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X-type interactions of loops in the flare of 25 September 1997

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Abstract. The evolution and properties of the GOES C7.2 class solar flare observed in the NOAA 8088 active region on 25 September 1997 were studied with data taken by the Wroclaw Large Coronagraph/MSDP in Hα, Yohkoh/SXT and GOES X-rays as well as SOHO/MDI magnetic and SOHO/EIT ultraviolet observations. The observed properties of the flare are consistent with a model in which the releases of the energy were caused by two successive X-type interactions of an expanding loop with two higher located, nearly parallel loops. Before the second interaction the lower loop was pushed from below by the eruption of the magnetic field manifested by eruption of a system of Hα threads. The total energy stored in the magnetic fields of three interacting loops, $E_{magn} \sim 1 \cdot 10^{31}$ erg, was almost one order greater than the whole thermal energy contained in the loops $E_{tot} \approx 1.2 \cdot 10^{30}$ erg. While the flare occurred in a stable system of magnetic loops, which apparently survived the flare, we find that the thermal energy was emitted at a cost of the annihilation of a fraction of the magnetic fields in the turbulent kernel.

Key words: Sun: X-rays, gamma rays – Sun: magnetic fields – Sun: flares – Sun: corona – Sun: chromosphere

1. Introduction

Images of the solar flares taken with the SXT telescope of the Yohkoh satellite usually revealed bright, compact sources of enhanced emission located at or close to the loop-tops (Acton et al., 1992; Feldman et al., 1994). These X-ray sources are located where the magnetic energy of interacting loops is transformed to thermal energy, initialising a very complicated complex of events observed in various wavelengths as a solar flare.

Many authors analysed various possible configurations of interacting magnetic loops. The configurations of the interacting loops observed on the Sun may be described using three main models only: the I-type coalescence (interaction of two nearly parallel loops), the Y-type coalescence (interacting loops are in contact only along a part of their lengths) and the X-type coalescence, when some parts of two loops crossed approximately perpendicularly (Sakai & de Jager, 1996).

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At present, observations do not allow direct confirmation of what type of field coalescence is occurring. Most analyses of the observational data concerning the coalescence of the loops described the I-type interactions (Kane et al., 1983, Kiplinger 1983, Takahashi et al., 1995, Inda-Koide et al., 1995), some describe the Y-type (Hanaoka, 1994, Nakajima, 1994, Farnik et al., 1996) and only a few describe X-type (de Jager et al., 1995).

In this paper we present the results of an analysis of the GOES C7.2 class solar flare observed in the NOAA 8088 active region on 25 September 1997. In our opinion this flare was caused by two successive X-type interactions.

2. NOAA 8088 active region before the flare

The NOAA 8088 active region appeared on the visible solar hemisphere on 21 September and it was observed up to 1 October 1997, when disappeared behind the western limb. The region reached its maximum area and number of spots on 25 September, passing across the central meridian, roughly 29 degrees to the south from the equator (SGD 639A). At the same time a much smaller NOAA 8087 active region was located to the north-east from the NOAA 8088. The regions were connected by extended system of loops well visible in the images taken by SOHO EIT and Yohkoh SXT telescopes, forming a huge, common and stable magnetic system (see Fig. 1). On 24 and 25 September there were no other sunspot groups on the Sun than NOAA's 8087 and 8088. Between 23 and 25 September the NOAA 8088 was the main, if not only, region producing solar flares on the whole visible hemisphere of the Sun (SGD 638A). All solar flares recorded during these three days were rather weak, reaching optical classes not greater than 1N and X-ray classes not greater than M6.0.

At the beginning of the observations (25 September 1997, 07:47 UT) the big leading spot (marked LS, see Fig. 2) and the western group of the following spots (marked FW) of the NOAA 8088 active region were located inside an area of negative polarity magnetic field (NPMF). Two spots of this group were directly inside the penumbra of the LS while another one was located next to the penumbra, forming together a long "peninsula" heading east from the LS.

A compact eastern group of the following spots (marked FE) was located inside the huge, slowly decaying area of the positive

