A CME-Producing Solar Eruption from the Interior of a Twisted, Emerging Bipole

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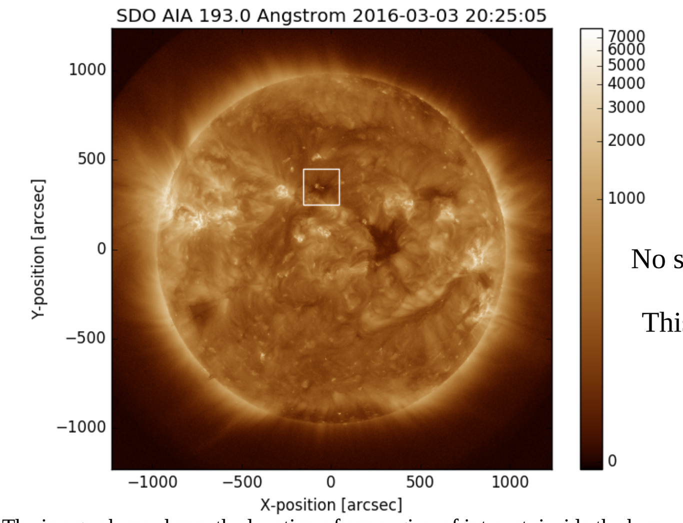
In a negative-polarity coronal hole, magnetic flux emergence, seen by the Solar Dynamics Observatory's (SDO) Helioseismic Magnetic Imager (HMI), begins at approximately 19:00 UT on March 3, 2016. The emerged magnetic field produced sunspots with penumbrae by 3:00 UT on March 4, which are a part of NOAA 12514. The emerging magnetic field is largely bipolar with the opposite-polarity fluxes spreading apart overall, but there is simultaneously some convergence and cancellation of opposite-polarity flux at the polarity inversion line (PIL) inside the emerging bipole. The emerging bipole shows obvious overall left-handed shear and/or twist in its magnetic field and corresponding clockwise rotation of the two poles of the bipole about each other as the bipole emerges. The eruption comes from inside the emerging bipole and blows it open to produce a CME observed by SOHO/LASCO. That eruption is preceded by flux cancellation at the emerging bipole's interior PIL, cancellation that plausibly builds a sheared and twisted flux rope above the interior PIL and fnally triggers the blow-out eruption of the flux rope via photospheric-convection-driven, slow tether-cutting reconnection of the legs of the sheared core field, low above the interior PIL, as proposed by van Ballegooijen and Martens (1989, ApJ, 343, 971) and Moore and Roumeliotis (1992, in Eruptive Solar Flares, ed. Z. Svestka, B.V. Jackson, and M.E. Machado [Berlin:Springer], 69). The production of this eruption is a (perhaps rare) counterexample to solar eruptions that result from external collisional shearing between opposite polarities from two distinct emerging and/or emerged bipoles (Chintzoglou et al., 2019, ApJ, 871:67).

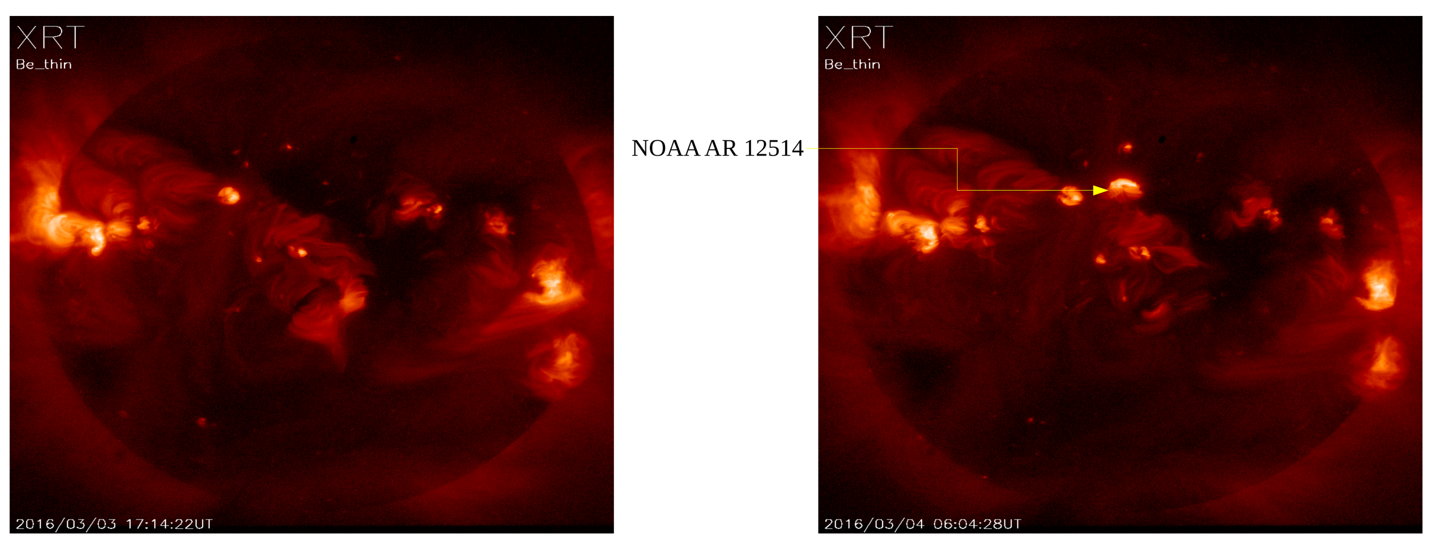
Overview of the Region in Various Wavelengths



