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FEATURES OF THE DEVELOPMENT OF A CIRCULAR SOLAR FLARE

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ABSTRACT. We present the results of the analysis of morphology and evolution of the circular solar flare using H-alpha images. H-alpha filtergrams were obtained with the Meudon spectroheliograph. The active region NOAA 9087 had a complex multipolar magnetic field configuration. New magnetic fluxes emerged during the evolution of this flare-productive active region. The high flare and surge activity was observed in the active region.

According to Solar Geophysical Data (SGD) the 3N/M6.4 class solar flare occurred on July 19, 2000 at 06:37 UT, peaked at 07:23 UT and lasted 2.5 hours. Two bright kernels appeared near large positive-polarity sunspot at the beginning of the flare. In a few minutes bright kernels occurred in the center of the active region near polarity inversion line. Space solar observatory Yohkoh detected a hard X-ray (HXR) coronal source in the 13.9-22.7 keV and 22.7-32.7 keV energy bands in this location.

New kernels appeared in the southern and eastern parts of the active region at the boundaries of the chromospheric network. They brightened sequentially clockwise, which may indicate a slipping reconnection. Magnetic reconnection was observed in the main phase of the flare in the eastern part of the active region. In the late flare phase arcade of post-reconnection EUV loops connected the main flare ribbon with the place of repeated reconnection. Additional heating may be required for the explanation of the long flare decay phase.

Flare ribbons of the circular shape were formed. The complex magnetic configuration of the studied active region and circular shape of the ribbons suggest that it had a fan-spine magnetic topology with null points. Possibly, flare ribbons are the locations of intersections of the fan quasi-separatrix layer with the chromosphere. They appeared as a result of heating or particle beam moving along a quasi-separatrix layer from a source in the corona.

Keywords: Sun, chromosphere, active regions, solar flares, magnetic reconnections, multi-wavelength observations.

АБСТРАКТ. В роботі представлено результати аналізу морфології та еволюції кругового сонячного спалаху із використанням H-альфа зображень. H-альфа фільтрограми отримано за допомогою спектрогеліографа обсерваторії в Медоні. Активна область NOAA 9087 мала складну конфігурацію багатополярного магнітного поля. Нові магнітні потоки з'являлися під час еволюції цієї спалахово-продуктивної активної області. Багато спалахів та викидів спостерігались у цій активній області.

Згідно з Сонячними геофізичними даними (SGD) сонячний спалах класу 3N/M6.4 виник 19 липня 2000 року о 06:37 UT, досягнув максимуму о 07:23 UT і тривав 2,5 години. На початку спалаху з’явилося два яскравих ядра біля великої сонячної плями з позитивною полярністю. Через декілька хвилин в центрі активної області поблизу лінії інверсії полярності виникли яскраві ядра. Космічна сонячна обсерваторія Yohkoh виявила корональне джерело жорсткого рентгенівського випромінювання (HXR) в енергетичних смугах 13.9-22.7 та 22.7-32.7 кеВ у цьому місці.

Нові ядра з’явились у південній та східній частинах активної області на межах хромосферної мережі. Вузли спалаху ставали яскравішими послідовно за годинниковою стрілкою, що може свідчити про ковзаюче магнітне перез'єднання. Повторне магнітне перез'єднання спостерігалося в основній фазі спалаху в східній частині активної області. У пізній спалаховій фазі аркада післяспалахових EUV петель з'єднувала основну спалахову стрічку з розташуванням місця повторного магнітного перез'єднання. Для пояснення тривалої фази спалаху може знадобитися додаткове нагрівання.

Спалахові стрічки мали круглу форму. Складна магнітна конфігурація досліджуваної активної області та кругла форма стрічок дозволяють припустити, що вона мала магнітну топологію типу "віяло-шип" з нульовими точками. Можливо, спалахові стрічки – це місця перетину шару віялової квазісепаратриси з хромосферою. Вони з’явились внаслідок нагрівання або переміщення пучка частинок вздовж квазісепаратрисного шару від джерела в короні.

1. Introduction

Solar flares occur as a result of magnetic reconnections. Magnetic reconnections can be initiated at null points, on separators, in quasi-separatrix layers. Fluxes of energetic particles from the reconnection region or heating of the lower atmosphere cause the appearance of flare kernels and ribbons in the chromosphere.

The magnetic topology is very important for the occurrence and development of the flares (Priest and Titov, 1996). The attention of many authors is directed to the study of three-dimensional magnetic field topology, containing 3D null points (eg, Aulanier et al., 2012, Guo et al., 2019).

