Available online at www.sciencedirect.com

SciVerse ScienceDirect

Advances in Space Research 50 (2012) 1445–1449

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

MHD simulation of magnetic field configuration above the active region NOAA 10365

A.I. Podgorny [a,*], I.M. Podgorny [b]

[a] Lebedev Physical Institute RAS, Leninsky Prospect, 53, 119991 Moscow, Russia
[b] Institute for Astronomy RAS, Pyatnitskaya Str., 48, Moscow 119107, Russia

Received 17 May 2011; received in revised form 6 May 2012; accepted 13 July 2012
Available online 21 July 2012

Abstract

The current sheet (CS) creation before a flare in the vicinity of a singular line above the active region NOAA 10365 is shown in numerical experiments. Such a way the possibility of energy accumulation for a solar flare is demonstrated. These data and results of observation confirm the electrodynamical solar flare model that explains solar flares and CME appearance during CS disruption. The model explains also all phenomena observed in flares. For correct reproduction of the real boundary conditions the magnetic flux between spots should be taken into account. The full system of 3D MHD equations are solved using the PERESVET code. For setting the boundary conditions the method of photospheric magnetic maps is used. Such a method permits to take into account all evolution of photospherical magnetic field during several days before the flare.

Keywords: Solar flare; CME; Current sheet; Magnetic hydrodynamics

1. Introduction

The primordial flare energy release takes place high in the solar corona (Hiei and Hundhausen, 1996; Lin et al., 2003). The observational data do not permit to determine a magnetic field configuration in the solar corona, so for its finding it is necessary to solve the magneto hydrodynamical (MHD) equations in the active region of the solar corona, using the observed distributions of the photospheric magnetic field for setting the boundary conditions. 3D MHD numerical simulations demonstrate CS creation in the corona before a solar flare appearance (Podgorny and Podgorny, 1992). In previous MHD numerical experiments the magnetic field of solar spots have been approximated by the field of dipoles under the photosphere (Podgorny and Podgorny, 1992, 2001; Bilenko et al., 2002). The results of these simulations permit to create the electrodynamical solar flare model (Fig. 1(a)). According to the solar flare electrodynamical model the energy accumulation for flares and CME occurs in the corona in CS magnetic field. CS creation takes place in vicinity of a magnetic field singular line due to focusing of MHD disturbances that propagate from the photosphere. Magnetic field lines during a flare are shown in Fig. 1(a) by thin lines. The Hall electric field $\mathbf{E}_h = \mathbf{j} \times \mathbf{B}/nec$ produces a system of field-aligned currents (FAC). Upward and downward FAC are closed in the chromosphere by the Pedersen current. Electron acceleration takes place in upward FAC produced visible luminosity in the flare ribbons and X-rays. Plasma inflow in CS during fast magnetic reconnection produces Lorenz electric field $\mathbf{E} = -\mathbf{V} \times \mathbf{B}/c$ that directed perpendicular to plane of Fig. 1(a). The protons gain energy up to several tens of GeV while they accelerated along a singular line (Podgorny et al., 2010). Simultaneously plasma acceleration takes place along CS by $\mathbf{j} \times \mathbf{B}/c$ force. The pattern of vector velocity in the CS vicinity (Podgorny and Podgorny, 2001) is shown in Fig. 1(b). The plasma accelerated upward is ejected from the Sun producing CME. The investigations

* Corresponding author.
E-mail addresses: podgorny@fian.fiandns.mipt.ru (A.I. Podgorny), podgorny@inasan.ru (I.M. Podgorny).

0273-1177/$36.00 © 2012 COSPAR. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.asr.2012.07.014

