A detailed study of emission lines from Fe\textsc{vii}, Fe\textsc{viii}, and Fe\textsc{ix} observed by the EUV Imaging Spectrometer on board the Hinode satellite is presented. Spectra in the ranges 170–212 Å and 246–292 Å show strongly enhanced lines from the upper solar transition region (temperatures $5.4 \leq \log T \leq 5.9$) allowing a number of new line identifications to be made. Comparisons of Fe\textsc{vii} lines with predictions from a new atomic model reveal new plasma diagnostics, however there are a number of disagreements between theory and observation for emission line ratios insensitive to density and temperature, suggesting improved atomic data are required. Line ratios for Fe\textsc{viii} also show discrepancies with theory, with the strong $\lambda 185.21$ and $\lambda 186.60$ lines underestimated by 60%–80% compared to lines between 192 and 198 Å. A newly identified multiplet between 253.9 and 255.8 Å offers excellent temperature diagnostic opportunities relative to the lines between 185 and 198 Å, however the atomic model underestimates the strength of these lines by factors of 3–6. Two new line identifications are made for Fe\textsc{ix} at wavelengths 176.959 Å and 177.594 Å, while seven other lines between 186 and 200 Å are suggested to be due to Fe\textsc{ix} but for which transition identifications cannot be made. The new atomic data for Fe\textsc{vii} and Fe\textsc{ix} are demonstrated to significantly modify models for the response function of the Transition Region And Coronal Explorer 195 Å imaging channel, affecting temperature determinations from this channel. The data will also affect the response functions for other solar EUV imaging instruments such as SOHO/EIT, STEREO/EUVI, and the upcoming AIA instrument on the Solar Dynamics Observatory.

**Key words:** atomic data – line: identification – Sun: corona – Sun: transition region – Sun: UV radiation

1. INTRODUCTION

The iron ions are extremely important for the study of the solar corona as they give rise to many strong emission lines in the extreme ultraviolet wavelength range 90–400 Å that have been exploited for over 40 years (Gabriel et al. 1966; Phillips et al. 2008). Resonance lines of species such as Fe\textsc{ix}, Fe\textsc{xii}, and Fe\textsc{xv} have been selected for observation by EUV imaging instruments such as the EUV Imaging Telescope (EIT) on SOHO (Delaboudinière et al. 1995), the Transition Region And Coronal Explorer (TRACE; Handy et al. 1999), and the Extreme Ultraviolet Imagers (EUVIs; Howard et al. 2008) on the twin STEREO spacecraft. Spectroscopically, the iron lines have been measured by a range of space instrumentation, from the early Orbiting Solar Observatories (OSOs), through to the Skylab S082A spectrometer, the Coronal Diagnostic Spectrometer (CDS) on board SOHO (Harrison et al. 1995) and, most recently, the Hinode/EIS instrument (Culhane et al. 2007). The complexity of the iron ions’ atomic structure leads to many emission line pairs that are sensitive to electron density and, indeed, iron ions form most of the best corona density diagnostics.

The iron ions Fe\textsc{x}–Fe\textsc{xiv} have received a lot of attention from observers and atomic physicists as they give rise to many strong lines in the solar spectrum. Fe\textsc{vii}–Fe\textsc{ix}, by comparison, have few strong lines and atomic calculations are less common. Fe\textsc{ix} has a single very strong emission line at 171.07 Å and a density diagnostic involving two lines at 241.74 and 244.91 Å, but few other lines had been identified in the solar spectrum until Young (2009) presented four new line identifications based on Hinode/EIS spectra. Fe\textsc{viii} gives rise to much weaker lines than the Fe\textsc{ix}–Fe\textsc{xiv} ions and none of them have diagnostic potential, so the ion has received little attention. However, Fe\textsc{viii} can make a significant contribution to the 195 Å imaging channel of the SOHO/EIT and TRACE instruments for polar plumes (Del Zanna et al. 2003) and coronal loops (Del Zanna & Mason 2003), while the high sensitivity of the Hinode/EIS spectrometer has led to Fe\textsc{vii} lines being observed regularly (Young et al. 2007a). Fe\textsc{vii} is predicted to form around $\log T = 5.4$ (Bryans et al. 2009) where the emission measure of typical coronal features is much lower than for the higher temperature iron ions (e.g., Raymond & Doyle 1981). In addition, the atomic structure for Fe\textsc{vii} produces a large number of emission lines of relatively weak strength rather than a few strong lines such as found for the higher ionization stages of iron. These facts combine to make the observed Fe\textsc{vii} solar spectrum very weak compared to the other iron ions and so it has been little studied.

The present work considers the lines of Fe\textsc{vii}, Fe\textsc{viii}, and Fe\textsc{ix} measured in the Hinode/EIS spectrum presented by Landi & Young (2009, hereafter Paper I), comparing measured intensities with predictions from atomic data in the CHIANTI atomic database (Dere et al. 1997, 2009) and investigating their diagnostic potential. The observed spectrum shows Fe\textsc{vii}–Fe\textsc{ix} lines that are strongly enhanced over typical quiet Sun and active region conditions, and thus is ideal for studying lines that are normally too weak to be observed. In addition, we discuss the formation temperatures of Fe\textsc{vii} and Fe\textsc{viii} which appear to be discrepant with other ions.

2. OBSERVATIONS AND DATA REDUCTION

The Hinode/EIS data set and data reduction method were described in detail in Paper I and are only summarized briefly here. The observation took place on 2007 February 21 at 01:15 UT, when the footpoint regions of active region AR 10942 were observed. Complete EIS spectra were obtained, and calibration
was performed with the standard EIS routine EIS_PREP. Spectra from a strong brightening near the base of some coronal loops were averaged, taking care to adjust for spatial offsets between images obtained at different wavelengths. A complete line list from the final, averaged spectrum was presented in Paper I and a differential emission measure (DEM) constructed. Emission line strengths from all ions formed in the range $5.4 \leq \log T \leq 6.0$ were analyzed, except for the iron ions Fe \textsc{vii–ix} which are studied in the present work.

In the following sections we will refer to the DEM curve derived in Paper I, which is reproduced in Figure 1 here. In addition, we also refer to the intensity images formed in various lines that are often valuable for determining the emitting species of unidentified lines or classifying blends. Figure 1 of Paper I shows images from a wide range of ions belonging to different temperatures. The term “class” is used to group together emission lines for which the image morphology is similar to one of these reference images. For example, class C lines are similar to Fe \textsc{vii} $\lambda 195.39$, class D lines similar to Fe \textsc{viii} $\lambda 185.21$, etc. The complete list of temperature classes is given in Table 1 in Paper I.

### 3. ION FRACTION COMPARISON

The abundance of the emitting ion is a key ingredient in the analysis of the emission of spectral lines. Ion abundance calculations rely on ionization and recombination rates that are continuously updated and improved both by laboratory measurements and by new ab initio calculations. Several data sets have been made available in the literature to provide reliable ion abundances as a function of temperature, a few of them published very recently.

Young et al. (2007b) noted that the temperature of maximum abundance, $T_{\text{max}}$, of Fe \textsc{viii} predicted by Mazzotta et al. (1998) appeared to be too low compared to observations. By comparing images obtained in several emission lines the authors demonstrated that the intensity distribution of Fe \textsc{viii}, predicted to be found at $\log T_{\text{max}} = 5.56$, was very similar to the intensity image of Si \textsc{vii} ($\log T_{\text{max}} = 5.76$). Since, in terms of atomic structure, Si \textsc{vii} is a much simpler ion than Fe \textsc{viii}, Young et al. (2007b) suggested the Mazzotta et al. (1998) ion fractions for Fe \textsc{viii} were incorrect. Using the observations from the 2007 February 21 data set we demonstrate that a similar effect is found for Fe \textsc{vii}. Figure 2 shows the intensity maps of the emitting region obtained with lines from Mg \textsc{v–vii} and Fe \textsc{vii–viii}. The top row compares a Fe \textsc{vii} image with images from Mg \textsc{v–vi}, and the bottom row compares Fe \textsc{viii} with Mg \textsc{vi–vii}. The intensity maps show that Fe \textsc{vii} and Mg \textsc{vi} images are very similar, implying similar $T_{\text{max}}$ values, while Fe \textsc{viii} and Mg \textsc{vii} are also very similar. The Mazzotta et al. (1998) calculations, however, place Fe \textsc{vii} closer to Mg \textsc{v} and Fe \textsc{viii} closer to Mg \textsc{vi} (see Table 1).

There have been several ion balance calculations performed over the past quarter of a century, and the Mazzotta et al. (1998) work is the most commonly used of recent years. Table 1 compares $T_{\text{max}}$ values for Mg \textsc{vi–vii} and Fe \textsc{vii–viii} from these calculations, including three recent works (Bryans et al. 2006, 2009; Dere et al. 2009). For each ion and calculation the ion fractions have been interpolated onto a temperature grid spaced at 0.01 dex intervals in $\log T$, with $T_{\text{max}}$ identified as the temperature where the ion fraction peaks. The values for Mg \textsc{vii–vi} are remarkably consistent, however a marked decrease is found for both Fe \textsc{vii} and Fe \textsc{viii} from the Arnaud & Raymond (1992) calculations onward. Interestingly, the older $T_{\text{max}}$ values of Shull & Steenberg (1982a, 1982b) and Arnaud & Rothenflug (1985) for Fe \textsc{vii} and Fe \textsc{viii} are more consistent with the intensity distributions shown in Figure 2.

In Figure 3, we compare the ion fractions for Fe \textsc{vii–ix} as a function of temperature. Significant differences are found between the curves, but the largest ones take place with the iron ion update of Arnaud & Raymond (1992), that resulted in differences of up to one order of magnitude from the previous calculations. Investigating the reasons for this lies beyond the scope of the present paper, but there are two main avenues to be considered: (1) the rates used for Fe \textsc{vii–ix} are incorrect, or (2) some other process (e.g., dynamics, density effects) may influence the Fe \textsc{vii–ix} ion fractions.

### 4. Fe \textsc{vii}

Fe \textsc{vii} lines in the wavelength range 170–300 Å have received little attention from solar spectroscopists as the lines are generally very weak and there have been no atomic data available to model the line intensities. However, two extensive atomic calculations have been published in recent years that allow the lines to be modeled, while the launch of EIS in 2006 has allowed the routine measurement of parts of the 170–300 Å window at high resolution and high sensitivity. The spectrum presented in Paper I shows strongly enhanced lines of Fe \textsc{vii} compared to normal quiet Sun or active region spectra and so presents an excellent opportunity for comparing theory with observations.

Atomic data suitable for modeling electron-excited emission lines have been published by Zeng et al. (2005) and Witthoeft & Badnell (2008) and these are the first calculations that yield data for the excited configurations of the ion that give rise to the emission lines in the extreme ultraviolet. The Zeng et al. (2005) calculations were performed using the Flexible Atomic Code (FAC; Gu 2003) which uses the distorted wave approximation, while Witthoeft & Badnell (2008) performed an R-matrix calculation using the intermediate-coupling frame transformation (ICFT) method of Griffin et al. (1998). Generally R-matrix calculations are considered superior to distorted wave as they allow the resonant enhancement of collision strengths to be accurately modeled, although for excited configurations and high energies the results should be similar. Witthoeft & Badnell (2008) made a comparison with Zeng et al. (2005)
Figure 2. Intensity maps of selected ions. The log $T_{\text{max}}$ values are from Dere et al. (2009).

Table 1
Calculated log ($T_{\text{max}}$/K) Values for Fe vii–viii and Mg v–vii

| Data Set                        | Mg v | Fe vii | Mg vi | Fe viii | Mg vii |
|--------------------------------|------|--------|-------|--------|--------|
| Shull & Steenberg (1982a, 1982b)| 5.44 | 5.64   | 5.63  | 5.88   | 5.81   |
| Arnaud & Rothenflug (1985)     | 5.43 | 5.61   | 5.63  | 5.82   | 5.80   |
| Arnaud & Raymond (1992)        | 5.43 | 5.42   | 5.63  | 5.57   | 5.80   |
| Mazzotta et al. (1998)         | 5.43 | 5.42   | 5.64  | 5.56   | 5.80   |
| Bryans et al. (2006)           | 5.44 | 5.42   | 5.62  | 5.56   | 5.78   |
| Dere et al. (2009)             | 5.45 | 5.41   | 5.63  | 5.61   | 5.78   |
| Bryans et al. (2009)           | 5.45 | 5.42   | 5.63  | 5.62   | 5.78   |

Since the atomic model constructed here is the first to yield intensity predictions for lines from excited configurations of Fe vii at typical coronal densities and temperatures, we outline briefly some of the properties of the lines in terms of diagnostic potential. First, above densities of $10^{9}$ cm$^{-3}$ the nine ground configuration levels of Fe vii are in a quasi-Boltzmann distribution, and thus relative populations change little relative to each other above this value. This means that emission line ratios show little density sensitivity at typical coronal densities of $10^{9}$–$10^{13}$ cm$^{-3}$. There is density sensitivity amongst some emission lines below $10^{9}$ cm$^{-3}$ which may be useful when studying coronal hole regions and specific diagnostics are highlighted in the sections below. The lines formed in the 170–300 Å range have a wide range of excitation potentials and so they can show significant temperature sensitivity. In the sections below we will highlight some useful temperature diagnostics and compare results from these ratios.

