ELECTRON TEMPERATURE, EMISSION MEASURE, AND X-RAY FLUX IN A2 TO X2 X-RAY CLASS SOLAR FLARES

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ABSTRACT

In this paper we present a statistical analysis of soft X-ray flare class and emission measure as a function of electron temperature determined for the time of maximum flare X-ray flux. The study includes 868 flares of X-ray class A2 to X2. Our work shows that their properties are very different, although large and small flares as seen by the 1–8 Å detector aboard the Geostationary Operational Environmental Satellite (GOES) records have similar appearances. The peak temperature of intense (major) flares is much higher than the peak temperature of weak (minor) flares. This finding has important implications on the nature of the flare-heating mechanism. For example, if a flare is a collection of elementary bursts, the plasma properties of the elementary-bursts occurring during peak emission of large flares and small flares must be different.

Using the relationship between electron temperature and emission measure in solar flares, we provide an estimate of the electron temperature during the peak emission of large stellar flares.

Subject headings: Sun: flares — Sun: X-rays

1. INTRODUCTION

On 1991 August 30 the Japanese Institute for Space and Astronautical Sciences launched the Yohkoh solar observatory (Ogawara et al. 1991). The Yohkoh satellite contains four major instruments: a soft X-ray telescope, a hard X-ray telescope, a set of wide-band X-ray to gamma-ray spectrometers, and a Bragg crystal spectrometer (BCS) package. Actual observations started in 1991 October when the activity of solar cycle 22 was still very high (see Fig. 1). During the next 3 yr, from 1991 October to 1994 December, while the transition from solar maximum conditions to solar minimum conditions occurred, the Yohkoh instruments observed hundreds of flares. In a sequence of three papers, Feldman et al. (1995b), Phillips & Feldman (1995), and Feldman, Doschek, & Behring (1995a) analyzed BCS spectra from some 768 flares. The analysis included the derivation of electron temperatures and emission measures during flare maximum times. Feldman et al. (1995b) presented results from 532 flares belonging to X-ray classes C2 and larger. (The X-ray classes are determined according to fluxes measured by the Geostationary Operational Environmental Satellite [GOES] 1–8 Å detector). Phillips & Feldman (1995) presented results from 208 flares belonging to X-ray classes B5–C2 and the results from 28 flares of X-ray class A2–A9 were presented in Feldman et al. (1995a). Flares of class A are the faintest flare events detectable by GOES.

The earlier studies showed that the maximum temperatures of X class flares are usually about $2.5 \times 10^7$ K and can occasionally be higher. In contrast, the average maximum temperatures of A class flares are about $5 \times 10^6$ K. While the average emission measure of the hottest flares is in excess of $1 \times 10^{50}$ cm$^{-3}$, the average emission measure of the cold flares can be smaller than $1 \times 10^{47}$ cm$^{-3}$.

The main thrust of this paper is to combine the results from earlier studies on all flares in the X-ray class A2–X2 in order to establish the general relationships between electron temperatures, X-ray classes, and emission measures. X-ray class B1–B4 flares had not been examined in previous studies. Therefore, for the sake of completeness we start our study by deriving emission measure and electron temperature measurements for time of peak emission for some 100 flares in the X-ray class B1–B4 range.

2. THE EXPERIMENT

The observations described in this paper were obtained by the BCS high spectral resolution spectrometers on Yohkoh and by the two broadband (0.5–4 Å and the 1–8 Å) ion chambers on GOES. Culhane et al. (1991) discussed the BCS package in detail. Donnelly & Unzicker (1974) and Garcia (1994a) describe the properties of the GOES ion chambers. We briefly describe below properties of the two instruments pertinent to the understanding of this paper.

2.1. The YOHKOH BCS

Four bent germanium crystals diffract radiation in four narrow wavelength ranges. Uncollimated solar X-rays are incident on each crystal, and the reflected radiation passes through a window of a sealed proportional counter with one-dimensional position encoding. A wedge-and-wedge readout provides the position encoding. Because the germanium crystals are bent, the Bragg diffraction condition is satisfied for different wavelengths at different locations along the crystal's length. In this configuration the detectors simultaneously record a complete spectrum covering a small wavelength region (channel). Photon counts are accumulated into either 128 or 256 wavelength bins. The BCS electronics recognizes and rejects background.

