

# SOLARNET-IV MEETING

## **The Role of Erupting Sigmoid in Triggering a Flare with Double Set of Ribbons**

By

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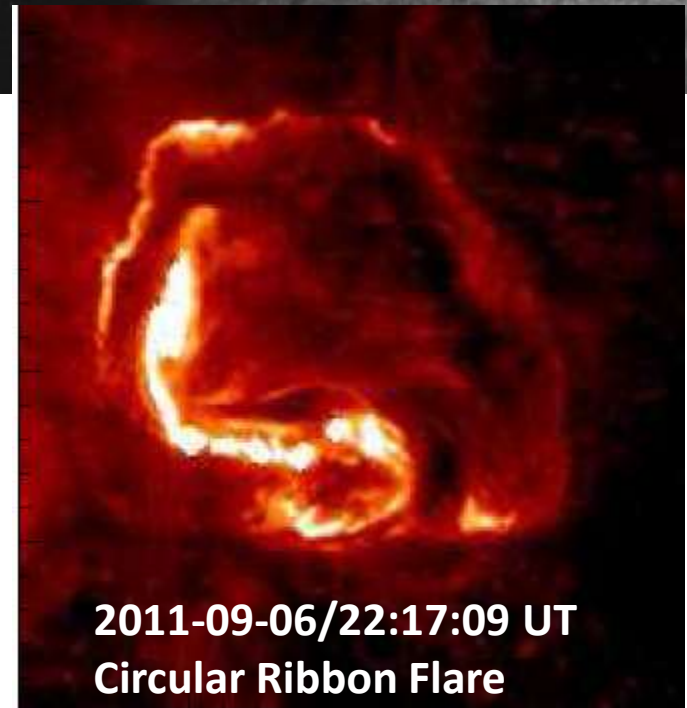
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# Outline:

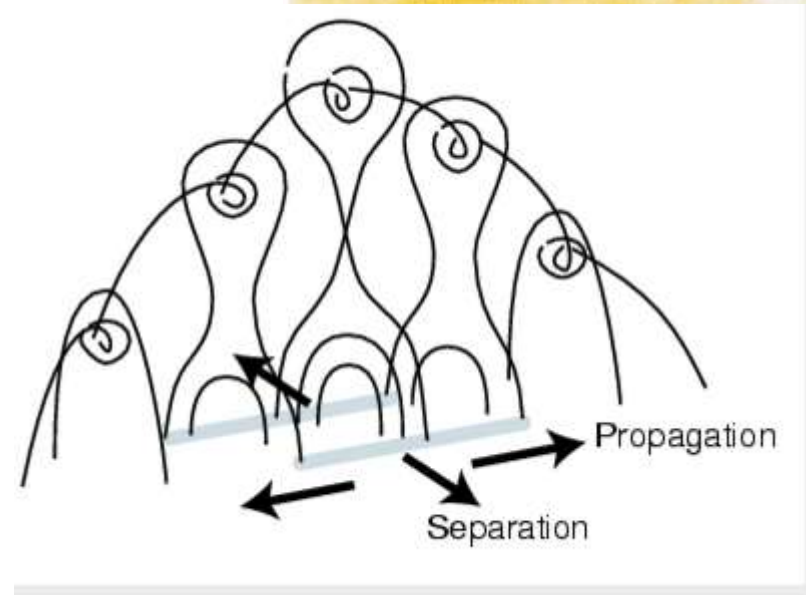
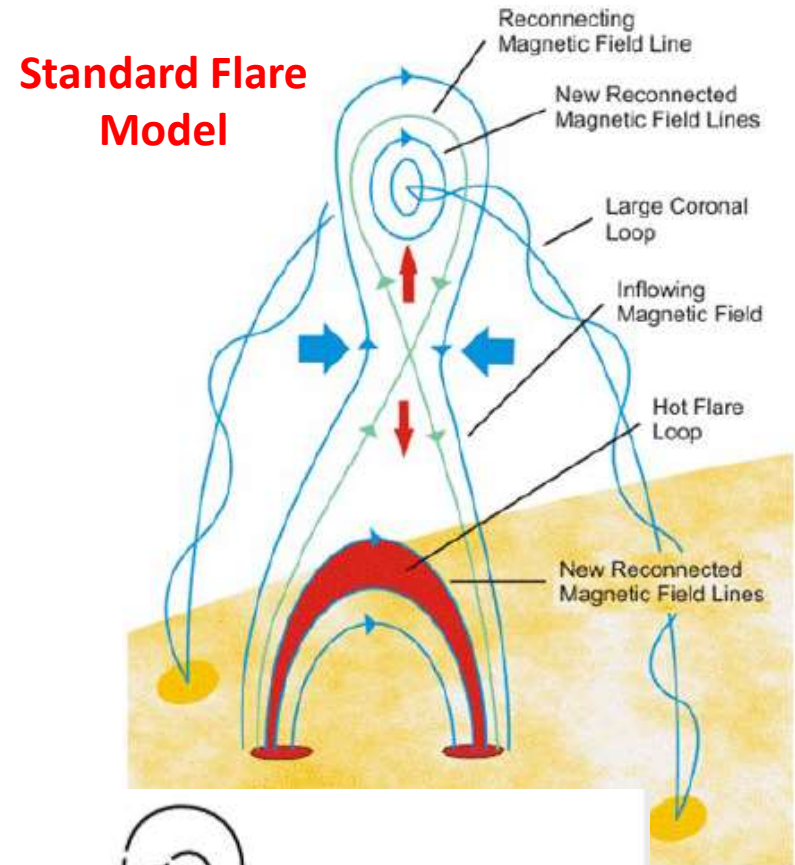
- 1). Brief history of solar flares
- 2). Motivation for the current work: Study of solar flare with parallel and circular ribbons
- 3). Observational data used
- 4). Analysis of solar flare and its interpretation using existing models
- 5). Key results and new findings

- ✓ **Solar flares** are the phenomena characterized as the release of free magnetic energy due to magnetic reconnection in the corona.
- ✓ The released magnetic energy is converted into kinetic energy to accelerate electrons and other energetic particles, as well as thermal energy, to heat the plasma.
- ✓ Formation of solar flare ribbons on both sides of the magnetic polarity inversion line (PIL) is known as a secondary process when accelerated electrons hit the low solar atmosphere.
- ✓ Morphology of flare ribbons is very important to understand the magnetic configuration of the flaring region.
- ✓ **Two-ribbon flares** are usually caused by the reconnection among the surrounding arcades underneath the erupting filaments or sigmoids, while the **circular ribbon flares** are believed due to null-point reconnection in a complex fan-spine magnetic configuration.

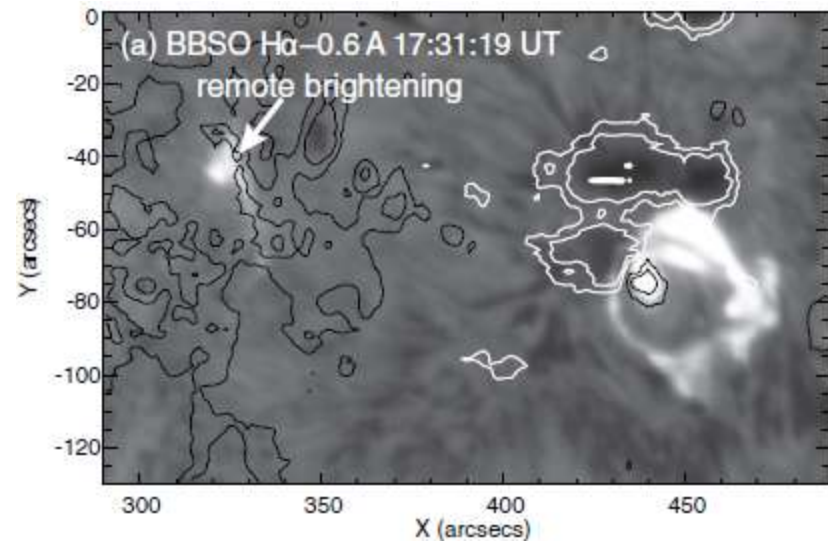
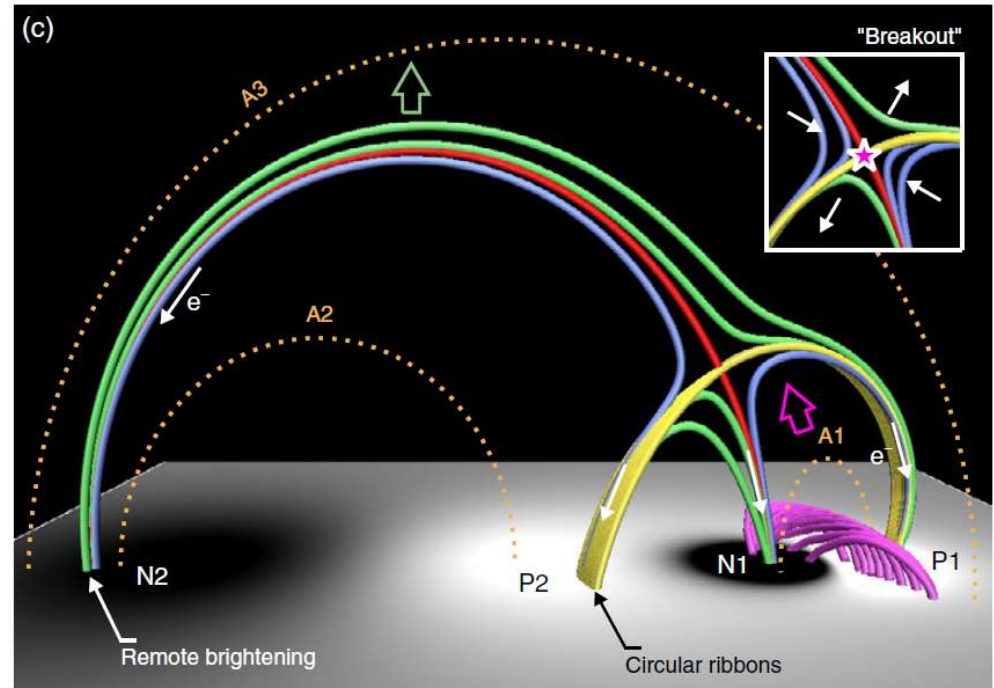
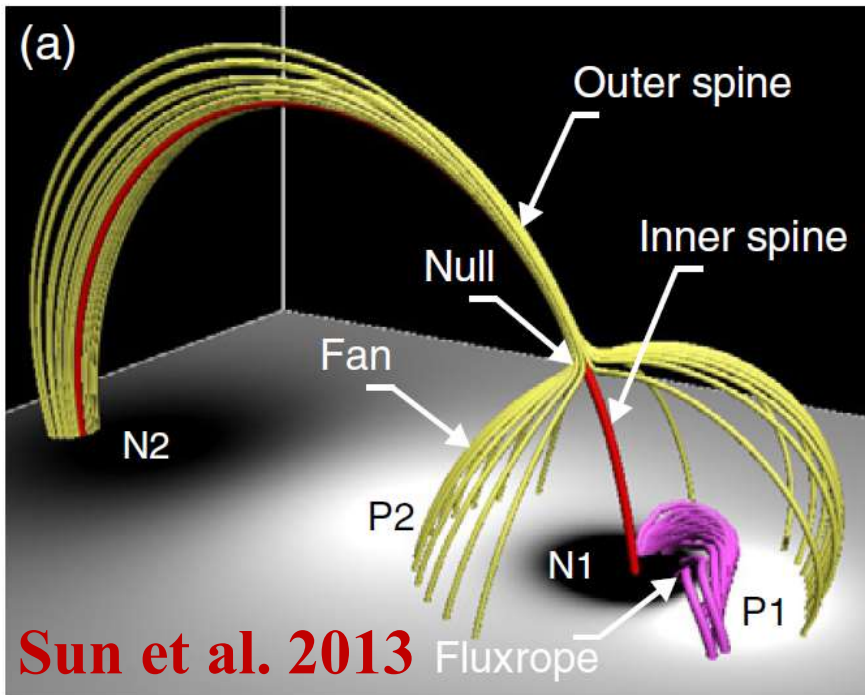


## Standard Flare Model Parallel Ribbons Flare

- ✓ Many models and theories have been proposed to interpret these energetic events (*reviews by Benz, 2008 and Shibata & Magara, 2011*).
- ✓ The “CSHKP” model based on the work of Carmichael (1964), Sturrock (1966), Hirayama (1974), and Kopp & Pneuman (1976) is a well-accepted two-dimensional (2D) model for solar flares.



