Twisted Magnetic Field Emergence, Interchange Reconnection, Flux Cancellation, and Blow-out Eruptions in a Small Coronal Hole

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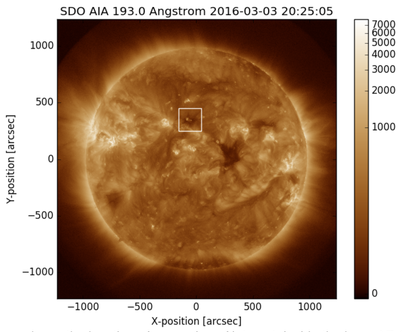
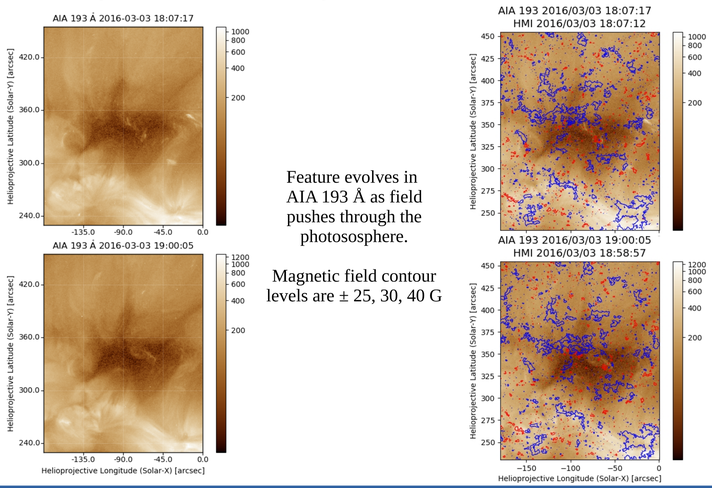
In this work, we report on the structure, evolution, and explosive behavior of an emerging-flux region of March 3-4, 2016. Flux emergence in a small coronal hole resulted in H-alpha brightening, subsequent eruptions, and the later development of a small sunspot. The initial emergence of a bipole, as seen in data from Solar Dynamics Observatory's (SDO) Helioseismic Magnetic Imager (HMI), was followed by the appearance of an anemone-type region, observed with SDO's Atmospheric Imaging Assembly (AIA) in multiple wavelengths (e.g., 193 Å, 211 Å, 304 Å, and 94 Å). We find that interchange reconnection of initially-closed emerging field with ambient open field affected the coronal hole, shifting the open field from one side of the emerging bipole to the other. A blow-out jet in this region is made by the eruption of a minifilament that forms over and erupts from a polarity inversion line between merging and cancelling opposite-polarity magnetic flux on the outside of the emerging bipole. There are three other blow-out eruptions from inside the emerging bipole; the largest of these makes a coronal mass ejection. Blow-out eruptions from inside emerging bipoles are rare. This emerging bipole had repeated blow-out eruptions from inside, probably because the emerging magnetic field was extremely twisted, which is evident from the sigmoid coronal form of the magnetic field.

-- *Dr. Panesar's work was supported by the NASA Postdoctoral Program (NPP).*



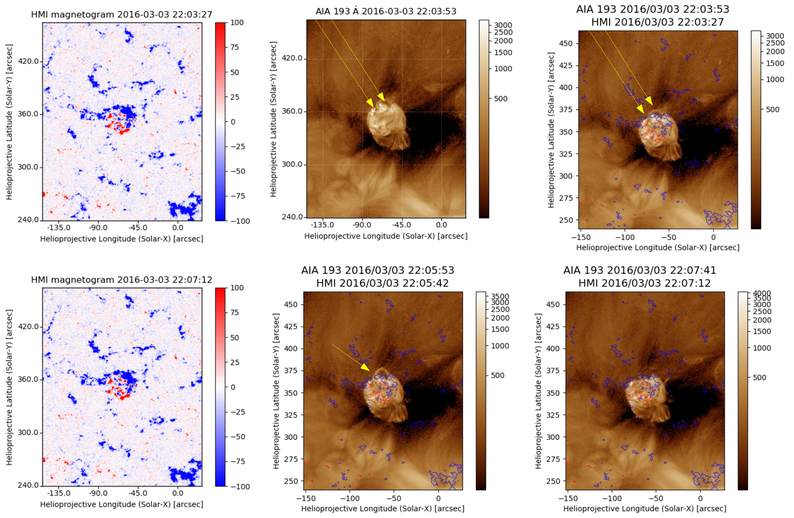
The image above shows the location of our region of interest, inside the box. AR 12512 is to the east.



