SOLAR FLARE IMPULSIVE PHASE EMISSION OBSERVED WITH SDO/EVE

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ABSTRACT

Differential emission measures (DEMs) during the impulsive phase of solar flares were constructed using observations from the EUV Variability Experiment (EVE) and the Markov-Chain Monte Carlo method. Emission lines from ions formed over the temperature range log $T_e = 5.8–7.2$ allow the evolution of the DEM to be studied over a wide temperature range at 10 s cadence. The technique was applied to several M- and X-class flares, where impulsive phase EUV emission is observable in the disk-integrated EVE spectra from emission lines formed up to 3–4 MK and we use spatially unresolved EVE observations to infer the thermal structure of the emitting region. For the nine events studied, the DEMs exhibited a two-component distribution during the impulsive phase, a low-temperature component with peak temperature of 1–2 MK, and a broad high-temperature component from 7 to 30 MK. A bimodal high-temperature component is also found for several events, with peaks at 8 and 25 MK during the impulsive phase. The origin of the emission was verified using Atmospheric Imaging Assembly images to be the flare ribbons and footpoints, indicating that the constructed DEMs represent the spatially average thermal structure of the chromospheric flare emission during the impulsive phase.

Key words: Sun: activity – Sun: chromosphere – Sun: corona – Sun: flares

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1. INTRODUCTION

In the standard model of solar flares, energy is deposited in the lower layers of the atmosphere by non-thermal electron beams that undergo Coulomb collisions when they encounter the dense chromospheric plasma. Hard X-rays are produced through thick-target bremsstrahlung radiation (Brown 1971) and impulsive emission from the flare footpoints is observable in soft X-ray, extreme ultraviolet (EUV), ultraviolet (UV), and white light radiation. The impulsive response in the EUV was first inferred over 40 yr ago (Donnelly 1969) using Sudden Frequency Deviations, sensitive to the broadband solar EUV irradiance in the 1–103 nm range. The impulsive EUV bursts were found to be correlated with hard X-ray emission (Kane & Donnelly 1971; Donnelly & Kane 1978), which provided evidence that non-thermal electrons were responsible for transferring energy to the lower atmosphere. The Yohkoh Soft X-Ray Telescope (SXT) provided imaging that showed that the impulsive phase emission was observable down to soft X-ray wavelengths (McTiernan et al. 1999; Hudson et al. 1994), indicating material at the flare footpoints was heated to temperatures of up to 10 MK. Further studies into the connection between footpoint soft and hard X-ray emission indicate that low-energy, non-thermal electrons directly heat the top of the dense lower atmosphere, producing the impulsive soft X-ray emission (Mrozek & Tomczak 2004; Mrozek et al. 2007).

The radiative losses from an optically thin plasma can be described by the differential emission measure (DEM), which indicates the amount of emitting material as a function of temperature. It is an observational quantity that potentially can be useful in determining flare heating mechanisms. Theoretical and semi-empirical models of flare heating show that the energy balance of the flaring atmosphere is dominated by thermal conduction and radiation (Machado & Emslie 1979; Machado et al. 1980). Models that make different assumptions about the heating function and energy balance can produce DEMs with different forms, e.g., Emslie & Nagai (1985).

The majority of previous flare DEM studies have focused on the coronal loop emissions and the only large-scale survey of flare DEMs in the literature is that of McTiernan et al. (1999). Using data from the Yohkoh SXT and Bragg Crystal Spectrometer, a Maximum-Entropy Method was employed to obtain the DEM for 80 flares ranging from high C- to low M-class. The flare DEM has been analyzed for several long duration X-class flares by Warren et al. (2013) using the Extreme-Ultraviolet Variability Experiment (EVE) instrument (Woods et al. 2012). Assuming a parameterized form for the DEM, a forward-fitting method was adopted to obtain synthetic spectra that best fit the EVE observations, demonstrating the capability of EVE to measure thermal flare plasma over a wide temperature range.

