THE RELATION BETWEEN HARD X-RAY AND TRANSITION-REGION LINE EMISSION IN SOLAR FLARES

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Abstract. Observational evidence suggests that both the hard X-ray and ultraviolet emission from the impulsive phase of flares result from an electron beam. We present the results of model calculations that are consistent with this theory. The impulsive phase is envisioned as occurring in many small magnetically confined loops, each of which maintains an electron beam for only a few seconds. This model successfully matches several observed aspects of the impulsive phase. The corona is heated to less than $2 \times 10^6$ K, maximum enhanced emission occurs in lines formed near $10^5$ K, and there is only slight enhancement between $10^5$ and $2 \times 10^6$ K. The slope of the observed relationship between hard X-ray and O V 1371 Å emission is also matched, but the relative emission is not. The calculations indicate that UV emission lines formed below a temperature of about $10^5$ K will arise predominantly from the chromospheric region heated by the electron beam to transition region temperatures. Emission lines formed at higher temperatures will be produced in the transition region. This should be detectable in density-sensitive line ratios. To account successfully for the impulsive UV emission, the peak temperature in the impulsively heated loops must remain below about $2 \times 10^6$ K. Thus our model implies that the impulsive heating takes place in different loops from the hotter gradual phase emission.

1. Introduction

That there is a physical link between the processes that produce hard X-rays (HXR) and emission from lines formed at transition-region temperatures has become increasingly evident over the past few years. Kane and Donnelly (1971) first showed this effect using observations of HXR and sudden frequency deviations produced by flares in the Earth's ionosphere. They found a relation between the peak energy in HXR and the energy emitted in the 10–1030 Å range. Woodgate et al. (1983) refined this relation using high time resolution observations in HXR between 25 and 100 keV and in the O V emission line at 1371 Å formed at $T \approx 2.5 \times 10^5$ K. They showed for several solar flares that the individual peaks in HXR and O V occurred within $\approx 0.5$ s of each other. Poland et al. (1984) found that the relationship between energy emitted in HXR and in O V was well defined for a given flare but varied from one flare to the next. Observations also suggest that to within 10 arc sec the O V and HXR are emitted from the same location (Poland et al., 1982). Taken together, these results provide strong evidence to support the view that the same energy release leads to HXR and O V line emission, and probably
all transition region and chromospheric emission during the impulsive phase of solar flares. The physical link between HXR and UV emission is usually assumed to be an electron beam that produces HXR by bremsstrahlung and UV emission by collisionally heating chromospheric plasma to near transition region temperatures (see e.g., Emslie et al., 1978).

Several investigations suggest that the impulsive phase consists of many short bursts. Woodgate et al. (1983) showed that there were several small peaks or bursts in both HXR and O\textsc{v} within the overall impulsive phase. Cheng et al. (1981) showed that there were individual bursts in HXR and Si\textsc{iv} and that each burst seemed to originate from a different location on the solar disk. Takakura (1975) studied HXR and microwave bursts during the impulsive phase and found that it was likely that several independent sources were triggered successively during a single flare. This view is also supported on the theoretical grounds that a large current, which would be required if the entire impulsive phase was one event, could not be sustained for the required length of time in a single loop (Spicer and Sudan, 1984).

Observations and model calculations also suggest that the maximum temperature of the gas in the structures responsible for the enhanced UV emission is below $2 \times 10^6$ K during the impulsive phase. Donnelly and Hall (1974) showed that emission from lines formed between approximately $2 \times 10^4$ and $2 \times 10^5$ K was significantly increased during the impulsive phase, emission from lines formed between $2 \times 10^5$ and $2 \times 10^6$ K was slightly increased, and emission from lines formed above $2 \times 10^6$ K was unchanged. This conclusion is supported by Widing (1982) and Widing and Hiei (1984) who also showed that the ‘cool’ impulsive emission was from a location on the solar surface separate from the hot ($T > 2 \times 10^6$ K) gradual phase emission. This view is also supported by computer models by Emslie and Nagai (1983) and Poland et al. (1984), which show that, when high temperatures are achieved during the impulsive phase, thermal conduction becomes important in determining the UV emission. The conduction dominated temperature distributions yield UV emission line intensities as a function of time that do not track the HXR time profile.

