EVIDENCE OF EXPLOSIVE EVAPORATION IN A MICROFLARE OBSERVED BY HINODE/EIS

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ABSTRACT

We present a detailed study of explosive chromospheric evaporation during a microflare which occurred on 2007 December 7 as observed with the Extreme-ultraviolet Imaging Spectrometer on board Hinode. We find temperature-dependent upflows for lines formed from 1.0 to 2.5 MK and downflows for lines formed from 0.05 to 0.63 MK in the impulsive phase of the flare. Both the line intensity and the nonthermal line width appear enhanced in most of the lines and are temporally correlated with the evaporation velocity. Our results are consistent with the numerical simulations of flare models, which take into account a strong nonthermal electron beam in producing the explosive chromospheric evaporation. The explosive evaporation observed in this microflare implies that the same dynamic processes may exist in events with very different magnitudes.

Key words: line: profiles – Sun: flares – Sun: UV radiation

1. INTRODUCTION

The well-known CHSPK model (Carmichael 1964; Sturrock 1968; Hirayama 1974; Kopp & Pneuman 1976) for two-ribbon flares states that the flares result from magnetic reconnection in the corona, accompanied by acceleration of energetic electrons and the bulk heating of coronal plasma. The nonthermal electrons produced in this process travel along the magnetic field lines toward the cold and dense chromosphere, in which they produce hard X-ray (HXR) emission by bremsstrahlung and heat the chromospheric plasma by Coulomb collisions. In addition, direct thermal conduction from the corona can also contribute to the heating of the chromosphere. The heated chromospheric material then expands upward to the coronal loop and finally forms the hot soft X-ray (SXR) flare loop.

Such a process, which was first described by Neupert (1968), is now known as chromospheric evaporation. The blueshift in extreme-ultraviolet (EUV) and SXR emission lines, evidence of this dynamic phenomenon, was observed by Acton et al. (1982), Antonucci et al. (1982), and Antonucci & Dennis (1983) using the Bent and Bragg Crystal Spectrometer (BCS) on board the Solar Maximum Mission (SMM; Acton et al. 1980), by Mariska et al. (1993), Mariska (1994), Ding et al. (1996), and Doschek & Warren (2005) using BCS on board Yohkoh (Culhane et al. 1991), by Czyrekowska et al. (2001), Brosius & Phillips (2004), and Milligan et al. (2006a, 2006b) using the Coronal Diagnostic Spectrometer (CDS; Harrison et al. 1995) on board the Solar and Heliospheric Observatory (SOHO), and recently by Milligan & Dennis (2009) using the EUV Imaging Spectrometer (EIS; Culhane et al. 2007) on board Hinode. It is accepted that the evaporation is considered gentle when the emission lines formed in the upper chromosphere, the transition region, and the hot corona all appear to be blueshifted. The process is said to be explosive when the lines formed in the upper chromosphere and transition region appear to be redshifted, while lines with higher formation temperatures appear to be blueshifted (Fisher et al. 1985b; Brosius 2003, 2009; Brosius & Phillips 2004; Milligan et al. 2006a, 2006b; Milligan & Dennis 2009; Raftery et al. 2009). The redshifts are thought to correspond to chromospheric condensation caused by the pressure gradient induced by the violent heating of the chromosphere or the transition region by the energetic electrons. Conversion from an explosive to a gentle chromospheric evaporation during flares was reported by Brosius (2009). Fisher et al. (1985a) performed a numerical simulation on the radiative hydrodynamic process of the flare atmosphere by thick-target electron heating. They found that an electron energy flux of $10^{10}$ erg cm$^{-2}$ s$^{-1}$ acts as a threshold, above which the chromospheric evaporation becomes explosive. When the energy flux falls below this threshold, the evaporation is gentle, through which the chromospheric plasma is depleted at a slower rate. This theory was verified by Milligan et al. (2006a, 2006b), who found within the CDS and the Reuven Ramaty High-Energy Solar Spectroscopic Image (RHESSI; Lin et al. 2002) observations of both a gentle chromospheric evaporation, in which the energy flux of the electron beam was below the threshold, as well as an explosive one, in which the energy flux was above the threshold.