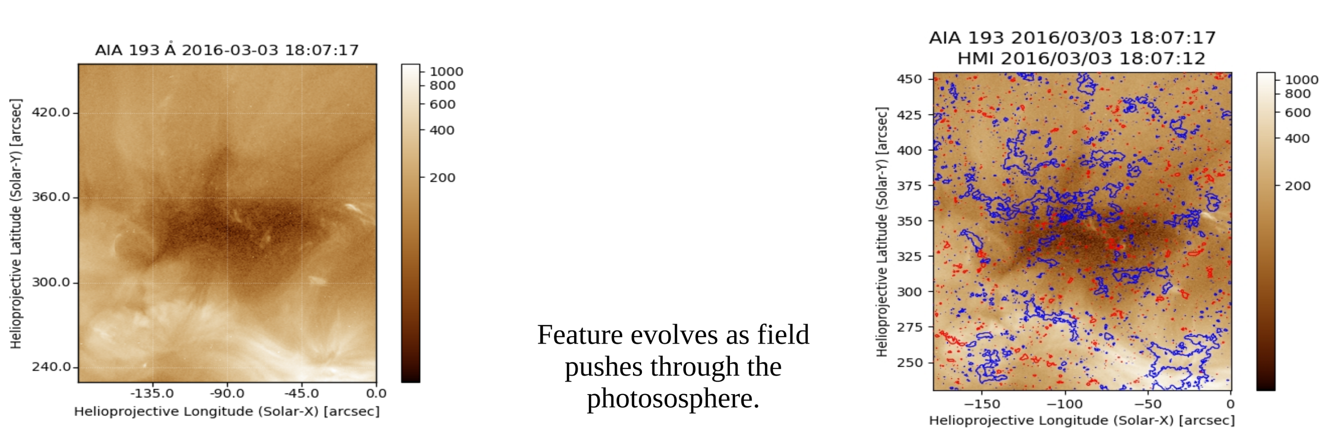
The image above shows the location of our region of interest, inside the box. AR 12512 is to the east.

Emergence began at ~18:44 UT in HMI (time estimated from movie), feature was seen in AIA 94, 193, 211, 304, and HMI
No spots in continuum until 2016 03/03, approximately23:43 UT.
Four main eruptions were seen in this region.
This poster is mainly concerned with the fourth eruption, which made a CME.

