Magnetic Flux Cancelation as the Buildup and Trigger Mechanism for CME-Producing Eruptions in two Small Active Regions

Alphonse C. Sterling
Ronald L. Moore
Navdeep K. Panesar

Supported by NASA's HGI program, and the MSFC/Hinode project.

Abstract

We follow two small, magnetically isolated CME-producing solar active regions (ARs) from the time of their emergence until several days later, when their core regions erupt to produce the CMEs. In both cases, magnetograms show: (a) following an initial period where the poles of the emerging regions separate from each other, the poles then reverse direction and start to retract inward; (b) during the retraction period, flux cancelation occurs along the main neutral line of the regions, (c) this cancelation builds the sheared core field/flux rope that eventually erupts to make the CME. In the two cases, respectively 30% and 50% of the maximum flux of the region cancels prior to the eruption. Recent studies indicate that solar coronal jets frequently result from small-scale filaments eruptions (Sterling et al. 2015), with those “minifilament” eruptions also being built up and triggered by cancelation of magnetic flux (Panesar et al. 2016). Together, the small-AR eruptions here and the coronal jet results suggest that isolated bipolar regions tend to erupt when some threshold fraction, perhaps in the range of 50%, of the region’s maximum flux has canceled. Our observed erupting filaments/flux ropes form at sites of flux cancelation, in agreement with previous observations. Thus, the recent finding that minifilaments that erupt to form jets also form via flux cancelation is further evidence that minifilaments are small-scale versions of the long-studied full-sized filaments. (Details are in Sterling et al. 2018, ApJ, 864, 68.)

Introduction

- Recent studies show that most coronal jets result from eruptions of minifilaments (Sterling et al. 2015).
- Thus jets seem to be analogous to large-scale eruptions:

Jets		CME-Producing Eruptions
Erupting minifilaments	<—>	Large-scale erupting filaments
Jet-base bright point (JBP)	<—>	Typical solar flares.

- Many jets result from magnetic flux cancellation (Panesar et al. 2016). (See Figure 1.)

- Here we consider what causes large-scale eruptions. Are they like jets, caused by flux cancelation?