Spatially resolved spectroscopic observations of the EUV emission from flare footpoints during the impulsive phase are rare, due to the requirement of needing the spectrometer slit placed over the correct location on the solar disk at the beginning of the flare. In a recent study, Graham et al. (2013) were able to obtain the impulsive phase emission measure distributions (EMDs) of flare footpoints for the first time using Hinode/Extreme-Ultraviolet Imaging Spectrometer (EIS; Culhane et al. 2007). The EMDs obtained for a number of B- and low C-class events showed chromospheric material at the footpoints heated to temperatures of up to log $T_e = 6.9$. A consistent emission measure gradient of $EM(T_e) \propto T_e^2$ was found for all events studied, which the authors interpret as a scenario where energy deposited by non-thermal electrons heats the top of the flare chromosphere, with lower layers of the atmosphere heated by conduction.

In this study, we present observations of impulsive phase emission made by the EVE instrument onboard the Solar Dynamics Observatory (SDO). The high cadence and almost continuous observations make EVE ideal for studying the evolution...
of solar flare plasmas. A DEM analysis is used to determine the spatially averaged thermal structure of the observed emission and imaging from the Atmospheric Imaging Assembly (AIA) instrument is employed to verify that the emission observed by EVE is originating from the flare ribbons and footpoints during the impulsive phase. In Section 2, the observations and analysis of EVE flare light curves are discussed, while the DEM construction technique is described in Section 3. The results of the DEM analysis are in Section 4, discussion and interpretation are in Section 5, and the conclusions are presented in Section 6.

2. OBSERVATIONS

The EVE MEGS-A instrument obtains Sun-as-a-star observations over the 6–37 nm wavelength range at a cadence of 10 s and a spectral resolution of 0.1 nm. This wavelength range includes emission lines from ions formed over a wide temperature range and the high cadence and nearly 100% duty cycle allow the study of the evolution of many solar flares as a function of temperature throughout the entire flare duration (Chamberlin et al. 2012). The EVE Level 2 Version 3 data release is used in this study as the line irradiance is in better agreement with theory compared with Version 2 (Del Zanna & Woods 2013).

In EVE observations, the response of the lower atmosphere to heating and ionization is easily observable as increased emission from chromospheric and transition region lines such as the He ii 30.4 nm doublet. Impulsive phase emission has also been observed from ions formed up to temperatures of \( \approx 0.5 \)–3 MK (e.g., Fe viii to Fe xvi) in the disk-integrated EVE spectra. The irradiance increases to a peak cotemporal with the He ii emission, then declines before reaching a second emission peak in the gradual phase as the coronal loops cool. Impulsive high-temperature emission from \( \approx 10 \) MK plasma is observable in EUV and XRT images of flare footpoints, but in EVE spectra the emission does not exhibit an impulsive time profile as it is indistinguishable from the coronal loop emission.

An analysis of the EVE flare light curves was made with the aim of detecting flares where the impulsive phase increase is sufficient to be detected above the pre-flare background emission and can be temporally isolated from any emission originating from the coronal loops in the gradual phase. Then, using the temperature coverage and high cadence of EVE, flare DEMs can be constructed over a wide temperature range and as a function of time. The aim of this study is to attempt to derive the thermal structure of the impulsive phase flare footpoints and ribbons from spatially unresolved EVE observations.

2.1. Flare Sample Selection

A method was defined to detect the strong impulsive phase emission in light curves created from EVE spectral line fluxes, which would provide a sample of flares to be investigated in the DEM analysis. It was based on the EVE temperature evolution code from Chamberlin et al. (2012) and was used to study the EUV light curves for a large flare sample consisting of all GOES flares of class C6 or higher from the beginning of EVE science operations on 2010 May 1 until 2012 October 31. This provided an initial sample of 455 flares. There were 38 flares rejected due to gaps in observations, preventing accurate identification of the impulsive phase peak, and a further 27 flares were excluded due to overlap in emission from previous events or if it appeared that multiple flares were counted as a single GOES event.