Ratios that are insensitive to the physical conditions of the atmosphere are also valuable as a check on the atomic physics parameters. In order to compare observed ratios with theory in these cases, we compute the theoretical ratio over the temperature range log $T = 5.4$–5.7 at 0.05 dex intervals, and the density range log $N_e = 8.0$–10.0 at 0.2 dex intervals. The listed theoretical ratio is then given as the average ratio over these ranges, and the “error” is the 2σ value of the ratio over the ranges (Table 5). The temperature range has been chosen as log $T = 5.4$–5.7 based on the discussion in Section 3. The

and found good agreement for both radiative decay rates and collision strengths. For this work we choose to use the Witthoeft & Badnell (2008) for our atomic model.

The Witthoeft & Badnell (2008) data have been put into the format used by the CHIANTI database, and will be made publicly available in a future version of the database. For inclusion in CHIANTI the collision strengths have been fitted with splines using the method outlined in Dere et al. (1997), while experimental energy levels have been taken from Ekberg (1981), Ekberg & Feldman (2003) and version 3 of the NIST database (Ralchenko et al. 2008). Many levels do not have experimental energies and for these the theoretical values of Witthoeft & Badnell (2008) were used. Some new and revised energy values are suggested from the present work and will be discussed below.
density range chosen is based on the density measured from the Mg vii $\lambda 280.75/\lambda 278.39$ diagnostic (see Paper I) and allowing for up to an order of magnitude variation from this value.

Table 4 in Paper I listed line intensities predicted from the DEM curve and for most of the Fe vii lines the predictions are lower than the observed intensities by factors of 2–5. The Fe vii lines were not included when deriving the DEM curve since no previous check of the Fe vii atomic data has been performed.

We believe the large underestimates of the intensities principally arise from the inaccurate ion fraction curve for Fe vii discussed in the previous section. The DEM predicted intensities include a convolution of the theoretical ion fraction curve and the DEM, and Figure 1 shows that the DEM has a rather low value at $\log T = 5.4$, the Fe vii $T_{\text{max}}$ value of Dere et al. (2009). If the ion fraction curve was shifted to around $\log T = 5.6–5.7$, then it would sample larger values of the DEM and so increased

**Figure 3.** Comparison of ion fraction data sets for Fe vii, Fe viii, and Fe ix, using the most recent calculations.
predicted intensities would result. In the Fe\textsc{vii} discussions that follow we will generally not refer to the DEM intensity predictions for this reason.

Before embarking on our analysis of the observed EIS lines we first consider the measured EIS wavelengths of those transitions that have been identified previously. The line list of Ekberg (1981) is the only comprehensive one in the literature for the 170–300 Å range and was derived from laboratory spectra. Table 2 gives the Ekberg (1981) wavelengths and the measured EIS velocities from the present spectrum for those Fe\textsc{vii} lines from Ekberg’s list that are clearly identified in the EIS spectra and that are either unblended or provide the dominant contribution to blended lines. Table 6 in Paper I presented velocities from the cool ions presented in that paper and it was noted all ions between O\textsc{iv} (log $T = 5.21$) and Mg\textsc{vii} (log $T = 5.76$) have velocities of around 40 km s$^{-1}$. Taking the average velocity of those lines identified to be unblended and without anomalies in Table 6 of Paper I, we derive a value of 40.4 km s$^{-1}$ (using the velocities in the $v_{\text{ref}}$ column of this table), with a standard deviation of 4.5 km s$^{-1}$. Fe\textsc{vii} belongs to this group of cool ions, even with the uncertainty in the ion fraction discussed in Section 3, and so we expect the ion’s line velocities to be consistent with the other cool ions. Therefore in Table 2 we indicate those emission lines for which the measured velocity is not consistent with the cool ion velocity of 40.4 km s$^{-1}$. We find 18 of the 25 lines show good agreement, giving confidence in the Ekberg (1981) measurements. The anomalous lines will be discussed in the following sections.

Since a number of new line identifications have been performed for Fe\textsc{vii} in this work, it is necessary to convert the measured wavelengths to rest wavelengths in order to derive new experimental energies for the upper emitting levels. For this we subtract the average cool ion velocity of 40.4 km s$^{-1}$ from the measured wavelengths.

### 4.1. Lines in the EIS LW Band

The Fe\textsc{vii} lines in the LW band consist of decays from two $n = 4$ terms, $3p^53d^5s^3\text{S}$ and $3p^63d^4p^1\text{P}$, together with decays from the $3p^53d^3\text{S}$, $\text{P}$, and $\text{D}$ terms. The latter two each give rise to two groups of lines corresponding to decays to the $3p^53d^3\text{S}$ and $3p^53d^3\text{F}$ terms in the ground $3p^53d^2$ configuration. Line ratios formed from the $3p^53d^3$ lines are relatively insensitive with regard to density and temperature, and we compare with the strongest line, $\lambda249.30$, below. There is significant temperature sensitivity when comparing lines from different configurations. We go through the LW lines by multiplet, starting with the longest wavelengths.

Four emission features are found between 289 and 291 Å, at the very end of the EIS wavelength range. These are principally due to the Fe\textsc{vii} $3d^2\text{S}^2 3\text{F}_2\rightarrow3d^4\text{s}^3\text{D}_J$ transitions, which were first identified by Brown et al. (2008) from EIS spectra. The strongest line is a blend of the $J = 4 \rightarrow J' = 3$ and $3 \rightarrow 2$ transitions, and also has the Si\textsc{ix} $\lambda290.69$ line in the short wavelength wing. The feature was fitted with two Gaussians forced to have the same width, with the short wavelength Gaussian representing the Si\textsc{ix} line. The remaining three emission features are unblended. Each of $\lambda289.68$, $\lambda289.83$, and $\lambda290.31$ shows only weak sensitivity to density and temperature relative to $\lambda290.72\pm290.76$, and the comparison with theory is shown in Table 5. $\lambda290.31$ is discrepant with theory, with the observed line being too strong, however both $\lambda289.68$ and $\lambda289.83$ agree with theory within the error bars. Table 2 shows that the measured velocities of $\lambda289.68$ and $\lambda289.83$ are discrepant with the standard cool ion velocity. The reference wavelengths for the $3d^2\text{S}^2 3\text{F}_2\rightarrow3d^4\text{s}^3\text{D}_J$ transitions given in Paper I are obtained from the energies of Ekberg (1981), who was able to obtain the $3d^4$ levels energies indirectly by measuring $4s\rightarrow4p$ transitions at wavelengths 1000–1400 Å and $3d\rightarrow4p$ transitions at wavelengths 200–300 Å. Since the EIS wavelengths are direct measurements of the $3d\rightarrow4s$ transitions then the velocity discrepancies for $\lambda289.68$ and $\lambda289.83$ may be due to uncertainties in the Ekberg (1981) $4s$ configuration energies.

The Fe\textsc{vii} model predicts two lines arising from the $3p^53d^3(4\text{P})^5\text{S}_2$ level whose theoretical wavelengths are 270.40 and 271.20 Å, with the latter being stronger by around a factor of 3. The spectra were searched in this region for two lines with the same ratio and wavelength separation, and whose images are consistent with a cool line. The lines observed in the atlas at 271.068 and 271.729 Å were found to match and so we identify these with the $3p^53d^3(4\text{P})^5\text{S}_2$ level for which we are thus able to establish an experimental energy value for the first time (Table 3). The longer wavelength line was used to revise the

### Table 2

| Reference wavelength ($\AA$) | Velocity ($\text{km s}^{-1}$) |
|-----------------------------|-------------------------------|
| 176.744                     | $30.5 \pm 10.9$               |
| 182.071                     | $46.1 \pm 16.8$               |
| 182.740                     | $24.6 \pm 14.7\text{c}$       |
| 183.539                     | $44.1 \pm 11.1$               |
| 183.825                     | $39.1 \pm 8.6$                |
| 184.752$^d$                 | $40.6 \pm 9.1$                |
| 184.886                     | $58.4 \pm 9.8\text{c}$        |
| 185.547                     | $43.6 \pm 8.5$                |
| 186.657                     | $56.2 \pm 12.9\text{c}$       |
| 187.235$^e$                 | $44.8 \pm 8.3$                |
| 187.692                     | $35.1 \pm 8.6$                |
| 188.396$^f$                 | $44.5 \pm 9.5$                |
| 188.576                     | $42.9 \pm 9.0$                |
| 189.450                     | $49.1 \pm 8.1\text{c}$        |
| 190.855                     | $36.8 \pm 7.7$                |
| 190.046                     | $42.6 \pm 7.9$                |
| 191.423                     | $53.4 \pm 7.9\text{c}$        |
| 201.855                     | $47.5 \pm 7.9$                |
| 207.712                     | $44.7 \pm 8.1$                |
| 208.167                     | $46.1 \pm 17.3$               |
| 265.697                     | $46.3 \pm 6.6$                |
| 289.678$^g$                 | $50.7 \pm 6.8\text{c}$        |
| 289.831$^e$                 | $54.8 \pm 6.1\text{c}$        |
| 290.307$^e$                 | $39.2 \pm 5.9$                |
| 290.756$^e$                 | $36.1 \pm 5.6$                |

Notes:

- From Ekberg (1981).
- Errors represent the EIS measurement errors combined with the ±0.005 Å errors on the Ekberg (1981) reference wavelengths.
- A $\text{c}$ symbol beside the velocity measurement indicates that it is discrepant with the average cool line velocity of $-40.4\text{ km s}^{-1}$ by $> 1\sigma$; symbol $\text{c}$ indicates a discrepancy of $> 2\sigma$.
- Blended with Ne\textsc{v} $\lambda184.735$ and Fe\textsc{xii} $\lambda184.803$.
- Blended with Fe\textsc{vii} $\lambda187.241$.
- Possibly blended with Mn\textsc{ix} $\lambda188.48$.
- Wavelengths not directly measured by Ekberg (1981), but deduced from other wavelength measurements.
energy since the shorter wavelength line is blended (see below), and a velocity shift of \(-40.4 \text{ km s}^{-1}\) was applied to determine the rest wavelengths, as described in the previous section. The rest wavelengths of the two decays from the \(5^{2}S_{2}\) level are then 271.067 and 271.692 Å for the decays to the \(3^{2}P_{1}\) and \(3^{2}P_{2}\) levels in the ground configuration, respectively. \(\lambda 271.69\) seems to be unblended and comparing with the strongest line from \(3p^{5}3d\) in the LB band, the \(\lambda 271.69/\lambda 249.30\) ratio shows weak sensitivity to density and temperature and the theoretical value agrees well with observations (Table 5). The observed line at 271.068 Å is a very broad feature, suggesting it is a blend of two or more lines, and Paper I showed that two \(O\nu\) lines contribute, although they cannot fully account for the line’s intensity. The \(Fe\nu\lambda 271.07/\lambda 271.69\) branching ratio is 0.31 and implies that \(Fe\nu\) contributes an intensity of 7.7 erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) to the blend.

Around 265–267 Å the \(Fe\nu\) model gives a line with known wavelength at 265.70 Å, and five lines with theoretical wavelengths due to \(3p^{5}3d^{2} \ 3^{2}P_{1}–3p^{5}3d^{4}(4F) \ 5^{2}D_{J}\) transitions. The known line is the only decay from the \(3p^{5}3d^{4}4\) configuration found in the EIS spectrum and Table 2 shows that the measured wavelength is consistent with the laboratory wavelength of Ekberg (1981). The \(\lambda 265.70/\lambda(290.72+\lambda 290.76)\) ratio is found to be an excellent temperature diagnostic (Figure 4), although it also shows some density sensitivity. Taking the Mg \(vi\) density of \(N_{e} = 9.15\), we find a temperature of \(T = 5.47^{+0.08}_{-0.07}\) which is cooler than the expected \(Fe\nu\) temperature (Section 3), but the discrepancy is not large. Note that \(\lambda 265.70\) is blended with a high-temperature Co \(xxvi\) line (Brown et al. 2008), but this makes no contribution in the present spectrum.

Studying images formed in the weak observed lines between 266 and 267.5 Å, the 267.29 Å line is found to be close in temperature to \(Fe\nu\). The line is broad, suggesting it consists of more than one transition, and we note that the 2–2, 2–1, and 2–3 transitions of the \(3p^{5}3d^{2} \ 3^{2}P_{1}–3p^{5}3d^{4}(4F) \ 5^{2}D_{J}\) multiplet are predicted to lie within 0.13 Å of each other. Summing the theoretical emissivities of each component and taking the ratio relative to \(\lambda 249.30\) we find good agreement between theory and observation (Table 5) suggesting that the observed line is indeed a blend of three \(Fe\nu\) components.

Of the other observed emission lines between 266 and 266.7 Å we believe that a weak feature at around 266.42 Å (not reported in Paper I) and the line measured at 266.623 Å have some cool component based on inspection of the images formed in the lines. The 1–1 and 1–0 components of the \(3p^{5}3d^{2} \ 3^{2}P_{1}–3p^{5}3d^{4}(4F) \ 5^{2}D_{J}\) multiplet are predicted to be blended and lie 0.7–0.8 Å to the short wavelength side of the earlier mentioned transitions and thus could be responsible for one or both of these emission lines. Brown et al. (2008) reported a \(Fe\nu vii\) transition at 266.42 Å but this will not be significant in the present spectrum. The 266.62 Å line was measured but not identified by Brown et al. (2008), and inspection of the line image suggests a line formed at around 1–1.5 million K in addition to the cool component. Due to the weakness of the two lines and the unknown contribution of blending it is not possible to make a definite identification of either of these observed lines with specific \(Fe\nu\) transitions.