Taken together, the observations and computer models provide a picture of the impulsive phase that is quite complex, with multiple bursts at different locations. The observations suggest that the impulsive phase takes place in multiple flux tubes. Each flux tube carries an electron beam only once or at widely separated times relative to the duration of an individual spike in the burst. They also suggest that the flux tubes which produce impulsive phase emission may not be the source of the gradual phase emission.

In this paper, we examine this idea. We assume that the impulsive phase takes place in a collection of flux tubes and investigate the observational consequences of bombarding the chromosphere with an electron beam of short duration which produces HXR and heat. Unlike earlier calculations (e.g., Nagai and Emslie, 1984; MacNeice et al., 1984) which sought to simulate the entire flare event in one loop, we are only attempting to simulate the impulsive phase. Thus we will limit the duration of the electron beam to only a few seconds. The purpose of these calculations is to simulate a single spike in the overall impulsive burst.
2. Model Calculations

2.1. Model Equations

We consider a magnetic half-loop of constant cross-sectional area along the spatial coordinate $z$ measured from the bottom. The plasma in the loop is composed of electrons and ions with total pressure $P$, mass density $\rho$, and fluid velocity $v$. For these calculations, we assume the ions and electrons are at the same temperature $T$ at each location. The equations of mass, momentum, and energy conservation are then

\[
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial z}(\rho v) = 0 ,
\]

(1)

\[
\frac{\partial}{\partial t}(\rho v) + \frac{\partial}{\partial z}(\rho v^2) = \rho g - \frac{\partial P}{\partial z} ,
\]

(2)

and

\[
\frac{\partial E}{\partial t} + \frac{\partial}{\partial z}\left((E + P)v - \kappa \frac{\partial T}{\partial z}\right) = \rho vg - L + S ,
\]

(3)

where

\[
E = \frac{1}{2} \rho v^2 + \frac{P}{\gamma - 1} .
\]

(4)

In these equations, $g$ is the gravitational acceleration along the magnetic field; $\gamma$ is the ratio of specific heats, taken to be $\frac{5}{3}$ in these calculations; $\kappa$ is the thermal conductivity; $L$ is the energy loss rate due to radiation; and $S$ is the heating rate. Expressions for the conductivity are given in Mariska et al. (1982).

The plasma is assumed to be fully ionized hydrogen and helium with an electron number density $N_e$ related to the mass density by the expression

\[
N_e = \frac{\rho Z}{\mu m_p(1 + Z)} .
\]

(5)

Here $Z$ is the mean ionic charge (1.059) and $\mu$ is the mean mass per particle in proton masses $m_p$ (0.5724). The pressure satisfies the equation of state,

\[
P = N k_B T ,
\]

(6)

where $N$ is the particle number density and $k_B$ is Boltzmann’s constant.

The radiation loss rate is given by the expression

\[
L = N_e N_p \Phi(T) ,
\]

(7)
where \( N_p \) is the hydrogen number density and \( \Phi(T) \) is a modified form of the radiative loss function due to Raymond (1979). Above a temperature of \( 10^5 \) K, we use the Raymond rates. Between \( 10^4 \) and \( 10^5 \) K, we follow the suggestion of McClymont and Canfield (1983) and use the expression

\[
\Phi(T) = 0.646 \times 10^{-23} T^3.
\]  

(8)

Between \( 10^4 \) and 9500 K, the radiative losses decrease linearly to zero.