Most of the observations mentioned above were focused on energetic events, since the velocity amplitude of the evaporated mass flows is expected to be strongly related to the energy flux of nonthermal electrons. There have been very few studies of chromospheric evaporation in small flares or microflares. Milligan (2008) reported weak blueshifts in the Fe vi line and Brosius & Holman (2009) found a clear case of gentle evaporation in microflares. In addition, Brosius & Holman (2007) reported evidence of explosive evaporation in a small flare-like transient, although it may have been related to a nearby M-class flare. Stoiser et al. (2007, 2008), using RHESSI data, found that the spectra of microflares can be fitted with a thermal component at low energies and a nonthermal power-law component at higher energies. Furthermore, they found that the intensity enhancement at 1600 Å and 171 Å wavebands, observed by the Transition Region And Coronal Explorer (TRACE; Handy et al. 1999), is simultaneous with the peak of the HXR light curve. Qiu et al. (2004) analyzed HXR and microwave emissions from microflares and corroborated the nonthermal character of these emissions. Therefore, these results suggest that the scenario of chromospheric heating predicted by the standard flare model should also apply to microflares.

In this paper, we present evidence of explosive chromospheric evaporation in a microflare with a GOES SXR class of B1.4. This
implies that the electron flux in microflares is not always low but may sometimes be comparable to that in much more energetic events. This also suggests that the same physical process exists in active events with quite different magnitudes. We give a description of the observations of this event in Section 2 and present our data processing method in Section 3. The results are shown in Section 4. We discuss the implication of our results and present a summary in Section 5.

2. OBSERVATIONS

The B1.4 two-ribbon flare occurred at ~4:30 UT on 2007 December 7 in NOAA AR 10977 near the solar disk center. The flare was observed by the Extreme-ultraviolet Imaging Telescope (EIT; Delaboudiniére et al. 1995) on board the SOHO spacecraft and the Solar Optical Telescope (SOT; Tsuneta et al. 2008) on board the Hinode spacecraft. The active region was scanned by EIS on Hinode repeatedly for the entire duration of the flare. The EIS observation of this event started at ~04:30 UT, using a 1′′ slit that rastered with a step of 1′′ and an exposure time of 30 s. The time gap between successive exposures is 2 s. The field of view (FOV) is 5′′ in the scanning direction and 240′′ in the slit direction. Therefore, a high raster cadence of 160 s for EIS was achieved, by sacrificing the spatial FOV. Scanning over the active region was repeated 40 times, covering the whole evolution of the flare. In addition, the same active region was rastered with EIS from 03:27 to 04:19 UT, using the 1′′ slit with a step of 3′′ and an exposure time of 50 s. This observation corresponds to the pre-flare phase. The FOV is 180′′ in the scanning direction and 512′′ in the slit direction.

Unfortunately, there is no observation by RHESSI for this event. Instead, we use the derivative GOES 1–8 Å light curve as a proxy of the HXR light curve, assuming that the Neupert effect (Neupert 1968; Kahler et al. 1970; Hudson 1991) is applicable. The GOES 1–8 Å and 0.5–4 Å light curves and the derivative of the former are plotted in Figure 1 to estimate the impulsive phase of the flare. From this figure, the flare onset is at ~04:30 UT, the impulsive phase is at ~04:35–04:40 UT, and the flare peak is at ~04:40–04:45 UT, followed by the decay phase.

To compare data sets from different wavebands, we first co-align images from different instruments. The EIT 195 Å image is co-aligned with the pre-flare intensity map for the Fe xii λ195.12 line of EIS. We track the EUV bright points seen by both instruments to obtain the offset. The image for the Ca ii H line of SOT is co-aligned with the pre-flare intensity map for the He ii λ256.32 line of EIS. We use the footpoints of the loops to obtain the offset. The line-of-sight (LOS) magnetic field measured by the Michelson Doppler Imager (MDI; Scherrer et al. 1995) on board SOHO is co-aligned with the image for the Ca ii H line of SOT. We then use some small magnetic structures to obtain the offset. In addition, it is known that there exists an offset between the short waveband (SW) CCD, on which the Fe xii λ195.12 line is observed, and the long waveband (LW) CCD, on which the He ii λ256.32 line is observed. The offset value commonly used is 16′′ in the N–S direction and 2′′ in the W–E direction. Finally, data from all different instruments are co-aligned to that for the He ii line of EIS. Note that the difference in the viewing angles from different instruments can be safely ignored. In this paper, we use the coordinates of the EIS He ii line for all of the images from other instruments.

