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An orphan penumbra observed with Hinode and DOT

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Abstract. Orphan penumbrae are filamentary structures, very similar to the penumbral filaments, but that are not adjacent to any sunspot umbra. We observed an orphan penumbra in NOAA 11089 during a coordinated observational campaign, involving the Hinode/SOT and DOT telescopes. The spectropolarimetric measurements indicate the presence of both significant upflows and downflows in the orphan penumbra region, that decrease in time. A neutral line is present in the region, with a strong horizontal component of the vector magnetic field. We investigate the association of such structure with other features in the low chromosphere.

Key words. Sun: photosphere – Sun: surface magnetism – Sun: magnetic topology – Techniques: polarimetric – Techniques: high angular resolution

1. Introduction

Penumbrae are regions which usually surround the umbra of solar sunspots, often with a circular symmetry. When observed with sufficient angular resolution, they appear to be formed by dark filaments, where the magnetic field is almost parallel to the photosphere, interspersed by bright regions.

Very rare observations have shown that there are features, called “orphan” penumbra, that appear to have some characteristics in common with penumbrae surrounding umbrae in active regions: they have a filamentary structure, but they are not close or clearly connected to any umbral region. They seem to have a lifetime of a few days. The investigation of such features is quite interesting because their evolution, dynamics and magnetic properties could give us important information for understanding the physical processes responsible for their formation and for normal penumbrae formation.

Kuckein et al. (2012a,b) observed an “orphan” penumbra in active region NOAA 10781 by means of a multi-wavelength, multi-height analysis of the vector magnetic field and of the velocities. They suggested that “orphan” penumbrae are formed in narrow photospheric inversion lines of compact active regions, and that these features are the photospheric manifestations of flux ropes in the photosphere.

In this work we analyze an “orphan” penumbra present in active region NOAA

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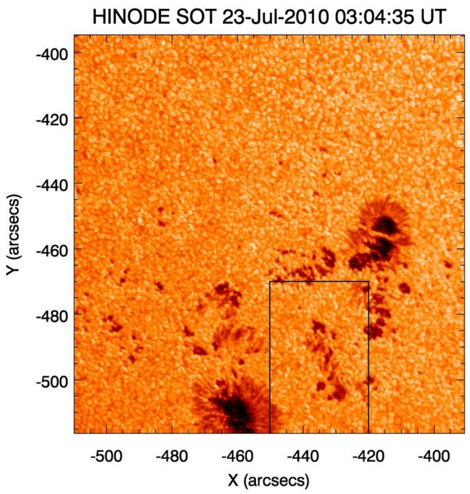

Fig. 1. Continuum intensity map of NOAA 11089 acquired by Hinode/SOT. The rectangle indicates the "orphan" penumbra in between the main sunspots of the active region. The sub-FOV is 30.″7× 47″.

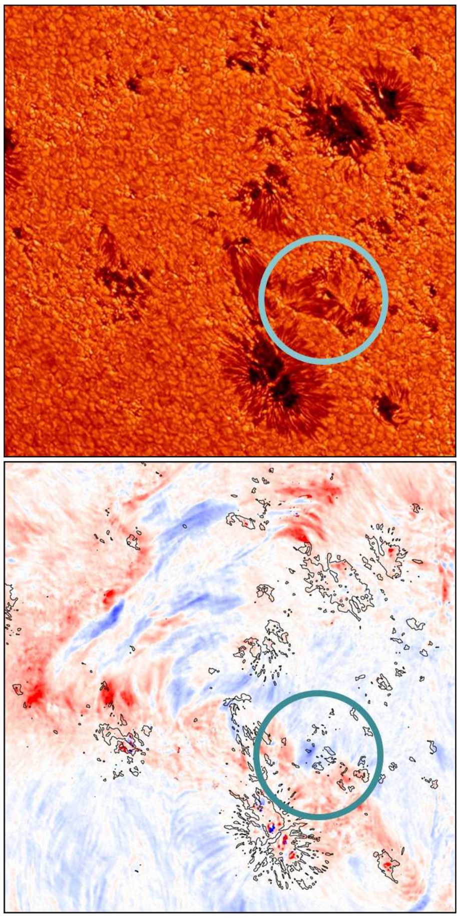

Fig. 2. Top: DOT filtergram in the continuum of the Hα line. Bottom: Hα Dopplergram. Doppler velocities are shown in the interval -20 km s^{-1} [blue] : +20 km s^{-1} [red]. Contours represent isophotes in the photosphere. The circle indicates the location of the western "orphan" penumbra.

