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THE ACTIVE REGION MAGNETIC FIELD ASSOCIATION WITH SOLAR FLARES

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Abstract. The powerful active region with a dipole type magnetic field distribution does not produce flares. For flare appearance the magnetic field distribution in the active region should not have a regular character – magnetic field sources must be intruded in the area of the opposite magnetic field component. The weak active region (AR) 11158 appeared on the eastern solar limb. The region becomes stronger and stronger traveling across the solar disk. The flare X2.2 appears, when magnetic flux is increased up to $\Phi > 10^{22}$ Mx. Six X-class flares are produced in the NOAA 10720. All of them appeared after northern and southern magnetic fluxes reached the critical value of $\sim 10^{22}$ Mx. The comparison of flare productive active AR with regions that produce no flare shows that the magnetic flux increasing is necessary, but not a sufficient condition for the flare occurrence. The strong AR (even at $\Phi > 10^{22}$ Mx) with a simple magnetic polarity-reversed line does not produce a powerful flare. No considerable change of AR 11158 active region is observed during the X-class flare. The observed weak localized change of the line-of- sight magnetic component does not produce appreciable influence on the magnetic field distribution in the active region during a flare. The SDO data with cadence of 45s have been used.

Introduction

The space craft measurements [1, 2] have shown that the solar flare energy is released in the corona above an active region (AR). The only source of energy in the corona, where $\beta = 8\pi nkT/B^2 \sim 10^{-6}$, is the magnetic field, but the potential magnetic field of photospheric sources cannot be transferred in plasma kinetic energy. 3D MHD numerical simulation shows that before the flare the current sheet is formed above AR. The magnetic energy stored in such a sheet is sufficient for a flare [3, 4]. In [5 - 8] it is concluded that flares can occur only over AR where the magnetic flux of AR becomes big enough. Analysis of magnetic flux [7, 8] in magnetic fields of NOAA 10486 and 10365 that produced a series of strong flares (class X) shows that such flares occur when the magnetic flux exceeds 10^{22} Mx. The flare appears, if field distribution on the photosphere is complex and has a complex polarity-inversion-lines. The work [8] also draws attention to the increased probability of large flare production at the strong magnetic field gradient across the polarity-inversion line. Here, we consider the magnetic field evolution of AR that produced of X-class flares, and to study AR magnetic field behavior before and during flares. Such information is needed to elucidate the mechanism of flares - whether the dissipation of magnetic energy during the flare occurs in the corona or on the solar surface. The results are also important for improving the flare prognoses.

The attempts to detect magnetic field evolution during a flare [9, 10] have demonstrated only a small (~100 G) field fluctuations at different points of AR, which the magnetic field reaches 3000 G. The work [10] draws attention to the movement of penumbra elements of of AR 11158, which are treated as the spot rotation with a speed of 90 deg/day. This movement began for the day before the X2.2 flare and continued after the flare, without showing any features during the flare.

Magnetograms of active regions during and before the flare

The AR 11158 began to form 02.11.2011 near the eastern limb (Fig. 1), and for four days became a strong region with two main complex polarity-inversion-lines and the strong fields of both polarities. This type of AR is highly likely to produce a powerful flare. Indeed, flares of classes C8 and then X2.2 appear (Fig. 1). The magnetograms show that NOAA 11158 magnetic fluxes of both polarities are increased within four days before the flare, and the distribution of the field was of complex nature with the intrusion of the field of one polarity in a spot of other polarity. It is clearly seen the sharp boundary between the magnetic fluxes of opposite polarity, indicating a large magnetic gradient across the polarity -reversion line. This is a typical preflare βγδ-configuration. Another important feature of the preflare evolution of this field is the lack of movement of magnetic fields that could lead to an accumulation of energy at the expense of helicity. The SDO HMI measurements are also demonstrate the growth of magnetic activity before the flares.

In Fig. 1 below the SDO measurements demonstrate the growth of X-rays activity before the flares with increasing the NOAA 11158 magnetic flux. Another important feature of the preflare evolution of this AR is the lack of movement in the magnetogramms, which could lead to an accumulation of energy at the expense of helicity.