Magnetic Evolution of Coronal Jet Region

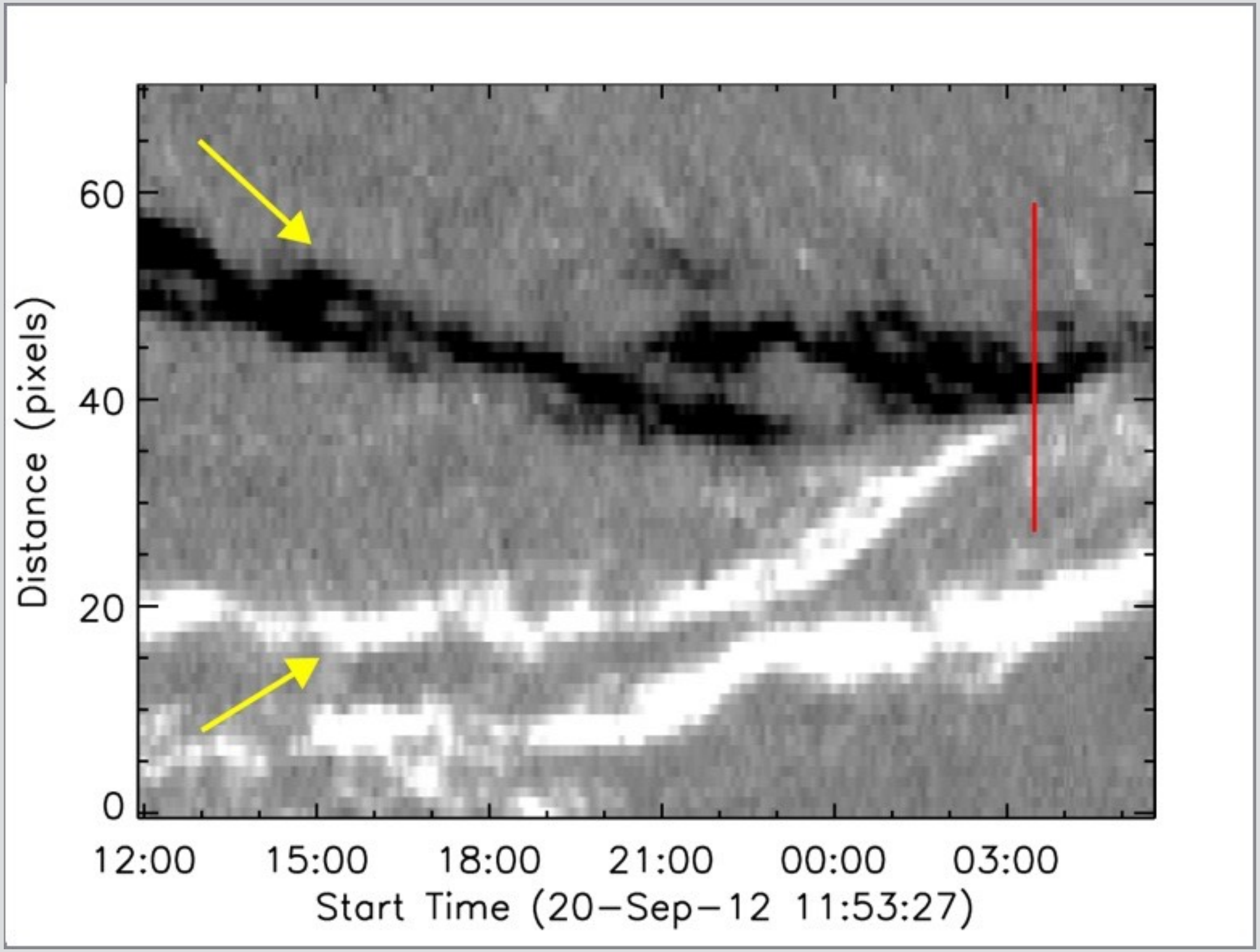


Figure 1. From Panesar et al. (2016). Near start on left, two magnetic elements (arrows) are about 15” (=30 HMI pixels) apart. Over 15 hours the elements converge. The coronal jet occurred near the time the two elements canceled (red line). Many other jets show similar behavior (e.g., Panesar et al. 2016, 2018; Young & Muglach 2014; Shen et al. 2012.)

Active Region Data Sets

- We want to study magnetic development of CME-producing active regions (ARs).
- Use SDO/AIA, SDO/HMI, and LASCSO and STEREO coronographs.
- Follow the AR development from emergence to eruption.
  - Regions must be (largely) magnetically isolated;
  - Birth-to-eruption lifetime less than one-disk passage.

- We examine two small ARs: ~10^{21} Mx; lifetime ~5 days.

Active Region #1: CME

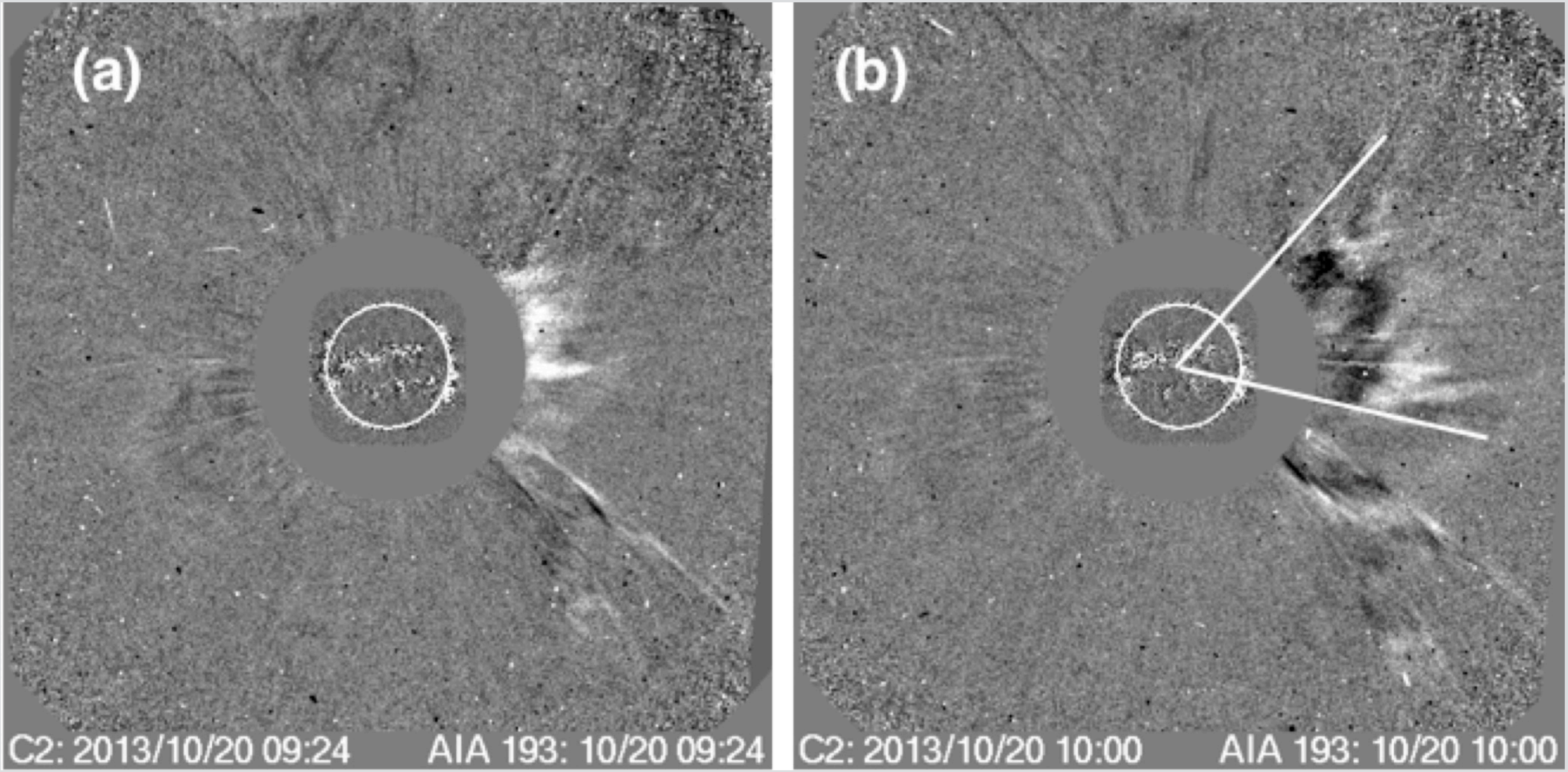


Figure 2. The CME was observed by LASCO. It subtends an angle of ~60^{o}. This is not as wide as major CMEs, consistent with the erupting AR being relatively small.

