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 umbras 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
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” penumbral areas are clearly visible in the active region,
but these observations do not show whether the main sunspots are losing part of their penum- 
bra or “orphan” penumbrae are forming inde-
pendently. Moreover, these “orphan” penum-
brae 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 “or-
phan” 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 coun-
terpart of the photospheric “orphan” penum-
bra appears as fibrils in the chromosphere, em-
bedded in a large scale Arch Filament System 
connecting the main sunspots. Upward mo-
tions are found in correspondence of the cen-
tral 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 obser-
vations does not allow us to follow the com-
plete evolution of the structure in the chromo-
sphere and lacks information about the mag-
netic configuration of this feature.

Hinode maps, taken after some hours, show 
that this “orphan” penumbra lies above a neu-
tral line and has a transverse magnetic field of 
~ 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 ho-
mogeneous. We also find peculiar plasma flows 
cospatial with the “orphan” penumbra: a cen-
tral upflow and downflows at the edge of the 
structure (see Fig. 3), that last for at least ~ 8 
hours. Note that these plasma motions are al-
ready present when Hinode observations be-

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” pro-
files of umbra, penumbra, and network, these 
asymmetries indicate the presence of a multi-
component magnetic atmosphere in the pixels.

This suggests that this structure has an “un-
combed” magnetic topology: magnetic field 
lines differently oriented along the line of sight.

In summary, the analysis of the data ac-
quired by different instruments has given the 
following information: i) the active region 
NOAA 10781 shows the presence of two “or-
phan” penumbralae; ii) the most wester penum-
bra is characterized by a very peculiar veloc-
ity distribution: in particular, its central part 
shows an upward motion lasting for at least 
~ 8 hours; iii) the penumbral fibrils seem to 
connect regions of opposite magnetic polarity; 
iv) the asymmetries detected in the Stokes pro-
files suggest an “uncombed” magnetic struc-
ture.

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