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SOLAR FLARES IN ACTIVE REGION NOAA 9042 ON 21 JUNE 2000

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ABSTRACT

During an analysis of the observations collected in the frame of the year 2000 observing season we have found an interesting event of two *sympathetic flares* in active regions NOAA 9042. Up to now we have analysed visible, UV, X-ray and radio data taken on 21 June 2000 (observations taken between 05 UT and 14 UT). We have found that an increase of the optical emission in the secondary flare occurred, at least partially, as a consequence of the exchange of the kinematic energy of the macroscopic motion of material, falling down onto the chromosphere, into the thermal energy in the loop anchorage regions, it means by the *infall mechanism.* The energy release of the primary flare was associated by emission of numerous *millisecond radio spikes* recorded with the 80 μs time resolution.

1. INTRODUCTION

The active region NOAA 9042 (N24W34) was observed on 21 June 2000 using the Large Coronagraph of the Wrocław Astronomical Institute, the 15-m radio telescope of the Toruń Centre for Astronomy, GOES and YOHKOH satellites. The Large Coronagraph (53cm/1400cm) provided us high spatial resolution narrow bandpass Hα filtergrams and Hα spectral images and velocity maps taken by MSDP (Multi-channel Subtractive Double Pass spectrograph) coupled with it. The observations were made between 05:20 UT and 14:20 UT. We have collected 50 MSDP scans over the whole active region as well as more than 30 filtergrams (see Fig. 1). Due to good observing conditions the quality of some images is very high. The 15-m radio telescope has possibility to record millisecond radio spikes with the time resolution of 80 μs. In our analysis we have used also the data recorded with X-ray instruments on-board of the GOES-10 and Yohkoh satellites (SXT *Soft X-ray Telescope*, HXT *Hard X-ray Telescope* and BCS *Bragg Crystal Spectrometer*).

2. FIRST FLARE

Since 08:10 UT we observed a small solar flare in the optical domain (see Fig. 1, marked R1). The GOES class of the flare was about C5, its impulsive phase started at 07:58 UT. The SXT telescope on-board of the Yohkoh satellite recorded a small loop at that time, filled with matter of a peak temperature of T_{max}=10 MK. This loop was located close to a big loop observed long before the flare. Analysis of the data taken with the BCS instrument revealed two sources of the X-ray emission: hot material in the first source did not exhibit motions, in the second one the material moved toward the observer in the time range from 07:58 UT up to 08:02 UT. The velocity of the material increased initially toward the observer from 0 km/s up to 120 km/s and afterwards decreased gradually to 0 km/s. The analysis of temperature and emission measure at the top of the big loop shows that the increase of the temperature was preceded by the increase of the emission measure.

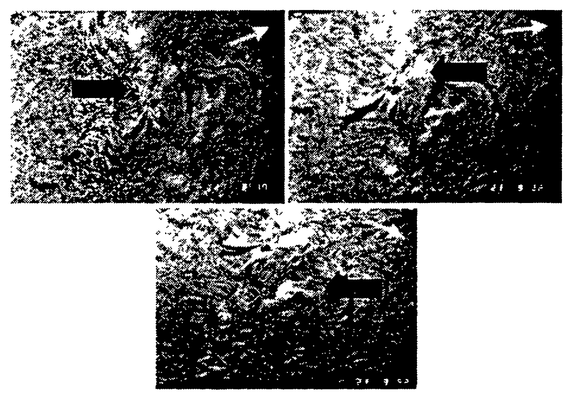

Figure 1. Filtergrams of the NOAA 9042 active region taken at the center of the Hα line at 08:17:05 UT (upper left panel), 09:22:06 UT (upper right panel) and 09:52:30 UT (bottom panel). Thick arrows mark the observed flares R1, R2 and R3. Thin arrows point to the north.

On the basis of the collected observational data we propose the following model of the flare:

1. The primary release of the thermal energy occurred as a result of annihilation of the magnetic fields in a region of collision of the surfaced magnetic field of the new, small magnetic loop with the already existing big one.