# What about circular ribbon flare !!



# Motivations:

- 1.) To understand the role of sigmoid eruption to trigger a flare with parallel and circular ribbons.
- 2). To understand the formation and dynamics of parallel and circular ribbons.
- 3). To understand the interaction of erupting sigmoid with the overlying magnetic configuration.
- 4). To investigate the possible mechanism for this kind of flare.

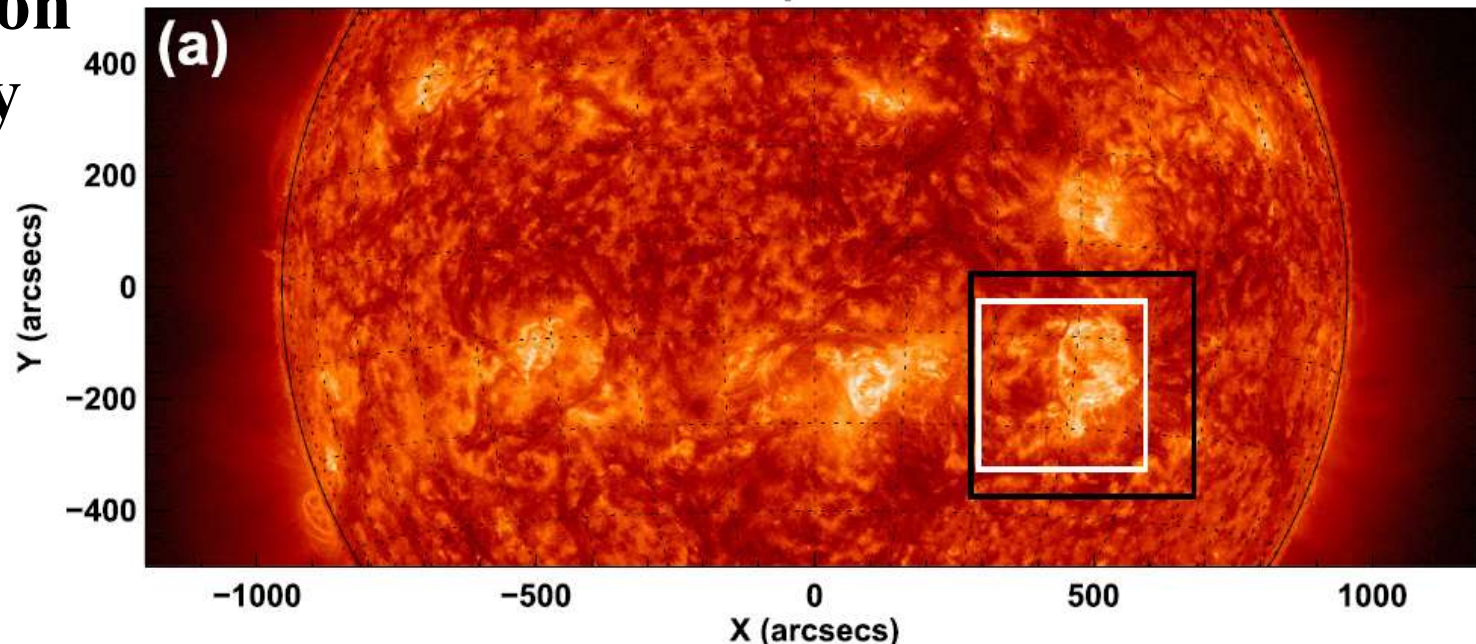
*“The flare event was an M7.3 class flare occurred on 18 April, 2014”*

# Observational Data Set used:

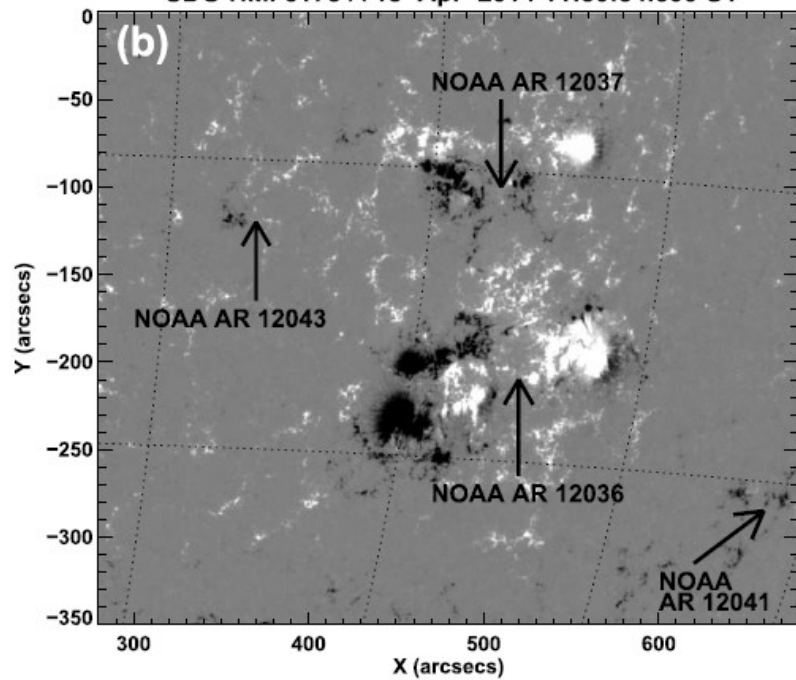
- Data in ultraviolet (UV) and EUV wavelengths are taken from the Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA; Lemen et al. 2012).
- Magnetic field data is collected from the SDO/Helioseismic Magnetic Imager (SDO/HMI; Schou et al. 2012; Hoeksema et al. 2014).
- RHESSI (Lin et al. 2002) is an X-ray imager observing the Sun in different energy bands between 3 and 1500 keV. We construct X-ray images using the PIXON algorithm with an integration time of 20 s.

# Active Region Morphology

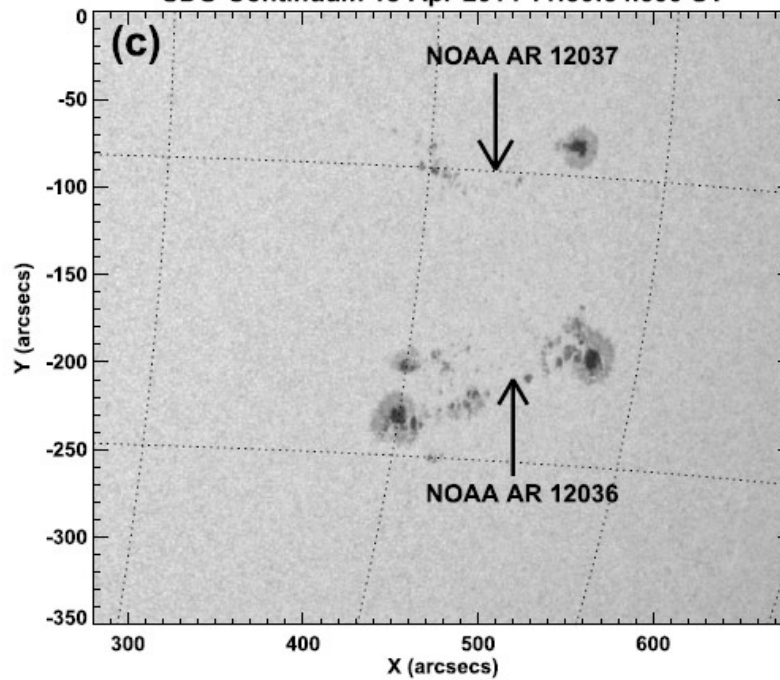
SDO AIA 304 Å 18-Apr-2014 11:30:07.120 UT



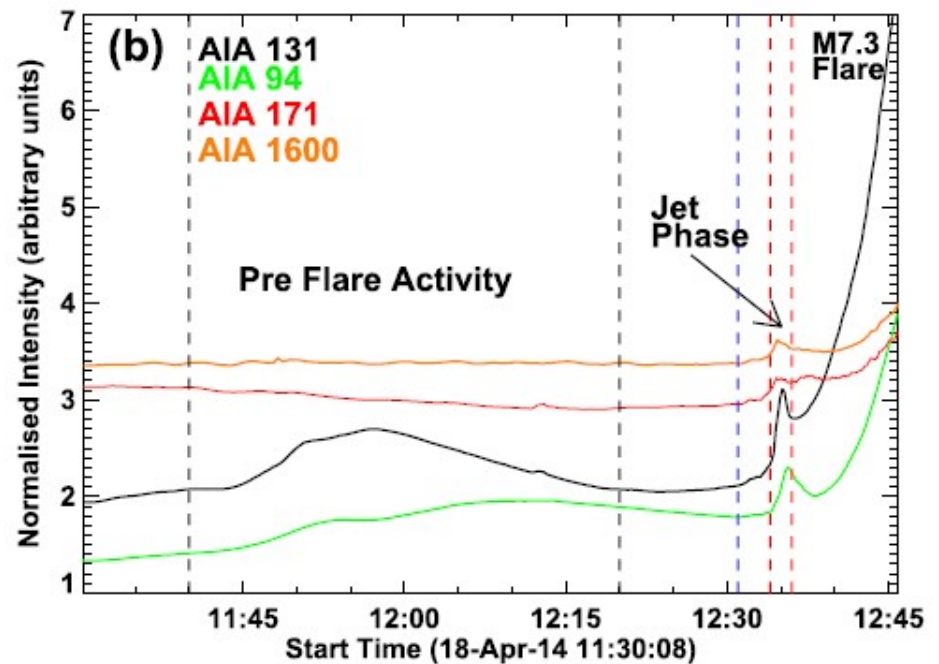
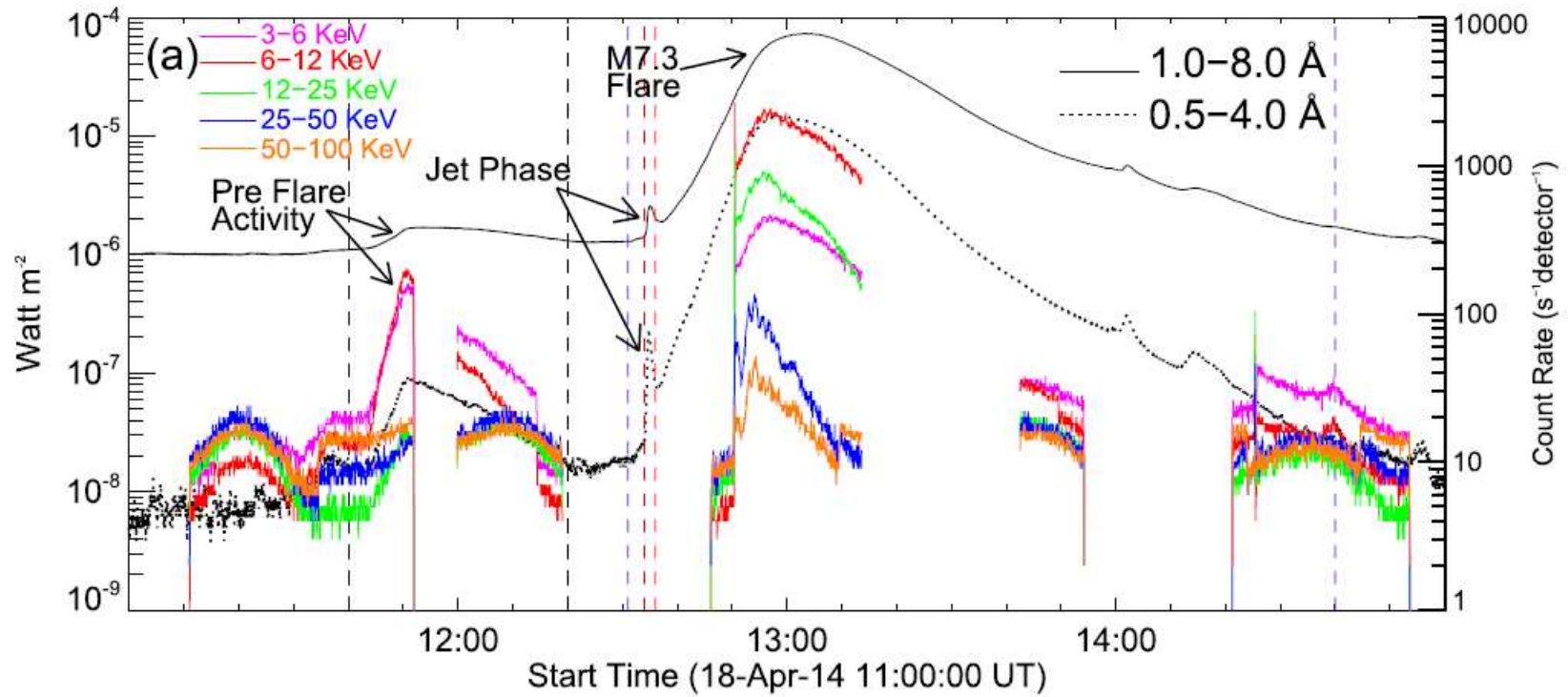
SDO HMI 6173 Å 18-Apr-2014 11:30:34.600 UT



