MHD Simulation of Plasma Eruption by Interaction between Emerging Flux and Coronal Arcade Field

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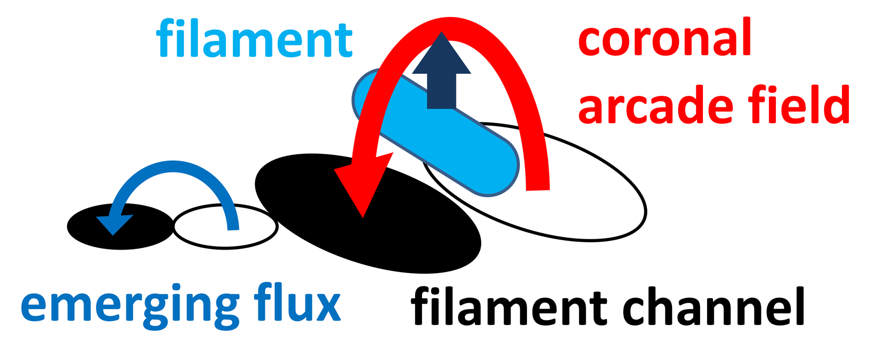
Abstract

Many kinds of eruptive phenomena, such as solar flares, filament eruptions and coronal mass ejections (CMEs) are seen in the solar atmosphere. One candidate to trigger those eruptions is an interaction between the newly emerging flux and the coronal arcade field. We investigate the triggering mechanism and their requiring conditions by 2.5-dimensional MHD simulation. As a result, two distinct mechanisms exist and these two are separated in the parameter space of the location of the emerging flux and eruptions by these two mechanisms are likely to occur with the strongly sheared arcade fields.

