“Physics of Auroral Phenomena”, Proc. XXV Annual Seminar, Apatity, pp.133-136, 2002

Polar Geophysical Institute

CURRENT SHEET DECAY AS A UNITED MECHANISM OF THE PHENOMENA ASSOCIATED WITH A SOLAR FLARE

A.I. Podgorny[1] and I.M. Podgorny[2]

[1]*Lebedev Physical Institute, Moscow, Russia*
[2]*Institute for Astronomy RAN, Moscow, Russia*
podgorny@inasan.rssi.ru

Abstract. The solar flare is an explosive phenomena in the corona above an active region. The flare is accompanied by ultra high-energy proton flux and coronal mass ejection that initiates shock waves in the interplanetary space. The fast electron precipitation into chromosphere produces visible radiation and soft and hard x-rays. The beams of fast electrons, accelerated upward, produce radio bursts. According to the modern data all these phenomena and their sequences can be explained in the frame of vertical current sheet decay in the corona. This current sheet is not a neutral one. It possesses the normal magnetic field component. The plasma flow along the sheet supplies the current sheet stability. The results of numerical 3D MHD simulations explain all stages of solar flare.

Introduction

The solar flare term was introduced by H. Newton in 1949 because of the appearance of bright local luminosity in the Sun, after which the strong Earth magnetospheric disturbances followed tens of hours later. The energy release in a big flare is of the order of 10^{32} erg. Many spacecraft measurements have demonstrated that a substorm appears due to a fast plasma cloud approaching the Earth magnetosphere. The fast plasma ejection from the Sun has been named a transient or Coronal Mass Ejection (CME). About 10^{11} g of plasma are ejected from solar corona at a typical CME. In 1993 the sensational Gosling paper appears. He declares that "solar flares play no fundamental role in producing large geomagnetic storms". Some investigators consider Gosling statement to be wrong (*Dryer*, 1998; *Podgorny and Podgorny*, 2001), but others often accepted his statement. The reason for this misunderstanding consists in very different conditions for observation of a solar flare and CME. Solar flares are observed in the Sun disk as a local increase of luminosity in the visible light and X-rays, but CME can not be observed in the background of the bright disk. CME can be seen, if the event appears in the limb. The Gosling statement also contradicts the solar flare electrodynamical model based on energy storage in the current sheet above an active region and its fast release due to the current sheet instability (*Podgorny and Podgorny*, 2001). According to the electrodynamical model, plasma is accelerated in the current sheet during a flare and is ejected in the interplanetary space producing the CME. This model has been discussed in previous Apatity seminars.

A solar flare is often accompanied by giant long-lived post flare loops. The giant loop energy is comparable to the solar flare.

Time-table of the solar explosive phenomena

Resent observations of solar flare and CME appearance were carried out near the limb. That permits to trace flare soft X-ray emission and to observe CME development in visible region out of solar disk. The observations demonstrate that both events (solar flare and CME) are produced simultaneously in the same place (*Zhang et al*., 2001). These data and some of the previous observations permit to draw the typical time dependence for most representative phenomena of an explosive solar event (Fig. 1). The narrow bursts of radio emissions (Fig. 1a) and hard X-rays (Fig. 1b) appear simultaneously. It should be noted that the first burst of hard X-ray is produced in the corona above the active region. It is connected with primary energy release. The soft X-ray (Fig. 1c) and visible (Fig. 1d) radiation are generated in the chromosphere. They are produced by fast electrons that gain energy in field-aligned currents and precipitate in the chromosphere. Fig 1e and 1f show that plasma acceleration of CME begins in the corona simultaneously with X-ray burst. So, CME and solar flare are produced in the same explosive event. The time dependence for neutron monitor curve presented in Fig. 1g is shifted left. This shift takes into account that the neutrons are produced by flare high energy protons (W>1 GeV) arriving to magnetosphere along the Arhimed curve. The start of proton appearance coincides with the appearance of hard X-ray emission, but duration of neutron is much longer. Apparently, the long duration of the neutron monitor pulse is determined by diffusion transport of protons in the interplanetary space.

