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EXTENDED SURFACES WITH INCREASED CURRENT DENSITY AND MAGNETIC FIELD CONFIGURATIONS IN THE VICINITY OF CURRENT DENSITY MAXIMA: MHD SIMULATION ABOVE THE ACTIVE REGION

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Abstract. The fast energy release in the solar corona is explained by solar flare mechanism of S.I. Syrovatsky, according to which the energy for flare is accumulated in the magnetic field of the current sheet. The observed manifestations of the flare are explained by the electrodynamic model of the solar flare proposed by I. M. Podgorny. To study the mechanism of a solar flare it is necessary to carry out MHD simulation above the active region, which is initiated several days before the flare. Here is the first attempt is make to solve the problem of coincidence of solar flare position obtained by MHD simulation with observed one using extended surface of magnetic lines, passing through the chain of current density maxima, which is found as result of MHD simulation.

Introduction

The primordial release of energy during solar flare in the solar corona above the active region at altitudes of 15 - 70 Mm is explained by solar flare mechanism of S.I. Syrovatsky [1], according to which the energy for flare is accumulated in the magnetic field of the current sheet. The numerous observations ([2] and others) show appearance of flares at such altitudes, which corresponds to results of MHD simulation above the active region. The observed manifestations of flare, appeared as result of fast magnetic energy release in the current sheet, are explained by the electrodynamic model of the solar flare proposed by I.M. Podgorny [3]. The model is based on observations and results of MHD simulation and uses analogies with the electrodynamic model of a substorm, previously developed by its author [4]. Since it is impossible to obtain the configuration of the magnetic field in the corona from observations, to study the physical mechanism of a solar flare it is necessary to carry out MHD simulations in the solar corona. Herewith, calculations must begin several days before the flare, when magnetic energy for the flare has not yet accumulated in the corona. When setting the problem, no assumptions were made about the mechanism of the solar flare. All conditions were taken from observations.

Methods of MHD simulation and search for solar flare positions using magnetic field configuration obtained by MHD simulation

MHD simulation is carried out above the active region AR 10365 in the computational domain in the corona in the form of rectangular parallelepiped 1×0.3×1 (the length unit was chosen $L_0 = 4\times10^{10}$ cm). The lower boundary of the computational domain y=0 (XZ) is located on the surface of the Sun and contains the active region. For the numerical solution of MHD equations, the absolutely implicit upwind finite-difference scheme, conservative relative the magnetic flux, has been developed [5]. Special methods were developed with the aim of constructing a scheme that remains stable for the maximum possible time step. The scheme was realized in the computer program PERESVET. Parallelization of calculations was carried out by computational threads on GPU using CUDA technology.

The magnetic field configuration obtained by MHD simulation is so complex that it is often impossible to determine directly the positions of singular lines and the current sheets appearing near them. For this purpose, a graphical search system [6] was developed, based on determining the positions of the current density maxima, which are achieved in the centers of the current sheets.

Results of MHD simulation: Arcade of magnetic lines passing through the chain of current density maxima

The comparison of the results of MHD simulation above the active region AO 10365 at 02:32:05 on May 26, 2003, three hours before the M 1.9 flare, with observations of microwave radio emission at a frequency of 17 GHz obtained with the Nobeyama radioheliograph, started in [7], is continued. In this moment the energy for solar flare is accumulated in the magnetic field and plasma of solar corona is heated by currents which creates this magnetic field. The magnetic field configuration is represented by lines passing through the current density maxima with numbers 145, 147, 194, 179, 4, 73, 105, 41, 12, 205, 123, 82, 84, 182 (Figure 1).

The magnetic field configurations at the selected points of the current density maxima indicate promotable conditions for the occurrence of flares at some maxima located in the region of bright flare emission. There is no significant dominance of the diverging magnetic field in the vicinity of these maxima. At the same time, maxima with such properties also occur outside the bright region of flare emission, and there are not many such maxima in the bright region compared to their total number.

