

## MAGNETIC ENERGY ACUMULATION IN THE CORONAL CURRENT SHEET FOR A SOLAR FLARE

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**Abstract.** The solar flare energy is accumulated above the active region (AR) in the solar corona in the magnetic field of a current sheet. For a current sheet creation the X-type magnetic field singular line should exist above AR with the magnetic flux ( $\Phi > 10^{22}$  Mkc). The numerical magneto-hydrodynamic calculations performed by different authors and laboratory experiments showed that the current sheet creation and energy accumulation in its magnetic field are created due to the focusing of magnetic disturbances. The current sheet is only known object in the space, providing the slow accumulation of the huge amount of energy and its explosive release. Being high in the corona, the flare practically does not distort the magnetic field of AR.

### Introduction

Solar flares - the explosive processes of energy release in the solar corona that occur on the background of stable work of the Sun fusion reactor and conservation of the solar constant. Unexpectedly, during a few minutes the energy  $10^{32} - 10^{33}$  erg, which corresponds to the explosion of a million of hydrogen bombs, is released above AR. The existence of such gigantic explosions has remained long time outside the focus of attention of researchers because the power of Sun radiation ( $\sim 10^{33}$  erg/s) at the solar flare increases only by a fraction of the percent.

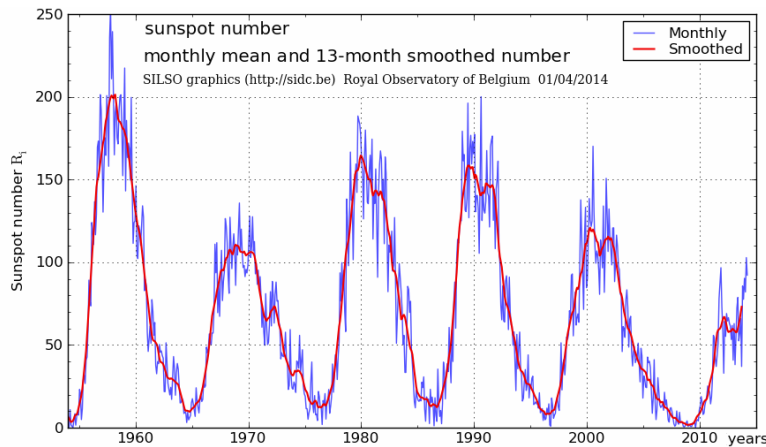
The first information about the solar flare has been appeared in 1860 by Karington, who reported the sudden appearance two visible bright spots on the Sun, which is accompanied by a strong magnetic storm on the Earth after  $\sim 18$  hours. A similar phenomenon occurred repeatedly, and in 1941 it was named solar flare by H.W. Newton. In 1946 it was shown that instead of the Fraunhofer hydrogen line the bright hydrogen emission line  $H_{\alpha}$  appears. There was impression that the energy release that causes the excitation of the hydrogen lines had been occurred by flare production on the Sun surface, and the term "chromospheric flare" was often used. Flares are observed on the solar disk in the AR. The AR is a place of concentration of dark spots (solar spots) with the temperature at  $1000^{\circ} - 2000^{\circ}$  below the photosphere temperature. The transverse size of a large sunspot is about  $10^{10}$  cm. The typical lifetime of a sunspot is about 10 days. The magnetic flux of northern or southern directions is concentrated in a sunspot. The magnetic field of a sunspot can reach several thousand gauss. The global solar magnetic field ( $\sim 1$  G) has dipole character. The direction of the dipole varies with a period of 11 years.

Observations of spots in the last 400 years have revealed the 11 year cycle of sunspot number change. At low solar activity usually about 10 spots is observed on the solar disk. In some rare cases, for example in the last activity minimum (2009 y), sunspots have been completely absent for a few weeks. During the big activity maximum the spot numbers exceed 150. Amplitude of the 11-year cycle undergoes strong modulation, and several authors drew attention to the existence of several long periods, which are superimposed on the clearly observed 11-year cycle. In periods of low activity, such as in the so-called Maunder minimum (1645 - 1715 years), 11 year maximums were virtually absent. During two cycles of activity in 1800 - 1820 years the number of spots does not exceed 50 (Dalton minimum). Unfortunately, reliable data on the number of sunspots became available only in the XX century. The last 70 years results of investigations of Royal Observatory of Belgium are shown in (Fig. 1). The attempts to establish empirical regularity modulation 11-year cycle have not been a successful, and the forecast of the next cycle is not unique.

