WHERE IS THE CHROMOSPHERIC RESPONSE TO CONDUCTIVE ENERGY INPUT FROM A HOT PRE-FLARE CORONAL LOOP?

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ABSTRACT

Before the onset of a flare is observed in hard X-rays, there is often a prolonged pre-flare or pre-heating phase with no detectable hard X-ray emission but pronounced soft X-ray emission, which suggests that energy is already being released and deposited into the corona and chromosphere at this stage. This work analyzes the temporal evolution of coronal source heating and the chromospheric response during this pre-heating phase to investigate the origin and nature of early energy release and transport during a solar flare. Simultaneous X-ray, EUV, and microwave observations of a well-observed flare with a prolonged pre-heating phase are analyzed to study the time evolution of the thermal emission and to determine the onset of particle acceleration. During the 20 minute duration of the pre-heating phase we find no hint of accelerated electrons in either hard X-rays or microwave emission. However, the total energy budget during the pre-heating phase suggests that energy must be supplied to the flaring loop to sustain the observed temperature and emission measure. Under the assumption of this energy being transported toward the chromosphere via thermal conduction, significant energy deposition at the chromosphere is expected. However, no detectable increase of the emission in the AIA wavelength channels sensitive to chromospheric temperatures is observed. The observations suggest energy release and deposition in the flaring loop before the onset of particle acceleration, yet a model in which energy is conducted to the chromosphere and subsequent heating of the chromosphere is not supported by the observations.

Key words: acceleration of particles – Sun: flares – Sun: radio radiation – Sun: UV radiation – Sun: X-rays, gamma rays

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1. INTRODUCTION

In the commonly accepted flare model, acceleration of particles (electrons and protons) takes place in the corona, near or above the top of magnetic loops. Beams of fast electrons precipitate downward along the loop and their energy is deposited in the chromosphere, where hard X-ray (HXR) bremsstrahlung is produced, visible as chromospheric footpoints. The energy deposition in the chromosphere leads to heating and expansion of the chromospheric plasma into the loop, called chromospheric evaporation. The hot plasma becomes visible as soft X-ray (SXR) coronal sources and EUV loops. In such a scenario, one would expect a close association of the HXR light curves and the SXR light curve, as first suggested by Neupert (1968) and indeed observed in a large percentage of flares (e.g., Dennis & Zarro 1993; McTiernan et al. 1999; Veronig et al. 2005). However, some flares exhibit a prolonged phase of pre-impulsive activity during which the SXR flux increases steadily with time but with no observed HXR emission (Acton et al. 1992). Battaglia et al. (2009) analyzed in detail a number of such pre-heating events observed with RHESSI (Lin et al. 2002). They see an increase in emission measure during the pre-heating phase which they attribute to an increase of the coronal loop density due to chromospheric evaporation caused by conductive heating of the chromosphere. Recently, Altintsep et al. (2012) re-analyzed two of these events, including radio observations. They find that an indication of a non-thermal electron population before an increase in HXR emission is observed, showing that acceleration might start before RHESSI is sensitive enough to see the associated HXR emission. However, the energy in these particles is not enough to explain the pre-heating. The authors further attribute the increase in emission measure to an increase of emitting volume, arguing that chromospheric evaporation is not necessary to explain the observations. However, regardless of this, a connection between the coronal source and the chromosphere has to be expected. Energy transported to the chromosphere, whether through conduction or particle beams or any other means, will change the chromospheric environment. This may not be observable in either X-rays or microwaves, but most likely in EUV. Recently, Fletcher et al. (2013) analyzed flaring ribbons before the onset of the impulsive phase where they clearly see emission in all wavelength channels of SDO/AIA (Lemen et al. 2012) and even suggest that the majority of GOES and RHESSI thermal emission in this early phase is of chromospheric origin.