Active Region #1: Magnetic Evolution

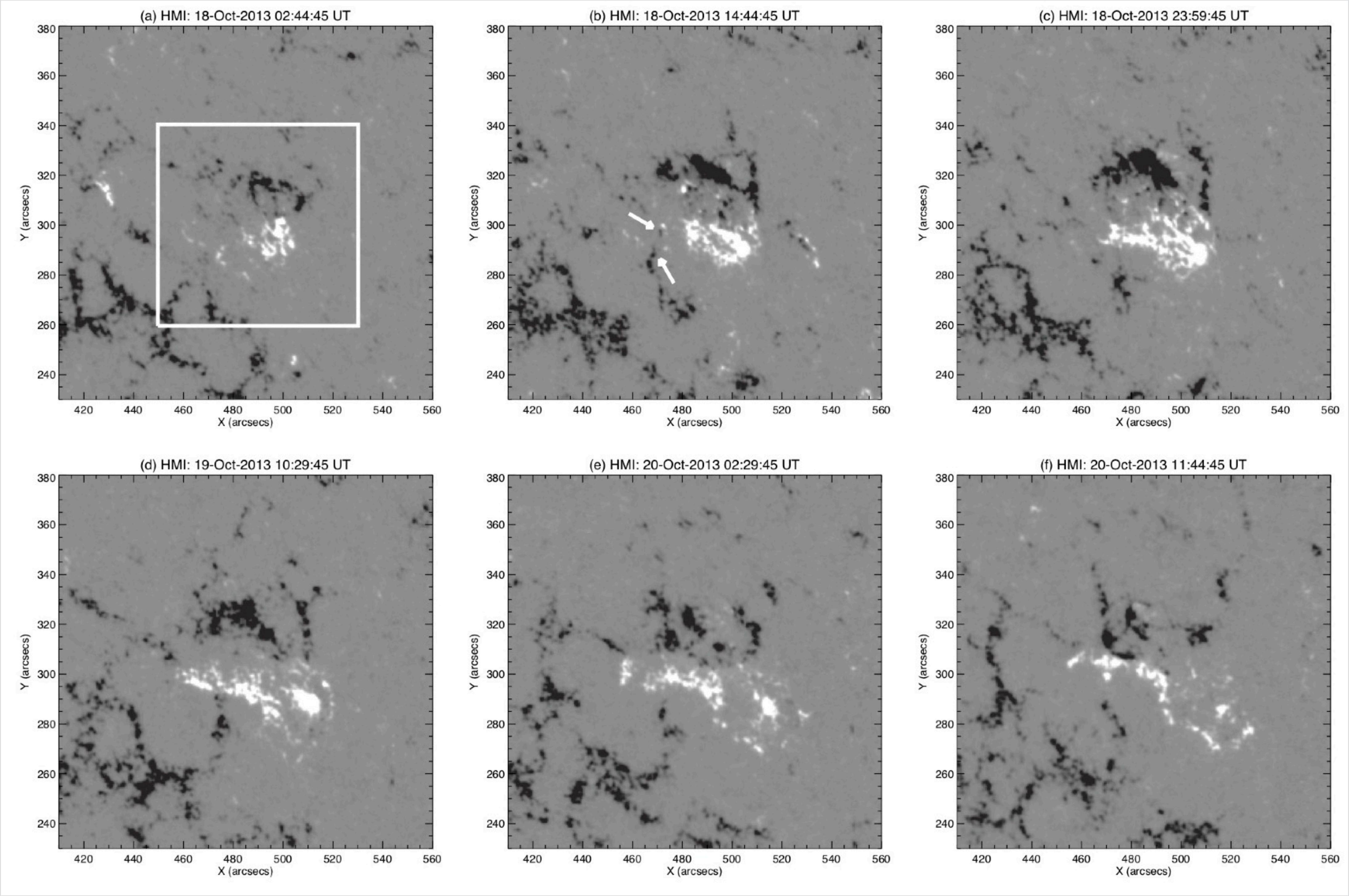


Figure 3. The region emerges and evolves over ~5 days. First the polarities separate, and then they come together. No major activity occurs until the polarities come together and converge, when a filament erupts producing the CME.