SDO-Continuum 18-Apr-2014 11:30:34.600 UT

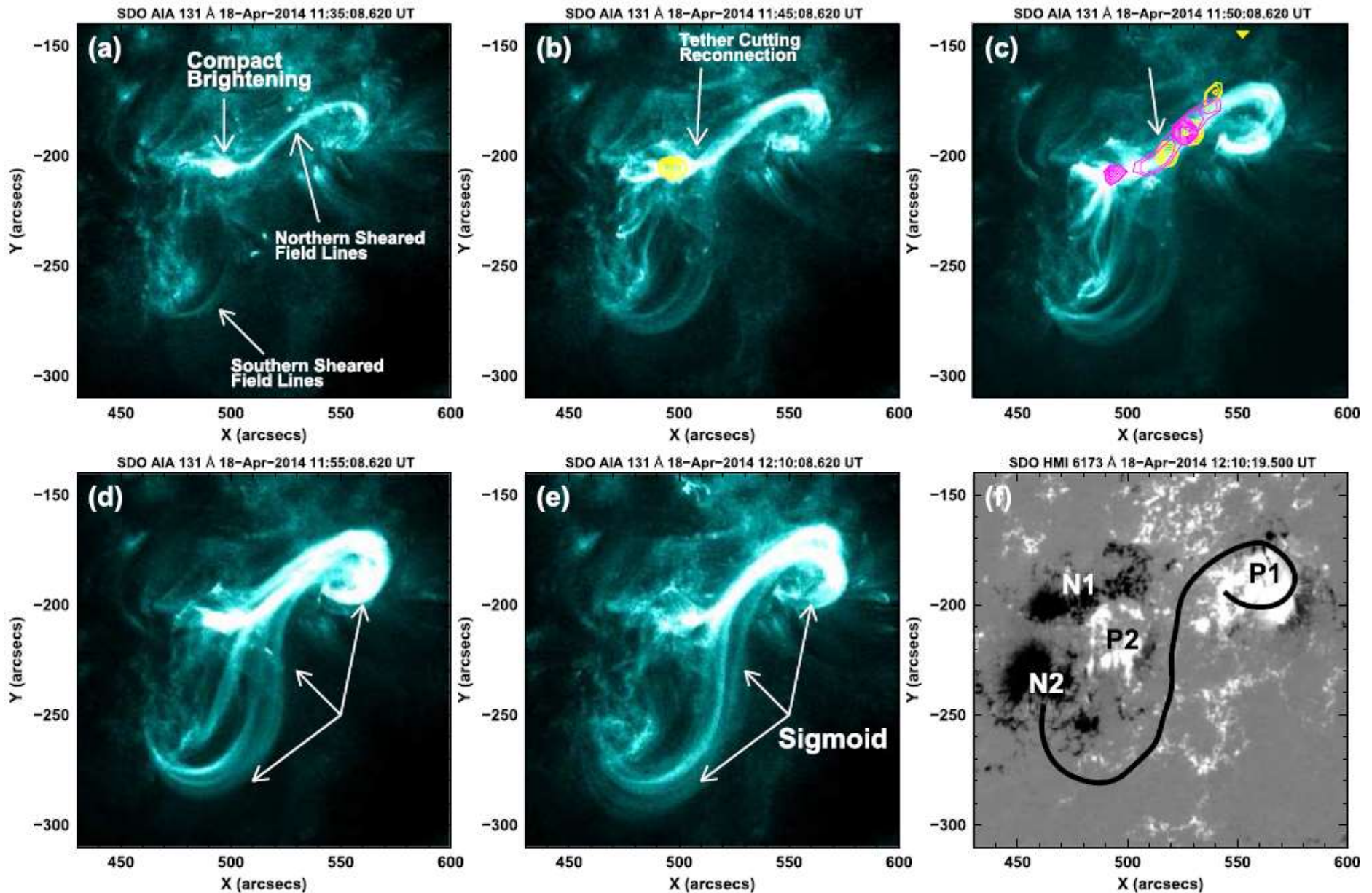




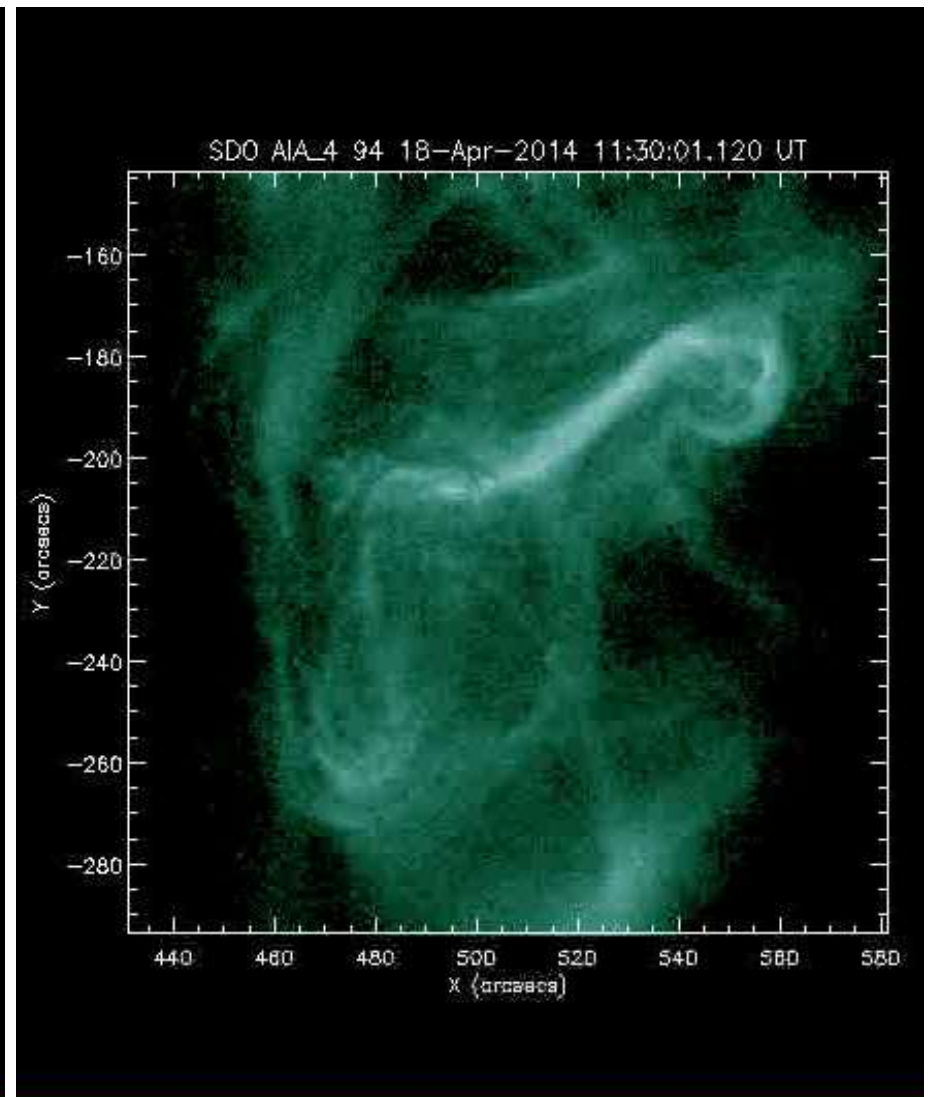
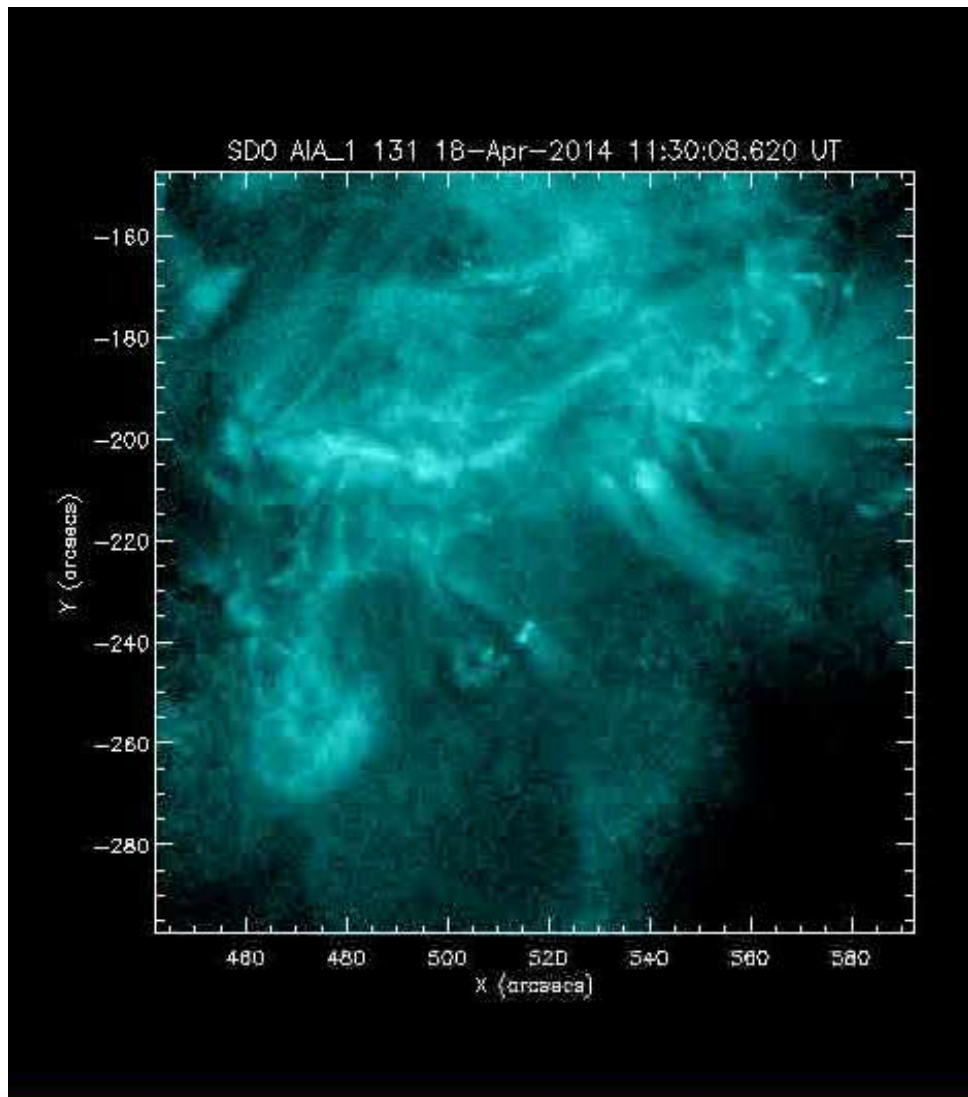


