"Physics of Auroral Phenomena", Proc. XXXI Annual Seminar, Apatity, pp. 126-129, 2008

Polar Geophysical Institute

MHD SIMULATION OF MULTIPLE CURRENT SHEET CREATION FOR SERIES OF ELEMENTARY FLARES

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

[1]*Lebedev Physical Institute RAS, Moscow, Russia podgorny@fian.fiandns.mipt.ru,*
[2]*Institute for Astronomy RAS, Moscow, Russia, podgorny@inasan.ru*

Abstract. MHD simulation is performed in the corona above the active region AR 0365 before the series of flares 26 and 27 May 2003. The special methods are developed which permit to set all conditions for MHD equations from observations. The behavior of the magnetic field and plasma near current sheets appeared in the corona is studied.

Introduction

To study the mechanism of solar flare and for improving of flare prognosis it is necessary to perform MHD simulations in the solar corona above an active region, where primordial flare energy release takes place. The fact of energy release high in the corona is established now by high resolution X-ray observations (see for example [1]). The flare energy can be stored in the magnetic field of a current sheet, which is created by focusing of disturbances near the singular line of the coronal magnetic field. Then after quasi-stationary evolution the current sheet transfers in an unstable state, and the instability causes the explosive energy release with all observational manifestations such as CME appearance, flare emissions, and particle acceleration described by electrodynamical model of the solar flare [2].

To perform MHD simulation for a real active region it is necessary take all conditions for MHD equations from observations. It is not supposed any mechanism of flare at setting of initial-boundary conditions. To study processes during the solar flare it is necessary to perform such simulations independently on preferred mechanism of the flare, would it be the current sheet or other one.

In early studies (see for example [3]) it has been used simplified magnetic field configurations, which approximated the observed field of spots by dipoles or monopoles. Such simulations permit to estimate energy for solar flare accumulated in the magnetic field of a current sheet. But they do not take into account the asymmetry of spots magnetic field and field between spots. So to find more precisely positions of current sheets and behavior of plasma and the magnetic field near them it is necessary to use directly distributions of the magnetic field observed on the photosphere for setting boundary and initial conditions. MHD simulations with such conditions have been performed in [6-8] and comparison of appeared current sheet position with the source of radio emission on the wave length 5.2 cm obtained on Siberian Solar Radio Telescope (SSRT, Irkutsk) confirm the solar flare mechanism based on fast energy release in a current sheet. These simulations have been done in the relatively small computational domain with the size 10^{10} cm. This domain contains active region AR 0365, but the field near the active region, which have influence on solution in corona above the active region, is not taken into account.