Active Region #1: Magnetic Field-Time Plot

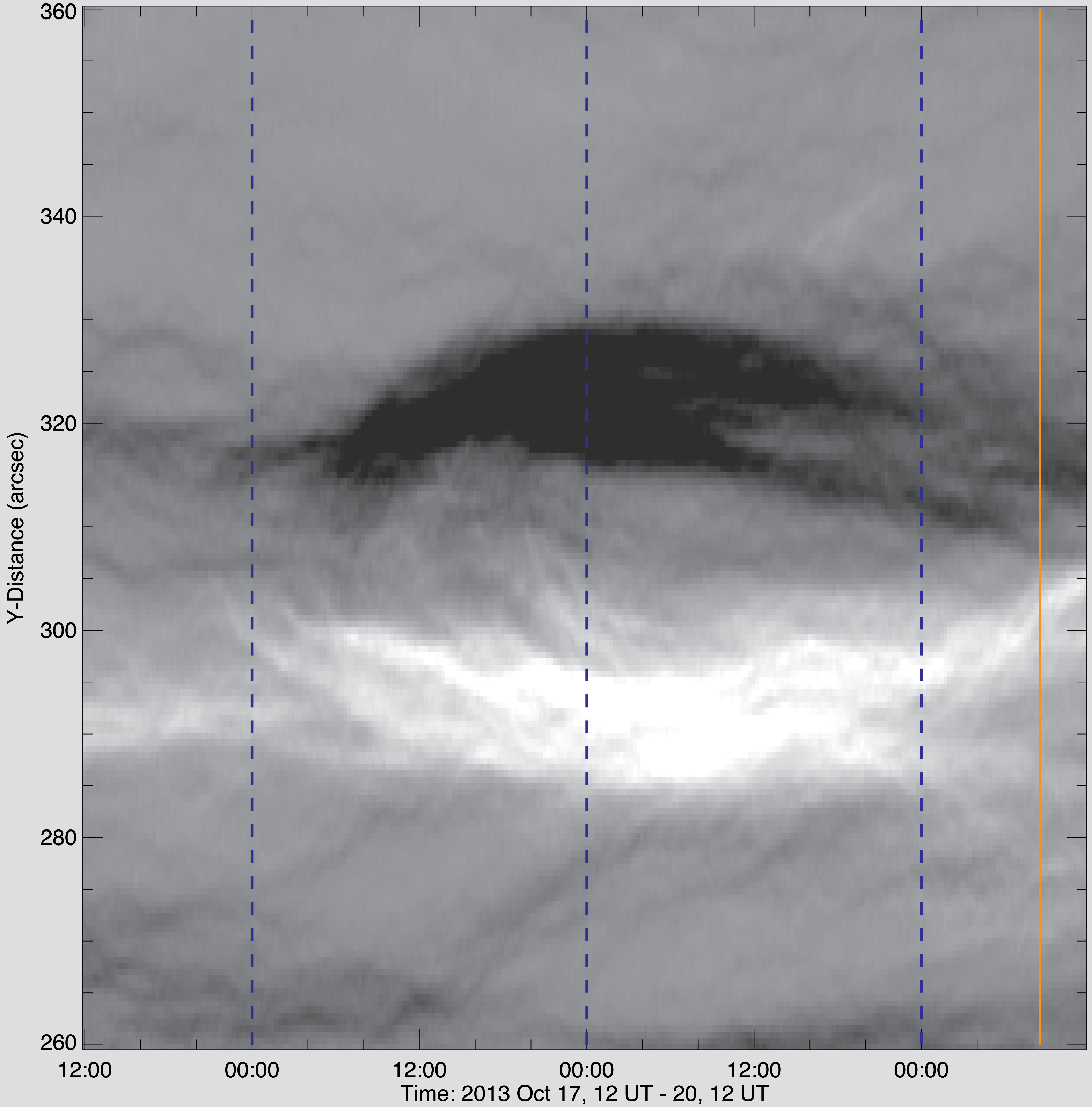


Figure 4. Magnetic polarities of the boxed region in Figure 3(a). Dashed lines show day boundaries, and the orange line shows when the CME-producing eruption occurred. Eruption occurs when the field elements cancel.