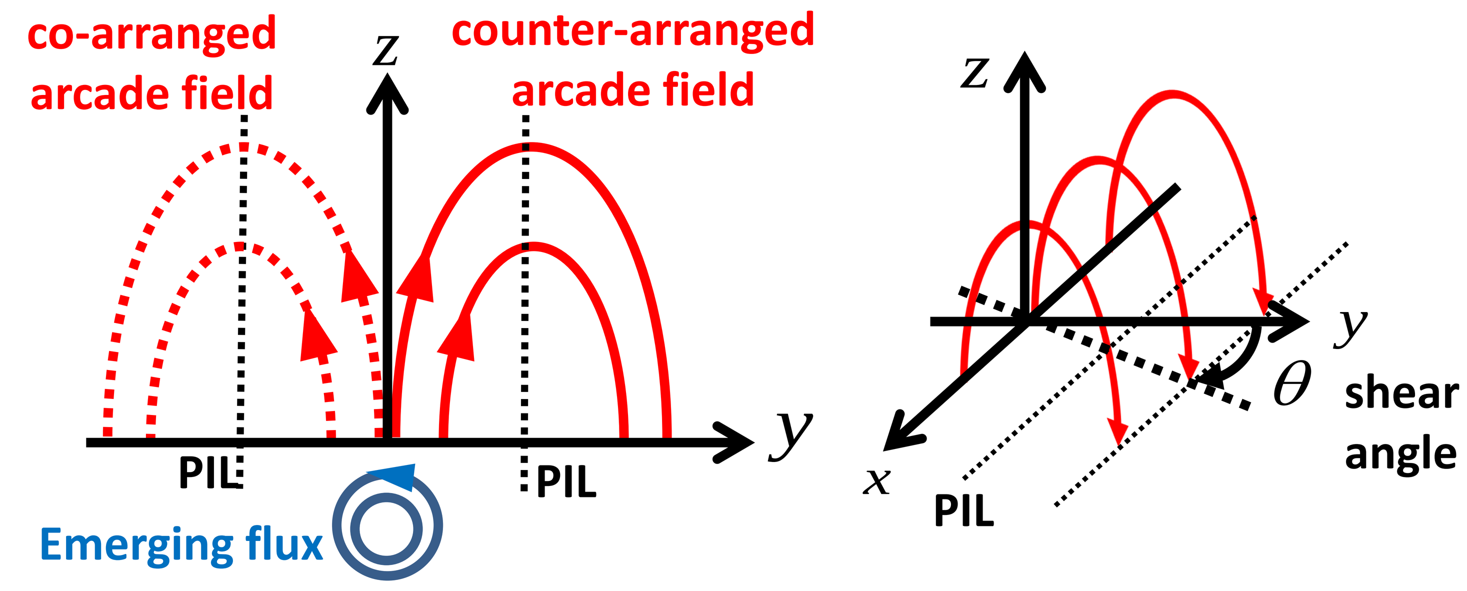
Introduction

Solar filaments appear along the polarity inversion lines (PILs) of the arcade magnetic fields called filament channels. Many observations reported the events in which eruptions occur when the emerging fluxes appear near the filament channels. Statistical studies of Feynman & Martin (1995) and Xu et al. (2008) suggested the reconnection between the emerging flux and the coronal arcade field plays an important role. We discuss the detailed mechanisms and their requiring conditions from the results of 2.5-dimensional simulations and parameter survey.



Numerical settings

Background gas is stratified under uniform gravity and specific temperature distribution which has four layers: the convection zone, the photosphere/chromosphere (10^4K), the transition layer and corona (10^6K). Force-free arcade fields are set so that initial condition is in mechanically equilibrium. A flux tube is buried in the convection zone, leading to emerge into corona by magnetic buoyancy. We call the left arcade to the flux tube 'co-arranged arcade', and the right arcade 'counter-arranged arcade' ,judging from the order of polarity. Parameter survey is done with respect to **the magnetic field strength, the location of the emerging flux and the shear angle of the arcade field**.



