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EMERGENCE OF A SMALL-SCALE MAGNETIC FLUX TUBE AND THE RESPONSE OF THE SOLAR ATMOSPHERE

S. VARGAS DOMINGUEZ[1], A. G. KOSOVICHEV[1,2,3] and V. YURCHYSHYN[1]

[1]*Big Bear Solar Observatory, NJIT, 40386 North Shore Lane Big Bear City, CA 92314-9672, U.S.A.*
[2]*Stanford University, Stanford, CA 94305, U.S.A.*
[3] *NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.*

Abstract. Cutting-edge observations with the 1.6-meter telescope at Big Bear Solar Observatory (BBSO) in California have taken research into the activity of the Sun to new levels of understanding of the structure and evolution of the solar atmosphere at high-resolution spatial and temporal scales. On August 7, 2013 the NST observed active region NOAA 11810 in photospheric and chromospheric wavelengths. The observations were performed as part of a program conducted jointly with NASA's Interface Region Imaging Spectrograph (IRIS) mission, Solar Dynamics Observatory (SDO) and Hinode satellite. These observations provided a unique view on the emergence of a buoyant small-scale magnetic-flux rope in the solar photosphere. The event is accompanied by response of the solar atmosphere once the newly emerged field interacts with the pre-existing overlying one. The reconnection process that takes place in the region produces jet emission and high-temperature points in the chromosphere and corona.

Key words: Solar magnetic fields - High-resolution - Solar atmosphere

1. Introduction

The 1.6 m New Solar Telescope (NST, Goode *et al*, 2010) operating at the Big Bear Solar Observatory provides high-resolution capabilities to study in detail the activity of the Sun at small-spatial scales. Figure 1 (*left panel*) shows a sketch of the telescope and the configuration of its instruments. The adaptive optics correction system, AO308, and the speckle image reconstruction technique (Wöger & von der Lühe, 2007) provide diffraction limited images (e.g see quiet Sun image in Fig. 1). Simultaneous observations with space-based facilities, i.e., IRIS, SDO and Hinode, allow us to investigate the linkage between different layers of the solar atmosphere from the photospheric surface to the corona. Emerging flux regions (EFR) are the target of multiple investigations from the observational and theoretical points of view as they transport magnetic field to the solar surface and generate a wide variety of structures at many spatial scales (Zwaan, 2005). It is thought that magnetic reconnection may play an important role in shaping the response of the solar chromosphere to the emerging magnetic flux. Some studies suggest that the interaction between emerging and ambient fields could inject mass and energy into the solar atmosphere (Archontis *et al*, 2005, Isobe *et al*, 2005). We present a multi-wavelength analysis of observations, acquired with the NST, the Interface Region Imaging Spectrograph (IRIS), the Solar Dynamics Observatory (SDO) and the Hinode mission, of a transient emerging flux event of 2013 August 7, resulting in generation of a surge/jet and compact heating at coronal-height locations.

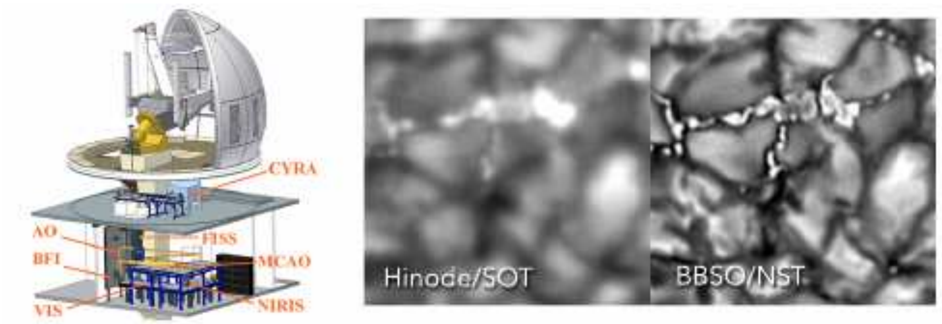

Figure 1: *Left*: New Solar Telescope of the Big Bear Solar Observatory and instrumentation: Adaptive Optics System (AO), Visible Imaging Spectrometer (VIS), Near InfraRed Imaging Spectro-polarimeters (IRIM, NIRIS), Cryogenic Infrared Spectrograph (CYRA), Broad-band Filter Imager (BFI), Fast Imaging Solar Spectrograph (FISS). *Right*: Comparison of simultaneous observations of a quiet Sun region with the space-based Hinode mission (G-band) and the NST (TiO) on August 3, 2010.

