HOT PLASMA IN NONFLARING ACTIVE REGIONS OBSERVED BY THE EXTREME-ULTRAVIOLET IMAGING SPECTROMETER ON HINODE

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ABSTRACT

The Extreme-Ultraviolet Imaging Spectrometer (EIS) on the Hinode spacecraft obtains high-resolution spectra of the solar atmosphere in two wavelength ranges: 170–210 and 250–290 Å. These wavelength regions contain a wealth of emission lines covering temperature regions from the chromosphere/transition region (e.g., Heii, Si vii) up to flare temperatures (Fe xxiii, Fe xxiv). Of particular interest for understanding coronal heating is a line of Ca xvii at 192.858 Å, formed near a temperature of $6 \times 10^6$ K. However, this line is blended with two Fe xi and six O v lines. In this paper we discuss a specific procedure to extract the Ca xvii line from the blend. We have performed this procedure on the raster data of five active regions (ARs) and a limb flare, and demonstrated that the Ca xvii line can be satisfactorily extracted from the blend if the Ca xvii flux contributes to at least ~10% of the blend. We show examples of the high-temperature corona depicted by the Ca xvii emission and find that the Ca xvii emission has three morphological features in these ARs: (1) “fat” medium-sized loops confined in a smaller space than the 1 million degree corona, (2) weaker, diffuse emission surrounding these loops that spread over the core of the AR, and (3) the locations of the strong Ca xvii loops are often weak in line emission formed from the 1 million degree plasma. We find that the emission measure ratio of the 6 million degree plasma relative to the cooler 1 million degree plasma in the core of the ARs, using the Ca xvii to Fe xi line intensity ratio as a proxy, can be as high as 10. Outside of the AR core where the 1 million degree loops are abundant, the ratio has an upper limit of about 0.5.

Key words: Sun: corona – Sun: UV radiation

Online-only material: color figures

1. INTRODUCTION

The Extreme-Ultraviolet Imaging Spectrometer (EIS; Culhane et al. 2007) on the Hinode spacecraft (Kosugi et al. 2007) measures coronal spectral line intensities, profiles, and Doppler shifts in two wavelength ranges: 170–210 and 250–290 Å. These wavelength regions contain a wealth of emission lines covering temperature regions from the chromosphere/transition region (e.g., Heii, Si vii) up to flare temperatures (Fe xxiii, Fe xxiv; Young et al. 2007; Brown et al. 2008). It also has the capability of imaging solar features by rastering the spectrometer slit over the region, forming images by integrating over the line profiles. For resolved lines (i.e., nonblend, or blended but extractable from line fitting procedures), these images generally represent emission from around their respective formation temperatures (e.g., Doschek et al. 2007a). Thus, EIS has better temperature discrimination than broadband imaging telescopes that form images from spectral responses that contain lines formed over a range of temperatures. Since launch EIS has obtained such high spatial resolution spectral images for many ARs in spite of being launched near solar minimum.

The EIS spectra give us the opportunity of obtaining accurate differential emission measures (DEM) at different locations in the active region (AR). This is important for solar irradiance applications (e.g., Warren et al. 2001) and coronal heating models (e.g., Klimchuk 2006). The construction of DEMs are bounded by the lowest and highest temperature lines that EIS can record. EIS can observe an abundance of lines at temperatures as low as a few hundred thousand degrees and as high as about $20 \times 10^6$ K (e.g., Young et al. 2007; Brown et al. 2008). The highest temperature lines available, from Fe xxiv and Fe xxiii, are only seen during flares. There are several relatively high-temperature lines, with formation temperature higher than 3 million degrees, which can appear in ARs in the absence of obvious flaring. As recently analyzed by Warren et al. (2008a), these lines are mostly from Fe xvii and Ca xv, xvi, xvi, xvii. Among them, Fe xvii and Ca xvii lines are of the highest formation temperature at $(5–6) \times 10^6$ K, and are of particular interest in that they can provide much needed constraints in coronal heating models (Parenti et al. 2006; Patsourakos & Klimchuk 2007).

The Ne-like Fe xvii lines are excited from the ground state to the first excited levels, which involve energies in the X-ray region equivalent to wavelengths around 15–17 Å. Many of the excited states have decay channels back to the ground state and produce strong Fe xvii X-ray lines near the above wavelengths that are well-known features in the solar X-ray spectrum as well as in the spectra of other stars and more exotic astrophysical objects. However, due to branching ratios and the fact that two of the lines arise from states where a return to the ground state is strictly forbidden by radiative decay, there are some Fe xvii lines that appear within the EIS wavebands. These lines were extensively studied during the Skylab era and spectroscopic results are summarized by Feldman et al. (1985) and Doschek (1991). Unfortunately, the extreme ultraviolet (EUV) Fe xvii lines are quite weak except during flares, and were not included in many of the EIS AR raster scans made up to now. The detailed analysis of Warren et al. (2008a) concluded that it is difficult at the current stage to use the Fe xvii spectra for quantitative analysis due to problems in atomic physics.

The Be-like Ca xvii line is relatively strong and is one of the lines included in most observations made with EIS. According to the CHIANTI atomic database version 5.2 (Dere et al. 1997; Landi et al. 2006), the emissivity of Ca xvii λ192.858 is
about a factor of 4 higher than that of the strongest Fe xvi line (204.65 Å) observable by EIS at their peak formation temperature ($(5–6) \times 10^6$ K; see also Figure 4 of Warren et al. 2008a).

The observed Ca xvi can even be at least a factor 20 stronger than Fe xvi when also taking into account their instrument effective areas. However, it is blended with two Fe xi and six O v lines. For certain data such as in flare loops, the Ca xvi line dominates the emission of the blend (e.g., Hara et al. 2008).

In most situations such as in nonflaring ARs, the contribution from Fe xi (and O v at certain locations) usually dominates, or is comparable to, the Ca xvi emission. Previous studies usually obtained the Ca xvi line intensity by subtracting some estimated Fe xi and O v contribution from the whole blend (e.g., as suggested by Young et al. 2007). This method works well in general but can produce large errors where Fe xi, Ca xvi and O v emissions are comparable with one another. In this paper, we present the first attempt to obtain the Ca xvi line by multi-Gaussian fitting of the entire profile of the blend. We believe that this specific procedure provides the best way to date for obtaining this Ca xvi line under a wide variety of conditions.