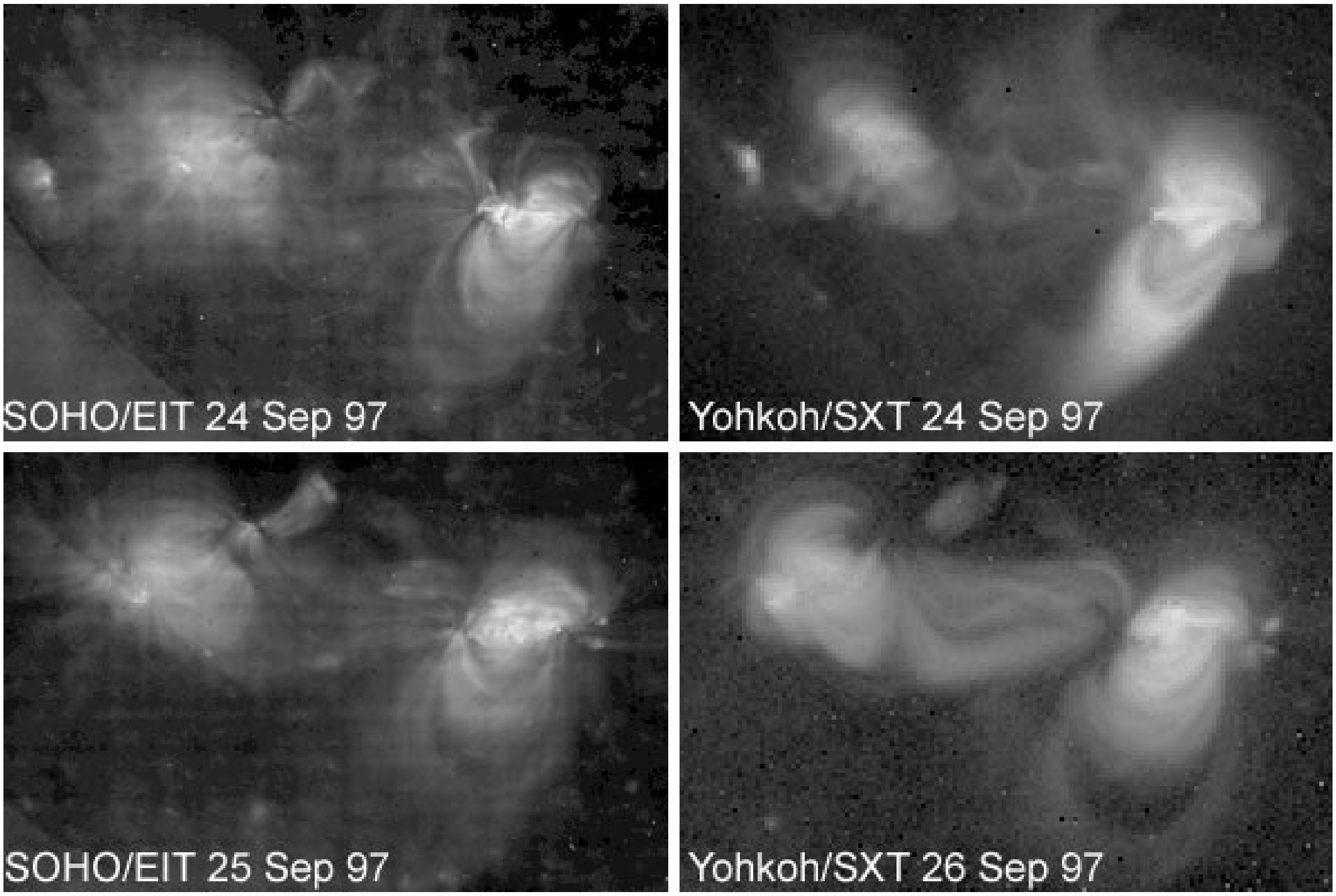

Fig. 1. NOAA 8088 and NOAA 8087 active regions before and after the flare on 25 September 1997. The left panels show SOHO/EIT 284 Å FeXV images while the right ones images taken with Yohkoh/SXT. The NOAA 8088 active region is at the right side of the image. North is up.

polarity magnetic field (PPMF). Separate areas of positive field covered the southern and eastern parts of the active region as well as to the south of the FW spots. The magnetic class of the whole group was estimated as $\beta\gamma$ (SGD 639A; SOHO/MDI magnetograms; 1997).

3. Observations

3.1. Hα *observations*

On 25 September 1997 we observed the NOAA 8088 active region using the Large Coronagraph with the Multi-Channel Double Pass Spectrograph (MSDP) and the Horizontal Telescope of the Wroclaw University. Because of cloudy weather, we succeeded in collecting three separate sequences of the observations only: from 07:47 UT to 08:50 UT, from 10:50 UT to 12:45 UT and from 14:20 UT to 14:40 UT. Early in the morning the seeing was rather moderate, but later on, after 12 UT it greatly improved (it was better than 1 $arcsec$).

Before 11:50 UT, when the evolution of the active region was rather slow, we obtained spectra and filtergrams with the Large Coronagraph. After 11:50 UT we obtained MSDP spectra only with the LC and simultaneously filtergrams using the Horizontal Telescope with a 0.5 Å band-pass Hα filter.

The Wroclaw MSDP has an entrance window covering a rectangular area of 325×41 $arcsec^2$ on the Sun and 9-channel prism-box creating 0.4 Å step in wavelengths between the adjacent channels. The spectra are recorded with a Photometrics SenSys KAF1400 (1317×1035 pixels, 12 bits) CCD camera. One CCD-pixel corresponds to 0.56 arcseconds spatially and 0.025 Å spectrally (Mein, 1977; Mein, 1991, Rompolt et al., 1994). During the observations the exposure time of the spectra was 30 ms while the overall time-step between the successive spectra, limited by the necessary subsidiary operations, was 6 seconds. The time resolution of the observations varies from 100 to 160 seconds in proportion to the scan length. The moments of the MSDP observations cited below correspond to the start of the appropriate scans.

We processed the MSDP images in a standard way using codes written originally in Fortran by P. Mein and translated by one of us to IDL without any significant changes, with one exception, that we used our own method of the correction of the flatness of the restored images, based on the analysis of the processed flat-field images (Roudier, 1991; Mein, 1997; Rudawy, 1996). The results reported below, concerning material up- and down-flows, were derived by taking into account the geometrical effect of the location of the observed region on the solar disk.

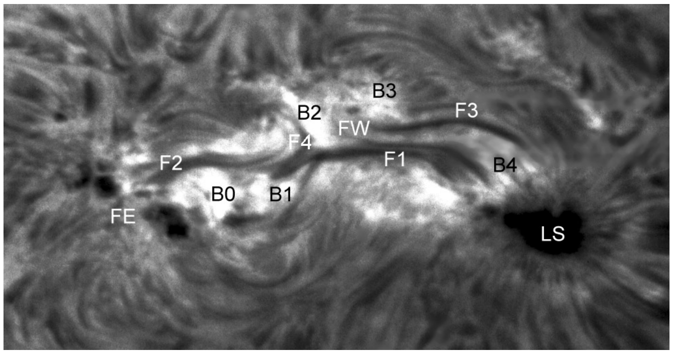

Fig. 2. Hα image of the NOAA 8088 active region taken with the Wroclaw Large Coronagraph (0.5 Å band-pass filter) on 25 September 1997 at 08:12 UT, three and half hours before the flare. Labelled structures are described in the main text.

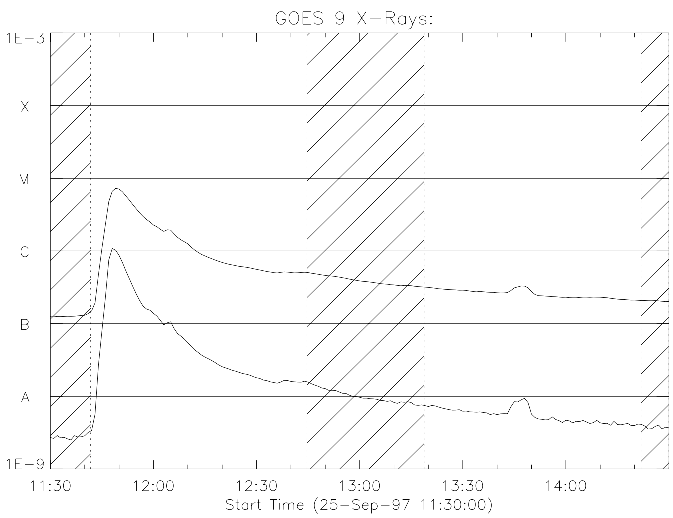

Fig. 3. X-ray flux curves recorded by the GOES 9 satellite between 11:30 UT and 14:30 UT on 25 September 1997. The upper and lower lines indicate the full disk soft X-ray flux through 1–8 Å and 0.5–4 Å, respectively. The striped regions show the Yohkoh satellite nights.

