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Flux Emergence in the Quiet Sun From the Photosphere to the Corona

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Abstract. We report preliminary results on the evolution of a small-scale bipolar magnetic feature, from its emergence at the photosphere to its brightening at the corona. We use imaging and spectral observations from the space-born Hinode (SOT/BFI, SOT/SP, EIS & XRT), TRACE (1550 Å, 1600 Å, 1700 Å) and SoHO (MDI hi-res) as well as the ground-based Dutch Open Telescope (G-band, CaII H and five positions along the Hα profile). The small-scale feature emerges, adjacent to the chromospheric network and shows all morphological characteristics of a small-scale magnetic bubble. The magnetic flux density increases, reaching a maximum value while fine-scale CaII H brightenings coalesce forming clusters of positive and negative polarity footpoints of a bipolar feature. The corresponding emerging magnetic flux tubes make their way to the chromosphere, pushing aside the ambient magnetic field, producing Doppler-shifted absorption features. At the upper chromosphere and transition region, imaged by EIS, the emission gradually increases. The connectivity of the quiet-Sun network gradually changes and part of the existing network connects to the newly emerged bipole. A few minutes after the bipole has reached its maximum magnetic flux density, the bipole brightens in soft X-rays forming a coronal bright point. The brightening is observed in all EIS transition region and coronal windows and is accompanied by Doppler-shifted Hα features.

Observations

Observations were taken on 15 October 2007. The following **Table** summarizes the instruments used and **Fig.1** provides a context of the observations.

Instrument	Bandpass	Time range	Cadence	Spatial scale
MDI	NiI 6767.8 Å	08:00 – 10:00	60 s	0.6''
SOT/BFI	CaII H/G-band	08:06 – 09:05	110 s	0.054''
SOT/SP	FeI 6301.5 Å	09:05, 09:15	2 rasters	0.32''
DOT	Hα (line center, ±0.35Å,±0.7Å)	08:32 – 09:53	30 s	0.109''
EIS	EUV	08:16 – 09:40	65 s + 2 rasters	1''/2''
XRT	'C-Poly'	08:02-10:00	25 s	1''
TRACE	1550,1600,1700 Å	08:59-09:44	30 s	0.5''

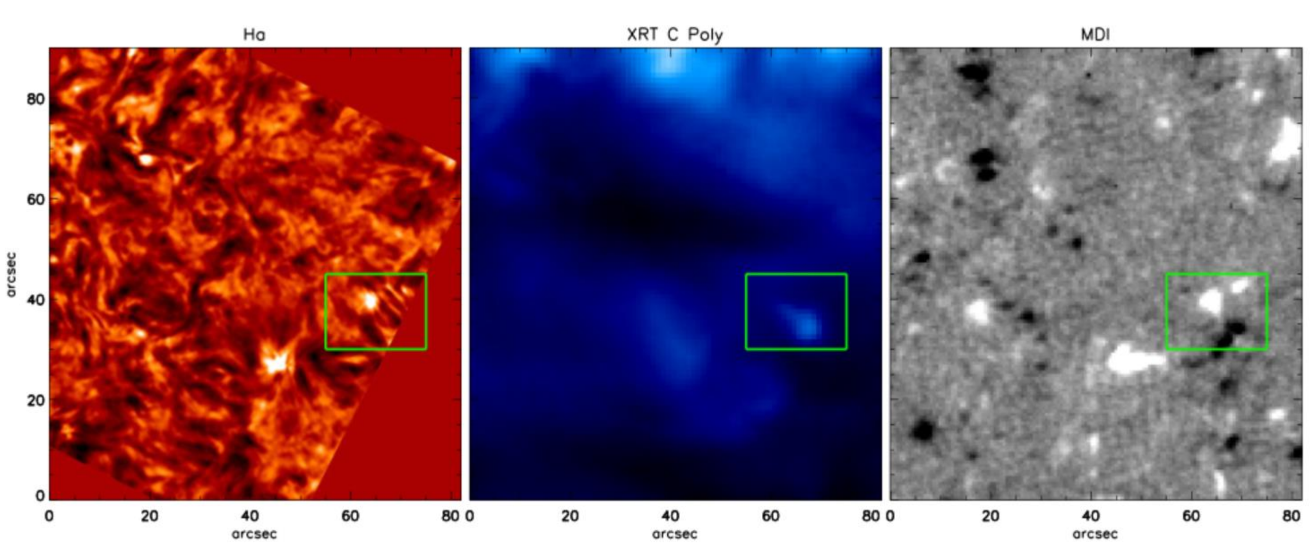

Figure 1. (from left to right). Hα line center filtergram of the solar disk center, taken on 15 October, 2007 by the Dutch Open Telescope (DOT; Rutten et al. 2004, A&A 413, 1183) and the corresponding soft X-ray filtergram (XRT; Golub et al. 2007, SoPh 243, 63) and MDI magnetogram (Scherrer et al. 1995, SoPh 162, 169). The green rectangles mark the area of interest, where the small bipole emerged.

