Magnetic Reconnection at the Earliest Stage of Solar Flux Emergence

Hui Tian[1], Xiaoshuai Zhu[2], Hardi Peter[2], Jie Zhao[3], Tanmoy Samanta[1], Yajie Chen[1]
[1]Peking University [2]Max Planck Institute for Solar System Research [3]Purple Mountain Observatory

On 2016 September 20, IRIS observed an AR during its earliest emerging phase for almost 7 hr, starting from the first sign of flux emergence. Such a unique observation allows us to study the detailed evolution of UV bursts during the earliest-stage flux emergence. SDO/HMI observed continuous emergence of small-scale magnetic bipoles. The emergence of magnetic fluxes and interactions between different polarities lead to the frequent occurrence of UV bursts, which exhibit as intense transient brightenings in the 1400 Å images. In the meantime, discrete small patches with the same magnetic polarity tend to move together and merge, leading to the enhancement of the magnetic fi elds and thus the formation of pores at some locations. The spectra of these UV bursts are characterized by the superposition of several chromospheric absorption lines on the greatly broadened profiles of some emission lines formed at typical TR temperatures, suggesting heating of the local materials to a few tens of thousands of kelvin in the lower atmosphere by magnetic reconnection. Some bursts reveal blue- and redshifts of ~100 km/s at neighboring pixels, indicating the spatially resolved bidirectional reconnection outflows. Many such bursts appear to be associated with the cancellation of magnetic fluxes. We also investigate the three-dimensional magnetic field topology through a magnetohydrostatic model and find that a small fraction of the bursts are associated with bald patches (magnetic dips). Finally, we find that almost all bursts are located in regions of large squashing factor at the height of ~1 Mm, reinforcing our conclusion that these bursts are produced through reconnection in the lower atmosphere.

History of Flux Emergence

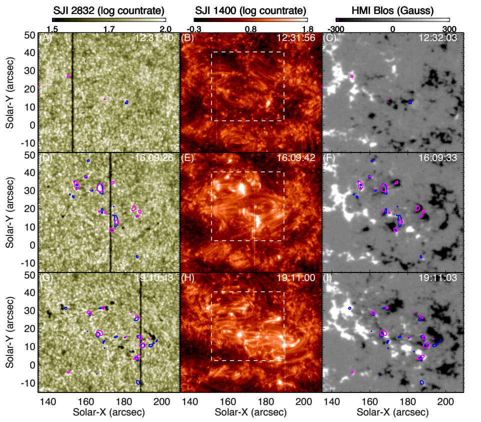

Figure 1. IRIS/SJI 2832 Å images, 1400 Å images, and HMI line-of-sight magnetograms taken around 12:32 UT, 16:09 UT, and 19:11 UT. Blue/purple contours mark the UV bursts seen in the 1400 Å/1700 Å images.

- Almost all existing IRIS observations of UV bursts (or IRIS bombs, Peter et al. 2014) were performed during relatively late stages of flux emergence (more than ~2 hr after the start of flux emergence; Toriumi et al. 2017).
- On 2016 September 20, IRIS observed an AR during its earliest emerging phase for almost 7 hr, starting from the first sign of flux emergence.

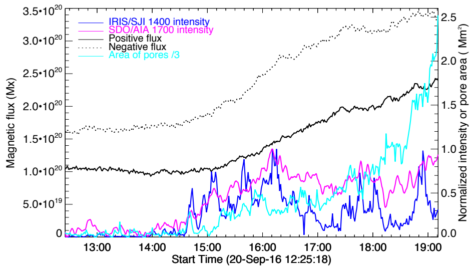

Figure 2. Temporal evolution of the AIA 1700 Å intensity, IRIS 1400 Å intensity, total area of pores, and positive and negative magnetic fluxes. Each of the two intensity (countrate) light curves has been normalized to the maximum intensity in the time series). The area of pores has been divided by 3 for the purpose of illustration.