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The four wavelength channels cover intervals around the Lyman $\alpha$ lines of Fe xxvi (1.78 Å) and the resonance lines of helium-like ions Fe (Fe xxv, $\lambda = 1.85$ Å), Ca (Ca xix, $\lambda = 3.18$ Å), and S (S xv, $\lambda = 5.04$ Å). In the usual flare mode, the BCS records a complete four-channel spectrum once every 3 s.

The large size of the BCS crystals combined with their narrow wavelength coverage results in an instrument that is an order of magnitude more efficient than similar instruments flown in the past. The BCS can therefore detect and make meaningful spectral measurements for faint flares of X-ray classes A and B. Because of the increased sensitivity of the BCS, saturation occurs during maximum emission of flares with X-ray class M2 and brighter.

The S xv and Fe xxv channels include four prominent He-like lines. The four lines belong to the transitions: $1s^2 1S_0-1s2p 1P_1$ (line w), $1s^2 1S_0-1s2p 3P_0$ (line x), $1s^2 1S_0-1s2p 3P_1$ (line y), and $1s^2 1S_0-1s2s 3S_1$ (line z). The Ca xix channel includes only lines w, x, and y. At relatively high temperatures of $T_e \geq 1.0 \times 10^7$ K for S xv, $T_e \geq 1.5 \times 10^7$ K for Ca xv, and $T_e \geq 2.2 \times 10^7$ K for Fe xxv, the emission comes primarily from the He-like lines. However, as the temperature decreases lines originating from Li-like ions formed by dielectronic recombination and by inner-shell excitation also become prominent. The most prominent among the dielectronic recombination lines in the S xv and Fe xxv channels are the $1s^2 2p \ 2P_{1/2,3/2} - 1s2s 2S_{1/2}$ (line k), $1s^2 2p \ 2P_{1/2,3/2} - 1s2p \ 2P_{3/2}$ (line l), and several lines due to transitions of the type $1s^2 3l \ 3l'2S_{1/2,3/2} \Delta l$ dominated by a transition called d13. The most prominent among the inner-shell excitation lines are the $1s^2 2s \ 2S_{1/2} - 1s2p \ 2P_{3/2}$ (line m) and the $1s^2 2s \ 2S_{1/2} - 1s2s \ 2P_{1/2}$ (line r). The only prominent Li-like lines in the Ca xix channel are the d13 group. (The letter notations w, x, y, z, k, j, q, and r were originally introduced by Gabriel 1972 and d13 by Bely-Dubau, Gabriel, & Volonté 1979.)

The relative intensities of the Li-like and He-like lines are temperature sensitive, and thus can be used as temperature indicators. Their temperature sensitivity is approximately of the form $I_l/I_w \approx 10^{-T} \exp -\Delta E/kT$, where $I_l$ is the intensity of a Li-like dielectronic recombination satellite line and $I_w$ the intensity of the He-like resonance line (w).

The emission measure for a flare can be determined from the temperature and total flux of a He-like resonance line. The flux ($F$) of the resonance line at the Earth in photons cm$^{-2}$ s$^{-1}$ is given by

$$ F = \frac{1}{4\pi R^2} \int N_g n_e C_{12} dV, $$

where $R = 1$ AU (in cm), $N_g$ is the ion ground state number density, $n_e$ is the electron density, $C_{12}$ is the collisional excitation rate coefficient (cm$^3$ s$^{-1}$) of the resonance transition, and $dV$ is the flare volume over which the emission occurs. At solar flare densities, the entire level population of a S xv, Ca xix, or Fe xxv ion is in the ground state $N_g$. The ground state number density $N_g$ can be expressed as an identity,

$$ N_g = \frac{N_e}{N_{e}/N_{He}} n_e, $$

where $N_{e}/N_{He}$ is the fractional ion abundance (which we define as $X(T_e)$) in ionization equilibrium at the electron temperature $T_e$, $N_{He}/N_e$ is approximately 0.8, and $N_{e}/N_{He}$ is the relative elemental abundance that we define as $A_{He}$. The value of $A_{He}$ can vary by as much as an order of magnitude between flares (McKenzie & Feldman 1992). As a result we have used the following average values: for S we adopt the value $A_{S} = 2.1 \times 10^{-5}$, which is 1.3 times the photospheric value, for Ca we adopt the value $A_{Ca} = 6.9 \times 10^{-6}$, which is 3.0 times the photospheric value, and for Fe we adopt the value $A_{Fe} = 6.47 \times 10^{-5}$, which is 2.0 times the photospheric value (Feldman 1992).