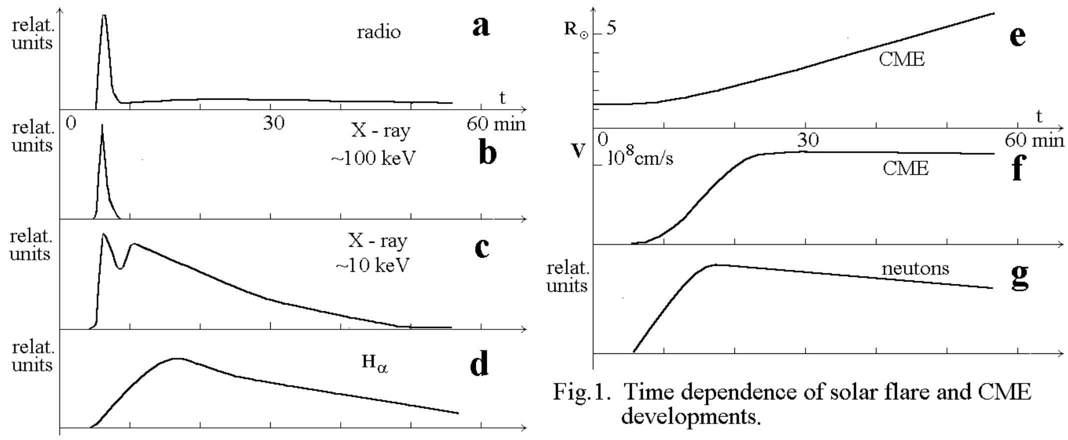

Fig.1. Time dependence of solar flare and CME developments.

The temporal relationship between presented in Fig. 1 time distributions shows, that all main phenomena of solar flares and CME are produced in a single explosive event in the corona.

Supra-arcade downflow phenomena and post-flare loops

In a number of explosive events, the soft X-ray images by Yohkoh spacecraft indicate a downward directed flow field in the region located above the flare arcade but below the place of primary energy release (*McKenzie and Hudson,* 2001). Plasma moves downward with the subalfvenic

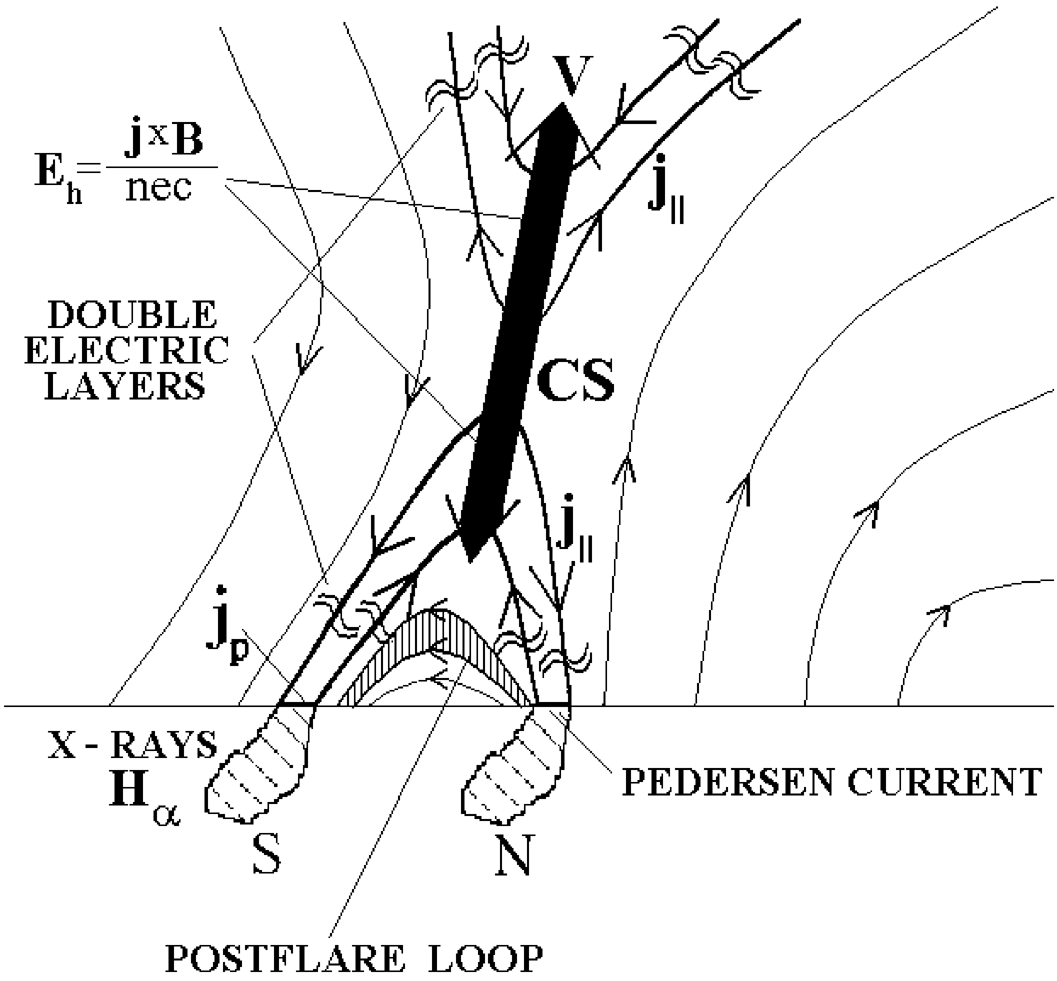

Fig.2. Electrodynamical solar flare model.