3.2. *X-ray observations*

A GOES C7.2 class solar flare occurred in the NOAA 8088 active region at around 11:40 UT. The SXT telescope of the Yohkoh satellite recorded the flare for the first time at around 11:48 UT and observed it during two orbits, up to 14:22 UT. Most SXT images of the flare were taken with the spatial resolution of 2.6 $arcsec$ (one pixel is equal to 1885 km) (Tsuneta et al., 1991). Fig. 3 shows the X-ray flux recorded by the GOES 9 satellite as well as periods of the Yohkoh SXT telescope observations. The hard X-rays emitted during the impulsive phase of the flare were not observed by the HXT telescope (Kosugi et al., 1991) because the "flare mode" was triggered a little too late. The BATSE instrument on the Compton Gamma Ray Observatory (Schwartz R. A., 1992) recorded a faint hard X-ray flux between 11:44 UT and 11:47 UT, but the signal recalculated to the parameters of the HXT telescope was weak (see Fig. 8).

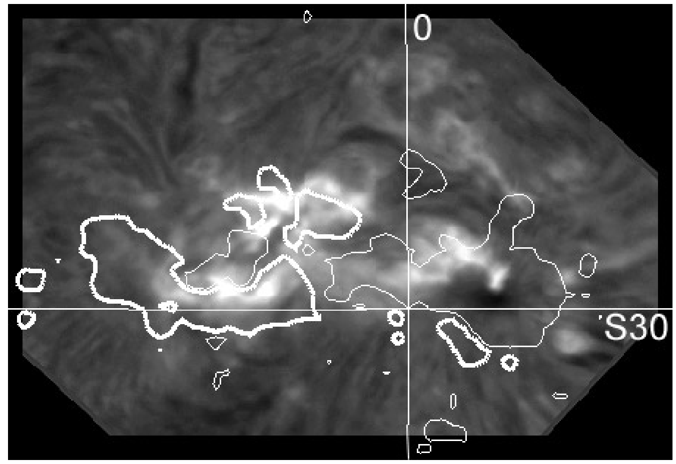

Fig. 4. Image of the flare taken in the center of the Hα line with the MSDP spectrograph at 12:09:25 UT and overplotted by the SOHO/MDI magnetogram taken at 12:53:00 UT. The thick lines corresponded to the positive polarity magnetic field while the thin lines to negative polarity magnetic field. The leading spot of the region is quite well visible.

4. Evolution of the flare on 25 September 1997

4.1. *Evolution of the flare observed in* Hα *line*

The filtergrams made at the beginning of the observations in the center of the Hα line showed several structures of different types, among others: a leading spot (LS) with a well-developed superpenumbra covering a half of their neighbourhood, many following spots, numerous long, dark threads as well as many brightenings located between the spots (see Fig. 2). The counterclockwise regular vortex structure of the superpenumbra was not present in a wide sector placed to the north-east from the LS. A bundle of the long threads F1, visible inside this sector, stretched from the outer border of the LS penumbra (NPMF) to a brightening B1 placed between LS and FE (PPMF). The threads headed toward the locations of the spots forming "peninsula" of the LS spot. The thread F3, running nearly parallel to the F1, was seen also between the penumbra of the LS spot and a small spot located in the PPMF area above the FW spots. Another bundle of the long dark threads F2 stretched from the vicinity of the FE spots (PPMF) to the brightening B2 (NPMF) around the FW spots. There were many other long, dark fibrils in this active region, but their evolution was not analysed.

Up to 11:50 UT the changes of brightness and morphology of the structures were rather slow. Between 07:58 UT and 08:36 UT a new, curved thread F4, rooted in the closest vicinity of the feet of the F1 threads in the brightenings B1 (PPMF) and inside the brightening B2 (NPMF) gradually appeared. This structure looks like a dark loop above the system of F1 and F2 threads. The only important macroscopic motions of the matter were down-flows along the ends of the threads F1, F2 and F3. The observed areas of the down-flows as well as the velocities of the motions varied in time but they did not exceed 10–15 $\mathrm{km\,s^{-1}}$. The exceptions were the east ends of the F1 and F2 threads. At 08:40 UT the velocity of the down-flow along the east end of