This Ca xvi line, combining with other Ca lines at lower ionization stages as suggested by Warren et al. (2008a), is therefore the most practical high-temperature line available to probe the high-temperature corona in the absence of flares.

In Section 2, we briefly describe the EIS spectrometer. In Section 3, we discuss the blending of the Ca xvi complex and the method to remove the Fe xi and O v components from the Ca xvi component. We show results of this procedure for five ARs and a limb flare in Section 4. In Section 5, we discuss the morphology and emission measure (EM) of the 6 million degree corona relative to the cooler plasma in these ARs. We give our summary in Section 6.

### 2. THE EIS ON HINODE

The EIS is described in detail by Culhane et al. (2007) and Korendyke et al. (2006). The instrument consists of a combination of multilayer telescope and spectrometer. The telescope mirror and spectrometer grating are divided into two segments, each of which is coated with different Mo/Si multilayers tuned to different wavelength bands: 170–210 Å and 250–290 Å. Light focused from the telescope onto the entrance aperture of the spectrometer enters the spectrometer and is then diffracted by the grating and focused onto two CCD detectors.

The telescope mirror is articulated and different regions of the Sun can be focused onto the spectrometer aperture by fine and coarse mirror motions. The entrance aperture of the spectrometer has four options: a 1′ slit, a 2′′ slit, a 40′′ slot, or a 266′′ slot. The slits/slots are aligned in the solar north/south direction. The CCD height is 1024′′. The heights for individual observations can be varied, with a maximum height for most observations to be 512′′.

EIS can be operated in several modes. Images of solar regions can be constructed by rastering a slit or slot in the west to east direction across a given solar area with a set exposure time at each step. At each raster position it is possible to obtain a complete spectrum for each wavelength band. However, it is also possible to select a small set of lines with specified spectral windows, the choices of lines depending on the objectives of the observation. The spatial resolution of EIS along the slit and in the direction of dispersion is approximately 2′′ (1′′ per pixel). The spectral dispersion is 0.0223 Å per pixel. The instrumental full width at half maximum (FWHM) of a line profile measured in the laboratory prior to launch is 1.956 pixels. Doschek et al. (2007b, 2008) adopted an FWHM width of 0.056 Å, similar to that found by Brown et al. (2008).

Prior to detailed data analysis, the level-0 data were calibrated by the standard calibration routines that remove the pedestal and dark current, electron spikes and hot pixels. Wavelengths were corrected for the slit tilt and thermal variations during the orbit. We refer Young et al. (2009) for details.

### 3. DATA REDUCTION

The main purpose of this work is to extract the Ca xvi 192.858 Å line from the blending with the O v and Fe xi lines. Table 1 lists the six O v transitions, two Fe xi transitions, and the Ca xvi transition in the λ192 blend which span a wavelength range of 0.165 Å. Also listed are the two Fe xi lines in the λ188 blend. To demonstrate the blend, we use the observation of AR10978 on 2007 December 11. The upper panels of Figure 1 show the raster images of the λ192 blend (upper left)

| Ion | Transition | Wavelength (Å) | Relative Strength | log10 T<sub>max</sub> |
|-----|------------|----------------|------------------|-------------------|
| Fe xi | 3s^23p^4, 1^P_2 - 3s^23p^4 3d^1^P_2 | 188.216 | 1.0 | 6.1 |
| Fe xi | 3s^23p^4, 1^P_2 - 3s^23p^4 3d^1^P_1 | 188.299 | 0.70 | 6.1 |
| Fe xi | 3s^23p^4, 1^P_1 - 3s^23p^4 3d^1^P_2 | 192.813 | 0.26 | 6.1 |
| Fe xi | 3s^23p^4, 1^P_1 - 3s^23p^4 3d^1^P_1 | 192.901 | 0.0052 | 6.1 |
| O v | 2s2p 3P_0 - 2s3d 3D_1 | 192.750 | 0.1729 | 5.4 |
| O v | 2s2p 3P_1 - 2s3d 3D_2 | 192.797 | 0.3193 | 5.4 |
| O v | 2s2p 3P_1 - 2s3d 3D_1 | 192.801 | 0.1296 | 5.4 |
| O v | 2s2p 3P_2 - 2s3d 3D_3 | 192.904 | 1.0 | 5.4 |
| O v | 2s2p 3P_1 - 2s3d 3D_2 | 192.911 | 0.1063 | 5.4 |
| O v | 2s2p 3P_2 - 2s3d 3D_1 | 192.915 | 0.00863 | 5.4 |
| Ca xvii | 2s^2 1S_0 - 2s2p 1P_1 | 192.858 | ... | 6.8 |

Notes.

- O v from Fuhr et al. (1999). For Fe xi, see Young (1998) and Brown et al. (2008). For Ca xvii, see Brown et al. (2008) (see also De Jager 1978).
- For Fe xi, the ratios are relative to the 188.216 Å line and are empirically determined (see Section 3.1). For O v, the ratios are relative to the strongest 192.904 Å line and are adopted from CHIANTI database v5.2.
- Peak formation temperature (in K) from CHIANTI database v5.2 with ionization equilibrium from Bryans et al. (2006).
Figure 1. Upper panel: raster images of the $\lambda 192$ blend (left) and the Fe $\text{xi} \lambda 188.216$ line (right). The fluxes of Fe $\text{xi} \lambda 188.216$ are obtained by fitting the $\lambda 188$ blend with two Gaussians. The fluxes of the $\lambda 192$ blend are obtained by summing across the profile of the entire blend that includes the Ca $\text{xvii}$ line, 2 Fe $\text{xi}$ lines and 6 O $\text{v}$ lines with background level subtracted. The raster observations were on AR 10978 on 2007 December 11 from 16:24:13 UT to 17:35:04 UT. The six plots below the two raster images are the spectra at the three marked locations for the $\lambda 192$ blend (middle panels) and the Fe $\text{xi} \lambda 188$ blend (lower panels). The results of the two-Gaussian fitting of the Fe $\text{xi} \lambda 188$ blend are also shown (dashed lines: the two Fe $\text{xi}$ components; dotted line: constant background level).