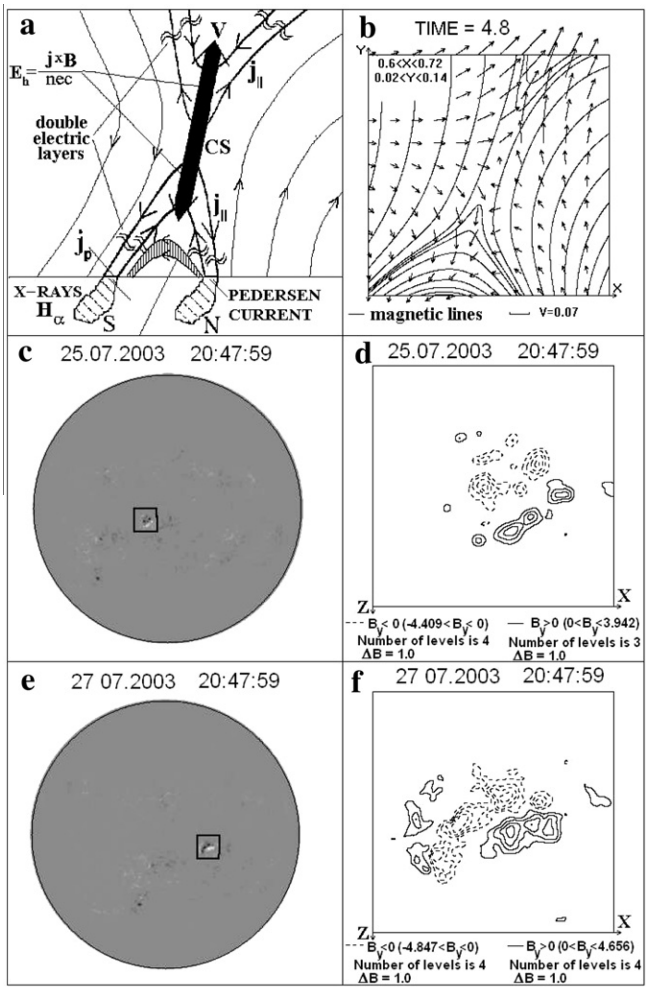

Fig. 1. (a) Solar flare model. Magnetic lines and FAC (thick lines). (b) Results of MHD simulation. Magnetic lines and velocity vectors in CS vicinity. (c) and (e) Position of numerical domain on solar disk. (d) and (f) Lines of the constant normal magnetic field component.

by Dryer (1998), Podgorny and Podgorny (2001) and Bilenko et al. (2002) indicate the possibility of such scenario of solar flare and CME appearance. It was shown that magnetic energy accumulation order of 10^{32} erg takes place. But the dipole field gives the magnetic field distribution only approximately. Here, for investigation of the magnetic field in the corona we use magnetic maps for setting boundary conditions directly. No assumptions are made about the mechanism of solar flare production. The possibility of CS appearance above an active region, and such a way demonstration of the possibility of energy accumulation for a solar flare is carried out for the real preflare conditions.

The mechanism of energy accumulation in the corona for solar flares was studied by several authors. The various possibilities of occurrence of solar flares were considered: the acceleration of a magnetic rope accompanied by pulling the field lines of a magnetic arch (Lin, 2004), the instability of a magnetic rope formed by rotation of sunspots (Torok and Kliem, 2005), and injection of magnetic helicity (Kusano, 2004; Chae et al., 2004; Chandra, 2009). When setting the initial conditions in numerical MHD simulation of these processes, Kusano (2003) assumptions are made about the mechanism of flare process development. Analyzing published investigations of magnetic twisting in the flare active regions, Wang et al. (2004) came to conclusion that the active region field is unable to create enough helicity for CME. It is concluded that the flare and CME appear due to the interaction of topologically independent magnetic flux systems.

In this paper, numerical simulations are done without any assumptions about the mechanism of flare energy accumulation. The energy accumulation as a result of CS appearance in the corona is demonstrated by numerical MHD simulation. The initial and boundary conditions are specified on the photosphere using the SOHO MDI magnetic field maps. The results of 3D MHD solution show the formation of CS in the corona before the flare. Using the initial and boundary conditions taken from observations of the active region NOAA 10365 before the real flare May 27, 2003, completely eliminates the subjective approach to the problem of energy storage for the flare. The simulation results show accumulation of the magnetic energy for the flare, but it is not artificially assumed at setting a numerical experiment.

2. The calculation of flare energy accumulation

The system of 3D MHD equations for compressible plasma accounting dissipation terms and anisotropy of the thermal conductivity is solved numerically in the dimensionless form in an active region of the solar corona:

$$\frac{\partial \mathbf{B}}{\partial t} = \mathrm{rot}(\mathbf{V}\times\mathbf{B}) - \frac{1}{\mathrm{Re}_m}\mathrm{rot}\left(\frac{\sigma_0}{\sigma}\mathrm{rot}\,\mathbf{B}\right) \quad (1)$$

$$\frac{\partial \rho}{\partial t} = -\mathrm{div}(\mathbf{V}\rho) \quad (2)$$

$$\frac{\partial \mathbf{V}}{\partial t} = -(\mathbf{V},\nabla)\mathbf{V} - \frac{\beta_0}{2\rho}\nabla(\rho T) - \frac{1}{\rho}(\mathbf{B}\times\mathrm{rot}\mathbf{B}) + \frac{1}{\mathrm{Re}\rho}\Delta\mathbf{V} + G_g\mathbf{G} \quad (3)$$

$$\frac{\partial T}{\partial t} = -(\mathbf{V},\nabla)T - (\gamma-1)T\,\mathrm{div}\,\mathbf{V} + (\gamma-1)\frac{2\sigma_0}{\mathrm{Re}_m\sigma\beta_0\rho}(\mathrm{rot}\,\mathbf{B})^2 - L(T) + K_B(\nabla T,\mathbf{B}) \quad (4)$$

The unit of the length L_0 is the size of the computational domain. Units of the magnetic field, plasma density, temperature, plasma velocity, and time are taken as correspondingly $B_0 = 300$ G, $\rho_0/m_i = 10^8$ cm^{-3}, $T_0 = 10^6$ K, the Alfvenic velocity $V_0 = V_A = B_0/\sqrt{4\pi\rho_0}$ and $t_0 = L_0/V_0$. $\mathrm{Re}_m = L_0V_0/v_{m0}$ is the magnetic Reynolds number, $v_{m0} = c^2/4\pi\sigma_0$ is the magnetic viscosity for the conductivity σ_0 at the initial temperature T_0, σ is the conductivity, $\sigma_0/\sigma = T^{-3/2}$. The cooling by radiation $L(T)$ and