# X-ray and Intensity Temporal Profiles

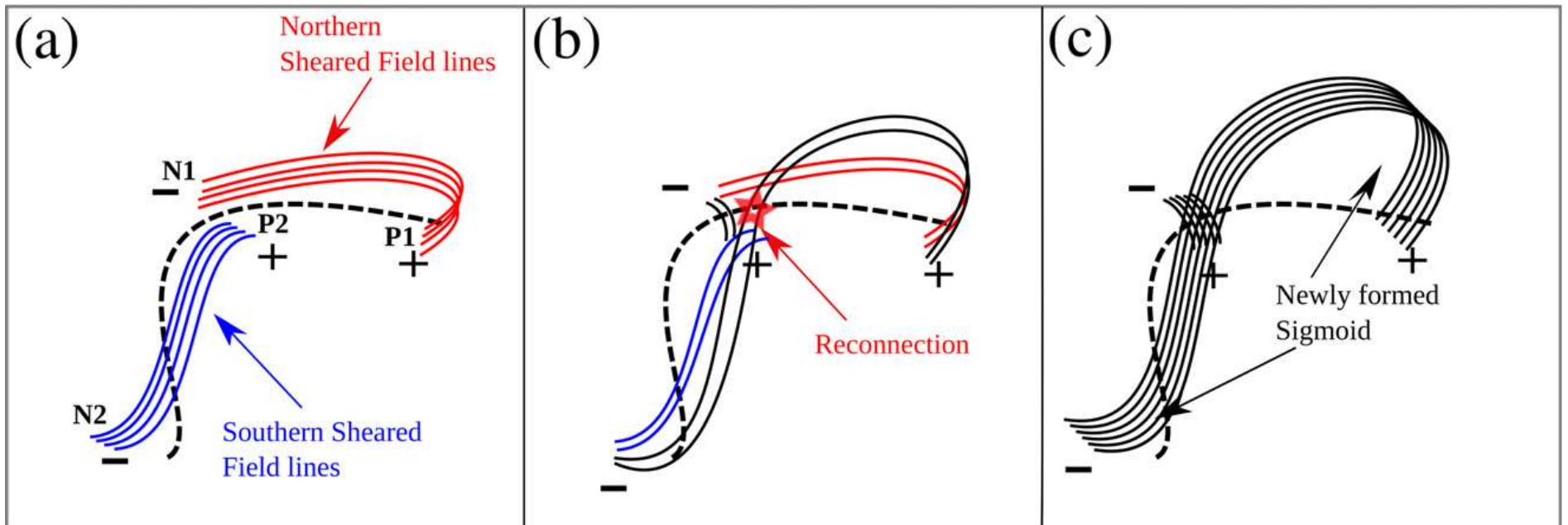
# Pre-flare Activity Phase: Formation and Appearance of the Sigmoid



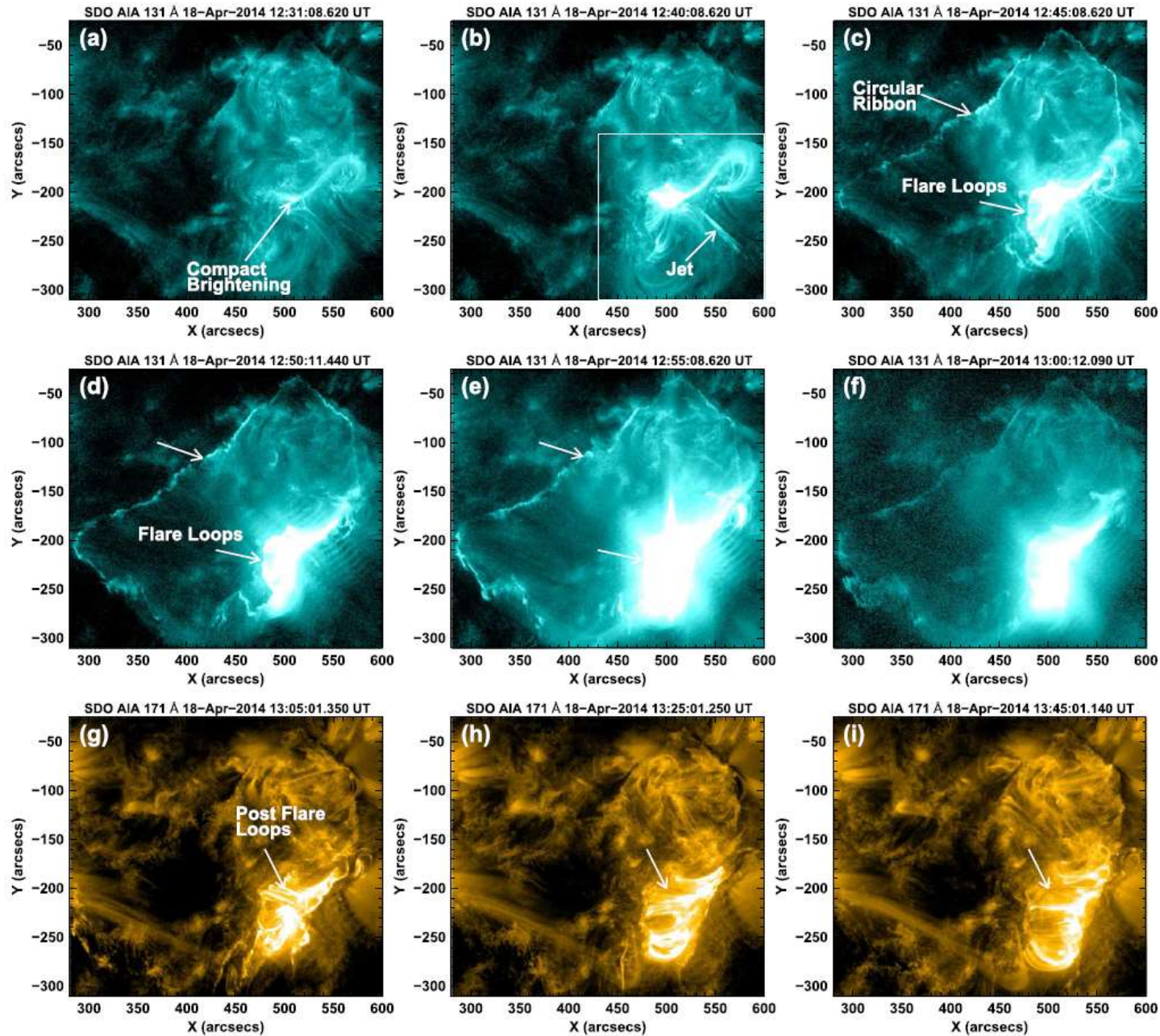
# AIA 131 and 94 Å animations: Flux Rope Formation