The flare energy is released in the form of radiation in a wide frequency range, including thermal X ray with  $T \sim 10$  keV, hard  $\sim 100$  keV beam X-rays, proton fluxes with relativistic energies and supersonic coronal mass ejections. The coronal mass ejection may exceed  $10^{15}$  g at the velocity of  $\sim 10^8$  cm/s, exceeding the solar wind velocity. A shock wave is formed at the front of a supersonic coronal mass ejection. Coronal mass ejections perturb of the Earth magnetic field producing the magnetic storms and auroras.

Long-term observations have shown that solar flares appearance on the solar disk in the AR. The impression that the flare occurs on the surface of the Sun entrenched the term "chromospheric flare". However, X-ray measurements on devices Yohkoh and RHESSI [1] revealed that the primary flare energy release occurs not on the surface of the Sun, but in the corona above AR at the height order of 20 000 km. Opportunity for energy storage for a flare in the current sheet magnetic field in the solar corona was previously considered by S.I Syrovatskii and was confirmed in the numerical MHD calculations [2, 3]. The reviews [4, 5] describes three-dimensional MHD numerical experiments performed in 2000 - 2013, in which it have been shown that the current sheet appears before the flare in the solar corona above AR, and the energy accumulated in the current sheet magnetic field is released during a flare. On the photospheric boundary the AR magnetic field distribution is set that measured in pre-flare state, and no assumptions

about the mechanism of flare is introduced. The numerical MHD calculations shows formation of the current sheet in the vicinity of the X-type magnetic field line. This means that the configuration of the field in the AR for the flare appearance must be quite complicated.



**Figure 1.** Number of sunspots according to the Royal Observatory of Belgium

### Conditions of flare appearance

It was shown in [6-9] that the main condition for the large flare generation is the AR magnetic flux exceeding  $10^{22}$  Mx. Neither the imbalance of the northern and southern fluxes, nor rate of the magnetic flux change are signs of the flare appearance. In [10] it is noted that a big flare occurs over the photospheric field configuration resembling the fractal development. It is shown in [6-9] that a flare occurs over AR with a complicated distribution of the magnetic field, when a singular magnetic field line of type X appears in the corona. In the vicinity of this singular line magnetic perturbations are concentrated arriving in the pre-flare state from the photosphere, and a current sheet appears. The simple bipolar AR, which lines in the corona have the form of arches, does not produce flares. This fundamental fact is confirmed here by the new data. One of the main results of the numerical MHD simulation is demonstration of the current sheet formation before a flare and the accumulation of energy in the magnetic field of this current sheet. The energy amount is sufficient for the observed flare and coronal mass ejection. This energy is released due to the current sheet transition in an unstable state and its decay. In the numerical solution of the complete system of 3D MHD equations with dissipative terms the initial and boundary conditions on the photosphere are set from the magnetic field measurements by SOHO or SDO spacecraft before a real flare [4, 5, 11]. No assumptions about the mechanism of a solar flare are used in these numerical MHD calculations. The results of calculations performed at the real situation demonstrate the current sheet creation and the energy accumulation in the magnetic field for a flare. Formation of the current sheet takes place due to freezing of the magnetic field in the plasma when the MHD perturbations propagating from the photosphere in the conducting plasma create currents in the corona. These currents are concentrated in the singular magnetic field line vicinity of the X- type magnetic line, accumulating the free magnetic energy in the corona. The rapid dissipation of this magnetic energy due to the transition of the current sheet in an unstable state takes place. Current sheet decay should produce the complex phenomena observed at the flare, including a coronal mass ejection and generation of relativistic protons [12].

Current dissipation in the corona during a flare should not disturb the magnetic flux in the AR, since the flare occurs high in the corona over of AR, and cannot cause a strong perturbation of the magnetic field frozen into the dense matter of the photosphere. Therefore, the flare should not produce of any significant impact on the evolution of the AR magnetic field. Given the short duration of the flare (10 - 30 min) compared with the duration of the evolution of the magnetic field prior to the flare (3 - 5 days), the probability of random disturbances in AR during a flare is small. Perturbations AR during a flare can only wear casual character, as it is sometimes the case in the evolution of AR before and after the flare.