The heating rate is divided into two components. A steady background rate \( S_0 \) represents the amount of energy input required to maintain the initial atmosphere. This heating is added as a uniform volumetric energy deposition. Superimposed on this is the flare heating \( S_b \). For this heating, we assume the source is a non-thermal electron beam of spectral hardness \( \delta = 4 \) injected into a fully ionized target. We use the result of Emslie (1978, 1983) and write the heating as

\[
S_b = \begin{cases} 
1.3 \times 10^{-18} \frac{N_e F}{E_1^2}, & \alpha = 0 \\
2.6 \times 10^{-18} \frac{N_e F}{\alpha^2 E_1^2} \left[ \frac{9}{4} - \frac{3}{4}(3 + \alpha)(1 - \alpha)^{1/3} \right], & \alpha \leq 1 \\
5.9 \times 10^{-18} \frac{N_e F}{\alpha^2 E_1^2}, & \alpha \geq 1,
\end{cases}
\]  

(9)

where

\[
\alpha = \frac{n}{1.3 \times 10^{17} E_1^2}.
\]  

(10)

Here \( F \) is the beam flux in ergs cm\(^{-2}\) s\(^{-1}\), which varies with time; \( E_1 \) is the low energy cutoff for the beam in keV; and \( n \) is the column number density of electrons.

Equations (1)–(3) are solved using the NRL Solar Flux Tube Model. Further details on the model equations and the solution technique are discussed in Mariska et al. (1982).

2.2. Initial Conditions

We consider a magnetic flux tube of length 7000 km bent into a semicircular half-loop. Within this configuration, we construct an initial equilibrium atmospheric model. At the base of the model is a 2000 km thick chromospheric region in hydrostatic equilibrium at a temperature of 9500 K. Above this region are a transition region and corona whose properties are found by solving the static force and energy balance equations subject to the constraint that the temperature gradient go to zero at the top boundary of the loop. This is accomplished by fixing the pressure at the base of the transition region and varying the background energy input until the proper temperature distribution is achieved. To investigate the effect of varying the initial density distribution, two base pressures were chosen for the calculations, 2.55 and 5.10 dynes cm\(^{-2}\). These values are
in the range expected for the preflare state (see e.g., Cheng et al., 1982). The background heating rates required for these two pressures are $1.64 \times 10^{-2} \text{ erg s}^{-1} \text{ cm}^{-3}$ and $3.82 \times 10^{-2} \text{ ergs cm}^{-3} \text{ s}^{-1}$, respectively.

All of the model calculations were performed on a finite difference grid consisting of 200 computational cells of variable resolution. The chromospheric region at the bottom of the loop is represented by 60 cells which increase exponentially in size from 1 km at 2000 km above the base of the model to 166 km at the base. Above this region are 100 cells, each 1 km in size. The transition region begins in the middle of this region. Finally, above this second region are 40 cells which increase in size exponentially from 1 km at the lower boundary of the region to 758 km at the top of the model.

Tests conducted during the SMM Solar Flare Workshop (Kopp, 1984) have shown that severe errors in the results from the type of calculations discussed here can result from an inadequately resolved spatial grid. The errors occur due to steep temperature gradients and appear as spurious velocities. In our calculations the temperature gradients remain relatively mild and the system cools back to its initial state before significant mass motions begin. Thus the grid chosen is adequate for the current calculations.

3. Results

Beginning with the two initial temperature-density models, we have performed a number of simulations of one of the elementary bursts that we believe make up the impulsive phase of a flare. In each of these, the beam energy flux rises and falls exponentially over a 4 s interval following the relation

$$F = \begin{cases} 
F_{\text{max}} \exp \left( \frac{t-2}{0.6} \right) - \exp \left( \frac{-2}{0.6} \right), & 0 \leq t \leq 2 \\
F_{\text{max}} \exp \left( \frac{2-t}{0.6} \right) - \exp \left( \frac{-2}{0.6} \right), & 2 \leq t \leq 4.
\end{cases}$$

(11)

The factor of 0.6 results in a somewhat more gradual rise in the flux early in the burst. For example, at 1 s, the value of $F$ is about 16% of the peak value. If the factor was unity, $F$ would be about 27% of the peak value. The results of the calculations do not depend significantly on the chosen value. For each initial model we have examined variations in the peak beam flux, $F_{\text{max}}$, from $5 \times 10^9$ to $1 \times 10^{11}$ ergs cm$^{-2}$ s$^{-1}$ and variations in the low energy cutoff from 25 keV to 8 keV. We begin by discussing the results of assuming a low energy cutoff of 20 keV and peak beam fluxes of $5 \times 10^{10}$ and $1 \times 10^{11}$ ergs cm$^{-2}$ s$^{-1}$. In the next section we discuss the variation of other parameters that affect the results.