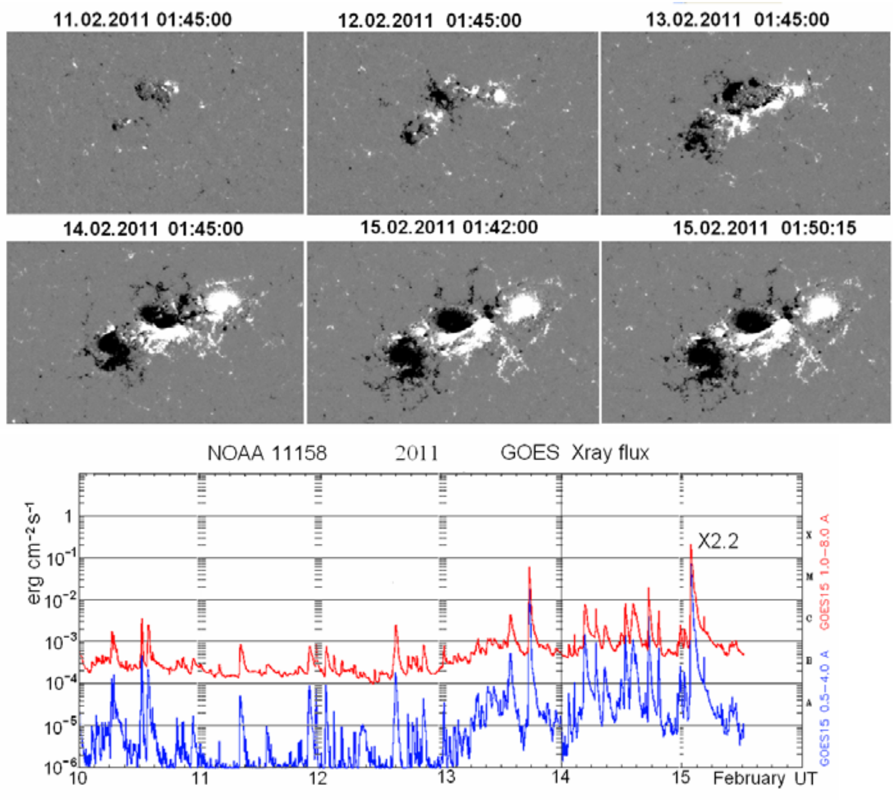

Fig. 1. Magnetograms NOAA 11158 show the development of the active region before the X2.2 flare 14.02.2011 and SDO measurements, showing an increase of flare activity.

Magnetogramms in Fig. 2, taken during the flare X2.2 15.02.2011 demonstrate also the high stability of the photospheric magnetic field just before the flare, throughout and after the flare. For more than two hours the magnetograms do not show any significant changes of the magnetic field, which can be attributed to the energy release of flares. These observations are fully consistent with the results of 3D MHD simulation that show the energy storage before the flare in the current sheet magnetic field high in the corona [3, 4], and the results of X-ray measurements, during the flare, which occurred on the limb. SDO data show that the primary flare energy release occurs in the corona.

A similar situation was observed during the major flare of X17, occurred over AR 10486 10.28.2003 (Fig. 3). Here also there is virtually unchanged magnetogram during the entire time of development and decay of the flare. The local field changes are not exceeding 1% - 2%. Such local micro changes has been observed in [9] in the flare X7.1 on January 20 2005.

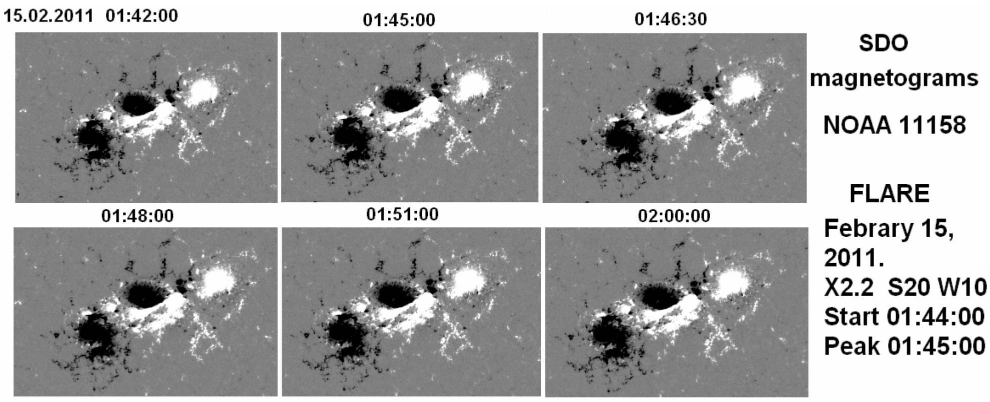

Fig. 2. NOAA 11158 magnetogram during the flare X2.2.

Fig. 4 shows the northern and southern magnetic fluxes of NOAA 10720 and dynamics of solar activity in AR during it passages across the solar disk. As for AR 10365, 10486 and 11158 observed increase of the flare activity with increasing magnetic flux [6, 7]. Flares of the X-class in NOAA 10720 also occur only at high magnetic flux order of 10^{22} Mx. The considerable change of magnetic flux in during the flare time is not observed. In the three cases analyzed the dynamics of AR, there is a significant disbalance between the northern and southern magnetic fluxes after the maximum of their values. It is not clear whether such a behavior of magnetic flux a natural.