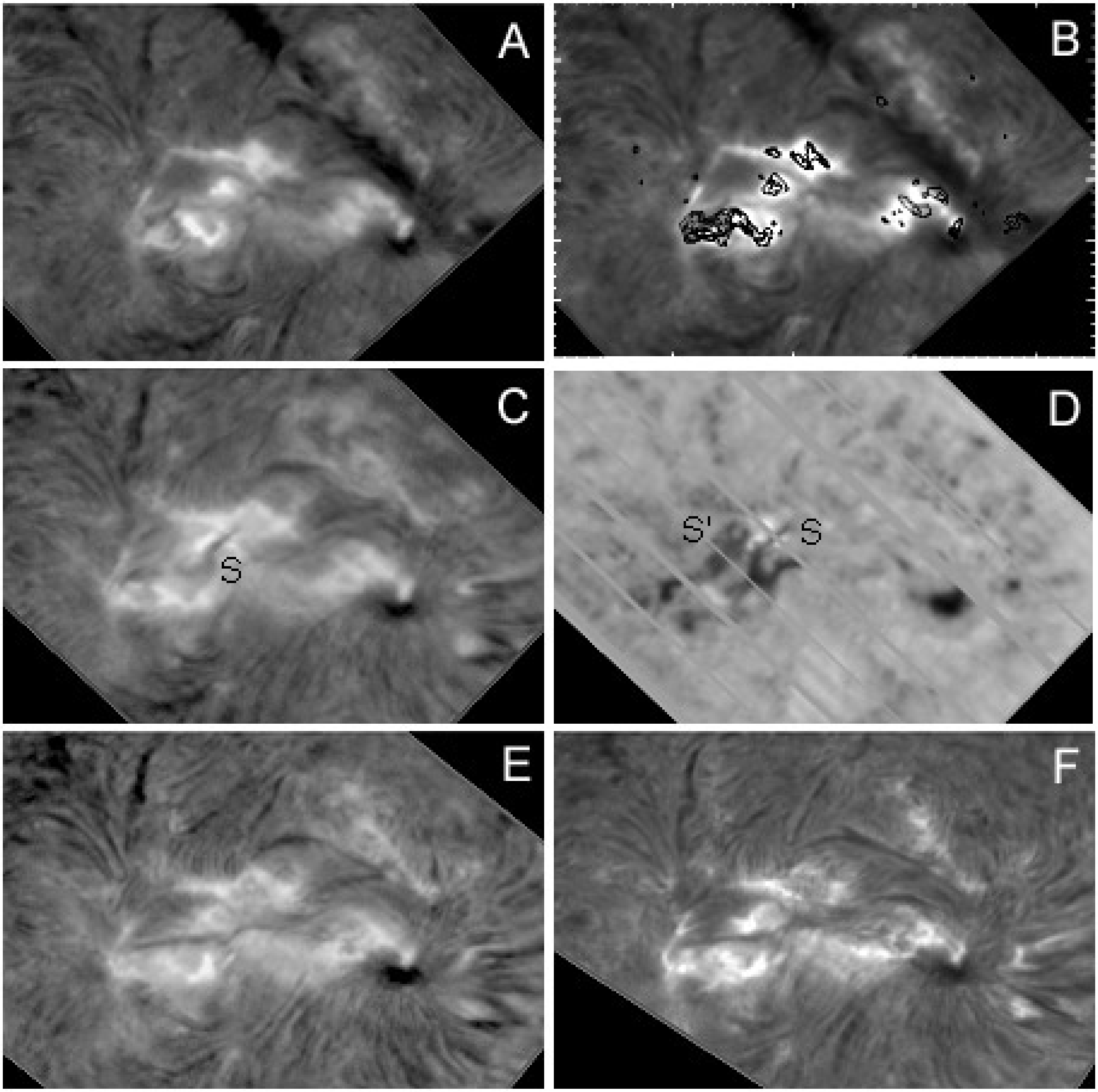

Fig. 5a–f. Evolution of the flare observed in Hα line with the MSDP spectrograph. The dimensions of panels are 200×150 arcsec^2 on the Sun. North is up. **a**–**b** emission in the center of the line at 11:50:31 UT and overplotted isocontours of the velocities from $+5\ \mathrm{km\,s^{-1}}$ to $+25\ \mathrm{km\,s^{-1}}$; **c** emission in the center of the line at 12:07:36 UT. S surge; **d** emission +0.8 Å from the center of the line. S and S' are the parts of the erupting system of threads; **e**–**f** emission in the center of the line at 12:20:16 UT and 12:42:48 UT respectively. In images a, b, **c** and **e** intensities are on **a** logarithmic scale.

the F1 threads was 20 $\mathrm{km\,s^{-1}}$ and at 10:57 UT the down-flow along the east end of some F2 threads reached 25 $\mathrm{km\,s^{-1}}$.

The profiles of the Hα line emitted from the brightenings of the active region were symmetric or only slightly asymmetric with the exception of the profiles emitted by the two brightenings B1 and B2, where the profiles were clearly asymmetric with flat or irregular cores.

At 10:52 UT, after the first break in observations caused by clouds, the threads F1 and F2 as well as the thread F3 seemed to form a common, continuous system or chain of threads. Apparently the eastern end of the F3 thread moved toward the F1 thread as well as the neighbouring ends of the F2 toward the F1. After this rebuilding the western part of the former F1 bundle of the threads was visible up to the border of the B4 brightening but the threads were much fainter. The matter still flowed down along the all feet of the new system of threads, but the in-flow of the matter from F1 threads into the brightening B1 was much slower than previously and covered much less area.

Just before 11:50 UT we observed visually for the first time a strong increasing of the emission of the B0 brightening and at 11:50:31 UT we started observations of the whole active region with MSDP spectrograph with higher frequency. During the flare four regions were particularly bright in Hα light. There were three brightenings mentioned before: B0 together with B1, B2, B3 and the brightening B4, which covered the north-east part of penumbra of the LS spot as well as the sector without the superpenumbral structure limited from south and north by the F1 and F3 threads. The brightest parts of the B0, B2 and B3, forming the kernels of the Hα flare, were located along and close to the inversion lines of the magnetic field (see Fig. 5).

The emission of the B0 (measured together with B1) reached main maximum at 11:52:31 UT and next, during the gradual decay of its emission, it has two secondary maxima at 12:02:24 UT and 12:07:36 UT. The brightening B2 has the first maximum of the emission at 11:52:31 UT and the second, a higher one at 12:05:52 UT. The emission of the B3 and B4 brightenings reached main maximum at 12:00:00 UT and secondary one at 12:07:36 and 12:09:25 UT respectively.

The profiles of the brightest parts of the flare kernels were reversed, exhibiting double maximum, while the profiles emitted from surrounding of the kernels were flat with multiple maxima and minima. The reversed profiles showed a tendency to be shifted toward the longer wavelengths, what may suggest a downflow of the matter in the Hα flare kernels with the velocities of the order of 5–7 $\mathrm{km\,s^{-1}}$. Outside the brightenings the matter still flowed down through the eastern end of F2 (with the velocities in some threads over 20 $\mathrm{km\,s^{-1}}$) and the western ends of F1 and F3.

Between 11:50 UT and 12:00 UT the flare kernels gradually changed their brightness and areas but the overall structure of the region did not change. At 12:00 UT the profiles of the Hα line emitted from the center of the B2 become quite asymmetrical and shifted to the blue, which was probably caused by the fast up-flow of the matter, exhibiting high velocity component along the line of sight.

At 12:05:52 UT we recorded the early phase of an eruption of the system of the threads F1, F2 and F3 (the onset of the eruption occurred after 12:02:24 UT, but the limited time-resolution of the MSDP data did not enable us to estimate the onset more precisely). The eruption occurred in the region of the junction of the F1 and F2 bundles of threads, over the B1 and B2 brightenings and over the neutral line of the magnetic fields (see Fig. 4). The erupting system of threads observed at 12:07:36 UT in the center of the Hα line looks like a single, big, curved surge rooted in the east end of the F1. The spatial velocity of the top of the surge was $35 \pm 10\,\mathrm{km\,s^{-1}}$. The image obtained +0.8 Å from the line center showed, that the F2 threads erupted also, but the matter moved much more horizontally outward the observer. After 12:10 UT the Hα brightenings faded out gradually and at 12:36 UT their brightness was comparable with the initial one, before the flare. The emitted profiles become non-reversed and nearly symmetrical.