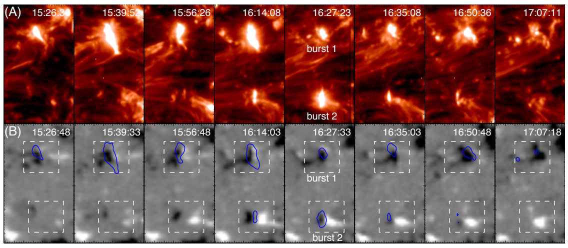

Figure 3. Sequences of IRIS 1400 Å images and HMI line-of-sight magnetograms in a small region enclosing bursts 1 and 2. Blue contours outlining the two UV bursts observed in the 1400 Å images are overplotted in the magnetograms.

- At the beginning, the region observed by IRIS appears to be a typical quiet-Sun region, showing obvious network structures in the HMI magnetograms and IRIS 1400 Å images. From the photospheric images, no sunspots can be identified in the region scanned by the IRIS slit.
- As time evolves, HMI observed continuous emergence of small-scale magnetic bipoles with a rate of ~10^{16} Mx/s. The emergence of magnetic fluxes and interactions between different polarities lead to the frequent occurrence of UV bursts, which exhibit as intense transient brightenings in the IRIS 1400 Å and AIA 1700 Å images. Flux cancellation with a rate of the order of ~10^{15} Mx/s can be clearly identified for many bursts.
- In the meantime, discrete small patches with the same magnetic polarity tend to move together and merge, leading to the enhancement of the magnetic fields and thus the formation of pores (small sunspots) at some locations.

Spectra of UV bursts

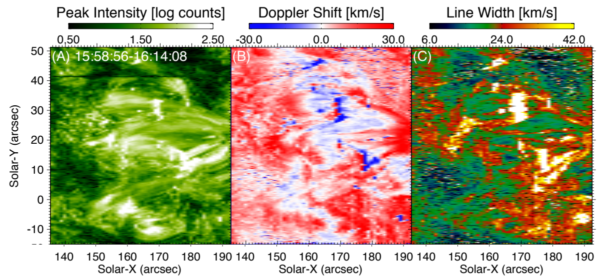

Figure 4. Images of the peak intensity, Doppler shift and line width obtained from a single Gaussian fit to the Si IV 1393.755 Å line profiles acquired during a raster scan.

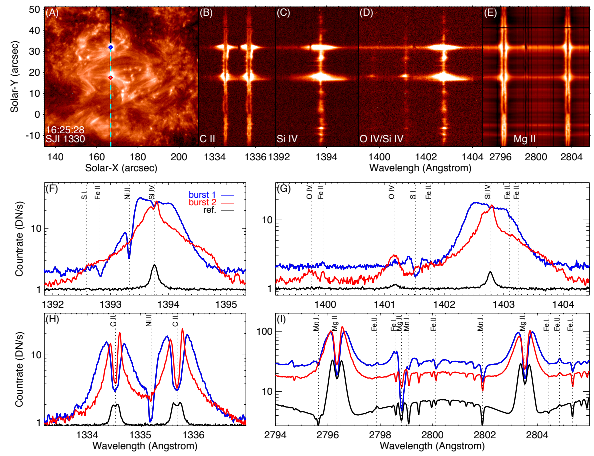

Figure 5. (A)-(E) IRIS 1330 Å image and spectra in four spectral windows taken at 16:25:28 UT. The cyan dashed line in (A) marks the slit position. (F)-(I) IRIS spectra of bursts 1 and 2 in four spectral windows. The reference spectra (black) are obtained by averaging the line profiles within the section marked by the black line in (A).

- Discrete patches of significant SGF Doppler shift or adjacent blue shift/red shift can be identified from the Dopplergrams shown in Figure 4. These patches are mostly locations of UV bursts and they appear to be related to the largest line widths.
- The spectra of these UV bursts are characterized by the superposition of several chromospheric absorption lines on the greatly broadened profiles of some emission lines formed at typical transition region temperatures, suggesting heating of the local materials to a few tens of thousands of kelvin in the lower atmosphere by magnetic reconnection.
- Some bursts reveal blue- and redshifts of ~100 km/s at neighboring pixels, indicating the spatially resolved bidirectional reconnection outflows.

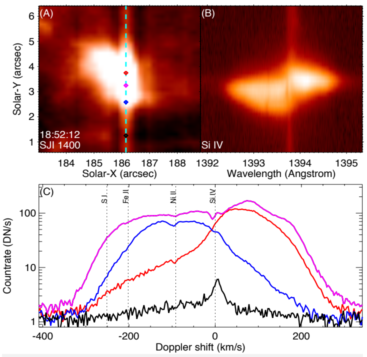

Figure 6. IRIS spectra of a UV burst. (A)–(B) IRIS 1400 Å SJI image and spectral image of the Si IV 1393.755 Å line taken at 18:52:12 UT. (C) The Si IV line profiles at the locations marked by the four diamonds with different colors.