3.1. Temperature and Emission Measure Distributions

Figures 1–4 show the results of the four simulations, which we have labeled cases A–D. Here we plot the temperature distribution in the lower portion of the atmosphere and
the volume emission measure distribution at selected times during the simulation. For clarity, we have separated the plots into pre- and postmaximum sections. The volume emission measures were determined at each time by calculating the product of $N_e^2$ and the volume in each of the finite difference cells used in the calculation. To calculate the volume, we assumed the flux tube had a cross-sectional radius of 300 km. These cell emission measures were then binned over a logarithmic temperature array, with each bin containing the sum of all the volume emission measures from cells within the temperature interval $\Delta \log T = \pm 0.15$ dex around the central temperature of the bin. This results in emission measures that are defined in the same way as the observational quantities, i.e., the value of $\int N_e^2 dV$ over a constant logarithmic temperature width centered on a given temperature (see e.g., Mariska, 1984).

All of the simulations show roughly the same overall behavior during the burst. Some heating occurs in the corona and transition region driving the transition region downward to higher densities. The most obvious heating takes place in a small region of the chromosphere just below the base of the transition region. The temperature in this region is raised by the additional energy deposition to about $10^5$ K in the 2 s rise time of the

Fig. 1. Temperature and emission measure distributions at various times during the flare for case A. The order of the times listed on the left panels corresponds to the ordering in temperature of the peaks in the 1600 km region and the ordering of the emission measure curves between log T of 4.8 and 5.0. For clarity the plots are separated into pre- and postmaximum sections. The initial model parameters are indicated in the upper left panel.
Fig. 2. Same as Figure 1, but for case B.

Fig. 3. Same as Figure 1, but for case C.
burst. During the decay this chromospheric region cools and is nearly back to the preburst state at the end of 4 s. The transition region also moves back out to lower densities. This rapid decay is due to the high radiative cooling rates in the dense relatively cool plasma. For example, at the peak of the flare heating, the radiative cooling time for the temperature enhancement in the chromospheric region is about 0.05 s for cases A and B (Figures 1 and 2). The coronal temperature is also raised by the burst, but decays much less rapidly. Thus, by the end of the burst, the coronal temperature is still quite close to its maximum value. Associated with the temperature rise and decay in the chromospheric material is a substantial increase and decrease in the volume emission measure at temperatures below $1.25 \times 10^5$ K. The increasing depth of the transition region also results in the slightly higher emission measures seen between $10^5$ and $3 \times 10^5$ K.

Comparison of cases A and B (Figures 1 and 2) and cases C and D (Figures 3 and 4) shows the effect of changing the initial model density distribution, but leaving the burst energy the same. In cases A and B, the maximum heating takes place at a column density of about $5 \times 10^{19}$ cm$^{-2}$. For the high density initial model, this location falls closer to the transition region and results in a somewhat narrower shape for the chromospheric temperature enhancement.
Comparison of case A with case C and case B with case D shows the effect of changing the maximum energy flux in the burst. As one would expect, more energy in the burst results in a higher peak temperature for the chromospheric temperature enhancement, and thus a slightly longer decay time for the return to preburst conditions.