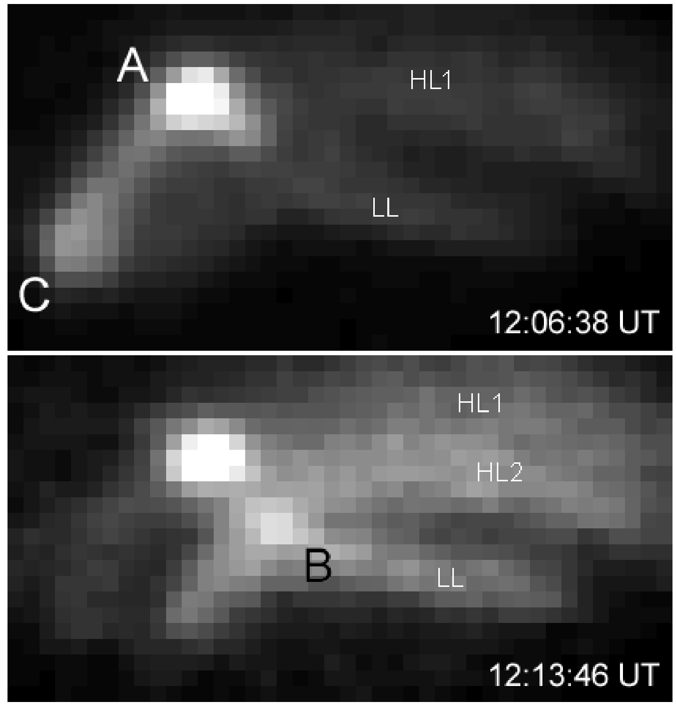

Fig. 6. Two images of the flare taken with the SXT telescope (Be119 filter, full resolution) at 12:06:38 UT and 12:13:46 UT. Both images are scaled to their maximum intensity. HL1, HL2 and LL are the magnetic loops while A and B are compact sources of soft X-ray emission. Source C is probably a foot-point of the HL1 loop.

4.2. Evolution of the flare observed in X-rays

According to the GOES 9 satellite flux-curves shown in Fig. 3, the evolution of the flare may be divided into three well separate phases: the early flare phase (lasting from 11:42 UT to 11:44 UT), the impulsive phase (from 11:44 UT to 11:47 UT) and the long decay phase (from 11:47 UT to around 14:20 UT). In the following sections we describe the development of the flare during these three phases.

Fig. 6 shows two images of the flare taken with SXT telescope with the Be119 filter. Two big, parallel loops (marked HL1 and HL2) were rooted between the LS spot (NPMF) and FE spots (PPMF) (see also Fig. 7). The feet of the loop were separated by about 58 000 km. Another one X-ray loop (marked LL) was rooted close to the last spots of the FE group (inside the PPMF area) and close to the FW spots (in the NPMF area). While the images shown are scaled to its maximum intensity, the fine, eastern part of the LL loop is not visible in the image taken at 12:06 UT. This loop is best visible in the images taken at 12:08 UT and in the few images taken around 12:38 UT. The feet of the LL loop were separated by around 53 000 km. The HL1, HL2 and LL loops, seen in projection against the solar disk, crossed nearly perpendicularly. The visible diameters of the all three loops were assumed to be constant and equal

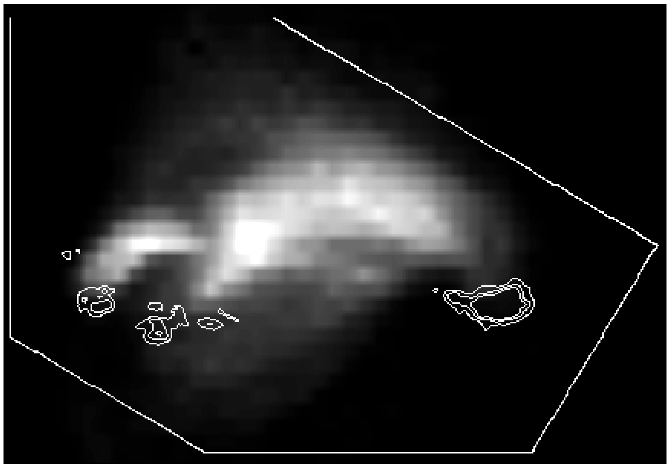

Fig. 7. SXT image of the loops (grey-scale) recorded at 12:38:44 UT with Al.1 filter and overplotted contours of the sunspots observed at 12:45 UT with MSDP in far red wing of the Hα line (+1 Å). The LS spot is on the right, FE spots are on the left. The SXT image was taken with half spatial resolution. The estimated coalignment error is ~ 5 arcsec.

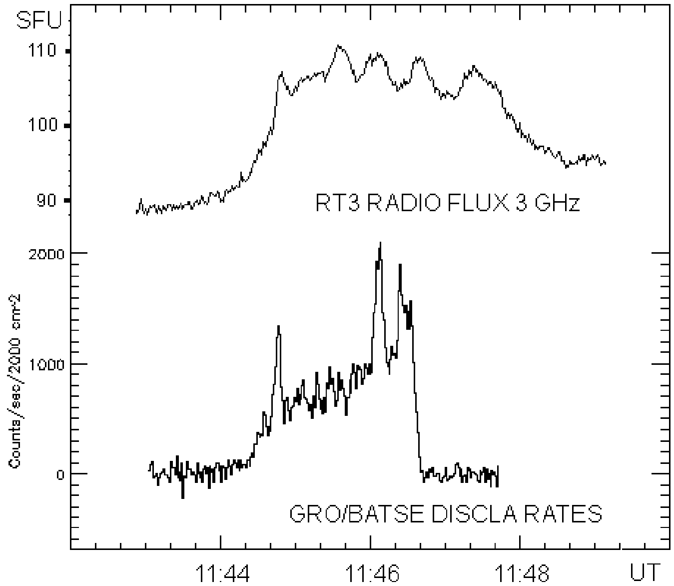

Fig. 8. Hard X-ray flux (25–50 keV) recorded with BATSE instrument of the GRO satellite (1.024 sec averaged) and 3 GHz radio flux (rescaled to 1 AU) recorded with RT3 radio telescope of the Ondřejov Astronomical Institute on 25 September 1997. The first and second pulses of the hard X-ray emission are well temporally correlated with the pulses of the radio emission at 3 GHz.

to $D_{HL1} \approx D_{HL2} \approx 5800\,\mathrm{km}$ and $D_{LL} \approx 4500\,\mathrm{km}$. Assuming a semicircular shape of the loops we can estimate their lengths as $L_{HL1} \approx L_{HL2} \approx 91\,000\,\mathrm{km}$ and $L_{LL} \approx 83\,000$ km. The volumes of the HL1 and HL2 loops were equal to $V_{HL1} \approx V_{HL2} \approx 2.4 \cdot 10^{27}\,\mathrm{cm}^3$ while the volume of the LL loop was about $V_{LL} \approx 1.3 \cdot 10^{27}\,\mathrm{cm}^3$.

