§26. Simulation Study of the Formation Mechanism of Sigmoidal Structure in the Solar Corona

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The observations by the soft X-ray telescope (SXT) onboard Yohkoh satellite found that typical structure of forward-S or inverse-S shape often appears in the soft X-ray images of the solar corona.[1] These typical morphology was named *sigmoid*.[2] Because sigmoids tend to appear associated with several eruptive events,[3] they are widely believed to be some precursor phenomena for eruptive flares.

Although several models have been proposed for the formation mechanism of sigmoid, they still remain as open questions how and why sigmoids are formed in prior to eruptive events. A widely believed idea is that the ideal kink instability of twisted field flux may cause the sigmoidal field. However, the observation indicates that there is no evidence of eruption for values of large-scale total twist approaching the threshold for the kink instability, though they sought 191 X-ray sigmoids.[4]

On the other hand, we revealed, using the new methodology based on vector magnetogram observations and the induction equation,[5] that the helicity injection process in flare productive active regions was highly complicated both in time and space, and that even the sign of the helicity injection often changed. Furthermore, it is also clarified that the soft X-ray radiance from the active regions is almost proportional to the probability of sign reversal of the magnetic shear on the photosphere.[6] These results imply that the solar coronal activity is sensitive to the complexity in the magnetic structure, particularly to the reversal of the magnetic shear.

Motivated by the observations of magnetic helicity, we investigated the nonlinear dynamics of a magnetic arcade, which is subject to reversal of the magnetic shear, in terms of the three-dimensional numerical simulations. The simulation model is constituted by the finite difference approximation and the Runge-Kutta-Gill method. The simulation results clearly show that sigmoidal structure can be formed as a consequence of the tearing mode instability, which grows on the shear inversion layer, as seen in Fig.1. The detail analysis of the geometrical relationship between the sigmoid and the shear inversion layer reveals that the field twist parameter of sigmoid is consistent with the Taylor's minimum energy state. It indicates that the sigmoidal formation is a sort of the magnetohydrodynamic relaxation process like the reversed-field pinch experiments.

The simulation also indicates that the tearing mode instability, which gradually proceeds on the boundary between the sigmoid and the environmental field, is followed by an explosive eruption. It is caused by magnetic reconnection of the cusp shape field lines, as shown in Fig.2. The cusp field can be created by the collapsing of magnetic arcade, which results from the annihilation of magnetic flux through the tearing mode reconnection. The mutual excitation of the two reconnections of the tearing instability and the cusp field plays a crucial role to trigger the eruption.

These results are consistent with the reversed-shear flare model[6,7] and well account for the causal relationship between the formation of sigmoid and the onset of flares.[8]

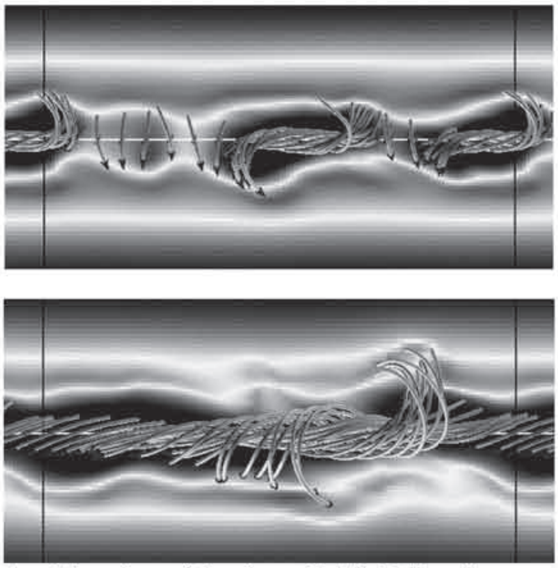

Fig. 1. Top view of the sigmoidal field lines in cases that the shear inversion layer is small (top) and large (bottom), respectively.

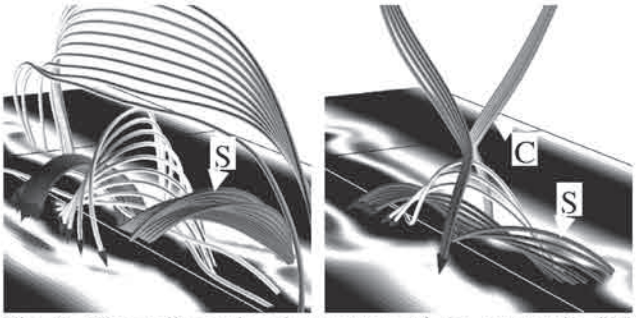

Fig. 2. Three-dimensional structure of the magnetic field lines in the formation phase of sigmoid (*left*) and the onset phase of eruption (*right*). Sigmoidal field and cusp field are denoted by S and C, respectively.

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