For each of the remaining 390 flares, the following analysis was performed. A pre-flare average irradiance was subtracted from each EVE wavelength bin to obtain the flare spectra. The irradiance of the strongest, isothermal emission lines formed over a temperature range of \( \log T_e = 5.8 \)–7.2 in the 6–37 nm wavelength range (see Table 1) were measured over the entire flare duration. Emission lines were then allocated into five temperature bins separated by 0.4 dex. The He ii 30.4 nm doublet was also used to provide a temperature point at \( \log T_e = 5.0 \) and the peak of He ii emission was employed as a proxy for the peak of the impulsive phase. The detection of the impulsive emission was made for each flare when the EUV light curves met the following criteria.

1. The time of peak He ii emission occurs before the time of peak emission in the \( \log T_e = 7.0 \) temperature bin.
2. The total irradiance of the \( \log T_e = 5.8 \)–6.2 emission at the time of the He ii peak must be greater than 3\( \sigma \) above the pre-flare average.
3. The derivative of the total \( \log T_e = 5.8 \)–6.2 irradiance must be negative following the He ii peak.

Condition 1 was used to discriminate between “impulsive” flares and long-decay events where there may be no easily defined end to the impulsive phase and where the 10 MK emission can be observed to peak before any of the lower temperature emission. Condition 2 rejects flares with no emission that can be observed with EVE above the background and Condition 3 is used to identify the decline in emission after the end of the impulsive phase, confirming that the increase has an impulsive time profile and was not due to gradual emission or increased pre-flare emission. Four examples of this detection are shown in Figure 1. From the sample of 390 flares, approximately 100 were found to meet the detection criteria. In this sample, the impulsive EUV emission from \( \approx 0.5 \) to 3 MK plasma is strong enough that it can be observed above the background emission and can be clearly distinguished from any gradual loop emission or increased pre-flare emission at these temperatures. The highest GOES X- and M-class flares that met the detection criteria were selected for inclusion in the DEM analysis. GOES and EVE light curves for these flares are shown in Figure 2; the latter were created by binning the flux of the emission lines in Table 1 as a function of temperature. A one minute boxcar smoothing was applied to the EVE light curves for presentation.

### Table 1

| Ion   | \( \lambda \) (nm) | \( \log T_e \) (K) | Ion   | \( \lambda \) (nm) | \( \log T_e \) (K) |
|-------|-------------------|-----------------|-------|-------------------|-----------------|
| Fe vii | 13.1          | 5.75            | Ca xvi | 19.285 | 6.75            |
| Fe ix  | 17.107         | 5.90            | Fe xvii | 9.393  | 6.85            |
| Fe x   | 17.453         | 6.05            | Fe xviii | 10.395 | 6.85           |
| Fe x   | 17.724         | 6.05            | Fe xix  | 10.835 | 6.95            |
| Fe xiv | 21.132         | 6.30            | Fe xx   | 12.184 | 7.00           |
| Fe xv  | 28.461         | 6.35            | Fe xxi  | 12.875 | 7.05           |
| Fe xvi | 33.541         | 6.45            | Fe xxii | 13.579 | 7.10           |
| Ni xvii| 24.918         | 6.45            | Fe xxiv | 19.202 | 7.25           |
| Ni xviii| 29.198       | 6.50            | Fe xxv  | 25.511 | 7.25           |
| Ca xvi | 20.860         | 6.70            | Ni xxvi | 16.537 | 7.40           |

**Notes.**

- a Blend of 13.094 and 13.124.
- b Blend of 6 O iv lines during the impulsive phase.
3. DEM CONSTRUCTION

