Studies of Microflares and C5.2 flare of September 27, 1998

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Abstract

On September 27, 1998, Big Bear Solar Observatory (BBSO) and Transition Region and Coronal Explorer (TRACE) coordinated observations from 16:00 to 19:00 UT to study properties of microflares on AR NOAA #8340. Fortuitously, a C5.2 flare occurred at 16:30UT in this active region. Hα and magnetograph movies were obtained at BBSO; CIV 1550Å , FeIX 171Å and FeXII 195Å movies were obtained by TRACE; both with a cadence about 1 minute. In this paper, we concentrate on the study of magnetic properties of 70 CIV microflares, as well as their relationship to the C5.2 flare. We obtained the following results: (1) We found two kinds of microflares: (a) microflares of transient brightenings with a time scale of 1 to 5 minutes (impulsive events). 90% of the microflares are of this form. Most of the events in this category are associated with well defined magnetic neutral lines, although a few of them are not located near a neutral line; and (b) microflares lasting half an hour or longer (persistent events). Seven events in three clusters belong to this category. All three sites are associated with a dominant magnetic polarity plus a very small element of opposite polarity. (2) More than a third of the impulsive microflares occurred near the C5.2 flare site indicating that a local instability is responsible for both the C5.2

flare and microflares. This indirectly support the avalanche theory of flare energy release, which predicts that a big flare may be associated with many small flares. Based on the morphologies of those events, we postulate that the persistent events may be due to loop interaction; while impulsive events may be associated with sheared loop structure.

1. Introduction

It is now widely accepted that magnetic fields play a fundamental role in defining the structure, mass and energy flow in the chromosphere and corona (Withbroe and Noyes, 1977). Nevertheless, we are still some distance from a complete understanding of the detailed mechanisms of energy and mass transport in the Sun. This lack is mainly due to our limited knowledge of various kinds of small scale dynamic structures which are thought to be important in mass and energy transport. As TRACE has been successfully launched, and the ground based observations at BBSO are significantly improved, we now have the unprecedented opportunity to study the small scale solar dynamics with high resolution to get insight into these important problems. Specifically, we are interested in studying transient brightenings in UV and Hα, called microflares. This kind of phenomena is worthy of study in detail because it may represent the small-scale cousins of flares in active regions. Because they are numerous, microflares may be partly responsible for heating and mass transport in the Sun.

Microflares were first named after balloon-borne hard X-ray observations showed tiny, impulsive bursts (Lin et al., 1984). Similar events were first identified in CIV 1548 Å images, taken with the Ultraviolet Spectrometer and Polarimeter on the Solar Maximum Mission (Porter et al., 1984, 1987, and 1995). They are short lived brightenings, and are associated with magnetic bipoles. Hα spectral counterparts of microflares have been identified by Canfield and Metcalf (1987). Even though microflares were first discovered in active regions, their occurrence was also found in the quiet Sun (Porter et al., 1987). Microflares may be also associated with a new phenomena found by SOHO: the transition region transient emissions–blinkers observed by CDS (Tarbell et al., 1997, Harrison, 1997). However, CDS lacks sufficient cadence for proper studies of those transient events–many short-lived events are not detected. Therefore, their birthrates may be under-estimated. Microflares demonstrate some properties of larger flares, like the non-thermal energy spectra shown in hard X-rays (Lin et al., 1984). Microwave radio observations have also provided evidence of the existence of non-thermal electrons in some microflares found in active regions (Gary et al., 1997, Gopalswamy et al. 1998) and the quiet Sun (Gary and Zirin, 1988; Krucker et al., 1997).

