Analysis of Magnetic Shear Change in Solar Flares

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Abstract

An X17 class (GOES soft X-ray) two-ribbon solar flare on 2003 October 28 is analyzed in order to determine the relationship between the timing of the impulsive phase of the flare and the magnetic shear change in the flaring region. EUV observations made by the *Transition Region and Coronal Explorer* (TRACE) show a clear decrease in the shear of the flare footpoints during the flare. The shear change stopped in the middle of the impulsive phase. The observations are interpreted in terms of the splitting of the sheared envelope of the highly sheared core field during the early phase of the flare. The timing information about the impulsive phase is from the hard X-ray (HXR, E>150 keV) light curve observed by the anticoincidence system (ACS) of the spectrometer SPI on board the ESA INTEGRA satellite. Some preliminary results about a statistical study of the shear motion of EUV footpoints in two-ribbon flares are shown on the right panel of this poster.

Introduction

▪ A two-ribbon structure in the chromosphere and transition region (e.g., in H α , UV, and EUV) is often seen during a solar flare, especially for those long-duration events associated with coronal mass ejections (CMEs). For two-ribbon eruptive flares, the generally accepted picture is: the flare energy release is driven by the eruption of a magnetic flux rope from the sheared core of a closed bipolar magnetic field (Moore 1988; Forbes 1992).

▪ Masuda, Kosugi and Hudson (2001) reported observations of the evolution of th e HXR (*Yohkoh*/HXT) footpoints from a strong to weak sheared structure, which was also found in H α (Sartorius Refractor at Kwasan Observatory, Asai et al., 2003), HXR (RHESSI) and microwave (Nobeyama Radioheliograph, Kundu, Schmahl, and Garaimov, 2004).

▪ In this work, we focus on the question: could the change from the impulsive to gradual phase be related to the magnetic shear change? To answer this question, we have selected a particularly well-observed X17 solar flare on 2003 October 28 which shows obvious shear change via the evolution of the EUV footpoints observed by TRACE, and examined the temporal evolution of the shear and the rate of change of the shear.

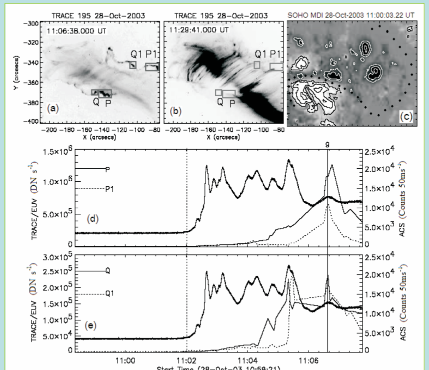

Figure 1 (a) Gray boxes representing EUV brightenings are overlaid on the EUV image closest in time to HXR Peak 9 which is marked as a vertical solid line. (b) Gray boxes representing EUV brightenings are overlaid on a later EUV image of the post-flare loops. (c) SOHO/MDI photospheric magnetogram overlaid with MDI contours where white and black contours refer to negative and positive magnetic filed, respectively. The black dotted line represents the locus of the filament. The field of view is 240''x160''. (d), (e) EUV light curves of the two brightening pairs "P"/"P1" and "Q"/"Q1". ACS/HXR light curve is represented by the thick solid line.

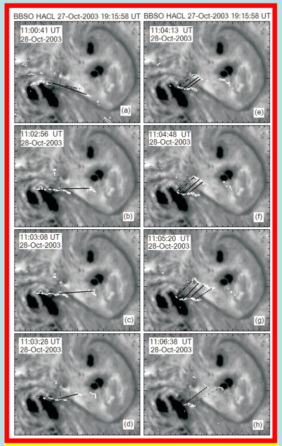

Figure 2 TRACE/EUV contours at different times are overlaid on an earlier H image from BBSO. The times of the EUV contours are marked on each image, and the black lines connecting to the EUV bright kernels represent the possible conjugate EUV footpoints (Fig. 1 shows an example about how to identify these conjugate footpints). Different kind of line refer to different group of brightening pairs. The field of view is 240''x160'' for each image.