11089, studying its evolution and topology using multi-wavelength, high-resolution observations carried out at the Dutch Open Telescope (DOT) and by the Hinode satellite.

2. Observations

Active region NOAA 11089 was observed for about 48 hours in July 2010 during a joint observational campaign between the DOT, the Swedish 1-m Solar Telescope, and the Hinode satellite. SDO satellite also provided a continuous full-disk coverage during the campaign.

DOT observed NOAA 11089 for about 1 hour, from 7:48 UT until 8:27 UT on July 22, acquiring filtegrams in the G band at 4305 Å, in the Red Continuum at 6550 Å, and spectroscopic scans along the Hα line at 6563 Å every 0.3 Å from -0.9 Å to +0.9 Å with respect to the line center. The cadence of these data is 30 s. Hα observations have a pixel size of 0.″1 and a field-of-view (FOV) of 77.″6 × 85″. All data were processed with "de-speckle" algorithms. Line-of-sight (LOS) velocities were deduced from Doppler shifts estimated by a Gaussian fit of the Hα line profile, taking the average line profile in the FOV as a reference.

The Solar Optical Telescope (SOT; Tsuneta et al. 2008) aboard the Hinode satellite (Kosugi et al. 2007) acquired 18 maps of NOAA 11089, scanning the region with the SP spectropolarimeter from 22:16:19 UT on July 22 to 02:03:05 UT on July 24 with a cadence of about 90 minutes. Full Stokes parameters were acquired along the Fe I line pair at 630.2 nm, with a pixel size 0.″32 (Normal Mode) and a