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2. The hot plasma filled entirely the small loop; it did not show any macroscopic motions.
3. The plasma in the adjacent leg of the big loop was also heated. That plasma while expanding filled partly the big loop pushing ahead an arch of relatively much cooler plasma. The expansion was evidenced by the observed material motion as well as by the initial increase of the emission measure at the uppermost part of the big loop owing to a density increase of the pushed material. Later on an increase of the temperature was observed in that uppermost loop region evidently caused by an inflow of some hot plasma to that place.

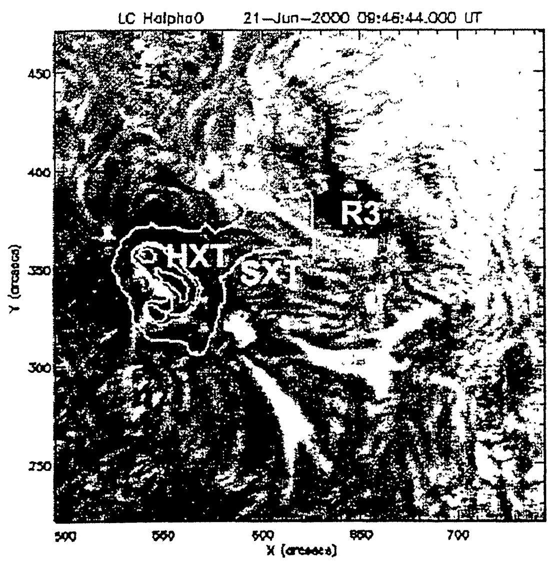

Figure 2. Composite image of the NOAA 9024 active region on 21 June 2002. The Hα filtergram (presented in negative) taken at 09:46:44 UT is over-plotted by isocontours of the soft X-ray emission from 09:34:14 UT and hard X-ray emission from 09:24 UT. A vertical, nearly straight right-most boundary of the soft X-ray isocontour is an artefact caused by the limited field of view of the SXT telescope.

4. SYMPATHETIC FLARES

Two solar flares (marked by R2 and R3 in Fig. 1) were observed in Hα (high resolution filtergrams and MSDP spectral imagery) in a sequence from 08:54 UT to 11:00 UT. When we began the observation of evolution of the R2 flare at 08:54 UT it just displayed a flare increased Hα emission. This flare came to an end at about 10:40 UT. The associated X-ray emission detected by GOES 8 satellite (see Fig. 3) began at 08:38 UT and reached the maximum intensity at 08:58 UT as an X-ray flare of class C5. Location of the R2 flare in Hα images was exactly at that place of the solar surface where the enhanced X-ray emission was seen on the images recorded by SXT (see the Fig. 2). The outmost plasma temperature and emission measure in the R2 flare X-ray kernel attained maximum temperature of T_{max}=9.9 MK and emission measure of EM=$8.3*10^{48}$ cm^{-3}.

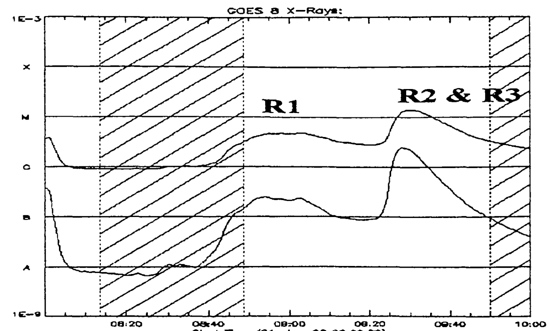

Figure 3. X-ray emission of the Sun detected by the GOES 8 satellite during the R1-R3 flares.

The second in sequence flare R3 started to brighten in Hα in between two remote systems of fibrils lying close together. We have detected this brightening for the first time at 09:22 UT, at the time when the flare R2 was very intense. The flare R3 attained maximum intensity in Hα at about 09:47 UT and came to an end at about 11:30 UT. The commencement of the X-ray impulsive phase of the flare R3 occurred exactly at the time of the very first brightening of it in Hα and at the time of high intensity in Hα reached by the flare R2, it means at 09:22 UT. The maximum intensity in X-rays attained by the input of both the flares, R2 and R3, was of the GOES class M1 and occurred at 09:30 UT. The R3 flare came to an end at about 12:00 UT.

