"Physics of Auroral Phenomena", Proc. XXIX Annual Seminar, Apatity, pp. 203 - 206, 2006

Polar Geophysical Institute

CURRENT SHEET OF SOLAR CORONA IS THE SOURCE OF SOLAR FLARE RADIO EMISSION

A. I. Podgorny[1], I. M. Podgorny[2], N. S. Meshalkina[3]

[1]*Lebedev Physical Institute RAS, Moscow, Russia podgorny@fian.fiandns.mipt.ru,*
[2]*Institute for Astronomy RAS, Moscow, Russia, podgorny@inasan.ru*
[3]*Institute for Solar-Terrestrial Physics SO RAS, Irkutsk, Russia*

Abstract. The direct evidence of the solar flare electrodynamical model based on current sheet creation is presented. Numerical MHD simulation of the solar flare May 27, 2003 at 02:53:28 is carried out. It is shown current sheet (CS) creation and energy storage in its magnetic field. The calculations carried out for the active region AR 0365 show solar flare energy accumulation with current sheet creation in the vicinity of a singular line. Photospheric magnetic maps are used in the PERSVET code for setting boundary conditions. The results of calculation are compared with distribution of the radio-emission brightness temperature obtained by observations on the SSRT radio telescope (Irkutsk). The maximal radio-emission intensity during the flare coincides with the current density maximum in CS. This result opens possibility to use MHD simulation for essential increase of solar flare prognosis quality.

Introduction

The flare electrodynamical model is based on numerical 3D MHD simulation of energy accumulation in the CS magnetic field [1, 2]. The model explains phenomena observed during a flare including visible ribbons, X-ray radiation, coronal mass ejection and spectra of solar flare cosmic ray [3]. According to the flare electrodynamical model CS appears due to focusing of disturbances propagating from the photosphere in the vicinity a singular line above an active region. The primary flare energy release in the corona predicted by the electrodynamical model has been demonstrated by measurements of hard X-ray emission [4]. There is a temptation to explain these results by CS decay and explosive magnetic energy dissipation due to magnetic reconnection, but no possibilities still exists to measure the magnetic field in corona and to prove this suggestion.

The CS creation and energy storage in a preflare state has been demonstrated in 3D MHD numerical simulation. For this purposes approximation of the active region magnetic field by the field of magnetic dipoles placed under the photosphere is used. This approximation permits to show that in the CS magnetic field the energy about 10^{33} erg has been accumulated before the Bastille flare [5]. But such approximation does not include all a peculiarities of the photospheric preflare magnetic field, and location of CS can not be obtained with a high precision. A method of setting the photospheric magnetic field as a boundary condition is now developed. In this paper we present results of 3D MHD numerical simulation of CS creation above the active region AR 0365 and compare positions of this CS and the brightness temperature maximum of radio-emission of the flare May 27, 2003 at 02:53:28.

Numerical simulation

For calculation of magnetic field distribution in the corona it is necessary to have magnetic vector distribution on the photosphere for setting boundary conditions. However we have possessed only data for the magnetic component directed along a line of sight. For this reason magnetic components parallel to the photosphere are taken from distribution of the potential magnetic field that is obtained in calculations using the photospheric line of sight component. For this purposes Laplas equation is solved with an inclined derivative as a boundary condition. Such approximation is possible because CS is located high in the corona, so the CS magnetic field does not influence strongly on the photosphere magnetic field. The SOHO MDI (http://soi.stanford.edu/magnetic/index5.html). magnetic maps are used. The system of resistive MHD equations for compressible plasma is solved with an absolutely implicit scheme conservative relative to the magnetic flux. This scheme is realized in the PERESVET code. The MHD equations, numerical methods, initial and boundary conditions described in [6]. Some other methods are developed that permit to get a stable solution in places of strong magnetic field gradients.

The calculations are carried out with a net 101×51×101 in the region ($0<x<1$, $0<y<0.5$, $0<z<1$) in dimensionless units. $L_0=1.2\times10^{10}$ cm is used as the length unit. The photosphere contains X and Z axes. X is directed to the West, Z is directed to the South, and Y is directed from the Sun.