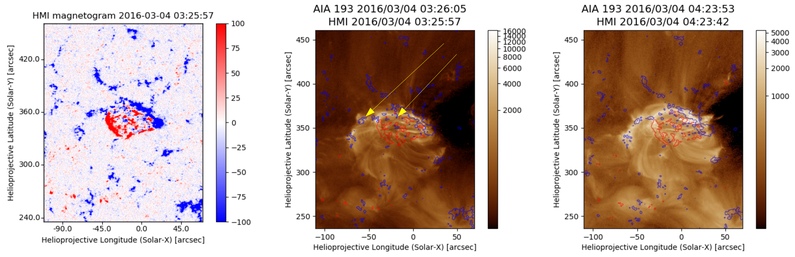
Feature evolves in AIA 193 Å as field pushes through the photososphere.

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

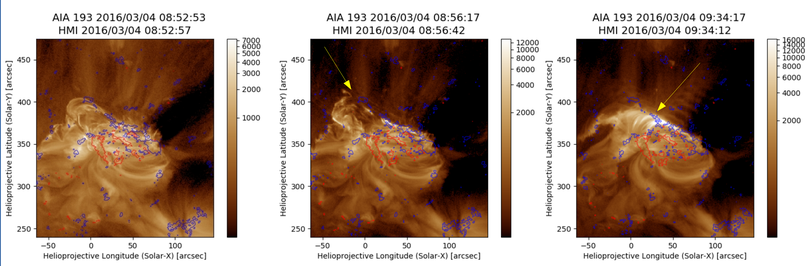
Note minifilaments anchored in bipoles, northeast side brightens in 193 Å, a rotation is seen, top loop opens, contours are ±75, 100 G -- only slight changes in the field, i.e., very little flux cancellation.



Flux continues to emerge, larger loops form rooted in bipoles close to the original location.



The middle figure shows the loops opening, on the right, post-flare-like loops form.

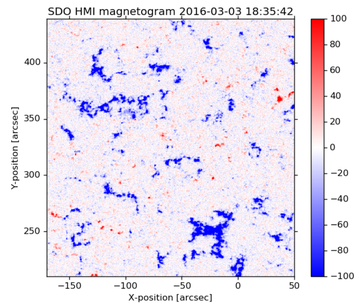


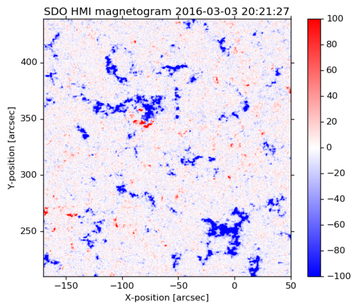
Acknowledgements

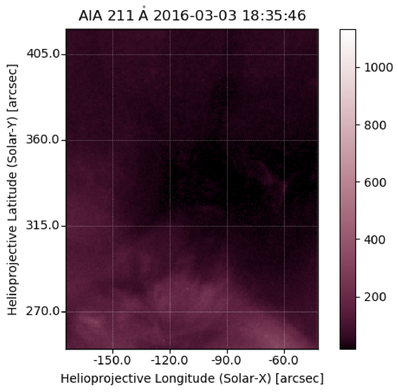
SDO Data Courtesy of NASA/SDO and the AIA, EVE, and HMI science teams.

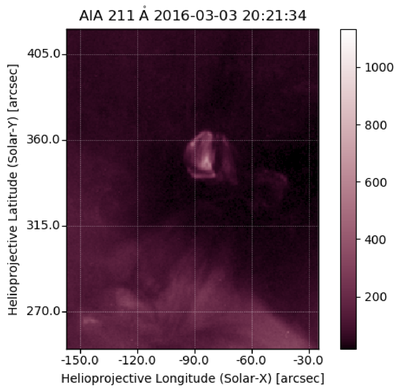
Hinode is a Japanese mission developed and launched by ISAS/JAXA, with NAOJ as domestic partner and NASA and STFC (UK) as international partners. It is operated by these agencies in co-operation with ESA and NSC (Norway).