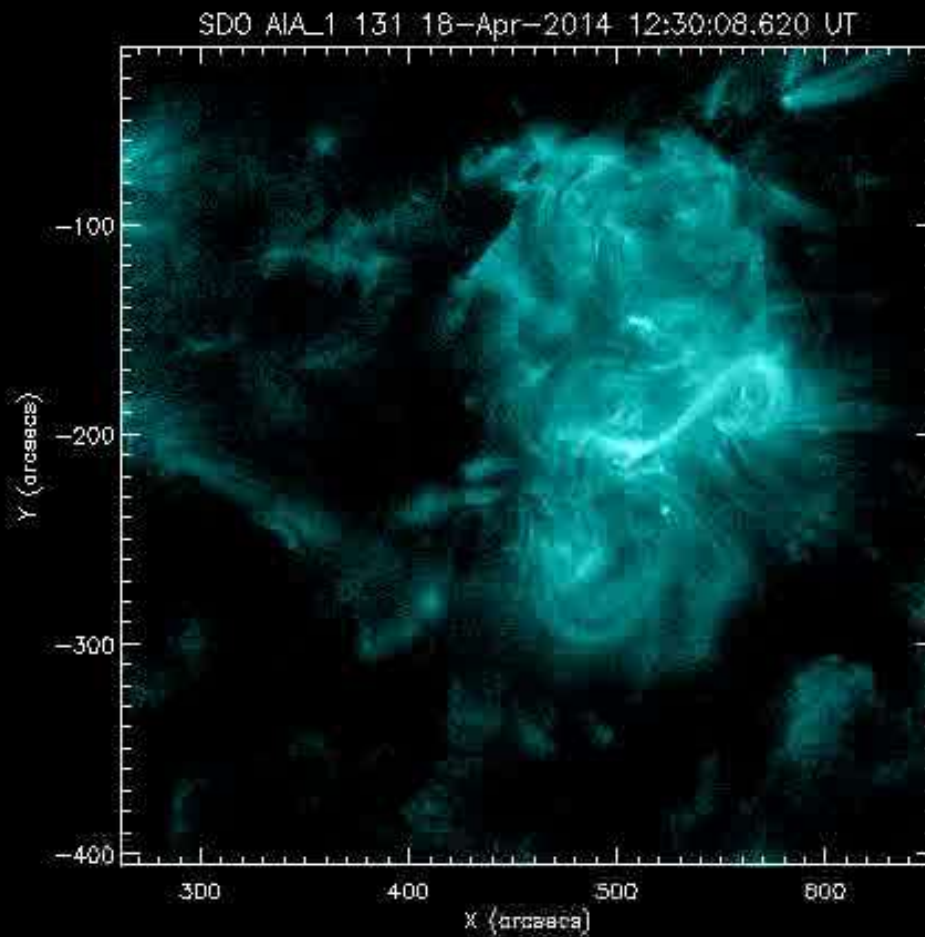
# Schematic of the Pre-Flare Phase



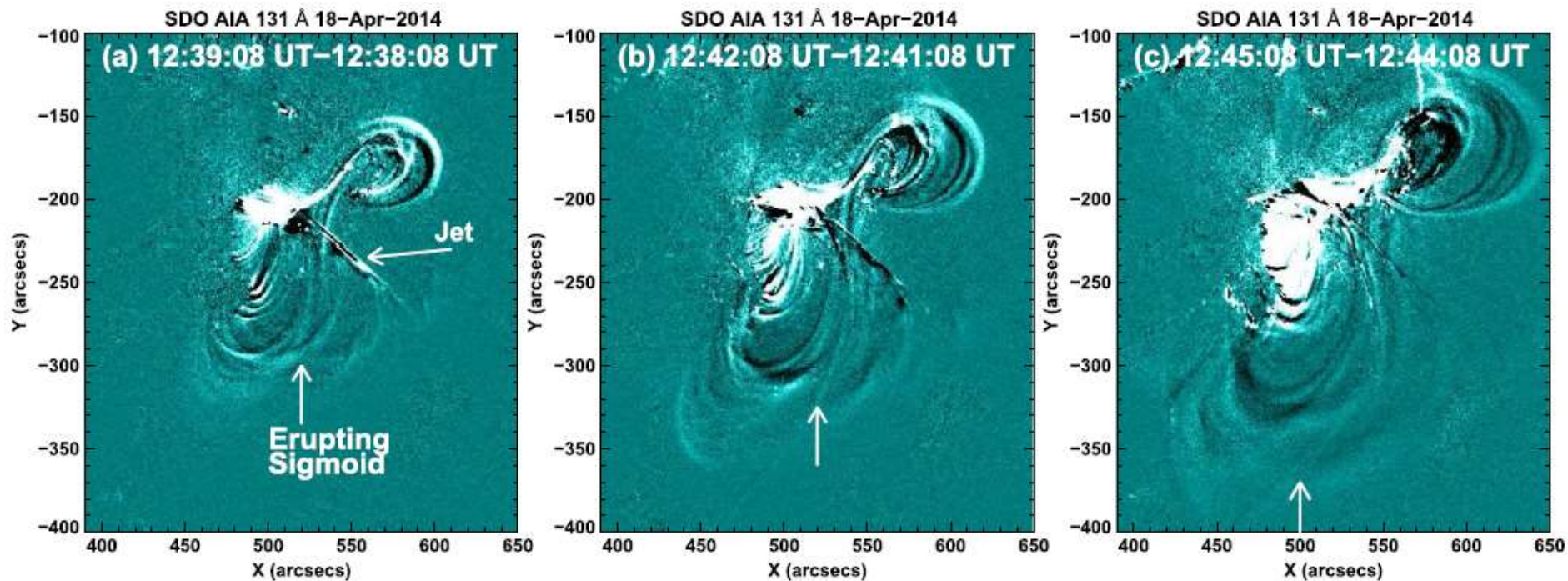
# Main Flare Phase: Sigmoid Eruption and M7.3 Solar Flare



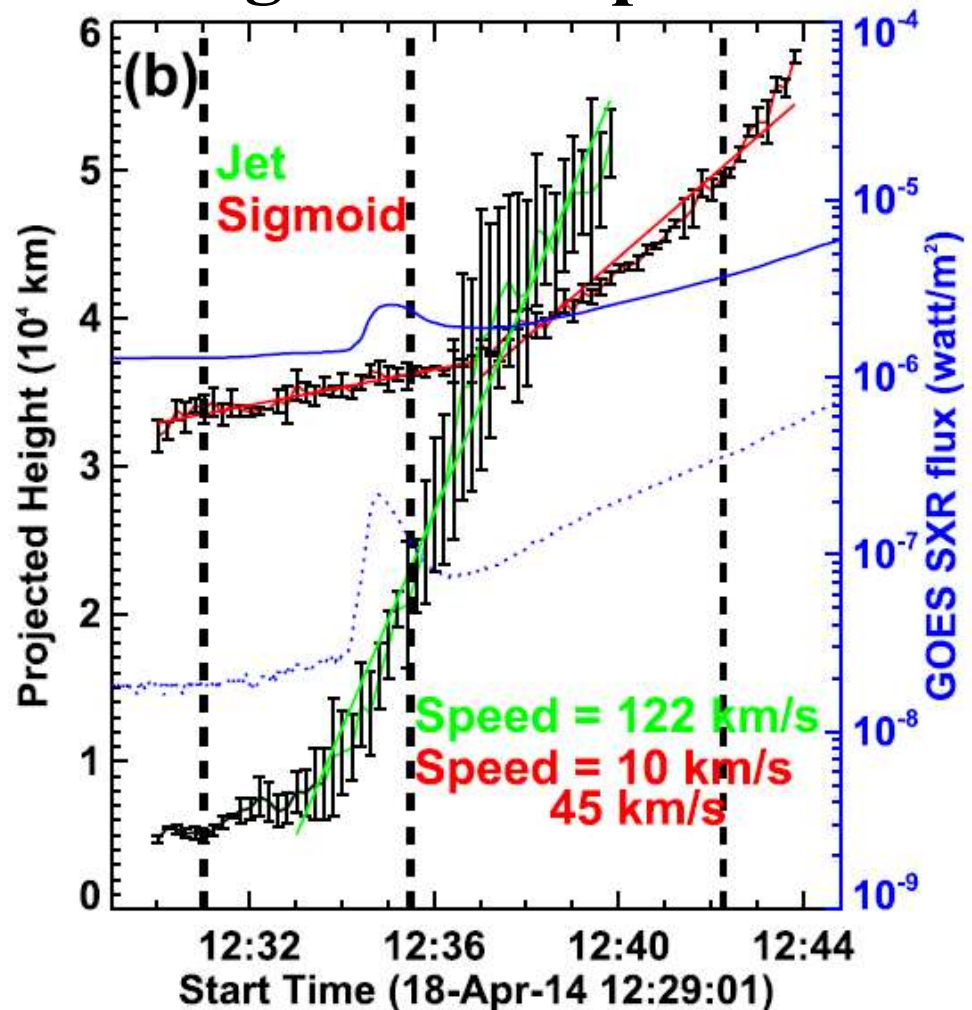
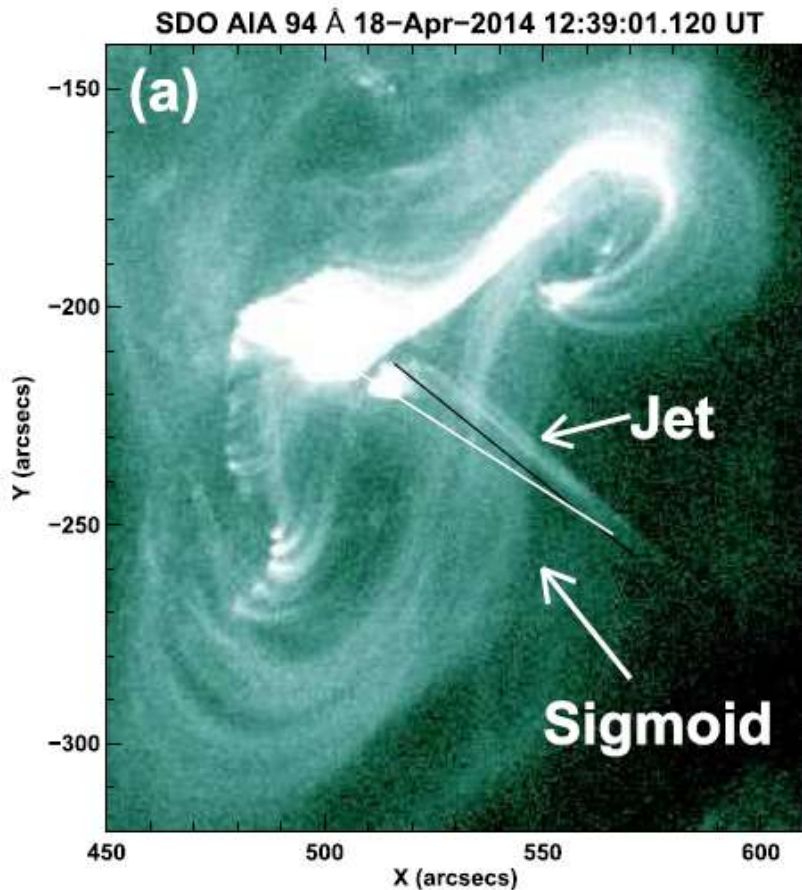
# SDO/AIA 131 Å animation: Sigmoid Eruption and M7.3 Solar Flare



# SDO/AIA 131 Å Running Difference Images: Sigmoid Eruption



# Kinematics of Jet and Sigmoid Eruption



Temporal correlation between the sigmoid eruption and GOES flux.

Formation of parallel ribbon with sigmoid eruption.

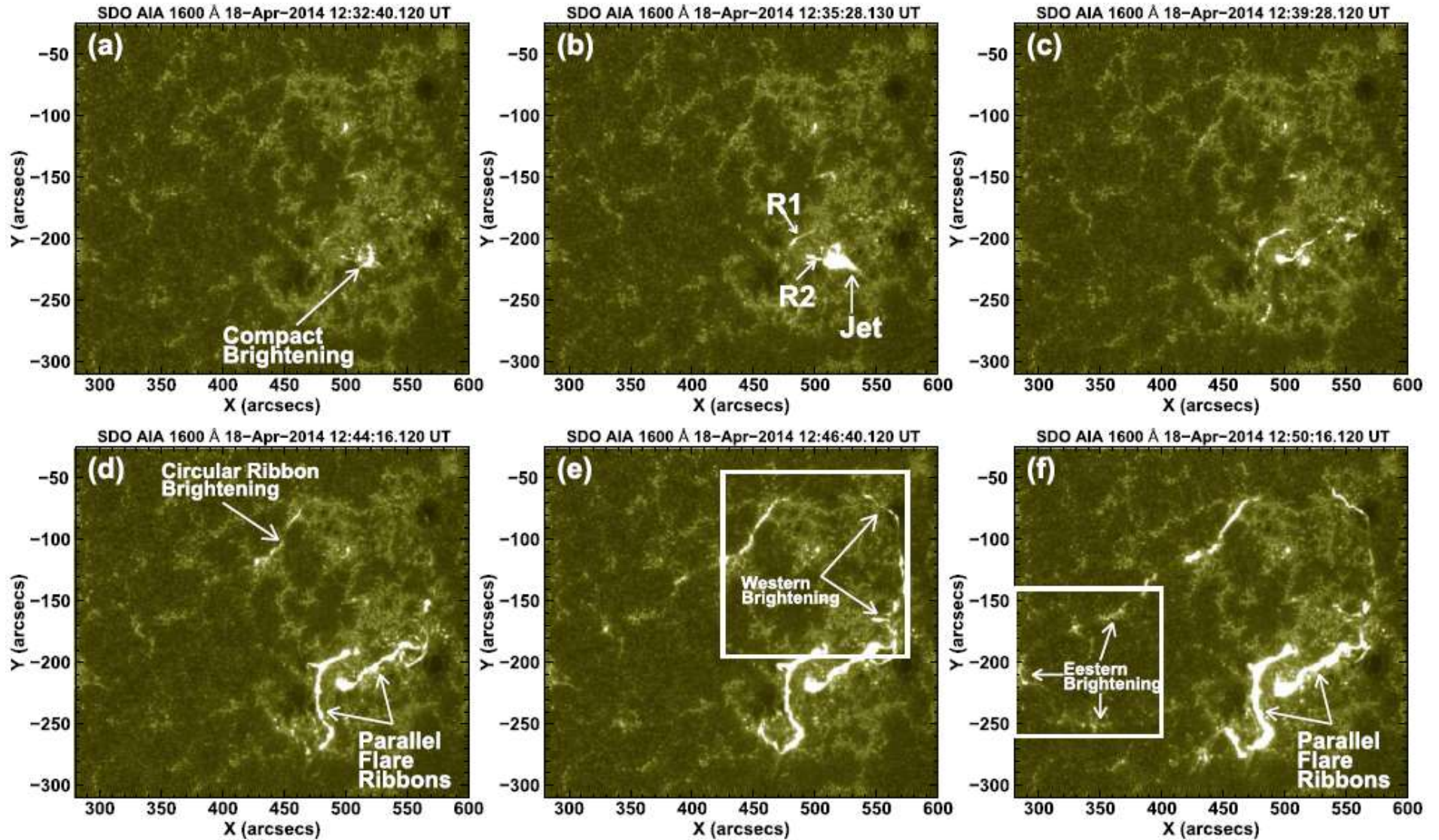
→ Evidence of sigmoid eruption and triggering of flare.