3.2. ULTRAVIOLET LINE EMISSION

The temperature and emission measure distributions, while easily obtained from the simulations, are not directly observed during a flare. What is observed are the flux of HXR and the emission in various UV, XUV, and X-ray emission lines. We calculate some of these observables by using the temperature-density distribution at each time in the simulation to calculate level populations and thus emissivities for lines of O\textsc{iii}, O\textsc{iv}, O\textsc{v}, and O\textsc{vi} ions. The level populations are calculated by solving a 10 level O\textsc{v} model ion, a 15 level O\textsc{iv} ion, and a 20 level O\textsc{iii} ion in each computational cell at each time of interest in the simulation. The O\textsc{vi} calculation assumes a simple two-level atom. The actual emissivity is calculated by assuming ionization equilibrium. Details of the sources for the atomic physics data for the ionization equilibrium and level population calculations are contained in Mariska et al. (1982).

<table>
<thead>
<tr>
<th>Ion</th>
<th>$\lambda$ (Å)</th>
<th>Log$T$</th>
<th>Case</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>O\textsc{iii}</td>
<td>1666</td>
<td>4.95</td>
<td>1840</td>
</tr>
<tr>
<td>O\textsc{iv}</td>
<td>1401</td>
<td>5.25</td>
<td>50.0</td>
</tr>
<tr>
<td>O\textsc{v}</td>
<td>1371</td>
<td>5.40</td>
<td>1.73</td>
</tr>
<tr>
<td>O\textsc{vi}</td>
<td>1032</td>
<td>5.45</td>
<td>1.56</td>
</tr>
</tbody>
</table>

Table I lists the maximum enhancements over the initial model values for selected emission lines from the oxygen ions that are abundant in the transition region. The effect of the substantial increase in emission measure at temperatures below $1.25 \times 10^5$ K is evident in the large increases in the O\textsc{iii} and O\textsc{iv} line emission. At the time of peak emission, essentially all of the O\textsc{iii} line emission comes from the heated portion of the chromosphere. For the O\textsc{iv} line emission, between 80 and 90\% of the emission is from the chromosphere. The O\textsc{v} ion is formed at a high enough temperature that less than 5\% of the emission comes from the chromospheric region at the time of peak emission. These differences in the location of the emitting region have diagnostic implications, which we discuss further in the next section. Although the various ions are formed at different locations in the atmosphere, the calculations predict that peak emission for all of them should coincide in time to within about 0.25 s.

Of primary concern here is the relation between the HXR emission from the elementary flare burst and the O\textsc{v} 1371 Å emission. Figure 5 shows the HXR power
produced by the electron beam plotted against the 1371 Å power for each of the four simulations. The HXR power is proportional to the energy deposited by the beam, with the efficiency determined using Equations (1), (3), and (8) in Emslie et al. (1978). For all but one case, there is a close relationship between the HXR emission and the 1371 Å emission. The one exception, case C, is the low density, high peak beam flux simulation where one would expect to see the largest lag between the decrease in HXR emission and the decrease in the UV emission. This close relation has been observed during the impulsive phase for a number of flares (Poland et al., 1984). There are also, however, some observed flares which show a lag.

4. Discussion and Conclusions

The purpose of our calculations has been to investigate the possibility that the observed relation between HXR and UV emissions during the impulsive phase of solar flares can be explained in the context of an electron beam yielding HXR emission and heat, which produces the UV emission. The results, however, can be applied to any process that yields HXR and heat. We have not attempted to match the observations exactly, since this would require a more accurate treatment of the physics than is now possible.
However, our observations do place limits on the possible physical interactions that are consistent with the observations.

The simplifying assumptions made for our calculations limit our ability to match the observations in detail. Chief among these is the representation of the chromospheric region as a constant temperature region with the radiative loss properties discussed in Section 2. The spatial grid is also too coarse to accurately determine the temperature gradient when much higher temperatures are attained. These assumptions are clearly an over simplification of a complex region of the solar atmosphere. We believe, however, that the level of approximation is adequate for determining the approximate relationship between the electron beam and UV emission under the conditions we have used. Clearly, a more sophisticated treatment is required for calculating chromospheric emission in lines such as Hα. The assumption of ionization equilibrium is also subject to some question on the short time scales of these simulations. Poland et al. (1984) found, however, that at the densities found in the Oiv emitting regions of the atmospheric models, the times to reach ionization equilibrium are rapid (less than 0.1 s). Departures from equilibrium may be more important in the coronal regions of the models where the densities are somewhat lower.

