

Improved atomic models for EUV imaging instruments

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1. Introduction

The EUV imaging instruments SOHO/EIT, TRACE and STEREO/EUVI have filters centered on key emission lines such as Fe IX $\lambda 171$ and Fe XII $\lambda 195$. Although these lines dominate their bandpasses in most conditions, weaker lines can make significant contributions, particularly if there are many from a single ion. Emission lines can only be included in instrument response functions if their wavelengths are known and atomic data is available for modeling them.

Using new atomic data and spectra from the Hinode/EIS instrument we demonstrate that Fe VII and Fe IX make a significant contribution to the Fe XII λ 195 bandpass that was previously unaccounted for. This affects the response function and the 171/195 filter ratio.

We have studied an EIS data-set that shows strongly enhanced emission from coronal loop footpoints at upper transition region temperatures ($\log T = 5.5\text{--}5.9$). Images from the data-set are shown below.

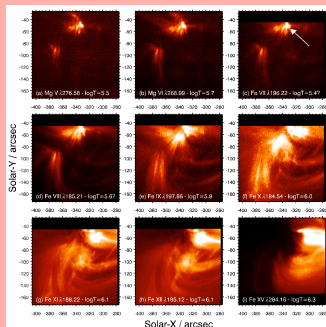


Figure 1. Images from the EIS active region observation of 21-Feb-2007, 01:15. The loop footpoints (indicated by the arrow on the Fe VII image) are very bright at temperatures log T=5.5 to 5.9. Note that comparisons of Mg V and VI with Fe VII and VIII suggest that the latter two ions are formed at hotter temperatures than predicted by theory.

Many previously unobserved lines were found and, by comparing images in emission lines formed across the whole EIS spectrum, it was possible to classify many as Fe VII or Fe IX lines.

2. Fe VII

Fe VII produces a large number of emission lines in the EUV, but atomic data for modeling these lines only became available recently (Witthoeft & Badnell 2008). Around 2000 transitions are predicted, mostly coming from the $3p^5 3d^3$ configuration.

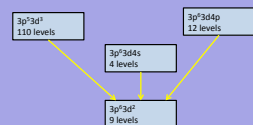


Figure 2. Schematic diagram showing the major decay channels for EUV lines of Fe VII.

With the new atomic data, the Fe VII spectrum in the EIS wavelength range can be predicted:

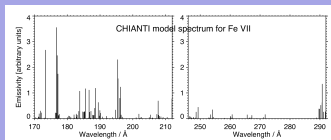


Figure 3. A synthetic Fe VII spectrum created using the atomic data of Witthoef & Badnell (2008), with new line identifications from Young & Landi (2009, in preparation). All emission lines are from Fe VII. The group around 195 Å is found in the EIS spectrum displayed in Figure 4.

In most conditions these lines are weak, however in loop footpoints they can be strongly enhanced and the figure below compares two EIS spectra in the vicinity of the strong Fe XII $\lambda 195$ line.

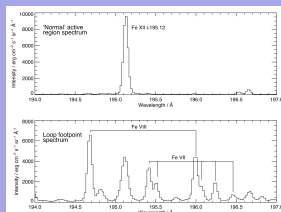


Figure 4. Hinode/EIS spectra in the vicinity of Fe XII $\lambda 195$. The upper panel shows a typical active region spectra where Fe XII dominates. The lower panel shows a spectrum from the loop footpoints of the 21-Feb-2007 data-set. Lines of Fe VII and Fe VIII are strongly enhanced, and comparable in strength to the Fe XII line.

These strong Fe VII transitions make a significant contribution to the Fe XII $\lambda 195$ response function and were previously not accounted for.

3. Fe IX

The strongest line from Fe IX is $\lambda 171.07$. There are many weak lines predicted between 160 and 200 Å that arise from decays of the $3s^23p^43d^2$ configuration to the $3s^23p^53d$ configuration (Figure 5). None of these had previously been identified and so were not included in atomic models for imaging instruments.