Sigmoid was rising about 11 minute before the first appearance of the circular flare

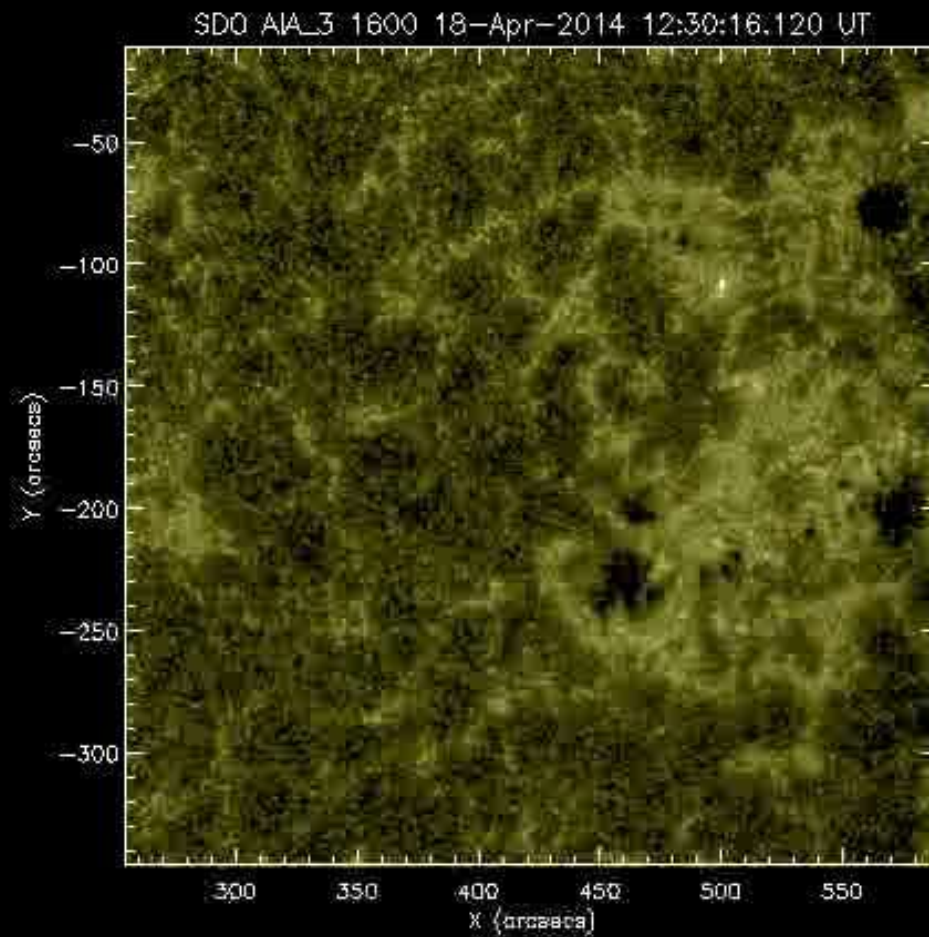
→ Evidence of null point reconnection.



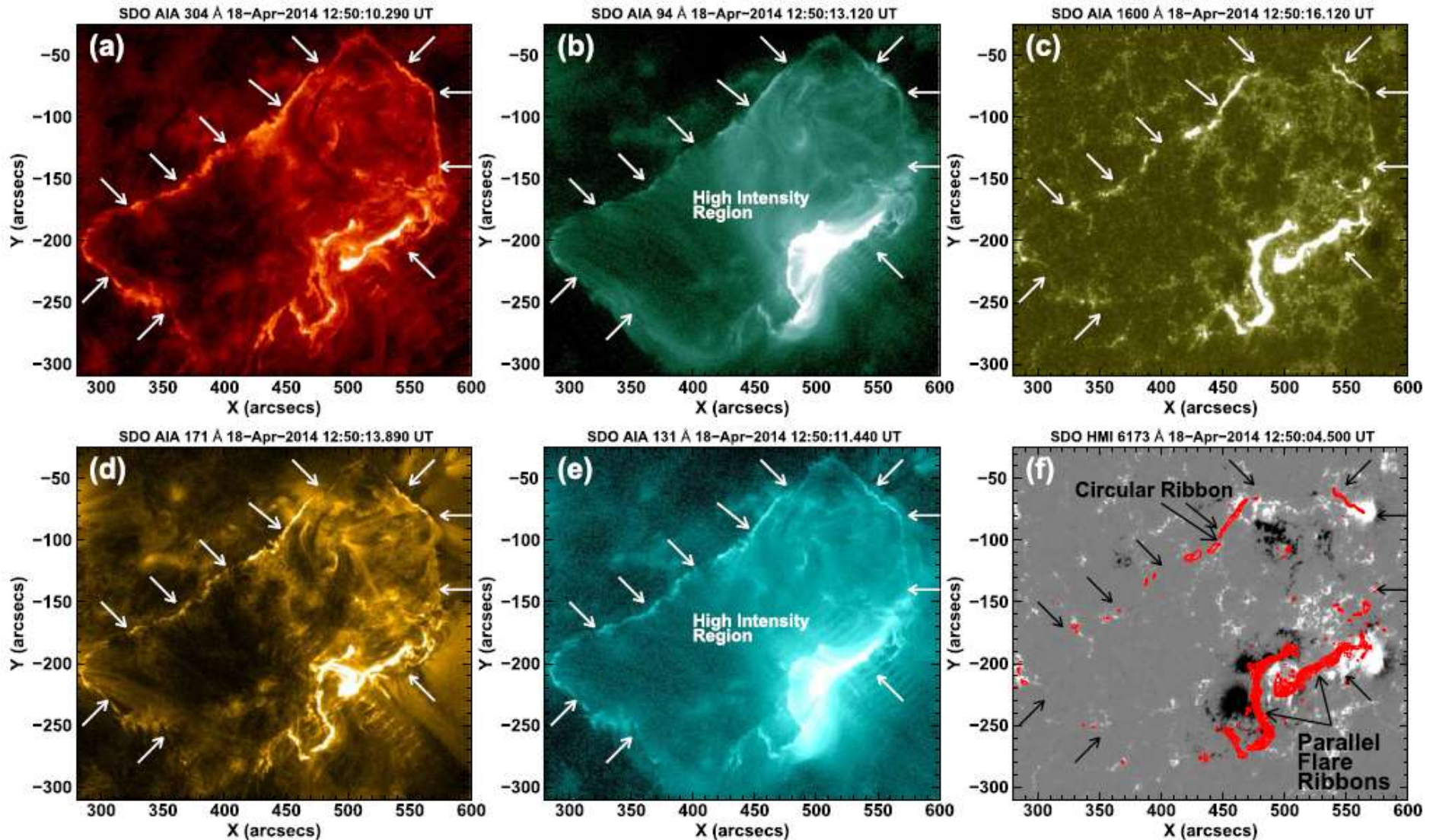
# Formation and Evolution of the Parallel Ribbons and the Large-Scale Quasi-Circular Ribbon



# AIA 1600 Å animation: Flare Ribbons Dynamics



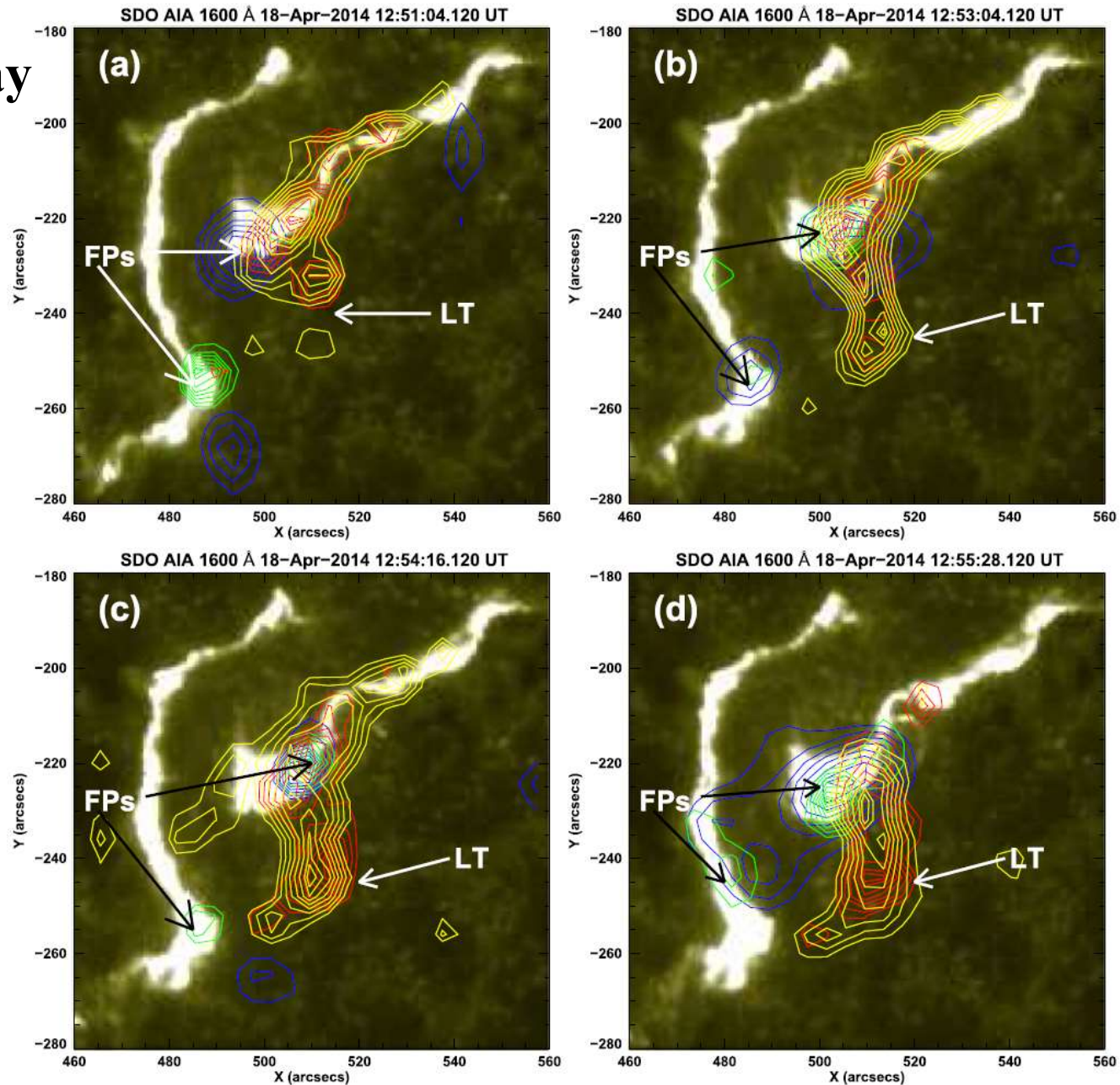
# Multi-wavelength nature of Flare Ribbons



Large-Scale Quasi Circular Ribbon → Evidence of Fan-Spine Like Magnetic Configuration.