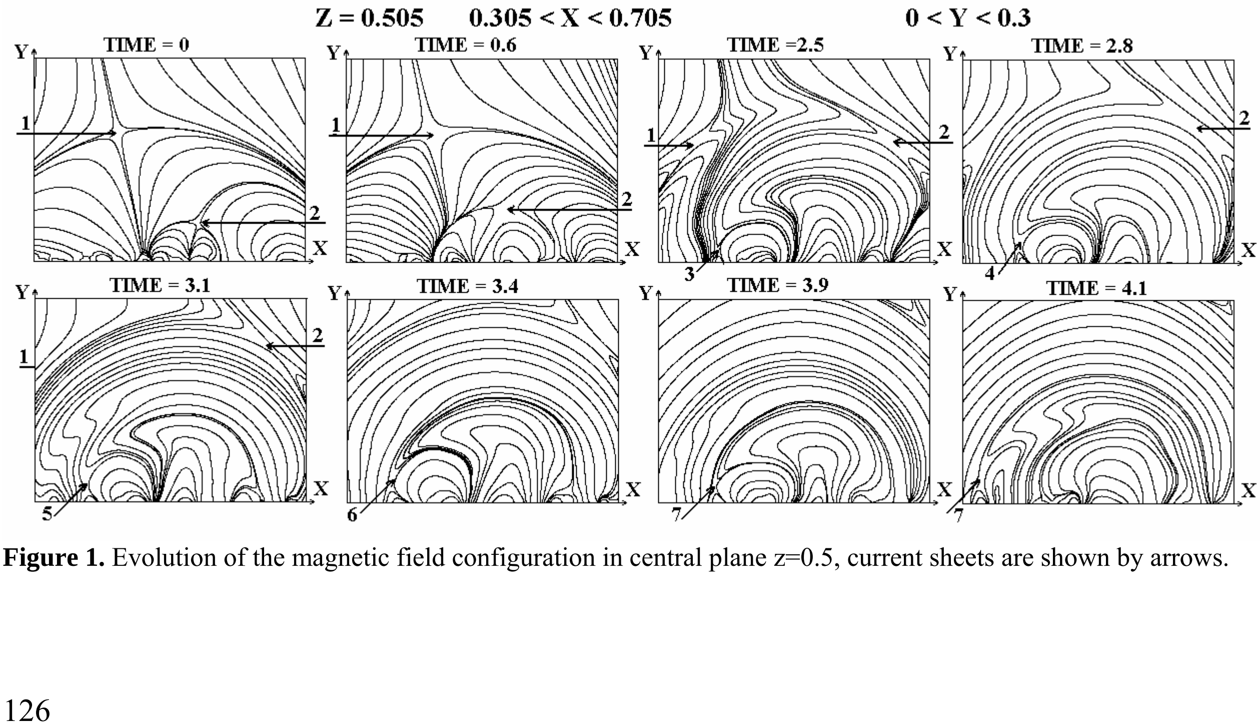

Figure 1. Evolution of the magnetic field configuration in central plane z=0.5, current sheets are shown by arrows.

In [9] it is shown, that to take into account all singularities of the magnetic field configuration, it is necessary to perform MHD simulations in a numerical domain which size is several times larger then the size of the active region. The simulations for AR 0365 have been done in the domain with the size 4×10^{10} cm. The simulations have been started several days before the series of flares 26 and 27 May 2003 produced by AR 0365. In this time moment strong disturbances in the corona were absent, and the potential magnetic field can be taken for setting initial conditions. To find the potential magnetic field the Laplace equation is solved numerically with oblique derivative boundary conditions on the photosphere. The distributions of the line-of-sight magnetic field component are taken from magnetic maps observed by SOHO MDI (http://soi.stanford.edu/magnetic/index5.html) for setting photospheric boundary conditions. Special methods are developed to obtain the potential field in such approximation to be stable solution of MHD equations system for using finite-difference scheme which is absolutely implicit and conservative relative to the magnetic flux. The space step of the finite-difference scheme is several order larger, then the thickness of a real current sheet, so the principle of limited simulation [10] is used. The details of setting the initial-boundary problem for MHD simulations in a real active region and numerical methods developed for this purposes are described in [6-9]. The numerical methods are described in [11].