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

and the Fe $\text{xi} \lambda 188.216$ line (upper right). We can see that the two images are very similar due to the predominant Fe $\text{xi}$ emission almost everywhere in the $\lambda 192$ blend. However, the contrast among some structures is different in the two images, indicating different contributions from the O $\text{v}$ and Ca $\text{xvii}$ lines relative to the Fe $\text{xi}$ emission. For example, the locations marked by “1” and “2” do not stand out in the Fe $\text{xi} \lambda 188.216$ image as in the image of the $\lambda 192$ blend, indicating significant emission from O $\text{v}$ or Ca $\text{xvii}$, and structures around point “3” are especially bright in the Fe $\text{xi}$ image indicating that the Fe $\text{xi}$ emission dominates. The six plots below the two raster images are the spectra at the three marked locations for the $\lambda 192$ blend (middle panels) and the Fe $\text{xi} \lambda 188$ blend (lower panels). Indeed, Point “1” shows a significant O $\text{v}$ emission (a second peak is at the right of the Fe $\text{xi}$ line). Point “2” shows a likely significant Ca $\text{xvii}$ emission judged from the broad width of the line profile due to the combination of Fe $\text{xi}$ and Ca $\text{xvii}$, as well as that the line peak is close to the rest wavelength of Ca $\text{xvii}$ but there is no comparable line shift in the Fe $\text{xi} \lambda 188.216$ line. Point “3” shows that the Fe $\text{xi}$ emission is dominant. Note that the line spectra seem to lie above different background levels at the three locations. This is mainly due to different intensities of the neighboring lines (e.g., Fe $\text{xi}$ 192.62 Å and Fe $\text{xiv}$ 192.63 Å are at the short wavelength side; see Brown et al. 2008). Most of
the instrument background is already subtracted by the standard calibration procedure (see Young et al. 2009 for details).

3.1. Procedure for Extracting the Ca xvii Line from the Blend

With nine lines in the blend and if we assume each line can be represented by a Gaussian, there would be 28 parameters to fit with (peak, width and centroid for each line, plus a constant background level). However, the number of free parameters can be reduced considerably. With simultaneous observation of the Fe xi \( \lambda 188.216/188.299 \) lines that are bright and easy to fit with a two-Gaussian profile (see lower plots of Figure 1), the spectral profiles of the two Fe xi \( \lambda 192 \) lines are essentially determined given that the rest wavelengths and their relative line ratios are known (see below), and that the line width and Doppler shift of all Fe xi lines are the same. Similarly, the combined profile of the six O v lines (i.e., six Gaussians) can be calculated from just three parameters: peak, width and centroid of the strongest O v \( \lambda 192.904 \) Å by prescribed line separations and ratios (see below). Adding in the Gaussian profile of the Ca xvii line (three parameters) and a constant background level, the number of free parameters for fitting the entire blend is thus reduced to only seven. A least-squares minimization algorithm (MPFIT) is used to fit the data and obtain the best-fit parameter values of the seven free parameters. Note that for the data we analyzed here, we chose the background being at a constant level. This would contribute to some systematic error in the fitted results since the blending by line wings of adjacent lines may give a false background level at either side of the concerned lines (e.g., see Figure 1). Young et al. (2009) adopted a method of identifying the background level but it requires a large spectral window. For most data we analyzed here, the concerned spectral windows are too narrow for us to do so. Nonetheless, we believe that the error caused by this assumption should be a small contribution to the overall uncertainty of the fitting procedure.

Below, we first describe in detail the methods and reasonings that arrive at our procedure of extracting the Ca xvii line out of the blend. A summary is then provided listing out individual steps of the procedure.

The rest wavelengths (see Table 1) of the six O v lines and line intensity ratios relative to O v \( \lambda 192.904 \) Å are taken from CHIANTI atomic database version 5.2 (Dere et al. 1997; Landi et al. 2006), specifically, from Fuhr et al. (1999), Tachiev & Froese Fischer (1999), and K. A. Berrington (2003, private communications). These O v line ratios are not sensitive to the electron density below \( 10^{10} \) cm\(^{-3} \) and the ratios increase by 25% for the 192.75 Å, 192.801 Å and 192.915 Å lines, and by 50% for the 192.797 Å and 192.911 Å lines at \( n_e = 10^{12} \) cm\(^{-3} \). For this work, we take the line ratios to be the average between \( n_e \) of \( 10^9 \) and \( 10^{10} \) cm\(^{-3} \) (at the O v peak formation temperature of 2.5 \( \times 10^5 \) K). They are 0.1729, 0.3193, 0.1296, 0.1063, 0.00863 for the 192.75 Å, 192.797 Å, 192.801 Å, 192.911 Å, and 192.915 Å lines, respectively. The standard deviations are only 1%–2% of the mean value.

The rest wavelengths (Table 1) of the Fe xi lines are taken from Brown et al. (2008). These adopted rest wavelengths are found to be consistent with the EIS data when compared with the line centroids from the fitting. The intensity ratios of the Fe xi lines, however, need special attention. The difficulty in calculating accurately the atomic data for Fe xi is known and has been extensively studied by Young (1998). According to Young (1998), Fe xi \( \lambda 188.299 \) is one of the most troublesome transitions due to complicated coupling of its upper level (see Table 1) with other levels. This would be the same situation for Fe xi \( \lambda 192.901 \) which has the same upper level. Therefore we choose to determine these line ratios from the EIS data. To do so, we studied three EIS off-limb quiet-Sun observations on 2007 March 9, 2007 March 11, and 2007 September 26. For each data set, we selected a spatial region off the solar limb that is free of obvious extended loops, then fitted the data with two Gaussians for both the \( \lambda 188 \) and \( \lambda 192 \) blends. For the \( \lambda 192 \) blend, it is reasonable to assume that the signal off limb should come dominantly from the two Fe xi lines because O v lines originate from the transition region lower down and high-temperature nonflaring loops are generally believed to be low lying and located only in the core of ARs (e.g., see Warren et al. 2008a). The fitting is performed for each pixel in the selected region. We find that the most probable ratio is 0.70 and 0.26 for 188.299/188.216 and 192.813/192.816, respectively. The scatter of the resulting 192.901/192.813 ratios is large. We take the average of the three median ratios for the three data sets and adopt the 192.901/192.813 ratio of 0.02. These empirical values can be compared with those in the CHIANTI database version 5.2 of 0.36, 0.21, and 0.084 for 188.299/188.216 and 192.813/192.816, and 192.901/192.813, respectively (at \( 1.26 \times 10^6 \) K, and \( 10^9 \) cm\(^{-3} \)). The large discrepancy in the 188.299/188.216 and 192.901/192.813 ratios is obvious. Current efforts are already underway to refine the calculation for this ion (see Young et al. 2007). Until more accurate atomic calculations are available for this ion, our choice of these intensity ratios is essentially empirical. One final note about the troublesome Fe xi atomic data is that CHIANTI version 5.2 lists a theoretical line at 192.832 Å (decay of level \( 3s^23p^33d \) \( 3S_1 \) to \( 3s23p41D_2 \)) whose strength is predicted to be about 25% (at \( n_e = 10^9 \) cm\(^{-3} \)) of that of Fe xi \( \lambda 192.813 \) Å. We find that this wavelength is likely wrong because it would otherwise predict a line a factor of 2.4 stronger at 203.331 Å (decay of level \( 3s^33p^33d \) \( 3S_1 \) to \( 3s23p41D_2 \)) which should be observable by EIS. We checked some EIS data for quiet-Sun, AR, and off-limb observations and looked for this line. We find that this 203.331 Å line either does not appear in the data, or has intensity less than 1/100 of the 188.216 Å line. Therefore, we conclude that the documented wavelength of 192.832 Å for this theoretical line is not correct and this line should not be included in the \( \lambda 192 \) blend.