# RHESSI X-ray Sources

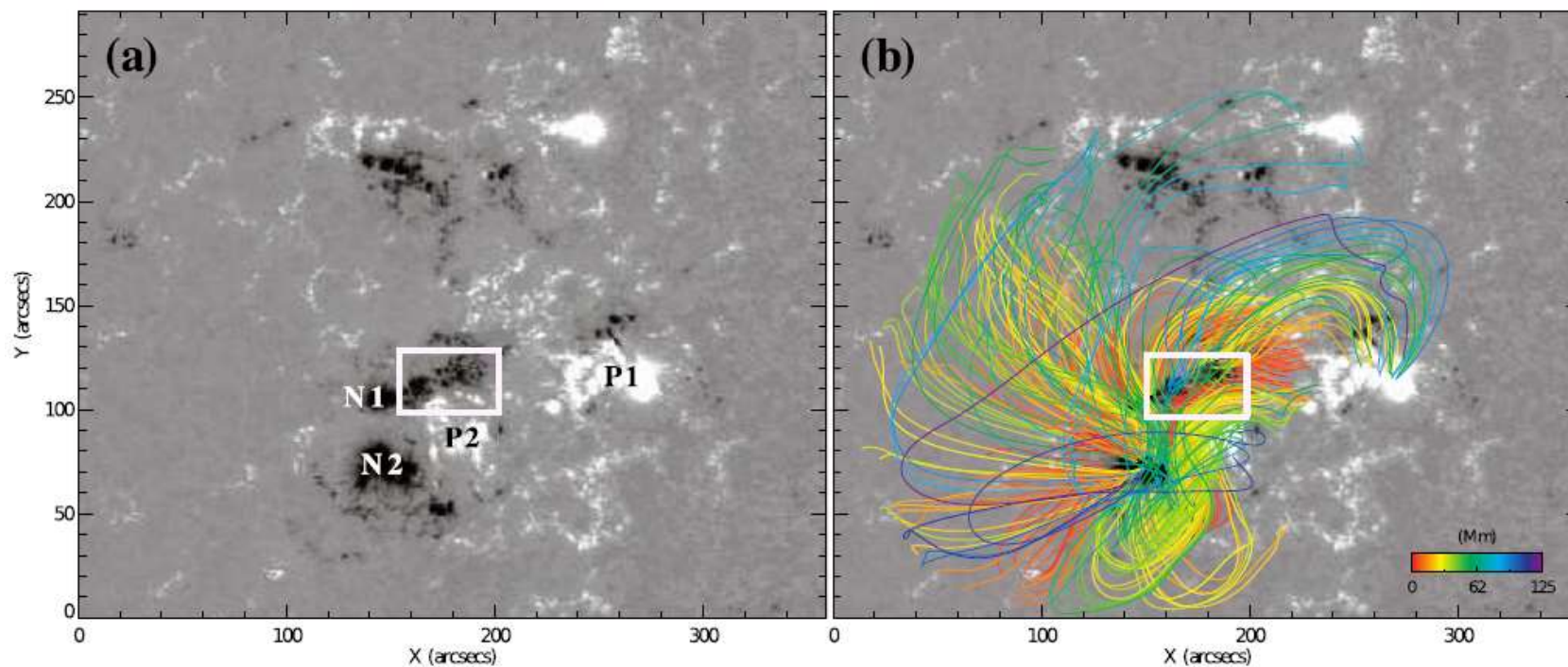
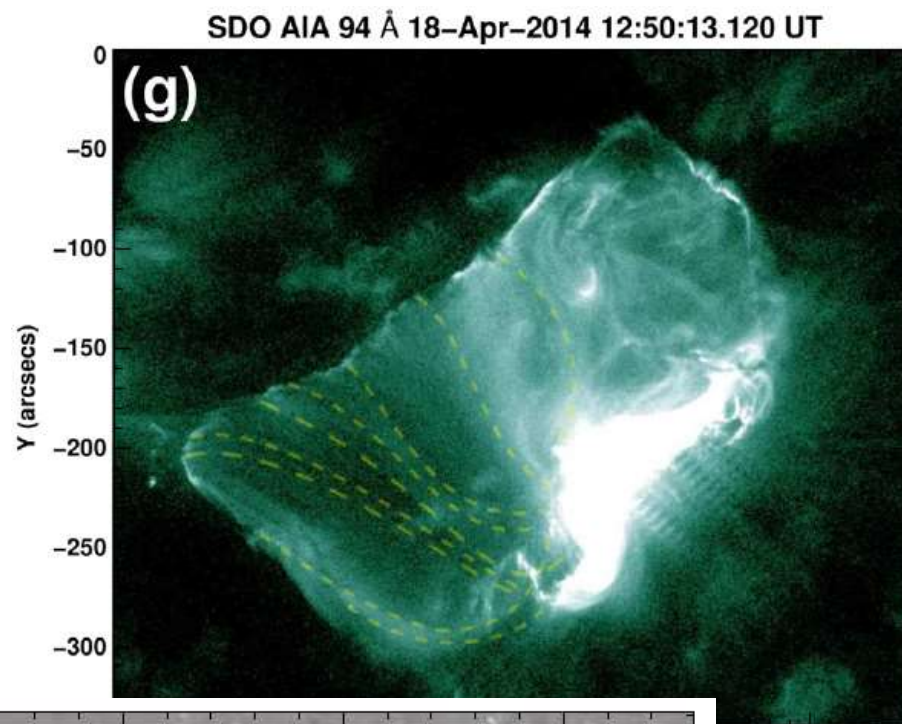
6-12 keV: Yellow  
12-25 keV: Red  
25-50 keV: Green  
50-100 keV: Blue



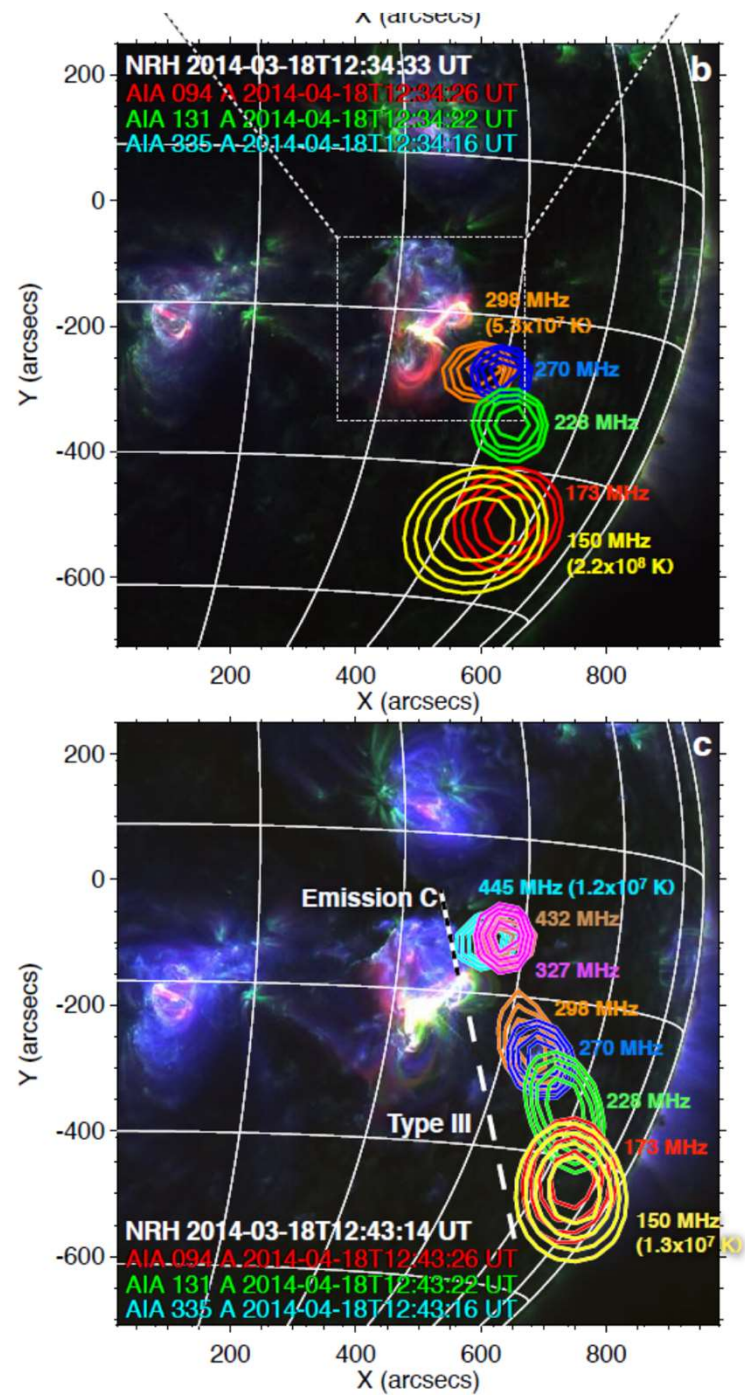
Observed HXR sources at the bright kernels of the ribbons and their separation motion.  
→ Evidence of sigmoid eruption and triggering of flare.

# NLFFF Extrapolation over the AR and Comparison with Observations

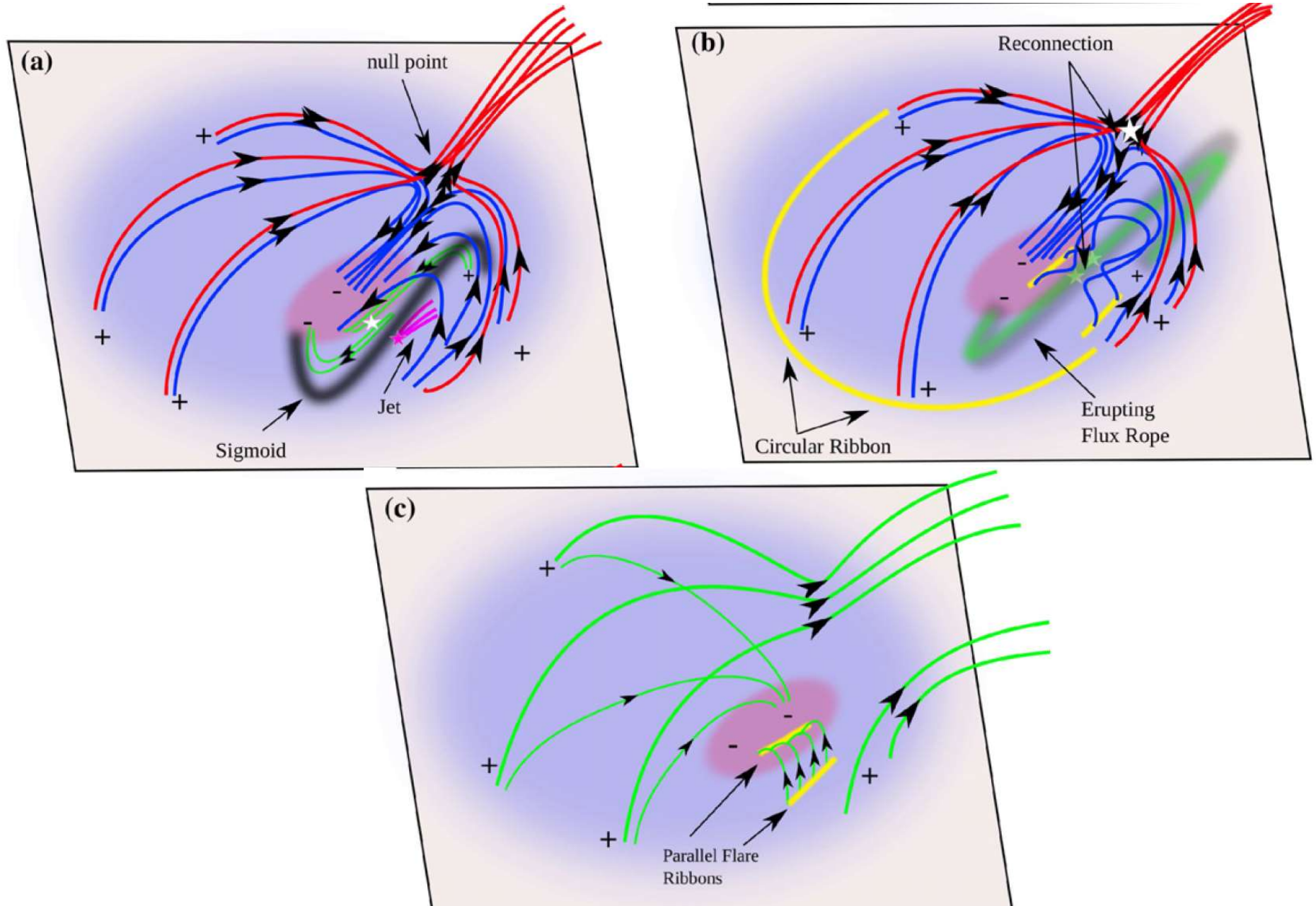
NLFFF extrapolation and high intensity region between the circular ribbon and main flare  
→Evidence of Fan-Spine Like Magnetic Configuration.