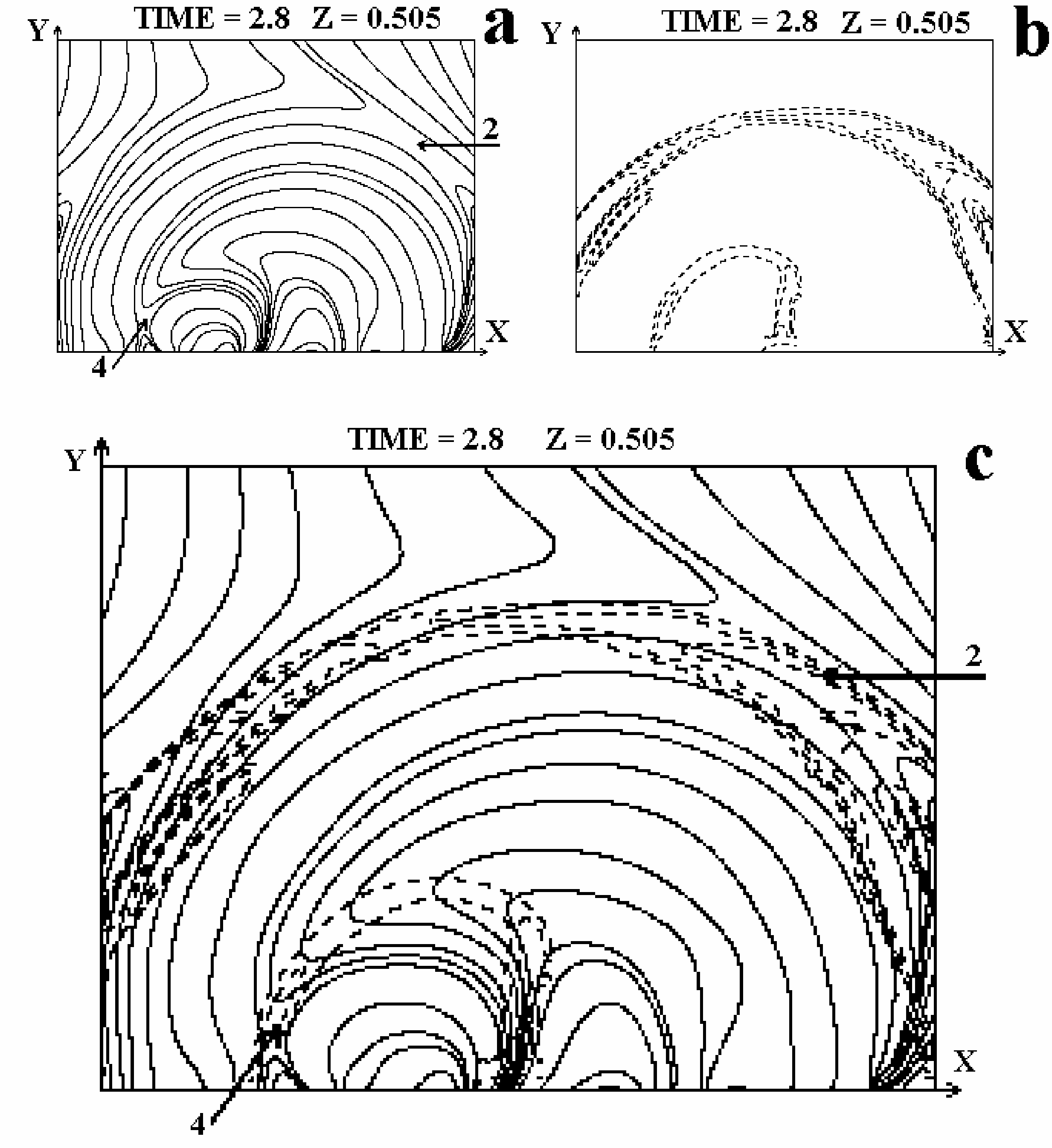

Figure 2. Magnetic field configuration (a), lines of equal current density (b), and magnetic field configuration together with lines of equal current density (c).

MHD simulations are performed in the computational domain (0≤ x ≤ 1, 0≤ y≤ 0.3, 0≤ z ≤ 1, in dimensionless units). The unit of the length is chosen as $L_0=4\times10^{10}$ cm. The Y-axis is directed away from the Sun normally to the photosphere. The XZ (y=0) plane is the photospheric plane with X-axis in the East to West direction and the Z-axis with in the North to South direction. The unit of the magnetic field B_0=300 Gauss is taken. The evolution of the magnetic field configuration in the central plane z=0.5 is shown briefly in Fig. 1. The details of dimensionless units and computational domain choosing and details of magnetic field configuration evolution in the central plane are contained in [9]. Here we study current sheet positions and plasma parameters distributions near the sheets in detail.

Magnetic field and plasma behavior near current sheets obtained by MHD simulations

In the magnetic lines pictures in the central plane (Fig. 1) it can be seen the magnetic field configuration deformed in X-points vicinities typically for current sheets (they are shown by arrows). It means that near each of X-point a current sheet appears with accumulated magnetic field energy. Appearing of several current sheets explain the series of flares in AR 0365. But such configuration in the vicinity of X-point does not mean that current sheet appears precisely in this X-point. It can be situated near this point and can be not precisely perpendicular to the central plane. The current sheet is situated in the X-point, if the current density maximum is coincided with this X-point. Fig. 2 shows that for current sheets 2 and 4 the current density maximums are situated near the X-points, but there is no precise coincidence. To find the current sheets positions and their situations in space the method is used, which is proposed in [7]. The position of the local maximum of absolute value of the current density |j| is found in 3D space. This maximum should be the center of the current sheet. The current sheet plane must be perpendicular to the plain, which contains the point of |j| maximum and which is perpendicular to the magnetic line passing through the point of |j| maximum. In this plain the magnetic field configuration of the current sheet must be represented.

