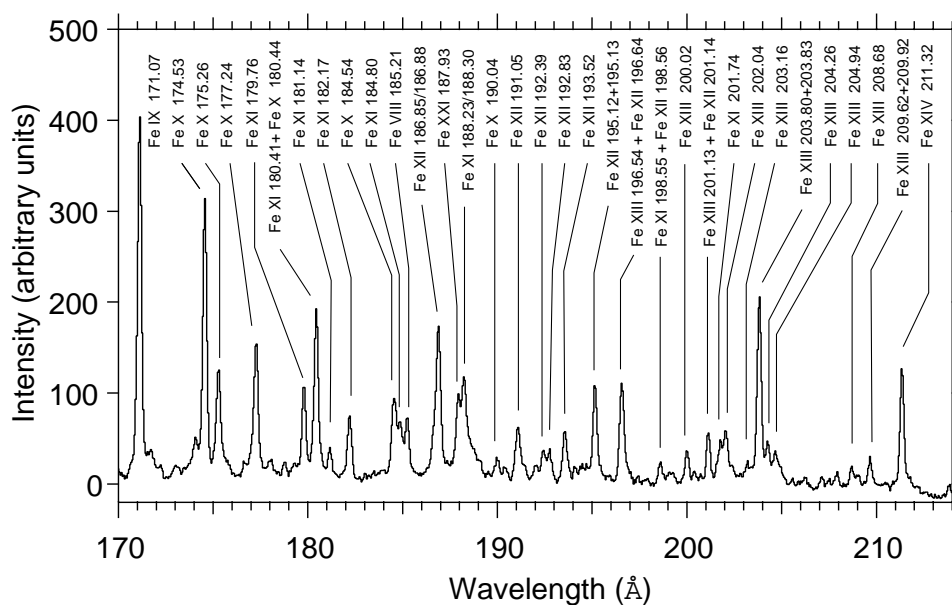


Figure 2. Iron spectrum taken on the LHD stellarator, covering the range 170 to 214 Å. The spectrum includes charge states from Fe VIII through Fe XIV.

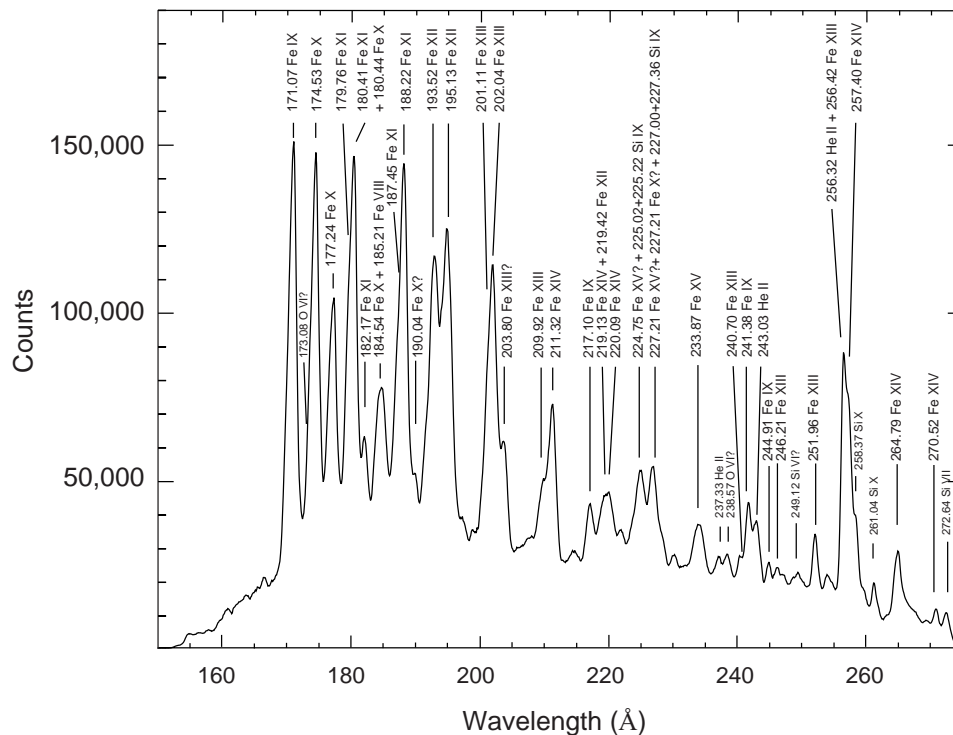


Figure 3. Solar spectrum taken by the EUV spectrometer on board the *CHIPS* satellite, covering the range 150 to 275 Å. Charge states from Fe VIII through Fe XV are labelled, as well as emission lines from other elements.

4. Conclusions

We have presented two laboratory spectra of iron and a spectrum of the solar disk dominated by iron. All three spectra are dominated by intermediate charge states of iron, showing good agreement between each other and the widely used CHIANTI atomic database. We find that the CHIANTI database is an accurate identification tool for the spectrum of iron around 200 Å.

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