Given the above limitations our calculations point out some important restrictions on the nature of impulsive phase heating. The most important observational restriction is that the Oiv emission must be monotonic with respect to the HXR emission and that there generally is not a significant hysteresis as occurred in the case C model shown in Figure 3. In the calculations of Emslie and Nagai (1985), where they examined both a longer energy input and many short inputs in the same loop, it was shown that under those conditions there was not a monotonic relation between energy input and Oiv emission. This result together with the observations by Donnelly and Hall (1974) showing enhancement only below $2 \times 10^6$ K suggests that in the impulsive phase plasma temperatures must remain relatively low ($< 10^7$ K).

The highest temperature achieved during the impulsive phase is a function of the balance between heating, conduction, and radiative cooling, as discussed in Poland et al. (1984). If the heating exceeds both radiative cooling and conduction at a given point the temperature will obviously rise. If this condition exists for more than a few seconds, the temperatures will rise to several million degrees, where radiative cooling does not increase significantly (in the range from $\approx 3 \times 10^5$ to $\approx 2 \times 10^7$ K it actually decreases), causing a ‘reservoir’ of energy to be built up. If this occurs the energy source can be shut off completely (no further HXR emission) and the transition region lines will continue to be enhanced (i.e. there would be a hysteresis in the log HXR vs log Oiv curve). There should also be an enhancement of lines formed above $2 \times 10^6$ K in this condition, since there would be an enhancement of material above normal coronal temperatures. We conclude from this that temperatures significantly above approximately $10^6$ K are not achieved in impulsively heated loops. Since soft X-ray observations show that temperatures greater than $10^6$ K are reached during a flare, this conclusion implies that the impulsive heating takes place in different loops from the hotter gradual phase emission.

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Although we have discussed the heating in terms of a beam, any source producing HXR and heat simultaneously, with low heating above $10^5$ K and a maximum of enhancement near $10^5$ K, would produce the same results. Thus our calculations support the idea that an individual flux tube carries an electron beam for only a short time or at widely separated times. The interval between bursts must be large enough for the loop to relax back to a configuration close to the preflare state. Otherwise the coronal temperature would increase to a value at which hysteresis would begin in the Ov lines.

While the duration of the burst is important for restricting the nature of the impulsive heating phase, the low energy cutoff for the beam is also important. For example, if the case A simulation is run with all parameters the same, except the low energy cutoff changed from 20 keV to 8 keV, then the resulting evolution of the temperature-density structure is significantly altered. The heating takes place higher in the atmosphere and produces a coronal temperature of about $4 \times 10^6$ K, which remains after the burst is over. This of course results in enhancements to all of the emission lines formed in the corona. Emission lines such as those of Ov show an increase of more than a factor of $10^3$ over the initial model and remain enhanced by more than a factor of 10 after the burst has ended at 4 s. These results are contrary to observations.

We have also examined cutoffs of 15 and 25 keV. The 15 keV calculations produce slightly more heating in the corona than the 20 keV cutoff calculations shown in Figures 1–4. In general though the response of the atmosphere and the UV emission are very similar. Only when the cutoff is near 8 keV does the bulk of the heating move close enough to the transition region and corona to produce a large change from the results presented in Figures 1–4. The 25 keV cutoff calculations result in the bulk of the heating taking place slightly lower in the chromosphere, but again do not significantly alter the results presented in Figures 1–4. A change in the spectral hardness of the beam from 4 to 6 also does not result in a significant change in the results presented in Figures 1–4.

The slopes of the observed HXR vs Ov curves compare well with the model slopes. The observations by Poland et al. (1984) showed that the relation between HXR and Ov could be reasonably well described by

$$\log \text{HXR} = c + s \log \text{Ov}.$$  

We have examined their plots and find that $s$ is approximately 6 in the observed curves. For the model calculations presented in Figure 5a, $s$ has a value of 7. Although this does not prove that the beam concept is correct it certainly adds support.