2. Observations

The NST observed a region in the vicinity of NOAA AR 11810 on August 17, 2013 from 17:00 UT to 19:00 UT acquiring filtergrams in the photospheric TiO 7057Å line (bandpass: 10Å) pixel size of $0.034''$ and the HeI 10830Å line (bandpass: 0.5Å) with a time cadence of 15 s. Simultaneous observations from space telescopes IRIS (C II transition region, 1330Å) , SDO (AIA channels and HMI data) and Hinode (Ca II H filtergrams) were also used in the analysis. Data were coaligned and we generated time series of images for every set.

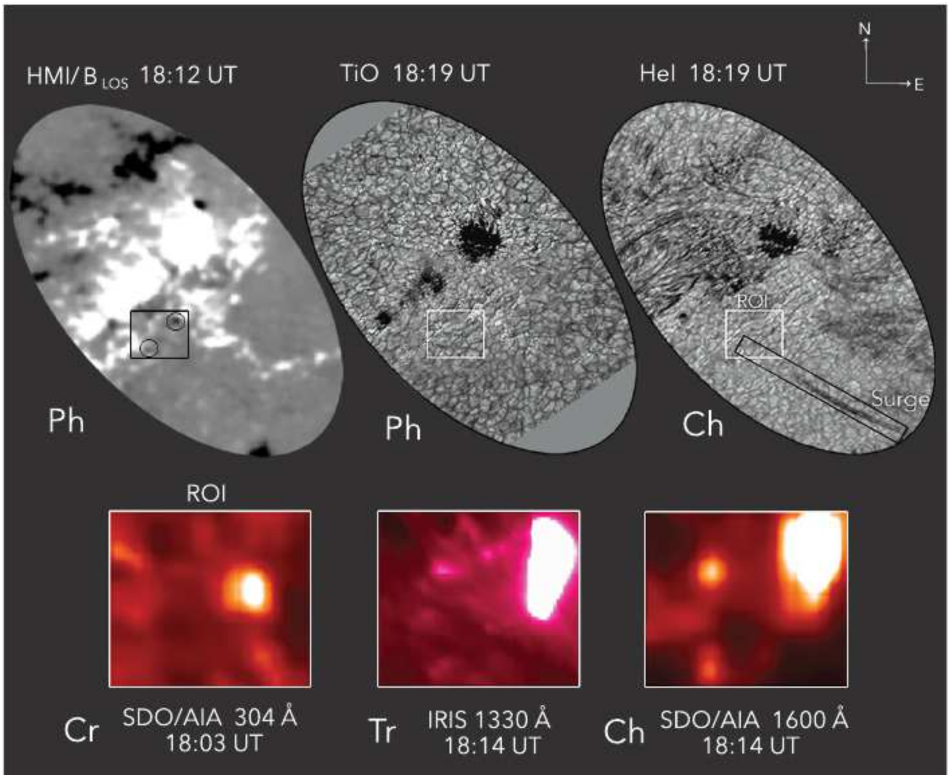

Figure 2: Selected images of NOAA AR 11810 acquired with the NST and satellite telescopes (IRIS, SDO) as labeled, displaying the configuration of the studied region in the photosphere (Ph), chromosphere (Ch), Transition Region (Tr) and corona (Cr). Boxes in the top panels extract the region of interest (ROI), the same shown in the low panels. Magnetogram from SDO/HMI data is displayed in the top-left image with regions of emerging negative polarity features encircled in black.