Active Region #2: CME

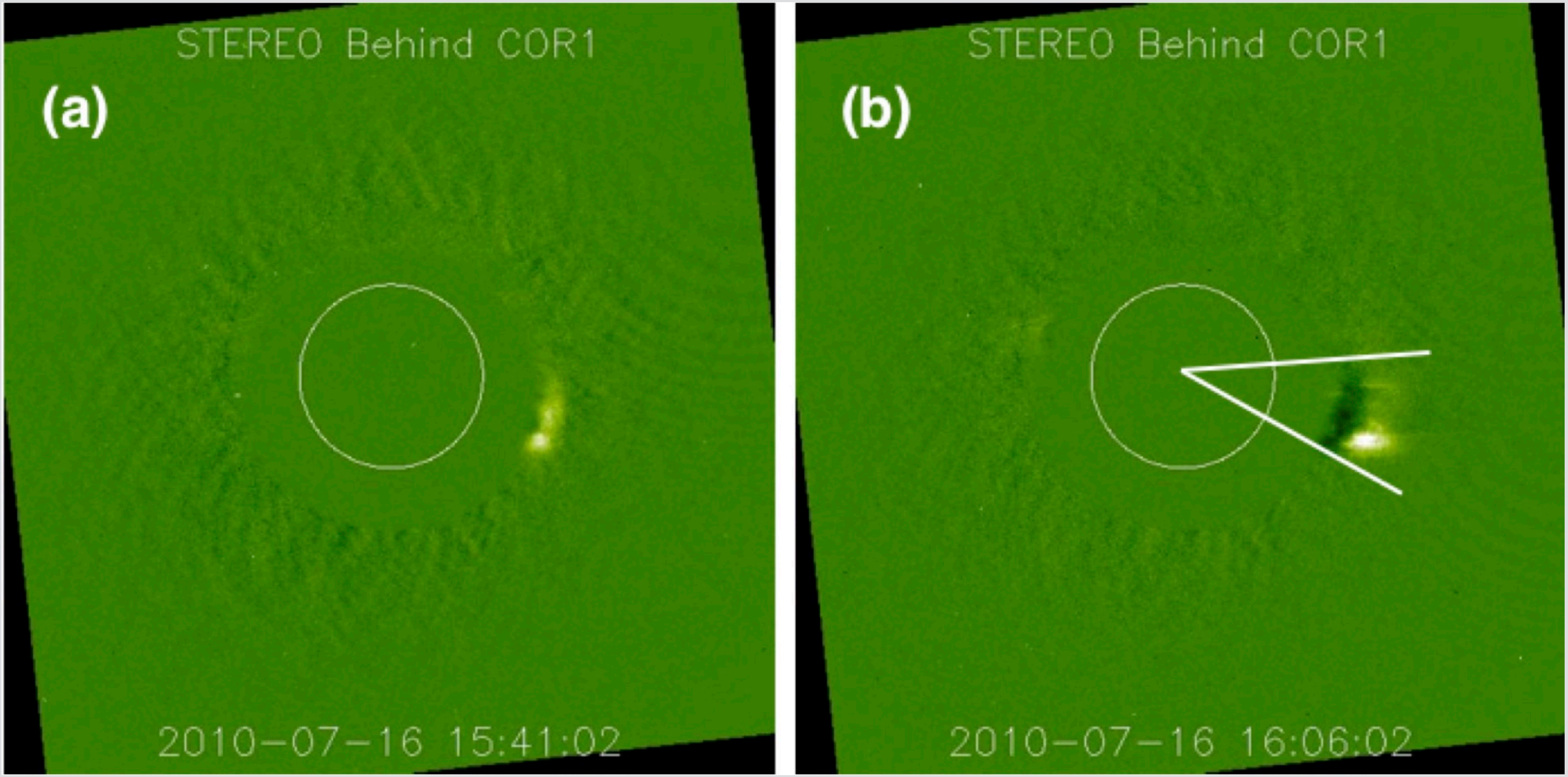


Figure 5. The CME was observed by STEREO B. It subtends an angle of ~35°. Again, this is a relatively narrow CME, consistent with the erupting AR being relatively small.