Our prescription for revising the energy levels for the \(5^{2}D_{J}\) term is to fit the broad line at 267.29 Å with two Gaussians of the same width, giving components at 267.245 and 267.303 Å with intensities 13.7 and 19.8 erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) (Paper I). The longer wavelength component is assumed to be the 2–2 transition (which is predicted to have the longest wavelength), yielding an experimental energy for the \(3p^{5}3d^{4}(4F) \ 5^{2}D_{2}\) level of 395.46 cm\(^{-1}\). The shorter wavelength measured line is assumed to be a blend of the 2–1 and 2–3 components. Note that the predicted ratio of the combined 2–1 and 2–3 transitions relative to the 2–2 transition is 0.72 in very good agreement with the measured ratio of 0.69. The \(5^{2}D_{3}\) energy value is derived using the \(3p^{5}3d^{2} \ 3^{2}F_{3}–3p^{5}3d^{4}(4F) \ 5^{2}D_{J}\) transition later in this section which yields a predicted wavelength for \(3p^{5}3d^{2} \ 3^{2}F_{2}–3p^{5}3d^{4}(4F) \ 5^{2}D_{1}\) consistent with the measured 267.245 Å line. We can then estimate an energy for the \(5^{2}D_{1}\) level by assuming that the measured wavelength at 267.245 Å corresponds to the \(3p^{5}3d^{2} \ 3^{2}P_{1}–3p^{5}3d^{4}(4F) \ 5^{2}D_{1}\) transition. The derived energy of 395.517 cm\(^{-1}\) is accurate to only around \(\pm 100\) cm\(^{-1}\) as the identified line is blended.
at 259.226 and 260.707 Å reveals they are cool lines, close to the region 257–259 Å and the strongest line belongs to the $\lambda$ line (Paper I). Based on the strength of the Fe line the $3p^3d^3(4P)\ ^3P$ transition is too strong to be consistent with the remaining intensity of the 259.226 Å line, and so we identify the observed 260.707 Å line with this transition. The new experimental energy for $3p^5d^3(4F)\ ^5F_3$ is given in Table 3 and the rest wavelength of the transition is 260.67 Å. The $\lambda 260.67$/$\lambda 249.30$ ratio is predicted to be weakly sensitive to density and temperature and the theoretical ratio is given in Table 5, however the observed ratio is around 25% lower. No other nearby, unidentified emission lines provide a better match in terms of intensity and so we are confident that the 2–3 transition does correspond to the observed 260.71 Å line.

Table 5

| Term\(^a\) | Ratio | Theory | Observation\(^b\) |
|------------|-------|--------|------------------|
| $3p^5d^3(4P)\ ^3P$ | $\lambda 184.89$/$\lambda 183.83$ | 0.238 ± 0.007 | 0.222 ± 0.034 |
| $3p^5d^3(4G)\ ^1F$ | $\lambda 185.55$/$\lambda 195.39$ | 0.343 ± 0.010 | 0.294 ± 0.018 |
| $3p^5d^3(4D)\ ^1D$ | $\lambda 186.65$/$\lambda 195.39$ | 0.454 ± 0.009 | 0.193 ± 0.032 |
| $3p^5d^3(4F)\ ^3D$ | $\lambda 189.45$/$\lambda 188.58$ | 0.542 ± 0.028 | 0.935 ± 0.129 |
| $3p^5d^3(4H)\ ^3G$ | $\lambda 194.5$/$\lambda 195.39$ | 0.265 ± 0.024 | 0.236 ± 0.010 |
| $3p^5d^3(4D)\ ^1F$ | $\lambda 196.42$/$\lambda 195.39$ | 0.698 ± 0.057 | 0.520 ± 0.013 |
| $3p^5d^3(4F)\ ^3F$ | $\lambda 201.86$/$\lambda 195.39$ | 0.359 ± 0.026 | 0.358 ± 0.013 |
| $3p^5d^3(4D)\ ^1G$ | $\lambda 207.71$/$\lambda 195.39$ | 0.067 ± 0.015 | 0.118 ± 0.006 |
| $3p^5d^3(4F)\ ^3G$ | $\lambda 248.64$/$\lambda 249.30$ | 0.319 ± 0.034 | 0.397 ± 0.036 |
| $3p^5d^3(4F)\ ^5F$ | $\lambda 249.30$/$\lambda 249.30$ | 0.593 ± 0.06 | 0.493 ± 0.067 |
| $3p^5d^3(4F)\ ^3D$ | $\lambda 254.52$/$\lambda 254.05$ | 0.373 ± 0.032 | 0.281 ± 0.035 |

Notes.

\(^a\) Ratios are grouped according to the spectroscopic term of the upper emitting level. Ratios are formed either between lines emitted from the same term, or one of these lines relative to a reference line ($\lambda 195.39$ for the EIS SW band, and $\lambda 249.30$ for the LW band).

\(^b\) A $\triangle$ symbol indicates a $\approx\sigma$ discrepancy between theory and observation. $\blacktriangledown$ indicates a $>2\sigma$ discrepancy.

\(^c\) Possibly blended with Ne vii $\lambda 184.95$.

\(^d\) The contribution of Fe vii $\lambda 196.45$ has been subtracted (see text for details).

Five lines from the $3p^63d^2\ ^3P_2$–$3p^5d^3(4F)\ ^5F_3$ multiplet are potentially observable in the EIS spectrum but experimental wavelengths are not available. They are predicted to lie in the region 257–259 Å and the strongest line belongs to the $J = 2$ to $J' = 3$ transition. Image inspection for two lines at 259.226 and 260.707 Å reveals they are cool lines, close in temperature to Fe vii and so are possible candidates. The 259.226 Å line has contributions from Cr vii and Al vii although these cannot fully account for the strength of the observed line (Paper I). Based on the strength of the Fe vii $\lambda 249.30$ line the $3p^63d^2\ ^3P_2$–$3p^5d^3(4F)\ ^5F_3$ transition is too strong
The next strongest line from the multiplet is the 1–2 transition which is predicted to be a factor of 0.59 weaker and 0.64 Å shorter in wavelength. Two candidates in the spectrum are the lines at 259.99 and 260.29 Å. Inspecting images of both lines show that they have a cool component in addition to a hotter component. The 259.99 Å line is a known Fe xiii transition and this is confirmed by the line image, while the 260.29 Å line appears to be formed around log $T = 6.0$. Due to the uncertainty in the identification of the 1–2 transition, we are not able to offer an experimental energy for the ($^4F$) $^5D_2$ level.

A group of four $3p^63d^2$ $^3F_{3/2}$–$3p^63d^3(^4F)$ $^5D_{J}$ ($J’ = 2, 3, 4$) transitions are predicted between 250 and 253 Å and some guidance as to the location of these lines is given by the earlier identification of the $3p^63d^2$ $^3P_2$–$3p^63d^3(^4F)$ $^5D_2$ transition. First, we note that the strongest line of the $3p^63d^2$ $^3F_{5/2}$ multiplet is predicted to be the 4–4 transition. The difference between theoretical energy and observed energy for the $^5D_2$ level derived previously is 3195 cm$^{-1}$. If we assume the $^5D_0$ level energy is also discrepant by this amount then the predicted wavelength of the 4–4 transition becomes 253.89 Å. The next strongest line from the multiplet is the 3–3 transition which, again using the energy correction from the $^5D_2$ level, is expected at 253.45 Å. This line is predicted to be a factor of 0.46 weaker than the transition from the $^5D_1$ level. There is a group of five lines close to these predicted wavelengths, the strongest being an Fe vii line at 253.98 Å (Section 5). The best matches with the Fe vii lines are the two lines measured at 253.56 and 254.09 Å. Images formed in both lines are consistent with other Fe vii images, and the measured ratio is close to the predicted ratio (Table 5). In addition, the $\lambda254.05/\lambda249.30$ ratio is in agreement with theory. The new experimental energies for the $^5D_1$ and $^5D_2$ levels are given in Table 3. With four of the five levels of the $^5D$ multiplet now assigned experimental energies, a revised energy for the remaining level, $^5D_0$, can be estimated. The average difference between the experimental and theoretical energies for $^5D_{1–4}$ is $-3269$ cm$^{-1}$ and subtracting this from the $^5D_0$ theoretical energy gives the value in Table 3. We estimate that this value is accurate to around $\pm 200$ cm$^{-1}$.

Two lines of the $3p^63d^2$ $^3F_{3/2}$–$3p^63d^3(^4F)$ $^5F_J$ multiplet are predicted to lie close to the short wavelength edge of the EIS LW band: the 4–4 transition at 246.17 Å, and the 4–5 transition at 246.69 Å. As for the previously discussed multiplet, these wavelengths can be revised based on the $3p^63d^2$ $^3P_2$–$3p^63d^3(^4F)$ $^5F$ transition identified earlier at 260.678 Å. The difference between the experimental and theoretical energies for $^5F_1$ that this identification implied is 4413 cm$^{-1}$. Adjusting the theoretical energies for the $^5F_4$ and $^5F_5$ levels by the same amount leads to new predicted wavelengths of 248.55 and 249.08 Å. The atomic model predicts that the short wavelength line is a factor 0.58 times weaker than the long wavelength line. Based on this information, we can identify the Fe vii lines with two lines at 248.67 and 249.33 Å whose ratio is 0.49 $\pm$ 0.07 and for which the images are consistent with other Fe vii lines. The new experimental energies for the upper levels of the two transitions are given in Table 3, and the rest wavelengths are 248.635 and 249.295 Å. These two identifications mean that three of five levels of the $^5F$ multiplet now have experimental energies, and these can be used to estimate improved energies for the remaining $^5F_1$ and $^5F_2$ levels. The average difference between theoretical and observed energies for $^5F_{3–5}$ is $-4575$ cm$^{-1}$, and applying this to the $^5F_{1,2}$ theoretical energies yields the energies listed in Table 3. These values should be accurate to around $\pm 200$ cm$^{-1}$.

$\lambda249.30$ is the strongest of the EIS Fe vii lines in the LW band arising from the $3p^63d^3$ configuration and the above paragraphs demonstrated that the ratios amongst the $3p^63d^3$ lines are in good agreement with theory—see also Table 5. We now consider ratios of $\lambda249.30$ against the strongest lines from the $n = 4$ multiplets.

$\lambda249.30/\lambda290.72+\lambda290.76$ is temperature sensitive while showing relatively weak density sensitivity (Figure 4). However, the observed ratio of $0.39 \pm 0.04$ is outside the range of variability of the theoretical ratio, being too high compared to theory by a factor of around 2. $\lambda249.30/\lambda265.70$ shows both temperature and density sensitivity, but if we calculate the theoretical ratio for a density of log $N_e = 9.15$ and temperature of log $T = 5.6$ we get a value of 2.83, which compares with the observed ratio of 6.07 $\pm$ 0.082. It thus appears that the atomic data from Witthoeft & Badnell (2008) overpredict the strength of the lines from the $n = 4$ configurations compared to the $3p^63d^3$ configuration, based on the EIS measurements.

This completes our survey of the Fe vii lines in the EIS LW waveband based on the new atomic model. We finish by noting that Ekberg (1981) listed eight transitions arising from levels in the $3p^63d^4p$ configuration that lie in the LW band. Only one of these, the $3p^63d^2$ $^1S_0$–$3p^63d^3p$ $^1P_1$ transition at 265.70 Å, was discussed above as the predicted intensities of the remaining transitions are all too low to be measured by EIS. For example, the strongest of the seven remaining transitions, $3p^63d^2$ $^2P_0$–$3p^63d^3p$ $^5D_1$ at 246.86 Å, is predicted to be 0.47 times weaker than $\lambda265.70$ by the atomic model. However, the instrument effective area is lower by further factor of 0.26 at the shorter wavelength, making it too weak to be detectable in the present spectrum.

4.2. Lines in the EIS SW Band

All the Fe vii lines expected in the EIS SW band are emitted from the $3p^53d^3$ configuration and Ekberg (1981) provided a large number of line identifications based on laboratory spectra. These identifications were determined by searching for emission lines whose spacing indicated that they represented decays from a single upper level to different lower levels in the ground configuration—the lower level energies being well known, and thus the line separations are accurately predicted. Ekberg (1981) also used theoretical calculations of level energies and radiative decay rates to identify the upper levels. We first make general comments about comparisons between the Ekberg (1981) line identifications and the Witthoeft & Badnell (2008) atomic model.

The $3p^53d^3$ configuration consists of 110 fine structure levels from 48 spectroscopic terms. There are many duplicate terms (for example, there are six $^3D$ terms) and so it is necessary to differentiate them by specifying the parent terms of the $3d^3$ sub-shell. Witthoeft & Badnell (2008) did not specify the parent terms, and so they have been derived separately using the AUTOSTRUCTURE atomic code by one of the present authors (P.R.Y.). By matching with the level ordering of the $3p^53d^3$ configuration levels of Ekberg (1981) we confirm all of the parent terms listed by Ekberg (1981), except for his ($^2F$)$^1D_2$ level, which we find to be ($^2D$)$^1D_2$. For the levels identified by Ekberg (1981), the Witthoeft & Badnell (2008) theoretical energy values are between 13,000 and 23,000 cm$^{-1}$ larger.

When comparing theoretical structure calculations with previously identified energy levels, there is a risk of mismatches...
due to level mixing. For example, if \(^1F_3\) and \(^3D_2\) levels are strongly mixed, then the level names become arbitrary and so one author may assign the name \(^1D_2\) to a level, while another author might assign \(^3D_1\).  To ensure that the same level identifications are used, it is necessary to study the strengths of the transitions predicted to arise from the levels. To check this in the present case we have gone through each level identified by Ekberg (1981) and compared his measured intensities for each line emitted by the level, and then compared with the predictions from the new atomic model. For all but one level, the strongest line predicted by the model agrees with the strongest line measured by Ekberg (1981). The one exception is the \(3p^3d^3(^2F)\) \(^3D_2\) level for which the model gives the decay to \(^3F_0\) to be the strongest, whereas Ekberg (1981) finds the decay to \(^3D_2\) to be the strongest. However, the differences are not large and no other nearby level in the model is consistent with the Ekberg (1981) intensities. We are thus confident that all the Ekberg (1981) levels are correctly matched with levels of the same name in the Witthoeft & Badnell (2008) model.