Previous space experiments such as SMM and HRTS have examined the relationship of microflares to other features, like X-ray bright points and UV explosive events. As a result, it was found that microflares seen in Hα and UV often correspond to He I dark points. which coincide with X-ray bright points in the corona (Porter et al., 1987, Moses et al., 1994). Therefore, it is expected that strong UV/Hα microflares also appear as transient X-ray bright points. In addition, it has been realized that UV microflares are different from UV explosive events in that microflares have lower velocities, are generally brighter than explosive events, and are associated with strong network regions or active regions (Porter and Dere, 1991; Moses et al., 1994). By contrast, explosive events are found at the edges of network where magnetic fields are relatively weak and of mixed polarity (Porter and Dere, 1991; Chae et al., 1998). A recent paper by Chae et al. (1998) demonstrated that explosive events are associated with magnetic reconnection. Therefore, observations suggest that both kinds of UV events, microflares and explosive events, result from magnetic reconnection. But we do not have an explanation as to how and why they are different from each other. Further, we do not know how important each of these events are in coronal heating. Comprehensive studies of microflares are needed to understand their magnetic origin and their contribution to local/global coronal heating.

On the other hand, the picture of major solar flares is not completely understood either. We know that they occur in magnetic neutral lines, and are probably due to magnetic reconnection. It is possible that a major flare may consist of numerous microflares associated with different loops which are clustered together. Theoretically, it has been proposed that the energy release process of solar flares can be understood as avalanches of many small reconnection events (Lu et al., 1993). Such a model explains the power-law distribution of flare energies quite successfully. So study of the relationship between a major flare and microflares in the same active region may shed light on this hypothesis. The joint BBSO/TRACE observation on September 27, 1998 provides an opportunity for such a study as it obtained comprehensive data of a C5.2 flare and many microflares.

We will first describe the setup of our observations, and then present the results and discussion.

2. Observations and Data Reduction

The BBSO/TRACE observations were jointly planned to run from 16:00UT to 19:00 UT on September 27, 1998. The target was NOAA region 8430. Our original scientific objective is to study active region microflares. However, a C5.2 flare happened to be observed in the same active region.

2.1 TRACE Observations

To increase the cadence of the observations, TRACE used a 512×512 sub-field observing mode, covering a field of view of $256'' \times 256''$ with a pixel size of $0.5''$. The observing sequence covers CIV 1550Å, Continuum 1600 and 1700Å, white light, FeXII 195Å, and FeIX 171Å, the cadence was 90 s for a complete cycle. Our analyses concentrate on one UV line: 1550Å , which has a temperature sensitive range around 100,000K. However, at this wavelength, TRACE uses a broad band filter, so its emission includes substantial amount of continuum leakage. If the temperature and density properties of microflares need to be studies quantitatively, the continuum background needs to be subtracted, by using combined TRACE 1600Å and 1700Å images. We did not remove the continuum background, since our primary purpose is to locate positions of microflares, and derive their association with magnetic fields.

2.2 BBSO VMG Observations

The BBSO Videomagnetograph system and its calibration procedures have been discussed by Varsik (1995). During our observations, we used 256 video frame integration. Stokes Q,U,V and I images were obtained to construct vector magnetograms. However, only V images (measurement of line-of-sight fields) were analyzed. The field of view of magnetograms is $360''$ by $240''$. The magnetic flux density sensitivity is about 2G, and the spatial resolution of the magnetograms is about 3 arcsec. BBSO also obtained Hα filtergrams and spectra, which are not discussed in this paper.

All images at the same wavelength are aligned by cross correlation method; then between different wavelengths from different observatories by network magnetic feature match. We are confident that the accuracy of alignments is within 2 arcsec.

In this paper we concentrate on the study of the magnetic properties of microflares, so TRACE CIV 1550Å and BBSO magnetograph data will be emphasized. In a subsequent paper, multi-wavelength properties of microflares will be explored by combining UV and EUV data from TRACE and Hα data from BBSO. The C5.2 flare itself is being discussed by Qiu et al. (1999).