EVE observations were used to construct the volume DEM (Equation (1)) using the Markov-Chain Monte Carlo (MCMC) procedure (Kashyap & Drake 1998) included in the PINToALE spectral analysis package. The contribution functions for each line were calculated using v7.1 of the CHIANTI atomic database (Dere et al. 1997; Landi et al. 2013) with the CHIANTI ionization equilibrium file, the standard coronal abundances (Feldman et al. 1992), and assuming an electron density of $10^{11}$ cm$^{-3}$:

$$\text{DEM}(T_e) = n_e^2 \frac{dV}{d\log T_e}. \quad (1)$$

3.1. Line Selection

Due to the low spectral resolution of EVE, blending of the many emission lines present at EUV wavelengths is a significant factor that had to be considered for each line used in the analysis. The number of emission lines to be fit changes as the flare evolves and the contributions to an observed emission feature from lines from different elements and ionization stages will

Figure 1. Four examples of flare light curves for events that exhibit strong impulsive phase emission. The dashed and dot-dashed lines are the pre-flare average and 3σ thresholds for the log $T_e = 5.8 - 6.2$ emission, which have been scaled upward by a factor of two for better visibility.

(A color version of this figure is available in the online journal.)

Figure 2. The GOES 1.0–8.0 Å and 0.5–4.0 Å light curves are shown for the events studied plotted in black and pink, respectively. The colored lines in each bottom panel are light curves of emission lines observed by EVE MEGS-A, created by binning the line flux of the emission lines listed in Table 1 as a function of peak line formation temperature. The log $T_e = 5.0$ temperature bin (red line) is the light curve of emission from the He II 30.4 nm doublet. A 1 minute boxcar smoothing was applied to the EVE light curves for presentation and the y-axis range is the same for each plot.

(A color version of this figure is available in the online journal.)
change during a flare. It is also known that there are inaccurate or missing atomic data for the wavelength ranges observed by EVE and AIA (e.g., Testa et al. 2012; Schmelz et al. 2013). The flare lines in the EVE spectral range have also been the subject of a study by Del Zanna & Woods (2013), who identified blends and lines suitable for emission measure (EM) analyses. The emission lines selected should be the dominant contribution to an observed feature, but there is also uncertainty in the measured line irradiance due to the adopted continuum and quiet Sun background. The full line list used is shown in Table 1, along with the theoretical central wavelength and peak temperature of the line contribution function. However, not all of the lines are suitable over the full flare duration.

There are many emission features in the 9–15 nm wavelength range from lines of Fe xvi to Fe xxiv, as well as the Fe xxiv 19.2 nm and 25.5 nm transitions that can be used to constrain the DEM at high temperature (log $T_e = 6.9–7.2$). The Fe xxiii 13.3 nm line has a known blend with Fe xx, while the Fe xviii 9.4 nm line is also blended with Fe xx. An emission feature close to the Fe xxiv 19.2 nm line at 19.3 nm is a blend of Ca xvii and several O v lines. During the impulsive phase, this feature appears to be dominated by O v emission, but is due to Ca xvii in the gradual phase. The line with highest peak formation temperature in the EVE wavelength range is Ni xxvi 16.54 nm (log $T_e = 7.4$), but this line is weak and it is difficult to accurately measure the line irradiance above the continuum emission.

The impulsive phase EUV emission allows the construction of the DEM to be extended down to temperatures of approximately log $T_e = 5.7–6.1$ using lines from Fe xviii to Fe x. Given the wavelength range and spectral resolution of MEGS-A, it is not possible to observe unblended lines from ions formed at lower temperatures. The feature at 13.1 nm is a blend of two Fe xviii transitions for which the summed contribution function of both lines is used. The Fe x 17.1 nm line is unblended and is used along with Fe x at 17.4 nm. Coronal dimming (Hansen et al. 1974; Hudson et al. 1996) affects the lowest ionization states of iron, Fe xviii–Fe xiv, and generally emission lines from these ions are not useable after the end of the impulsive phase for the X- and M-class events studied. Even for flares without coronal dimming, emission from lines formed at “quiet” coronal temperatures does not show any significant increase during the gradual phase of the flare.