Attempts to detect magnetic field AR perturbations that correlated with the flare occurrence, carried out repeatedly, but without any success. A number of studies examined the possibility of energy supply from AR during a flare due to the magnetic helicity injection from the photosphere, i.e. to observe the possible current increasing along the magnetic field lines of AR during a flare. However, the correlation between the appearance of the helicity injection and flare occurrence was not detected. Any significant changes in the magnetic field AR was not registered during the flare, which could be attributed to the fast energy influx from the photosphere. The lack of flare correlation with appearance of strong photospheric disturbances excludes the possibility of mechanisms for development of photospheric flares. A detailed study of this phenomenon is presented in this paper.

Analysis of the dynamics of a ARs before class X flares made in [6-9] showed that large flares occur over ARs with the magnetic flux greater than  $\Phi = 10^{22}$  Mx. Typical behavior of the AR magnetic flux that appeared on the visible disk and gave a series of large flares is shown in Fig. 2. Vertical arrows indicate the time occurrence of large (Class X) flares. However, the condition  $\Phi > 10^{22}$  Mx is the necessary but not a sufficient. Flares occur only over the

AR having complex magnetic field distribution, when singular magnetic lines X-type exist in the corona over AR. Current sheets can be formed in the vicinity of such singular lines and accumulate magnetic energy for a flare, as it predicted by the flare electrodynamic model [4, 5].

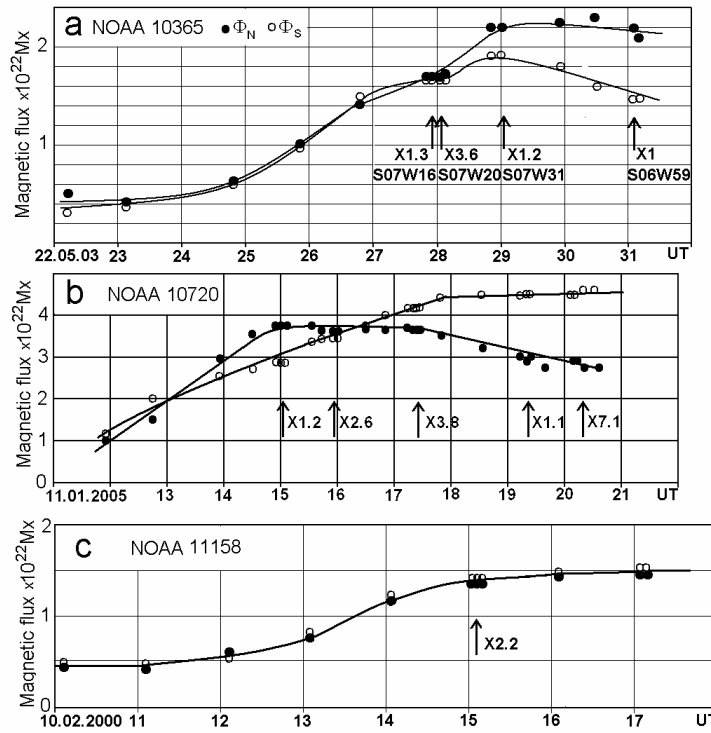


Figure 2. Solar flare production above the strong complicated active regions

**The magnetic field of the active region during a flare**

If the energy accumulation and the explosive flare phenomena occur high in the corona, the magnetic flux and the magnetic field distribution in the active region (i.e., on the surface of the Sun) must not change during the flare. The analysis of magnetic field distributions before the flare X3.4, during the flare, and after the flare confirms these conclusions [6-8]. The distribution of the field during flare remains unchanged with high accuracy. The North and South AR magnetic field fluxes (Fig. 3) remain also unchanged during a flare.

Analysis of a number of ARs shows that strong short-term changes in the magnetic field distribution in the AO are not initiating a flare. An example of such an event is shown in Fig. 4. So, solar flare appearance is not produced by magnetic pulses on the solar surface. The source of flare energy is located in the corona above AR.