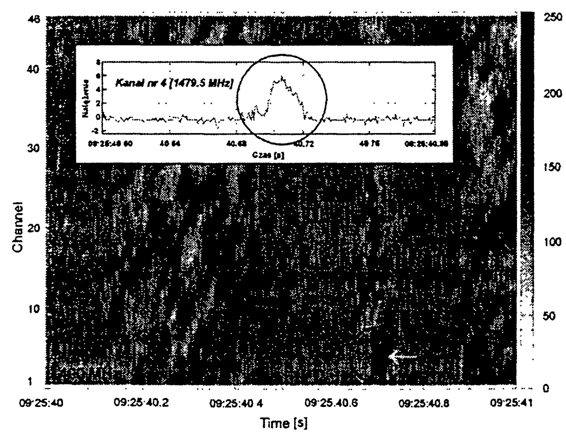

Figure 4. Solar radio burst with millisecond spikes observed with the Toruń 15-m radio telescope and a fast spectrometer. The plot represents the total power in arbitrary units.

A solar radio burst was observed between 09:24:00 UT and 09:30:08 UT with the 15-m radio telescope at the Toruń Center for Astronomy, equipped with a fast spectrometer covering the range of 1352 to 1490 MHz and

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acquiring 80 μs time resolution (see Fig. 4). The fast spectrometer was originally designed and is continually used for observations of the pulsars. Numerous millisecond radio spikes were recorded between 09:24:56 and 09:26:00 UT - it means at the time of the high Hα-intensity of the flare R2 and the beginning of the flare R3 as well as just at the commencement of the flare R3 impulsive phase observed in X-rays. The spikes were very short in time (few tens of ms) and of narrow frequency band (only few percent of the central frequency). The radio telescope used recorded radiation from the whole solar disk but the observed event can be attributed to the R2-R3 flares, which occurred exactly at that time.

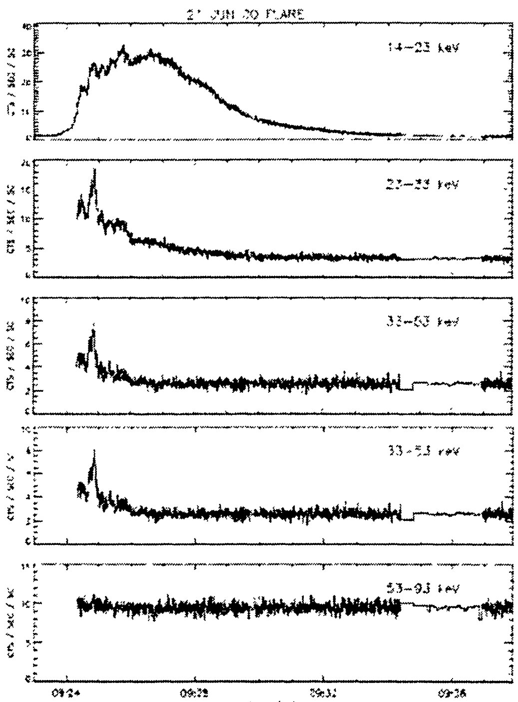

Figure 5. Solar hard X-ray burst observed with the HXT telescope on-board of the Yohkoh satellite. The beginning of the hard X-ray emission occurred about 10 seconds before the burst of the radio millisecond spikes.

A solar hard X-ray burst was observed between 09:23:50 UT and 09:35 UT with the HXT telescope on-board of the Yohkoh satellite (see Fig. 5). The significant increases of the signals were detected in all instrumental channels inside 14-53 keV energy range, but there was not observed any increase in the 53-93 keV channel. The beginning of the hard X-ray emission occurred about 10 seconds before the burst of the radio spikes described above.
Strong X-ray emission from the R3 flare, typical for a region of magnetic field annihilation, has not been recorded by SXT - at that time the R3 region was just at the outskirts of the telescope full-resolution mode field of view. Nevertheless, using SXT full-disk images taken at 10:46 UT it was found that an extended arch of intensified X-ray emission in the shape of a "tongue" anchored at the R2 flare site was seen in projection to spread eastwards of that flare up to the region of the flare R3 and even further on (see Fig. 2). As a result of a detailed analysis of the high spatial resolution Hα filtergrams, MSDP spectral images (both an output of our Large Coronagraph) and UV pictures (from SOHO/EIT) we succeeded in identifying some long cool and hot arches connecting the region of the flare R2 with the region of the flare R3. These arches were very likely a part of an extended system of highly stretched loops filled by various temperatures plasma. It is not unlikely that while the western bundle of these individual loops being anchored in the flare R2, a part of their opposite legs was anchored in the flare R3 region and another part somewhere at the end of the "tongue".