Result and Discussion

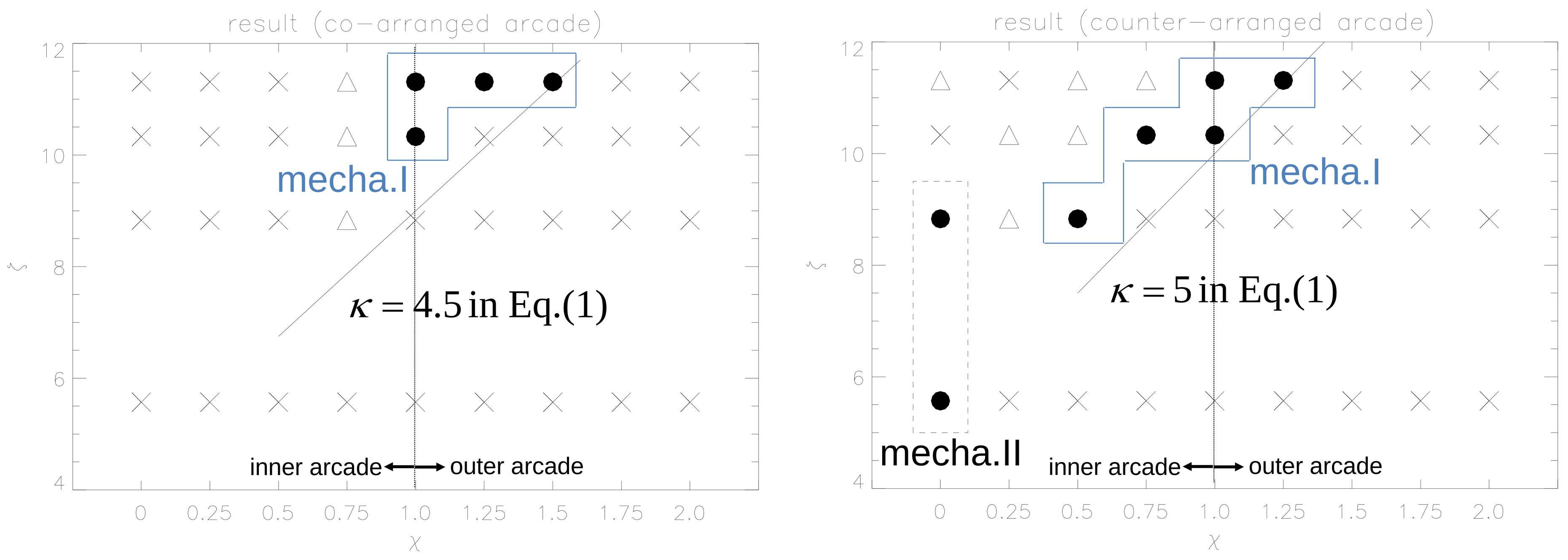


Fig.1: result of parameter survey about the field strength and the location of emerging flux
●: Erupt, △: Plasmoid is formed but not erupt, ×: no formation and eruption
Eruptions by mechanism I are in blue boxes and eruptions by mechanism II are in dashed line box.

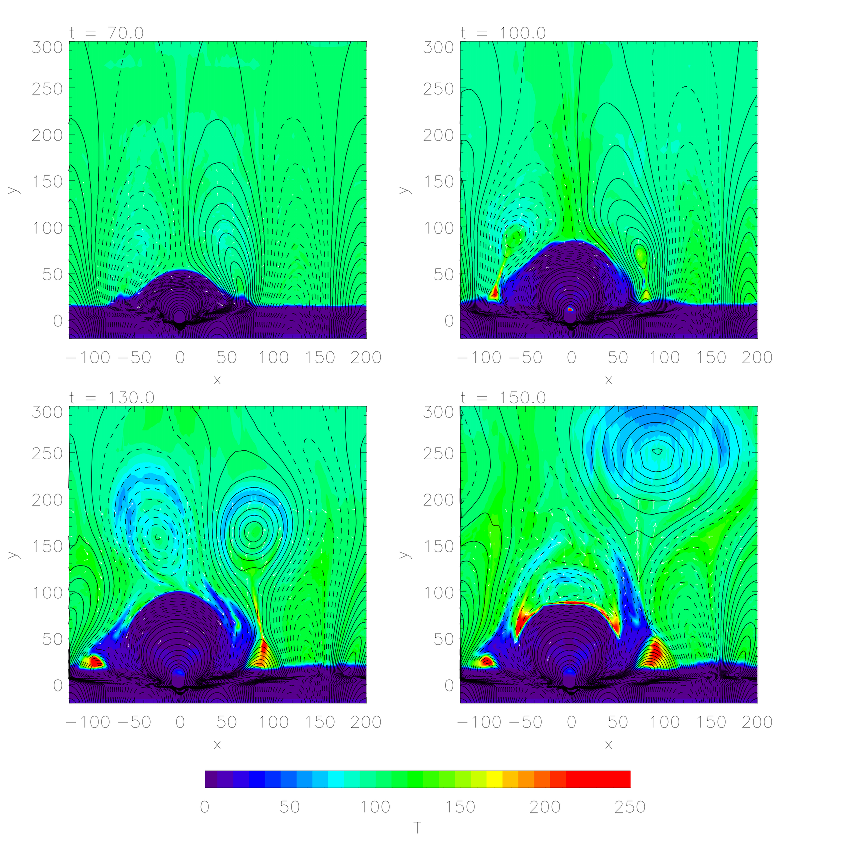


Fig.2: time evolution of mechanism I. Normalized by length L=300km, temperature T=10000K