In the following paragraphs we will systematically go through each of the 11 spectroscopic terms in the Fe \(\text{VII}\) \(3p^3d^3\) configuration that give rise to the EIS SW lines, starting with the longest wavelength lines. In order to check the consistency of the line intensities we will make three types of comparison: (1) ratios of lines emitted from the same upper level (branching ratios); (2) ratios relative to the strongest line from a multiplet; and (3) ratios relative to the strongest line in the EIS SW band, the \(3p^3d^32\) \(^3F_2\)-\(3p^3d^3(^2H)\) \(^3G_5\) transition, \(\lambda 195.39\). Since all of the Fe \(\text{VII}\) transitions in the EIS SW band are due to \(3p^3d^32\) \(-\) \(3p^3d^3\) transitions, we will not refer to configurations in the notation below. Thus, e.g., \(^1F_4\)\(^2H\) \(^3G_5\) refers to the \(3p^3d^2\) \(^3F_4\)-\(3p^3d^3(^2H)\) \(^3G_5\) transition.

Working through the Fe \(\text{VII}\) lines from the longest wavelengths in the SW band through to the shortest, we begin with the two lines from the \(^2(F)\) \(^3G_1\) level: the decay to \(^3F_2\) at 207.71 Å and the decay to \(^3F_1\) at 208.17 Å. The former is the stronger and the wavelength is consistent with the Ekberg (1981) laboratory measurement (Table 2). Comparing with the strongest Fe \(\text{VII}\) line seen in the EIS spectrum, \(\lambda 195.39\), the \(\lambda 207.71/\lambda 195.39\) ratio is found to be relatively insensitive to density and temperature and the measured line ratio is around 25% larger than predictions (Table 5). The \(\lambda 208.17\) line can also be identified in the spectrum and, although very weak, the observed intensity is consistent with the \(\lambda 207.71\) line (Table 4), while the derived velocity is also consistent with other cool lines (Table 2).

The strongest line from the \(^2(F)\) \(^3G_4\) level is the decay to \(^3F_3\) at 201.86 Å. This line is observed in the EIS spectrum partly in the short wavelength wing of the stronger Fe \(\text{XIII}\) \(\lambda 202.04\) line, and the wavelength is consistent with the Ekberg (1981) laboratory measurement (Table 2). The strength of \(\lambda 201.86\) is compared with the strong \(\lambda 195.39\) Fe \(\text{VII}\) line in Table 5, however the observed line is stronger than predictions by a factor of 2. A further line from the \(^2(F)\) \(^3G_4\) is the decay to \(^3F_2\) at 202.38 Å, which is predicted to be a factor of 5.0 less than \(\lambda 201.86\). In the EIS spectrum at this wavelength there is a feature that can be fitted with two Gaussians giving the two lines at 202.344 and 202.420 Å in the line list table (Paper I). Neither of these wavelengths is consistent with the Fe \(\text{VII}\) line. The stronger line at 202.42 Å was identified as a blend of Fe \(\text{X}\) and Fe \(\text{XIII}\) by Brown et al. (2008). However, the Fe \(\text{XIII}\) identification is incorrect as the \(3s2p^3(^2P_1)3s3p^4dP_0\) transition actually occurs at 203.16 Å. An image formed in the 202.42 Å line is clearly consistent with Fe \(\text{X}\) and there is a suggestion that a cool line contributes at the footpoint regions, but this is not clear. The Fe \(\text{VII}\) \(\lambda 202.38/\lambda 201.86\) branching ratio implies that Fe \(\text{VII}\) contributes an intensity of 10 erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) to the measured line at 202.42 Å.

The \(3F_3\)\(^2H\) \(^3G_4\) multiplet is the most important group of Fe \(\text{VII}\) lines observed by EIS as they lie very close to the peak sensitivity of the instrument, making them the strongest Fe \(\text{VII}\) lines. However there are problems reconciling the Ekberg line identifications with the atomic model and the measured EIS line intensities. The situation is complicated by the fact that the model predicts further lines from the \(^3F-(a^2D)^3F\) and \(^1G-\(^2H\)\) \(^3H\) \(^3G_5\) multiplets to lie close to the \(3F_3\)\(^2H\) \(^3G_4\) multiplet.

The strongest lines from the \(3F_3\)\(^2H\) \(^3G_4\) multiplet are given by Ekberg at 195.39 Å (4–5), 196.42 Å (3–4), and 196.05 Å (2–3). The atomic model predicts the relative strengths to be 1.0:0.68:0.35. Lines can be seen corresponding to each of the Ekberg lines in the EIS spectra, however their ratios are 1.0:0.20:0.36. The \(3F_3\)\(^2H\) \(^3G_4\) line is thus clearly discrepant with theory by a factor of 3.

In the vicinity of these three lines in the EIS spectra we find two unidentified lines at 195.51 and 196.24 Å whose images are consistent with Fe \(\text{VII}\). The measured ratios of these lines relative to 195.40 are 0.52 and 0.51 and are thus more consistent with the predicted intensity of the \(3F_3\)\(^2H\) \(^3G_4\) transition. The theoretical model of Fe \(\text{VII}\) predicts that the \(3F_3\)\(^2H\) \(^3G_5\) and \(3F_3\)\(^2H\) \(^3G_4\) transitions lie between the wavelengths of \(3F_3\)\(^2H\) \(^3G_5\) and \(3F_3\)\(^2H\) \(^3G_4\). We thus believe that the observed line at 195.51 Å is actually the \(3F_3\)\(^2H\) \(^3G_4\) transition, and we use the measured wavelength to derive a new experimental energy for the \(3F_3\)\(^2H\) \(^3G_4\) level which is given in Table 3. The rest wavelength for the \(3F_3\)\(^2H\) \(^3G_4\) transition is then 195.480 Å. We stress that there is some uncertainty over this identification on account of the fact that the \(\lambda 195.48/\lambda 195.39\) ratio is discrepant with the prediction from the atomic model as shown in Table 5 with \(\lambda 195.48\) apparently too weak in observations by around 25%, however no better solution for the identification of this strong transition can be found.

To explain the decays to \(^1F_3\) and \(^3F_3\) that Ekberg identified with \(^2H\) \(^3G_4\), we find that they are consistent with transitions from \((a^2D)^3F_4\). The theoretical data of Witthoeft & Badnell (2008) place \((a^2D)^3F_4\) very close in energy to the \((2H)^G\) levels, implying the decays to the \(3F\) ground term will be close in wavelength. In addition, the predicted \(3F_3-(a^2D)^3F_4\) to \(3F_3-(a^2D)^3F_4\) intensity ratio is 0.44, consistent with Ekberg’s measured ratio of 0.47. (The predicted \(3F_3-(2H)^G\) \(^3G_4\) intensity ratio is 0.04 and so is inconsistent with Ekberg’s measurements.) By making the identification of the \((a^2D)^3F_4\) level with Ekberg’s transitions we transfer Ekberg’s experimental energy for \((2H)^G\) \(^3G_4\) to \((a^2D)^3F_4\) and this energy is given in Table 3. No experimental energies were available for the \((a^2D)^3F_4\) and \((a^2D)^3F_4\) levels and so we have used the difference between the experimental and theoretical energies for \((a^2D)^3F_4\) to adjust the theoretical energies for these two levels, and the new values are given in Table 3. With regard to the EIS spectra, the \(\lambda 196.42\) line that we identify with \(3F_3-(a^2D)^3F_4\) is partly blended with Fe \(\text{XIII}\) \(\lambda 196.52\) (note the revised wavelength of this transition suggested by Young et al. 2009) as well as another Fe \(\text{VII}\) line, the \(3F_3\)\(^2H\) \(^3G_3\) transition at 196.45 Å. Inspection of the observed feature shows an emission line with an extended shoulder on the long wavelength side, corresponding to dominant Fe \(\text{VII}\) emission and a weak Fe \(\text{XIII}\) component. It can be fitted with two Gaussians forced to have the same width (Table 4 of Paper I) and the...
The strongest transition from the \((a^2D)^3F\) term is \(3^F_{2}-(a^2D)^3F_{3}\), and with the theoretical \((a^2D)^3F_{1}\) energy revised as above the predicted wavelength becomes 194.728 Å. The predicted ratio relative to \(\lambda 195.39\) is 0.152 ± 0.007, while that relative to \(\lambda 196.42\) is 2.28 ± 0.48 placing the expected intensity somewhere between 34 and 61 erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\). A possible candidate is the line measured at 194.82 Å in the present spectrum. Inspecting the image formed from this line suggests that it is mostly due to Fe \(\text{x}\) (see Section 6), however by forming an image toward the short wavelength side of the line, a cool component similar to Fe \(\text{vii}\) can be seen. The line at 194.82 Å is broader than the nearby Fe \(\text{viii}\) \(\lambda 194.66\) and Fe \(\text{ix}\) \(\lambda 197.86\) lines suggesting that it is a blend of two lines, and the measured intensity of the line is consistent with its being due to Fe \(\text{vii}\) \(\lambda 195.39\) and the Fe \(\text{ix}\) \(\lambda 196.21\) transitions. Despite this we do not make a definite identification of the Fe \(\text{vii}\) transition as the observed line and so do not revise the \((a^2D)^3F_{1}\) energy. Analysis of high-resolution laboratory spectra may possibly be able to confirm the identification.

Returning to the \(3^F_{1}-(\ell H)^{3}G_{J}\) multiplet, we note that the image formed in the \(\lambda 195.39\) line shows a contribution from a coronal line which is consistent with Fe \(\text{x}\). Bromage et al. (1977) identified the Fe \(\text{x}\) \(3s^23p^2\; ^2P_{3/2}-3s^23p\; ^1S\; 3d^2\; ^2D_{3/2}\) transition with a line at 195.399 Å in laboratory spectra, however Keenan et al. (2008) identified the transition with a line at 195.32 Å in solar spectra. Based on several different spectra taken with EIS, Brown et al. (2008) identify the Fe \(\text{x}\) transition with the laboratory wavelength, and find no line corresponding with the line observed by Keenan et al. (2008). For this work we have inspected a quiet Sun off-limb spectrum (where Fe \(\text{vii}\) is negligible) and confirm that the Fe \(\text{x}\) wavelength is 195.40 Å. Note that the Fe \(\text{x}\) model in CHIANTI does not give an observed wavelength for the transition, instead the theoretical wavelength of 195.316 Å is used—see Del Zanna et al. (2004). We can use the CHIANTI model to estimate the contribution of Fe \(\text{x}\) to the Fe \(\text{vii}\) \(\lambda 195.39\) line: Fe \(\text{x}\) \(\lambda 195.40/\lambda 184.54\) is found from CHIANTI to be density sensitive, ranging from 0.025 at \(\log N_{e} = 8\) to 0.057 at \(\log N_{e} = 12\). If we use the density derived from Mg \(\text{vii}\) of \(\log N_{e} = 9.15\), then the predicted Fe \(\text{x}\) ratio is 0.032. The measured Fe \(\text{x}\) \(\lambda 184.54\) intensity is 504.3 erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\), giving a predicted Fe \(\lambda 195.40\) intensity of 16 erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\)—only a 7% contribution to the measured line at 195.42 Å.

The Fe \(\text{vii}\) \(3^F_{2}-(\ell H)^{3}G_{J}\) transition, \(\lambda 195.48\), lies close to the Ni \(\text{xxv}\) \(3s^23p^2\; ^2D_{3/2}-3s^3s\; ^1S\; 3d^2\; ^1D_{2}\) transition at 195.52 Å (Brown et al., 2008), but this line is negligible in the present spectrum as it is formed at log \(T = 6.4\). The \(F_{2}-(\ell H)^{3}G_{J}\) transition, \(\lambda 195.05\), lies in the long wavelength wing of the stronger Fe \(\text{vii}\) \(\lambda 195.97\) line, and a Gaussian fit is necessary to separate the components. Brown et al. (2008) list a \(\Omega\) transition between the Fe \(\text{viii}\) and Fe \(\text{vii}\) lines, but there is no evidence for this line here.

The \(1^G_{4}-(\ell H)^{1}H_{5}\) transition is predicted by the atomic model to be 0.53 times the intensity of the \(3^F_{2}-(\ell H)^{3}G_{3}\) transition at 195.39 Å, and the theoretical wavelength is 1.06 Å longward of this transition. Therefore the observed line at 196.24 Å is an excellent match. The other only line predicted to arise from the \(\ell H)^{1}H_{5}\) level in the EUV is the decay to \(3^F_{2}\) which occurs around 10 Å shorter in wavelength compared to the decay to \(1^G_{4}\). The atomic model predicts this line to be 43 times weaker and so it cannot be observed by EIS. The measured wavelength of the 196.24 Å line is used to derive a new energy value for the \(\ell H)^{1}H_{5}\) level, and this is given in Table 3. The rest wavelength of the transition is then 196.217 Å. Note that \(\lambda 196.21/\lambda 195.39\) is a good density diagnostic and Figure 5 shows the variation with density at three temperatures. For the present spectrum, choosing the temperature of log \(T = 5.55\) we find a density of \(\log N_{e} = 8.68 ± 0.08\), which is significantly lower than the values from the Mg \(\text{vii}\) and Si \(\text{vii}\) density diagnostics (Paper I). To obtain the Mg \(\text{vii}\) density, the observed \(\lambda 196.21/\lambda 195.39\) ratio would have to be increased by only 10% which is a relatively small discrepancy compared to other ratios discussed in this section.