3. Results

Naturally, our first step is to identify all the CIV 1550Å microflares, from the 3-hour long TRACE movie. The identification is easy since CIV 1550Å observations are very sensitive to small scale brightenings. Figure 1 shows the center position of 70 microflares which were identified. Please note that 62 events are located in magnetic neutral lines; only 8 events (marked by two boxes) occur in unipolar regions. Because this number is not small, to understand the physics of this exception is important. All eight of these events are short-lived impulsive events (will be defined and discussed below). There is no apparent difference between these events and neutral line associated transient events. The properties compared for neutral line and non-neutral line related impulsive microflares include: shape (elongated), lifetime (1 to 5 minutes) , size (5 to 10 arcsec) and peak intensity (4 to 5 times of the background intensity). These non-neutral line events could be due to brightening in the middle section of long loops. We do not have sufficient information in the current study to understand the physics of non-neutral line related microflares. We note that in the first microflare paper by Porter et al. (1984), the authors also found that some microflares occurred away from magnetic neutral lines.

In our study of the temporal evolution of microflares, we found that there are two kinds of microflares: impulsive (short-lived) and persistent (long-lived) events. There are only 7 long-lived events clustered in three sites (marked as “a”, “b” and “c” in Figure 1). We demonstrate the one-hour history of these three sites in Figures 2 and 3. In Figure 2, we marked two long-lived brightening sites “a” and “b”. Event “a” lasted almost the entire hour although there seems to be a certain decrease in intensity at 16:13UT. Event “b” started from roughly 16:46 UT, and peaked before the last frame. It lasted about 30 minutes (the decaying phase of this event is not shown in the figure). In the right column of the figure, we show the evolution of magnetic fields in the same field of view. It is obvious that both “a” and “b” are located at unbalanced neutral lines, i.e., junction between dominant white polarity plus a small chunk of negative polarity. Site “b” corresponds to a canceling magnetic bipole; while site “a” does not show obvious decrease of magnetic flux. Figure 3 shows the third long-lived microflare site. Again, the microflare “c” lasts over 30 minutes; it is located in a unbalanced neutral line; and flux cancellation is observed, and is demonstrated in the right column. In Figure 4, we show examples of several impulsive microflares, which typically last less than 5 minutes. The location of this sub-field is marked as “d” in Figure 1. There is no obvious flux cancellation across the neutral line associated with these impulsive microflares. However, the flux cancellation may be occurring below the sensitivity of the VMG system. The 256 integration and 3 arcsec resolution may prevent us from seeing flux cancellation at a small rate lower than $10^{1}7$ Mx/min. In addition, flux cancellation in unbalanced neutral lines is easier observe, because a substantial portion of the flux of minority polarity disappears during the cancellation process. Other differences between impulsive and persistent microflares are:

(1) Impulsive events are elongated and often show two small ribbons. They may be miniature two ribbon flares; persistent events are rounder, and they may be associated with X-ray bright points. Events in cluster "a" and "b" are associated with some jets observed in FeXII 195Å images, similar to the jets observed by Chae et al. (1999). Bright 195Å jets are shown in Figure 5, during the peak intensity of microflares ("a" at 16:05UT, 16:22UT, and "b" at 16:53 UT). Figures 2 and 5 cover an identical field of view and same period. No 195Å jets were observed to be associated with any impulsive event.

(2) Impulsive events are probably associated with a well defined magnetic neutral line, while the persistent events are associated with one dominant polarity plus a tiny piece of opposite polarity. Magnetic configuration of jets associated with persistent events may be similar to that of X-ray jets discussed by Shibata et al. (1992), while impulsive events may be due to eruption of twisted loops (Priest, 1982), since loop brightenings while rising are often observed.