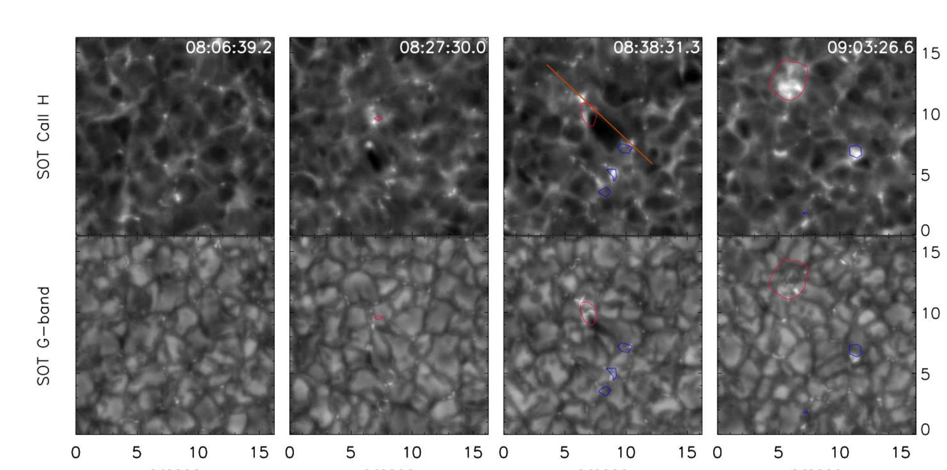

Figure 2. Upper row: four snapshots of the emerging bipole in CaII H, taken by the Solar Optical Telescope (SOT; Tsuneta et al. 2008, SoPh 249, 167). Lower row: co-temporal G-band filtergrams. Red (blue) contours mark positive (negative) magnetic field higher than 40 G. The red line marks the position of the x-t slices shown in Fig.4

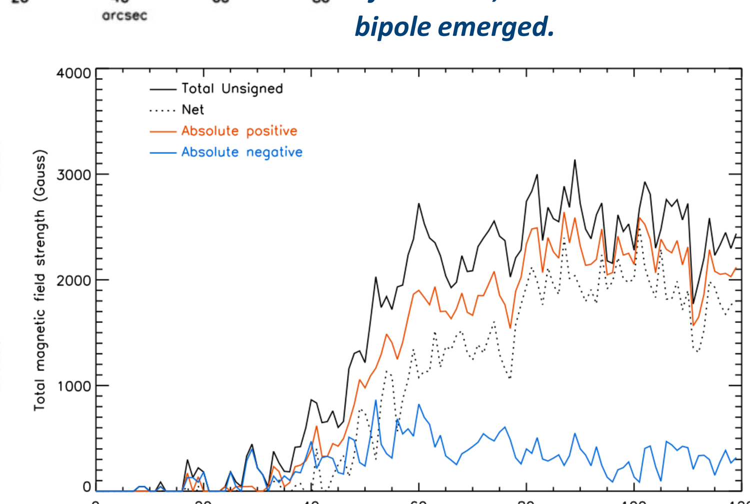

Figure 3. The evolution of the magnetic field inside the green rectangle region in Fig.1. Plotted as a function of time are the total unsigned (solid black line) and net flux (dotted black line) as well as the total absolute positive (red line) and negative magnetic field (blue).

Appearance at the photosphere

Fig.2 shows *CaII H* and *G-band* filtergrams (SOT) of the emerging bipole, while **Fig.4** contains *x-t* slices (taken along the red line in **Fig.2**), which show the evolution of the bipole up to the chromosphere.

At the photosphere a series of very fine-scale bright points appear at intergranular lanes, moving in roughly opposite directions, following events of anomalous granulation and dimmings at *CaII H* (see e.g. Tortosa-Andreu & Moreno-Insertis, 2009, A&A 507, 949) and form conglomerations of small-scale opposite polarity patches. The apparent expansion speed, as measured from the MDI *x-t* slice (**Fig.4a**) is ~2 km/s, comparable to granule expansion velocities derived with Local Correlation Tracking (see e.g. Gulielmino et al. 2010, ApJ 724, 1083). The bipole is not one monolithic structure. This is indicative of small-scale, continuous loop-like structures emerging at the photosphere, gradually breaching the minimum temperature region (Martínez-González et al, 2010, ApJ 714, L94). The magnetic patches that represent the footpoints of the bipole, increase in strength (**Fig.3**) reaching a maximum after ~60 min. The positive polarity then further increases until ~90 min, while the negative polarity slightly decreases