The \((a^2D)^3D_{2}\) level gives rise to only one line capable of being seen by EIS: the decay to \(3^D_{2}\) at wavelength 192.006 Å. This line is blended with Fe \(\text{viii}\) \(\lambda 192.01\) and a coronal line, which we believe to be due to Fe \(\text{x}\). The Fe \(\text{vii}\) \(\lambda 192.01/\lambda 195.39\) ratio is weakly sensitive to density and temperature with a value of 0.041 ± 0.007, and so the Fe \(\text{vii}\) contribution to the 192.01 Å line can be estimated as 9.2 ± 2.5 erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) (12% of the total line intensity), using the measured \(\lambda 195.39\) intensity. In Section 5, the Fe \(\text{viii}\) contribution to the observed 192.02 Å line is estimated to be 54%.

Ekberg (1981) identified lines from the \(J = 2\) and \(J = 3\) components of the \((\ell F)^{3}D_{J}\) multiplet, but not from the \(J = 1\) component. We discuss first the identified lines. The strongest line predicted by the atomic model is the \(3^P_{2}-(\ell F)^{3}D_{1}\) transition at 188.58 Å which lies in the wing of the stronger Fe \(\text{ix}\) \(\lambda 188.50\) line. A simultaneous 15 Gaussian fit was performed over the range 187.71–189.13 Å due to the lack of nearby continuum around these lines. The Fe \(\text{vii}\) line is found to be much weaker than expected: \(\lambda 188.58/\lambda 195.39\) has a theoretical value of 0.489 ± 0.068, yet the observed ratio is 0.253 ± 0.034. The next strongest line from the \((\ell F)^{3}D_{3}\) level is the decay to \(3^F_{2}\) at 187.24 Å which is blended with Fe \(\text{viii}\) \(\lambda 187.24\) and, as noted in Section 5, Fe \(\text{vii}\) appears to contribute more than half of the measured intensity. This actually makes it a little stronger than \(\lambda 188.58\) whereas theory predicts it to be almost a factor of 4 weaker. A further line emitted from the \((\ell F)^{3}D_{2}\) level is the decay to \(3^D_{2}\) at 182.07 Å. Although predicted to be only 0.13 the strength of \(\lambda 188.58\), a line can be identified in the wing of Fe \(\text{xi}\) \(\lambda 182.16\) that appears to be the Fe \(\text{vii}\) transition. The line fit parameters in the line list table of Paper I are derived by forcing the Fe \(\text{vii}\) line to have the EIS instrumental width of 56 mÅ, otherwise an unrealistically narrow line results. The line velocity is consistent with the other Fe \(\text{vii}\) transitions (Table 2), but the \(\lambda 182.07/\lambda 188.58\) ratio of 0.407 ± 0.164 is significantly discrepant with theory. These results suggest that the atomic data for the \((\ell F)^{3}D_{2}\) level are in error.

The strongest line predicted from the \((\ell F)^{3}D_{2}\) level is at 189.45 Å and this can be identified in the EIS spectrum. Comparing with the strongest line from the \((\ell F)^{3}D_{3}\) level, the \(\lambda 189.45/\lambda 188.58\) ratio shows weak sensitivity to density and temperature but the observed ratio is almost a factor of 2 stronger than the predicted ratio (Table 5). This is consistent with
the problems discussed in the previous paragraph with regard to the \((2F)^3D_1\) level, and we note that \(\lambda 189.45/\lambda 195.39\) is in better agreement with theory (Table 5). The next strongest line predicted from \((2F)^3D_2\) is the decay to \(^1D_2\) at 188.40 Å which, however, is observed to be stronger than \(\lambda 189.45\); the observed \(\lambda 188.40/\lambda 189.45\) branching ratio is almost a factor of 2 larger than the predicted value (Table 5). Table 4 in Paper I lists a Mn ix transition as a possible blend to \(\lambda 188.40\), contributing 30% to the observed line intensity based on the DEM intensity prediction. As mentioned in Paper I, the experimental wavelength of the Mn ix line is only accurate to \(\pm 0.05\) Å and so it could actually be bending with the nearby Fe ix \(\lambda 188.50\) line, but the large Fe vii branching ratio discrepancy suggests it is more likely to be a blend with Fe vii \(\lambda 188.40\). A decay to the level \(^3F_3\) gives a line at 182.74 Å which is seen in the EIS spectra, although the wavelength shows a small discrepancy compared to the Ekberg (1981) laboratory wavelength (Table 2). The \(\lambda 182.74/\lambda 188.40\) branching ratio is consistent with theory (Table 5), however. A further decay to \(^3P_2\) is predicted at 189.76 Å, with the \(\lambda 189.76/\lambda 189.45\) branching ratio suggesting an intensity of around 9 erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\). A line at this wavelength cannot be clearly seen in the spectrum, however.

Ekberg (1981) did not report any lines from the \((2F)^3D_1\) level, however the atomic model predicts three potentially observable lines. The Witthoeft & Badnell (2008) atomic data yield predicted wavelengths for these lines, but more accurate predicted wavelengths can be obtained by making use of the experimental energies of the \((2F)^3D_{2,3}\) levels. We first note that the Witthoeft & Badnell (2008) theoretical energy for \((2F)^3D_1\) is 568 459 cm\(^{-1}\), while the average difference between the theoretical and observed energies for \((2F)^3D_{2,3}\) is +22006 cm\(^{-1}\). We thus estimate a revised energy for \((2F)^3D_1\) of 546454 cm\(^{-1}\), which has an accuracy of around \(+2000\) cm\(^{-1}\). The strongest line emitted by \((2F)^3D_1\) is the decay to \(^3P_0\) with a predicted wavelength of 189.97 Å which is accurate to around \(+0.7\) Å. It is insensitive relative to the strongest line from \((2F)^3D_2\) \((\lambda 189.45\) with a value 0.508 \(+0.040\), which makes it a good match for the line observed at 189.36 Å; the observed ratio being 0.574 \(+0.039\). Images formed in the 189.36 Å line are also consistent with Fe vii. If this identification is correct then we also expect two further lines at 182.436 and 189.499 Å in the spectrum whose ratios relative to the stronger line are 0.43 and 0.68, respectively. There is a weak line seen at 182.430 Å however the ratio relative to the 189.36 Å line is 0.708 \(+0.185\), and so higher than theory predicts. If a line exists at 189.499 Å it will partly blend with the observed Fe vi line at 189.481 Å. The line width of the latter is not anomalously broad and so the predicted line at 189.499 Å is either not there, or anomalously weak. Because of these problems we do not identify the observed 189.359 Å line with the Fe vii \(^3P_0/(2F)^3D_1\) transition.

The strongest transition predicted from the \((b^2D)^1D_2\) level is the decay to \(^1D_2\) at 186.66 Å, which places it in the wing of the strong Fe vii \(\lambda 186.60\) line. Performing a two Gaussian fit to \(\lambda 186.60\) reveals a weak line in the long wavelength wing, however the wavelength is longer than expected based on the reference lines (Table 2). Brown et al. (2008) identified the line at this wavelength as a Ni xiv transition, however the intensity predicted for this line using the DEM is < 1 erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) and so it can be ignored in the present case. If we assume that Fe vii accounts entirely for the measured line, then the discrepant wavelength suggests that the two Gaussian fit may not be accurately measuring the weak line. This is also suggested by a look at the \(\lambda 186.66/\lambda 195.39\) ratio, which is weakly sensitive to temperature and density: Table 5 shows that \(\lambda 186.66\) is weaker than expected by more than a factor of 2. Two further lines are predicted to arise from the \((b^2D)^1D_2\) level: the decays to the \(^3P_{1,2}\) ground levels at wavelengths 187.69 and 187.99 Å, respectively, and the branching ratios are 0.13 and 0.11. Based on the measured intensity of \(\lambda 186.66\) the lines should be very weak, but a line is observed at 187.71 Å that is consistent with the expected position of \(\lambda 187.69\) (Table 2) and for which the image is consistent with Fe vii. The observed intensity, however, is much stronger than expected (Table 4), with the measured line at 187.71 Å almost half the strength of \(\lambda 186.66\). A line is observed at 187.972 Å but we believe this is a Fe x transition (Section 6). Fe vii \(\lambda 187.99\) will lie in the long wavelength wing of the this line, but no significant feature is found here implying the line is weak.

The \((2G)^1F_3\) level gives rise to two lines at 185.55 Å and 186.87 Å, and the branching ratio \(\lambda 186.87/\lambda 185.55\) is 0.218. Lines at both wavelengths are observed, but \(\lambda 186.87\) is blended with a Fe xii feature that is itself a blend of two lines at

Figure 5. Theoretical ratios formed from lines found in the EIS SW band. The left panel shows the density sensitive \(\lambda 196.22/\lambda 195.39\) ratio, with curves calculated at temperatures of \(\log T = 5.40\) (dotted line), 5.55 (solid line), and 5.70 (dashed line). The right panel shows the temperature sensitive \(\lambda 176.75/\lambda 195.39\) ratio, with curves calculated at densities of \(\log N_e = 8.5\) (dotted), 9.0 (solid), and 9.5 (dashed).
186.85 and 186.89 Å. Assuming $\lambda_{185.55}$ is unblended, Fe vii is predicted to contribute $14.4 \pm 0.9$ erg cm$^{-2}$ s$^{-1}$ sr$^{-1}$ (8%) to the measured feature at 186.88 Å. $\lambda_{185.55}/\lambda_{195.39}$ is relatively insensitive to density and temperature, but the observed ratio is around 40% below the predicted value (Table 5).

Ekberg (1981) identified emission lines from the $J = 1$ and $J = 2$ components of the $({^4P})^3 P_1$ term, but for the $J = 0$ component only one line is predicted by the atomic model—the decay to $^3 P_1$—and so Ekberg’s method of identifying multiple lines from a single level cannot be applied. An improved estimate of the $^3 P_1 - ({^4P})^3 P_0$ wavelength can be made, however, by taking the average energy difference between the observed and theoretical energies for the $({^4P})^3 P_1,2$ levels, and applying this to the theoretical energy of $({^4P})^3 P_0$. The resulting energy is given in Table 3 and we estimate that it has an accuracy of around ±500 cm$^{-1}$. The predicted wavelength for $^3 P_1 - ({^4P})^3 P_0$ is then 185.34 Å with an accuracy of around ±0.2 Å. This line is insensitive relative to the strongest line from the $({^4P})^3 P_2$ term, $\lambda_{183.83}$, with a theoretical value of 0.250 ± 0.024, and so should have an intensity around 23 erg cm$^{-2}$ s$^{-1}$ sr$^{-1}$. No obvious candidate in the EIS spectrum can be found, but possibly it is blended with the strong Fe viii $\lambda_{185.21}$ line.

The $({^4P})^3 P_1$ level gives rise to three lines of comparable strength at wavelengths 184.75, 184.89, and 185.18 Å, corresponding to decays to the $^3 P_{0,1,2}$ levels in the ground configuration. They are each predicted to be around one quarter of the strength of the $^3 P_2 - ({^4P})^3 P_2$ transition at 183.83 Å. $\lambda_{185.18}$ is blended with the strong Fe viii $\lambda_{185.21}$ line and makes a <2% contribution. Table 4 of Paper I indicates that $\lambda_{184.89}$ is blended with Ne vii, although it was noted that the measured wavelength is not consistent with the Ne vii wavelength. If the measured intensity is assumed to be entirely due to Fe vii then $\lambda_{184.89}/\lambda_{183.83}$ is in good agreement with theory (Table 5).

The measured wavelength, however, shows a discrepancy of around 20 km s$^{-1}$ (Table 2). The image formed in the line is consistent with the formation temperatures of both Ne vii and Fe vii. Table 4 in Paper I indicates that Fe vii $\lambda_{184.75}$ is blended with Fe xi and Ne v, and based on the measured Fe vii $\lambda_{183.83}$ line intensity Fe vii would be expected to contribute around 60%. However, the DEM predictions for Ne v and Fe xi account for 80% of the measured intensity. No other Ne v line is found in the spectrum so an independent check of the line’s intensity is not possible (Paper I), while the Fe xi line is strongly density dependent relative to other Fe xi lines such as $\lambda_{188.23}$ so the predicted contribution depends critically on the density chosen for the DEM analysis. We note that the measured wavelength of the 184.777 Å line is consistent with Fe vii $\lambda_{184.75}$ (Table 2). The image formed in the $\lambda_{184.75}$ line clearly reveals a blend with a coronal line with temperature around that of Fe xi, however a cool component can also be seen.

Two potentially observable lines are predicted from the $({^4P})^3 P_2$ level: the decay to $^3 P_1$ at 183.54 Å and the decay to $^3 P_2$ at 183.83 Å. Lines at both wavelengths are found, but the observed $\lambda_{183.54}/\lambda_{183.83}$ ratio is a factor of 2 lower than theory (Table 5). The $\lambda_{183.83}/\lambda_{195.39}$ ratio is relatively insensitive to density and temperature, and theory agrees well with observation (Table 5).