3. DATA PROCESSING

Considering that the 2′′ offset between the two CCDs of EIS in the W–E direction is non-negligible compared to the 5′′ FOV in the scanning direction, we only select the emission lines from the LW CCD for this study, as listed in Table 1. Figure 2 shows the spectrograms observed using EIS for four lines in time sequence. The vertical axis is along the slit direction and the horizontal axis is for the wavelength dispersion. There are intensity enhancements and redshifts in the Mg v and Si viii lines, as well as co-spatial blueshifts in the Fe xiv and Fe xv lines whose formation temperatures are much higher. To increase the signal-to-noise ratio, we bin the pixels in the slit direction between the two horizontal solid lines over which the line profiles do not change much. Furthermore, the binning is also done for every two columns in the scanning direction for the same purpose. The spectra from one binned pixel are then analyzed in detail. Figure 3 shows the EIS He ii line intensity image, the EIT 195 Å image, the SOT Ca ii H image, and the LOS magnetic field measured by SOHO/MDI. The region between the vertical lines indicates the EIS FOV in the scanning direction. The cross in each panel indicates the location of the pixel to be studied in detail. Figure 4 shows the spatial distribution of line intensity, Doppler velocity, and line width for the Fe xii λ195.12 raster before the flare.
Figure 2. Spectra observed by the EIS detector for four emission lines at three different times. The vertical axis is along the slit and the horizontal axis is for the wavelength dispersion. Subpanels (a), (b), and (c) represent spectra at 04:30:13, 04:35:35, and 04:38:16 UT, respectively. We bin the pixels in the slit direction between the two solid lines to increase the signal-to-noise ratio.

Figure 3. EIS intensity map for the He$\text{II}$ $\lambda$256.32 line observed from 03:27 to 04:19 UT prior to the flare occurrence, SOHO/EIT 195 Å image, Hinode/SOT Ca$\text{II}$ H image, and magnetogram from SOHO/MDI. The flare onset was at around 04:30 UT. All the images are co-aligned to the EIS intensity map. The vertical lines indicate the EIS FOV in the scanning direction. The cross in each panel indicates the spatial pixel that is studied in detail.

First, a reliable rest-wavelength measurement is critical to the measurement of the Doppler velocities of the evaporated plasma. It is known that the rest centroid of lines varies because of the EIS detector temperature variation during the Hinode orbit. We set the rest wavelength using the quiescent region in the EIS raster from 01:15 to 03:27 UT and that from 03:27 to 04:19 UT. The average line center over the bottom 50″ in the slit direction is fitted by a sinusoidal function, which varies with time as

$$\varphi = 0.001996 + 0.01742 \sin \left[ \frac{\pi}{2942} (t - 2132) \right],$$

where $\varphi$ (in Å) is the average line center subtracted by the default one, i.e., the line center listed in Table 1, and $t$ (in s) is the time relative to 01:15:13 UT on 2007 December 7. The mean fitting error is 1.1 mÅ, corresponding to $\sim 1.5$ km s$^{-1}$ for the Fe$\text{xii}$
The average line center and the fitting result for this line are shown in Figure 5. For lines not observed during 01:15–04:19 UT, the variation curve of the Fe\textsubscript{xii} \(\lambda\)195.12 line is applied to them, since it is the strongest and cleanest line in EIS observations (L. K. Harra 2010, private communication).

Second, line blending is also important for the measurement of Doppler velocities, as well as the intensity and width of emission lines. For the lines that we select, the He\textsc{ii} \(\lambda\)256.32 line is blended with the Si\textsc{x} \(\lambda\)256.37, Fe\textsc{xiii} \(\lambda\)256.42, and Fe\textsc{xii} \(\lambda\)256.41 lines (Young et al. 2007). We find that the blending is evident in the region with coronal loops; however, the He\textsc{ii} line is the dominant component at loop footpoints and in quiescent regions. Therefore, the He\textsc{ii} line shows a profile that can be fitted by only one component in the region that we study.