The Feature was Also Seen in Hinode/XRT



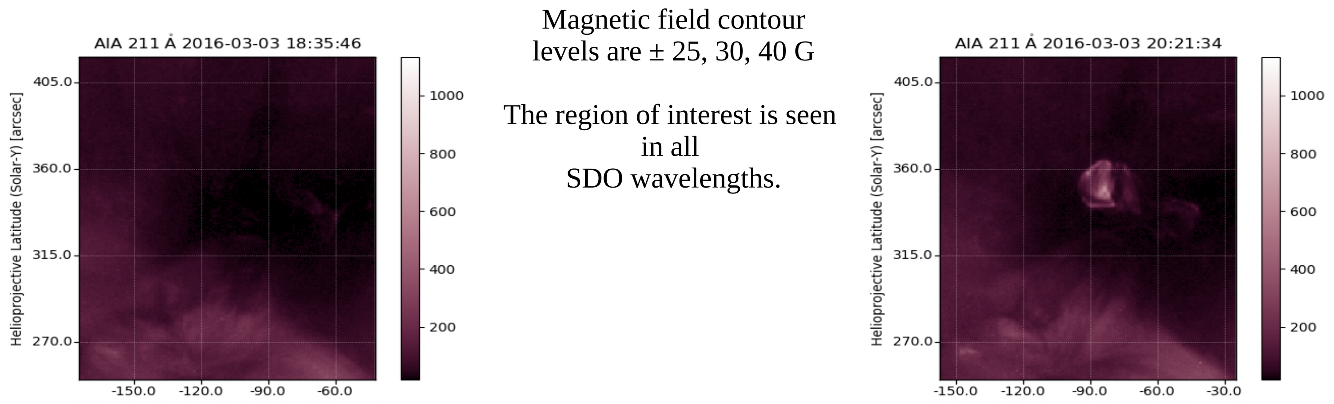
On the left, Hinode XRT shows the coronal hole into which our region of interest emerged. On the right, XRT observes the region at disk center at 6:04 UT on March 4, 2019. Sunspots were visible by 3:00 UT on March 4 in HMI continuum. NOAA numbered our region of interest, AR 12514, which was located at N14W11 (03/04/2400Z), with an area of 20 millionths of the solar hemisphere, nine visible spots, and a magnetic classification of β. By March 8 when AR 12514 was close to the limb, no spots were visible.

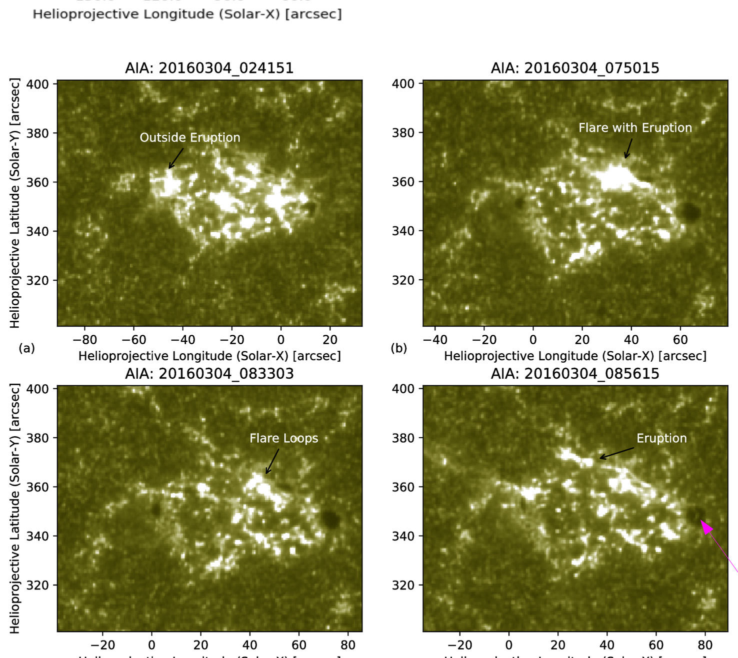


Feature evolves as field pushes through the photosphere.

Magnetic field contour levels are ± 25, 30, 40 G

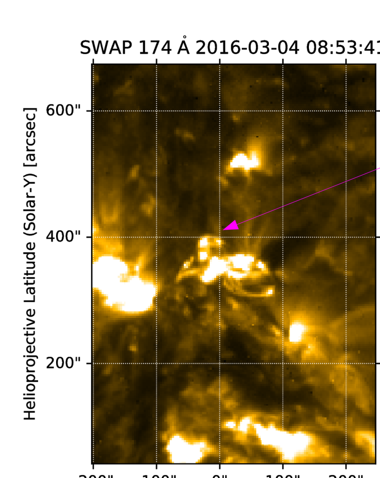
The region of interest is seen in all SDO wavelengths.





Flare Emission

AIA 1600 Å images, show an outside eruption at 02:41 UT, and inside eruptions at 07:50 UT and 08:56 UT. The 02:41 eruption created a brightening in AIA 193 Å, but no ejected material. In (b), the brightening in 1600 Å is mirrored in 193 Å, and is located at the source region for the fourth eruption; it produced a B3 flare in GOES. Note in (d) flare emission in the umbra of the leading spot, an indication that the umbral field opened.