Active Region #2: Magnetic Evolution

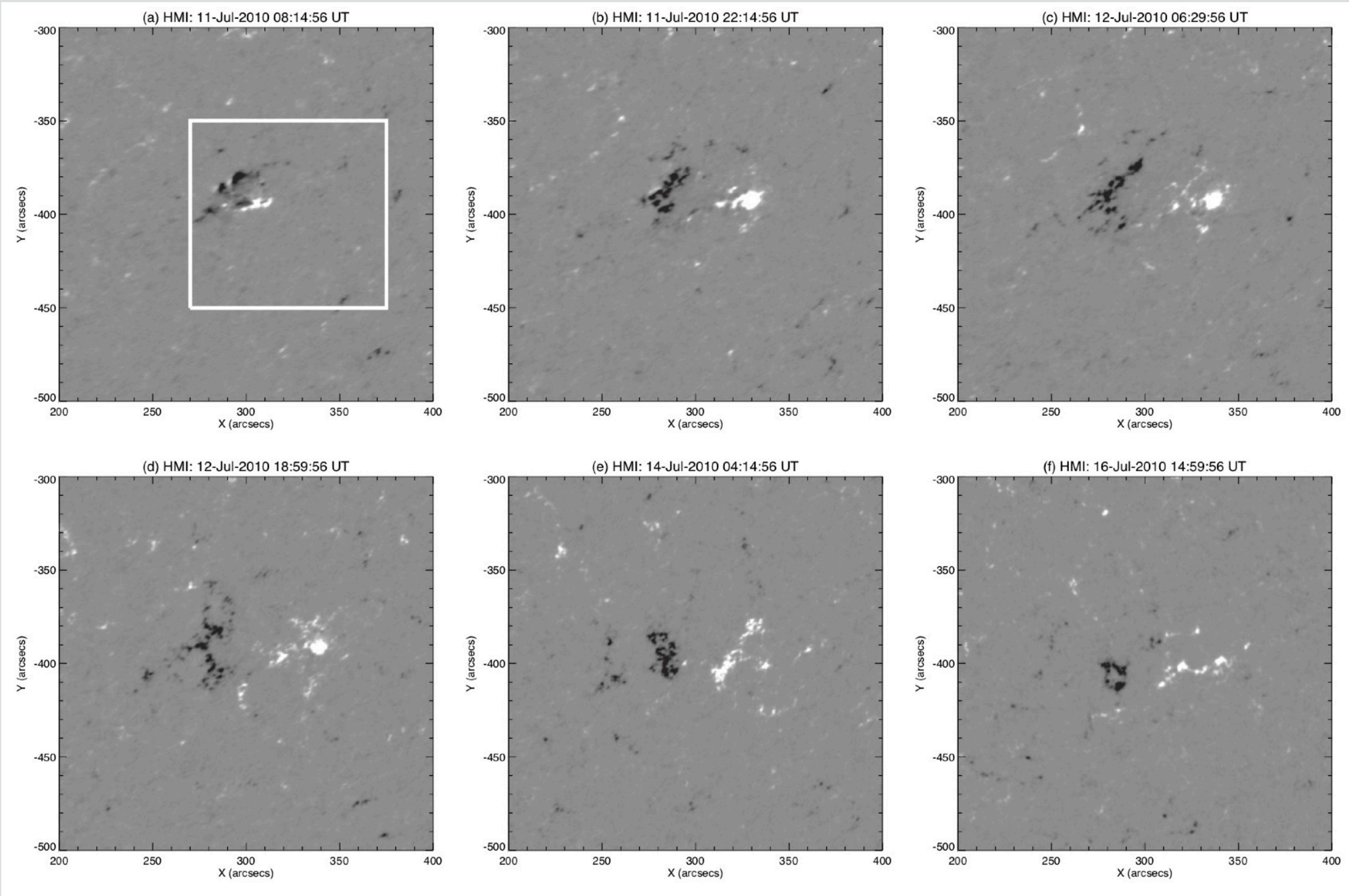


Figure 6. Similar to Fig. 3, but for the second AR. Again, the region emerges and evolves over ~5 days; first the polarities separate, and then they come together. No major activity occurs until the polarities come together and converge, when a filament erupts producing the CME.