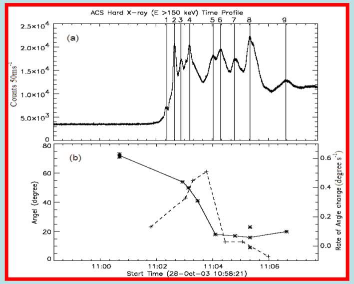

Figure 3 HXR light curve and the temporal evolution of the shear angle and the change rate of this angle. (a) The ACS/HXR light curve of the solar flare on 2003 October 28. (b) The evolution of the shear angle (solid line with asterisk sign), and the evolution of the change rate of this angle (dashed line with plus sign).

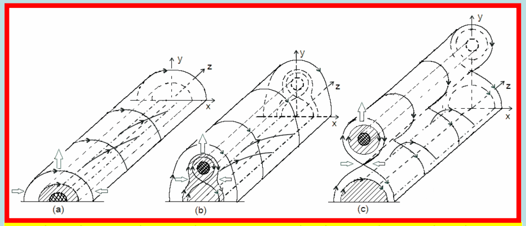

Figure 4 Cartoon of the evolution of the magnetic field in the standard model of solar flares. (a) Pre-flare magnetic field configuration with highly sheared core field region (double shaded) surrounded by relatively less sheared envelope (single shaded), and the most outer part is unsheared field. (b) Magnetic reconnection occurs in the relatively less sheared envelope (single shaded) magnetic field region. (c) The relatively less sheared envelope splits completely, and magnetic reconnection occurs in the region where the field is almost unsheared. Note that the direction of the magnetic field is represented by the arrows on the field lines.

Conclusions

❖ ***The EUV brightening pairs start at a position close to the magnetic inversion line but widely separated along the inversion line (Fig. 2a), and change to straight across and far from the inversion line (Fig. 2d) gradually during the impulsive phase.***

❖ ***The shear change is very fast during the early impulsive phase, but stops in the middle of the impulsive phase (Fig. 3b). The change from impulsive to gradual phase does not correspond to the cessation of magnetic shear change in this event.***

❖ ***This observed shear change can be understood in terms of the standard model for solar flares (e.g., Moore et al. 1995, 2001).*** According to this model the pre-flare magnetic field contains a highly sheared core field overlying the magnetic inversion line (MIL) with a relatively less sheared envelope, which is underlying the unsheared magnetic field (Fig. 4a). As soon as the pre-flare configuration becomes unstable to eruption, the core sheared field begins to erupt, and this allows the legs of the sheared immediate envelop to impact together and begin reconnecting just below the risin g core field (Fig. 4b), which can explain the conjugate footpoints start as highly sheared. ***In this model the cessation of shear change of the footpoints during the early impulsive phase corresponds to the splitting of the sheared envelope of the highly sheared core field (Fig. 4c) .***

A statistical study of shear motion of EUV footpoints in two-ribbon flares

We have selected 45 two-ribbon solar flares listed in the TRACE Flare Catalog (http://heawww.harvard.edu/trace/flare_catalog/index.html) observed by TRACE from 1998 to 2005 according to the following criteria:

- **We only consider flares in which two long and roughly parallel ribbons are seen during the flare.**
- **Most parts of the two ribbons are inside the field of view (FOV) of TRACE.**
- **TRACE has obtained several good images during the rise and impulsive phase, from which we can see the two ribbons and their evolution clearly.**
- **Those limb flares for which the two ribbons and their evolution cannot be seen are not considered.**