According to Seaton (1964) $C_{12}$ can be expressed as

$$ C_{12} = 8.63 \times 10^{-6} \frac{\Omega_{12} \exp -\left(\frac{\Delta E_{12}}{kT_e}\right)}{T_e^{1/2}}, $$

where $\Omega_{12}$ is the collision strength, $\omega_1$ is the statistical weight of the initial level, and $\Delta E_{12}$ is the transition energy.

Substitution of equations (2) and (3) into equation (1) gives

$$ F = \frac{8.63 \times 10^{-6}}{4\pi R^2} \frac{0.84_{He}}{0.4_{He}} \frac{\Omega_{12} G(T_e)}{\omega_1} \left(n_e^2 \Delta V\right), $$

where $\Delta V$ is the average volume of plasma at temperature $T_e$, and $G(T_e)$ is commonly called the contribution function and is denoted as

$$ G(T_e) = X(T_e) \frac{\exp -\left(\frac{\Delta E_{12}}{kT_e}\right)}{T_e^{1/2}}. $$

Equation (4) relates the emission measure to the temperature, total flux, and other relevant atomic quantities. In practice we derive the temperature and emission measure from an interactive fit of synthetic spectra to actual spectra, using atomic data for collision strengths and dielectronic factors provided by sources such as Bely-Dubau et al. (1982).

Figure 2 illustrates the behavior of $G(T_e)$ as a function of temperature for S xv, Ca xix, and Fe xxv. In the calculations we have used $F(T_e)$ values by Arnaud & Rothenflug (1985). The function $G(T_e)$ for S xv, Ca xix, and Fe xxv reaches maximum values at temperatures of $T_{Max} = 1.4 \times 10^7$ K, $2.5 \times 10^7$ K, and $5.2 \times 10^7$ K, respectively. As seen from Figure 2, once the temperature decreases to a third of its $T_{Max}$ value, $G(T_e)$ decreases by an order of magnitude. At still lower temperatures, $G(T_e)$ rapidly declines to

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very low values. Therefore, it is safe to assume that whenever the He-like spectra, emitted by the highest atomic number ion present in the plasma, indicate a temperature of $0.33 \times T_{\text{Max}}$ or lower, for all practical purposes, this temperature defines the maximum temperature of the bulk of the flaring plasma.

2.2. The GOES 1–8 and 0.5–4 Å Detectors

The GOES 1–8 Å detector consists of an ion chamber filled with 800 mm Hg of argon gas and covered by a 0'002 thick Be window. The GOES 0.5–4 Å detector consists of an ion chamber mostly filled with 180 mm Hg of xenon gas and covered by a 0'02 thick Be window. Figure 3 shows the actual efficiencies of the ion chambers. Garcia (1994a) describes in detail the ion chamber calibration procedures.

The X-ray spectrum to which the 0.5–4 Å detector is sensitive is relatively simple. It consists of a continuum due primarily to free-free and free-bound processes. In addition, it includes line radiation due mostly to H-like, He-like, and nearby satellite transitions emitted by solar abundant elements Ar, Ca, Fe, and, to a lesser extent, Ni. In high-temperature flares, lines from all four elements (Ar, Ca, Fe, and Ni) contribute to the spectra. However, as the temperature decreases contributions from the H-like lines and later the He-like lines of each element will diminish. First the radiation from the higher $z$ elements will decrease and later radiation from the lower $z$ elements will also decline. At $1.5 \times 10^7$ K only relatively few He-like Fe and H-like Ca ions are present in the flare plasma. At temperatures of $8 \times 10^6$ K and below, the only remaining substantial contributors to the line spectra belong to S ions.

The X-ray spectrum to which the 1–8 Å detector is sensitive is much more complex. The main reason for the complexity is due to the nonzero efficiency of the 1–8 Å ion chamber at wavelengths between 8 and 17 Å. The line spectrum between 1 and 8 Å, and specially at wavelengths greater than 8 Å, is much richer than at wavelengths less than 4 Å. In addition to the spectral lines present in the 0.5–4 Å detector range, lines from the H-like, He-like ions of Ne, Mg, and Si are also prominent in the detector's window. In addition, a large number of lines from $2l-3l'$ type transitions of several Fe ionization stages which appear in the 8–17 Å wavelength range also contribute to the line spectra. The contribution of the longer wavelength lines becomes significant at low plasma temperatures.