Third, for most of the emission lines that we select, adopting a one-component Gaussian function can fit the line profiles very well. However, in some cases, there appears a blue-wing asymmetry in the Fe\textsc{xiv} \(\lambda\)264.79 and Fe\textsc{xv} \(\lambda\)284.16 lines. We then need to apply a two-component Gaussian fit to these lines.

Finally, the function that we use to fit the line profile is

\[
\Psi = A + Bx + a_0 \exp\left[-\frac{(x - a_1)^2}{2a_2^2}\right],
\]

where \(x\) (in Å) is the wavelength, \(a_0\) (in erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) Å\(^{-1}\)) is the peak value of the profile, \(a_1\) (in Å) is the line center,
Figure 6 shows the line profiles from the binned pixels at ∼04:35 UT around the point marked by the cross in Figures 3 and 4. It is clear that all the lines, except for the Fe\textsuperscript{xv} λ284.16 line, show a symmetric Gaussian profile. For the case of the 

\begin{equation}
\Psi = A + B x + \sum_{i=1}^{n} a_{i,0}\exp\left[-\frac{(x - a_{i,1})^2}{2a_{i,2}^2}\right], \tag{3}
\end{equation}

where \(n\) is the number of Gaussian components required.

We perform fits to 10 emission lines for nine rasters covering the rise and decay phases of the flare. The details of the physical parameters deduced from the fits are presented in the following sections.

4. RESULTS

4.1. Temperature-dependent Evaporation Velocity

Figure 6 shows the line profiles from the binned pixels at ∼04:35 UT around the point marked by the cross in Figures 3 and 4. It is clear that all the lines, except for the Fe\textsuperscript{xv} λ284.16 line, show a symmetric Gaussian profile. For the case of the
Fe xv line, we need to use a two-component fit to properly account for the blueshifted component. Several emission lines may exist in the wavelength window of a line, e.g., the Fe x line. In this case, a multi-component Gaussian fit (one component for each line) is applied for the wavelength window. In this case, a multi-component Gaussian fit (one component for each line) is applied for the wavelength window.

From Figure 6, we find that the Si vii line and those formed at lower temperatures show redshifts, while the Fe x and those formed at higher temperatures show blueshifts. The blueshift in the Fe xv \(\lambda 284.16\) line yields an upward velocity of \(\sim 100\) km s\(^{-1}\). The velocities for the 10 lines are plotted as a function of their formation temperature in Figure 7. Note that the Si vii and Mg vii lines are formed at nearly the same temperature; therefore, their Doppler velocities are very close, as expected. A similar behavior is found for the Si x and S x lines. A cubic polynomial and a linear function are used to fit the upward and downward flow velocities, respectively, as a function of their formation temperature. The results show that the lines from He ii to Si vii are redshifted by \(v_{\text{down}} = 33.4 - 22.7 T\) and those from Fe x to Fe xv are blueshifted by \(v_{\text{up}} = 246 - 538 T + 370 T^2 - 83.9 T^3\), where the quantities \(v\) and \(T\) are in units of km s\(^{-1}\) and MK, respectively. The fitting results are shown as dashed lines in Figure 7. Note that adopting a polynomial function of higher orders can fit all the velocity points, both positive and negative. As a test, we find that a quartic polynomial, \(v = 28.9 + 35.8 T - 143 T^2 + 106 T^3 - 25.1 T^4\), can fit all the points well except for that of Fe x; however, doing so only makes sense mathematically and does not illustrate the physical significance.