We summarize the procedure into sequential steps as follows. (1) Obtain the peak, width and centroid of Fe xi \( \lambda 188.216 \) Å from two-Gaussian fitting of the Fe xi \( \lambda 188 \) blend. (2) The peaks of the Gaussians for Fe xi \( \lambda 192.813 \) Å and Fe xi \( \lambda 192.901 \) Å are then 0.26 and 0.0052 times that of Fe xi \( \lambda 188.216 \) Å, respectively. The centroids have the same Doppler shift and the widths are the same as that of Fe xi \( \lambda 188.216 \). The combined Gaussian functions for the two Fe xi \( \lambda 192 \) lines are then calculated. (3) For a given Gaussian peak, width and centroid of the O v \( \lambda 192.904 \) line, the Gaussian peaks of the Fe xi \( \lambda 192 \) lines are then calculated. (4) Adding the Gaussian function for Ca xvii (specified by peak, width and centroid) and a constant background level, the best-fit values for the seven free parameters, thus the Ca xvii and O v line parameters, can be obtained by fitting the entire function with the data by a least-squares minimization algorithm (e.g., MPFIT). Note that the adopted value of 0.26 for the Fe xi \( \lambda 192.813 \) to \( \lambda 188.216 \)
ratio is consistent with that suggested in Young et al. (2007), and should be independent of the electron density because both transitions originate from the same upper level. This eliminates the uncertainty caused by variations in density across the AR.

In this work, the procedure is performed for each x-y pixel (1″ by 1″ area) of the raster data. In order not to obtain unrealistically large or small line widths from the fitting, the line widths (here we define as the 1/e half width of the Gaussian profile divided by \sqrt{2}) are limited to the range of 0.02 Å-0.045 Å (i.e., FWHM of 0.047 Å and 0.106 Å, respectively). The instrument width is around 0.024 Å (i.e., FWHM of 0.056 Å, see the previous section). Thus 0.02 Å is a reasonable lower limit. The upper limit of 0.045 Å is also reasonable judging from our experience of fitting several Fe xi and Fe xvi lines for several ARs that the widths are rarely larger than 0.045 Å. Because the rest wavelengths of Ca xvii and O v 192.904 Å are only 0.04 Å apart, in order not to confuse one line for the other during the fitting process, we limit the range of the centroid shift of both lines by ± 0.04 Å (~60 km s⁻¹). Therefore, special measures need to be taken if a given data point is known to have a very large Doppler shift in either line (e.g., judged by other lines at similar formation temperature). Note that we have tested this procedure under various assumptions, e.g., relieving the limits for line width or line centroid. We obtain similar results. The differences among them are especially small at locations where Ca xvii or O v lines are strong. This indicates the robustness of this procedure to obtain strong emission features from both lines.

3.2. Uncertainty Investigation for Ca xvii

To understand the limitations of this deconvolution algorithm of the multi-Gaussian fitting, we have performed a series of Monte Carlo simulations. In these simulations we have held the total counts in the Fe xi 192.813 Å line fixed and varied the relative contribution of Ca xvii and O v to the blend. For every profile we add Poisson noise to each spectral pixel and pass the composite profile to the fitting routine exactly as it was applied to the actual data. As a measure of the error we compute the ratio of computed to input line intensity. An example Monte Carlo simulation is shown in Figure 2. This process was repeated 1000 times for each value of relative Ca xvii and O v intensity so that statistics on the errors can be accumulated. The total O v intensity is varied from 0.1 to 10 times the Fe xi intensity while the Ca xvii intensity is varied from 0.1 to 100 times the Fe xi intensity. A total of 96,000 simulated profiles were fit.

The results of these simulations are shown in Figure 3. It suggests that when the Ca xvii intensity is comparable to the flux in the Fe xi 192.813 Å line the error is approximately 20% or less. These simulations, however, also indicate that it is not possible to extract the Ca xvii intensity accurately once it falls below about 10% of the flux in the Fe xi 192.813 Å line. At these levels the error in the Ca xvii intensity is approximately 100%. Note that the error in the Ca xvii intensity is less dependent of the O v contribution. We thus find that whether or not this Ca xvii line can be successfully extracted from the blend does not depend on the counting statistics alone. It also depends on how bright it is relative to the Fe xi and O v emission. Similar situation applies to the extraction of O v in the blend. In the case of O v (lower two panels of Figure 3), the errors not only depend on the relative intensity of O v to Fe xi, but also depend on the Ca xvii to Fe xi ratio, especially when the Ca xvii contribution is larger than Fe xi. Based on this study, we choose a criterion that if the Ca xvii (or O v) intensity out of the fitting is larger than 10% of the whole blend, it is regarded as trustable. It should be remembered that these Monte Carlo simulations only account for statistical variations. Potential systematic errors, such as the assumed relative intensities of the O v components or the assumed Fe xi 192.813 to 188.216 Å ratio, are not included.