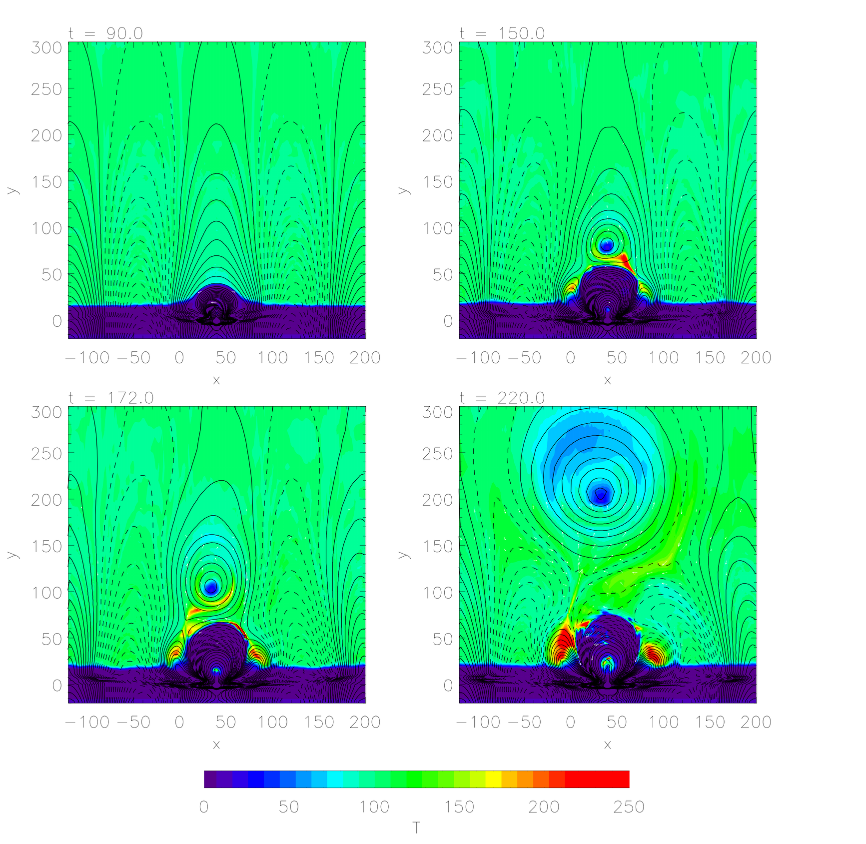


Fig.3: time evolution of mechanism II. Normalized by length L=300km, temperature T=10000K