The shortest wavelength Fe vii lines observed by EIS are the $^3 F_j - ({^4F})^3 F_j$ transitions, and the $4–4$ transition at 176.75 Å is in fact the strongest of all the Fe vii lines predicted by the atomic model for typical coronal conditions. The low effective area at this wavelength means the line is rather weak in the EIS spectrum, but it appears to be unblended. The $\lambda_{176.75}/\lambda_{195.39}$ ratio is weakly sensitive to density but does show temperature sensitivity as shown in Figure 5. Using the density of log $N_e = 9.15$ derived from Mg vii $\lambda_{280.72}/\lambda_{278.39}$ (Paper 1) we find a temperature of log $T = 5.07 \pm 0.10$, much lower than the formation temperature of the ion. To yield a temperature of log $T = 5.6$ (which we believe to be the $T_{\text{max}}$ of the ion) would require an observed ratio of 1.55. Therefore the actual observed ratio is around a factor of 2 lower than expected.

Two additional lines from the $^3 F_j - ({^4F})^3 F_j$ multiplet are predicted to be observed—the $3–3$ transition at 176.93 Å and the $2–2$ transition at 177.17 Å—but both are blended with stronger lines from other species. $\lambda_{176.93}$ is blended with a stronger Fe ix line (Section 6) and we estimate the Fe vii contribution to be 132.8±28.1 erg cm$^{-2}$ s$^{-1}$ sr$^{-1}$ as the $\lambda_{176.75}/\lambda_{176.93}$ ratio has weak sensitivity to density and temperature with a theoretical value of 0.712 ± 0.085. We note that the measured line is broad, consistent with a blend of two lines with slightly different wavelengths. $\lambda_{177.17}$ is blended with Fe x $\lambda_{177.24}$ and, using the $\lambda_{177.17}/\lambda_{176.75}$ theoretical ratio of 0.505 ± 0.045 we estimate that a Fe vii contribution of 94.2 ± 18.4 erg cm$^{-2}$ s$^{-1}$ sr$^{-1}$.

Finally, we finish this section by comparing lines from the two EIS wavelength bands. The strongest lines emitted by the $3^p_5^3 d^3$ configuration in the two bands are $\lambda_{195.39}$ and $\lambda_{249.30}$. Their ratio is weakly sensitive to density, but strongly temperature sensitive (Figure 6) and the measured ratio gives a temperature of log $T = 5.37^{+0.04}_{-0.01}$ which is close to the $T_{\text{max}}$ value given by Bryans et al. (2009) but less than the temperature where we believe Fe vii is actually formed at. For the ratio to yield higher temperatures, the measured $\lambda_{249.30}$ intensity would have to be weaker than what is actually observed. Comparing $\lambda_{195.39}$ with the $\lambda_{290.72}+\lambda_{290.76}$ self-blend that arises from the $3^p_5^3 d^4 s$ configuration, the ratio is again temperature sensitive, yielding a temperature of log $T = 5.63 \pm 0.02$ which is more consistent with the apparent formation temperature of Fe vii.

4.3. Summary of Fe vii Results

The survey of the Fe vii lines in the previous sections have revealed a number of new line identifications in both the SW and LW bands of EIS. The atomic model constructed from the Withee & Badnell (2008) data for CHANTI yields several line ratios that are good diagnostics of temperature or density. Comparing theory with the EIS observations shows many areas where good agreement is found, but also a number of significant problems. To summarize briefly the main points:

1. The ratio of lines from the $3d4p$ and $3d4s$ configurations, $\lambda_{265.70}/(\lambda_{290.72}+\lambda_{290.76})$, is a temperature diagnostic.
2. Within the LW band (246–291 Å) the atomic model overpredicts the strength of the lines from the $3d4p$ and $3d4s$ configurations compared to the lines from the $3p^5 3d^3$ configuration by a factor of around 2.
3. $\lambda_{195.39}/(\lambda_{290.72}+\lambda_{290.76})$ is a temperature diagnostic and the derived temperature is close to the expected value for Fe vii.
4. Comparing strongest lines from the $11 3^p_5^3 d^3$ spectroscopic terms in the SW band:

   a) lines from $({^2F})^3 G_j, ({^2H})^3 H_j, ({^2F})^3 D_j$, and $({^4P})^3 P$ are generally consistent with the $\lambda_{195.39}$ reference line;
   b) lines from $({^2F})^3 D_j, (b^2 D)^3 D_j, (c^4 G)^3 F$, and $({^4F})^3 F$ are too weak relative to $\lambda_{195.39}$ by around a factor of 2;
and Table 6 shows the velocities derived from the EIS spectrum for these lines are available from Ramonas & Ryabtsev (1980), but both are negligible in the present spectrum. Since the observed ratio is only 14% below the high

5. Fe \textit{viii}

The ground configuration of Fe \textit{viii} has only two energy levels, $^2D_{3/2,5/2}$, and the EUV spectrum in the range 160–260 Å consists principally of decays from the levels in the $3p^53d^2$ configuration to this ground term. Line identifications are known for all lines between 160 and 200 Å, but for 200–260 Å there are a large number of transitions that are unidentified. The EIS instrument observes the wavelength ranges 170–212 and 246–292 Å and so some of these transitions can be found, but we first focus on the known transitions.

The three terms $3p^53d^2(^2F)$ $^2D$, $3p^64d$ $^2P$, and $3p^53d^2(S)$ $^2P$ give rise to nine lines between 185 and 198 Å, all of which are observed in the present spectrum. Reference wavelengths for these lines are available from Ramonas & Ryabtsev (1980), and Table 6 shows the velocities derived from the EIS spectrum using these rest wavelengths. The error bars are derived from the measured centroid uncertainties (Paper I), the estimated uncertainty of ±0.002 Å in the EIS wavelength scale (Brown et al. 2007), and the uncertainties in the measured wavelengths of Ramonas & Ryabtsev (1980) of ±0.003 Å. The velocities of the lines unaffected by blending are all less than the typical cool line velocity of +40.4 km s$^{-1}$ (Section 3), with an average of +33.0 km s$^{-1}$. Paper I noted that ions formed above log $T = 5.8$ showed smaller velocity shifts of around +20 km s$^{-1}$, thus the Fe \textit{viii} velocities could indicate that it is intermediate between the cool ion and hot ion populations.

Fe \textit{viii} line ratios formed from the nine lines between 185 and 198 Å show very little density sensitivity above 10$^9$ cm$^{-3}$ as the two ground levels are in a quasi-Boltzmann equilibrium above this value. For this reason the lines are little value as density diagnostics in typical coronal conditions. Temperature sensitivity is also weak for these lines. Below 10$^9$ cm$^{-3}$ significant density sensitivity sets in and this is highlighted for the three strongest Fe \textit{viii} lines observed by EIS in Figure 7. These ratios may be of value in coronal hole or off-limb regions where the density is low, however, the present spectrum reveals some anomalies. The observed λ185.21/λ186.60 ratio is found to be 1.28 ± 0.02 which yields a density of log $N_e = 8.16 ± 0.05$, significantly below that found from Mg \textit{vii} in Paper I. There are high temperature blends for both lines (Young et al. 2007a), but both are negligible in the present spectrum. Since the observed ratio is only 14% below the high

**Table 6**

| Wavelength (Å) | Fe \textit{viii} Velocities (km s$^{-1}$) |
|---------------|-----------------------------------------|
| 185.213       | 30.7 ± 5.8                              |
| 186.601       | 36.9 ± 5.8                              |
| 187.235$^a$   | 43.2 ± 7.5                              |
| 189.006$^b$   | 34.4 ± 7.3                              |
| 193.967       | 32.5 ± 6.4                              |
| 194.662       | 27.7 ± 5.6                              |
| 195.972       | 32.1 ± 5.5                              |
| 196.650$^c$   | 21.4 ± 5.6                              |
| 197.362       | 38.0 ± 5.5                              |

Notes.

$^a$ Blended with Fe \textit{vii} λ187.235.

$^b$ Blended with Fe \textit{vii} λ192.006 and an unknown hotter line.

$^c$ Blended with Fe \textit{xii} λ196.640.
density limit of the ratio we believe the discrepancy is most likely due to atomic data uncertainties. λ194.66/λ186.60 shows some temperature sensitivity in addition to density sensitivity, however, the measured ratio is 0.402 ± 0.006, significantly above the range of sensitivity of the ratio. Since the two lines are both strong and unblended this, again, we believe is due to inaccurate atomic data.

More generally we can investigate atomic data issues through studies of insensitive line ratios. We divide the ratios into Groups 1, 2, and 3 which give an indication of the expected accuracy of the atomic data. Group 1 consists of branching ratios, Group 2 consists of insensitive ratios formed from lines belonging to the same multiplet, while Group 3 consists of insensitive ratios formed from lines belonging to different multiplets. Table 7 presents a comparison between the observed ratios and theoretical ratios calculated with CHIANTI. The atomic model for Fe viii in CHIANTI consists principally of the electron collision data and radiative decay rates of Griffin et al. (2000), supplemented with additional data from Czyzak & Krueger (1966) and decay rates calculated by the CHIANTI team (Dere et al. 2001).

Table 7

| Group | Ratio       | Theory       | Observation |
|-------|-------------|--------------|-------------|
| Group 1 | λ187.24/λ186.60 | 0.046        | 0.097 ± 0.004 |
|       | λ196.65/λ197.36 | 0.151        | 0.498 ± 0.014 |
|       | λ193.97/λ194.66 | 0.101        | 0.090 ± 0.004 |
| Group 2 | λ192.01/λ197.36 | 0.215 ± 0.023 | 0.398 ± 0.019 |
|       | λ255.13/λ253.98 | 0.561 ± 0.064 | 0.395 ± 0.019 |
|       | λ255.37/λ253.98 | 0.556 ± 0.111 | 0.678 ± 0.026 |
|       | λ255.71/λ255.13 | 0.694 ± 0.099 | 0.500 ± 0.036 |
| Group 3 | λ197.36/λ194.66 | 0.385 ± 0.015 | 0.422 ± 0.007 |
|       | λ194.66/λ197.36 | 0.191 ± 0.033 | 0.305 ± 0.004 |
|       | λ197.36/λ185.21 | 0.073 ± 0.013 | 0.129 ± 0.002 |
|       | λ206.75/λ197.36 | 0.306 ± 0.070 | 0.261 ± 0.021 |

Notes.

a A < symbol indicates a > 1σ discrepancy between theory and observation.

b Indicates a > 2σ discrepancy.

c Blended with Fe vii λ187.235.

d Blended with Fe vii λ192.006 and an unknown hotter line.

e Blended with Fe xii λ196.640.

None of the Group 1 measured ratios agrees with theory, although λ193.97/λ194.66 is within 11% of the observed value. λ187.24 is a known blend with Fe vii (Brown et al. 2008), and thus we can use the Fe vii ratio to estimate a Fe viii contribution of 62.2 ± 4.2 erg cm⁻² s⁻¹ sr⁻¹, however Section 4 shows that this is inconsistent with the Fe vii atomic model. Note that the Fe viii intensity predicted from the DEM shown in Table 4 of Paper I is significantly higher than that predicted from the branching ratio. This is because the DEM overpredicts the strength of the strong λ186.60 line. λ196.65 is a known blend (Brown et al. 2008; Young et al. 2009) with a Fe xii transition. Using the branching ratio to subtract the Fe viii component leaves an intensity of 50.2 erg cm⁻² s⁻¹ sr⁻¹ for Fe xii. Young et al. (2009) noted that the Fe xii λ196.64/λ186.88 ratio is relatively insensitive to density, and we find a value of 0.27 after the Fe viii correction. In active regions where Fe xii is much stronger than Fe viii, Young et al. (2009) found λ196.64/λ186.88 ratios of between 0.24 and 0.32, consistent with the value of 0.27 found here. This gives some confidence that the Fe viii λ196.65/λ197.36 branching ratio is consistent with theory.

For the Group 2 and 3 ratios the theoretical values are evaluated as the averages of the ratios calculated over the density range log \( N_e = 8.0–10.0 \) and temperature range log \( T = 5.65–5.95 \), the former calculated at 0.1 dex intervals, and the latter at 0.05 dex intervals. The error on the theoretical value is set to be the 3σ variation of the ratio over the density and temperature ranges.

The Group 2 ratio λ192.01/λ197.36 involves lines emitted from the \( 3p^23d^2(^1S) \) \(^2P \) term and Table 7 shows that it is discrepant with theory. This is due to a blend of λ192.01 with both a coronal line and a line from Fe vii (Section 4). Images formed in the line suggest the coronal line is probably Fe xi and indeed Brown et al. (2008) list the \( 3s^23p^4 \ 3P_1–3s^23p^6(^2D)3d^3S_1 \) transition from this ion. This identification is questionable, though, given the inconsistent identifications from this upper level given by Brown et al. (2008): the decay to the ground \(^3P_2 \) level is listed at both 187.45 Å and 188.30 Å, and the decay to the ground \(^1D_2 \) level is listed at both 201.74 Å and 202.70 Å. Only the 187.45 and 201.74 Å identifications are consistent with the 192.02 Å line. The CHIANTI model for Fe xi has only a theoretical energy for the \(^3S_1 \) level, with
the decay to the $^3P_1$ level listed at 191.21 Å. Using the Fe viii $\lambda 192.01/\lambda 197.36$ theoretical ratio we estimate a contribution of 41.5 ± 4.5 erg cm$^{-2}$ s$^{-1}$ sr$^{-1}$ of Fe viii to the measured 192.01 Å intensity. The remaining Group 2 ratios are discussed later in this section with regard to the newly identified $3p^53d^2D_{1/2} – 3p^53d^2(3F)D_{1/2}$ transitions. Note that the strong lines from the $3p^53d^2(3F)^2F$ and $3p^64d^2P$ terms show temperature and density sensitivity and so are not included in Table 7. $\lambda 185.21/\lambda 186.60$ was discussed earlier, while the ratio formed from lines from the $3p^64d^2P$ term, $\lambda 195.97/\lambda 196.46$, has an observed ratio of 0.68 ± 0.01 which is very close to the high density limit of the theoretical ratio and implies a density log $N_e$ > 8.64, which is consistent with the Mg vii density value from Paper I. The remaining Group 3 ratio is in better agreement with theory and is discussed below.