4. ACTIVE REGION CORONA AT SIX MILLION DEGREES

4.1. 2007 December 11, AR 10978

Figures 4 shows again the raster images of the λ192 blend (upper left panel) and Fe xi 188.216 Å (upper right panel, which
Section 3.2, we do not take into account those pixels that have an intensity ratio lower than 10% of the blend. On the other hand, the O\textsc{v} emission exhibits typical transition region/chromospheric network structure with several spotty small-scale brightenings within the AR. The Ca\textsc{xvii} loops appear more like “fat bundles” instead of thin threads like those seen in Fe\textsc{xi}. The length of these loops is comparable to the size of the AR “core” (i.e., area of sunspots where the EUV/X-ray emission is also the brightest), and is not as extended as some Fe\textsc{xi} loops that are commonly seen from the 1–2 million degree corona. This indicates that these high-temperature loops are low lying and are associated with areas of strongest magnetic field strengths. There is some diffuse emission surrounding these Ca\textsc{xvii} loops. Outside of the loops and the diffuse regions, the Ca\textsc{xvii} emission appears featureless. Those featureless areas generally have Ca\textsc{xviii} fluxes smaller than 10% of the blend.

One interesting feature is that the locations with bright Ca\textsc{xvii} emission, e.g., at points “2” and “5,” appear dark in the Fe\textsc{xi} emission. The two thin loops seen in Fe\textsc{xi} just south of point “5” (upper right panel of Figure 4) appear to enclose the bright Ca\textsc{xvii} emission in between them. The bright Fe\textsc{xi} structure east and south of point “3” (the coronal “moss”; Berger et al. 1999) appears to surround the Ca\textsc{xvii} loops and could be the footpoints of these Ca\textsc{xvii} loops. In fact, many locations with bright Fe\textsc{xi} emission seem to be void of the Ca\textsc{xvii} emission, and vice versa. This indicates that these loops have distinct temperature structures among them. Many of them have a narrow DEM distribution along the line of sight that is concentrated either at around 1 million degrees, or at a higher temperature such as 6 million degrees, but not both. See Section 5.1 for more comparisons.

The XRT image is strikingly similar to that of Ca\textsc{xvii}. The response function of the Be\textsc{med} filter is peaked at 10 million degrees and its value falls below 10% of the peak value at temperatures lower than 3 million degrees (Figure 6). Therefore, it is suitable to make direct comparison with the Ca\textsc{xvii} image. The similarity between the two images gives strong proof that our extraction procedure to obtain the Ca\textsc{xvii} emission is correct.

The structure of the Fe\textsc{xvi} emission shows certain similarities with both Fe\textsc{xi} and Ca\textsc{xvii}. This is not surprising given that the formation temperature of Fe\textsc{xvi} lies in between that of Fe\textsc{xi} and Ca\textsc{xvii}. Note that the Fe\textsc{xvi} emission appears largely diffuse and uniform, especially outside of the core of the AR where many extended, distinct Fe\textsc{xi} loops are seen. This indicates that...
the plasma at $\sim$3 million degrees is more uniformly distributed across the AR, while the 1 million and 6 million degree plasmas have more localized structures.

We have applied this same procedure to five more raster data sets. The results are shown in Figures 7–11, along with the XRT and Fe xvi images when available. Below, we discuss the Ca xvi structure for each of them.

### 4.2. 2007 December 15, AR10978

This same AR was observed twice on December 15, one from 00:13:49 UT to 05:32:40 UT (“Observation 1”) and the other from 18:15:49 UT to 23:34:40 UT (“Observation 2”). The results are shown in Figures 7 and 8. This AR on this day shows obvious differences in morphology from that on December 11. The Ca xvi emission from Observation 1 (Figure 7) exhibits a large extended loop toward the south which resembles the shape of post-flare loops. This AR had been producing many B- and C-class X-ray flares since December 11, which included seven flares on December 14 alone. The only C-class event that occurred in this AR within one day of both EIS observations was a C1.1 X-ray flare on 14:11 UT, December 14. These flares are possible causes of this extended Ca xvi loop feature. It is interesting to note that these extended Ca xvi loops ($X$ between 600$''$ and 750$''$, $Y$ between $-200''$ and $-300''$) enclose the smaller, cooler Fe xi loops (which appear mostly dark below $Y = -250''$ for the same $X$ range, see also Section 5.1), which also agree with the standard picture of post-flare loops. Such a loop structure in the Fe xvi emission is visible but not as obvious. Several bright loops and some diffuse emission in Ca xvi can be seen at the heart of the AR, but only faint Ca xvi emission, if any, existed around the outer region where many Fe xi and Fe xvi emissions were present. The XRT image (Be_med filter) again shows a very good match with the Ca xvi emission. The XRT movie taken during that time shows that the X-ray emission is very dynamic with various loops brightening and fading. For example, the “$\Omega$”-shaped loop at the top was a transient feature that was seen both in X-rays and Ca xvi.

Observation 2 (Figure 8) was taken 18 hours later. The large post-flare loops in Ca xvi have disappeared (note that there was only one X-ray flare, a B3.8, from this AR in between the two observations) and the diffuse emission at the core of the AR is...
Figure 5. Examples of the fitting results for the 2007 December 11 data (Figure 4). Points 1, 2, 3 are the same as those in Figure 1. Green dashed line is the two Fe \text{xi} components. Blue dash-dot line is the Ca \text{xvii} line. Red solid line is the six O \text{v} components. The horizontal black dotted line is the background level. The yellow dashed line is the sum of all fitted components. The black solid line with error bars is the data. Points 1 and 4 have strong O \text{v} emission. Points 2 and 5 have strong Ca \text{xvii} emission. Points 3 and 6 are dominated by the Fe \text{xi} emission. The derived fluxes with errors (in erg s^{-1} cm^{-2} sr^{-1}) from the multi-Gaussian fitting for Fe \text{xi} 192.813 Å, Ca \text{xvii}, and O \text{v} 192.904 Å are listed on the plots. (A color version of this figure is available in the online journal.)