mechanism I

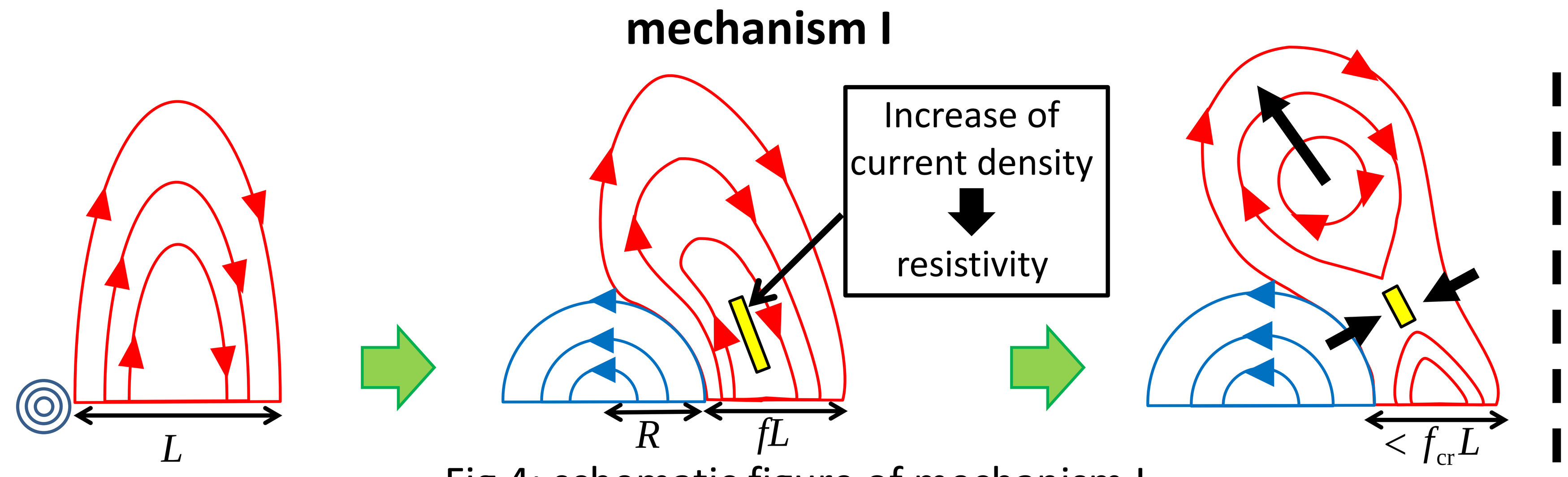


Fig 4: schematic figure of mechanism I

Fig 2 shows the time evolution of an eruption by mechanism I. In mechanism I, reconnection is triggered around the PIL of **the arcade field compressed by the emerging flux**, leading to formation and eruption of a plasmoid. The compression rate f (see Fig.4) can be evaluated by equilibrium of magnetic pressure. Thin current sheet is formed with enough compression (sufficiently small f), leading to trigger the reconnection. Assuming that the eruptions occur under $f<f_{cr}$, the condition for eruption can be

$$\frac{\zeta}{1+\chi} > \kappa, \qquad \zeta \equiv \frac{\Phi_e}{\Phi_a}, \qquad \kappa \equiv \frac{\pi}{2}\ln[qR]\frac{1-f_{cr}}{f_{cr}}, \qquad (1)$$

where, Φ_e :amount of flux of emerging flux Φ_a : amount of flux of arcade field
R :extended radius of emerging flux f_{cr} :critical compression rate
χ :distance from PIL to emerging flux normalized by arcade half width