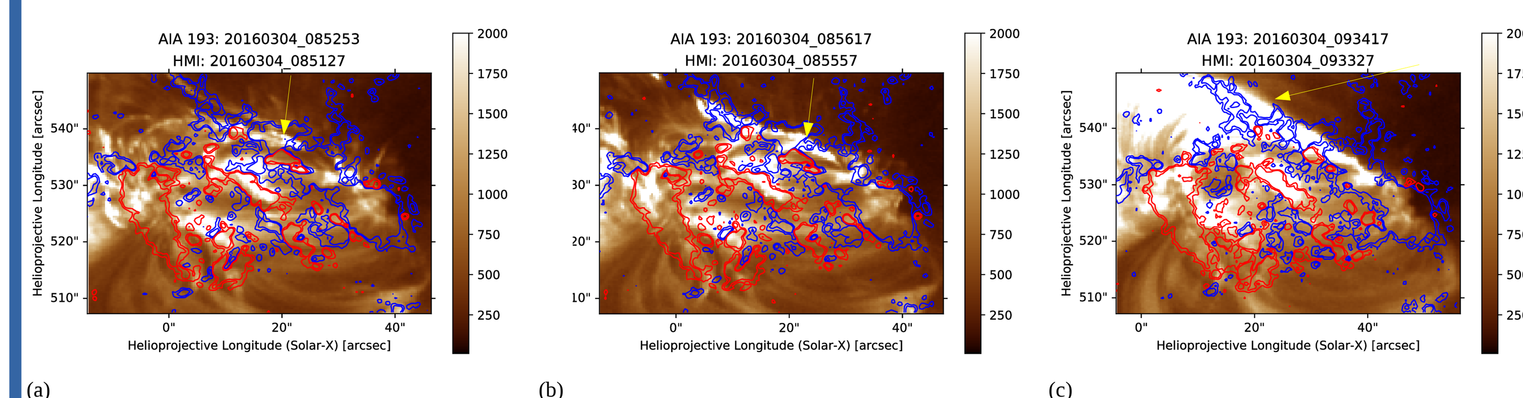
Erupting material

At 174 Å, PROBA2's SWAP instrument also saw material being ejected from the region.

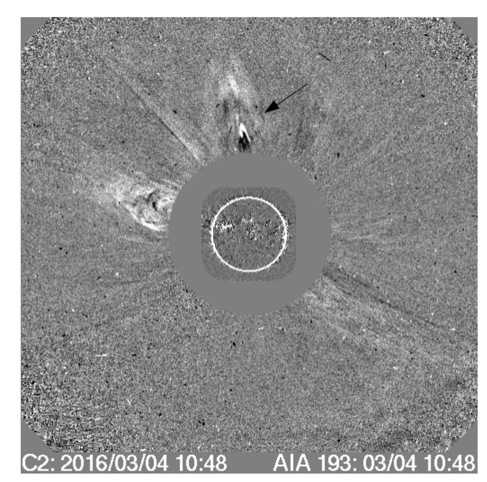
DATE (2016)	START (UT)	END (UT)	Characteristics
Mar 3	21:58:17	22:09:41	This eruption originated from flux cancellation of old negative polarity and newly-emerged positive polarity on the outside edge (northeast) of the region.
Mar 3/4	23:09:41	01:37:53	This eruption originated from cancellation of new negative flux with new positive flux on the southwest edge of the emerging overall bipolar region.
Mar 4	02:22:41	04:17:29	The eruption, of relatively long duration, began in the southwest area of the Active Region, inside the emerging flux region, and likely provided helicity loading to the main eruption at 08:40 that created the CME.
Mar 4	08:40:17	09:15:41	This eruption produced an X-ray flare (B-class) as seen from GOES, followed by flare loops, and the ejection that produced the CME.

TABLE 1: The table shows start/end times of the major eruptions, and summarizes characteristics.