The skeleton of the magnetic topology in the active region determines the geometry of flare ribbons (Guo et al., 2019). Flare ribbons can form at the intersection of the quasi-separatrix layer with the lower atmosphere (Mandrini et al., 1991). Study of morphology and evolution of flare kernels and ribbons can provide information about the topology of the magnetic field and mechanisms that contributed to flare occurrence and development.

We analyzed the sequence H-alpha images to study an evolution and morphological features of the two-ribbon solar flare on July 19, 2000 in the chromosphere of the active region NOAA 9087.

2. Active region, flare and observational data

The active region NOAA 9087 was observed on the solar disk from 15 to 27 July 2000. It had a multipolar magnetic field configuration, which became more complicated every day. Its flare activity increased gradually. A 3N/M6.4 flare occurred on July 19 at coordinates S18E10. It took up a large area on the disk. According to Solar Geophysical Data, the H-alpha flare began at 06:37 UT, its main maximum was at 07:23 UT, and the end was at 09:01 UT. It lasted for almost 2.5 hours and belonged to the class of long-term events (LDE - Long Duration Event).

In the paper (Chornogor and Kondrashova, 2020) the data of space-born and ground based observations of this flare were analyzed. The hard X-ray (HXR) and soft X-ray (SXR) data were obtained at the Yohkoh Telescopes (HXT and SXT) and Geostationary Operational Environmental Satellite (GOES). The full-disk magnetograms and EUV-images were provided by the Solar and Heliospheric Observatory (SOHO) Michelson Doppler Imager (MDI) and Extreme ultraviolet Imaging Telescope (EIT). Radio data were obtained with Learmonth Solar Radio Spectrograph, white light images in Big Bear Solar Observatory (BBSO).

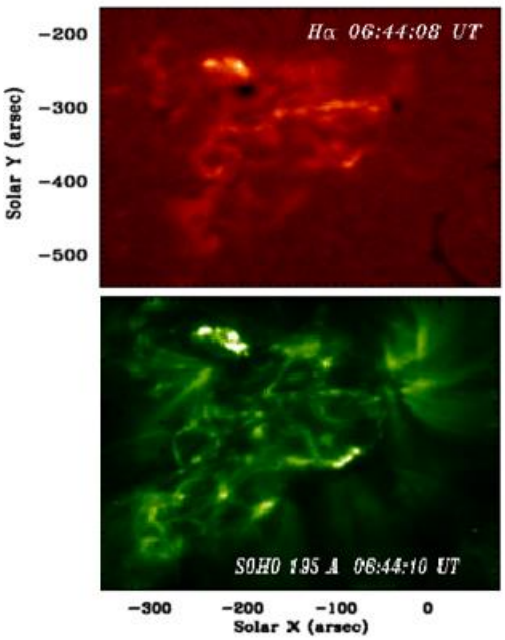

Figure 1: H-alpha image at 06:44:08 UT and SOHO 195A image at 06:44:10 UT

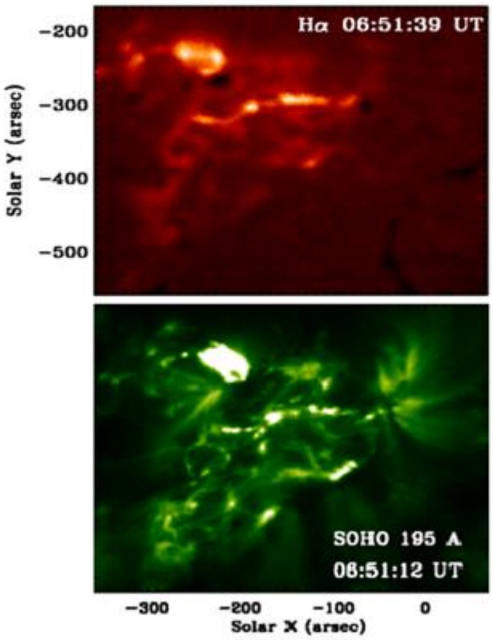

Figure 2: H-alpha image at 06:51:39 UT and SOHO 195A image at 06:51:12 UT

Wavelenght light curves for hard X-ray and soft X-ray fluxes, radio solar flux, H-alpha intensity were presented. Times of burst peaks are given in table. H-alpha intensity peaks are 06:50:33, 07:01:11, 07:07:34, 07:18:12 UT. The main H-alpha peak of the flare was at 07:23 UT.

To study the flare evolution in the chromosphere, in this work we used the H-alpha line filtergrams. Filtergrams were obtained at the Meudon spectroheliograph in time steps from 30 seconds to 1 minute. EUV images also used in this work.

3. Flare evolution in the chromosphere

The flare studied began with the appearance of two bright kernels near a large spot of positive polarity (Fig. 1). The SOHO 195A image is also shown in the figure for comparison of the development of the flare in the chromosphere and the corona. A few minutes later, the intensity of the plages in the center of the group, near the polarity inversion line, increased (Fig. 2). In the first place of the flare, there was an arcade of post-flare loops.