Garcia (1994a) provides comprehensive tables for calculating electron temperatures and emission measures based on GOES fluxes. The paper also provides comparisons with previous calculations.
3. ELECTRON TEMPERATURE DETERMINATION

Two methods commonly are used for deriving temperatures from soft X-ray plasmas. The first method, as was discussed above, uses intensity ratios of dielectronic recombination satellite lines to the resonance line of a He-like ion. The second method uses broadband flux ratios from detectors such as GOES detectors.

The practical use of each method requires the following: (i) a good understanding of the atomic physics of the spectral lines and continuum emission involved, (ii) a knowledge of the plasma state ionization conditions, and (iii) the efficiency of the detectors as functions of wavelength. In addition, the second method requires knowledge of the relative elemental abundances of the ions contributing to the spectra. The first method depends only on a few nearby lines from two consecutive most abundant degrees of ionization from the same element. The second method depends on emission from several ions emitted by many elements over a wide spectral range. Therefore, we consider the temperatures obtained by the first method to be more representative of the highest temperature portion of the flare plasma, recognizing that the flare plasma is nonisothermal.

The exact ionization conditions in flaring plasmas are difficult to determine. Therefore, we assume steady state ionization equilibrium conditions in the temperature determination. The BCS temperature determined from the highest atomic number spectra recorded represents the maximum temperature of the bulk of the hot plasma. The broadband temperatures from GOES can be considered mostly as an average temperature of all of the plasma involved in the flare process.

We have determined plasma temperatures by comparing spectra from the He-like Fe xxv, Ca xix, and S xv channels with theoretical spectra. Figures 4a and 4b show the appearances of the theoretical spectra (left panel) and the matching BCS spectra (right panel) in the Fe xxv and S xv channel ranges, respectively, at temperatures of \( \sim 0.5T_{\text{Max}} \), \( \sim 0.33T_{\text{Max}} \) and \( \sim 0.25T_{\text{Max}} \).

Thomas, Starr, & Crannell (1985), and Garcia (1994a) have developed methods for determining electron temperatures from flux ratios of the GOES 0.5–4 Å and 1–8 Å channels. They refer to the broadband detector temperature as an effective color temperature. Thomas et al. (1985) give analytical expressions for the color temperature as a function of the \((0.5–4.0\,\text{Å})/(1–8\,\text{Å})\) flux ratio. Garcia (1994a) presents a table of numbers for temperature as a function of the \((1–8\,\text{Å})/(0.5–4\,\text{Å})\) GOES ratios of ion chamber electric currents.

In our work we use temperature determined from BCS to calculate emission measures from GOES data. Figure 5 is a plot of the electron temperature determined from the dielectronic recombination to He-like line ratios versus the \((0.5–4\,\text{Å})/(1–8\,\text{Å})\) GOES flux ratios. The solid and dashed curves represent the color temperature that the Thomas et al. (1985) and Garcia (1994a) methods give for the same ratios. As seen, at relatively high temperatures \(T_e > 1.2 \times 10^7\,\text{K}\) the Thomas et al. (1985) ratios are a factor of \(\sim 1.4\) times lower than our values for the same flux ratios. The agreement between our values and the Garcia (1994a)
values for the relatively hot flares is somewhat better. At lower temperatures ($T_e < 1.0 \times 10^{7}$ K) the agreement between the BCS and the GOES observations is quite good.

4. ELECTRON TEMPERATURE DURING FLARE MAXIMUM VERSUS X-RAY CLASS

4.1. X-Ray Class as Measured by the 1–8 Å Detector

The X-ray class as determined by the 1–8 Å GOES detectors is a measure commonly used to define the importance of a flare. Figure 6 gives the distribution of X-ray class versus BCS temperature for all of the flares in our sample. The distribution includes flares spanning four orders of magnitude in X-ray class from A2 to X2. Flares marked by filled circles have X-ray magnitudes of M2 or larger and are also from Feldman et al. (1995b). As mentioned, during peak emission such flares often saturate the BCS detectors. Flares marked with plus signs are from the study by Feldman et al. (1995b), those marked by asterisks are from the study by Garcia (1994a).
the Phillips & Feldman (1995) work and those by an “x” from the Feldman et al. (1995a) analysis. Flares marked by open circles were analyzed during the present study.