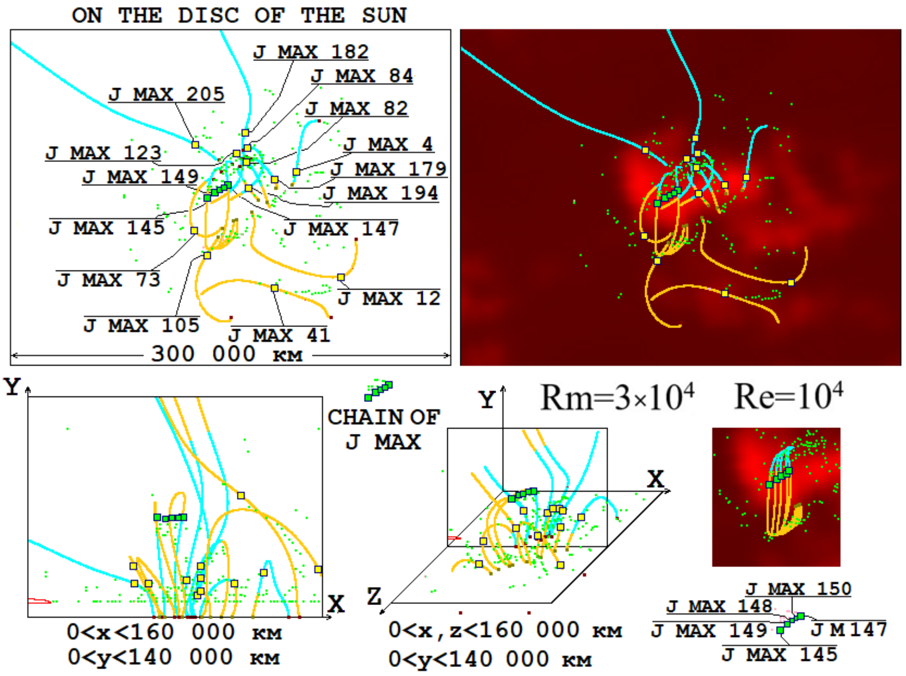

Figure 1. Positions of current density maxima in the computation domain of the corona in space, and their projections onto the central plane of the computation domain and onto the picture plane (perpendicular to the line of sight). The distribution of microwave radio emission at a frequency of 17 GHz, obtained on the solar disk using the Nobeyama radioheliograph, is superimposed on the picture plane. The magnetic field configuration is represented by magnetic lines passing through the selected current density maxima, and their projections onto the planes.

The problem of coincidence the regions of bright flare emission with the flare positions found from the MHD simulation results can be solved by the occurrence of a surface of increased current density passing through a chain of current density maxima. The maxima of this chain with numbers 145, 149, 148, 150 and 147 are shown in Figure 1 as green points. Magnetic lines on the solar disk passing through the maxima of this chain are shown separately on an enlarged scale.

Figure 2 shows the plane and three-dimensional configurations near the chain maxima in a square and a cube of 12,000 km in size. The two-dimensional region is a square of 12,000 km in size with the center at the point of the selected current density maximum, with the plane of the square being perpendicular to the magnetic field vector at the point of the selected maximum. The three-dimensional region is a cube of 12,000 km in size with the center at the point of the selected current density maximum, so that the two-dimensional region is the central plane of this cube, i.e. the plane passing through the center of the cube parallel to two faces of the cube and, accordingly, perpendicular to the other four faces of the cube. These configurations do not have properties that could significantly promote to the flare release of energy. In plane configurations, the divergent magnetic field dominates the X-type field, although not very strongly, and in three-dimensional configurations, the field lines do not diverge much along the singular line, which means a relatively large longitudinal component of the magnetic field, stabilizing the explosive instability.

