論文の内容の要旨

論文題目
Surface Magnetic Flux Maintenance In Quiet Sun
(太陽静穏領域における磁束維持に関する研究)

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The mechanism of magnetic flux maintenance on the solar surface in quiet regions is investigated based on the observation.

Magnetic structure on the solar surface attracts many solar physicists not only because it causes various solar energetic activities but also because it is an actual example of magneto-convection systems on the stellar surface. Despite its importance in solar physics and plasma physics, how magnetic flux is maintained in quiet regions is still hidden in a veil. A recent paper, Parnell et al. (2009), reports a new clue. They find that the frequency distribution of flux content on the solar surface is maintained as a power-law distribution with an index of -1.85 ± 0.14. Two scenarios of its maintenance are suggested there. One is the maintenance by the surface processes among magnetic field, namely merging, splitting, emergence, and cancellation of magnetic patches on the solar surface. The other is that it represents a frequency distribution of buoyant magnetic flux tubes generated by dynamo mechanism in the convective layer below the surface. For the discrimination of these scenarios, the key investigation is a quantification of the occurrence rates of surface processes. We perform it by means of the stable high-resolution data by a recent spacecraft, *Hinode*, and an auto-detection code of surface processes developed in the thesis.

The thesis is consisted of 6 chapters. We summarize the previous studies and the purpose of the thesis in Chapter 1. The description of data sets and method of the auto-detection code is explained in Chapter 2. The main results and discussions are described in Chapter 3–5. The summary of the thesis and the future studies are shown in Chapter 6.

In Chapter 2, the description of data sets and method of the auto-detection code are shown. We use two data sets of magnetograms obtained by the *Hinode* spacecraft. One has higher time resolution but an intermediate duration (data set 1). The other has a long duration but lower time resolution (data set 2). The developed method of the detection and tracking of magnetic patches is also explained in this chapter (Figure 1).

In Chapter 3, we investigate statistical properties of detected patches, namely the frequency distribution of the flux content, lifetime, and proper velocity. The frequency distributions of flux content are power-law distributions with indices of -1.79 ± 0.18 and -1.93 ± 0.07. They are also consistent with the previous result obtained by Parnell et al. (2009). It supports that the surface processes on the solar surface maintain the frequency of flux content, not the injection from below the photosphere. The average lifetimes of magnetic patches are 17.3 minutes in data set 1 and 23.2 minutes in data set 2. These different values show that the obtained lifetimes depend on the temporal resolution of the data sets, i.e. they become shorter as measured with a better resolution. It leads an interpretation that a large part of apparent lifetime is determined by apparent effects, namely surface processes with the patches below the detection limit, not by the actual disappearance of magnetic patches. In the larger flux range, the lifetime is found to saturate at around 60 minutes in both data sets. We also investigate proper velocity of patches in data set 1. The averaged obtained proper velocity is 1.2 km s^{-1}. The flux dependence of proper velocity is found to be small, as a power-law index of -0.23.

In Chapter 4, we investigate frequencies of magnetic processes. It is found that the occurrence rates of emergence and cancellation are much less than those of merging and splitting. Further, the frequency distributions of merging, splitting, and cancellation, are investigated (Figure 2-4). We found that probability distribution of merging has weak dependence on flux content, with a power-law index of 0.28. On the other hand, the frequency distribution of cancellation has a power-law distribution with an index of -2.48 ± 0.24.

In Chapter 5, we summarize magneto-chemistry equation (Schrijver et al., 1997) and make discussions of the results in the previous chapters based on it. First we discuss what the process has the significant roles in flux maintenance in quiet regions. The more frequent occurrence rates of merging and splitting than those of emergence and cancellation suggests that mainly splitting and merging maintain the structure of magnetic field on the solar surface. Second, we discuss the frequency distribution of splitting, which could not be fitted in a simple power-law function. Based on the idea of detection limit, it is found that the probability distribution of splitting does not have the significant difference from the analytical solution with a constant time scale in parents and daughter flux content. Further analysis of magneto-chemistry equation shows that splitting has a time-independent solution of a power-law distribution with an index of -2. At last, we discuss the reason of the steep slope of frequency distribution of cancellation. Our discussion is based on the assumptions that the patch motions are driven by convection which has random flow direction with constant velocity and that the power-law distribution of flux content is predominantly maintained. The steep slope is naturally obtained there. The derived power-law index is very similar to that of the emergence (Thornton & Parnell, 2011). It suggests that large parts are re-emergences of submerged loops through cancellations.