The temperatures and the times of flare maximum were determined for each event as follows. In their study, Feldman et al. (1995b) used spectra and intensities in the Fe xxv channel. Temperatures were determined at the time of peak Fe xxv emission. Since the BCS spectra of X-ray class M2 flares during maximum are saturated, temperatures are determined from spectra recorded at earlier times. Thus the temperatures assigned to M2 and brighter flares are only lower limits. Spectra from the Ca xix channel were used to determine time of maximum emission and temperature for $8.5 \times 10^6$ K and hotter flares in the Phillips & Feldman (1995) study. Spectra in the S xv channel were used to determine the time of maximum emission and temperature for all other flares.

The most striking characteristic of Figure 6 is the almost linear relationship between X-ray class, or more precisely the log (flux) measured by the 1–8 Å GOES detector, and BCS electron temperature. (The associations between X-ray classes and fluxes are as follows: A1 $\Rightarrow 1 \times 10^{-8}$ W m$^{-2}$, B1 $\Rightarrow 1 \times 10^{-7}$ W m$^{-2}$, C1 $\Rightarrow 1 \times 10^{-6}$ W m$^{-2}$, M1 $\Rightarrow 1 \times 10^{-5}$ W m$^{-2}$, X1 $\Rightarrow 1 \times 10^{-4}$ W m$^{-2}$, X10 $\Rightarrow 1 \times 10^{-3}$ W m$^{-2}$).

The average relationship between flux and temperature can be approximated as

$$F(T_e) = 3.5 \times 10^{0.185 T_e - 9.0},$$

where $F(T_e)$ is the flux measured by the 1–8 Å GOES detector in units of Watts m$^{-2}$ and the temperature is in units of $10^6$ K. Garcia (1994b) also found that this linear relationship extends to greater than X10 flux intensities for temperatures derived directly from the two-channel GOES measurements. This relationship is expressed in the inverse form

$$T_{neu} = 52.4 + 8.2 \log (x),$$

where $T_{neu}$ is the temperature for normal flares (not associated with interplanetary photons) and $x$ is the GOES X-ray flux.

The $F(T_e)$ versus $T_e$ curve of Figure 6 is limited by X-ray classes of X2 and A2. We do know that several times in each solar cycle giant flares occur. The X-ray class of these very bright flares is $\sim$ X20, an order of magnitude larger than the flux of the X2 flares. The temperatures of the brightest flares are known to approach and at times to exceed $T_e = 3.0 \times 10^7$ K. The highest X-ray class flare recorded in cycle 21 was X18 (Garcia & McIntosh 1994). At present, GOES detectors are not sensitive to fluxes from X-ray class flares below the A1 level.

4.2. An Alternative Definition of X-Ray Classes Based on the GOES 0.5–4 Å Detector Fluxes

As described in § 4.1, the fluxes in the 1–8 Å GOES detector have been traditionally used to define the X-ray class. In this section we describe the distribution of the X-ray class versus temperature for the Yohkoh flares, according to their fluxes in the 0.5–4 Å GOES detector. The study includes flares with X-ray classes of B5 and brighter. Since only a small fraction of B4 and fainter flares produce measurable fluxes in the 0.5–4 Å GOES detector, faint flares are not fully represented in the distribution. Figure 7 is a display of the X-ray classes according to the 0.5–4 Å flux versus the BCS electron temperature. The ordinate in Figure 7 represents the flux measured by the 0.5–4 Å GOES detector. By analogy to Figure 6 we have made the following assignments: B1 $\Rightarrow 1 \times 10^{-8}$ W m$^{-2}$, C1 $\Rightarrow 1 \times 10^{-7}$ W m$^{-2}$, M1 $\Rightarrow 1 \times 10^{-6}$ W m$^{-2}$, and X1 $\Rightarrow 1 \times 10^{-5}$ W m$^{-2}$. The average relationship between flux and temperature can be approximated as

$$\Psi(T_e) = 1.1 \times 10^{0.263 T_e - 10},$$

where $\Psi(T_e)$ is the flux measured by the 0.5–4 Å GOES detector in units of W m$^{-2}$ and the temperature is in units of $10^6$ K.