The brightest compact source of the X-ray emission (Jakimiec et al., 1998; Phillips et al., 1998) A was located at the place of crossing of the HL1 and LL loops. It was bright during the whole first orbit of the Yohkoh. Non-saturated images were made after 11:59 UT only but the saturated images taken between 11:48 UT and 11:52 UT show a strong source of X-ray emission located at the same place as the source A. An other bright area (marked C), located to the south-east of A, in the eastern foot of HL1 loop, was visible to 12:09 UT only. Before 12:06 UT the third area situated to the south of A brightened, located in the cross-point of the HL2 loop and the LL loop (marked B). The averaged time profile of the emission intensities of the all three areas observed with both the Be119 and Al12 filters is very similar to the flux curves registered by GOES 9 satellite, even with the small "bump" registered at 12:08 UT. The brightest area A gave a major contribution to GOES flux profile, while B and C much smaller one. Maximum of emission of the B area, seen as a bump, was registered with Be119 filter at about 12:08 UT whereas the maximum with Al12 filter was 20 seconds later.

The BATSE instrument of the GRO satellite recorded between 11:44:40 UT and 11:46:40 UT an increase of the hard X-ray flux (25–50 keV) with three significant pulses observed at around 11:44:45 UT, 11:46:06 UT and 11:46:25 UT (see Fig. 8). At nearly the same time as hard X-ray increased a 3 GHz radio flux burst was observed with the RT3 radiotelescope of the Ondřejov Astronomical Institute. This telescope recorded five well separated pulses. The third and fifth pulses have double maxima, similarly to the structure of the pulses of radio emission observed during a few other flares (Kiplinger et al., 1983). Two radio pulses only, observed at around: 11:44:50 UT and 11:46:06 UT, were well time-correlated with the pulses of hard X-ray emission.

During the second orbit of the Yohkoh satellite the SXT telescope still recorded the images of the same, very stable system of the HL and LL loops. They did not change the configuration significantly. The image of the X-ray loops was very similar to EIT images taken before and after the flare (see Fig. 1). At 13:44 UT an area situated to the west from the system of loops brightened strongly. This bright area was probably responsible for the small increase in the GOES flux-curve registered at around 13:45 UT.

5. Proposed model of the flare

On the basis of the described observational data we constructed a possible scenario of the flare. The images taken with the EIT telescope of the SOHO satellite (Delaboudinière et al., 1995) in light of the FeXII and Fe XV lines before the flare, on 24 September 1997 as well as after the flare, on 25 September 1997 show a stable system of the bright coronal loops, rooted inside the NPMF region around the LS spot and between the FE spots inside the PPMF area. One can see a very similar system of the coronal loops on the images taken with the SXT telescope (see Fig. 6 and Fig. 9). At 11:40 UT a strong source of the soft X-ray emission appeared in the place of the crossing of the HL1 and LL loops (the source marked A on the Fig. 9 panel B). We assume that this emission was caused by the annihilation of the

