

## Abstract

Using high-resolution spectropolarimetric data acquired IBIS, as well as SDO/HMI observations, we studied the penumbra formation in AR NOAA 11490 and in a sample of twelve ARs appeared on the solar disk on 2011 and 2012, with  $\beta$ -type magnetic configuration. The results concerning the leading polarity of AR NOAA 11490 show that the onset of the classical Evershed flow occurs in a very short time scale, 1-3 hrs, while the penumbra is forming to the side away from the opposite polarity of the AR. Conversely, studying the formation of the first penumbral sector around the following proto-spot, we found that a stable penumbra forms in the area facing the opposite polarity, in contrast with the results of Schlichenmaier et al. (2010). Analyzing the sample of twelve ARs, we noticed that there is not a preferred location for the formation of the first penumbral sector. We also observed before the penumbra formation an inverse Evershed flow, with changes its sign when the penumbra appears. Furthermore, the analysis suggest that the time needed to form the penumbra may be related to the location where the penumbra first appears.

## IBIS Observations

NOAA 11490 was observed by IBIS on 2012 May 28 from 14:20 UT to 14:38 UT and May 29 from 13:49 UT to 14:32 UT. The data consists of 14 and 30 scans with 67 s cadence of:

- Fe I 617.3 nm, 24  $\lambda$  in spectropolarimetric mode
- Fe I 630.25 nm, 30  $\lambda$  in spectropolarimetric mode
- Ca II 854.2 nm, 25  $\lambda$  in spectroscopic mode

## SDO/HMI Observations

To study the whole evolution of the penumbra formation in AR 11490 we also analyzed SDO/HMI SHARPs data:

- continuum filtergrams and Dopplergrams in the Fe I 617.3 nm line from May 28 at 14:58 UT to May 29 at 14:58 UT with 12 minutes of cadence and a resolution of 1";
- the components  $B_r$ ,  $B_\phi$ ,  $B_\theta$  of the vector magnetic field  $B$ ;
- To analyze the twelve ARs we used:
- continuum filtergrams and Dopplergrams in the Fe I 617.3 nm line in 2011 and 2012 during the maximum of solar cycle 24;

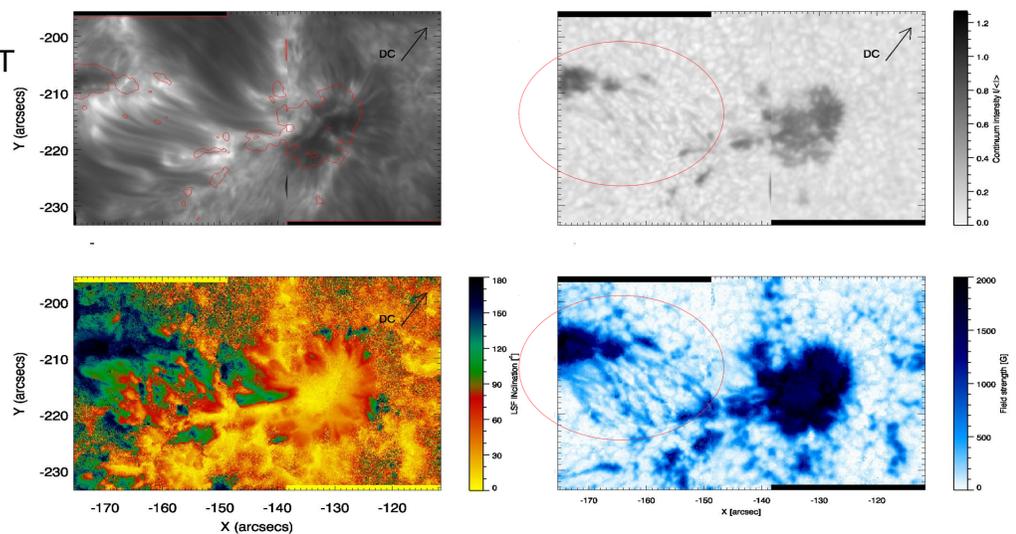


Fig. 1: IBIS data: map in the line center of the Ca II 854.2 nm (top left panel), map of the continuum intensity (top right panel) in the Fe I 617.3 nm (right panel), map of the inclination angle and the magnetic field strength (bottom left and right panel) on May 28 at 14:21 UT obtained from SIR inversion of the Stokes profiles of the Fe I 617.3 nm line.