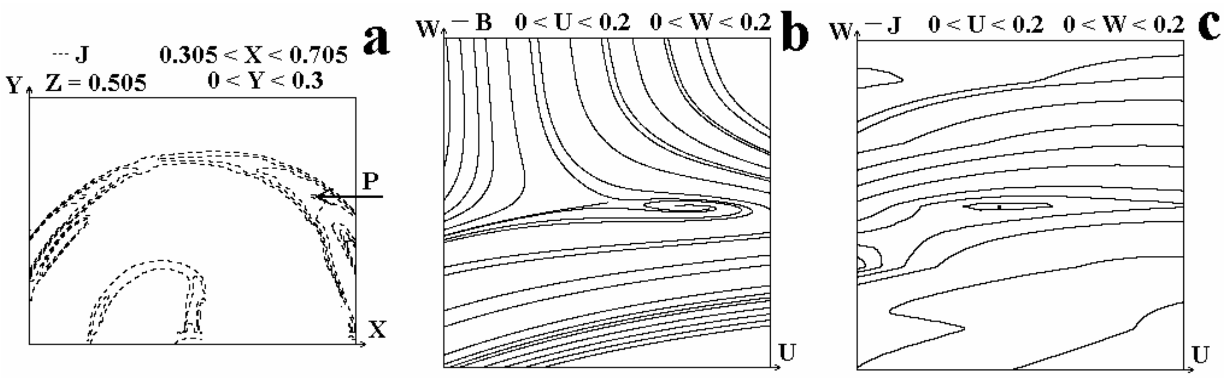

Figure 3. (a) Lines of equal current density, the arrow shows projection of the |j| maximum position for current sheet 2 on central plane (the point P). (b) The magnetic field configuration and (c) lines of equal current density in the plane perpendicular to the sheet.

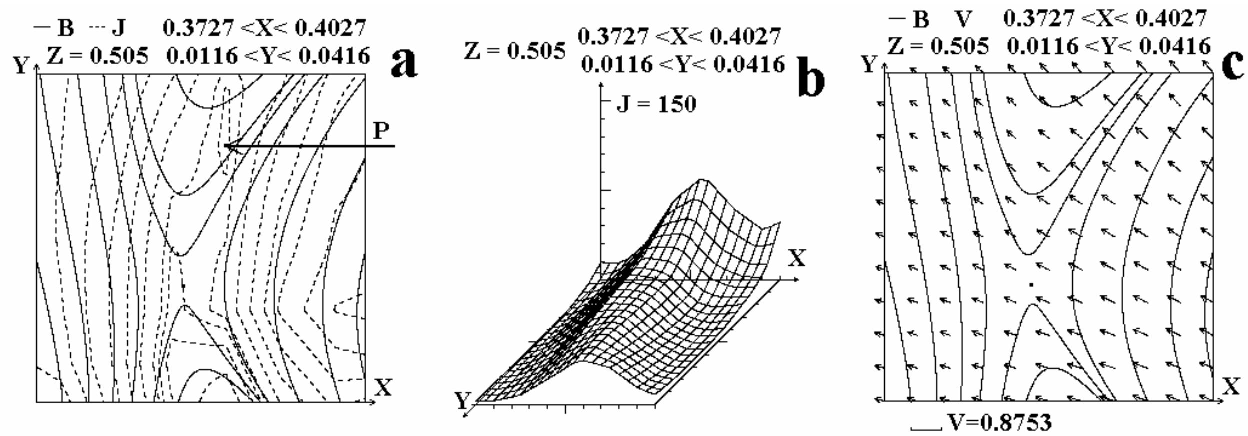

Figure 4. The magnetic field configuration, the current density distribution, and the plasma flow in the central plane z=0.5 for current sheet 4 in details. Position of |j| maximum is shown by the arrow as the point P.

The point of local |j| maximum for the current sheet 2 is situated near the central plane. The coordinates of this point are (x,y,z) = (0.59000, 0.255, 0.605). The projection of this point on plane z=0.5 is shown on Fig.3a by arrow as P. The magnetic field vector in this point is (B_x, B_y, B_z) = (-0.02907, 0.01635, -0.01222). In the plane perpendicular to this vector magnetic field configuration and the current density distribution are typical for current sheets (Fig.3b, c). The spiral-type magnetic configuration near the sheet is appeared due to overlay of bottle configuration and the field of a current directed perpendicular to this plane. It is not interesting from point of view of disturbances focusing in the vicinity of a singular line.

Figure 4 presents plasma parameters behavior in central plane near current sheet 4 in the small region with the size 0.03: $0.3727 < x < 0.4027$, $0.0116 < y < 0.0416$, $z = 0.5$. The point of the local |j| maximum for the current sheet 4 (0.39000, 0.035000, 0.5) is situated in the central plane, it is shown by the arrow as P in Fig.4a. The magnetic field vector in this point is $(B_x, B_y, B_z) = (0.09641, 0.09055, 0.1344)$. Plasma parameters behavior in the plane perpendicular to this vector is presented in Figure 5 in the small region with the size 0.03. In this plane the magnetic field configuration and the current density distribution are mostly pronounced to the current sheet. The plasma flow is directed perpendicular to the sheet, and the value of the plasma velocity is different on both sides of the sheets (Fig. 5c). It means that the current sheet moves as whole to the boundary of the active region. In the system of coordinates, which is moved together with the current sheet, plasma flows into the sheet from both its sides and then it flows along the sheet and is ejected from the sheet edges.