In Chapter 6, the conclusion of the thesis is given. We conclude that the surface processes maintain the frequency distribution of flux content. Further we suggest a new picture of flux maintenance in quiet regions from the above discussions. Our interpretation of flux maintenance is summarized as follows:

1) Frequency distribution of the flux content is maintained to a power-law distribution by merging and splitting on the solar surface.

2) The frequency of cancellation can be interpreted as a result of collisions of patches under motions driven in random direction with constant velocities.

3) Most of emergences are interpreted as re-emergences of submerged loops recognized as cancellations.

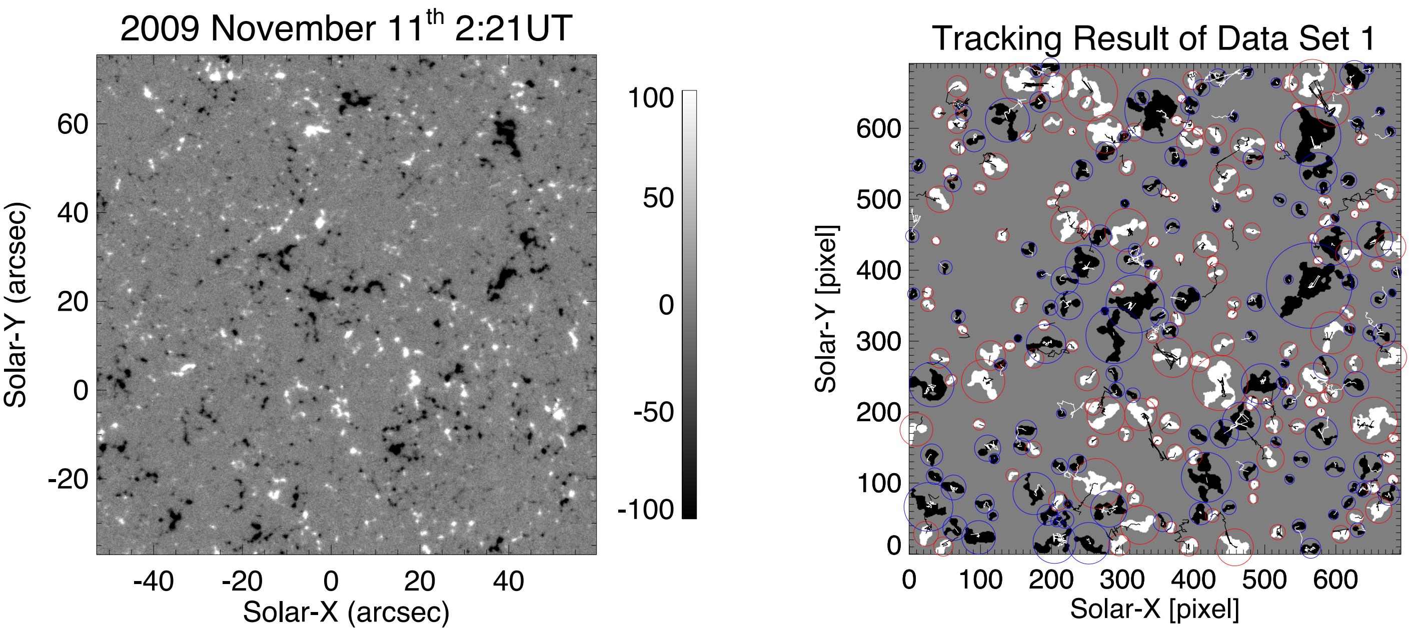

Figure 1:

(Left) Example of $Na_I D_1$ magnetograms obtained by *Hinode* satellite. The magnetogram is taken at 2:21UT on 2009 November 11th.

(Right) Two-leveled magnetogram and the result of tracking by our method. The white and black backgrounds indicate the line-of-sight polarity, positive and negative respectively. The red and blue circles mean the radius of the detected patches and the black and white solid line indicate the paths of center of the gravity of patches.