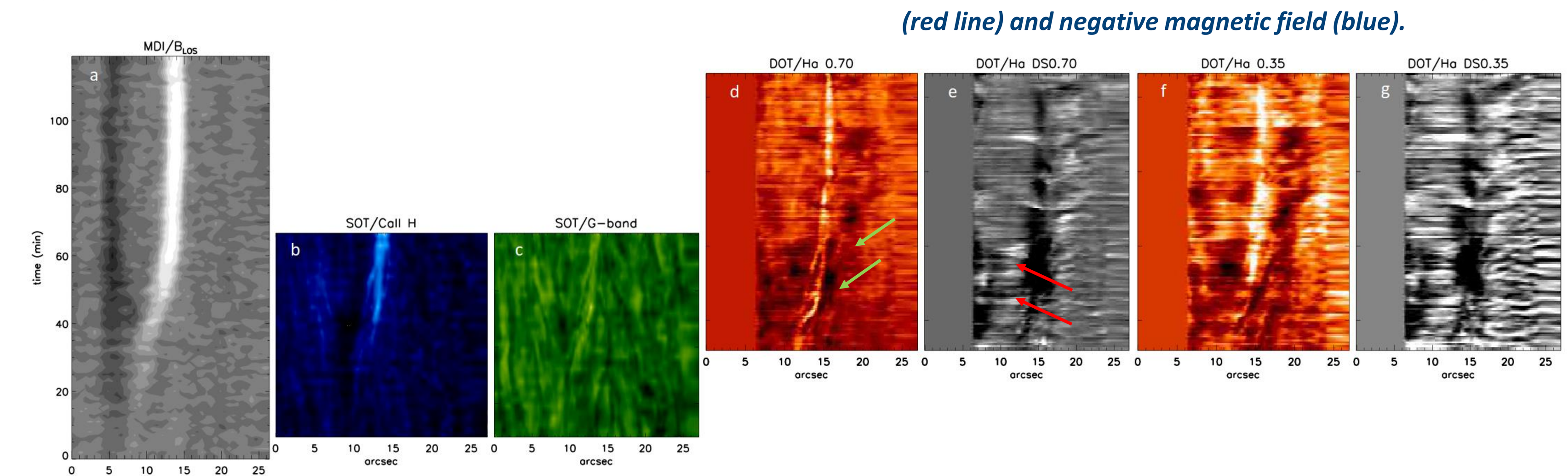

Figure 4. From left to right: x-t slices of MDI, CaII H, G-band and Hα averaged wing intensity and DS at 0.70 Å and 0.35 Å from line center. Since the different bandpasses have different time coverages (see Table I), the slices are shifted accordingly in respect with a common vertical time axis (MDI ordinate).

Interaction with the chromosphere

As proxies for the chromospheric intensities and velocity proxies we use the following

$$I_{\mathrm{avg}}(\Delta\lambda) = \frac{I(+\Delta\lambda) + I(-\Delta\lambda)}{2} \quad \text{and} \quad \mathrm{DS} = \frac{I(+\Delta\lambda) - I(-\Delta\lambda)}{I(+\Delta\lambda) + I(-\Delta\lambda)}$$

for Δλ=0.35 or 0.7 Å from the *Hα* line center. *DS* is the Doppler signal, which is positive (negative) for upward (downward) motions.

At the wings of *Hα*, ±0.7 Å from line center the magnetic footpoints are visible (Leenaarts et al. 2006, A&A 449, 1209) as well as chromospheric features. As the bipole expands, it pushes the ambient chromosphere, creating absorption features ahead of the moving footpoint (*green arrows* in **Fig.4d**). Some of these are associated with upflows (positive *DS*). Positive *DS* at ±0.35 and ±0.7 Å above the bipole itself indicate the rising motion (*red arrows* in **Fig.4e**). Above the positive footpoint (the negative is outside the *Hα* FOV), downflows (negative *DS*) are detected.