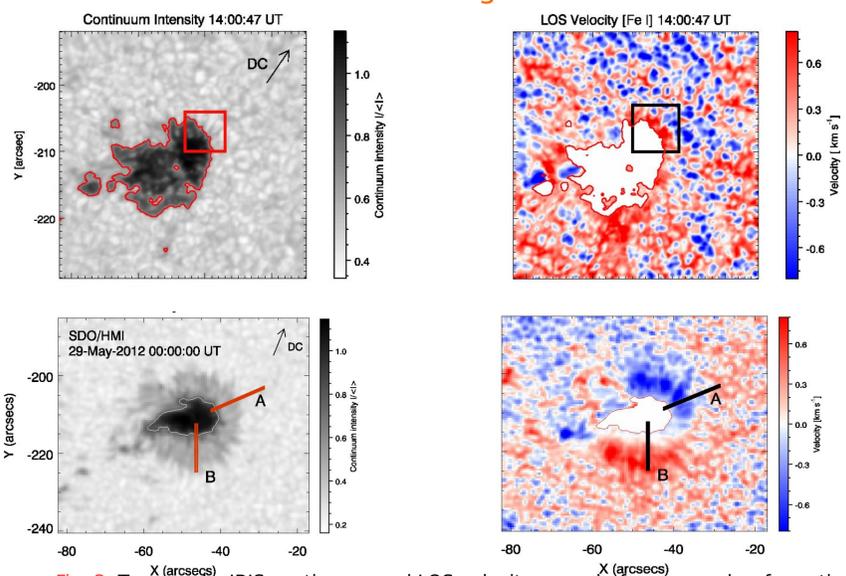


Fig. 3: Top panels: IBIS continuum and LOS velocity maps before penumbra formation. Bottom panels: SDO/HMI continuum and dopplergram after the penumbra formation

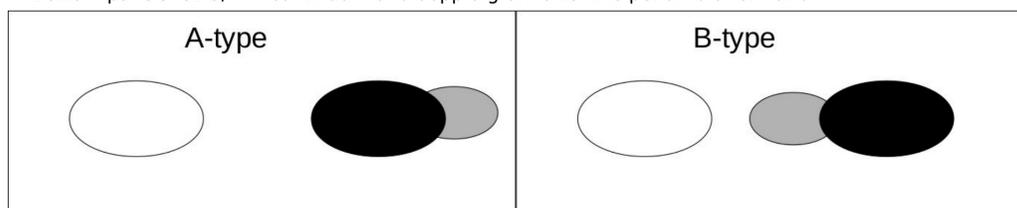


Fig. 4: Cartoon representing the criterion used to classify the penumbra formation for the selected ARs. White and black oval represent the following and preceding protospot, respectively. Grey ovals represent the first stable penumbral sector.

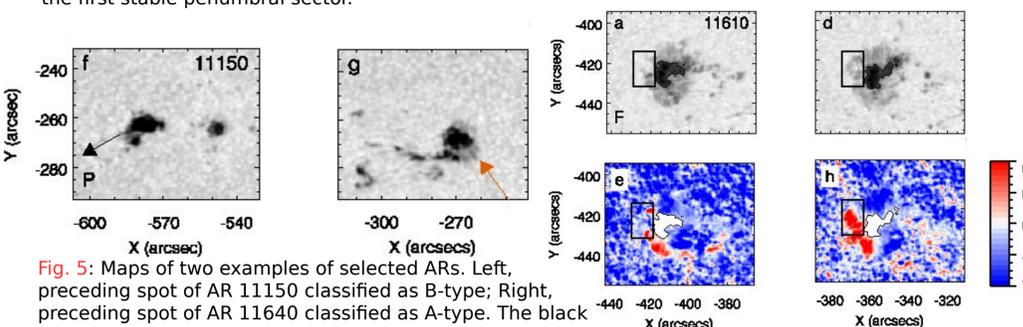


Fig. 5: Maps of two examples of selected ARs. Left, preceding spot of AR 11150 classified as B-type; Right, preceding spot of AR 11640 classified as A-type. The black and orange arrows indicate the opposite polarity region and the side where the first penumbral sector appears, respectively.