The maxima of chain are located close to each other and the field configurations in their vicinity are very similar, so that an assumption arises that all the chain maxima belong to the same current sheet of considerable width (~50,000 km), i.e. an extended surface with increased current density. This assumption is confirmed by the study of plane and three-dimensional configurations in a square and in a cube with a larger size of 80,000 km with the center in the 148th maximum located in the middle of the chain (Fig. 3, second row). The square is the central plane of the cube. Magnetic lines in the cube passing through the maxima of chain form an arcade (Fig. 3, last figure of the second row).

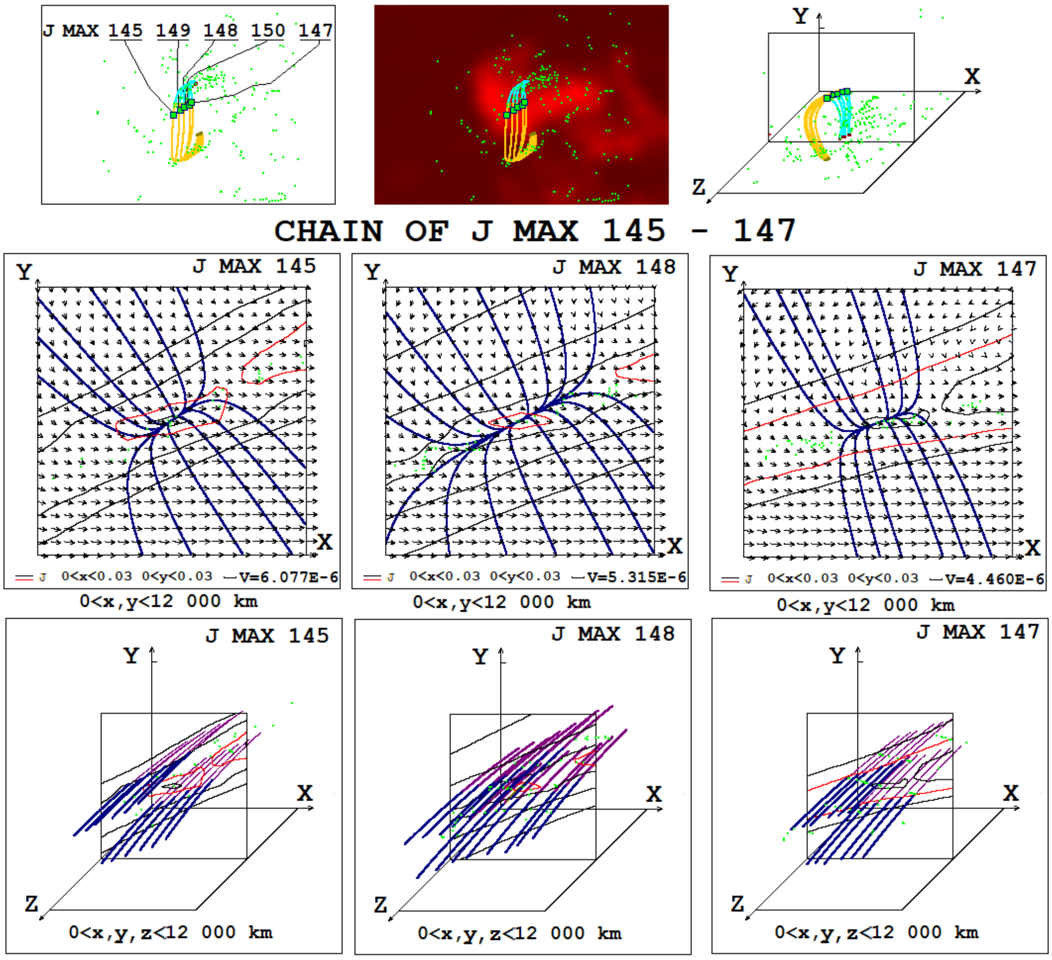

Figure 2. Plane and spatial configurations in regions of 12,000 km in size with centers at the points of the chain of maxima.