velocity. These flare events were associated with CME. It means that a flare is associated with plasma acceleration upward and downward. Such conclusion is in agreement with the flare electrodynamical model (Fig. 2). Fine lines in Fig. 2 show magnetic field lines. The magnetic field configuration corresponds to a vertical current sheet that appears above the active region due to disturbances focusing in the vicinity of a singular (neutral) line (*Podgorny, Podgorny*, 2001). Thick lines show field-aligned currents generated by Hall electric field **j**×**B**/nec in the current sheet. Plasma inflows in the current sheet from the left and from the right sides. It flows together with frozen-in magnetic lines. After magnetic lines reconnection plasma flows along the sheet. The **j**×**B**/c force accelerates plasma in both sides of a vertical current sheet (upward and downward). During the evolution, the current sheet becomes unstable, and the force increases rapidly. The downward acceleration is not so effective as the upward one, because the downward flow meets the strong magnetic field of arcade. The plasma temperature in the flow increases during reconnection. This hot plasma moves together with frozen-in magnetic field lines. The magnetic lines are piled up on top of a magnetic arc and produce a hot flare loop. New field lines arrive with hot plasma. The flow pattern produces impression that the bright front of a hot loop moves upward. Such development of loop with hot plasma on its outer part is observed (Forbes, 2000). The shadow area shows the hot part of the loop on top of arcades in Fig. 2. The fast electrons confined in the loop can produce long duration X-ray (Fig. 1c).

Bastille solar flare

The Bastille flare appeared 14 July 2001 above the NOAA 9077 active region. It was investigated by numerous instruments. The flare was associated with powerful CME. 3D MHD simulation was carried out (*Bilenko et al*., 2002) for investigation, if the energy for the Bastille flare had been accumulated in a current sheet in the corona indeed. The NOAA 9077 active region consists of seven spots. For setting the initial conditions the data obtained from 150-Foot Solar Tower at Mount Wilson Observatory (*ftp://howard.astro.ucla.edu/pub/obs/fits*) are used.