As discussed in the avalanches model (Lu et al. 1993), a major solar flare may be associated with a number of small flares. One indirect way to test the model is to investigate if the site of a big flare is favorable for microflares. In Figure 6, we overlay locations of microflares on the CIV 1550Å image of the C5.2 flare. Comparing Figures 1 and 6, we found that 25 microflares are associated with neutral lines that are related to the C5.2 flare. The length of neutral lines in this flaring region, is only 15% of the total length of all the neutral lines in this active region; however, 40% of impulsive microflares occurred along these three small neutral line sections. We propose that a magnetic instability in the area of the C5.2 is responsible for both C flare and microflares in the same area. This indirectly supports the avalanche theory: small (micro) flares and bigger flares are related. During a big flare, many sections of neutral lines may erupt, and the energy release of the flare may consist of many small amount energy released in the form of microflares. Another explanation is that frequent small events may trigger a bigger event. In a recent paper by Rovira et al (1999), the authors found that a group of X-ray bright points occurred in less sheared neutral lines and a group of sub-flares occurred in more shared neutral lines in the same active region. So they concluded that smaller and larger events are spatially separated. Our results contradict their results–we found that larger and smaller events are spatially related. Note that results of both papers are based on very limited examples.

4. Discussions

After studing 70 microflares, and a C5.2 flare, we conclude the following:

(1) There are two kinds of microflares: (a) 63 of the microflares are impulsive events with a time scale of a few minutes. Most of them are associated with local magnetic neutral lines, and a cluster of them avoided neutral lines; we could not find a difference between neutral line and non-neutral line related impulsive events; and (b) 7 microflare in three clusters are persistent events with a time scale of about half hour or longer. All three are associated with a dominant polarity plus tiny bit of opposite polarity. Two out of the three clusters are associated with observable magnetic cancellation. For impulsive microflares, they tend to occur in well defined neutral lines.

Are persistent events a superposition of continual impulsive events? The cadence of this TRACE data set is too low to allow us to study the light curves of persistent events with sufficiently high temporal resolution to answer this question. It is remarkable to note that 7 persistent events may release same amount of energy as that of the 67 impulsive events, since the lifetime of impulsive events is an order of magnitude shorter than that of persistent events.

(2) More than 40% of impulsive microflares occurred near the C5.5 flare site, indicating the instability at that site is responsible for both the C5 flare and microflares. This indirectly supports the avalanche model – a larger flare may be causally connected to smaller events in the same unstable region. This is a important subject, further observations need to be made to study more flare samples.

Comparison of microflares at two difference lines (CVI 1550Å and FeXII 195Å) reveal that 195Å jets are associated with over half of the persistent events, and are not associated with any impulsive events. Besides that, such a comparison did not lead to any substantial results. Both persistent and impulsive CVI events may or may not have counterparts in the coronal FeXII images, depending on the intensity of the CIV emissions. This is another topic remained for further study, including comparison with Hα images.

Based on our limited examples, we found evidence that persistent microflares may be due to loop interaction/reconnection such as the jet model proposed by Shibata et al. (1992). Impulsive events may be due to the eruption of sheared flux loops, such as in the classical two ribbon flare model.

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FIGURE CAPTIONS

Fig. 1 Center positions of all 70 microflares observed from 16:00 to 19:00 UT, September 27, 1998, by CIV 1550Å filtergrams of TRACE. The background is a line-of-sight magnetogram observed at 17:00UT by BBSO. "a" "b" and "c" are three sites of persistent microflares demonstrated in Figures 2 and 3; "d" marks the position of the sub-field discussed in Figure 4.

Fig. 2 Time sequence of TRACE 1550Å images showing first two persistent microflare sites, "a" and "b". The right column shows the evolution of magnetic field in the same field of view.

Fig. 3 Time sequence of TRACE 1550Å images showing the third persistent microflare site "c", as the evolution of magnetic fields in this field of view.

Fig. 4 Time sequence of TRACE 1550Å images showing a few impulsive microflares.

Fig. 5 Time sequence of TRACE FeXII 195Å images showing the same two persistent microflare sites, "a" and "b" as in Figure 2. Again the right column shows the evolution of magnetic field in the same field of view. The jets are clearly demonstrated ejecting from the base of microflares at their maximum intensity.

Fig. 6 Comparison of locations of microflares (+) with the location of the C5.2 flare (gray scale image). This figure has an identical field of view as that of Figure 1.