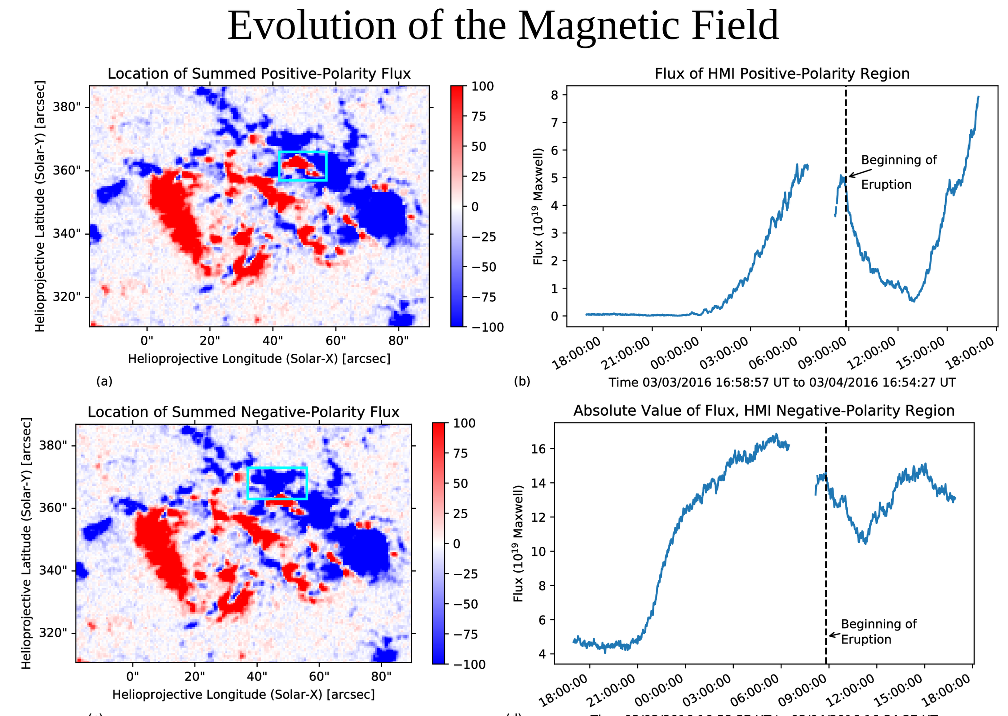
Eruption 4



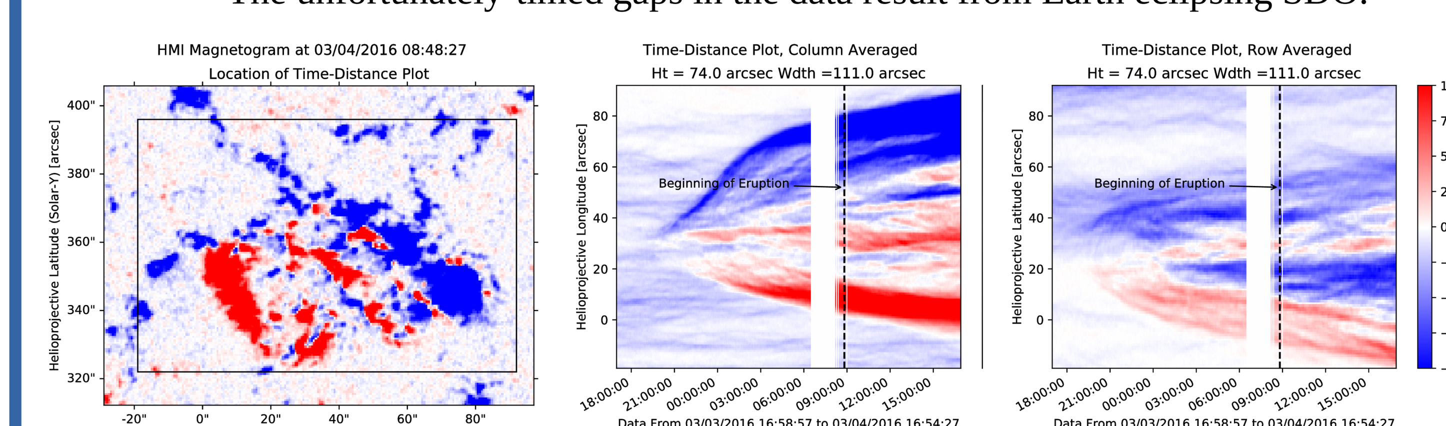
The arrows in (a) point to the neutral line and base of the loop that lifts off, ejects material, and makes the CME In (b), the loop has opened. In (c), a post-eruption flare arcade loops forms. Contours are at ±25 and ±70 Gauss. This blowout eruption made a B6 GOES X-ray flare and a CME to the north at about 09:48 UT, which is more fully developed an hour later as seen in SOHO C2 (below) at 10:48 UT.