5. EMBISSION MEASURE VERSUS ELECTRON TEMPERATURE

Figures 8, 9, and 10 give the emission measures versus BCS temperatures obtained from fluxes in the 1–8 Å and 0.5–4 Å GOES detectors and from the BCS He-like resonance lines. The symbols used in the figures are the same as those used in Figure 6. As seen from Figures 8, 9, and 10, the slopes of the lines representing the functional dependencies of the log (emission measure) versus electron temperature
distributions are somewhat smaller than the slopes representing the log (flux) versus temperature distributions. Emission measures vary slightly more than three orders of magnitude as the BCS electron temperature varies from $4.0 \times 10^6$ to $2.5 \times 10^7$ K.

The increase in spread for data points having temperatures lower than $1.0 \times 10^7$ K may be due to background effects of radiation from active regions, i.e., the BCS is uncollimated and observes the entire Sun. In the case of GOES, the low-temperature X-ray measurements are also affected by the background created by the ambient energetic electron population.

An estimate of the average emission measure EM($T_e$) as a function of temperature $T_e$ can be obtained from the expression

$$EM(T_e) = 1.7 \times 10^{0.13T_e+46.0},$$

where EM($T_e$) is given in units of cm$^{-3}$ and $T_e$ in units of $10^6$ K. It should be noted that the expression for the EM($T_e$) is an average from all three plots (1–8 Å, 0.5–4 Å, and BCS). Also the 0.5–4 Å EM($T_e$) has the shape of a broken power law.

Figures 11, 12, and 13 show emission measure ratios of GOES (1–8 Å)/BCS versus electron temperature, of GOES (0.5–4 Å)/BCS versus electron temperature, and of GOES (1–8 Å)/GOES (0.5 Å) versus electron temperature, respectively. On the average the emission measures derived from the GOES detectors are a factor of 2–3 times larger than the emission measures derived from BCS. The agreement between emission measures derived by the two GOES detectors is somewhat better. They are essentially identical when computed from GOES X-ray derived temperatures. The discrepancy in the emission measure values is due most likely to the nonisothermal nature of the plasma at or near flare maximum and the different temperature sensitivities of BCS and GOES. Variations in elemental abundances and failure to accurately subtract the active region contributions may also add to the discrepancies. It is important to note that if the GOES temperatures according to Thomas et al. (1985) or García (1994a) were used in calculating emission measures, the discrepancy between the BCS and GOES emission measures would be even larger for the hotter flares. García (1994a) found EMs $\sim 2.2$ to 2.7 times larger than the Hinotori results using temperatures derived directly from the GOES X-rays using Raymond and Mewe spectra, respectively.
of S xv, Ca xix, and Fe xxv are linearly proportional to the electron temperature.

4. For the very faint X-ray class A flares the emission measure can be as small as $1 \times 10^{46}$ cm$^{-3}$ while for the bright X-ray class X2 flares it can approach $1 \times 10^{50}$ cm$^{-3}$. (For the very bright X20 flares the emission measure can approach $1 \times 10^{53}$ cm$^{-3}$.)

5. As the X-ray fluxes measured by the GOES detectors vary by four orders of magnitude, between X-ray class A2 and X2, the electron temperatures during peak emission change by a factor of 6 between $4 \times 10^6$ and $2.5 \times 10^7$ K. (If the very large flares in the X-ray class X2–X20 are included this conclusion would be modified, i.e., as the X-ray fluxes measured by the GOES detectors vary by five orders of magnitude, between X-ray class A2 and X20, the electron temperatures during peak emission change by a factor of 7 between $4 \times 10^6$ and $3.0 \times 10^7$ K. Garcia & McIntosh 1992 found temperatures of up to $5.0 \times 10^7$ for soft X-ray flares during solar cycles 21 and 22.)

6. In our sample of approximately 868 flares we did not find any bright flares (X-ray class M1 or larger) that had temperatures lower than $T_e < 1.5 \times 10^7$ K during peak emission. We also did not find in our sample of faint flares (X-ray class A9 or lower) any that had temperatures higher than $T_e > 1 \times 10^7$ K during peak emission.

Very bright flares are known to occur in stars (e.g., Stern, Underwood, & Antiochos 1983). Estimates for some stellar flare emission measures run as high as $1 \times 10^{53} - 1 \times 10^{54}$ cm$^{-3}$. If the temperature versus emission measure relationship found for solar flares and expressed in equation (9) applies also to stellar flares, the electron temperatures of the hottest plasma regions of these flares may be as high as $5 \times 10^7$ K.

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