Figure 6. Emissivities (G(T)) of Fe \text{xi} λ188.216, Fe \text{xvi} λ262.976, Ca \text{xvii} λ192.858, and the temperature response function for the Be_med and Al_poly filters of Hinode/XRT. The curves are all normalized to their respective maximum. The emissivities are obtained from CHIANTI database version 5.2 with ionization equilibrium from Bryans et al. (2006). The XRT effective areas are calculated using the standard calibration routines available in SolarSoft with CCD contamination layer taken into account at 2007 February 2, 11:00 UT (Al_poly filter) and 2007 December 11, 17:13 UT (Be_med filter). The default APED model is used to calculate the XRT temperature response function. (A color version of this figure is available in the online journal.)

more obvious. This is the same for the XRT image. To examine more quantitatively the change in line intensity between the two time periods, we calculated the mean values of Fe \text{xi} and Ca \text{xvii} fluxes in 100 pixel^2 areas. We found that the change in Fe \text{xi} λ188.216 intensity is actually quite small—less than a factor of 5 around the AR core (Y between −100″ and −200″) and less than a factor of 10 elsewhere. The most significant change occurred where the Ca \text{xvii} post-flare loops were, i.e., the Fe \text{xi} emission was depleted where and when these Ca \text{xvii} loops were prominent during Observation 1 but these depletions were “filled in” by the time of Observation 2 (i.e., its intensity became about the same level as the surroundings). This does not seem to be due to the slight change in orientation between the two observations due to solar rotation. Interestingly, the Ca \text{xvii} emission increased by a factor of 20–200 nearly across the entire region except where those post-flare loops were. Those Ca \text{xvii} loops were around a factor of 100 brighter than their surroundings during Observation 1 but became about the same brightness as the surroundings at Observation 2. We also note that this post-flare loop feature can be seen in Fe \text{xvi} at roughly the same location. All these suggest that the entire region became brighter from Observation 1 to Observation 2 with more increase in Ca \text{xvii} than in Fe \text{xi}, and the post-flare loops seen in Ca \text{xvii} during Observation 1 may have cooled and become part of the 1–3 MK corona.

4.3. 2006 December 02, AR 10926

AR 10926 was observed on 2006 December 2 from 14:06:32 UT to 14:55:45 UT (Figure 9). The dynamical properties of this AR have been presented by Doschek et al. (2007b). The Ca \text{xvii} structure is similar to that of the 2007 December 11 data. That is, it is confined to the core of the AR and is composed of
several loops with both “fat” and diffuse appearances. There are three places where the loops are particularly bright. It is not clear if they are related to the two C1 X-ray flares that occurred earlier that day at 00:18 and 07:00 UT (there was one B2 flare in between), or these loops are part of the quiescent AR structure. There are no XRT observations during this period. The Fe xvi emission has the same characteristics as AR 10978: bright, localized loops like those of Ca xvii, and diffuse, uniform emission occupying the same space with the Fe xi loops.

4.4. 2006 December 17, AR 10930

AR 10930 was observed on 2006 December 17 from 16:15:27 UT to 18:29:39 UT at the west limb (Figure 10). A C2.0 X-ray flare occurred at 14:47 UT and the post-flare loops were prominent in all observed lines. In particular, the high-temperature Ca xvii loop shows a cusp shape at the loop top and is situated above the cooler loops (e.g., Fe xi emission, also see Section 5.1), consistent with the standard flare model. The readers are referred to Hara et al. (2008) for detailed EIS data analysis for this limb flare event. In this work, the careful extraction of the Ca xvii line out of the blend enables us to see a more realistic structure of the Ca xvii emission. We see that, besides the prominent “fat” loops and the loop-top cusp, the post-flare loops are embedded in an extended, diffuse emission of ~6 million degrees. There is no footpoint brightening in either Ca xvii or O v. The transition region structure on the solar disk is nicely seen in the O v image.

4.5. February 02, 2007, AR10940

The raster observation of this AR was performed from 10:42:12 UT to 11:52:37 UT (Figure 11). The temperature and density structures of this AR have been investigated by Doschek et al. (2007a), and the coronal “moss” in this AR has been discussed by Warren et al. (2008b). The Ca xvii emission existed only at the northwest part of the region in the form of several loops, and it is much fainter than in other ARs studied here. This high-temperature loop structure is similar to the X-ray (Al_poly) and Fe xvi images shown in Figure 11, as well as the Fe xiv and Fe xv raster images shown in Doschek et al. (2007a). But unlike Ca xvii, these images also exhibit brighter emission at lower temperatures (e.g., around 2–3 million degrees) at other parts of the AR. As in other cases, most of these Ca xvii loops are situated where the Fe xi emission is fainter (see Section 5.1). Similar to AR 10978 (2007 December 11 data), the “moss” structures (Warren et al. 2008b) lie approximately along the sides of the Ca xvii loops (see also Figure 12), indicating that...
they are associated with the footpoints of these hot Ca xvi loops. Also interesting is that the O v structure in general follows the morphology of Fe xi. We checked the line profiles of the blend as well as the fitting results, and conclude that the O v structure displayed here is real. Therefore, part of this AR contains a particularly cool component. The Hα image (e.g., from http://mlso.hao.ucar.edu) of this AR shows a distinct L-shaped filament at its east and south sides which roughly follows the shape of these Fe xi/O v loops. It is likely that this filament is related to the O v loops seen here.

5. 6 MILLION DEGREE VERSUS 1 MILLION DEGREE CORONA

5.1. Spatial Structure and Morphology

To show more clearly the relative location between the hot Ca xvii and the cool Fe xi emissions, Figure 12 shows the raster images of Fe xi λ 188.216 (obtained from the Two-Gaussian fits) overplotted with the contours of Ca xvii λ 192.858 fluxes for the six data sets. Similar to the Ca xvii images shown above, those pixels with Ca xvii flux less than 10% of the blend are not taken into account. The coronal moss structures in the 2007 February 2, and 2007 December 11 data are indicated, showing that they generally surround the bright Ca xvii loops. We can see that most locations with strongest Ca xvii emission are where the Fe xi emission is relatively weak. This is especially clear for the 2006 December 2 (upper left), 2007 February 2 (lower left), and 2007 December 11 (upper right) data. It is not so clear in the 2007 December 15 data (both observations) probably because the AR was observed at a more slanted view angle. As mentioned in Section 4.1, this implies a narrow DEM distribution along the line of sight that is concentrated either at around 1 million degrees, or at a higher temperature such as 6 million degrees, but not both. Furthermore, judging from that the Fe xvi emission (with peak formation temperature at 2.5 million degrees) coexists with both the Fe xi and Ca xvii emissions, we can imagine that the DEM distribution at an AR loop probably has an FWHM of around 2 million degrees, not much narrower and not much wider, and the peak temperature at one given moment is determined by the history of heating and cooling of the loop (see Figure 6). We need to emphasize that a given line emission at a given location is a convolution of its emissivity with the DEM distribution along the line of sight. A detailed DEM analysis is necessary to demonstrate if the above inference is indeed true.