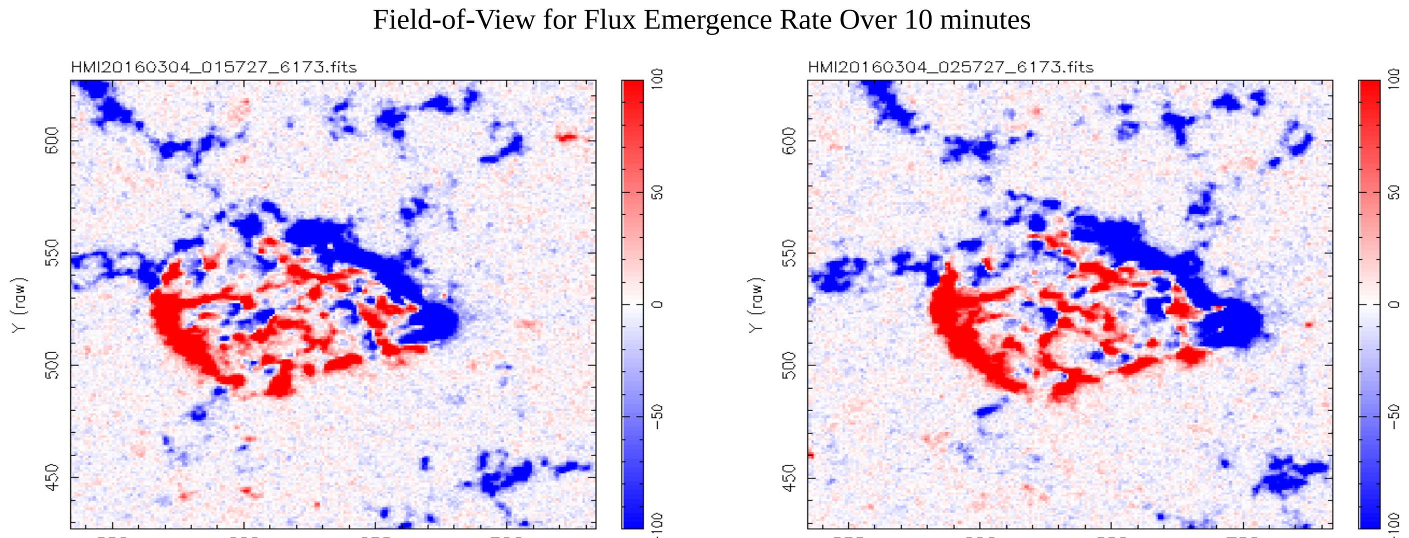
Evolution of the Magnetic Field



The unfortunately-timed gaps in the data result from Earth eclipsing SDO.

