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High-resolution observations of the umbral filament in AR NOAA 12529

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Summary. — Recent observations have shown in some sunspots the presence of structures that have been called umbral filaments (UFs). These consist of bright filamentary features intruding sunspot umbrae, different in morphology, evolution, and magnetic configuration from usually observed light bridges. We report on the properties of an UF observed inside the umbra of the giant leading sunspot in active region NOAA 12529. We analysed high-resolution observations taken in the photosphere with the spectropolarimeter aboard the *Hinode* satellite and in the upper chromosphere and transition region with the *IRIS* telescope. These observations were complemented with data from the *Solar Dynamic Observatory* satellite and from the INAF-OACT equatorial spar to study the evolution of this structure. We find that the UF harbours a strong horizontal component of the magnetic field and a portion with polarity opposite with respect to that of the umbra. In the upper atmospheric layers, the structure is cospatial to a bundle of filaments, which appears to be rooted in the sunspot umbra. We propose that the UF is the photospheric counterpart of a flux rope touching the sunspot and giving rise to penumbral-like filaments in the umbra via magneto-convection.

1. – Introduction

Light bridges (LBs) are bright features that intrude sunspots from the leading edge of penumbra into the umbra. They are often observed during the decay phase of the sunspot evolution [1] and are classified in terms of their internal structure [2]. When observed at high spatial resolution, LBs usually exhibit a granular pattern and have weaker field strength than their surrounding umbral cores [3-5].

Recent observations showed the presence of uncommon filamentary structures within a sunspot umbra [6]. These features appear as curled filaments that intrude from the penumbra well into the umbra. [6] proposed to refer to these structures that do not resemble typical LBs in morphology or in evolution as umbral filaments (UFs). We have studied a similar feature, which was observed inside the umbra of the giant preceding sunspot of active region (AR) NOAA 12529 [7, 8].

2. – Observations

The bipolar AR NOAA 12529 passed across the solar disk on April 2016. The preceding sunspot showed a heart-shaped appearance, due to a bright umbral intrusion.

We have used continuum filtergrams, Dopplergrams, and vector magnetograms acquired by *SDO*/HMI. We have found that this intruding feature, identified as an UF, is long lived, lasting for about five days. Moreover, it is characterized by a strong horizontal magnetic field, with a portion of the structure having opposite polarity to that of the hosting sunspot. Simultaneous full disk images of the chromosphere acquired in the

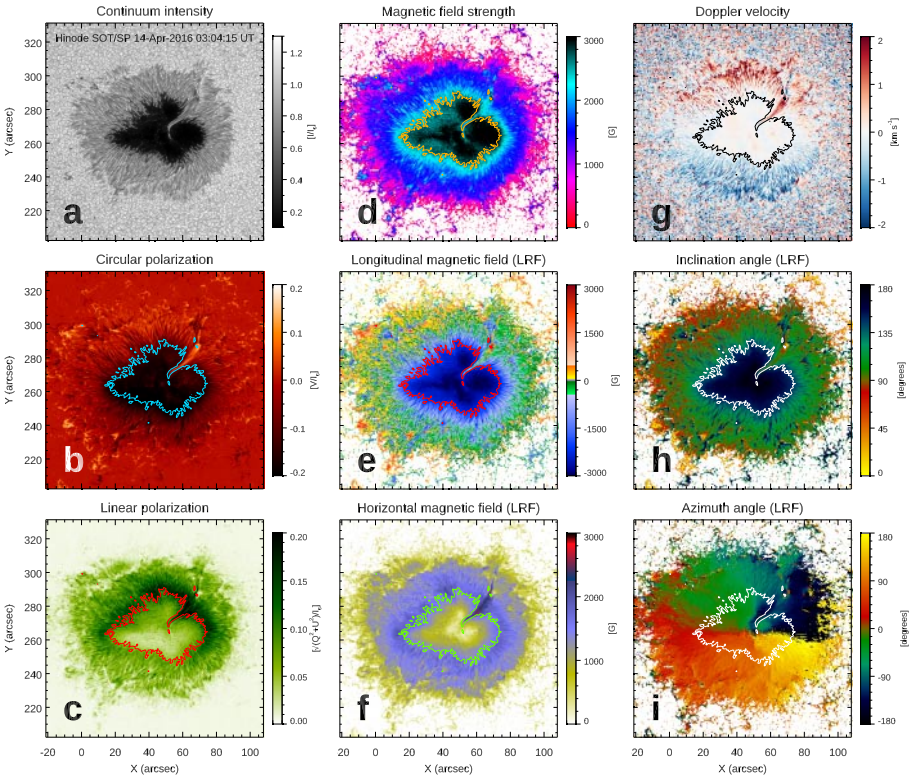

Fig. 1. – *Left panels:* Maps of the continuum intensity (**a**), circular polarization signal (**b**), and linear polarization signal (**c**) of the preceding sunspot of AR NOAA 12529. *Middle and right panels:* Maps of the physical quantities retrieved by the SIR inversion: field strength (**d**), longitudinal (**e**) and horizontal (**f**) component of the vector magnetic field, Doppler velocity (**g**), inclination (**h**) and azimuth (**i**) angles of the vector magnetic field. The contours represent the continuum intensity at the umbra boundary, $I_c = 0.5$.

Hα line by INAF–Catania Astrophysical Observatory and *SDO*/AIA EUV filtergrams indicate that a small filament is rooted in the umbra, being cospatial to the UF.

In a subsequent analysis, we have benefited from high-resolution observations acquired in the photosphere by the *Hinode* SOT/SP and in the chromosphere and transition region by the *IRIS* spacecraft, at the time of the central meridian passage of AR NOAA 12529.

SOT/SP spectropolarimetric measurements take advantage of a spatial deconvolution technique that removes the stray light contamination. They have been inverted using the SIR inversion code [9]. The map of the normalized continuum intensity (I_c) indicates the absence of any granular pattern in the UF at the diffraction-limited resolution of SOT/SP (see Figure 1a). That leads us to exclude that this structure is a granular (or segmented) LB. Moreover, we detect a very large horizontal component of the magnetic field along the UF (Figure 1c, 1f). This rules out that the UF is a kind of LB, since the latter would be characterized by a field-free configuration or by weaker magnetic fields than the surroundings. In addition, a large part of the UF exhibits magnetic polarity opposite to that of the umbra (Figure 1b, 1e, 1h). Finally, we observe that the UF is generally characterized by normal Evershed flow (Figure 1g).

IRIS images show curved features, with a length of about $50''$, which have one edge cospatial to the UF observed in the photosphere. Both in the upper chromosphere and in the transition region elongated bright structures together with darker patches are found to follow the same curved paths, suggesting the presence of a bundle of filaments.

3. – Conclusions

The penumbral-like appearance of the UF seems to be related to strong horizontal fields present in the photosphere, as pointed out by recent studies of penumbra formation [10-12]. The overall scenario provides evidence that the UF is the counterpart of a flux rope overlying the sunspot umbra, likewise in the models proposed by [6].

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