The impulsive phase DEMs are constructed using emission lines from Fe xviii to Fe x and Fe xiv to Fe xxiv and the solution obtained is then independent of abundance. Any variation in the adopted iron abundance will only result in the DEM changing by a scaling factor. There is a gap in the temperature coverage from Fe xvi at log $T_e = 6.4$ to Fe xviii at log $T_e = 6.9$. Emission lines from ions of Ca and Ni, which have peak line formation temperatures in this range, are present in EVE spectra, but in the impulsive phase the irradiance increase from these lines is too weak to be used reliably. In the decay phase emission lines from Fe xv to Fe xxiv, Ni xvii, Ni xviii, Ca xvi, and Ca xvii can be used.

3.2. Line Fitting

As EVE observes the full disk emission, it is necessary to perform a quiet Sun background subtraction to obtain the flare emission. This is an important consideration in the analysis to ensure accurate measurement of the flare excess irradiance, in particular for the lower temperature lines during the impulsive phase for which the irradiance increase is weak. For each event analyzed, a suitable time range to adopt as the background was initially chosen based on the lowest flux in the GOES 1–8 Å channel in the hour prior to the flare start time. EVE irradiance light curves were then checked to ensure that the adopted background interval did not contain any excess EUV emission due to the gradual or late phase emission of a prior flare. The observed irradiance in each wavelength bin was averaged over a 5 minute time interval and subtracted to obtain the excess flare emission.

Emission lines were fit with Gaussian profiles using non-linear least squares regression. Line fits were weighted by the uncertainty estimate provided for each spectral bin in the Version 3 data release. To account for the variation in free-free emission during solar flares (Milligan et al. 2012) and the pseudo-continuum of the many weak lines present, the line flux was measured above the local continuum using a linear background fit over a wavelength range of at least 1 nm. The integrated line flux was estimated as the area under the Gaussian profile above the adopted continuum and uncertainties in line flux were estimated from the statistical uncertainties on the Gaussian profile parameters returned by the least squares fitting.

3.3. Markov-Chain Monte Carlo Routine

The initial conditions of the PINTofALE MCMC procedure were set to run for 500 simulations, at a temperature binning of 0.05 dex, and the range of the DEM solution was allowed to vary over 6 orders of magnitude. The maximum temperature range was log $T_e = 5.5–7.5$ when emission lines from Fe xviii to Fe xxiv were used. If lines were excluded, e.g., Fe xviii to Fe xiv due to coronal dimming, then the DEM construction was performed over a temperature range dependent on the emission lines available to use in the flare spectra at each time bin, and extended to 0.2 dex beyond the lowest and highest peak line formation temperatures.

4. RESULTS

For each of the nine flares in Table 2, the best-fit solution from 500 MCMC simulations is plotted in Figure 3 as an emission measure distribution and the EM loci curves showing the maximum possible emission at each temperature are also overplotted. The ratio of the observed line flux to the line flux predicted by the DEM model is displayed under each EMD.

4.1. Impulsive Phase

The impulsive phase DEMs are shown for each flare in Figure 3; these DEMs have been constructed using line fluxes at the peak of the impulsive phase emission. For each of the nine events studied, a similar distribution is found. At low temperatures, the DEM increases from a few 100,000 K and reaches a peak at approximately 1–2 MK. The DEM then
decreases and reaches a minimum at 3–4 MK. After this minimum, the DEM increases again and there is a broad, high-temperature component in the solution from 7 to 30 MK. Several events also exhibit a double peaked distribution at high temperature, with peaks at $\log T_e = 6.9$ and 7.3 (8 and 20 MK).