Figure 6. The dopplergram of the NOAA 9042 showing the transport of material from the flare R2 region to the flare R3 area. The material moving up (towards the observer) was presented in black; the material moving down to the solar surface is presented as an elongated structure in white. The images used for calculation were obtained in the blue and red wings of the Hα line (-0.7Å and +0.7Å) at 09:40:19 UT (using MSDP).

After start of the impulsive phase of the flare R2 (from about 09:22 UT) begun just from it transport of material and energy, of a long duration, along the both cool and hot arches, up to the place of location of the flare R3. The arches composing an active region filament filled by cool plasma were seen in absorption in the wings of the Hα hydrogen line in the MSDP images. The filament owing to a disturbance caused by the flare R2 underwent an activation, was lifted to the corona and bent into a reversed S-like structure (as seen in projection against the disk, see Fig. 6). The filament displayed its fine arch-like structure during the activation. The dopplergrams constructed on the basis of the MSDP images clearly show that there was a continuous mate-

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rial flow along the activated filament arches from the northern part of the flare R2 region up to the region of the flare R3. Some easily identifiable places of the fine arches anchorage were seen just to the north from the flare R2 kernel as well as along the southern and eastern border of the flare R3 region.
The arches filled by hot plasma were seen in emission very clearly in the FeXII 195Å. The arches along which the transport of material from the flare R2 to the flare R3 was observed were oriented in the East-West direction and had a straight-line form (in projection). This gives evidence that the UV arches are rather low-lying structures (see Fig. 7). The process of material flow from R2 to R3 is quite well seen in a movie composed of a consecutive series of the FeXII 195Å images.

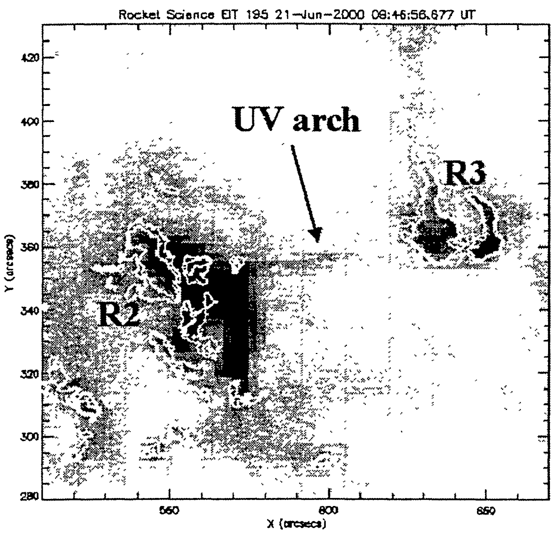

Figure 7. A SOHO/EIT FeXII 195 Å image (presented in negative) taken at 09:46:57 UT with over-plotted selected isocontours of the LC Hα line center image taken at 09:46:44 UT. An arrow indicates the UV arch. Material transport proceeded from the flare R2 to the flare R3.

As a result of detailed analysis of the observational material we can say that most of the local increase of the Hα emission intensity in the flare R3 were situated closely to the identified places of the long arches anchorage. That is closely to the places where the cool and hot material was flowing down to the chromosphere along the fine individual arches.

On the basis of the accessible observational data we can draw the following conclusions:

1. The main source of the energy release of the both observed flares (R2 and R3) was located in the magnetic system connecting the flares, rather close to R2.

2. The flares R2 and R3 formed a system of so called *sympathetic flares* (Richardson, 1931 and 1951; Becker, 1958; Smith, 1965), which appeared at the feet of a common huge magnetic system. The transfer of the energy and matter between two flares took place along the system of the loops connecting both flares. The R3 flare was in fact an integral part of the R2 flare and appeared as a consequence of the R2 flaring activity.

3. The increase of the optical emission in R3 flare occurred, at least partially, as a consequence of the exchange of the kinematic energy of the macroscopic motion of material, falling down onto the chromosphere, into the thermal energy in the loop anchorage regions – by the *infall mechanism* (Hyder, 1967a, 1967b; Nakagava and Hyder, 1969).

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