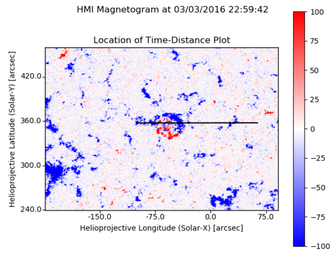
Emergence began at ~18:44 UT in HMI
(time estimated from movie)
seen in AIA 94, 193, 211, 304, and HMI
No spots in continuum until 2016 03/03 23:43 UT



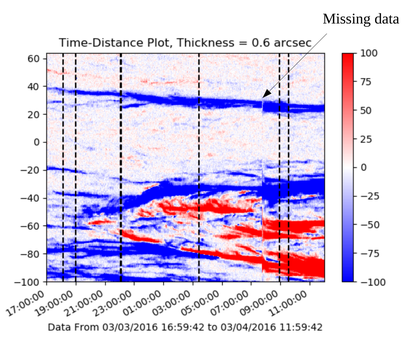




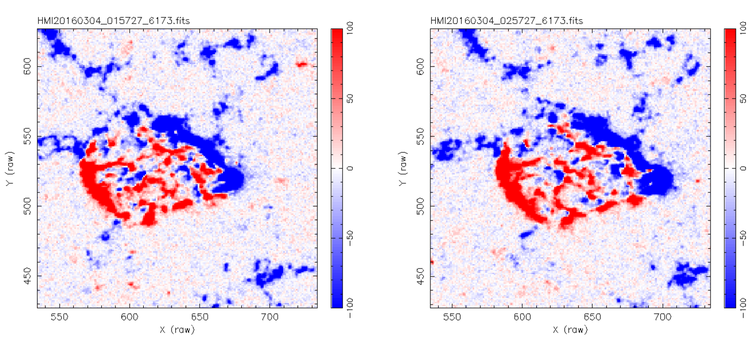




Time-Distance Plot Location: The length of the cut is 164 arcsec, height is 0.6 arcsec, selected to cut through the bipole at (-73, 357) arcsec.

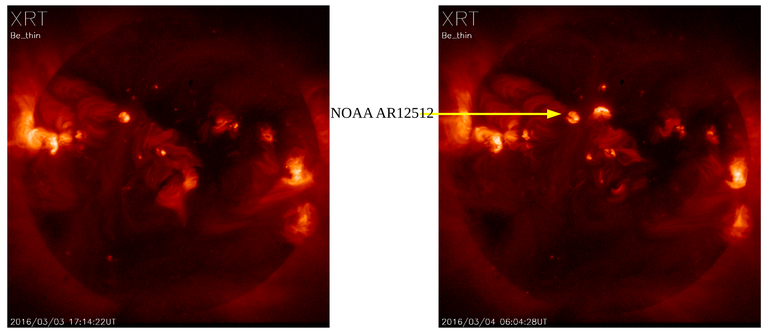


Time-Distance Plot: Vertical lines indicate evolutionary features. At 18:07 UT the anemone structure could be seen forming in AIA 193 Å. At 22:03, a minifilament has formed (in AIA 193 Å) anchored in a bipole to the northeast of the emerging flux region. At 22:07, the loop created by the minifilament is gone. Transitioning to 4 March at 04:03, larger loops are forming close to the location of the original bipole. By 08:56, the loop opens and post-flare-like loops form. The discontinuity seen in the plot is from missing data on 4 March 06:29:42 UT - 08:19:12 UT.