Here we present multi-wavelength observations of a flare with a prolonged (≈20 minutes) pre-heating phase. RHESSI images and spectra are combined with SDO/AIA observations, as well as data from the Nobeyama Radioheliograph (NoRH; Nakajima et al. 1994) and Nobeyama Radio Polarimeter (NoRP; Nakajima et al. 1985) to investigate the temporal evolution of the hot loop and the response of the chromosphere during the pre-heating phase. Hard X-ray and radio data suggest that there were no significant non-thermal particles present during the first 20 minutes of the flare. However, the emission measure increases continuously during this phase, indicating continuous heating of the coronal source. Assuming Spitzer conductivity, the total energy flux toward the chromosphere is calculated. In this scenario, a large amount of energy is expected to be deposited at the chromosphere, yet we observe no significant increase in emission at 304 Å, 1600 Å, or 1700 Å or in any of the other AIA EUV channels. This is in contradiction to our expectations.
and lacks an immediate explanation. In Section 2, we describe data analysis in the different wavelengths. In Section 3, the time evolution of the total flare energetics is presented. The results are discussed in Section 4. Conclusions are drawn in Sections 4 and 5.

2. DATA ANALYSIS

The flare (SOL2011-08-09T03:52) occurred on 2011 August 9 with the first hard X-ray HXR peak at 03:25 UT. The soft X-ray SXR flux started to increase at around 03:00 UT, 25 minutes before the HXR peak. Note that the flare peak in the GOES light curve was observed only 25 minutes afterward (at around 03:25 UT), but RHESSI went into the night at 03:35 UT. Thus, the whole time interval analyzed here can be viewed as pre-flaring activity and the main HXR peak was probably missed by RHESSI. Equally there was a short SXR burst at an earlier time (around 02:40 UT). Since the SXR flux returned to its near background level before 03:00 UT and RHESSI images suggest that the location of this earlier peak was displaced by \(\sim 10\) arcsec, we chose the start time of the time-interval of interest as 03:00 UT, when RHESSI imaging became possible. We divide the flare into three distinct phases according to the evolution of the X-ray light curves. (1) Pre-heating (until \(\sim 03:20\) UT). No noticeable HXR or microwave emission is observed during this phase, but the SXR emission gradually increases. (2) Onset of particle acceleration. The SXR flux increases by one order of magnitude and a tail toward higher X-ray energies becomes gradually visible in the spectrum (from \(\sim 03:20–03:24\) UT). (3) HXR peak with peak time at around 03:25 UT. During this phase, HXR emission is observed up to 40 keV. In this work we focus on phase 1 and the transition to phase 2. Figure 1 (top) shows RHESSI light curves at 6–12 keV and 25–40 keV, GOES light curve, and the flare integrated Nobeyama 17 GHz and 34 GHz light curves, illustrating the three phases.

2.1. X-Ray Analysis

RHESSI spectra were fitted using OSPEX starting from 03:00 UT over time intervals of \(\sim 30\) s. The spectrum was fitted with a single thermal component giving the temperature and emission measure up until 03:22 UT, when a tail to higher energies started to appear. This tail was fitted with a soft (photon spectral index \(\gamma \geq 6.5\)) non-thermal power-law component. Note that at this time the live-time of the RHESSI detectors was \(\sim 90\%\) and it is possible that up to 50% of the high energy flux consisted of pile-up counts (Smith et al. 2002). Indeed, fitting a pile-up component as provided by OSPEX leads to a smaller non-thermal flux by one order of magnitude and to a steeper spectral index of \(\gamma = 7.1\). Thus, the fitted non-thermal component has to be viewed as an upper limit during this phase. Figure 2 shows the RHESSI spectrum near the start of the pre-heating (phase 1), the first appearance of the high-energy tail (phase 2), and the HXR peak (phase 3). In addition to the RHESSI thermal parameters, the background-subtracted GOES emission measure and temperature were determined using the GOES utilities in SolarSoftWare (SSW). However, the GOES emission measure could only be determined reliably after 03:20 UT, possibly due to the limited sensitivity of GOES and low counts prior to this time.