In Table 3, the peak temperature and total emission measure of the low-temperature component for $\log T_e \leq 6.6$ is shown. The re-constructed DEMs broadly reflect what is seen from the flare EUV light curves; strong, impulsive phase increases are generally in the range 0.8–1.2. Each line was also checked to look for systematic errors in the choice of emission lines used in the analysis. It was found that the measured flux of the Fe xx 12.18 nm emission line was greater than that

| Event | Time   | log EM (cm$^{-3}$) | log $T_e$ (K) |
|-------|--------|-------------------|---------------|
| 2011 Mar 09 | 23:21:08 | 48.88 | 6.15 |
| 2011 Jul 30 | 02:07:54 | 47.67 | 6.20 |
| 2011 Aug 04 | 03:52:55 | 47.74 | 6.15 |
| 2011 Sep 06 | 22:18:53 | 48.89 | 6.50 |
| 2011 Sep 07 | 22:36:54 | 48.11 | 6.20 |
| 2011 Sep 24 | 09:35:58 | 47.78 | 6.15 |
| 2011 Nov 03 | 20:21:19 | 47.69 | 6.25 |
| 2012 Jul 06 | 23:06:34 | 47.68 | 6.20 |
| 2012 Oct 23 | 03:15:51 | 47.70 | 6.25 |
predicted line flux was found to be on average 17% greater than the predicted flux. Synthetic spectra were generated from the constructed DEMs and the CHIANTI database as an additional check to help identify a possible blend, but do not show any other strong emission lines within the Fe xx line profile. It is possible that an unidentified emission line could be contributing to the measured line flux. The observed flux of the Fe xiv 21.1 nm line also tends to be higher than the model prediction, indicating the measured line flux was found to be on average 17% greater than predicted by the DEM model for every event studied. The measured line flux was found to be on average 17% greater than the predicted flux. Synthetic spectra were generated from the constructed DEMs and the CHIANTI database as an additional check to help identify a possible blend, but do not show any other strong emission lines within the Fe xx line profile. It is possible that an unidentified emission line could be contributing to the measured line flux. The observed flux of the Fe xiv 21.1 nm line also tends to be higher than the model prediction, however this line has large observational uncertainties.

To investigate whether the choice of ionization equilibrium data or adopted DEM method had any affect on the solution obtained, several checks were performed to verify the structure in data or adopted DEM method had any affect on the solution obtained when using the CHIANTI data. Synthetic spectra were generated from the constructed DEMs and the CHIANTI database as an additional check to help identify a possible blend, but do not show any other strong emission lines within the Fe xx line profile. It is possible that an unidentified emission line could be contributing to the measured line flux. The observed flux of the Fe xiv 21.1 nm line also tends to be higher than the model prediction, however this line has large observational uncertainties.

A different construction method to obtain the DEM was also investigated. The Naval Research Laboratory (NRL)-EVE method (Warren et al. 2013) was used, which assumes a parameterized form of the DEM as a sum of Gaussians. The wavelength ranges used in the least-squares minimization were altered to cover the Fe xix and Fe x emission lines from 17 to 18 nm and the Fe xiv 21.1 nm line. The temperature range was set to cover log T_e = 5.5–7.5 with 10 Gaussian components and, following the procedure outlined in Warren et al. (2013), the underlying continuum was removed by subtracting the lowest irradiance in each 1 nm interval from the observed spectra.

The MCMC and NRL-EVE results are shown in Figure 5 for eight events. To directly compare the results of the two methods, the output of the MCMC routine is divided by logarithmic irradiance in each 1 nm interval from the observed spectra. The low-temperature peak in the distribution is reproduced in the NRL-EVE code and generally a good agreement is found between the two different methods, particularly in the case of the 2011 March 09, 2011 August 04, and 2011 September 24 flares (Figure 5, panels a, c, and f, respectively).

The small number of unblended emission lines available in the MEGS-A wavelength range limits the analysis as the structure of the solution is not well constrained at low temperature. Any DEM analysis is sensitive to the adopted line fluxes and uncertainties and it is possible that the structure in the derived DEMs may change due to updated instrument calibration in the future. The results presented in this study are obtained from the most recent EVE data version, using the most up-to-date atomic data available, an abundance free construction, and verified using a second construction method that gives solutions in good agreement with the MCMC method.