The theoretical Fe viii model in CHIANTI predicts eight emission lines between 203 and 208 Å, two of which are sufficiently strong to be easily observable in the present EIS spectrum. First, we note that the theoretical energies of Griffin et al. (2000) for the levels that give rise to the lines in the 185–200 Å range are all overestimates of the experimental energies. If we assume the energies for the levels that give rise to the 203–208 Å lines are also overestimated by a similar amount, then the levels should lie up to 4 Å longward of the theoretical wavelengths. The strongest lines predicted by CHIANTI are the $3p^63d^2D_{5/2} – 3p^53d^2(3G)^2G_{7/2}$ transition at 203.08 Å and the $3p^63d^2D_{3/2} – 3p^53d^2(3P)^2D_{5/2}^o$ transition at 205.01 Å, whose strengths should be 0.31 ± 0.07 and 0.26 ± 0.05 of the $\lambda 197.36$ Fe viii line. A line at 206.78 Å is the best match, in terms of intensity, to the $^2G_{7/2}$ transition and we tentatively identify this transition. The image formed in the line is consistent with other Fe viii images, and the Group 3 insensitive ratio, $\lambda 206.75/\lambda 197.36$, shown in Table 7 is consistent with theory. The new experimental energy for the $3p^53d^2(3G)^2G_{7/2}$ level is given in Table 8, and is derived assuming that a +33 km s$^{-1}$ wavelength shift applies to the Fe viii lines as discussed earlier in this section. The error bar is derived using the measured centroid uncertainty, the EIS wavelength scale uncertainty of ±0.002 Å (Brown et al. 2007), and the uncertainty of the Fe viii velocity which is taken as the standard deviation of the six velocity measurements of the unblended Fe viii lines (Table 6). Two lines at 208.68 and 208.84 Å could be the $3p^63d^2D_{3/2} – 3p^53d^2(3P)^2D_{5/2}^o$ transition, however the former has a significant Cr vii contribution (Paper I), while the latter is too strong to be completely due to Fe viii. We thus do not make an identification for this transition in the spectrum.

New Fe viii Level Energies

| Level | Energy (cm$^{-1}$) |
|-------|------------------|
| $3p^53d^2(3F)D_{1/2}$ | 391115 ± 6 |
| $3p^53d^2(3F)D_{3/2}$ | 391997 ± 6 |
| $3p^53d^2(3F)D_{5/2}$ | 393463 ± 12 |
| $3p^53d^2(3G)D_{1/2}$ | 395610 ± 12 |
| $3p^53d^2(3G)D_{3/2}$ | 485505 ± 14 |

![Figure 8](image_url)

**Figure 8.** Theoretical variation of the $\lambda 185.21/\lambda 255.34$ ratio as a function of temperature. The ratio has been calculated for densities of 10$^9$ cm$^{-3}$ (solid line) and 10$^8$ cm$^{-3}$ (dashed line). There is little density sensitivity above 10$^9$ cm$^{-3}$.

Four emission lines between 253.9 and 255.8 Å that are normally weak become very prominent in the current spectrum. Their wavelengths and separations are close to those predicted by CHIANTI for four lines of the Fe viii $3p^53d^2D_{1/2} – 3p^53d^2(3F)^2D_{1/2}^o$ multiplet, for which only theoretical wavelengths are available, and images formed in the lines are very similar in morphology to the Fe vii and Fe viii lines. We thus identify the observed lines with the Fe viii transitions. The new experimental energy values for the $^2D_J$ levels are given in Table 8 which have been derived in the same manner as the $3p^53d^2(3G)^2G_{7/2}$ discussed earlier. For the levels that decay to the excited $^2D_{3/2}$ level in the ground configuration, the $^2D_{5/2}$ energy of 1836 cm$^{-1}$ of Ramonas & Ryabtsev (1980) has been used. An uncertainty of ±10 cm$^{-1}$ was assumed for this value.

Three ratios can be formed between the four lines that are relatively insensitive to density and temperature, and a comparison between observation and theory is shown in Table 7 (Group 2 lines). Only one of the three ratios agrees with theory within the error bars, but the disagreements are not large.

All four lines are predicted to show significant temperature sensitivity relative to the shorter wavelength lines between 185 and 200 Å. In particular, we highlight the $\lambda 185.21/\lambda 255.34$ ratio which shows very little density sensitivity, and the temperature variation is shown in Figure 8. However, the observed ratio of 7.75 ± 0.23 gives a very low temperature of log $T$ ≈ 5.3, well below the expected temperature of maximum ionization of Fe viii (Section 3). This implies that the $\lambda 255.37$ line is observed to be around factors of 3–4 stronger than predicted by theory. It was noted earlier that insensitive ratios amongst the SW lines suggest that the CHIANTI model is underestimating the strength of the $\lambda 185.21$ line by 60%–80%. If this is the case, then the ratio curves plotted in Figure 8 would be raised by this amount, making the derived $\lambda 185.21/\lambda 255.37$ temperature even lower.

This raises the question of whether the transitions between 254 and 256 Å actually are Fe viii transitions. First, we note that images formed in each line are consistent with other Fe vii lines. The line separations are consistent with the theoretical energies of Griffin et al. (2000), and the observed wavelengths are within 1%–2% of the theoretical wavelengths. If the lines are not due to Fe viii, then the transitions must be nearby in the spectrum, but a similar set of four lines with the correct
intensities cannot be found. The only other ion species that we believe can be responsible for the lines is Fe vili, but the observed lines are factors of 5–10 stronger than the lines predicted from the Fe vili atomic model in this wavelength range.

Our conclusion is thus that the observed lines are the Fe vili $3p^53d^22D_{3/2} - 3p^53d^2(3F) 2D_{7/2}$ transitions but that the observed intensities do not match the Fe vili atomic model. To fix the discrepancy would require the theoretical model to yield a greater level of excitation to the $2D$ levels. This can be achieved by cascading from higher levels or increased resonance excitation, both of which could be possible if the $3p^43d^3$ configuration is included in the scattering calculation.

We summarize the results of the comparison between the Fe vili atomic model and the EIS spectrum as follows.

1. The $3p^63d^22D_{5/2} - 3p^53d^4(1G) 2G_{7/2}$ has been identified at a rest wavelength of 206.753 Å leading to a new experimental value for the $2G_{7/2}$ energy.
2. Four transitions of the $3p^63d^22D_{5/2} - 3p^53d^2(3F) 2D_p$ multiplet have been identified between 253.9 and 255.7 Å, leading to new experimental energies for the four $2D$ levels. The Fe vili atomic model, however, underestimates the lines’ strengths by a factor between 3 and 6.
3. The two strong lines at 185.21 and 186.60 Å emitted from the $3p^63d^2(F) 2F$ term are underestimated by the atomic model by around 60%–80% compared to lines from the $3p^64d^2P$ and $3p^53d^2(S) 2P$ terms. In addition, the ratio of the two lines is discrepant with theory by around 10%–20%.
4. The $\lambda_{185.21}/\lambda_{255.34}$ ratio is an excellent temperature diagnostic but yields temperatures significantly lower than expected due to the atomic data discrepancies highlighted above.
5. The group of four nearby lines at 193.97, 194.66, 195.97, and 197.36 Å show good agreement. $\lambda_{195.97}/\lambda_{194.66}$ could be a useful density diagnostic in conditions where the density is $\ll 10^9$ cm$^{-3}$.

The discrepancies highlighted above suggest that a new atomic calculation for Fe vili is required. A new laboratory study of Fe vili would also be valuable for classifying the large number of unidentified transitions between 200 and 260 Å.

6. Fe ix

The CHIANTI 5 atomic model was revised following the new line identifications of Young (2009) and is made available in CHIANTI 6 (Dere et al. 2009). The new model is described in more detail below and is compared with the Fe ix lines in the 2007 February 21 spectrum. In addition, we highlight a number of observed lines that are likely to be due to Fe ix but for which definite transition identifications are not possible.

Four new Fe ix line identifications were performed by Young (2009) and the energy levels for the ion have been updated for CHIANTI 6 (Dere et al. 2009). The $3p^5(1P)3d^22G_J$ levels were the first of the 109 levels of the $3p^53d^2$ configuration to be identified by any author, so they can be used to provide energy corrections to the entire set of $3p^43d^2$ levels. These lead to improved wavelength estimates for other transitions arising from the $3p^43d^2$ levels, a number of which are expected in the EIS SW band. Since only one level multiplet has been identified, the average difference between the experimental energies (from Young 2009) and theoretical energies (from Storey et al. 2002) has been calculated and subtracted from each of the other fine structure levels of the $3p^43d^2$ configuration. The energy subtracted is 43297 cm$^{-1}$, and it shifts the predicted wavelengths by around 14 Å compared to the values in CHIANTI 5.2 (Landi et al. 2006). This method of adjusting the level energies is very simplistic and the accuracy of the new wavelengths will not be high (perhaps a few Å), but they should be more accurate than the previous estimates. The change in the Fe ix wavelengths following the energy shift is illustrated in Figure 9. Of particular interest are a strong triplet arising from the $3p^4(1D)3d^23D_J$ levels between 177 and 180 Å and the group of weak lines between 188 and 199 Å that lie in a wavelength region where the EIS sensitivity is high. Before considering these transitions, however, we discuss the previously identified transitions.

The strong $\lambda_{171.07}$ resonance line is found at the extreme short wavelength end of the EIS SW band where the instrument effective area is very low. Despite this, the line is well resolved and, when converted to calibrated intensity units, becomes almost a factor of 4 stronger than every other line in the spectrum.

The four lines identified by Young (2009) are all found in the present spectrum. The strongest line, $\lambda_{188.50}$, is partially blended with weak lines in the short and long wavelength wings and is difficult to fit accurately as there is no nearby continuum level. The fit parameters shown in Paper I resulted from a simultaneous 15 Gaussian fit to lines between 187.71 and 189.13 Å. A line in the short wavelength wing at 188.424 Å is due to Fe vili and perhaps also a line of Mn ix (see the discussion in Paper I), while another Fe vili line is found in the long wavelength wing at 188.603 Å. $\lambda_{189.94}$ is partially blended with Fe x $\lambda_{190.04}$ but is easily resolved with a double-Gaussian fit. $\lambda_{191.22}$ and $\lambda_{197.86}$ are both unblended. The $\lambda_{197.86}/\lambda_{171.07}$ temperature diagnostic highlighted by Young (2009) yields a temperature of $T = 5.86 \pm 0.04$ which is in agreement with the $T_{eff}$ value of 5.82.

The $3p(1P)3d^23G_{3,4}$ levels that give rise to the $\lambda_{189.94}$ and $\lambda_{191.26}$ lines also give rise to three weaker lines that are potentially observable in the present spectrum. $3G_4$ decays to $3p^33d^3F_3$ with an expected wavelength of 188.686 Å, and the branching ratio is 0.092 relative to $\lambda_{189.94}$. This line is observed in the spectrum with wavelength 188.685 ± 0.007 Å, and the $\lambda_{188.686}/\lambda_{189.941}$ ratio is 0.134 ± 0.034, within 2σ of theory. There is a S xi line expected at 188.675 Å which blends with the Fe ix line, but using the calculated DEM gives a predicted intensity of only 2.2 erg cm$^{-2}$ s$^{-1}$ sr$^{-1}$, therefore the Fe ix line dominates. An image formed in the 188.685 Å line confirms that it is a blend of a cool line around the temperature of Fe ix and a hotter line.

The $3G_3$ ground state gives rise to $\lambda_{191.22}$ and has six additional decays, two of which are potentially observable in the EIS spectrum. $3G_3$ decays to $3p^33d^3F_3$ at 189.582 Å, with a branching ratio of 0.248. It is a good wavelength match to an observed line at 189.596 Å, but the observed ratio is significantly lower than theory at 0.076 ± 0.016. The image formed in the line, however, is consistent with a formation temperature close to Fe ix. The next strongest line from $3G_2$ is the decay to $3p^33d^1D_2$ at 199.986 Å with a branching ratio of 0.112. This line is blended with Fe xii $\lambda_{200.02}$ and contributes around 25% to the observed feature (Paper I). The image formed in this line is dominated by the Fe xii component, however a weak cool component can be identified, particularly if the image is formed in the short wavelength wing of the line.

The $3p^43d^23F_J - 3p^5(1D)3d^23D_{J-1}$ ($J = 4, 3, 2$) triplet of lines is predicted at 177.419, 178.185, and 179.263 Å, and are the strongest of the predicted lines between $\lambda_{171.07}$ and $\lambda_{188.50}$ (see the bottom panel of Figure 9). Although
the lines are comparable in strength to the longer wavelength triplet, the EIS effective area is much lower around 177–180 Å making the lines more difficult to identify. A good candidate for the stronger line is the observed line at 176.968 Å. It contains a Fe \text{ix} component, but Section 4 demonstrated that this transition makes a contribution of 30%. The remaining intensity of $313 \pm 51 \text{ erg cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$ is consistent with the theoretical $\lambda 177.419$ line: the $\lambda 177.419/\lambda 188.50$ theoretical ratio is $\approx 0.7$, giving a predicted intensity of 263 erg cm$^{-2}$ s$^{-1}$ sr$^{-1}$ using the measured $\lambda 188.50$ intensity.