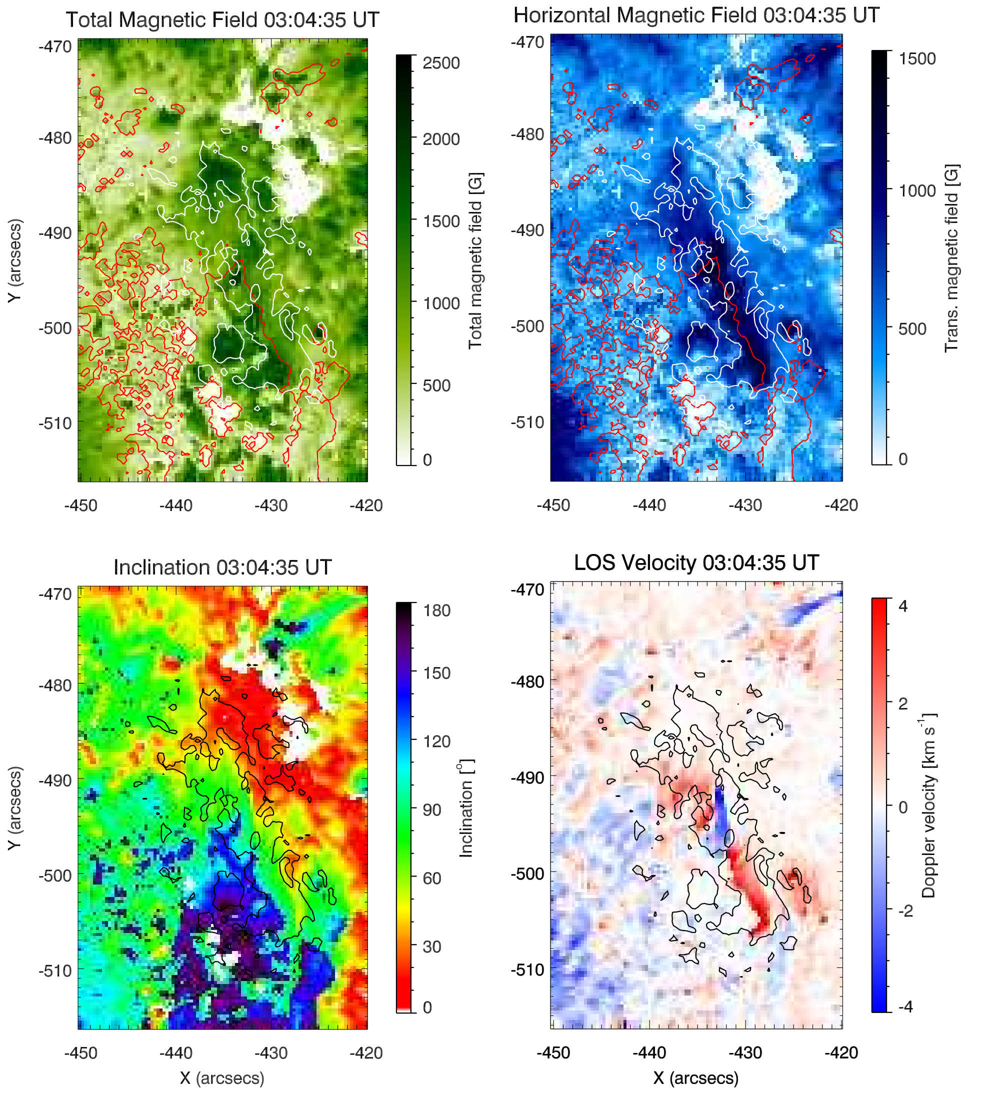

Fig. 3. Maps of physical parameters obtained from CSAC inversions. The FOV is the same of the rectangle in Fig. 1. White (black) contours represent isophotes of the western "orphan" penumbra. Red lines indicate polarity inversion lines. Pixels with total polarization degree < 1% are not considered.

FOV of about 120″ × 120″. Maps of the physical parameters were obtained from the standard Milne-Eddington inversions (CSAC Hinode level-1.5 data). Azimuth ambiguity was solved using the Non-Potential Field Calculation code (Georgoulis 2005). LOS velocities were calibrated assuming that plasma in sunspots is globally at rest. Figure 1 shows an image of NOAA 11089 in the continuum of the Fe I line.

3. Preliminary results

We analyzed the large-scale evolution of NOAA 11089 from July 22 to July 24 using SDO full-disk data. Two "orphan" penumbrae are clearly visible in the active region, but these observations do not show whether the main sunspots are losing part of their penumbra or "orphan" penumbrae are forming independently. Moreover, these "orphan" penumbrae appear to fragment during their evolution.

Hinode and DOT observations allowed us to study more in detail the evolution of the most western "orphan" penumbra, located in between the two main sunspots of NOAA 11089, as shown in Fig. 1.

DOT observed the active region allowing us to follow the evolution of the western "orphan" penumbra, visible in the photosphere in the continuum of Hα line (see Fig. 2, top panel). The penumbra covers an area larger than umbra regions and seems to be linked with the southern umbra by filamentary structures.

Hα line core images show that the counterpart of the photospheric "orphan" penumbra appears as fibrils in the chromosphere, embedded in a large scale Arch Filament System connecting the main sunspots. Upward motions are found in correspondence of the central zone of the western "orphan" penumbra, while downflows are observed at the edges of the structure (see Fig. 2, bottom panel). Unfortunately, data coverage from DOT observations does not allow us to follow the complete evolution of the structure in the chromosphere and lacks information about the magnetic configuration of this feature.

Hinode maps, taken after some hours, show that this "orphan" penumbra lies above a neutral line and has a transverse magnetic field of $\sim$ 1200 G, as shown in Fig. 3. In this region, the inclination of the vector magnetic field is close to 90° and the azimuth angle is quite homogeneous. We also find peculiar plasma flows cospatial with the "orphan" penumbra: a central upflow and downflows at the edge of the structure (see Fig. 3), that last for at least $\sim$ 8 hours. Note that these plasma motions are already present when Hinode observations begin.

We find some asymmetries of Stokes profiles in the "orphan" penumbra: Stokes Q, U, and V profiles show a very asimmetric shape in individual points, and Stokes I has often an asymmetric profile in these points. If we compare such profiles with "classical" profiles of umbra, penumbra, and network, these asymmetries indicate the presence of a multicomponent magnetic atmosphere in the pixels. This suggests that this structure has an "uncombed" magnetic topology: magnetic field lines differently oriented along the line of sight.

In summary, the analysis of the data acquired by different instruments has given the following information: i) the active region NOAA 10781 shows the presence of two "orphan" penumbrae; ii) the most wester penumbra is characterized by a very peculiar velocity distribution: in particular, its central part shows an upward motion lasting for at least $\sim$ 8 hours; iii) the penumbral filaments seem to connect regions of opposite magnetic polarity; iv) the asymmetries detected in the Stokes profiles suggest an "uncombed" magnetic structure.

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References

Georgoulis, M. K. 2005, ApJ, 629, L69
Kosugi, T., et al. 2007, Sol. Phys., 243, 3
Kuckein, C., Martínez Pillet, V., & Centeno, R. 2012, A&A, 539, A131
Kuckein, C., Martínez Pillet, V., & Centeno, R. 2012, A&A, 542, A112
Tsuneta, S., et al. 2008, Sol. Phys., 249, 167