Active Region #2: Magnetic Field-Time Plot

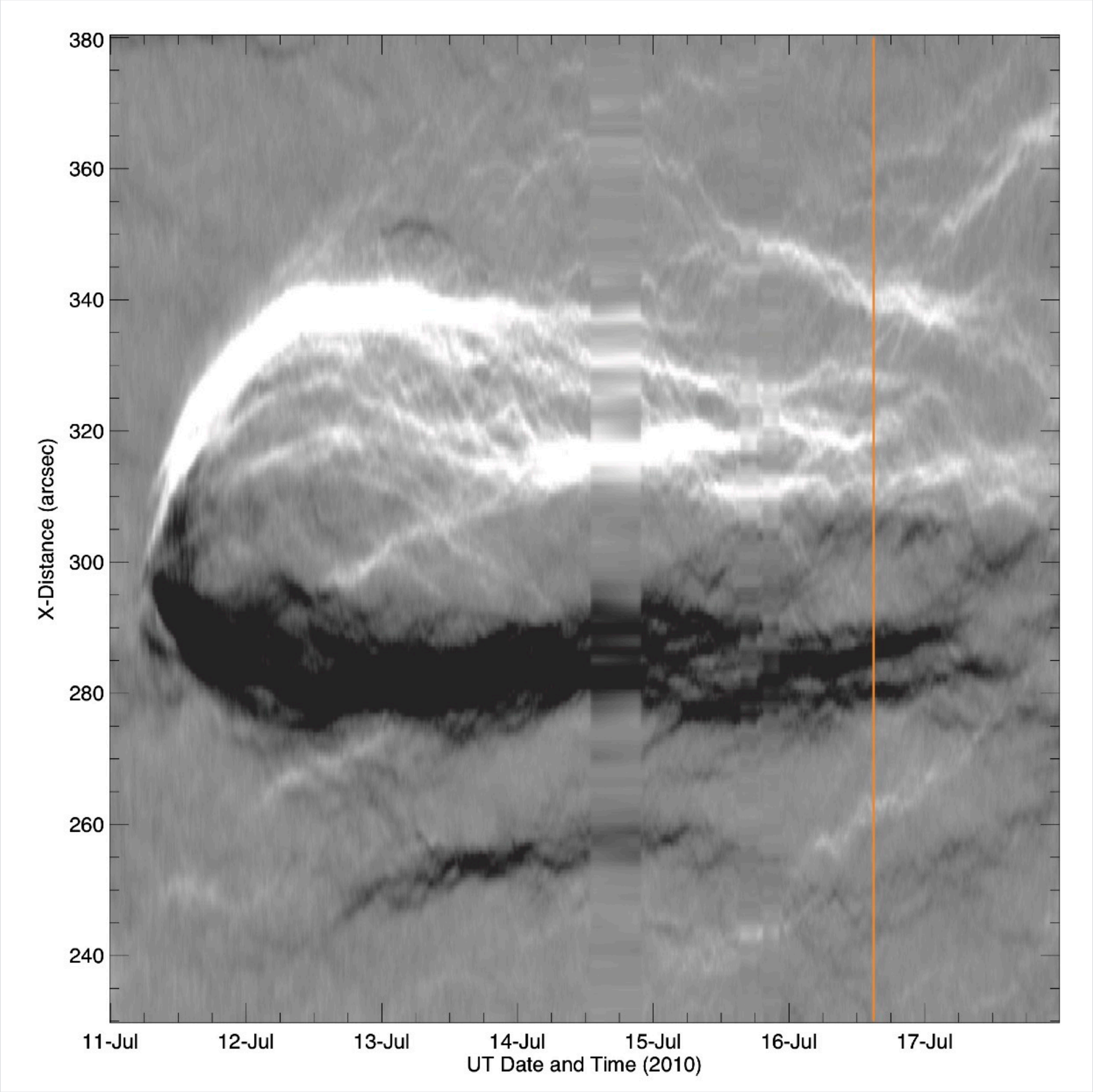
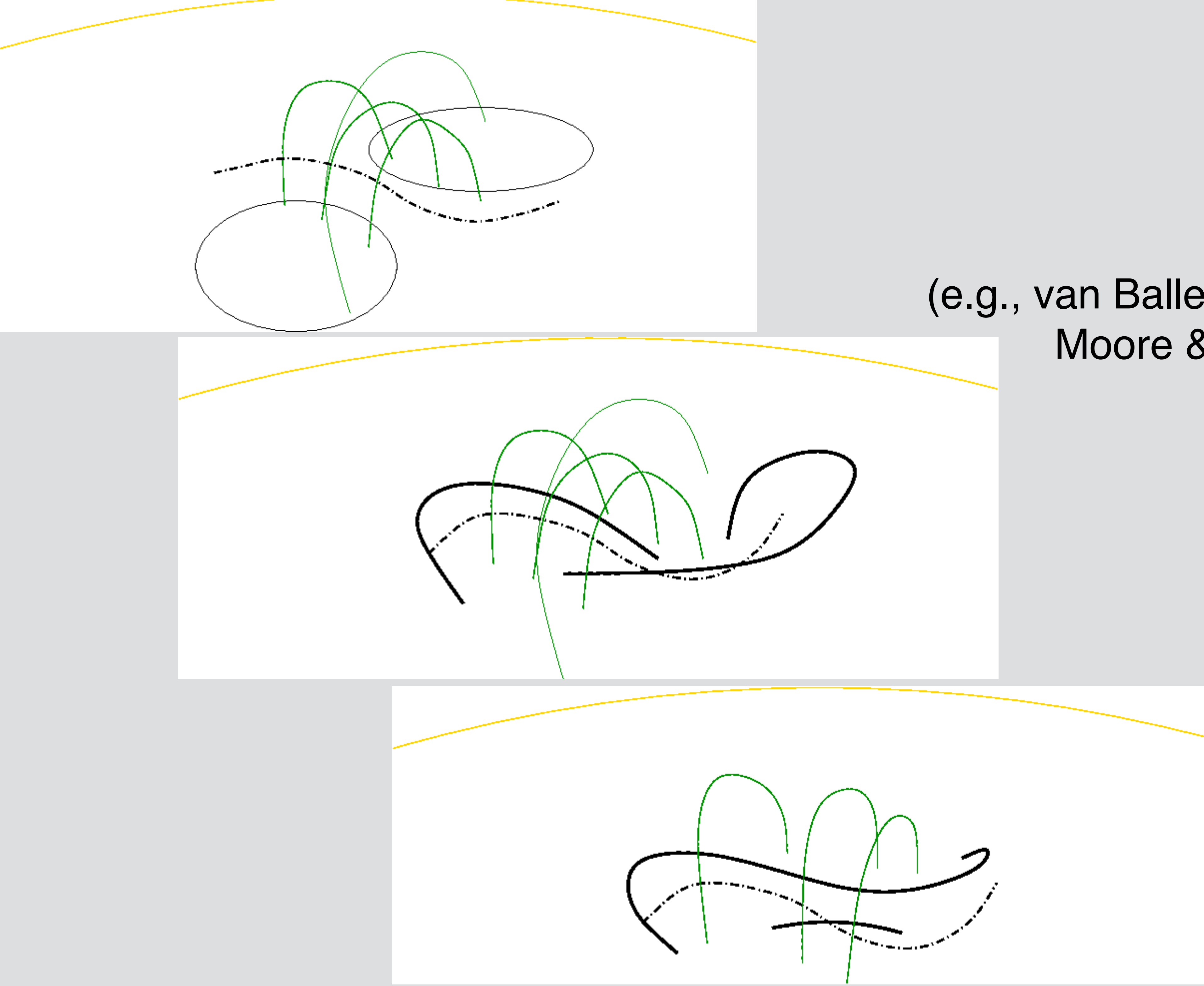


Figure 7. Magnetic polarities of the boxed region in Figure 6(a). The orange line shows when the CME-producing eruption occurred. Again, the eruption occurs when the field elements are canceling.