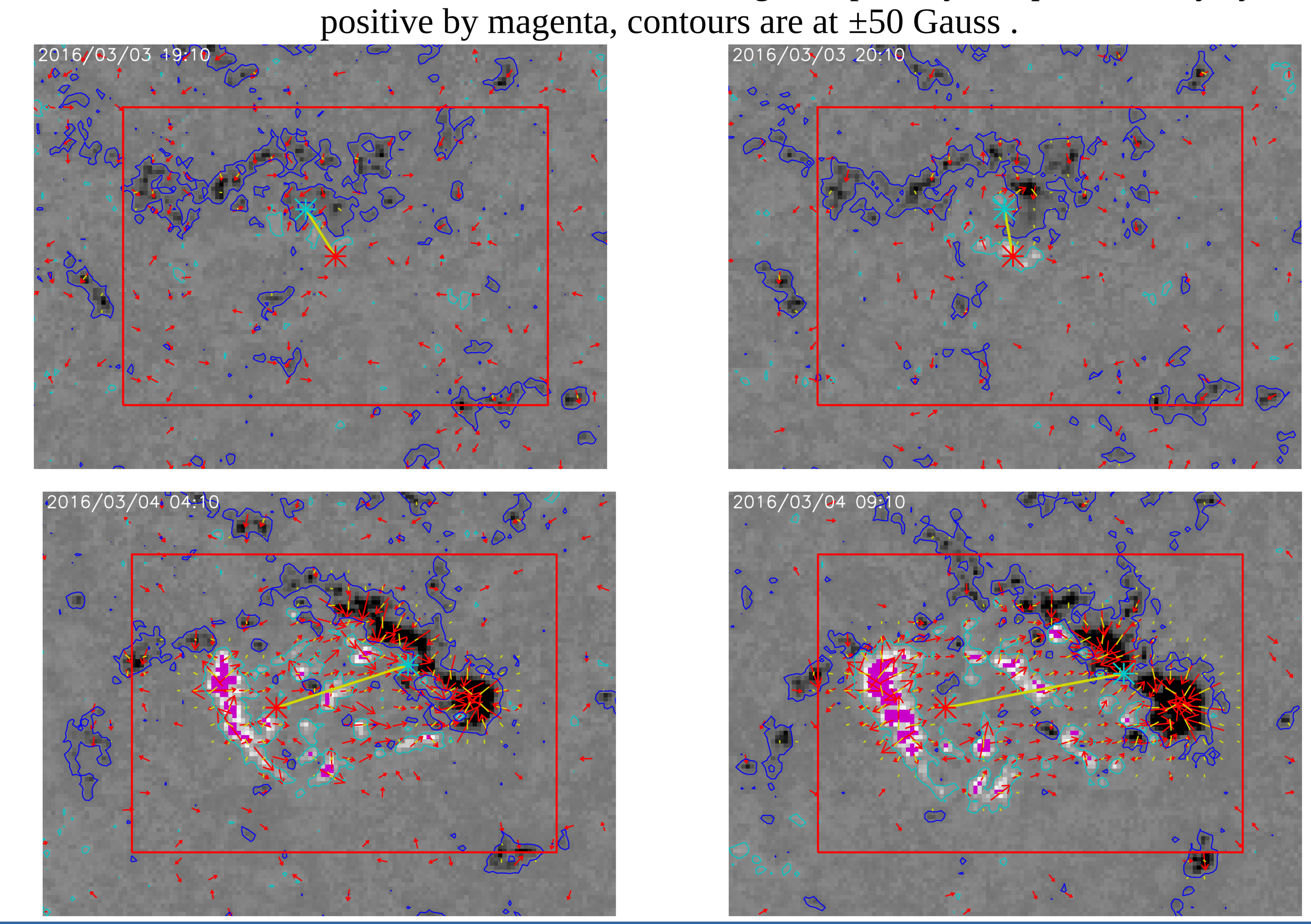


Field-of-View for Flux Emergence Rate Over 10 minutes

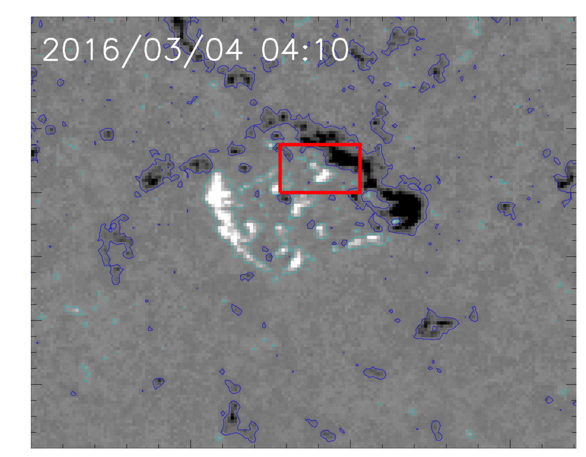


These magnetograms show the field-of-view used to calculate the approximate flux emergence rate between 19:00:27 and 19:10:12, which is 7.86 x 10^{15} Mx/s.

Magnetic-Field-Centroid separation and rotation. Note the clockwise rotation and lengthening distance between centroid locations with time. Negative polarity is represented by cyan, positive by magenta, contours are at ±50 Gauss .