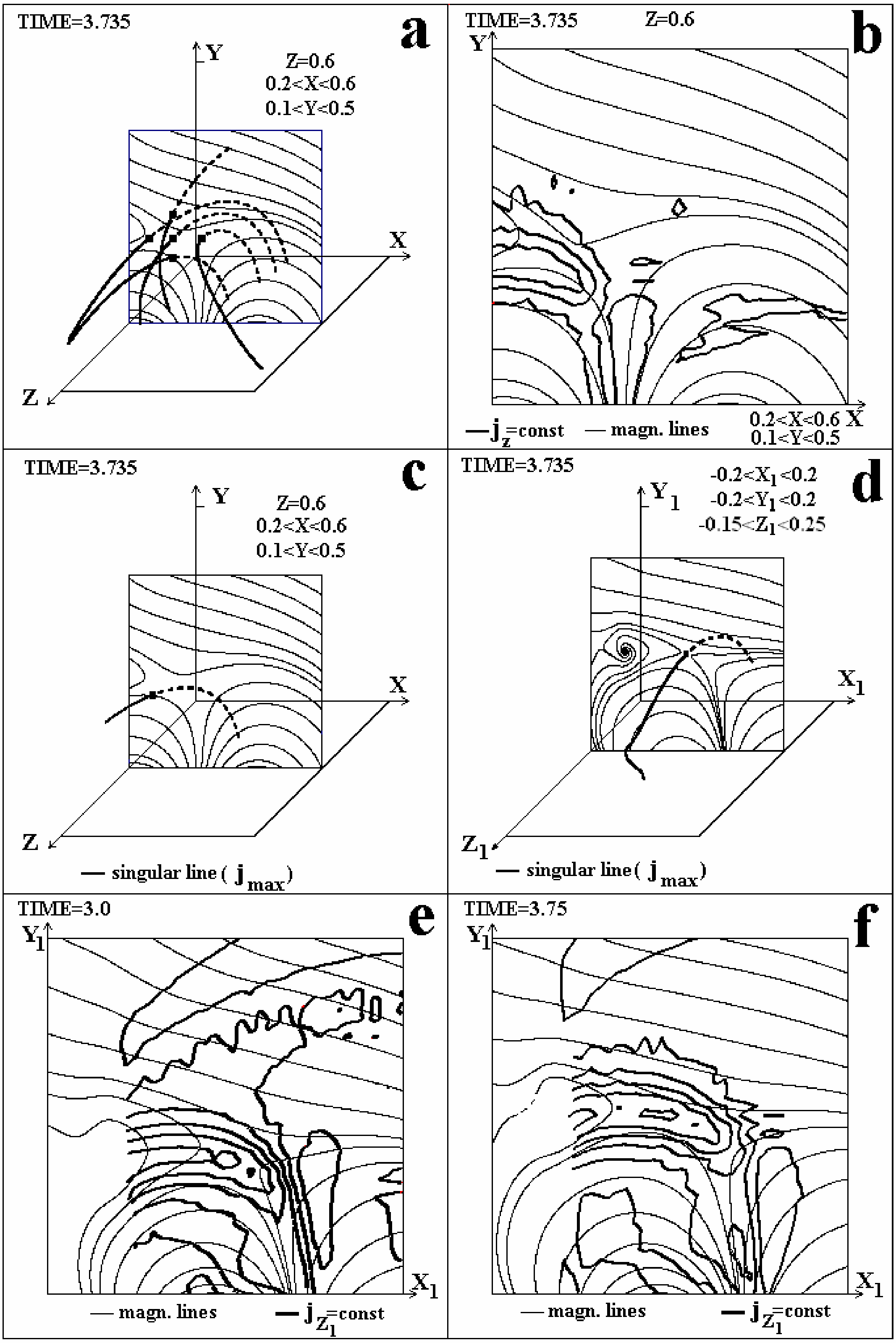

Figure 1. (a) magnetic line projections on the z=0.6 plane and magnetic lines in 3D space (thick lines, broken lines are located behind the z=0.6 plane); (b) magnetic lines and lines j_Z=const (thick lines) in the z=0.6 plane; (c) the singular line that intersects the plane z=0.6; (d, e, f) the singular line (thick line), magnetic lines, and lines of j=const; axis Z_1 is directed along the singular line; axes X_1 and Y_1 are perpendicular to the singular line in the point (x=0.25, y=0.25, z=0.6).

The numerical magnetic viscosity of the net 101×51×101 exceeds the physical magnetic viscosity by 8 orders of magnitude. At such viscosity the magnetic field diffusion prevents to CS creation. Because of that the time of photospheric magnetic field change is chosen much less than in a reality. Such numerical simulation permits to establish the fact of CS creation, its position, and magnetic field behavior in CS vicinity.