### 4.2. Temporal Evolution of the Evaporation

Fortunately, the EIS observations for this study cover the initial, the impulsive, and the decay phases of the flare. We thus investigate the temporal variation of the line intensities, Doppler velocities, and line widths for nine emission lines from He ii to Fe xv. Since there are many lines in the window of the Fe x \(\lambda 257.26\) line, it is difficult to measure and fit this line accurately in some cases. Therefore, the Fe x \(\lambda 257.26\) line is not selected for the study of temporal evolution behaviors. However, this line is still included in the study of temperature-dependent velocities, since it is the only line formed at around 1.0 MK. Note that the He ii line is blended with some other lines as discussed in Section 3. However, we find that the line shows a rather symmetric Gaussian profile, implying the dominance of the main component, especially at the loop footpoints. Thus, the He ii line is included in the following investigation.

Figure 8 shows the temporal variation of the line intensities, Doppler velocities, and line widths for the nine emission lines. Note that for the Fe xv line, the parameters for both the blueshifted component and the stationary component are plotted. The intensities of all the emission lines increase significantly in the impulsive phase. This is generally consistent with the scenario predicted by the evaporation model (Fisher et al. 1985a, 1985b, 1985c; Liu et al. 2009), in which the dense chromospheric plasma is heated to temperatures similar to those in the transition region and the corona, resulting in intensity enhancements of emission lines formed at these temperatures. For the Fe xv line, in particular, its two-component feature seems to contradict the theoretical model that predicts no stationary component during the impulsive phase of a flare. However, the emission of the Fe xv line is dominated by the enhanced blueshifted component, while the emission from the stationary component of the Fe xv line only slightly increases during the impulsive phase. Therefore, the blueshifted component is clearly flare-related, while the stationary component observed in the impulsive phase seems to be mostly from a non-flare emission source.

In the decay phase of the flare, the intensity of each line generally decreases but remains above their pre-flare value for almost an hour. The plots of He ii, Si x, S x, Fe xv, and Fe xv line intensities as a function of time reveal later second peaks during \(\sim 04:40-04:50\) UT (see Figure 8, the first and the last four panels in the left column). This later peak in the decay phase could be induced by hotter plasma cooling back down into coronal passband. The similarity between the He ii and the coronal lines may be attributed to the coronal lines blended with the He ii line, as discussed in Section 3.

In particular, the evolution of the Fe xv line is more interesting. The later peak in this line is mainly from the stationary component and much higher than the pre-flare intensity; the blueshifted component contributes \(\sim 23\%\) of the total intensity. Note that the stationary component is not absolutely static, as mentioned above. It has a velocity of about 10–20 km s\(^{-1}\). The plasma being cooled down near the top of coronal loops, which is probably overlapped with the footpoint along the LOS, could contribute to the enhancement of this low-velocity component. A more accurate determination of the source regions of the blueshifted and stationary components is limited by the small FOV of EIS.

Recently, Peter (2010) found that the Fe xv line always exhibits a blue-wing asymmetry in active regions. Therefore, flows that are not related to the flare may partly contribute to the blueshifted component. We should then be cautious about explaining the fitting results especially in the later stage of the flare. However, in the impulsive phase, the intensity of the blueshifted component is significantly enhanced. The fitting results can reasonably reflect the plasma dynamics that is caused by the flare itself.

The widths of most of the lines follow a pattern that is well consistent with that for line intensities, i.e., a significant increase in the impulsive phase and a gradual decrease in the decay phase.
Figure 8. Time variations of the line intensities integrated over wavelength (in erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\)), Doppler velocities (in km s\(^{-1}\)), and line widths (in mÅ) for the nine emission lines. In the first eight rows, we fit the line profiles with a single Gaussian component only. In the last row, we use the two-component fit, where the dashed line is for the blueshifted component and the dot-dashed line is for the stationary component. The time is relative to 04:00 UT.

One may notice that this pattern is not evident for the widths of the Mg \(V\), Mg \(VI\), and Mg \(VII\) lines. Note that the signal-to-noise ratio in these lines is lower than that in other lines, except for the time period in and shortly after the impulsive phase, when the line intensity is the most enhanced. Therefore, the measurement for these lines may be less reliable than that for other lines, as revealed by the larger error bars at some data points for the Mg \(VI\) line. Nevertheless, these uncertainties do not conceal the general scenario, i.e., the significant line broadening in the impulsive phase.
5. DISCUSSIONS AND SUMMARY

We report a case of an explosive chromospheric evaporation during the impulsive phase of a microflare. We calculate in detail the line intensity, the Doppler velocity, and the line width for 10 emission lines formed from 0.05 to 2.5 MK. For 9 out of the 10 lines, we further study the temporal evolution. Our key findings are summarized as follows.