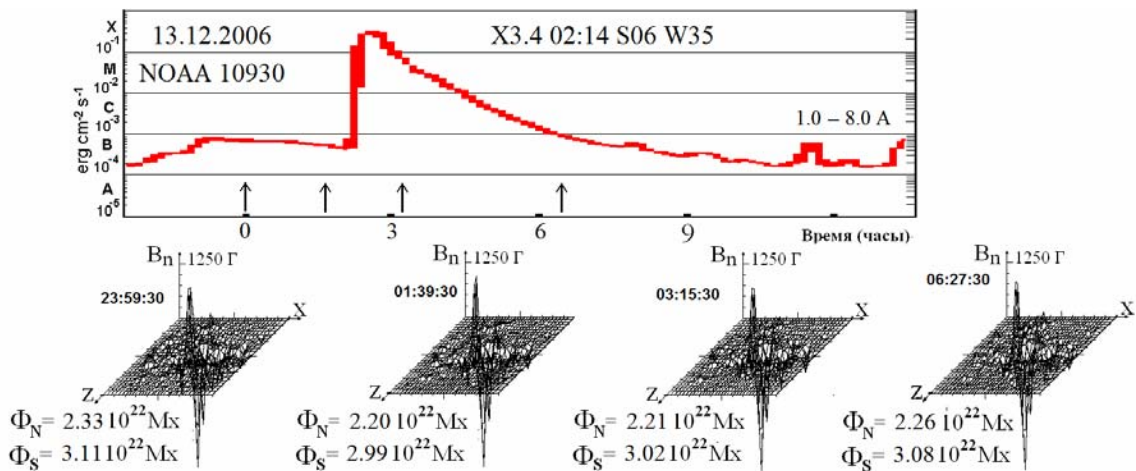


Figure 3. Magnetic field distribution during the flare

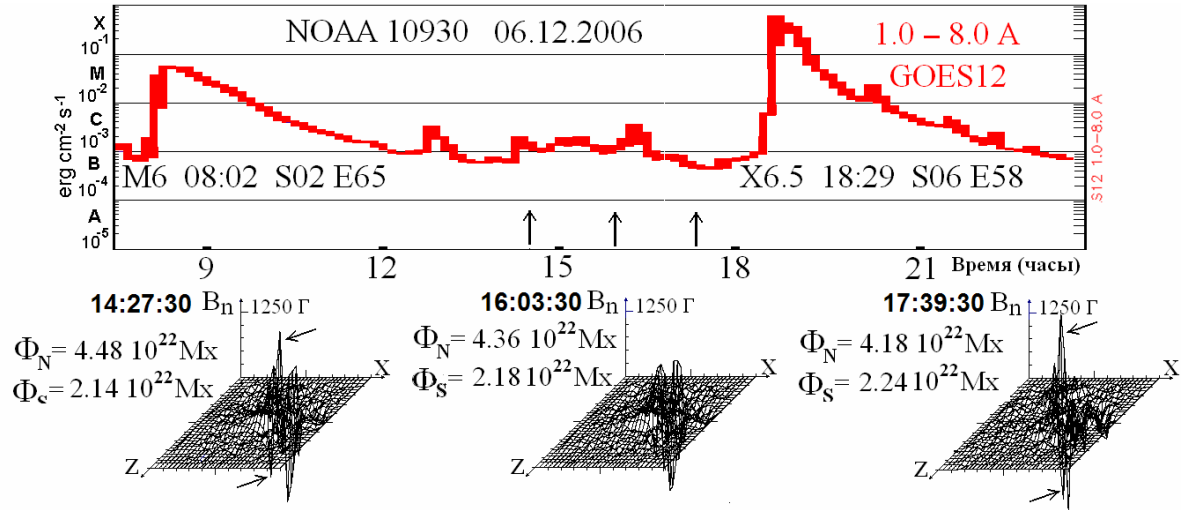


Figure 4. Solar flares are not connected with the strong change of magnetic disturbance in the active region

### Conclusion

The current sheet is the only known object in space, which is able to accumulate magnetic energy and then to release it explosively. Current sheet in the geomagnetic tail is causing geomagnetic storms. The role of the current sheet in the Earth's magnetosphere became known only after the spacecraft measurements whose orbits have crossed the geomagnetic tail. To investigate such possibility in the solar flares is still lacking the measurements in the corona, and the only approach to the analysis of the magnetic field configuration in the flare process is the three-dimensional MHD numerical simulation of the field dynamics at the initial and boundary conditions taken from the measurements in the pre-flare behavior of AO.

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