Some problems appear at analyzing CS evolution above a complicate active region. The AR 0365 was chosen for simulation, because of its magnetic field is not very complicated. The potential field above this AR in 3 days before the flare May 27, 2003 has been used as the initial magnetic field. The observed change of this photospheric magnetic field leads to evolution of the coronal magnetic configuration that simulated by solving MHD equations.

The singular line intersects the plane z=0.6 in the interval $0.2<x<0.5$. Calculations show that a powerful CS appears in vicinity of this singular line. We compare positions of calculated CS and the biggest radio emission burst.

Analysis of magnetic field behavior in planes perpendicular to the photosphere shows that the best conformity of a magnetic configuration to the CS magnetic field (Figure 1) is revealed in the plane z=0.6 (in dimensionless units). However, the zero X-point in the plane z=const is not exactly coincides with the point of a singular line intersection of this plane. As a result the maximum of the current density component perpendicular to the z=0.6 plane is not coincide with the X-point determined as a zero point for the magnetic plane components (Figure 1b). The exact coincidence must occur only at perpendicular intersection of a plane by a singular line. Several methods are developed for singular line search. The most effective criterion is based on finding of the current density maximum. The singular line that contains the current density maximum in the point (x=0.25, y=0.25, z=0.6) is shown in 3D space in Figure 1(c). Figures 1(d), 1(e) and 1(f) show lines of j_{max}=const and magnetic field configurations in a “singular line coordinate”. The Z_1 axis is tangential to the singular line; X_1 and Y_1 are perpendicular to this line. The good coincidence of the current density maximum and X-point can be considered as evidence that the singular line has been found correctly. It is reasonable to conclude that the maximum of plasma heating must occur in this point during a flare, because here the current density maximum is situated.

The Figure 1(e) and 1(f) present magnetic field configurations and lines of j=const at different times. It is seen only a negligible shift of the singular point. At time interval of 12 hours before the flare, there is no change of singular point photospheric coordinates. This fact permits to obtain singular point coordinates in any time of this interval in spite of different time scales in calculations and in the reality. The singular point position in a calculation region moves with an active region on the solar disk due to Sun rotation.

Flare radio emission

The May 27, 2003 flare at 02:53:28.54 has produced the strong increasing of the brightness temperature observed by the SSRT radio telescope on the wave 5.2 cm. The radio emission maximum coincides with soft X-rays maximum (Figure 2). The detected maximum of brightness temperature was 1.24×10^7 K^o. Distribution of radio emission intensity of the flare May 27, 2003. at 02:53:28.54 in the active region AR 0365 is shown in Figure 3(b) in the figure plane (perpendicular to a line of sight). The magnetogram of the magnetic field component along a line of sight is also shown. The SOHO MDI (http://soi.stanford.edu/magnetic/index5.html) is used. Heliocentric coordinates of the brightness temperature maximum are S6.58 W5.97. This maximum is shown by the cross in Figure 3(b).

Coordinates of the singular point of the numerical domain are (x=0.2482, y=0.2502, z=0.6). Its heliocentric coordinates on May 27, 2003 are S7.541 W4.692. The B(normal)=const lines calculated in potential approximation on the photosphere are shown in Figure 3(a). Lines of equal intensity of radio emission the flare magnetogram are shown in Figure 3(b) for comparison. The position of the flare is marked by a cross in both figures. The cross in Figure 3(a) is projection of the point (x=0.2482, y=0.2502, z=0.6) on the photosphere along a normal, and the cross in Figure 3(b) is the position of radio emission maximum. Positions of the current density maximum and the maximum of the radio emission intensity coincide with the accuracy of 1^o. The inexactitude does not surpass the accuracy of setting of boundary conditions on the photosphere, the accuracy of calculation, and accuracy of obtaining coordinates on the solar disk.

This result demonstrates possibility to employ numerical MHD simulation for essential improving the solar flare prognosis. It is necessary to develop further perfect numerical methods. A preliminary consideration shows that improving of the calculation method permits to perform calculation in rather short time.

Conclusion

Comparison of results of numerical MHD simulation and radio emission observation demonstrates convincing evidence of correctness of electrodynamical solar flare model based on energy accumulation in the magnetic field of a CS appeared above an active region. These results demonstrate also possibility to investigate the mechanism of solar flare creation by numerical methods.

Acknowledgments. Authors acknowledge fruitful cooperation with A. T. Altyntsev, B.B. Grechnev, and A. I. Hlystova. The work is supported by RFBR 06-02-16006, 04-02-39003 and RI-112/001/045(SS-477.2003.2).