While certain aspects of our calculations support the concept of the impulsive phase consisting of a series of short electron beam bursts occurring in several loops, we have not completely matched the observations. First, we have not matched the relative emissions in HXR and Ov. The observed ratio of Ov/HXR is on the order of 10 to 100 while the calculated ratio is on the order of only 0.1. Thus, for a given power out in HXR, a larger power out in Ov is required. It may be possible to increase the emission by more carefully adjusting the cutoff. The difficulty with that approach however is that hysteresis appears to set in when the enhancement in Ov emission becomes large enough. While we have plotted actual energies in Figure 5, it should be noted that only
the relative values are fixed by the calculations. This is because the actual energies are
determined by our choice of cross sectional radius for the flux tube. Our choice of
300 km may in fact be somewhat smaller than in an actual flare.

It is also possible to reduce the HXR emission for a given total energy input. Our
calculation assumes that all of the energy input is the result of a nonthermal electron
beam. The effects of the beam, however, are treated in a rather simple fashion. For
example, we have not considered the possible heating effects of return currents, which
are not included in our calculations. We also do not consider the possibility that
two-dimensional effects are important or the possible effects of direct nonthermal
excitation of O v. We hope to perform more sophisticated calculations in the near future.

A second aspect that we do not match is the overall time of the burst. Our computed
bursts last over a period of only 4 s while the duration of the impulsive phase is several
minutes. This could be explained by the impulsive phase consisting of several loops (e.g.,
Kouveliotou et al., 1984), where any given loop must cool to almost the preflare state
before it flares again.

Thus, we have not produced a model flare, but we have shown that the impulsive
phase emission, HXR and transition region lines, are not associated with a hot
(> 10^6 K) gas. Even for the flares that do show a hysteresis effect, the temperatures
cannot exceed a few million degrees. Our calculations using an electron beam model also
predict that most of the enhancement will be near or below 10^5 K, in agreement with
observations. While these calculations don't match the observations exactly, they do
suggest that we are consistent with them on some important points. Perhaps a better
initial model in the transition region and chromosphere, a more accurate treatment of
radiation and conduction in this region, and a more sophisticated beam heating model
would yield the observed result. The number of possible parameter variations is large
and their examination is beyond the scope of this paper. The similarities do however
provide some useful predictions for future observations, which will then guide detailed
calculations.

The differences in the relative contribution of the chromosphere and the transition
region to the emission from lines of O iv and O v have some important observational
consequences. Initially, the lines from both ions are formed in the transition region,
where the preburst electron densities are about 5.5 x 10^{10} cm^{-3} and 3.8 x 10^{10} cm^{-3}
for the line forming regions of O iv and O v in case C. At maximum emission, the O iv
lines are predominantly formed in the chromosphere where the electron density is about
2.1 x 10^{12} cm^{-3}, while the O v lines are predominantly formed in the transition region
where the electron density is about 1.9 x 10^{11} cm^{-3}. These changes are reflected in
density-sensitive lines of O iv and O v. The ratio of the 1407 Å line to the 1405 Å line
of O iv changes from 0.73 for the case C initial model to 2.1 at peak emission, indicating
the more than order of magnitude change in the density of the emitting region (see e.g.,
Doschek, 1984). The O v lines that are sensitive to density, however, change by only
a small amount, indicating that the density of the O v emitting region has not increased
to the 10^{12} cm^{-3} range. These changes suggest that observations of density-sensitive
lines formed in the temperature range of the O iii to O v ions may provide significant
information on the nature of the impulsive phase. We anticipate acquiring those observations in the near future.

Our simple model for describing the connection between HXR emission and UV emission during the impulsive phase of solar flares highlights the importance of obtaining detailed observations of these events over a wide temperature range. Only then will it be possible to determine the temperature density structure of the atmosphere with sufficient detail to further constrain the energy deposition mechanism.

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