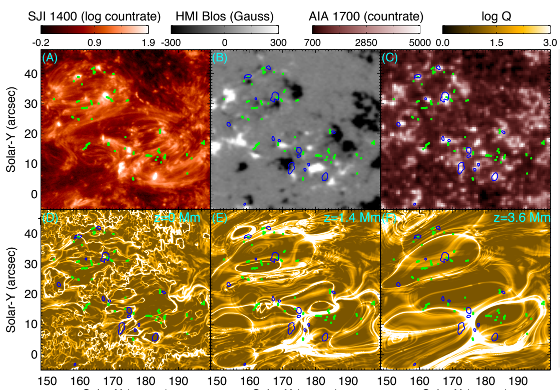

Figure 7. (A)–(C) IRIS/SJI 1400 Å image, HMI line-of-sight magnetogram and SDO/AIA 1700 Å image taken at 16:36 UT. (D)–(F) Images of the squashing factor at the heights of 0 Mm, 1.4 Mm, and 3.6 Mm above the photosphere. Blue contours outlining the compact brightenings in the 1400 Å image at 16:36 UT are overplotted in other images. The green dots indicate locations of bald patches.

Magnetic field topologies

- By inputing the vector photospheric magnetograms measured by HMI to a magnetohydrostatic model (Zhu et al. 2016), we have reconstructed the three-dimensional magnetic field structures for the UV bursts.
- A small fraction of the bursts are associated with bald patches (magnetic dips).
- Almost all bursts are located in regions of large squashing factors around the height of z=1 Mm, supporting the suggestion that UV bursts are powered by magnetic reconnection in the lower solar atmosphere.
- Considering their coincidence with not only bald patches but also separatrices, these reconnection events are similar to Ellerman bombs (Pariat et al. 2004). Indeed, our recent investigation has shown that roughly half of the UV bursts are likely related to Ellerman bombs (Tian et al. 2016).

References

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Poster

3. Magnetic coupling and mass flux through the atmosphere

UV bursts at the earliest stage of flux emergence

Hui Tian[1], Xiaoshuai Zhu[2], Hardi Peter[2], Jie Zhao[3], Tanmoy Samanta[1], Yajie Chen[1]

[1]*School of Earth and Space Sciences, Peking University, Beijing, China*
[2]*Max Planck Institute for Solar System Research, Göttingen, Germany*
[3]*Purple Mountain Observatory, CAS, Nanjing, China*

On 2016 September 20, IRIS observed an active region during its earliest emerging phase for almost 7 hours. SDO/HMI observed continuous emergence of small-scale magnetic bipoles with a rate of $\sim 10^{16}$ Mx s^{-1}. The emergence of magnetic fluxes and interactions between different polarities lead to frequent occurrence of ultraviolet (UV) bursts, which exhibit as intense transient brightenings in the 1400 Å images. In the meantime, discrete small patches with the same magnetic polarity tend to move together and merge, leading to enhancement of the magnetic fields and thus formation of pores (small sunspots) at some locations. The spectra of these UV bursts are characterized by the superposition of several chromospheric absorption lines on the greatly broadened profiles of some emission lines formed at typical transition region temperatures, suggesting heating of the local materials to a few tens of thousands of kelvin in the lower atmosphere by magnetic reconnection. Some bursts reveal blue and red shifts of ~ 100 km s^{-1} at neighboring pixels, indicating the spatially resolved bidirectional reconnection outflows. Many such bursts appear to be associated with the cancellation of magnetic fluxes with a rate of the order of $\sim 10^{15}$ Mx s^{-1}. We also investigate the three-dimensional magnetic field topology through a magneto-hydrostatic model and find that a small fraction of the bursts are associated with bald patches (magnetic dips). Finally, we find that almost all bursts are located in regions of large squashing factor at the height of ~ 1 Mm, reinforcing our conclusion that these bursts are produced through reconnection in the lower atmosphere.