With this identification the $^3F_j-^3D_2$ transition can be tentatively identified with the observed 177.603 Å line based on wavelength separation and expected intensity. The theoretical $\lambda 178.185/\lambda 177.419$ ratio is 0.51 for a density of $10^9 \text{ cm}^{-3}$ which, using the estimated intensity of the measured 176.968 Å line above, yields a predicted intensity of 160 erg cm$^{-2}$ s$^{-1}$ sr$^{-1}$ in excellent agreement with the measured line intensity (Paper I). Brown et al. (2008) identified a line seen in quiet Sun and active region spectra at this wavelength with S \text{x} $\lambda 177.545$ and Ni \text{xiv} $\lambda 177.560$, however, using the DEM distribution we can demonstrate that these lines each contribute less than 1 erg cm$^{-2}$ s$^{-1}$ sr$^{-1}$ to the observed line at 177.603 Å. Based on wavelength separation and predicted intensity, there are two candidates for the theoretical $\lambda 179.263$ line ($^3F_3-^3D_1$ transition): the measured lines at 178.708 and 179.22 Å. The line is expected to be a factor of 0.27 weaker than $\lambda 177.419$ which is consistent with both lines’ measured intensities. We note that the Fe \text{ix} transition $3p^53d^23F_j-3p^4(^3P)3d^23F_h$ has a predicted wavelength of 177.572 Å and a predicted intensity around 80% of $\lambda 179.263$ thus it could account for one of the two observed lines.

In summary, we identify the observed 176.968 and 177.603 Å lines with the 4–3 and 3–2 components of the $3p^4(^1D)3d^2^3D_{J=1}$ triplet, but do not make an identification for the 2–1 component. New experimental energies for the $3p^4(^1D)3d^2^3D_{2,3}$ levels are given in Table 9. The values have been derived by adjusting the measured wavelengths by the average velocity shift of the $\lambda 188.50, \lambda 189.94, \lambda 191.22$, and $\lambda 197.86$ lines (+16 km s$^{-1}$), and the uncertainties are a combination of the measured wavelength uncertainties, the uncertainties of the four reference wavelengths, and the uncertainties of the lower level energies (see Young 2009, for more details). An updated theoretical energy for the $^3D_1$ level is also given in Table 9 and is derived from the new $^3D_{2,3}$ energies by determining the average difference in theoretical and experimental energies for these levels and subtracting this from the theoretical $^3D_1$ energy. We estimate that this energy is accurate to $\pm 250 \text{ cm}^{-1}$.

No other Fe \text{ix} lines can be definitively identified from the EIS spectrum. However, Table 10 gives a list of measured lines that we believe are due to Fe \text{ix} or have a component due to Fe \text{ix}. The lines have been identified through comparisons of their image intensity distributions as described in Paper I, and also by comparing the Paper I spectrum with that of Young (2009) which shows stronger Fe \text{ix} emission relative to Fe \text{vii}.

![Fe IX spectra comparison](image)

**Figure 9.** Theoretical Fe \text{ix} spectra calculated with CHIANTI 5.2 (top panel) and CHIANTI 6 (bottom panel). Each emission line is represented by a vertical line, the length of which corresponds to the line’s emissivity. The strong $\lambda 171.07$ line dominates, extending beyond the plots’ bounds to Y-values of 98. The four lines identified by Young (2009) are indicated in the bottom panel.

**Table 9**

| Level        | Index$^a$ | Energy (cm$^{-1}$) |
|--------------|-----------|--------------------|
| $3p^4(^1D)3d^2^3D_1$ | 110       | 990913 $\pm$ 24   |
| $3p^4(^1D)3d^2^3D_2$ | 111       | 992393 $\pm$ 30   |
| $3p^4(^1D)3d^2^3D_3$ | 112       | 993321 $\pm$ 250$^b$ |

Notes.

$^a$ Index of the level in the CHIANTI 6 Fe \text{ix} atomic model.

$^b$ Energy derived from theoretical level splittings.
and Fe \textsc{viii} and so is valuable for discriminating between these three ions for weak lines.

Table 11 gives a list of the six strongest unidentified lines in the range 170–212 Å which are thus the best candidates for the suggested \textsc{Fe ix} lines in Table 10. The intensities are presented relative to 197.86 Å, computed for a temperature of $T = 5.8$ and density $N_e = 9.0$. A short hand notation is used so that $3\, ^3P_2 \rightarrow \, ^3P_1 \, D_3$, for example, corresponds to the transition $3p^5 3d\, ^3P_2 \rightarrow 3p^4 (1 \, P) 3d\, ^3D_3 \, D_3$. The strongest of the six theoretical transitions is 197.174 Å, and we note that a further decay from this line’s upper level is to the $3p^3 3d\, ^3F_3$ level with a branching ratio of 0.267. Identifying 197.174 Å with the strongest of the observed lines at 194.816 Å implies the decay to $3\, ^3F_4$ occurs at 199.536 Å which is close to the observed 199.613 Å line. However, the difference in wavelength (corresponding to a velocity of 117 km s$^{-1}$) is too large given the accuracy of the measured EIS wavelengths and the $\Delta$P level energy values (Edlén & Smith 1978), and so we do not identify the observed 194.816 Å line with the line of theoretical wavelength 197.174 Å.

Identifying the 197.174 theoretical line with the observed line at 192.642 Å would imply the decay to $3\, ^3F_4$ would occur at 197.255 Å, however no observed line is found at this wavelength. Finally if 197.174 Å was identified with the observed line at 187.971 Å, then the $3\, ^3F_4$ decay would be found at 192.361 Å. This latter line would blend with \textsc{Fe xii} 192.39 Å and we note that a line is found in the short wavelength wing of this line at 192.313 Å, however this is 75 km s$^{-1}$ away from the expected position of the \textsc{Fe ix} line and so the identification cannot be made.

Since no positive identification can be made for the strongest of the six lines in Table 11, then we do not attempt to find identifications for the remaining lines. A new laboratory study that can clearly separate \textsc{Fe ix} lines from the numerous blending species found in the solar spectrum would be extremely valuable for further classifying the many \textsc{Fe ix} lines in the 170–200 Å wavelength range.

7. EFFECTS ON RESPONSE FUNCTIONS OF EUV IMAGING INSTRUMENTS

Solar EUV imaging instruments such as SOHO/EIT, TRACE, and SECCHI/UVI employ multilayer optical coatings to pick out narrow wavelength regions centered on specific EUV emission lines. For example, each of these instruments has a channel centered on the 195.12 Å line of \textsc{Fe xii}. Although images formed in this channel are dominated by \textsc{Fe xii} and thus principally reveal plasma at temperatures of 1.5 MK, many other emission lines within $\pm 10$ Å contribute to the channel and can modify the response of the channel to temperature. For example, observations of flares with TRACE (Gallagher et al. 2002) have shown that the 195 channel becomes dominated by \textsc{Fe xiv} λ192.03 (formed at 20 MK) in the flare region, while Del Zanna et al. (2003) showed that lines of \textsc{Fe vili}, \textsc{Fe x}, and \textsc{Fe xi} make a significant contribution to polar plume emission.

To determine the response of an EUV imaging channel to plasma temperature it is necessary to compute synthetic spectra for a set of isothermal plasmas using an atomic code. By convolving the synthetic spectra with the instrument response function, one can predict the instrument signal as a function of temperature. Since different wavelength channels will have different responses to temperature, ratios formed from the channels (referred to as filter ratios) can be used to determine the plasma temperature (Moses et al. 1997). This method depends critically on the completeness of the atomic models. For example, for the TRACE satellite the CHIANTI atomic database was used to derive the instrument response function but, prior to the version 3 release (Dere et al. 2001), CHIANTI contained no atomic data for \textsc{Fe vili} which led to the errors in the response function for the 195 channel highlighted by Del Zanna & Mason (2003).

For this work a new atomic model for \textsc{Fe vili} has been prepared that predicts many new lines in the EUV that were not previously included in CHIANTI. In addition, the \textsc{Fe ix} model has been revised significantly since the version 5.2 CHIANTI release (Landi et al. 2006) with new lines identified and many lines with theoretical wavelengths shifted to new wavelengths. The present section investigates the effects on response functions for the TRACE instrument.

The TRACE response functions currently in Solarsoft were derived using CHIANTI 5. To investigate the effects of the new \textsc{Fe vii} and \textsc{Fe ix} models we use CHIANTI 5 with the \textsc{Fe vii} and \textsc{Fe ix} data replaced with the new data. We use software developed by Brooks & Warren (2006) that derives the TRACE filter responses as a function of temperature using the CHIANTI spectra.

The left and middle panels of Figure 10 show the revised response functions for the TRACE 173 and 195 channels. The 173 channel has a greater sensitivity to \textsc{Fe x} λ174.53 than \textsc{Fe xi} λ171.07 and so the curve peaks at the $T_{\text{max}}$ of \textsc{Fe x}. The \textsc{Fe ix} lines between 170 and 180 Å shown in the lower panel of Figure 9 make a small increase to the response function, particularly the $3\, ^3P_2 \rightarrow 3\, ^1D_3 \, ^3F_J$ transitions discussed in Section 6. Many \textsc{Fe vii} lines between 170 and 180 Å also increase the response function, with the $3\, ^3P_2 \rightarrow 3\, ^1D_3 \, ^3F_J$ $J = 2, 3, 4$ transitions making the largest contribution.

The 195 channel response function shows a much greater change. In particular, a dip in the function that occurred at log $T = 5.8$ disappears due to the many \textsc{Fe ix} lines now found...
between 188 and 200 Å that were previously absent. The Fe\textsuperscript{vii} lines between 195 and 197 Å also make a significant increase to the response function around log $T = 5.4–5.7$.

Forming a ratio of the 173 and 195 channel response functions yields the function shown in the right panel of Figure 10. Although significant structure is seen, the most important feature is the fall between log $T = 5.8$ to 6.3 which is the temperature range where Fe\textsuperscript{x}, Fe\textsuperscript{x}, and Fe\textsuperscript{xii} are formed. Since in most coronal conditions these ions dominate the channels’ emission, the slope means that the channel ratio 173/195 can be used to diagnose temperatures in the range log $T = 5.8–6.3$. This feature was first exploited for the SOHO/EIT instrument (Moses et al. 1997) which has very similar channels to TRACE, and has been used in a number of TRACE analyses, particularly studies of coronal loops (Lenz et al. 1999; Aschwanden et al. 2000). Comparing the curves derived with CHIANTI 5.2, with and without the new Fe\textsuperscript{vii} and Fe\textsuperscript{x} data, shows a significant change in the response function ratio at log $T = 5.9$: the new ratio curve is a factor of 2.3 lower than previously. For log $T \geq 6.0$, however, the change is $\leq 20\%$.

### 8. SUMMARY

Eleven new line identifications have been performed for Fe\textsuperscript{vii}, leading to the assignment of eight new experimental energies for the $3p^53d^3$ configuration, and the revision of two level assignments. Four new line ratio diagnostics for temperature and density have been highlighted, although discrepancies with values obtained through other methods were found. Good agreement with theory is found for around half of the Fe\textsuperscript{vii} lines, but there are many discrepancies of up to a factor of 2. The problems are most likely due to the atomic data for this ion. A laboratory study of Fe\textsuperscript{vii} would be valuable, particularly for confirming line identifications.

Five new line identifications have been performed for Fe\textsuperscript{viii}, leading to five new experimental energies in the $3p^53d^2$ configuration. Comparing observed line intensities with theory has revealed a number of problems for the Fe\textsuperscript{vii} ion. The strong transitions between 185 and 187 Å arising from the $3p^53d^2(3\,F)$ $2\,F$ term are not consistent with the lines between 192 and 198 Å emitted from the $3p^64d\,^2\,P$ and $3p^63d^3(1\,S)^2\,P$ terms, being underpredicted by the atomic model by 60%–80%. In addition, the newly identified multiplet from the $3p^53d^2(3\,F)^4\,D$ term around 253–256 Å is observed to be stronger than predicted by theory by factors of between 3 and 6 compared with the lines in the EIS SW wavelength band. A new atomic study would be valuable for investigating these problems, while a new laboratory study of Fe\textsuperscript{viii} between 170 and 260 Å is required to identify the many unidentified transitions in this range.

Young (2009) identified the four strongest Fe\textsuperscript{x} lines in the EIS spectra and additional identifications have been performed here. In addition, a number of emission lines have been classed as Fe\textsuperscript{x} lines based on image morphology but specific atomic transitions could not be assigned. A laboratory study of Fe\textsuperscript{x} lines around 160–200 Å is required to make further progress.

Solar EUV imaging instruments such as SOHO/EIT, TRACE, STEREO/EUVI, and the upcoming Solar Dynamics Observatory/AIA require accurate atomic models for modeling the dependence of the instruments’ filters to plasma temperature. Using the new atomic data and line identifications of Fe\textsuperscript{viii–x} we have modeled the TRACE 173 and 195 filter response functions, demonstrating a significant change to the 195 filter response at temperatures log $T = 5.4–6.0$. This leads to a modification of the TRACE 173/195 filter ratio that can affect coronal temperature determinations.

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### REFERENCES

Arnaud, M., & Raymond, J. C. 1992, ApJ, 398, 394
Arnaud, M., & Rothenflug, R. 1985, A&AS, 60, 425
Aschwanden, M. J., Nightingale, R. W., & Alexander, D. 2000, ApJ, 541, 1059
Bromage, G. E., Cowan, R. D., & Fawcett, B. C. 1977, Phys. Scr., 15, 177
Brooks, D. H., & Warren, H. P. 2006, ApJS, 164, 202