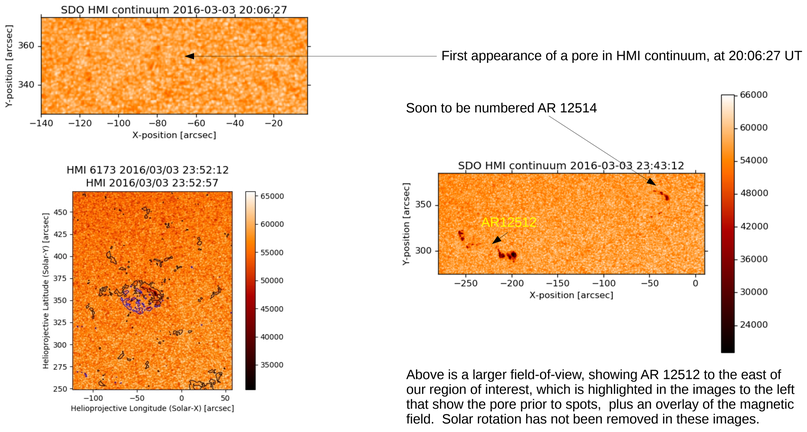


These magnetograms represent the field-of-view used to calculate the approximate flux emergence rate between 19:00:27 and 19:10:12, which is 7.86 x 10^{15} Mx/s

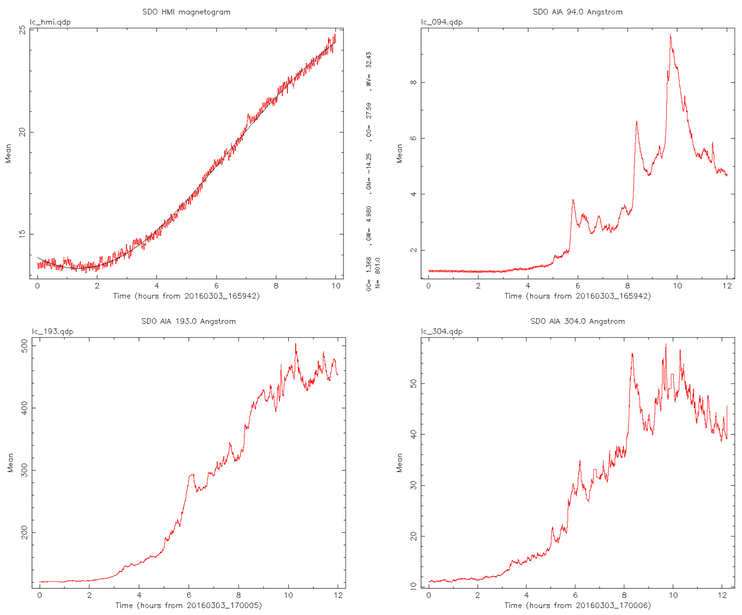
The Feature was Also Seen in Hinode/XRT



Using http://solarmonitor.org, on March 4 at 20:58, AR 12512 was seen on the central meridian in HMI-6173 Å. Sunspots were visible to the west of AR 12512 at the location of our region, where there were none the day before. NOAA had numbered the region AR 12514 by March 5 at 21:10. By March 8 when AR 12514 was close to the limb, no spots were visible.



Above is a larger field-of-view, showing AR 12512 to the east of our region of interest, which is highlighted in the images to the left that show the pore prior to spots, plus an overlay of the magnetic field. Solar rotation has not been removed in these images.



The light curves above help identify the beginning of the flux emergence and show times of brightening in various wavelengths. There are bad data files at ~23:10 UT, which corresponds to the first burst at about six hours from 17:00 UT. The animation in AIA 193 Å shows increasing size of the feature, but no major brightenings until 4 March 07:52, which accounts for the steady brightness increase in the line plot.

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 magnetic "bubble" increased in size from approximately 20'' x 20'' to 40'' x 40'' from 2016 03/03 18:44 UT to 2016 03/04 02:55, 8 hours 11 minutes.
3. Flux emergence begins between 17:30 UT and 18:44 UT, followed by brightening in AIA 211 (~19:05 UT), 304 (~19:12 UT), 193 (~19:30 UT), and 94 (~20:00 UT) Angstroms.
4. All jets occurred with minifilament eruptions.
5. In contrast to the work of Panesar, Sterling, and Moore (2018), this anemone region showed little flux cancellation, all eruptions were the result of flux emergence and interaction with the open-field of the coronal hole.

References: 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.
Panesar, Navdeep K., Sterling, Alphonse C., Moore, Ronald L., ApJ, 853, 2, 2018.