Flux-Cancelation Percentages:

	(% flux canceled)
• For CH jets (~10 events):	45
• For QS jets (~10 events):	37
• Small AR Event 1:	29
• Small AR Event 2:	51

(Panesar et al. 2016, 2018; Sterling et al., 2018):



(e.g., van Balleggoijen & Martens 1989, Moore & Roumeliotis 1992)

(Moore et al. 2001)

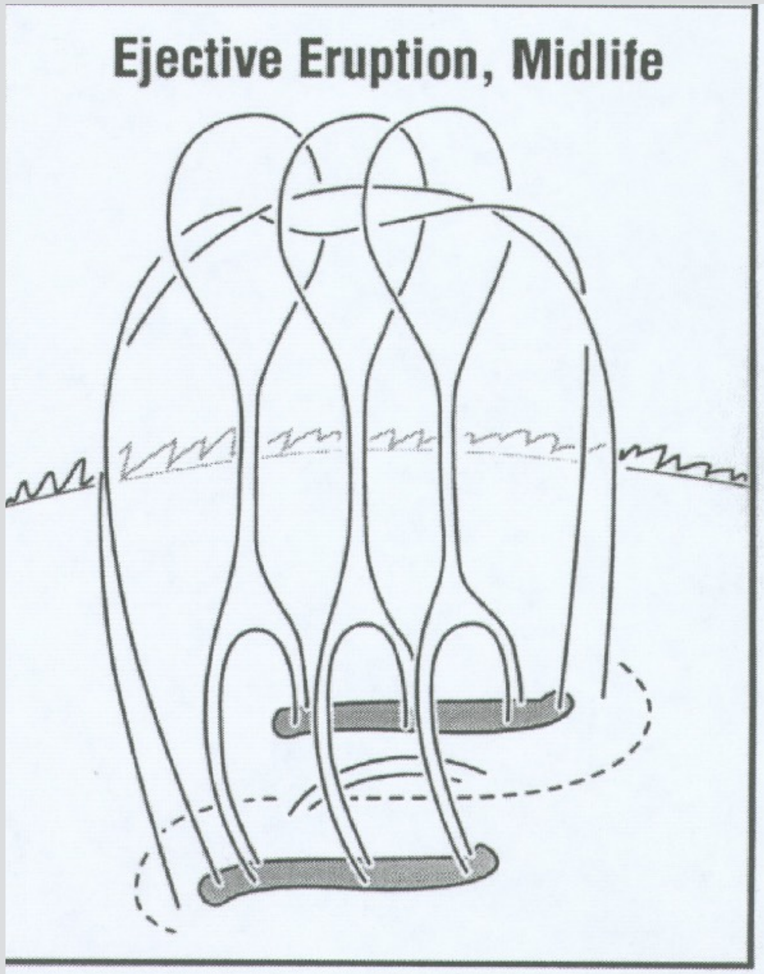


Figure 8. Our two ARs are (more-or-less) isolated from other magnetic structures. Their poles separate, and then come together and cancel. We speculate that the cancelation builds a magnetic shear and/or flux rope, that erupts to produce the CME. Similar processes were inferred from our jet studies (e.g., Panesar et al. 2018).

So, for these two small ARs:

- Both are relatively magnetically isolated from other solar regions.
- Both began with flux emergence, following by separating poles, and then converging poles.
- Filaments formed and eruptions occurred during the retracting phase, as flux cancelation was occurring.
- Thus the small ARs behave as scaled-up coronal jets: flux cancelations leading to (mini)filament eruptions!

- It may be that many eruptions (on small and large scales) occur when ~50% of the total flux of the region has canceled.

(Details: Sterling, Moore, & Panesar 2018.)

Summary

- Our two small ARs were approximately magnetically isolated.
- Poles of both ARs emerged, separated, and then came together and canceled after ~5 days.
- Major activity did not occur until the fields canceled, when filaments erupted producing CMEs.
- Thus in both these two ARs, and in many solar coronal jets, the filament eruptions (leading to CMEs) and minifilament eruptions (leading to jets) occurred when flux canceled (~50% of the original flux).
- Needed: Simulations based on *flux cancelation*!

Image:
Alphonse Sterling
21 August 2017,
Lewisville, Idaho

REFERENCES

Moore, R. L., & Roumeliotis, G. 1992, in “Eruptive Solar Flares,” 69.

Moore, R. L. et al. 2001, ApJ, 552, 833

Panesar, N. K., Sterling, A. C., & Moore, R. L. 2016, ApJ, 822, 23L

Panesar, N. K., Sterling, A. C., & Moore, & R. L. 2018, ApJ, 853, 189

Shen, Y. et al. 2012, ApJ, 745, 164

Sterling, A. C., Moore, R. L., Falconer, D. A., & Adams, M. 2015, Nature, 523, 437

Sterling, A. C., Moore, & Panesar, N. K. 2018, ApJ, 864, 68

van Ballegooijen, A. A., & Martins, P. C. H. 1989, ApJ, 343, 971

Young, P. R., & Muglach, K. 2014, PASJ, 66, S12