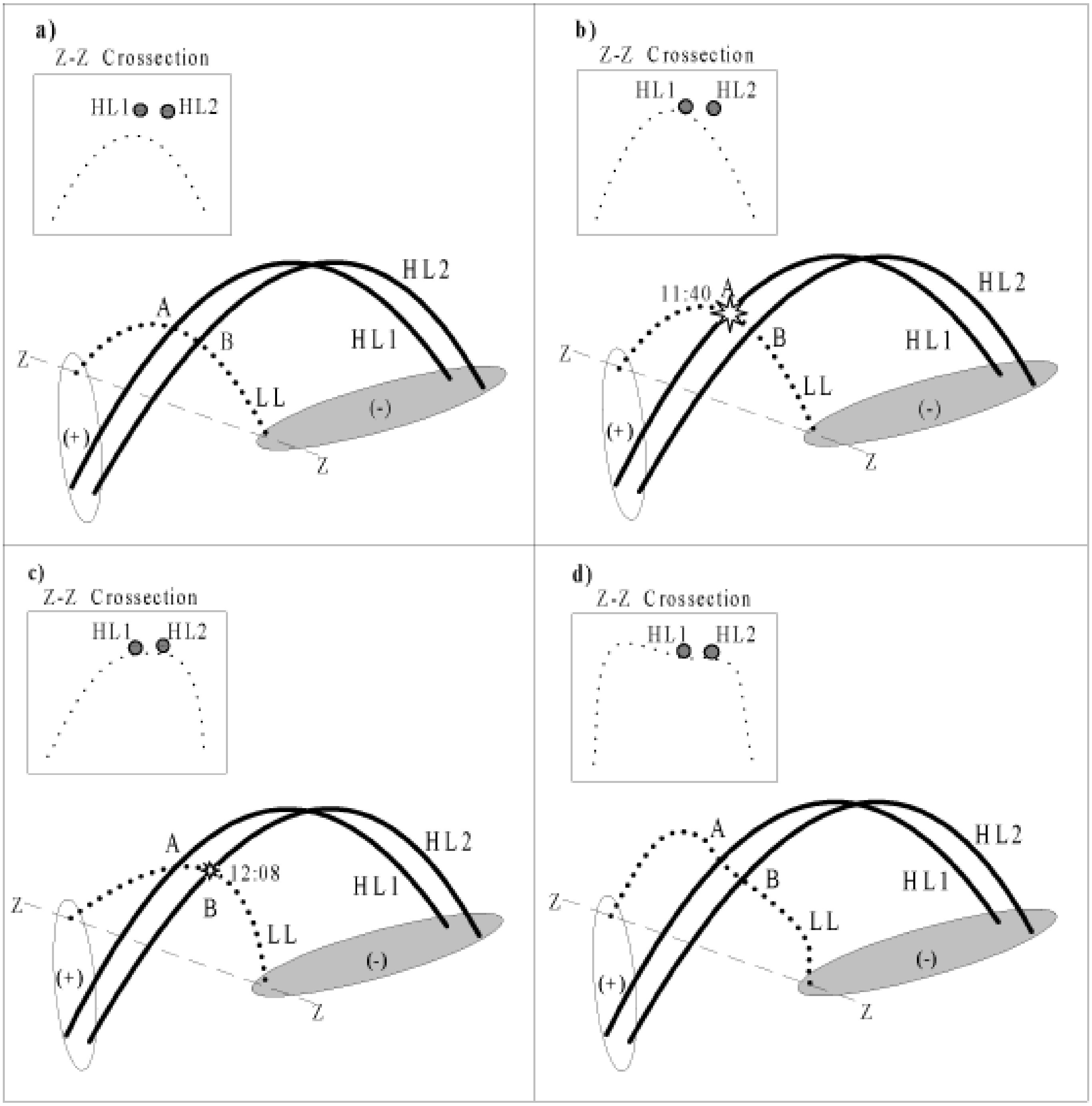

Fig. 9a–d. A schema of the flare on 25 September 1997. **a** Before the flare a two big loops (HL1 and HL2) were seen over an X-ray loop (LL). The HL and LL loops crossed each others nearly perpendicularly; **b** At 11:40 UT an X-type collision of the HL1 loop with the expanding loop LL occurred in point A. After the collision the expansion of the central part of the LL loop was stopped by the stiff HL1 loop and only the side parts of LL could still expand; **c** At 12:08 UT the next X-type collision happened between the loops HL2 and LL in the point B; **d** The loops after the flare. The HL and LL loops were separated. The eastern part of the LL loop was lifted a little higher than before.

magnetic fields during an X-type collision of the HL1 loop with the expanding loop LL (Sakai & de Jager, 1996).

An interaction of two magnetic flux tubes leads to formation of a current sheet. Jakimiec (1990) showed however, that a laminar current sheet is not able to heat any significant amount of plasma up to temperatures $\sim 10^7$ K and thus it is necessary that a turbulence develop to enhance the energy release and to diminish energy losses by thermal conduction. He suggested that turbulent flare kernels should develop which seems to be in a full agreement with our observations of X-ray flare kernels (see also Jakimiec et al., 1998; Phillips et al., 1998).

Table 1. Physical parameters of the flare on 25 September 97

Parameter	GOES (11:48)	SXT (12:06)
T [K]	$12.4 \cdot 10^{6}$	$8.5 \cdot 10^{6}$
EM [cm^{-3}]	$7.3 \cdot 10^{48}$	$4.5 \cdot 10^{48}$
N_e [cm^{-3}]	$2.9 \cdot 10^{11}$	$2.7 \cdot 10^{10}$

After collision the expansion of the central part of the LL loop was stopped by the stiff HL1 loop and only the side parts of LL could still expand.

The eruption of the system of the threads, visible in the Hα light, was associated with the rise of a magnetic system, which very likely acted as a piston on the LL loop, pressing it from bottom toward the HL2 loop. The geometry of the observed Hα eruption and magnetic polarisation of the threads' roots show that the magnetic field of the "piston" was nearly parallel to the magnetic field of the LL loop. At 12:08 UT appeared the second, much fainter source of the soft X-ray emission, located in the cross-point of the HL2 loop and in the expanding western part of the LL loop (marked B in Fig. 9 panel C). We assume that this brightening was caused by the X-type collision between the HL2 and LL loops. After the flare there was no annihilation of the magnetic fields in the A and source B anymore. We suppose that the magnetic fields of the loops underwent partial annihilation only. In the Fig. 9 panel D a sketch of the loops after the flare is given. The eastern part of the LL loop looks as being lifted a little higher, while the central and western parts seems to be blocked by the loops HL1 and HL2. While there was not more energy generation it the cross-points of the loops, probably the loops underwent separation. To sum up, the first X-type collision of the HL1 and LL loops occurred during the main maximum of the flare observed by the GOES satellite and the second X-type collision of the loops HL2 and LL appeared during the small, temporal increase of the emission during the on the decay phase of the flare.

Two maxima of the Hα emission from the B0 and B1 brightening, observed at 11:52:31 UT and 12:07:36 UT, located in the eastern feet of the HL loop, were caused by the energy release in the source A. The emission of the B4 brightenings, located in the opposite foot of the HL loop, reached main maximum at 12:00:00 UT and secondary one at 12:09:25 UT. They could be caused by A and B sources respectively. We did not find any visible loops connecting B2 and B3 brightenings with the observed sources of energy, but the time correlation of the enhancements of the Hα emission with energy releases in A and B sources is clear.

An estimation of the total thermal energy contained in the loops during the impulsive phase of the flare was made on the basis of the GOES satellite data because there are no SXT observations covering this phase of the flare. We calculated temperature and emission measure from GOES data (Thomas at al. 1985). The temporal variations of the emission measure (EM) and temperature (T) of the flare were evaluated (see Fig. 10). Between 11:51 UT and 11:57 UT a diagnostic diagram has a slope

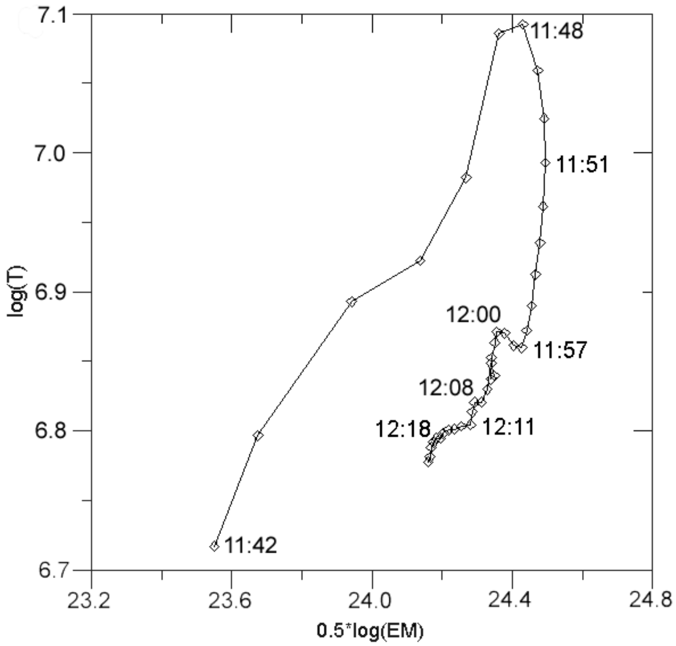

Fig. 10. Diagnostic diagram of the flare on 25 September 1997 calculated from GOES data

of two, which means that during this period the flare matter was efficiently cooled and there was no energy release. After 11:57 UT up to 12:00 UT the temperature of the matter increased a little, but then it was cooled again. At 12:08 UT and 12:11 UT a release of the energy occurred in the source B what stopped the temperature decrease. After 12:18 UT we observed constant cooling of the matter. Under assumption that the energy accumulated in the magnetic fields was converted to the thermal energy during a short period before observed maximum of the emission, the amount of the thermal energy released in the source A could be estimated as the maximum of the thermal energy contained in the flaring loops.