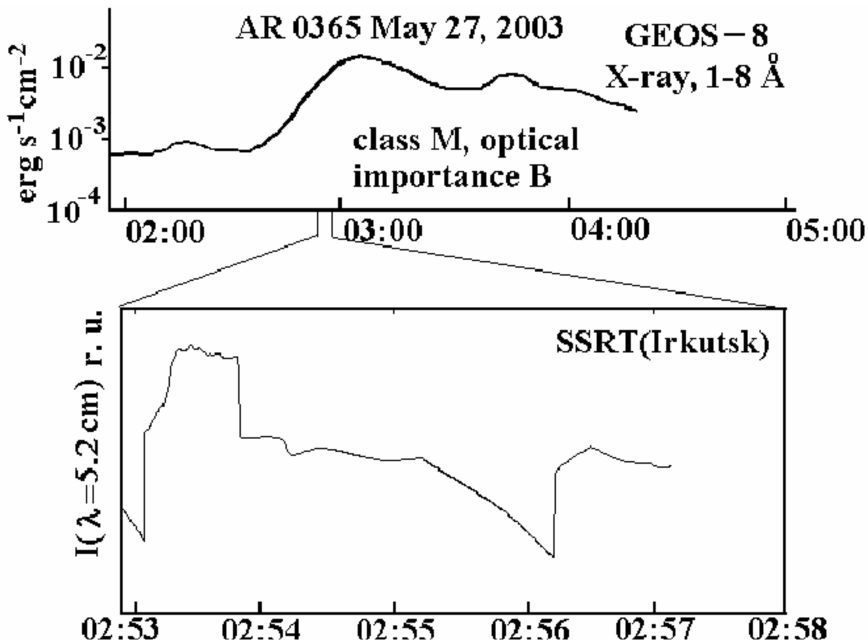

Figure 2. X-ray burst and radio emissions on the wave λ-5,2 cm.

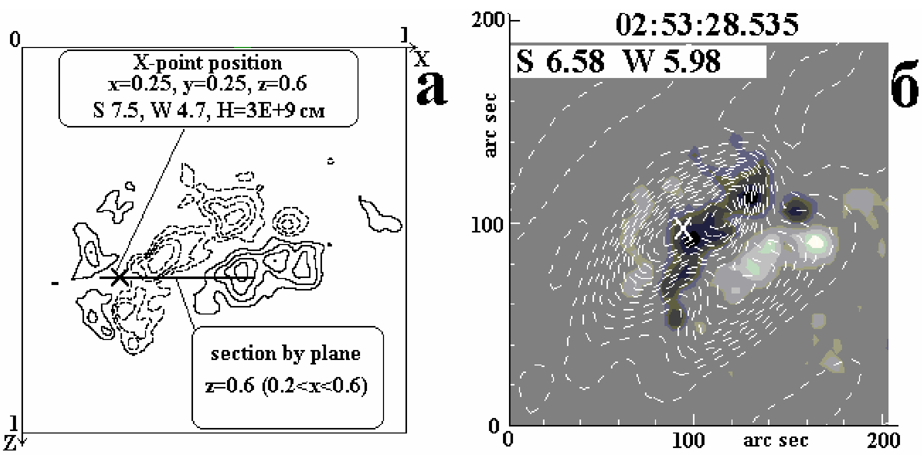

Figure 3. (a) lines of constant normal component of photospheric magnetic field (broken lines show negative field), the cross shows the point (x=0.25, y=0.25, z=0.6); (b) intensity of radio emission and the flare magnetogram, the cross shows the bright temperature maximum.

References

1. Podgorny A. I. and Podgorny I. M.: *Solar Phys*. **139**, 125 (1992).
2. Podgorny A. I. and Podgorny I. M.: *Astronomy Report*. **45**, 60 (2001).
3. Balabin Yu. V., Vashenuk E. V., Mingalev O. V, Podgorny A. I., and Podgorny I. M.: *Astronomy Report*. **49**, 837. (2005).
4. Masuda, S.; Kosugi, T., Hara, H., Tsuneta, S., and Ogawara, Y.: *Nature*. **371**, 495 (1994).
5. Bilenko I. A., Podgorny A. I., Podgorny I. M.: *Solar Phys*. **207,** 323 (2002).
6. Podgorny A. I. and Podgorny I. M.: *Comput. Mathematics and Mathemat. Physics*. **44**, 1784 (2004).