§31. Simulation Study of the Solar Flare Triggering Mechanism

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Solar flares are the most explosive phenomena in our solar system, and it is believed to be caused by an abrupt liberation of free energy accumulated in the solar coronal magnetic field through magnetic reconnection. However, the triggering mechanism of flares has not yet been well understood, and the fundamental questions, how and why reconnection starts as an explosive process in flare events, still remain to be solved.

Recently, we developed a new methodology, which enables the measurement of the magnetic helicity flux through the photospheric solar surface,[1,2] and using that we investigated the correlation between the flare onset and the injection of magnetic helicity into the corona.[3,4] As a result, it was first found that solar flares tend to occur in a region where the sign of magnetic shear is steeply reversed above the solar surface, although there is no clear correlation between the amplitude of magnetic helicity and the flare onset.

Based on the facts, we hypothesized that flares could be caused by the reversal of magnetic shear, and we developed the three-dimensional magnetohydrodynamic (MHD) numerical simulations,[5] aiming to examine the hypothesis. The photospheric boundary condition was modeled by applying a slow foot-point motion, which reverses the pre-loaded magnetic shear, on the vicinity of magnetic neutral line. The calculation was carried out using the finite difference scheme, in which 256x256x512 grid points were contained in the early phase, and they were extended to 256x256x1024 grid points in the late phase, using the cubic spline interpolation technique.

The simulation results clearly indicated that the reversal of magnetic shear can cause a large scale eruption of the magnetic arcade through a series of two different kinds of magnetic reconnections.[6] The first reconnection is initiated by the resistive tearing mode instability growing on the magnetic shear inversion layer, and it annihilates the sheared magnetic fluxes, which are oppositely directed along the magnetic neutral line, as shown in Fig.1. As a result of that, the magnetic arcade collapses into the reconnection point because the reduced axial magnetic flux along the arcade axis cannot sustain the tension force of magnetic loop, and the new current sheet is generated above and below the shear inversion layer. The generation of new current sheets is followed by another magnetic reconnection, which drives the eruption of the sheared magnetic arcade, as seen in Fig.2. Because the high speed downward stream out of the second reconnection point further drives the first reconnection, mutual excitation of two reconnections may explain the explosive property of flare onset. This process can be understood as a self-exciting process of magnetic reconnection in the three-dimensional space.

The simulation results not only well explain the onset mechanism of flares, but also are consistent with the several properties observed in pre-flare phase. For instance, the tearing mode reconnection on the magnetic shear inversion layer may account for the formation of sigmoidal structure in the coronal magnetic field, which is widely thought as a precursor of eruptive flare events. Furthermore, it was recently revealed by the TRACE satellite observations that the UV brightening in the pre-flare phase expanded from a point where the magnetic shear was steeply reversed near the magnetic neutral line. The all results from the simulation as well as the observations strongly support the hypothesis that solar flares can be caused by the reversal of magnetic shear.

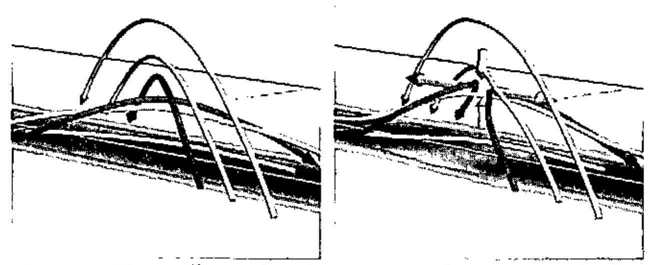

Fig. 1. Three-dimensional structure of the magnetic field lines (*left*) before and (*right*) after magnetic reconnection at the magnetic shear inversion layer. Thick arrows illustrate the typical flow around the reconnection point.

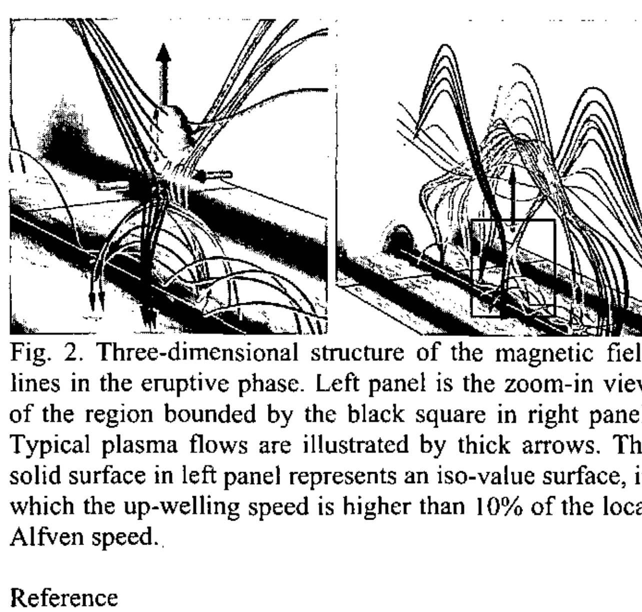

Fig. 2. Three-dimensional structure of the magnetic field lines in the eruptive phase. Left panel is the zoom-in view of the region bounded by the black square in right panel. Typical plasma flows are illustrated by thick arrows. The solid surface in left panel represents an iso-value surface, in which the up-welling speed is higher than 10% of the local Alfven speed.

Reference

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