The spatial morphology shown would have important implications on how an AR corona is heated and cooled. It is likely that only a fraction of the AR loops (in a nonflaring AR) is
heated to very high temperature (∼6 MK) at one given moment, and these high-temperature loops are obviously tied to regions with strongest magnetic field strengths. This is not surprising since it is commonly acknowledged that the coronal heating rate is related to the photospheric magnetic field strength by some power law (e.g., Yashiro & Shibata 2001; van Driel-Gesztelyi et al. 2003; Schrijver et al. 2004). Do these hot loops subsequently cool, or are they repeatedly heated and never cool significantly? Are those extended 1 MK loops (or even 3 MK loops) all remnants of the once-hot loops, or are some of them never heated to 6 MK at all? High time cadence observations to look for time variations from spectral lines covering a wide range of temperatures and in a variety of loops would shed lights on these questions (e.g., Mariska et al. 2007). The Ca XVII line provides essential information for the high-temperature end of the AR corona and is a useful and viable spectral line for understanding the thermal structure and heating processes in ARs (Parenti et al. 2006; Patsourakos & Klimchuk 2007).

5.2. Emission Measure

EIS observations of ARs generally contain many lines that allow a DEM analysis to probe the temperature structure, and contain certain line pairs that are suitable for density diagnostics (Young et al. 2007, 2009). As mentioned in Section 1, Ca XVII is the most practical line to extend the temperature analysis of nonflaring ARs to its high end. We will present such DEM analysis in a separate paper. In this paper, we only explore the temperature structure using Fe XI λ188.216 and Ca XVII λ192.858 lines as proxies of the 1 million and 6 million degree corona. That is, we calculate the ratio of the EM at 6 MK to that at 1 MK using the emissivities at the peak formation temperatures of the two lines:

\[
\frac{EM_{6MK}}{EM_{1MK}} = \frac{I_{Ca XVII} A_{Fe}/A_{Fe,ph} \varepsilon_{Fe XI}(T_e = 1.26 MK)}{I_{Fe XI} A_{Ca}/A_{Ca,ph} \varepsilon_{Ca XVII}(T_e = 6.3 MK)},
\]

where \( I \) is the line flux, \( A_{el}/A_{el,ph} \) is the elemental abundance relative to its photospheric value and \( \varepsilon(T_e) \) is the emissivity (or contribution function) which is a function of the electron temperature and density. In this simple calculation, we assume an electron density of \( 10^{10} \) cm\(^{-3} \), therefore \( \varepsilon_{Fe XI}(T_e = 1.26 MK)/\varepsilon_{Ca XVII}(T_e = 6.3 MK) \) is 17.1. This assumption of the electron density is reasonable for ARs, especially for bright features (e.g., Doschek et al. 2007a; Young et al. 2009). The emissivity of Ca XVII λ192.858 is insensitive to the electron density, and the emissivity of Fe XI λ188.216 increases by ∼30% if the density is \( 10^9 \) cm\(^{-3} \) instead. We assume

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**Figure 9.** Upper panels: raster images of the λ192 blend (left) and Fe XI λ188.216 (right). The raster observations were for AR10926 on 2006 December 2 from 14:06:32 UT to 14:55:45 UT. Middle panels: images of Ca XVII λ192.858 (left) and O V λ192.904 (right) derived from this work. Lower panel: raster image of Fe XVI λ262.98. There is no XRT image available during this EIS raster observations.

(A color version of this figure is available in the online journal.)
Figure 10. Top panels: raster images of the \( \lambda 192 \) blend (left) and Fe\( xvi \) \( \lambda 188.216 \) (right). The raster observations were for AR10930 on 2006 December 17 from 16:15:27 UT to 18:29:39 UT. Bottom panels: images of Ca\( xvii \) \( \lambda 192.858 \) (left) and O\( v \) \( \lambda 192.904 \) (right) derived from this work. No XRT data were taken during the raster observations. The Fe\( xvi \) \( \lambda 262.98 \) line was not included in this EIS study.

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

\[ \frac{A_{Fe}}{A_{Fe,ph}} = \frac{A_{Ca}}{A_{Ca,ph}} \]
given that both are low first ionization potential (FIP) elements so the ratio should not be far off from 1 whether the FIP effect is present or not. The emissivities are obtained from the CHIANTI database version 5.2 (Dere et al. 1997; Landi et al. 2006). Specifically, readers are referred to Tachiev & Froese Fischer (1999) for O\( v \) lines, Young (1998) for Fe\( xii \) lines, and Zhang & Sampson (1992) for the Ca\( xvii \) line. We adopt the ionization equilibria from the updated compilation of Bryans et al. (2006). The photospheric abundances are adopted from Grevesse & Sauval (1998).

Figure 13 shows the results for the 5 AR data sets (excluding the limb flare data on 2006 December 17). The left panels show the probability distribution function (PDF) plots for Fe\( xii \) \( \lambda 188.216 \) (dashed line) and Ca\( xvii \) (solid line) fluxes. The right panels are the PDF plots for \( EM_{6MK}/EM_{1MK} \). All pixels in the raster images shown in Figures 4, and 7–11 for individual ARs are included, but those with Ca\( xvii \) flux less than 10\% of the blend are not taken into account in the PDF. As a result, the PDF plots for \( \log_{10}(EM_{6MK}/EM_{1MK}) \) have a cutoff at around −0.35 (i.e., \( \log_{10}(17.1 * 0.26 * 0.1) \) where 17.1 * 0.26 is the emissivity ratio of \( \varepsilon_{Fe\text{XII},192.813}(T_e = 1.26MK)/\varepsilon_{Ca\text{xvii},192.858}(T_e = 6.3MK) \), 0.1 is the 10\% cutoff point). We see that: (1) The intensity of the Fe\( xii \) emission has a narrow distribution mostly within a factor of 10, even though the most probable intensity can be different. This is true for all ARs studied here. This indicates that the mechanisms for producing the 1 MK corona are not much different for different ARs. (2) The intensity of the Ca\( xvii \) emission has a wider distribution which may be partly due to the uncertainty of the extraction procedure. It seems to consist of two components, a “bright” (high intensity “wing”) component from those ultrabright Ca\( xvii \) loops that is different for different ARs reflecting subtle differences in coronal heating, and a main component which is probably from the diffuse Ca\( xvii \) emission and, like Fe\( xii \), is similar for all ARs. (3) \( EM_{6MK}/EM_{1MK} \) can be as high as 10 at the core of the ARs. Outside of the AR core where the 1 million degree loops are abundant and the Ca\( xvii \) emission is relatively weak, we can put an upper limit on \( EM_{6MK}/EM_{1MK} \) to be about 0.5. Below this upper limit, the Ca\( xvii \) emission cannot be extracted from the blend with confidence. This information, as well as the morphology and spatial structures discussed in previous sections, can serve as empirical constraints for coronal heating models (e.g., Schrijver et al. 2004; Parenti et al. 2006; Warren & Winebarger 2007; Klimchuk et al. 2008). This study implies that at the core of some ARs, the heating needs to be high enough to produce EM at 6 million degrees 1–10 times higher than that at 1 million degrees. On the other hand, outside of the AR core where long, 1 million degree loops are abundant, the heating should be low enough so that \( EM_{6MK}/EM_{1MK} \) does not exceed \( \sim 0.5 \).