RHESSI imaging was possible starting from 03:00 UT. CLEAN images show the presence of a single X-ray source at all times and energies, i.e., the 6–12 keV source is co-spatial with the 25–50 keV source and no HXR footpoints are observed.
Figure 2. Top: RHESSI spectra at three different times, corresponding to the three flare phases. The dashed lines give the background at the corresponding time. The thermal fit model only is indicated to better illustrate the appearance of a “tail” above the thermal emission toward higher energies later in the flare. The fitted temperature and emission measures at the three times were 10 MK/1.7 × 10^{46} cm^{-3}, 15.9 MK/6.8 × 10^{46} cm^{-3}, and 20 MK/4.7 × 10^{47} cm^{-3}. The spectrum at 03:02:28 UT was dominated by non-solar emission at energies larger than ~15 keV (compare Figure 1) and is not shown.

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

Figure 3. AIA images in four wavelength channels at three different times corresponding to phases 1-3. 30, 50, and 70% contours from RHESSI MEM_NJIT 6–12 keV images taken over ≈one-minute intervals around the time of the AIA image are overlaid.

(A color version of this figure is available in the online journal.)
the southern footpoint appears during phase 2 (see Figures 3 and 4). Background-subtracted light curves from each region are presented in Figure 1 for comparison with the RHESSI light curves where the background time was taken at 02:30 UT. Beyond light curves, AIA data is also used for differential emission measure (DEM) analysis to investigate the temporal evolution of the emission measure and, ultimately, the density of the loop using an independent method from the RHESSI analysis. Here we use the regularization method developed by Hannah & Kontar (2012). The DEM was calculated for the two regions of interest. Representative examples for the three phases are shown in Figure 4. The DEM shows two peaks in temperature, one at around 2 MK and one at around 10.2 MK.

2.3. Microwave Analysis

RHESSI is a high background instrument and non-thermal HXR emission has to reach quite high intensity for RHESSI to be observed. It has thus been argued (e.g., Altyntsev et al. 2012)
that particle acceleration may start much earlier, but the HXR emission is too faint to be observed by RHESSI. Microwave observations give an independent measurement of non-thermal particles and thus help constrain the onset of particle acceleration. Radio observations from Nobeyama at 17 GHz and 34 GHz were available during the whole duration of the flare presented here. Figure 1 shows the light curve at 17 GHz. Comparison between RHESSI 25–40 keV light curves and Nobeyama 17 GHz light curves suggests a temporal correlation between the two emissions with the rise of the radio emission being simultaneous with the rise of the HXR emission. There was no significant increase of microwave emission before phase 3, suggesting that particle acceleration was indeed minimal during the pre-flare phase. This is supported by an in-depth analysis of NoRP spectra. We derived pre-flare average flux densities and their $1\sigma$ variations within the time interval 02:40 UT to 02:55 UT. None of the NoRP frequency channels show any sustained increase above their $1\sigma$ levels during phase 1. Over the same period, images at 17 and 34 GHz reveal stable emissions from the active region. Taking the maximum brightness temperatures $T_b$ of each frame, we found the average $T_b$ during phase 1 to be $2 \pm 0.1 \times 10^7$ K and $2 \pm 0.3 \times 10^7$ K at 17 and 34 GHz, respectively. Such values can be reasonably explained by optically thin free-free emission from a thermal plasma at 2 MK (or even hotter), with a density of $\approx 1.2 \times 10^{10}$ cm$^{-3}$, in agreement with our SXR and EUV analysis. The spectral index $\log(T_b(17\text{ GHz})/T_b(34\text{ GHz})) / \log(17/34) = -3.3$ is steeper than the theoretical value of $-2$ expected for an isothermal source, and this can be explained by a contribution of gyroresonant emission at 17 GHz (Dulk 1985).