The magnetic flux of the active region NOAA 10720 before the X-type flare

Investigations carried out for the flare in AR 10365 and 10486 have shown that powerful flares (X-type) begin to occur after increasing the magnetic flux of AR up to 10^{22} Mx [6, 7]. In this paper we studied AR 10720, that gave a series of X-type flares. We used measurements of the magnetic field component directed along the line-of-sight on the SDO. The magnitude of this component depends on the angle of view. To eliminate this dependence and determine the normal to the solar surface magnetic field component, the Laplace equation has been solved using the oblique derivative of the magnetic potential as the photospheric boundary conditions. This method is developed in [6, 7].

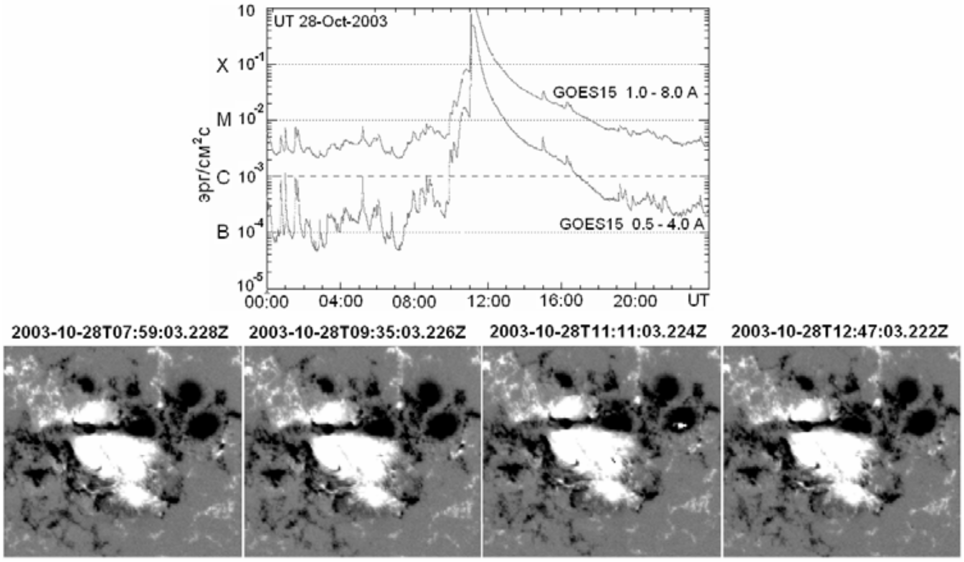

Fig. 3. X-ray flux during the flare and the SOHO MDI magnetograms 10.28.2003, demonstrating the high stability of NOAA 10486 during the flareX17

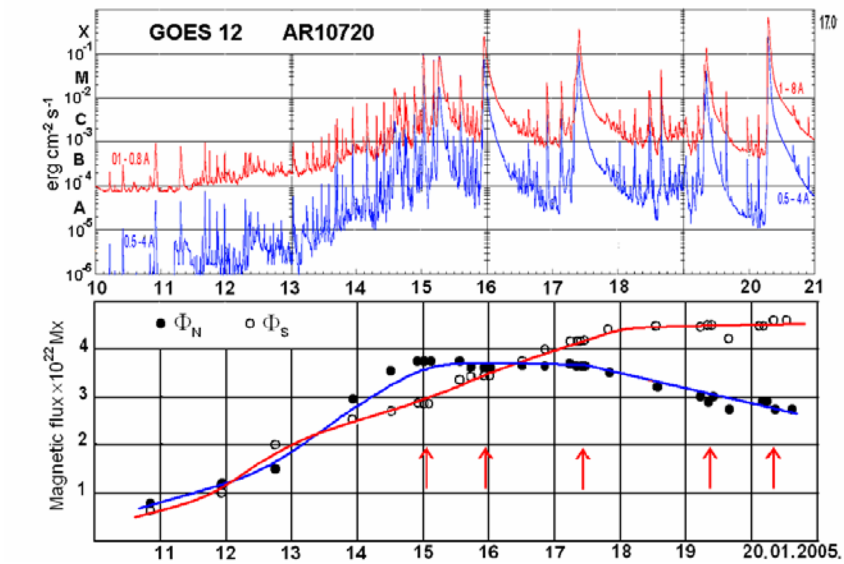

Fig 4. Powerful X-ray pulses and time dependence of NOAA 10720 magnetic flux.