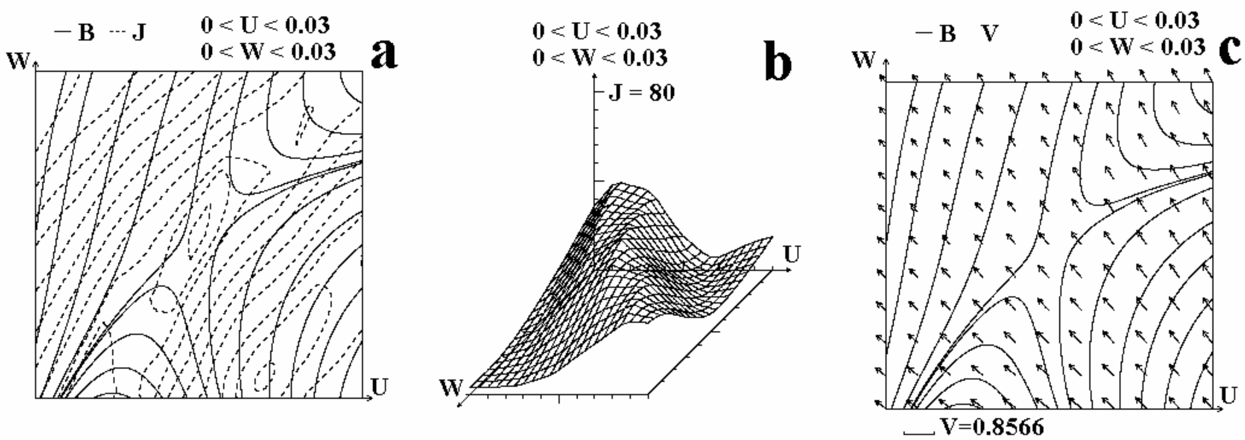

Figure 5. The magnetic field configuration, the current density distribution, and the plasma flow in the central plane z=0.5 for the current sheet 4 in the plane perpendicular to the sheet.

Conclusion

The positions of current sheets and their situation in 3D space are found. The magnetic field configurations and current density distributions for the current sheet are mostly pronounced in planes perpendicular to the sheet. To find current sheet positions more precisely in a future it is necessary to avoid strong currents, which are not associated with the sheets, but are caused by unrealistic fast changing of magnetic field on the photosphere in performed calculations. Changing of the magnetic field on the photosphere must be better corresponded to real evolution. For this purpose it will be used more fast computers and new numerical methods, which are developed now. It is also necessary to found positions of X-ray and radio sources from MHD simulations for comparing with observations. These sources of emission are supposed to be situated in the current sheets and places of intersection of magnetic lines passed from the sheet with the photosphere.

Acknowledgments. This work was supported by RFBR grant № 06-02-16006.

References

1. Lin R. P., Krucker, S., Hurford, G. J., *et al.*: 2003, *Astrophys. J.* **595**, L69.
2. Podgorny, A. I. and Podgorny, I. M.: 2006, *Astronomy Report*. 50, 842.
3. Bilenko I. A., Podgorny A. I., Podgorny I. M.: 2002, *Solar Phys.* **207**, 323.
6. Podgorny A. I., Podgorny I. M, Meshalkina N. S.: 2006: Proc. Physics of 29 Annual Seminar. Apatity. P. 203.
7. Podgorny A. I., Podgorny I. M, Meshalkina N. S.: 2007: *Solar System Research*. **41**, 322.
8. Podgorny A. I., Podgorny I. M, Meshalkina N. S.: 2008: *Journal of Atmospheric and Solar-Terr. Phys*. **70**, 621.
9. Podgorny A. I., Podgorny I. M, Meshalkina N. S.: 2007: Proc. Physics of 30 Annual Seminar. Apatity. P. 133.
10. Podgorny I. M.: 1978, *Fund. Cosmic Phys.* **1**, 1.
11. Podgorny A. I. and Podgorny I. M.: 2004: *Comput. Mathematics and Mathemat. Physics*. **44**, 1784.