3. EVOLUTION OF FLARE ENERGETICS AND CHROMOSPHERIC RESPONSE

The RHESSI SXR light curve (fitted temperature $\sim 11$ MK) and the AIA 131 Å loop-light curve (peak in temperature response at $\sim 12$ MK) exhibit a similar pattern during phase 1. The 94 Å loop-light curve (peak in temperature response at
The flare volume is then approximated as the volume can be calculated. The source area used in the further visibility forward fitting gives the FWHM 50% contours in each image were used as an estimate of realistic uncertainties. For CLEAN and MEM_NJIT the visibility forward fitting to get an estimate of the source volume of the flaring loop can be estimated. We combine images made during phase 1, while the emission measure of the footpoint EUV loop in both temperature ranges increases continuously in the 6–12 keV light curve but overall the temperature does not increase significantly. The total AIA emission measure of the flare presented here, a regime is reached where the conductive heat flux is locally limited. This can be accounted for by multiplying the classical conductive flux with a reduction factor $\theta = A \times \exp(-b(\ln R + c)^2)$ with $A = 1.01, b = 0.05, c = 6.63$ and $R = \Lambda_{\text{sat}}/L_\text{th}$ where $\Lambda_{\text{sat}}$ is the electron mean free path and $L_\text{th}$ the temperature scale length (Campbell 1984; Battaglia et al. 2009). The time evolution of the total thermal energy and the conductive losses in classical Spitzer conductivity (Spitzer 1965) are given as

$$L_{\text{cond}} = 10^{-6}T^{7/2} l_\text{loop}^2 [\text{erg s}^{-1} \text{cm}^{-2}],$$

where $l_\text{loop}$ is the length of one loop leg. The total loss through a loop with footpoint area $A$ is then $L_{\text{tot, cond}} = A \times L_{\text{cond}}$ erg s$^{-1}$. However, for sufficiently large temperature gradients, such as occur in solar flares, the heat flux is expected to saturate, where two regimes of flux saturation can be defined (Gray & Kilkenny 1980). Battaglia et al. (2009) showed that for typical flare densities and temperatures, including the conditions in the flare presented here, a regime is reached where the conductive heat flux is locally limited. This can be accounted for by multiplying the classical conductive flux with a reduction factor $\theta = A \times \exp(-b(\ln R + c)^2)$ with $A = 1.01, b = 0.05, c = 6.63$ and $R = \Lambda_{\text{sat}}/L_\text{th}$ where $\Lambda_{\text{sat}}$ is the electron mean free path and $L_\text{th}$ the temperature scale length (Campbell 1984; Battaglia et al. 2009). The time evolution of the total thermal energy and the conductive losses is shown in Figure 6 where we assumed a footpoint area of $A = 3.7 \times 10^{16}$ cm$^2$ (compare Section 3.1) and a loop half-length of $l_\text{loop} = 5.8 \times 10^8$ cm, estimated from AIA 131 Å images. The coronal radiative losses are several orders of magnitude smaller than the conductive losses during pre-flare conditions and can therefore be neglected. The figure suggests that the time integrated conductive flux, even in the case of locally limited conductivity, is larger than the total thermal energy content and that energy of the order of $10^{10}$ erg cm$^{-2}$ is deposited into the chromosphere at each second. We now compare this with an estimate of the energy that is radiated away from the chromosphere. Since the thermal parameters and the DEMs are changing slowly during phase 1 we assume an equilibrium state between input energy and radiated energy and investigate one representative time-interval. The radiated energy from the footpoints per unit volume at a given temperature $T$ can be written as

$$E_R(T) = \Lambda(T) \times \frac{\text{EM}}{V} = \Lambda(T) \times n_e^2 [\text{erg cm}^{-3} \text{s}^{-1}],$$

where $\Lambda(T)$ is the radiative loss function. This is related to the DEM as

$$E_R(T) \frac{dh}{dT} = n_e^2 \frac{dh}{dT} \Lambda(T)$$

$$E_R(T) \frac{dh}{dT} dT = \text{DEM}(T) \Lambda(T) dT,$$
with $\text{DEM}(T) = n^2 dh/dT$. Assuming that all energy that is input by conduction is radiated away, then the radiated energy per unit area $A$ is:

$$\int E_R(T) dh = \int_{T_{\text{min}}}^{T_{\text{max}}} \text{DEM}(T) \Lambda(T) dT = \frac{F_{\text{cond}}}{A}.$$  (6)