Discussion

Analysis of magnetic fluxes in strong AR confirm the conclusions of [8, 11] that the condition for appearance of large (X-class) flares above such AR with the magnetic flux greater than 10^{22} Mx is a necessary but not sufficient. An example of the AR with the magnetic flux exceeding 10^{22} Mx, which produces no powerful flare, is AR 11190-11192. Fig. 5 shows distributions of the normal magnetic field component of AR 11190-11192 and NOAA 10365. The results of X-ray GOES measurements are also show. The values of the north and south magnetic fluxes in these AR are almost the same ~ 1.6×10^{22} Mx. However, only AR 10365 with complicated field distribution has produced a series of X-class flares, although the flare activity of the simple AR 11190-11192 does not exceed the C3. In AR 10365 local sources with north and south polarities are distributed randomly and their location cannot be classified as a simple dipole group (β-region). with simple preceding and following solar spots. The maxima of positive and negative polarities are distributed irregularly. At such situation the conditions for the formation of singular magnetic lines in the corona and, consequently, the possibility of flare production are appeared The demonstration in the numerical experiment the appearance of a current sheet with a large magnetic field should be a direct indication of the flare occurrence in the near future, but for the exact prediction of flare requires numerical simulation of the situation above AR in real time.

AR 11190-11192 has another type of field distribution (β-region). Here there is a distinct interface between magnetic sources of different polarity. It is clearly revealed two separate parts of the region, each of which contains magnetic sources of one direction. Parts of the region with different direction of the field are separated by the only inversion-polarity line (line of zero normal component).. Such a bipolar-type distribution of field sources on the photosphere must match to the magnetic loops in the corona, without singular lines and zero magnetic points.

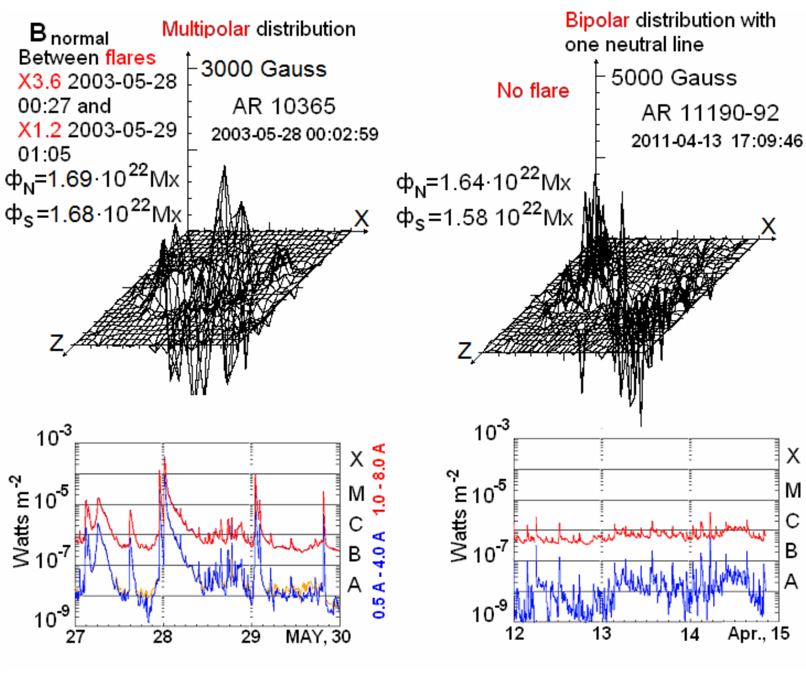

Fig. 5. The distributions of the magnetic field in AR's with strong magnetic flux for γ-type and β-type regions. X-rays shown are at the bottom.

Another feature of AR, causing big solar flares, is a compact arrangement of sunspots, providing a strong magnetic field gradient across the polarity inversion line. Only above such regions the strong current sheet can be created in the corona.

A number of β-type AR with large magnetic fluxes of northern and southern polarities, which separated by a distinct line of field inversion, have been observed in April-May 2011 (NOAA 11183, NOAA 11226, etc.). These regions are not produced X-class flares.

The existence of sources of the northern and southern polarities throughout γ-region, which produce complicated field with distribution of a multipolar character, leads to the formation of several singular magnetic lines in the corona [11]. In the vicinity of each singular line a current sheet can be formed. The series of flares is explained by appearance of several current sheets.

The absence of strong changes in the magnetic field distribution is clearly seen in all the investigated flares, including the long-X3.8 flare in AR 10720, is indicating the energy release in the corona. The conservation of magnetic flux in active regions during a flare has been reported also in [7]. These results demonstrate that energy released during the flare is accumulated in the corona before this flare. Such energy accumulation in a current sheet is demonstrated in 3D MHD numerical simulation, when initial and boundary conditions have been constructed from magnetic field measurements in a real active region.

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