1. We measure Doppler velocities over an area in the flare ribbon. The emission lines formed in the temperature range of 0.05–0.63 MK are redshifted and those in the range of 1.0–2.5 MK are blueshifted, implying a clear case of explosive chromospheric evaporation.

2. The upflows and the downflows show a dependence on temperature, i.e., \( v_{\text{up}} = 246 - 538T + 370T^2 - 83.9T^3 \) and \( v_{\text{down}} = 33.4 - 22.7T \), where the quantities \( v \) and \( T \) are in units of km s\(^{-1}\) and MK, respectively. The transition between upflows and downflows lies in a very narrow temperature range of \(<0.3\) MK.

3. Both a significant line intensity enhancement and a line broadening are found and correlated with the development of the flare. The Fe \( \text{xv} \) \( \lambda\)284.16 line, the hottest line in this observation, shows a blue-wing asymmetry in the impulsive phase. Thus, the line profile comprises a relatively stationary component and a blueshifted component. The latter disappears in the late decay phase.

The most meaningful result is that we find explosive chromospheric evaporation in a microflare, with a division between upflows and downflows at a temperature of \( \sim 0.7–1.0 \) MK. Explosive evaporation has previously been observed in C-class and larger flares and was found to be co-spatial and co-temporal with HXR emissions (Milligan et al. 2006a; Milligan & Dennis 2009). In the event presented here, the upflows shown in hotter lines are definitely co-spatial and co-temporal with the downflows shown in cooler lines, consistent with previous studies. Furthermore, we find that the mass flow velocities are temporally correlated with the derivative \( \text{GOES} 1–8\) A light curve, i.e., the proxy of HXR light curve. The intensities of these lines are significantly enhanced in the impulsive phase and quickly decrease after the flare peak time. Therefore, the evaporation is likely induced by a nonthermal electron beam during the impulsive phase, as predicted by the theoretical electron beam heated model (Fisher et al. 1985a, 1985b, 1985c). Fisher et al. (1985a) found an energy flux of \(10^{30}\) erg cm\(^{-2}\) s\(^{-1}\) as a threshold for the explosive evaporation, which was later verified by observations of Milligan et al. (2006a, 2006b) and Milligan & Dennis (2009). Our observations imply that the energy flux of the electron beam in a microflare may be comparable to that in much bigger events, though the beam should be restricted to a rather smaller area, resulting in a very small integrated flux, as observed in this B-class flare. It is worth mentioning that Hannah et al. (2008) found nonthermal emission in remarkably high energies (>50 keV) in an A-class microflare, showing direct evidence of nonthermal electron beam heating in a microflare. We note that the velocities of the downflows (20–30 km s\(^{-1}\)) and the upflows (100 km s\(^{-1}\)) are somewhat smaller than typical values in more energetic events. This may partly be due to the insufficient spatial resolution of the EIS scanning observations, in which the observed line profiles are indeed a convolution of those in the heated region and those in the nearby quiescent region. Owing to the smaller EIS FOV in this study, we are unable to estimate the exact spatial scale of the evaporation, except that it is \( \sim 10'' \) in the N–S direction. We suspect that the brighter flare ribbon to the west of the EIS FOV (see Figure 3, left panel) may exhibit even more significant evaporation than what we observe in the EIS FOV. By comparison, Milligan (2008) studied a microflare using EIS and \( \text{RHESSI} \) observations. They found only a weak blueshift of 14 km s\(^{-1}\) in the Fe \( \text{xv} \) line in the flare ribbon without any co-spatial HXR emission. Moreover, Brosius & Holman (2009) found a gentle chromospheric evaporation in the impulsive phase of a microflare, which also has no detectable HXR emission. Therefore, our event implies the possible existence of a small-scale strong electron beam in microflares. For comparison, Jess et al. (2008) detected a strong white-light emission, though restricted to a very small area, in a relatively small flare. Note that the white-light emission, like the explosive evaporation scenario, is also thought to be powered by a strong electron beam in the conventional point of view (Hudson 1972).