Date	Class	Band pass (Å)	EUV Shear Angle start (°)	EUV Shear Angle end (°)	HXR $T_{IP\ end}$ (UT)	GOES Peak (UT)
1998-09-23	M7.1	1550 195				07:13
1999-06-22	**M1.7**	**1216 195**	**58±2 18:20**	**34±2 18:24**	**18:23 18:24**	**18:29**
1999-06-23	M1.7	1216	69±2 06:50	18±2 06:57		07:09
2000-02-08	**M1.3**	**171 1600**	**63±2 08:44**	**26±2 08:51**	**08:52**	**09:00**
2000-04-12	**M1.3**	**171**	**38±2 03:31**	**11±2 03:33**	**03:32**	**03:35**
2000-06-04	M3.2	171 1600	64±2 22:06	39±2 22:09		22 :10
2000-06-06	X2.3	171 1600	64±2 15:11	42±2 15:21		15:25
2000-06-10	M5.2	195 1600	59±2 16:47	24±2 16:53		17:02
2000-07-14	**X5.7**	**195**	**68±2 10:24**	**18±2 10:26**	**10:27**	**10:24**
2000-11-08	M7.4	171				23:28
2000-11-24	X2.3	1600			15:09	15:13
2000-11-24	**X1.8**	**1600**	**56±2 21:49**	**16±2 21:52**	**21:54**	**21:59**
2001-01-20	M3.5	1600				18:47
2001-01-20	M7.7	1600				21:20
2001-03-24	M1.7	171 1600	80±2 19:37	50±2 19:55		19:55
2001-04-09	M7.9	171 1600	62±2 15:25	30±2 15:30		15:34
2001-04-10	**X2.3**	**171**	**55±2 05:08**	**8±2 05:22**	**05:32**	**05:26**
2001-04-11	M2.3	171	77±2 12:57	46±2 13:07		13:26
2001-04-26	**M7.8**	**171 1600**	**47±2 13:07**	**2±2 13:09**	**13:10**	**13:12**
2001-06-15	M6.3	195	58±2 10:06	44±2 10:12		10:13
2001-07-19	M1.8	171 1600	47±2 09:59	27±2 10:02		10:04
2001-08-25	**X5.3**	**284**	**37±2 16:28**	**18±2 16:30**	**16:32**	**16:45**
2001-10-19	X1.6	171	74±2 16:23	45±2 16:38		16:30
2001-12-26	**M7.14**	**1600**	**71±2**	**57±2 05:16**	**05:13**	**05:40**
2002-03-14	**M5.7**	**171**	**64±2 01:42**	**30±2 01:47**	**01:53**	**01:50**
2002-04-10	**M1.6**	**195**	**57±2 19:01**	**19±2 19:04**	**19:04**	**19:07**
2002-07-29	**M4.7**	**171 1600**	**60±2 10:31**	**42±2 10:36**	**10:39**	**10:44**
2002-07-31	**M1.2**	**171**	**51±2 01:40**	**1±2 01:51**	**01:52**	**01:53**
2002-10-22	M1.0	195	76±2 15:32	46±2 15:33		15:35
2002-10-25	M1.5	195	87±2 17:26	43±2 17:36		17:47
2003-05-29	**X1.2**	**195 1600**	**74±2 00:56**	**45±2 01:02**	**01:04**	**01:05**
2003-05-31	M9.3	195	67±2 02:19	38±2 02:22		02:24
2003-06-11	X1.6	1700	75±2 20:04	39±2 20:06		20:14
2003-08-19	**M2.7**	**171 1600**	**70±2 09:49**	**47±2 10:00**	**10:02**	**10:06**
2003-10-24	**M7.6**	**195 1600**	**70±2 02:27**	**42±2 02:44**	**02:56**	**02:54**
2003-10-28	**X17.2**	**195**	**78±2 11:00**	**10±2 11:04**	**11:05**	**11:10**
2005-07-07	M4.9	171 1600				16:29

Table I Two-ribbon flares with shear change of footpoints and ribbons' separation. The 4th column shows the shear angle of the earliest brightening pair identified by the post flare loops, and the 5th column shows the shear angle of the later brightening pair at the time when the shear change stops. The 6th column shows the time when the hard X-ray impulsive phase stops.