The current density maxima are not located at the top of loop. It is necessary to construct a magnetic configuration at the top of loop, where there should be practically no diverging field superimposed on the X-type field and where solar flares are most likely to occur. Such a construction is also necessary to verify the coincidence of the surface of the magnetic lines passing through the chain of current density maxima with the surface of increased current density. In the upper row of Figure 3, the chain maxima points are marked in green, and the points lying at the tops loop are marked in yellow. These points at the top of arcade lie in the central plane of a large cube which center is located at the top of arcade. They are situated in the region of increased current density, as can be seen from their location in the central plane onto which the current density level lines are plotted (Fig. 3, first pictures of the second and third rows), which confirms the coincidence of the surface of arcade lines with the surface of increased current density.

The plane maxima in the central plane at the top of arch are marked in red. The points of intersection of the magnetic lines passing through these plane maxima with the central plane of the chain of maxima are also marked in red in the upper row of Figure 3.

Eight lines, five of which pass through the maxima of the chain and three through the plane maxima of the current density, represent an arcade, which is presented in a large cube (80,000 km) with the center at the point at the top of the arcade (Fig. 3, last figure of the third row).

Magnetic field configurations (Fig. 4) in the vicinity of the loop top points in the central plane of 12,000 km in size have properties that promote the development of flare instability. In most of these small regions, the X-type field dominates, while in other regions, the diverging field dominates very weakly. In the three-dimensional configuration, the field lines diverge significantly in the direction along the singular line, which means that the longitudinal component of the magnetic field is relatively weak, so that it will not be able to stabilize flare instability.

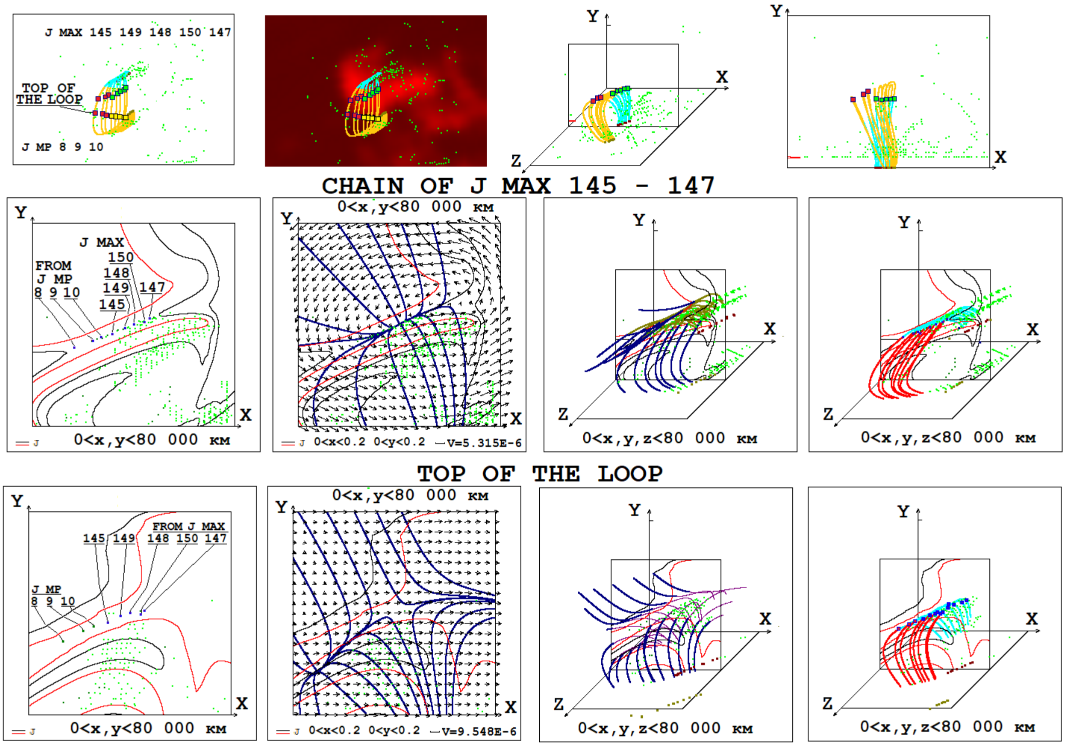

Figure 3. Plane and spatial configurations in large regions of 80,000 km. In the central part of one of these regions there is a chain of maxima. In the central part of another region there are points at the top of an arch located on magnetic lines coming out from the points of the chain of maxima.