Imada et al. (2007) reported temperature-dependent velocities in the decay phase of an X-class flare. They found that the upward velocities in lines of below 1.0 MK show a weaker dependence on temperature, and those in lines of higher than 1.0 MK show a stronger dependence on temperature. In our event, however, the cooler lines show downward velocities. In addition, we observe a significant temperature dependence of upflows (downflows) during the impulsive phase rather than in the decay phase. Thus, the situations in these two events are quite different. Our observations are more like that of Milligan & Dennis (2009), who studied a C-class flare and found temperature-dependent velocities in the impulsive phase. However, the transition temperature between upflows and downflows in our event is \( \sim 0.7–1.0 \) MK which is lower than the value obtained by Milligan & Dennis (2009), i.e., \( \sim 1.5–2.0 \) MK. Theoretically, the existence of temperature-dependent velocities was predicted by Fisher et al. (1985c), who considered a single burst of energetic electrons, and by Liu et al. (2009), who adopted a continuous electron deposition in flare dynamic models. We find that the distribution of velocities, as shown in Figure 7, is quite consistent with the simulation results of Liu et al. (2009), see their Figure 10, panel c). Thus, the upward and downward velocities may be interpreted as follows. Energetic electrons deposit energy in the chromosphere, where the local pressure is enhanced to exceed that of the overlying corona. Such a pressure gradient can drive the heated plasma both upward and downward. The short-lived EUV brightenings, which last for about 5 minutes, are due to either a short duration of electron injection or a high radiative cooling rate in the condensed plasma.

We study in detail the temporal evolution of the line intensities and widths for the nine emission lines, as well as their Doppler velocities, using the high spectral resolution EIS observations. The line intensities are significantly enhanced in the impulsive phase of the flare, accompanied by the temperature-dependent velocities as mentioned above. We find a later second peak in the decay phase (\( \sim 04:40–04:50 \) UT) for intensities of coronal lines, in contrast to the intensity decrease observed in the cooler lines. The most likely explanation could be the hotter plasma with temperatures much higher than 2 MK cooling back down into the coronal passband. Unfortunately, the Fe \( \text{xv} \) line is the hottest line in this observation, thus we are unable to implement a direct comparison between the light curves of coronal lines and those of lines formed in much higher temperatures. Note that such an intensity increase in the decay phase can now be checked by the Extreme-ultraviolet Variability Experiment (EVE; Woods et al. 2010) instrument on board the \textit{Solar Dynamics Observatory}. 
We also find a significant line broadening, i.e., the line width increases by ∼60%, in association with the intensity enhancement. By checking carefully the line profiles pixel by pixel, we confirm that the line broadening during the impulsive phase is of physical significance. There are two interpretations of the line broadening. On one hand, they can be interpreted as an enhancement of the nonthermal velocity induced by certain physical processes. For example, Chen et al. (2010) reported an enhancement of the nonthermal velocity induced by certain processes that were only thought to exist only in bigger flares. On the other hand, an insufficient Alfvén wave amplitudes. On the other hand, an insufficient resolution is also a possible cause. If there exist spatially unresolved components in each pixel that are heated differently and exhibit different mass flows, the spatially integrated line profile should be more broadened than the profile in each component. For instance, Doschek et al. (2008) proposed an origin of the line broadening due to the multiplicity of flows. We think that either one or both could work, i.e., the velocity dispersion along the LOS and/or the spatial difference lead to the observed line broadening.

In summary, we report clear evidence of explosive chromospheric evaporation in a B-class microflare. Temperature-dependent upward and downward velocities and line broadenings are observed in the impulsive phase of the flare. This event implies that the evaporated flows could possibly be induced by energetic nonthermal electrons. The evidence, however, is not very solid, since there are no observations from RHESSI for this event. Nevertheless, our findings provide a scenario in which a small flare may be locally “very energetic” and possess physical processes that were only thought to exist only in bigger flares.

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