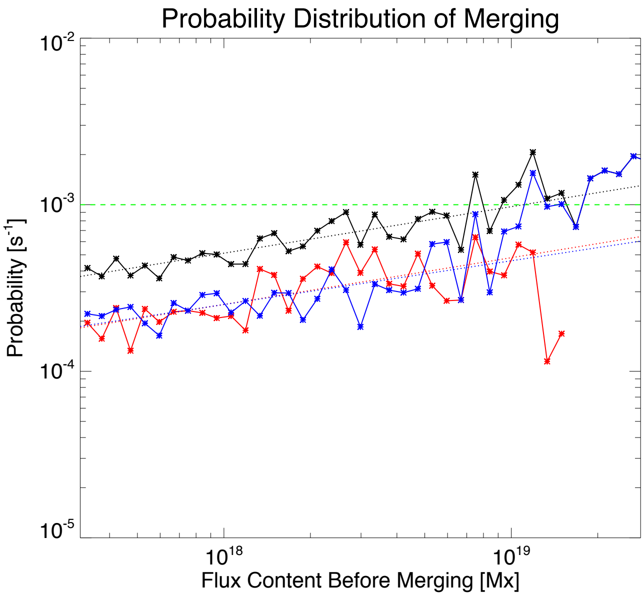

Figure 2:

The apparent probability distributions of merging in data set 1. The red/blue/black solid lines indicate observational results for the positive/negative/both patches. The red/blue/black dashed lines indicate fitting results with a range of $10^{17.5}$- 10^{19} Mx. The power-law indexes of the fitting lines are 0.28, 0.26, and 0.28. Horizontal dashed line indicates a time scale of 33 minutes.

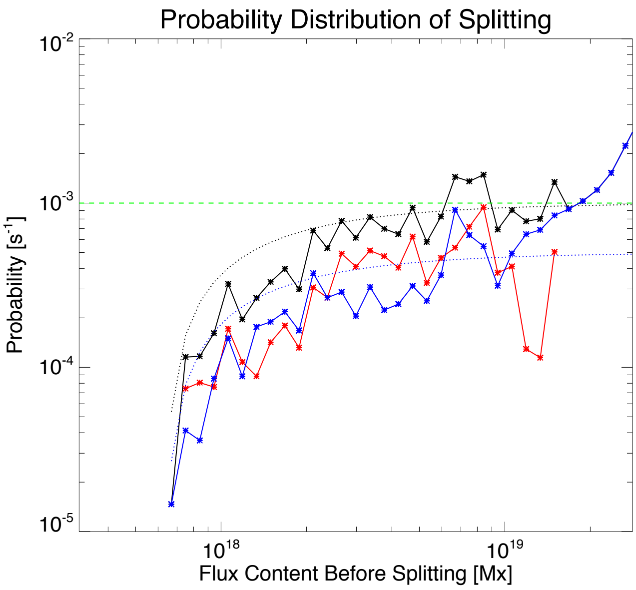

Figure 3:

The apparent probability distributions of merging in data set 1. The detection limit is set as $10^{17.5}$ Mx. The red/blue/black solid lines indicate observational results for positive/negative/both patches. The blue and black dashed lines indicate analytical curves with constant frequencies on parents' and daughter's flux content, 5.0×10^{-4} s^{-1} and 1.0×10^{-3} s^{-1} (See discussion in Section 5.3.2 for more detailed discussions). Horizontal dashed line indicates a time scale of 33 minutes.

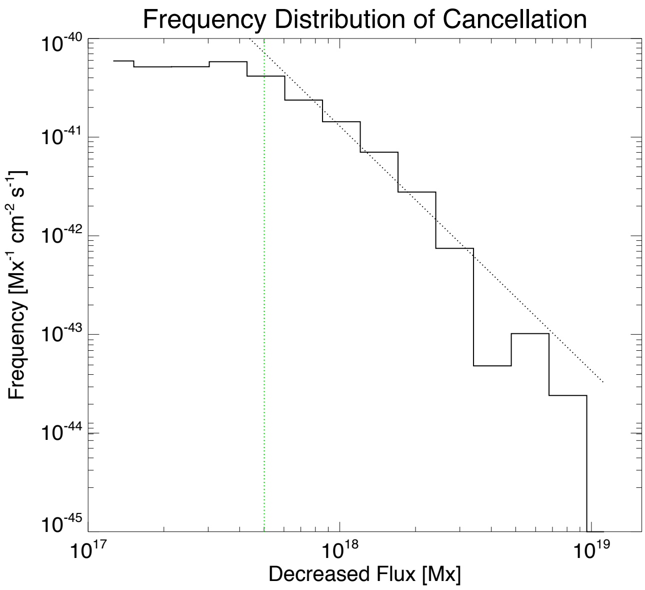

Figure 4:

Frequency distribution of cancellation of decreased flux content. Histogram and dashed line indicate observational result and fitting result with a power-law distribution, respectively. The vertical green line shows detection limit, $\phi_{th} = 10^{17.7}$ Mx. The fitted power-law index is −2.48.