4.3. Location of Flare Emission

Images from SDO/AIA (Lemen et al. 2012), shown in Figure 6, were used to provide spatial information about the flare emission, providing a context for where in the atmosphere the EUV emission observed by EVE is originating from at different points in the flare evolution. For each flare, a comparison is shown between the impulsive phase (left panels) and the decay phase (right panels). Intensity contours from the 94 Å channel (Fe xviii, peak response at log T_e = 6.9) at the 10% and 50% levels are overplotted on images from the 304 Å channel. Images during the impulsive phase are shown from as close as possible to the time of the EVE observations used to construct the DEMs shown in Figure 3, based on the exposure time to limit the amount of detector saturation.

At the peak of the impulsive phase, the 10% contours from the 94 Å channel outline the flare ribbons with the highest intensity emission originating from several localized regions, i.e., the flare footpoints/ribbons. The decay phase images and contours show the flare loop arcades. This imaging provides evidence to support that, for these events, the high-temperature EUV emission during the impulsive phase is originating from the...
flaring chromosphere, while during the decay phase the emission is from the coronal loops. Despite the spatially unresolved nature of the EVE observations, the imaging indicates that the EVE flare spectra can be used to determine the (spatially averaged) thermal structure of the chromospheric flare emissions during the impulsive phase.

5. DISCUSSION

The DEMs derived from EVE observations suggest that the EUV emission originates from a region with a peak temperature of 1–2 MK, with a large decrease in emission from ions above Fe X. In some events, there is no Fe XIV emission observable in the EVE flare spectra at the peak of the impulsive emission. This is similar to the EMDs derived from Skylab NRL spectroheliograph observations (Widing & Hiei 1984). The impulsive EUV source in the Skylab study showed increased emission from O vi to Fe xiv, with a possible maximum at Fe X and weak increases from lines above typical quiet Sun coronal temperatures. AIA imaging of the flares in this study supports the idea that the hot emission (8–10 MK) observed by EVE is also originating from the flare ribbons and footpoints.

A recent example of impulsive phase DEMs—and the first study of the temperature distribution of plasma at flare footpoints—is the study of Graham et al. (2013), who found a distribution that was constantly increasing in temperature up to log $T_e = 6.9$, with a gradient $\propto T^4$. The EVE results presented in this study show significant differences in the structure of the distribution at low temperature but similarly show a peak in the distribution at around log $T_e = 6.9$. It may not be appropriate to directly compare the two sets of results, as the EMDs derived from EIS observations were constructed from the total line-of-sight emission, with no pre-flare emission subtracted.

As part of a study into flare ribbon energetics, Fletcher et al. (2013) determined DEMs of footpoints using AIA observations during the early phase of an M1.0 flare. The AIA-derived DEMs presented exhibited a peak in the distribution at approximately 1 MK, a decrease at temperatures of 3–6 MK, and a high-temperature peak at 10 MK. While the line-of-sight quiet coronal emissions will increase the magnitude of the DEM at low temperature, these results are very similar to what is obtained from the spatially unresolved EVE observations. This may support the conclusion drawn from the comparison with the AIA imaging, which is that the DEMs derived in this study represent the spatially averaged thermal structure of the flare ribbon and footpoints.

6. CONCLUSIONS

This study has focused on determining the DEM of the impulsive phase flare emission using data from the EVE MEGS-A instrument. Using the MCMC method and the NRL-EVE code, impulsive phase DEMs were constructed from log $T_e = 5.5–7.5$ for nine M and X-class flares. A similar distribution in the reconstructed DEMs is found for each event studied. There is a low-temperature component peaking at 1–2 MK, and a broad high-temperature component from 7 to 30 MK, with a minimum in the solution at 3–4 MK. Excellent agreement is found between the two independent methods and the solutions are able to produce line irradiance and synthetic spectra that match the EVE observations. However, the structure in the solution is not well constrained at low temperature due to the lack of unblended emission lines in the EVE MEGS-A wavelength range. Imaging of the flare emission from AIA verifies the location of the emission observed by EVE during the impulsive phase, providing evidence that the DEMs obtained represent the
spatially averaged thermal structure of the flare footpoints and ribbons.

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