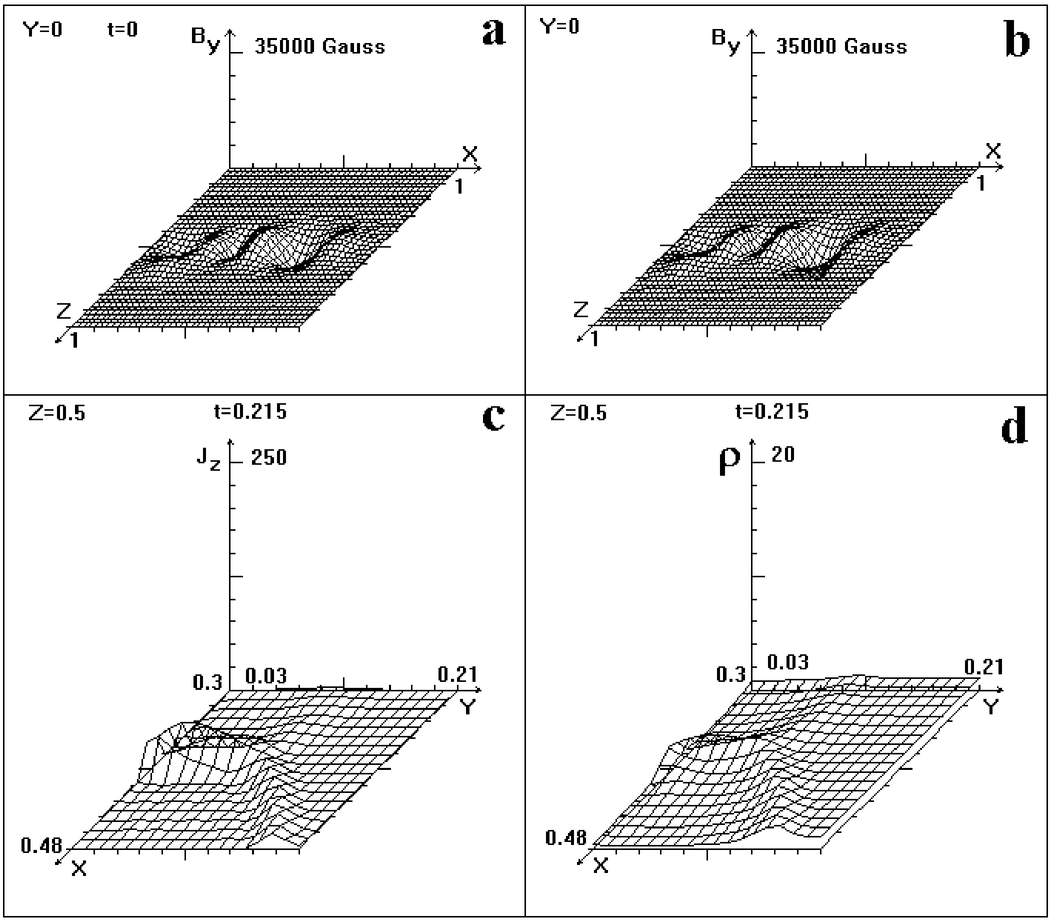

Fig. 3. Magnetic field distributions on the photosphere (a and b), current (c) and density (d) distributions in the current sheet.

Fields of vertical magnetic dipoles placed below the photosphere approximate the magnetic field of NOAA 9077 active region. Each of dipoles simulates a certain magnetic spot. Four days prior to the flare the spot 3 had increased two times. The dipole 6 increased between June 10 and 12. The magnetic field B_y distribution on the photosphere before magnetic field changing is presented in Fig. 3a. This magnetic field contains the neutral line above dipole 4. Fig. 3b shows the same distributions as in Fig. 3a, but for the new dipole values. The linear interpolation of magnetic field change is set in the photospheric boundary condition.

The results of MHD numerical simulation demonstrate current sheet appearance in the vicinity of the neutral line due to photospheric magnetic field change. Distributions of current density and plasma density in the current sheet are shown in Fig. 3c and Fig. 3d respectively. The current sheet is divided into two branches ("moustaches") at its upper age. Such behavior of plasma parameters corresponds to creation of slow shocks, which Petschek had predicted.

The numerical results show that energy accumulated in the current sheet $\iiint \mathbf{B}^2 dv - \iiint \mathbf{B}^2_{potential} dv$ is about 5×10^{32} erg. 3D integrals are taken in the vicinity of CS. Decay of this CS can produce a powerful solar flare. It should be emphasized that the numerical experiment has been carried out without any assumption about the mechanism of solar flare production. We just used photospheric magnetic measurements as the boundary conditions and calculated magnetic field distribution above the NOAA 9077 active region. Calculations demonstrate the current sheet creation and energy storage due to focusing of MHD disturbances that arrive from the photosphere. These disturbances are generated during preflare change of the magnetic field in the active region.

Conclusion

There are many observational data that confirm that the validity of the electrodynamical flare model is based on a current sheet decay above the active region. Flares and CME appear in the same explosive events. Plasma is ejected upward from the vertical current sheet producing a CME. Plasma ejection downward is responsible for hot plasma production on the outer part of a post flare loop. Long duration X-ray radiation can be explained by fast electron confinement in the loop.

Numerical MHD experiments demonstrate current sheet creation above an active region due to focusing MHD disturbances that arrived from the photosphere. The only necessary condition for current sheet creation is existence of the magnetic singular (neutral) line and corresponding photospheric disturbances. No assumption about the mechanism of solar flare production is introduced in these experiments.

Acknowledgments. This work was supported by Russian Foundation for Basic Research (project 01-02-16196) and Russian «Astronomiya» State Program.

References

Bilenko I. A., Podgorny A. I., Podgorny I. M. Current sheet above the NOAA 9077 active region prior to the flare on 2000 July 14. *Solar Phys*. 2002. In press.

Dryer M. et al. The solar minimum active region 7978, its 2.6X/1B flare, CME, and interplanetary shock propagation on 9 July 1996. *Solar Phys*. 181, 159, 1998.

Forbes T. G. Solar and stellar flares. *Phil. Trans. Soc. Lond. A.* 358, 711, 2000.

Gosling J. T. The solar flare myth. Journ. *Geophys. Res*. 98, 18937, 1993.

McKenzie D. E. and H. S. Hudson. Downflows and structure above LDE arcade: Possible signature of reconnection? *Earth Planet Space*. 53, 577, 2001.

Podgorny A. I., Podgorny I. M. Numerical simulation of a solar flare produced by the emergence of new magnetic flux. *Astronomy Reports*. 45, 60, 2001.

Podgorny A. I., Podgorny I. M. The mechanism of energy release and FAC generation during substorms and solar flares. *Phys. of Auroral Phenomena (Proc. 24 Apatity Seminar)* 2002, P. 92.

Zhang J., Dere K. P. Howard R. A. et al. On the temporal relationship between CME and flares. *Astrophys. J.* 599, 452, 2001.