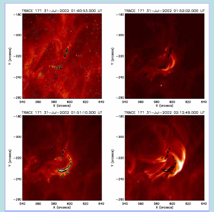

Figure 5 TRACE/EUV brightenings and post flare loops of a solar flare on 2002 July 31. The images on the top panel show the earliest brightenings at 171Å represented by black contours are overlaid on an early EUV image and a later image with post-flare loops. The bottom panel is similar to the top panel, but for the later brightenings at the time when shear change stops.

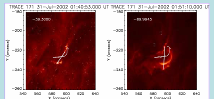

Figure 6 Two EUV images observed by TRACE. The left picture shows the earliest EUV brightenings, and the white number shown on the image is the angle between the two white lines, one of them is the line connecting the two EUV brightenings, and the other is the magnetic inversion line (SOHO/MDI). The picture on the right is similar to the one on the left, but for the later brightenings at the time when shear change stops.

An example shows how to measure the shear angle:

- Look through all the images taken by TRACE during this flare to select one image with the first two conjugate footpoints (which can be identified by the post flare loop (top panel in Fig. 5), highly sheared) at the early beginning of the flare. In the mean time, we also will find the time when the shear change stops, then choose two conjugate footpoints (which can be identified by the post flare loop (bottom panel in Fig. 5), less sheared). on the image at this time.
- Measure the start and end shear angles (the angle between the line connecting the two conjugate footpoints and the magnetic inversion line (MIL)) (i.e., Fig. 6).

Date	GOES Peak (UT)	Class	Bandpass (Å)
2001 May 05	08:56	M1.0	171
2001 Aug 05	15:31	M1.7	171, 1600
2001 Aug 05	22:24	M4.9	171, 1600
2001 Oct 31	08:09	M3.2	171
2001 Nov 10	00:50	M1.0	1600
2001 Dec 29	05:45	M1.1	1600
2002 Jan 02	12:52	M2.4	1600
2003 Jan 22	04:44	M1.2	171

Table II Two-ribbon flares without shear change of footpoints and ribbons' separation.

Preliminary Results

➢ **In sum, 82% (37 out of 45) two-ribbon flares (M and X class) observed by TRACE show shear change of footpoints, which is listed in Table I.** The shear angles (the angle between the line connecting the two conjugate EUV brightenings and the line perpendicular to the MIL) of 29 events have been measured. The angles of each event measured at the early beginning and at the time when the shear change stops are shown in Table I. The shear angles of 6 events are difficult to measure.

➢ In the 29 events with measured shear angle, 17 events have corresponding HXR observations, which provide information about when the impulsive phase stops. Therefore, we are able to check whether the time of cessation of the shear change is related to the time when the impulsive phase stops. We find that these two times are very close to each other in a few events, but **in most of the events, the cessation of shear change is earlier than the time when impulsive phase stops.**

➢Eight of the 45 events show no measurable shear change. We find that **there is no ribbon separation in those 8 two-ribbon flares which have no shear change of the conjugate footpoints.**

Reference and Acknowledgement

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The authors sincerely thank Drs. S.K. Antiochos, J. Lin, and G.L. Huang for fruitful discussions. Y.N. Su is grateful to Drs. E. E. DeLuca, M. Weber, and J. Cirtain for their help with data reduction, and she also would like to thank Drs. B. Schmieder, Dr. A. Berlicki, and P. Demoulin for helpful discussions and their hospitality during her stay in Meudon. Y.N. Su is also grateful to Drs. J. Qiu and H.S. Ji for their help with BBSO data process. The authors wish to thank the team of TRACE, SPI/ACS, SOHO/MDI, SOHO/EIT, Yohkoh/HXT, RHESSI, and NJIT/BBSO for providing the valuable data, and especially thank Dr. A. Bykov for letting us use his private SPI/ACS data. The TRACE analysis was supported at Smithsonian Astrophysics Observatory (SAO) by a contract from Lockheed Martin. Y.N. Su was also supported by SAO Predoctoral Fellowship and the NSFC projects No. 10333030 and 10273025.