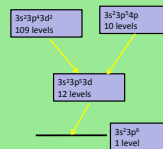
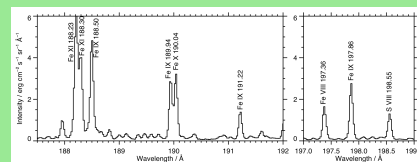


Figure 5. Schematic diagram showing the major decay channels for EUV lines of Fe IX.

Young (2009) identified four of the transitions in Hinode/EIS spectra:

Wavelength	Transition
188.497 Å	$3s^2 3p^3 3d^1 \text{ } ^4F_4 - 3s^2 3p^4 ({}^3P) 3d^2 \text{ } ^3G_5$
189.941 Å	$3s^2 3p^3 3d^1 \text{ } ^4F_3 - 3s^2 3p^4 ({}^3P) 3d^2 \text{ } ^3G_4$
191.216 Å	$3s^2 3p^3 3d^1 \text{ } ^4F_2 - 3s^2 3p^4 ({}^3P) 3d^2 \text{ } ^3G_3$
197.862 Å	$3s^2 3p^3 3d^1 \text{ } ^4P_1 - 3s^2 3p^5 4p \text{ } ^1S_0$

Figure 6. EIS footpoint spectrum showing new Fe IX lines.



From these lines the remaining Fe IX transitions can be accurately predicted and the spectrum is shown below.

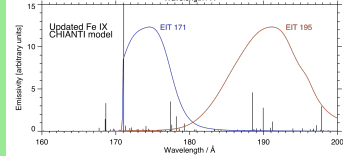


Figure 7. The black lines show a synthetic Fe IX spectrum computed with CHIANTI, with wavelengths adjusted according to Young (2009). The strongest line is $\lambda 171$, but there are many weak lines arising from the $3d^2$ configuration. The response functions for the EIT 171 and 195 channels are overplotted, and show that Fe IX makes a significant contribution to the 195 channel.

4. Effect on TRACE response functions

The TRACE response functions currently in Solarsoft were calculated using version 5.2 of the CHIANTI atomic database. Using the new atomic data and line identifications for Fe VII and Fe IX we have recomputed the 171 and 195 response functions and the results are shown below.

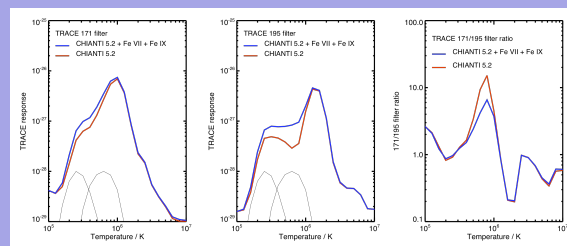


Figure 8. The left and middle panels compare the response functions computed with CHIANTI 5.2 (red) and CHIANTI 5.2 supplemented with the new Fe VII and Fe IX atomic data (blue) for the 171 and 195 channels, respectively. The functions are increased by the new data in the log $T=5.5-6.0$ region, particularly for 195. At the bottom of both plots are shown the ionization fraction curves for Fe VII and Fe IX (from Mazzotta et al. 1998) to show their ranges of formation. The right panel plots the 171/195 filter ratio (which is used to derive plasma temperatures). The new curve is lower by up to a factor 3 over the region log $T=5.5-6.0$.

5. Summary

A combination of high resolution spectra from Hinode/EIS and new atomic data have been used to calculate new synthetic spectra suitable for computing response functions for solar imaging instruments such as SOHO/EIT, TRACE and STEREO/EUVI. A large change to the 195 response function is found, affecting the 171/195 filter ratio in the log $T = 5.5$ -6.0 range. The new data will be valuable for the upcoming AIA instrument on the Solar Dynamics Observatory.

References

- Mazzotta, P. et al. 1998, A&AS, 133, 403
 Witthoeft, M. C., & Badnell, N. R. 2008, A&A, 481, 543
 Young, P. R., 2009, ApJ, 691, L77