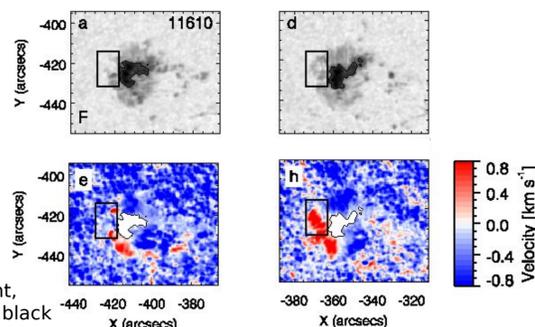


Fig. 6: Zoom of the continuum and LOS velocity maps of the following sunspot of AR 11610.

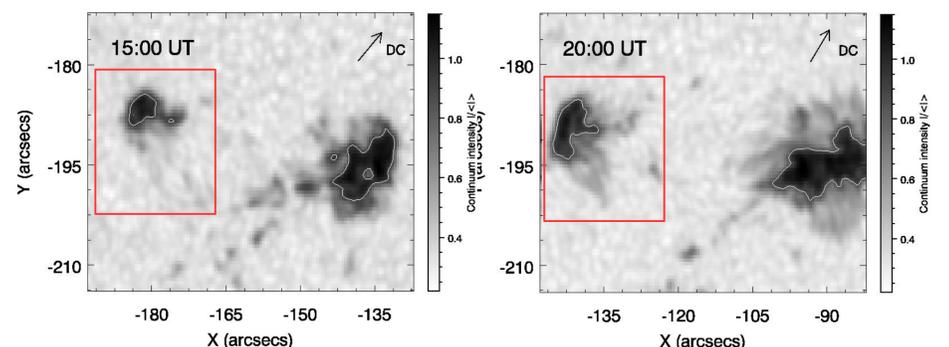


Fig. 2: SDO/HMI data: Detailed maps of formation of the first sector of the penumbra in the area toward the opposite polarity on May 28 2012.

## Results

- The onset of the EF occurs in a short time scale, 1-3 hrs
- The following protospot of AR 11490 forms a penumbra in the area toward the opposite polarity, where elongated granules, filamentary magnetic field in photosphere and and AFS in the chromosphere are visible, in contrast with the results of Schlichenmaier et al. (2010).
- Analyzing a sample of ARs, with  $\beta$  magnetic configuration, we found that there is not a preferred location for the formation of the first penumbral sector.
- Before the penumbra formation we saw inverse EF that changes its sign when the filaments appear, confirming what Murabito et al. (2016) found.
- The analysis of the twelve sample highlight that the time needed for the penumbra formation may be related to the location where the first penumbral sector appears

## References

- Murabito, M, Romano, P, Guglielmino, S., L., Zuccarello, F., Solanki, S. K., ApJ, 825, 75, 2016  
 Murabito, M, Romano, P, Guglielmino, S., L., Zuccarello, F., ApJ, 834, 76, 2017  
 Murabito, M, Zuccarello, F., Guglielmino, S., L., Romano, P, ApJ, 855, 58, 2018  
 Schlichenmaier, R., Rezai, R., Bello Gonzalez N., and T. A. Waldmann, A&A 512, L1, 2010

## Acknowledgements

This work has received funding from the European Commission's Seventh Framework programme under the grant agreement SOLARNET (project n 312495). This work was also supported by the Istituto Nazionale di Astrofisica (PRIN-INAF-2014), by the University of Catania (PRIN-MIUR 2012) and by Space Weather Italian Community (SWICO) Research Program.