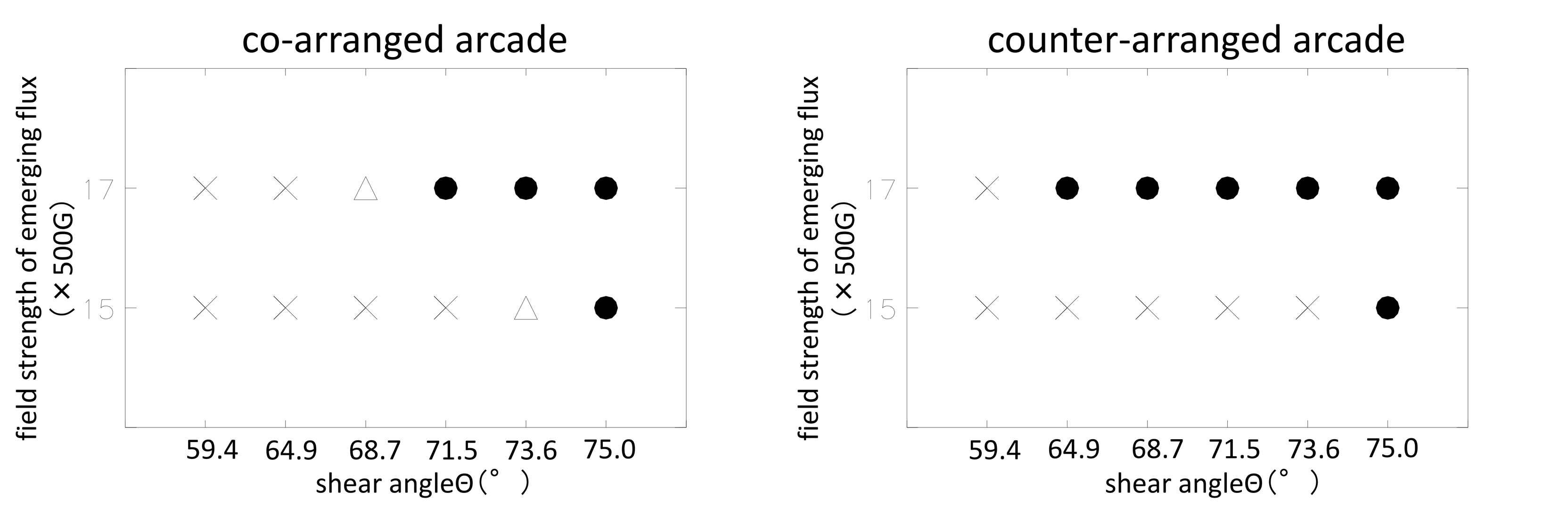


Fig 5 : result of parameter survey about shear angle of arcade field

Fig. 5 shows the result of parameter survey about shear angle of arcade field. Eruptions are likely occur with strongly sheared arcade fields. Because the strongly sheared arcade field has a large current density in it, reconnection is easy to triggered. Namely, strongly sheared arcade fields have a large critical compression rate f_{cr} and small κ in Eq. (1).

mechanism II

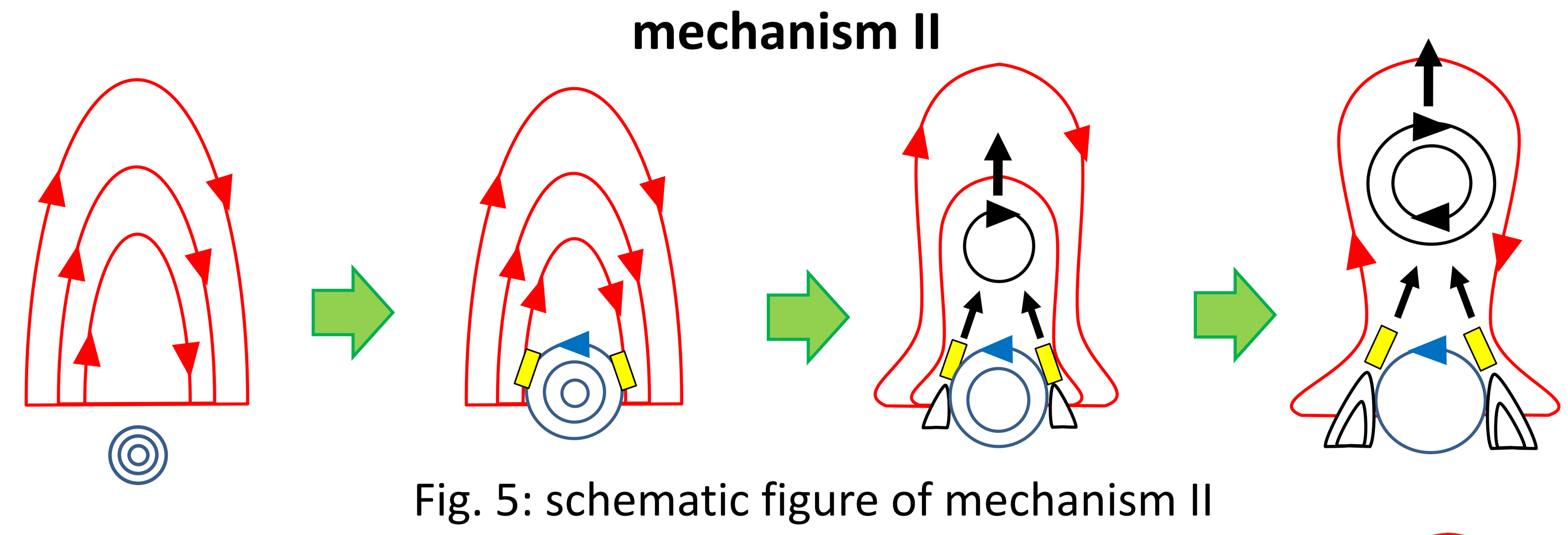
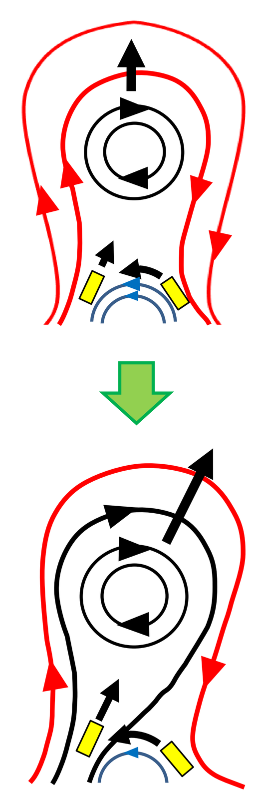