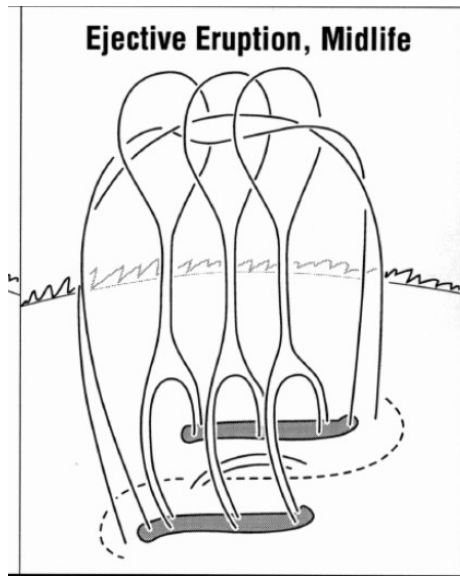


Carley et al. 2016

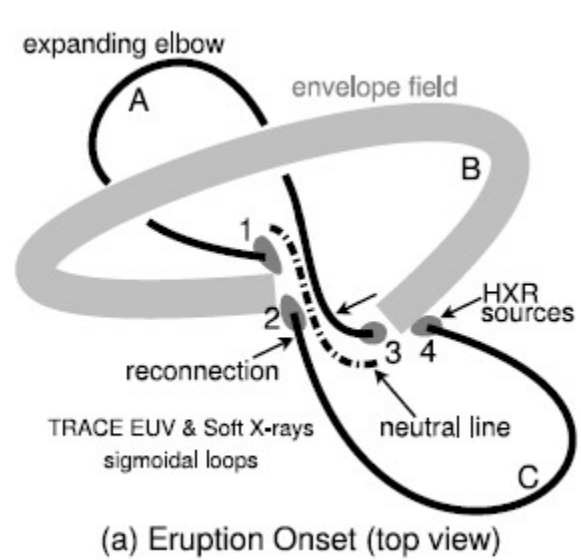


# Schematic Representation of the Magnetic Field changes during Main Phase of the Flare

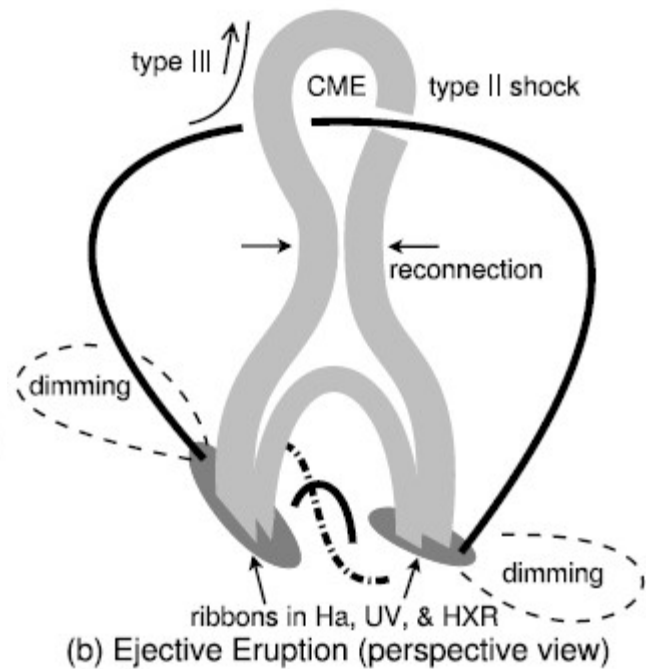




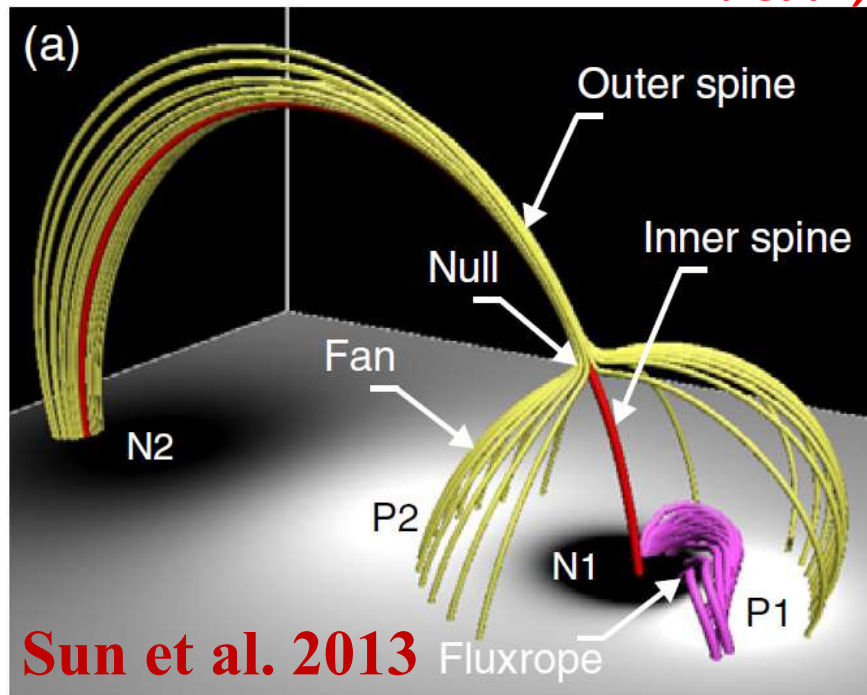
**Moore et al. 2001**



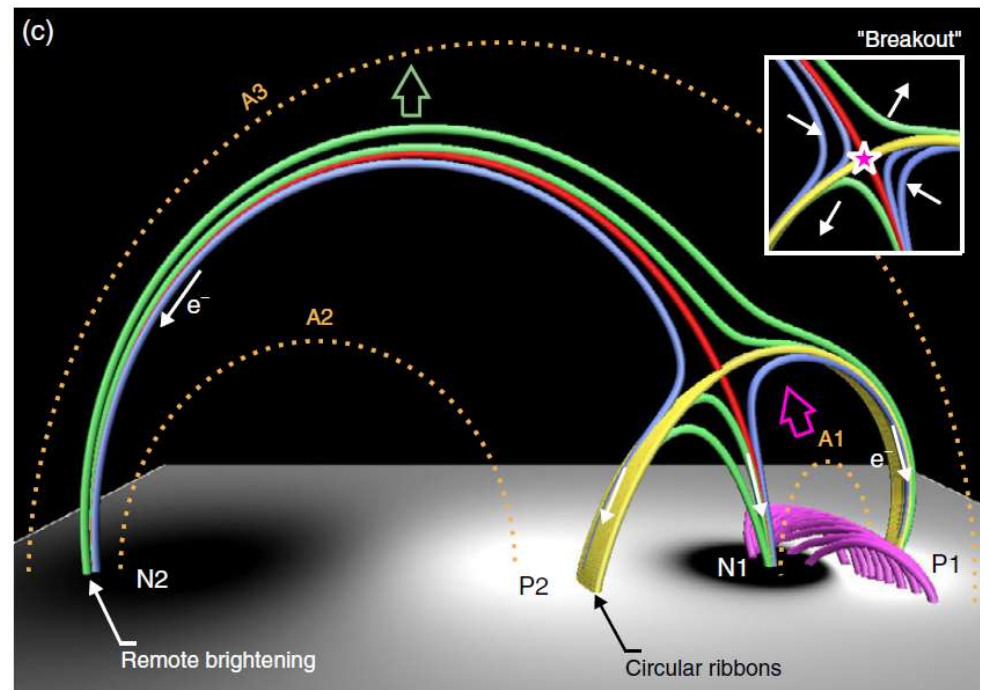
**Liu et al., 2007**



**(b) Ejective Eruption (perspective view)**



**Sun et al. 2013**





## Key findings of this work:

- 1). Several observational signatures and NLFFF results suggest the existence of a large-scale fan-spine type magnetic configuration with a large sigmoid embedded in a section of the fan dome.
- 2). Our observations show two main stages of evolution of the whole event, i.e., pre-flare and main flare, including a nearby jet activity.
- 3). During the pre-flare phase, we observed the formation and appearance of the sigmoid underneath the southern section of the fan-dome structure.
- 4). The internal tether-cutting type reconnection below the pre-existing sigmoid may be responsible for the sigmoid eruption.
- 5). Our analysis suggests that the erupting sigmoid triggers two stages of reconnection. The first stage is the reconnection between the legs of surrounding arcade field lines at the wake of the erupting sigmoid, which could produce the two parallel ribbons. The second stage involves the null-point reconnection, leading to the formation of the large-scale circular ribbon.
- 6). *To the best of our knowledge, for the first time, we suggest a mechanism for this type of flare consisting of a double set of ribbons triggered by an erupting sigmoid in a large-scale fan-spine-type magnetic configuration.*

# Publication information of this work

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## THE ROLE OF ERUPTING SIGMOID IN TRIGGERING A FLARE WITH PARALLEL AND LARGE-SCALE QUASI-CIRCULAR RIBBONS

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### ABSTRACT

In this paper, we present observations and analysis of an interesting sigmoid formation, eruption, and the associated flare that occurred on 2014 April 18 using multi-wavelength data sets. We discuss the possible role of the sigmoid eruption in triggering the flare, which consists of two different sets of ribbons: parallel ribbons and a large-scale quasi-circular ribbon. Several observational evidence and nonlinear force-free field extrapolation results show the existence of a large-scale fan-spine type magnetic configuration with a sigmoid lying under a section of the fan dome. The event can be explained with the following two phases. During the preflare phase, we observed the formation and appearance of the sigmoid via tether-cutting reconnection between the two sets of sheared fields under the fan dome. The second, main flare phase features the eruption of the sigmoid, the subsequent flare with parallel ribbons, and a quasi-circular ribbon. We propose the following multi-stage successive reconnection scenario for the main flare. First, tether-cutting reconnection is responsible for the formation and the eruption of the sigmoid structure. Second, the reconnection occurring in the wake of the erupting sigmoid produces the parallel flare ribbons on the both sides of the circular polarity inversion line. Third, the null-type reconnection higher in the corona, possibly triggered by the erupting sigmoid, leads to the formation of a large quasi-circular ribbon. For the first time, we suggest a mechanism for this type of flare consisting of a double set of ribbons triggered by an erupting sigmoid in a large-scale fan-spine-type magnetic configuration.

*Key words:* Sun: activity – Sun: flares – Sun: magnetic fields – Sun: X-rays, gamma rays



**Thank You**