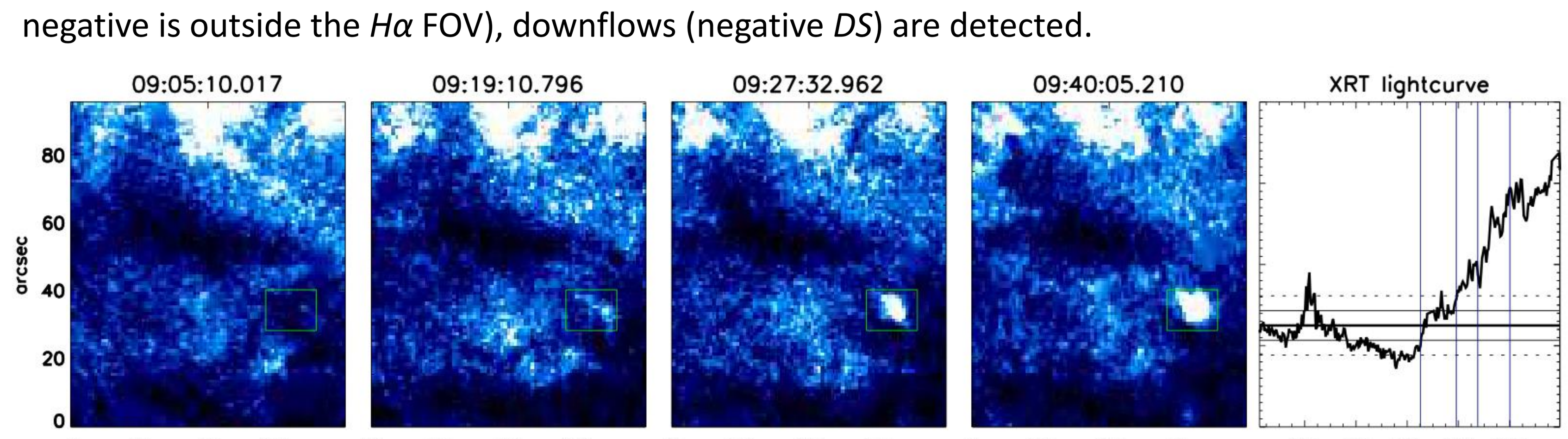

Figure 6. Four sample XRT images ('C-Poly') showing the evolution of the region-of-interests (green rectangle). The last panel shows the temporal variation of the total emission within the region. The horizontal lines mark the average (thick solid) and the 1- and 2-σ ranges (thin solid and dashed lines). Vertical blue lines mark the times of the four images. The peak at t~25 min is que to spikes and does not represent any intrinsic variation.

Transition region and coronal brightening

The EIS instrument (Culhane et al. 2007, SoPh 243, 63) took series of 40'' slots as well as two rasters (2'' slit) which sample plasma at the upper chromosphere and the transition region. The time series of the slots show increasing emission in all EUV channels as the bipole "reaches" transition region temperatures. In **Fig.5** we show the EIS slot images taken before and after the brightening, found at ~(30'',40'') in the *HeII*, *SiVII* and *FeXII* channels.

In **Fig.6** we show four sample soft X-ray images, taken by the "C-Poly" detector of the XRT, showing the same quiet region, before and after the coronal brightening. The lightcurve of the region shows that the newly emerged region starts to brighten about ~60 min after its appearance at the photosphere, only a few minutes after it has reached its maximum magnetic field strength. The soft X-ray brightening is preceded by a dimming, as the cold plasma contained in the emerging region was pushing aside the ambient corona (Martínez-Sykora et al, 2008, ApJ 679, 871).

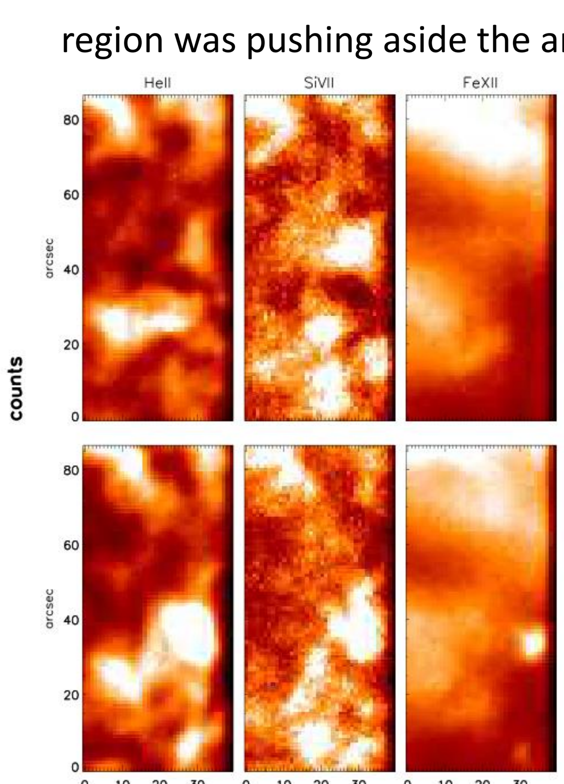

Figure 5. Sample EIS slot intensigrams taken before (08:51 UT) and after (09:38 UT) the brightening of the magnetic bipole.

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