A surge occurred at one of its footpoints, which then fragmented into several jets. Then a tunnel of bright loops appeared to the southwest of this place (Fig. 3). The flare kernels in the central part of the active region became very bright. Possibly, they were caused by a hard X-ray burst the peak of which was observed at 06:57 UT.

According to the data of the hard X-ray telescope HXT on board Yohkoh, the coronal source of hard X-ray radiation in the L (13.9-22.7 keV) and M1 (22.7-32.7 keV) bands located above the line of polarity inversion. A new kernels has appeared in the southern part of the active region (Fig. 4).

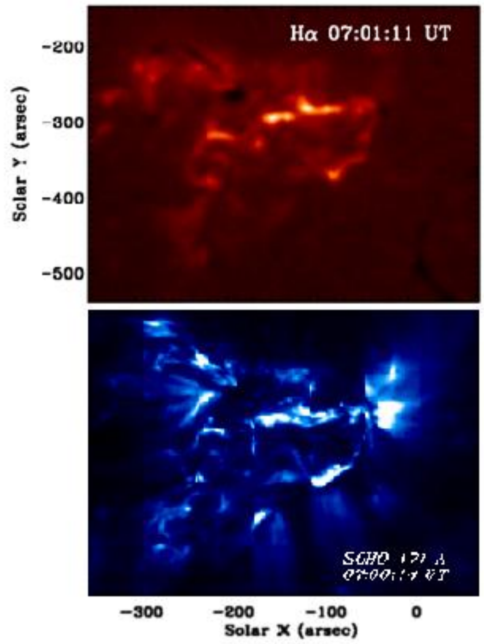

Figure 3: H-alpha image at 07:01:11 UT and SOHO 171A image at 07:00:14 UT

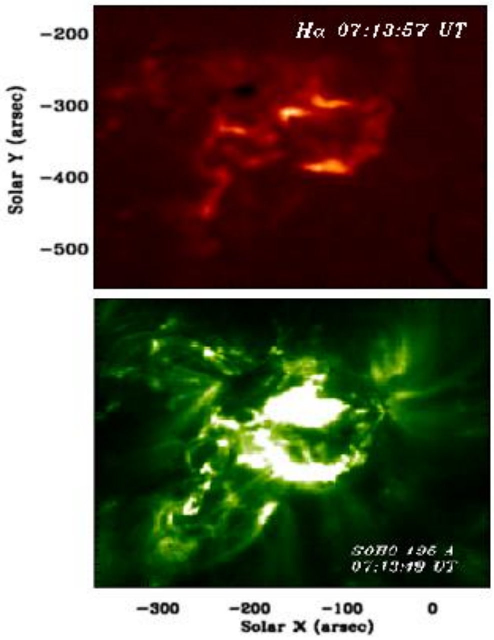

Figure 5: H-alpha image at 07:13:57 UT and SOHO 195A image at 07:13:49 UT

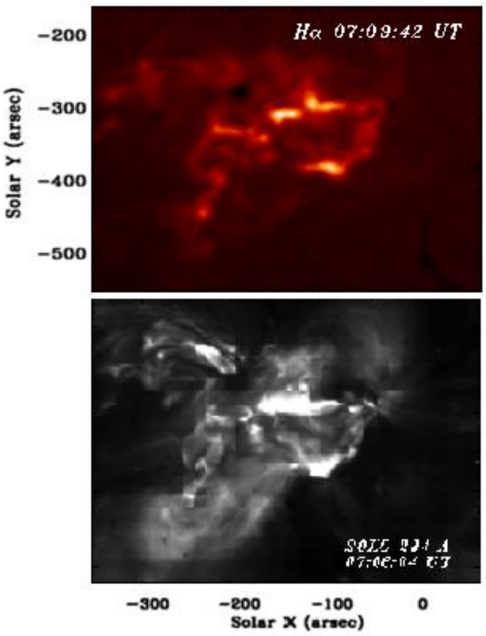

Figure 4: H-alpha image at 07:09:42 UT and SOHO 284A image at 07:06:04 UT

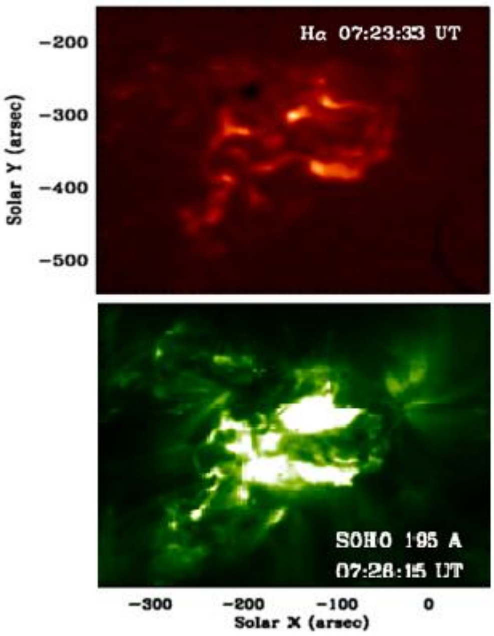

Figure 6: H-alpha image at 07:23:33 UT and SOHO 195A image at 07:26:15 UT

The flare ribbons formed had a circular shape. It can be assumed that the studied flare was circular. At 07:13:57 UT the flare occupied almost entire central and southern parts of the active region (Fig. 5). The SOHO 195 A and 304 A images also show the circular shape of the flare.

Circular flares are usually associated with a magnetic fan-spine topology containing 3D null points (Yang et al., 2015). Flare ribbons can be located at the intersection of the fan with the photosphere. The maximum brightness of all kernels was at the main H-alpha peak of the flare at 07:23 UT.

The images, obtained in the main phase of the flare, show the intersection of bright EUV-loops in the eastern part of the active region, indicating magnetic reconnection (Fig. 6). The response of the chromosphere is visible in the H-alpha images. Further development of the flare took place in the southern and eastern parts of the active region (Fig. 7).

The brightening of the kernels of the flare studied occurred mainly consistently in different places of the active region, which may indicate slipping reconnection (Aulanier et al., 2006). This type of magnetic reconnection can occur when field lines pass through the quasi-separatrix layer and