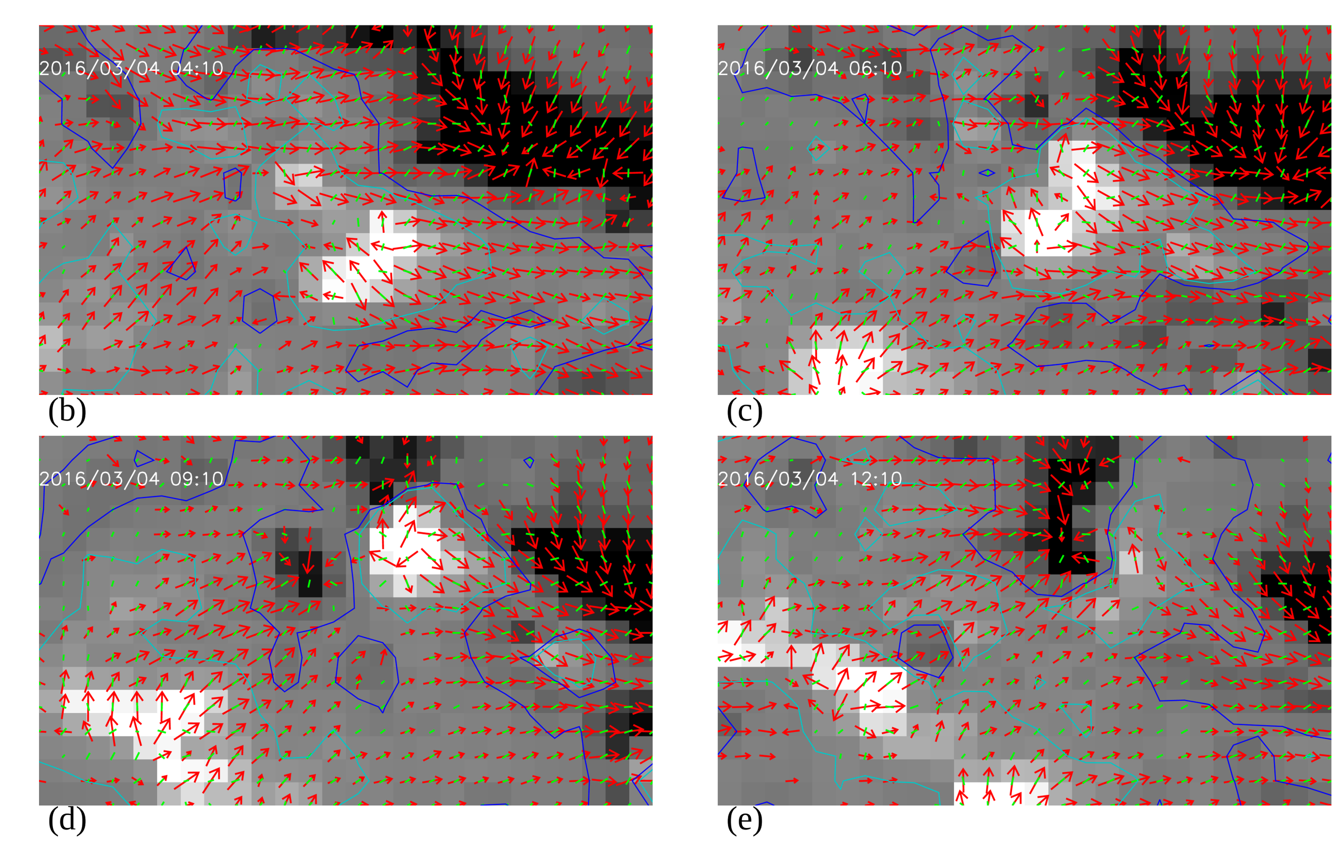


Vector Magnetograms



(a)

(a) The boxed area shows the location on the HMI magnetic-intensity map of the zoomed-in vector magnetograms (b), (c), (d), and (e). The red arrows are the observed field, the green are potential. Arrow length is scaled so that the longest represents 250 Gauss. Contours are 50 Gauss.
(b) Note the magnetic shear between positive (white) and negative (black) flux patches.
(c) At 6:10 the positive patch appears slightly larger with more positive polarity in the box, but the negative appears smaller. There is still a lot of shear.
(d) Approximately twenty minutes after the eruption, negative polarity has broken up and positive decreased in size.
(e) Shear has decreased and the positive flux patch has mostly cancelled.



Summary/Results:

1. The flux-emergence rate over ten minutes was 7.86 x 10^{15} Mx/s. In contrast, From Vemareddy et al. (2015) the rate of positive flux emergence over four days from NOAA 11158, a region that produced a X.2 flare, was 4.4 x 10^{16} Mx/s, suggesting that for larger regions, the flux rate will be higher.

2. The unsigned magnetic flux in the small-boxed region interior to the emerging flux region, increases to a maximum and begins to decrease before the beginning of the major eruption. There is a decrease in flux following the eruption, consistent with the flux cancellation seen in the vector magnetograms.

3. The time-distance plots and the centroid plots illustrate that the active region emerges, separates, and rotates clockwise.

4. The eruption that made a CME began from a site of flux cancellation in the interior of the emerging-flux region, perhaps the first time this has been observed.

References: 1. Moore and Roumeliotis in Eruptive Solar Flares, 1992, ed. Z. Svestka, B.V. Jackson, and M.E. Machado [Berlin:Springer], 69.
2. Panesar, Navdeep K., Sterling, Alphonse C., Moore, Ronald L., ApJ, 853, 2, 2018.
3. van Ballegooijen and Martens, 1989, ApJ, 343, 971.
4. Vemareddy, P., Venkatakrishnan, S., Karthikreddy, S., *Flux Emergence in the Solar Active Region NOAA 11158: The Evolution of Net Current*, arXiv:1502.05458 [astro-ph.SR], 2015.

Acknowledgments

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