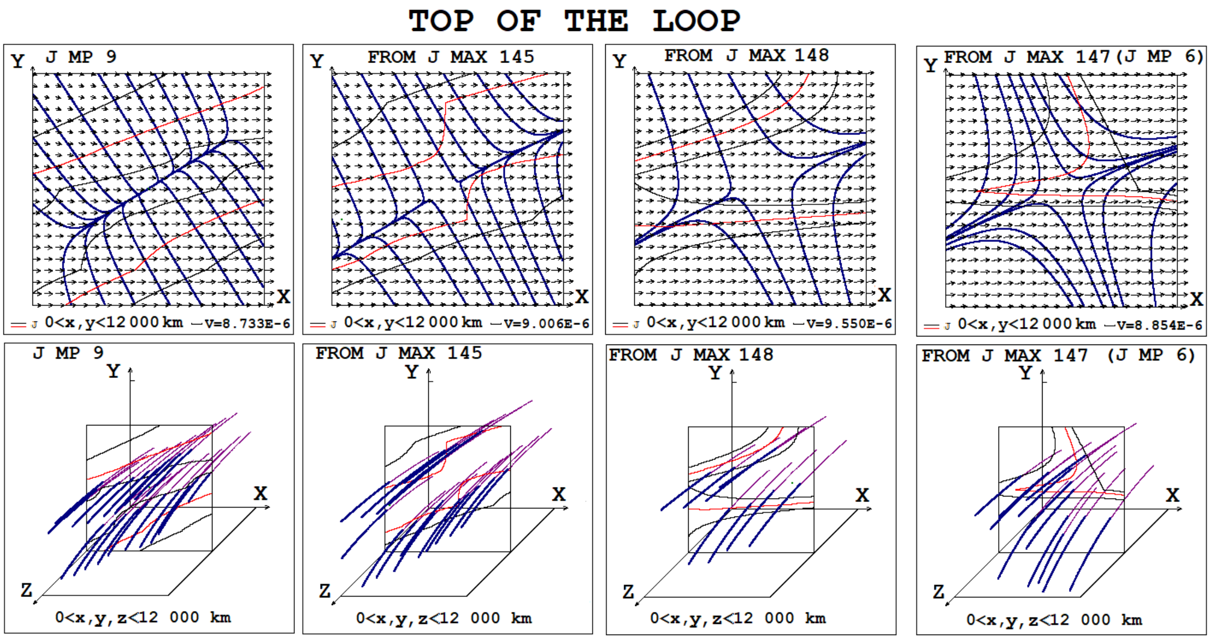

Figure 4. Plane and spatial configurations in regions of 12,000 km in size with centers at the points at the top of the arch located on magnetic lines coming out of the points of the chain of maxima.

Comparison of two-dimensional and three-dimensional configurations in small regions of 12,000 km in size for the points of the chain of maxima and the points at the top of the arcade (Fig. 2 and Fig. 4) shows a much more promotable situation for the occurrence of flare instability at the loop tops, rather than at the points of the chain maxima. The same result is obtained by comparing the magnetic field configurations in large regions (80,000 km in size) at the location of the chain of maxima and at the top of the arch (Fig. 3).

Conclusion

Occurrence of arcade of magnetic lines with increased current density can solve the problem of coincidence regions of bright flare emission with the positions of flares found from the results of MHD simulation. The instability leading to the main energy release of the flare can begin at the top of the arcade, where the properties of the magnetic field configuration promote to the occurrence of instability of the current sheet. Further, the instability can spread to the entire region of the current sheet, which is confirmed by the location of the entire arcade with an increased current density in the region of bright flare emission.

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