Fig. 5: schematic figure of mechanism II

Fig 3 shows the time evolution of mechanism II, and Fig.5 is its schematic view. Eruptions by mechanism II are seen only when the location of the emerging flux is around the PIL of **the counter-arranged arcade field**. A long current sheet is formed between the emerging flux and the arcade field, and multiple reconnections occur in it, leading to formation of plasmoids. The prominent two reconnections provide a flux and grow a plasmoid to erupt. When one of two prominent reconnection exceeds the other, **the outflow from one reconnection connects to the inflow of the other reconnection** (see right schematic figure). This causes an efficient eruption of a plasmoid.



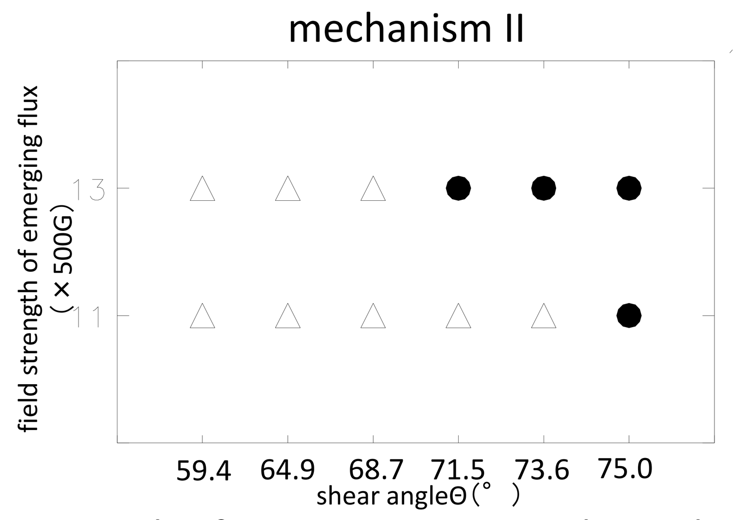


Fig 6 : result of parameter survey about shear angle of arcade field

Fig. 6 shows the result of parameter survey about shear angle of arcade field. Formation of plasmoids can be seen in all cases of counter-arranged arcade, but in no casee of co-arranged arcade. Eruptions are likely to occur when the shear angle is larger, this is because the strong current sheet is formed between the emerging flux and the strongly sheared arcade field.

Summary

The mechanisms of solar eruptions and their requiring conditions are investigated by 2.5-dimensional MHD simulations. Two distinct mechanisms are obtained.
mechanism I: The mechanism when the location of the emerging flux is around the footpoints of the arcade fields. Eruptions are likely to occur when the field strength of the emerging flux is larger or when its location is closer to the arcade. The requiring condition can be represented by brief equation.
mechanism II: The mechanism when the location of the emerging flux is around the PIL of the arcade field. Eruptions are likely to occur when the field strength of the emerging flux is smaller and when the location of the emerging flux is closer to the PIL of counter-arranged arcade field.

Reference : Feynman,J. & Martin,S.F. 1995 , J.Geophys.Res.
Xu,X., Fang,C. & Chen,P.F. 2008, Chinese A&A