As a final note, one may wonder if these Ca\( xvii \) emissions indeed come from a plasma at around 6 MK, and not from a lower-temperature plasma, say 3 MK, where its EM happens to be large enough to produce EM at 6 million degrees 1–10 times higher than that at 1 million degrees. The other hand, outside of the AR core where long, 1 million degree loops are abundant, the heating should be low enough so that \( EM_{6MK}/EM_{1MK} \) does not exceed \( \sim 0.5 \).

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temperatures are in between the Ca xvii and Fe xvi formation temperatures (Figure 6). We also check one of the brightest Ca xvii emission in this data set and obtain a $T_e$ of $4.85 \times 10^6$ K. The second approach is to start from the EM. If we assume that the Fe xvi emission solely comes from a plasma at 3 MK, the EM would be $7.4 \times 10^{28}$ cm$^{-5}$ and $9.1 \times 10^{28}$ cm$^{-5}$ for points 1 and 2, respectively. If there is no plasma above this temperature, such emission measures would produce only 2.9% and 2.3% of the observed Ca xvii emission. Similarly, the EM at 6 MK, if it is the only source for the observed Ca xvii emission, would be too small to be also the only source for the observed Fe xvi emission. Both approaches are actually two faces of the same conclusion: the temperature structure is probably multithermal (along the line of sight), and the observed Ca xvii emission can at least partly come from a plasma at 6 MK. As emphasized throughout this paper, the appropriate way of investigating temperature structure is to perform a DEM analysis. Such efforts have been underway and we do see that the EM at 6 MK can be comparable to that at 1 MK at certain locations where the Ca xvii emission is strong. Such results will be presented in a separate paper.

6. SUMMARY

We have developed a specific procedure to extract the Ca xvii $\lambda$192,858 line from the blending with two Fe xi and six O v lines in the Hinode/EIS data. We have performed this procedure on the raster data of five ARs and a limb flare, and demonstrated that the Ca xvii line can be satisfactorily extracted from the blend if the Ca xvii flux contributes to at least $\sim$10% of the blend. This Ca xvii line can thus be used to probe the thermal structure of the AR corona at its high-temperature end and provide valuable constraints for coronal heating models. We believe this procedure extracts the Ca xvii emission more accurately from the blend, compared with those by subtracting the contribution of Fe xi and O v based on other observed Fe xi and O v lines. The latter may be satisfactory when Ca xvii emission is a major fraction of the blend but the error can be much larger when Ca xvii is faint or even comparable to other lines in the blend. To perform a detailed DEM analysis, this procedure is preferable so as to obtain more accurate information about the thermal structure near 6 million degrees. The main results of this study are summarized below.

Figure 11. Upper panels: raster images of the $\lambda$192 blend (left) and Fe xi $\lambda$188.216 (right). The raster observations were for AR10940 on 2007 February 2 from 10:42:12 UT to 11:52:37 UT. Middle panels: images of Ca xvii $\lambda$192.858 (left) and O v $\lambda$192.904 (right) derived from this work. Lower left: image of Hinode/XRT (Al_poly/Open filter) at 11:00:04 UT. Lower right: raster image of Fe xvi $\lambda$262.98. (A color version of this figure is available in the online journal.)
Figure 12. Raster images of Fe\textsc{xi} $\lambda$188.216 overplotted with contours of Ca\textsc{xvii} $\lambda$192.858 fluxes; upper left: AR 10926 (2006 December 2); middle left: AR 10930 (2006 December 17); lower left: AR 10940 (2007 February 2) with locations of the coronal moss marked, upper right: AR 10978 (2007 December 11) with locations of the coronal moss marked, middle right: AR 10978 (2007 December 15, observation 1), lower right: AR 10978 (2007 December 15, observation 2). The contour levels (log$_{10}$Flux, all in erg/s/cm$^2$/sr) are: black—2.45, green—2.05, white—1.65 except for AR 10930 (black—3.6, green—3.1, white—2.7) and AR 10940 (black—1.9, green—1.6).

(1) The Ca\textsc{xvii} emission is the strongest around the AR core and appears as fat, low-lying loops coexisting with some weaker, diffuse emission surrounding those bright Ca\textsc{xvii} loops. This implies that the AR corona can be largely heated to very high temperature (greater than 5 million degrees) only where the photospheric magnetic fields are the strongest.

(2) The striking similarity in morphology between the Ca\textsc{xvii} emission and the X-ray emission from XRT indicates that our procedure for extracting the Ca\textsc{xvii} out of the blend is accurate, and the spatial structure across a nonflaring AR is very similar in the range of 5–10 million degrees. On the other hand, the different spatial structures/morphologies exhibited among Ca\textsc{xvii}, Fe\textsc{xvi}, and Fe\textsc{xii} lines indicate that the DEM distribution below $\sim$6 MK at any given location in an AR probably has an FWHM of around 2 million degrees, not much narrower and not much wider. Detailed DEM analyses are required to unambiguously differentiate the thermal structure and evolution among spatial structures.

(3) The EM ratio of the 6 million degree plasma relative to the cooler 1 million degree plasma in the core of the ARs, using the Ca\textsc{xvii} to Fe\textsc{xii} line intensity ratio as a proxy, can be as high as 10. Outside of the AR core, where the 1 million degree loops are abundant, this study places an upper limit of about 0.5 for the ratio. This information, as well as the morphology and spatial structures discussed here, provide empirical constraints for coronal heating models.
Figure 13. Left panels: PDF plots for Fe xii λ188.216 (dashed line) and Ca xvi (solid line) fluxes. Right panels: PDF plot for the ratio of the EM at 6 million degrees to that at 1 million degrees using Equation (1). For the PDF of Ca xvi fluxes and EM ratios, only those pixels with Ca xvi fluxes larger than 10% of the blend are included.

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