The first maximum of the contained thermal energy occurred at 11:48 UT, when the emission measure was $EM = 7.3 \cdot 10^{48}\,\mathrm{cm}^{-3}$ and the temperature $T = 12.4\,\mathrm{MK}$. The volume of the loops was $V_{tot} \approx 6.1 \cdot 10^{27}\,\mathrm{cm}^{3}$. The thermal energy contained during the main maximum of the flare $E_{therm} \sim 3kTV\sqrt{EM/V}$ in the source A was $E_{therm}(A) \sim 1.1 \cdot 10^{30}\,\mathrm{erg}$. The two secondary releases of the thermal energy, seen as two bumps on the GOES flux curves occurred in the B and A sources. The thermal energy contained in source B up to 12:06 UT was $E_{therm}(B) \sim 4.5 \cdot 10^{28}\,\mathrm{erg}$. At the same time the whole thermal energy contained in the flaring loops was $E_{tot}(GOES) \approx 5 \cdot 10^{29}\,\mathrm{erg}$. The energy contained in source A before 12:11 UT, caused perhaps by the temporal increase of the energy release from the turbulent kernel (Jakimiec, 1990; Jakimiec & Fludra 1991) was $E_{therm}(A) \sim 6 \cdot 10^{27}\,\mathrm{erg}$.

On the basis of the images taken with the SXT telescope at 12:06 UT with Al12 and Be119 filters we evaluated the emission measure $EM = 4.5 \cdot 10^{48}\,\mathrm{cm}^{-3}$ and temperature $T = 8.5\,\mathrm{MK}$ of the flare (Tsuneta et al., 1991). The total thermal energy contained at that moment inside the three loops was

$E_{tot}(SXT) \sim 5.8 \cdot 10^{29}$ erg. This result agreed well with the estimation of the total thermal energy made on the basis of GOES data for the same moment. It means that very likely only three analysed loops took part in the whole flare.

We can roughly estimate the strength of the photospheric magnetic fields in the feet of the colliding loops on the basis of the SOHO/MDI (Scherrer et al., 1995) as greater than $B \sim 200$ Gs. While the diameters of the loops were nearly constant, the total energy stored in the magnetic fields of the three loops $E_{magn} \sim B^2V/8\pi$ was greater than $E_{magn} \sim 1 \cdot 10^{31}$ erg. This energy was almost one order greater than the whole thermal energy contained in the loops during the flare $E_{tot} \approx 1.2 \cdot 10^{30}$ erg. While the observed flux of the hard X-rays was small, we assumed that the energy released during the flare as a non-thermal particles was relatively small. The studied flare occurred in a stable system of the magnetic loops, which survived the flare, we suppose that the thermal energy was released on the cost of the magnetic fields annihilation in the turbulent kernel (source A).

The Hα flare started just before 11:50 UT as an enhancement of the emission from the B0 with B1 and B2 brightenings. These brightenings were located in the feet of the HL loops (B0 with B1) and below the source A. The estimated cooling time of the source A ($V_A \approx 9 \cdot 10^{25}\,\mathrm{cm}^3$, $T = 12.4 \cdot 10^6$ K) by radiation equal to $t_{rad} \approx 3kT/N_e\phi(T)$ was $t_{rad} \approx 22\,sec$ while the cooling time by conduction $t_{cond} \approx 2N_ekTL^2/(\chi T^{7/2})$ was two orders longer (4600 sec), so the source A was cooled mainly by radiation (van der Oord & Mewe, 1989). The estimated cooling time of source A agree well with our observations of the first Hα emission just before 11:50 UT.

The time profile of the hard X-ray emission registered by the BATSE instrument has three non-periodical pulses. From a numerical simulation Zhao and co-workers found (Zhao et al., 1993) that configuration of the interacting loops is reflected by the time profile of the plasma temperature. The I- and Y-type interactions caused many equally spaced in time pulses of the temperature while the X-type interaction caused only one single pulse. The pulses of the hard X-ray observed during the considered flare are clearly non-periodical, so we assume that the observation is not inconsistent with our model of the event. The observed time delay between BATSE and radio pulses agree well with the expected delay for the disturbation propagated along the loops of the observed lengths with the velocity equal to the estimated Alfvén velocity $v_A = 1770\,\mathrm{km\,s^{-1}}$.

6. Conclusion

Solar flares are very complicated complexes of events observed in various wavelengths (Švestka et al., 1992). These events are observed from the highest layers of the corona down to the photosphere, but they are connected even with processes going on deep below the solar surface. Especially suitable for analysing and modelling of solar flares are multi-wavelength observations, made simultaneously from the ground and from space.

The analysis of the observed properties and evolution of the GOES C7.2 class solar flare observed in the NOAA 8088 active region on 25 September 1997 was made on the basis of the Hα, X-rays and magnetic observations. It enables us to construct a model of the on-going physical processes. We find that the releases of the energy were caused by two successive X-type interactions of an expanding loop with two higher located, nearly parallel loops. What is most interesting, before the second interaction the lower loop was pushed from below by the magnetic field of an erupting system of the Hα threads.

The total energy stored in the magnetic fields of the three interacting loops $E_{magn} \sim 1 \cdot 10^{31}$ erg was almost one order greater than the whole thermal energy released during the flare $E_{tot} \approx 1.2 \cdot 10^{30}$ erg. The flare occurred in a stable system of the magnetic loops, which survived the flare, we suppose that the thermal energy was emitted on the cost of the magnetic fields annihilation in the turbulent kernel.

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