Using the observed footpoint DEM at 03:10 UT (compare Figure 4) and the radiative loss function from CHIANTI for coronal abundances at a density of $10^{10}$ cm$^{-3}$, available through SSW, we get a radiated energy per unit area of the order of $6 \times 10^6$ erg cm$^{-2}$ s$^{-1}$, where we integrated over the whole temperature range for which the DEM was calculated ($\log T_{\text{min}} = 5.7$, $\log T_{\text{max}} = 7.5$). The conductive energy input, assuming a symmetrical loop with two footpoints of area $A = 3.7 \times 10^{16}$ cm$^2$, would be $E_{\text{cond}} \sim 3.4 \times 10^9$ erg cm$^{-2}$ s$^{-1}$, or, in the case of classical Spitzer conductivity, $E_{\text{cond}} \sim 8.0 \times 10^9$ erg cm$^{-2}$ s$^{-1}$. Thus, the conductive energy input is expected to be a factor of between 600 and 1400 times larger than what is observed to be radiated away in the EUV between $10^5$ and $10^7$ K. We note that the assumption of conductive flux driving radiative losses from the transition region means that we should narrow our range of temperature integration to that appropriate to the transition region, rather than this whole range which includes coronal temperatures. However, since it is not possible obtain a good transition region DEM from the AIA data, or to determine the exact boundary between transition region and corona from the observations, integration over the whole temperature range was done and the resulting radiative losses have to be viewed as upper limits. Note also that the DEM may contain emission from the foreground corona, particularly at lower temperatures up to $\log T \sim 6.5$ (see Battaglia & Kontar 2012, for an extended discussion). Under this assumption, the radiative losses would be a factor of 2 smaller, leading to an even larger discrepancy with the input energy by conduction.

On the other hand, the conductive losses depend on the loop length. Another method to estimate the loop length is to measure the footpoint separation and assume a semi-circular loop. In the present case, this results in a half-length of $l_{\text{loop}} = 1.45 \times 10^9$ cm, which is a factor of 2.5 more than our initial estimate. Thus the conductive losses could be reduced by about the same factor.

4. DISCUSSION

The total energy calculation in the previous section suggests release of large amounts of energy during the pre-heating phase and subsequent heating of the loop. In a Spitzer model of thermal conduction, one would expect conductive heating of the chromosphere and subsequent evaporation. This would result in increasing emission measure of the coronal loop and, if the loop volume remains constant, increasing density as observed by Battaglia et al. (2009). The flare presented here displays a prolonged pre-heating phase with increasing emission measure at a (constant) temperature of $\sim 10^7$ K. A conductive flux of the order of $5 \times 10^{26}$ erg s$^{-1}$ suggests large energy deposition into the chromosphere but the estimate of the radiated energy based on the observed footpoint differential emission measure suggests that little energy does reaches the chromosphere. This is puzzling and lacks an immediate explanation. Observational uncertainties and the limitations of the available data and methods can only account for factors of 2–3 in both the calculated conductive energy input as well as the radiated energy whereas the observed discrepancy is a factor of at least a few hundred. Possible physical explanations include (1) absorption of the observed EUV wavelengths by low-lying cool structures; (2) the energy is conducted elsewhere in the active region; (3) inhibited conduction by trapping or “bottling up” of the electrons in the loop; (4) narrow, tenuous optically thin radiating part of...
the plasma so that the bulk of the heat is deposited instead into the deeper, denser chromosphere where the energy is radiated at wavelengths we are not observing. In the following, we discuss these four explanations in detail.