3. Results and Discussion

Data from all different instruments and channels are used to investigate the emergence and response of the magnetic flux rope from photosphere up to the corona. Figure 2 illustrates context of the NST (IRIM and TiO) images displaying a large part of NOAA AR 11810. The figure shows the extracted portions of the chromospheric/transition region filtergrams (SDO/AIA 1600Å and IRIS 1330Å), and coronal (SDO/AIA 304Å) images, in a vicinity of a group of solar pores. The region is disrupted by the appearance of an elongated absorption feature (surge) as indicated in the top-right image in Fig. 2. The total lifetime of the surge is ∼1 hour in which it displays at least three periods of ejection and retraction.

The TiO images show an intense activity of bright features, particularly in the nearest vicinity around the pores. The enhanced-brightness photospheric structures match the locations where HeI dark-absorbing features seem to be rooted. At about 18:00 UT, time series of the photospheric TiO images reveal an area of intense abnormal granulation occurring immediately before and during the development of the surge, suggesting a connection between the two phenomena. For further analysis we extracted a Region Of Interest (ROI, see boxes in Fig. 2) in the location where distorted granules are generated. Figure 3 shows a sequence of TiO images displaying the evolution of the ROI in a 1-hour interval. Distortion of granules and the formation of a "sandwiched-like" structure is visible (third panel). Dark and wide intergranular lanes accompanied the development of the region.

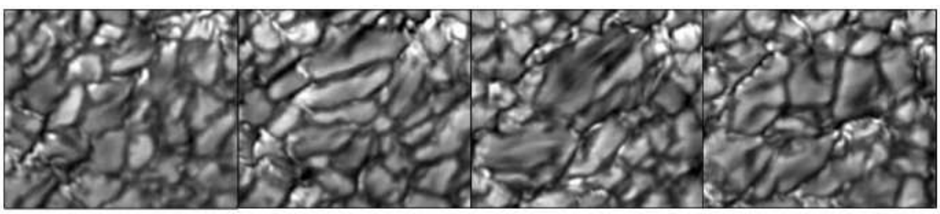

Figure 3: Selected NST/TiO images showing the region of magnetic flux emergence. The interaction of the emerging field with the photospheric convective pattern is evidenced by the development of abnormal granulation and the appearance of dark threads. The sequence spans for 1 hour.

By using the SDO/HMI data we can follow the evolution of the photospheric magnetic field and Doppler velocities. Top-left panel in Fig. 2 shows one of the line-of-sight magnetograms showing a dominant positive magnetic polarity (*in white*) and some small-scale negative patches part of the emerging magnetic flux tube, in the ROI (small box) at 18:12 UT. At this time we detected the first signs of the plasma surge in HeI 10830Å line shown in Fig. 2 (top-right image) and it is also close to the moment of the jet enhancement observed in the IRIS data. The intensity variations computed over AIA and IRIS channels show that the coronal response is the strongest at 18:03 UT (304 and 193Å) whereas chromospheric emission measured in 1600 and 1700Å AIA channels, peaked at 18:13 UT. The direction of the jet/surge emission is parallel to the overlying ambient fields, whereas the emerging loops are almost perpendicular to them, as reveled from the Hinode chromospheric CaII H images.

This research has shown new observational comprehension on the process of emergence of small-scale magnetic flux that emerges from the solar interior, deforms the granulation pattern at the photospheric level and triggers the response of upper atmospheric layers. Localized heating and a plasma jet/surge in the chromosphere are triggered by the horizontal flux tube rising up from the upper convection zone. One possibility of such response is a reconnection scenario, like the ubiquitous small-scale reconnection argued by Shibata *et al.* 2007, which perhaps can explain the ejection of the jet/surge, together with the heating of localized point-like regions up to a million degrees in the corona. Further analysis of the data is presented in Vargas Domínguez, Kosovichev & Yurchyshyn, 2014.

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