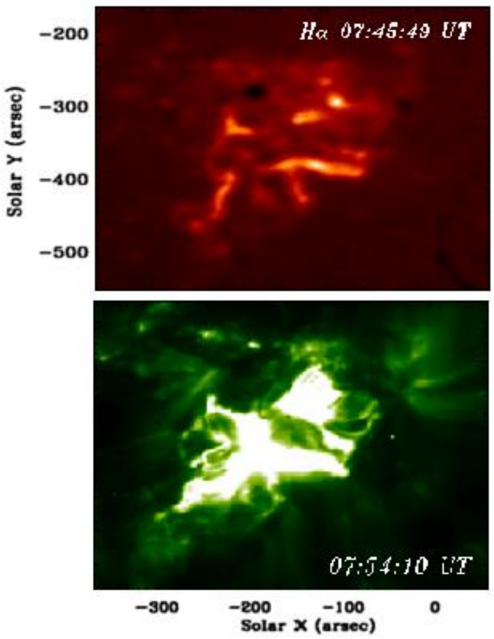

Figure 7: H-alpha image at 07:45:49 UT and SOHO 195A image at 07:54:10 UT

undergo continuous successive reconnections. In the flare studied, the brightening of kernels occurred clockwise in the main.

4. Conclusions

• The evolution of the two-ribbon 3N/M6.4 flare on 19 July 2000 in the chromosphere was analyzed on the base of the H-alpha filtergrams. Analysis of H-alpha images shows that the state of the chromosphere was constantly changing during the flare. The energy was released sequentially in different places of the active region.

• The kernels appeared along the polarity inversion line sequentially and were located at the boundaries of the chromospheric network.

• The successive appearance of flare kernels may indicate slipping magnetic reconnection in the flare. The flare ribbons were round. It can be assumed that there was a magnetic topology of the fan-spine type, containing null points. In the main phase of the H-alpha flare, the images show loops intersecting over in the eastern part of the active region, which are clearly visible in observations of EIT 195 A. They indicate magnetic reconnection.

• The arcade of the EUV loops after reconnection connected the main flare ribbon with the location of these loops in the late phase in one and a half hour after the flare maximum. Additional heating may be required to explain the long decay phase of the flare.

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References

Aulanier G., Janvier M., Schmieder B.: 2012, *A&A*, **543**, id.A110, 14 p.

Aulanier G., Pariat E., Demoulin P., DeVore C. R: 2006, *Solar Phys.*, **238**, № 2, 347.

Chornogor S. N., Kondrashova N. N.: 2020, *KPCB*, **36**, № 3, 140.

Guo J., Wang H., Wang J., et al.: 2019, *ApJ*, **874**, № 2, article id. 181, 10 p.

Mandrini C.H., Demoulin P., Henoux J.C., Machado M.E.: 1991, *A&A*, **250**, 541.

Priest E. R., Titov V. S.: 1996, *Philosophical Transactions: Mathematical, Physical and Engineering Sciences,* **354**, № 1721, 2951.

Yang K., Guo Y., Ding, M. D.: 2015, *ApJ*, **806**, №2, article id. 171. 13 p.