The first possibility is absorption by photo-ionization shortward of the Lyman edge at 912 Å, by neutral hydrogen or neutral/once-ionized helium present in low-laying cool structures—typically the dark, cool inclusions in the transition region “moss” (e.g., De Pontieu et al. 2009). In this case the observed footpoint DEM would be reduced and we would be underestimating the radiated energy in Equations (5)–(7). The analysis of De Pontieu et al. (2009) shows that for vertical viewing the absorption of EUV emission results in a decrease of a factor two, with a further reduction, thought to be a geometrical “line of sight” effect varying as the cosine of the source position angle. For the flare under study here, the position angle is roughly 60 degrees, giving an additional factor two of absorption, or a factor four overall. This would reduce the measured DEM by about the same factor and thus the emitted energy would still be two orders of magnitude smaller than the conducted energy. An increased absorption would be possible if the absorbing material were cooler or denser than typical moss; an increase of 5–6 in the optical depth would be sufficient. However, the footpoint densities that we find are consistent with moss plasma elsewhere on the Sun. The temperature can change the balance of absorbers (H/He/He ii/He iii) in the absorbing material, but to investigate this would require modeling that is outside the scope of this paper. We note that even if such absorption were present, one would still expect some increase of emission even from the absorbed lines, which is not seen. Furthermore, absorption of this kind could not explain why there is no significant change in the 1600 Å emission, longward of the 912 Å edge.

The second possibility is that the magnetic connections between the coronal source and the chromosphere are much more diverse than in our simple model with one magnetic loop and two footpoints. Indeed, AIA images suggest that there are multiple, fainter loops present during the whole pre-heating phase. It is therefore feasible that the energy is conducted to many different locations. We investigate this possibility by analyzing the time evolution of the emission at different locations around the main flaring loop in several AIA wavelengths. We define a grid of 25 squares and calculate the time evolution of the total flux within each square. Figure 7 shows AIA images at 304 Å and 1600 Å at ~03:23:53 UT (flare peak) to illustrate where the footpoints appear during the main phase. The time evolution of the total flux within each square is overlaid. In addition, within each square the time evolution of the flux of each pixel is shown. The figure suggests that there are random brightenings in some regions during phase 1 but there is no correlation between any of these brightenings and the RHESSI or GOES light curves, neither for the square-averaged flux, nor the pixel-by-pixel flux evolution. Thus, while some energy could be conducted to “elsewhere” near the main flare site, the amount would not be enough to account for the total conducted flux. One could also consider a situation where the bulk of the energy is conducted away to the solar wind on open field-lines. However, the magnetic connectivity of the observed active region does not support such an interpretation. The third possible explanation is the existence of a process inhibiting thermal conduction so that it is significantly less than either the classical Spitzer rate or the locally limited rate described earlier in the paper. One possibility for this, explored by Brown et al. (1979), is the “bottling up” of hot electrons by an ion-sound turbulent front, arising from the ion-sound turbulence generated when a hot electron population streams into a cooler ion population. The turbulence collisionlessly scatters the hot electrons, inhibiting their progress along the field, and reducing the rate of conduction. First of all, we note that the electron and ion populations in the loop can be at different temperature. The electron temperature $T_e \sim 11$ MK and density at this temperature of $n_e \sim 5 \times 10^9$ cm$^{-3}$ mean that the electron-electron collision timescale $\tau_{ee}$ is short, and the electrons form a collisionally relaxed distribution. (Benz 2002, p. 49) gives $\tau_{ee} \sim 0.267 T_e^{-3/2}/(\Lambda n_e)$, where $\Lambda$ is the Coulomb logarithm, $\Lambda = \ln (8 \times 10^8 T_e/n_e)$. In the coronal loop $\Lambda = 20.9$, so $\tau_{ee} \sim 0.1$ s which is short compared to the evolution timescale of the source. The timescale for protons to equilibrate with the electrons is $m_p/m_e$ times longer, or $\sim 170$ s. So if at a given location in the loop there will be an interval of some perhaps 100 s during which the electrons are hotter than the ions, and the condition for generation of the ion-acoustic turbulence is valid. According to Brown et al. (1979), a hot electron population in a loop will produce two narrow ion-acoustic turbulent fronts expanding along the loop at a speed $v_F$ equal to the local ion sound-speed:

$$\nu_F = c_s = \left( \frac{kT_e}{m_p} \right)^{1/2} \tag{7}$$

Giving $v_F \sim 300$ km s$^{-1}$, or $\sim 0.4$ per second. The hot source would therefore expand to fill the estimated loop half-length $l_{loop} = 5.8 \times 10^8$ cm in $\sim 20$ s, much shorter than the duration of the observations. The analytical results of Brown et al. (1979) show that the hot electron confinement time is thus $(m_p/m_e)^{1/2}$ times longer than the free-streaming time of the thermal electrons out of the loop, a result found also in the numerical experiments of Arber & Melnikov (2009). This can be compared to the conduction timescale given by classical Spitzer conductivity (e.g., Aschwanden 2005, p. 700):

$$\tau_{Spitz} = \frac{21}{5} \frac{kL^2}{n_e^2 T_e^{5/2}} \tag{8}$$

evaluating this expression gives the ratio of the inhibited conduction timescale compared to the Spitzer conduction timescale:

$$\frac{\tau_{IA}}{\tau_{Spitz}} = 1.9 \times 10^5 \frac{T_e^2}{n_e L} = 7.9 \tag{9}$$

for the observed parameters of the source. The conductive flux is reduced by the same factor, compared to the classical Spitzer conductive flux. Observationally we require conduction to be limited by a factor $\sim 10^3$ (see Section 3.2) compared to what classical conductivity would predict. We note also that toward the bottom of the loop the ion temperature drops (and the electron-ion temperature ratio increases), which will affect the generation of ion-acoustic turbulence, but this was also studied by Arber & Melnikov (2009), who found only a very weak dependence of confinement time on $T_e/T_i$. Therefore, bottling of the hot source by ion-sound turbulence as proposed by Brown et al. (1979) is insufficient to explain the observations. Another mechanism to confine electrons was proposed by Spicer & Emslie (1988) in the form of an electrostatic trap. However, this only works for non-collisional electrons and is therefore not applicable in our case.

The fourth explanation could be that the bulk of the energy is deposited into the deeper, denser chromosphere and the
Figure 7. AIA images at 304 Å and 1600 Å at ~03:24 UT showing the loop footpoints overlaid with a grid of 25 squares. The time evolution of the total flux within each square is given in black (normalized to the maximum in each square). The color coded lines (see the top right square for the color key) give the pixel-by-pixel flux within each square. The vertical dotted lines give the end times of phases 1 and 2.

(A color version of this figure is available in the online journal.)
radiation emitted at wavelengths not observed by AIA, without there being any significant radiation component in the EUV where we measure the DEM. However, in a conductively heated atmosphere this appears unlikely. How would the bulk of the energy be transported from the corona to this depth, passing through the upper chromospheric and transition region layers without heating those layers and producing detectable emission? For example in the similar situation of the TRACE moss (e.g., Berger et al. 1999; Fletcher & de Pontieu 1999), the overpressure of the hot coronal SXR loops means that the hydrostatic structure places the million-degree plasma in a fairly dense region of the atmosphere (transition region or upper chromosphere densities) where it radiates strongly. The pressure in the moss is 1–2 dynes cm$^{-2}$; the pressure in the coronal loop here, from the measured density and temperature is 7 dynes cm$^{-2}$. Therefore one would expect the million-degree plasma to appear at even deeper, denser locations in this event, and radiate more strongly than does the moss, which is not the case.

5. CONCLUSIONS

We present observations of a pre-flare hot coronal loop seen by RHESSI at 10 MK that does not seem to be energetically (in terms of thermal conduction) connected to the chromosphere. The pre-flare activity as seen in SXR light curves and images and EUV light curves and images lasts for ~20 minutes before the onset of HXR emission. Energy calculations suggest a conductive energy flux of the order of $10^{10}$ erg s$^{-1}$ cm$^{-2}$ deposited into the chromosphere. However, no chromospheric response is observed. The coronal source appears to be thermally isolated from the chromosphere, yet none of the possible explanations (increased absorption, thermal conduction to elsewhere in the active region or the solar wind, trapping or “bottling up” of electrons in the loop, heat deposition to the deep chromosphere with) is applicable for the conditions in the present flare.

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