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Spectro-polarimetric analysis of a short lived solar active region

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Summary. — The physical processes related to the formation, evolution and disappearance of solar active regions are not completely clear. High-resolution solar spectro-polarimetric data are needed to investigate these processes with unprecedented details. Here we present the analysis of the short-lived NOAA 12549 active region using high-resolution spectro-polarimetric data acquired with the GREGOR solar telescope and the GRIS instrument, inverted using the SIR code.

1. – Introduction

Magnetic fields play a crucial role in the formation and evolution of solar active regions and they regulate the whole cycle of solar activity. The processes of formation, evolution and disappearance of active regions have some aspects that are not yet entirely clear [1] because of the difficulty inherent in the observation of these phenomena, which require the use of large diameter solar telescopes with their suite of spectro-polarimetric instruments. Solar spectro-polarimetry is a powerful and suitable tool to study this kind of processes; in fact, the various state of polarization at different wavelengths have encoded a lot of information about the physical, thermodynamical and magnetic state of the solar emitting plasma.

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2. – Synthesis and inversion codes

The radiative transfer for polarized light is of fundamental importance for solar astrophysics and the core of this theory is represented by the Radiative Transfer Equation (RTE) [2-5]: $d\mathbf{I}/d\tau = \mathbf{K}(\mathbf{I} - \mathbf{S})$, where $\mathbf{I} = (I, Q, U, V)^T$ is the Stokes vector containing the four Stokes profiles I, Q, U and V (respectively, the total intensity, the vertical linear polarization, the oblique linear polarization and the circular polarization), τ is the optical depth, $\mathbf{K}$ is the propagation matrix (which describes the phenomena of absorption, dispersion and dichroism) and $\mathbf{S}$ is the source function.

Using synsthesis and inversion codes it is possible to *synthetize* the Stokes profiles starting from the atmospheric parameters (magnetic field vector, temperature, density, line-of-sight (LoS) velocity, electronic temperature, etc.) or, viceversa, to *invert* the RTE in order to derive the atmospheric parameters that generate the observed Stokes profiles. Nowaday there are several synthesis and inversion codes in the solar physics community. One of the most used is the SIR (Stokes Inversion based on Response function) code [6-9], which operates in Local Thermodynamical Equilibrium (LTE) conditions, and it is able to retrieve the stratification of the atmospheric parameters along the solar photosphere using the concept of *nodes*, in which the atmosphere is discretized.

3. – Dataset and data analysis

The high-resolution spectro-polarimetric dataset of the short-lived NOAA 12549 active region has been acquired with the GREGOR solar telescope [10, 11] located at the Teide Observatory (Tenerife, Spain) and using the GREGOR Infrared Spectrograph (GRIS) instrument [12] during an observing campaign from the 27th of May to the 3rd of June 2016. The resolution of the data is 0.18 arcsec (approximately 120 km on the solar surface), the Field-of-View (FoV) is 70×35 arcsec^2 and the spectral region of interest includes the two Fe I spectral lines at 1564.8 nm and 1565.2 nm.

The data have been reduced using the GREGOR pipeline, which allows the dark, flat-field and polarimetric calibrations. Afterwards the spectral continuum of the data have been rectified and normalized using a polynomial function. The rectified and normalized data are then calibrated in wavelength. The data reduced in this way are therefore inverted using the SIR code, with four cycle, four nodes in temperature, three nodes for magnetic field strength and line-of-sight (LoS) velocity and two nodes for the inclination and azimuth of the magnetic field, starting from two different atmospheric models: a quiet Sun model [13] and an umbra model [14]. The best solution is choosen using a merit function. As one might expect, and after some tests, it was concluded that the code correctly chooses the inversion made with the umbra model for the dark region (the pores) and the inversion made with the quiet Sun model for the granulation region.

In this work we report the most interesting data and inversion results of the preceeding pore of NOAA 12549 on the 29th May 2016 at 11:58 UT. In Fig. 1 the maps of the four Stokes profiles of the preceding pore are shown. In Fig. 2 maps of the temperature, magnetic field strenght, magnetic field inclination and LoS velocity of the preceding pore are shown.

The comparison between the temperature and the LoS velocity maps, in the region close to the light-bridge dividing the pore, indicates the presence of strong motions of downflow in the colder regions. Furthermore, in the temperature map, it is possible to observe the presence of a contour of higher temperature (approximately 6600 K) along the entire perimeter of the pore. Regarding the decay phase of the active region, it

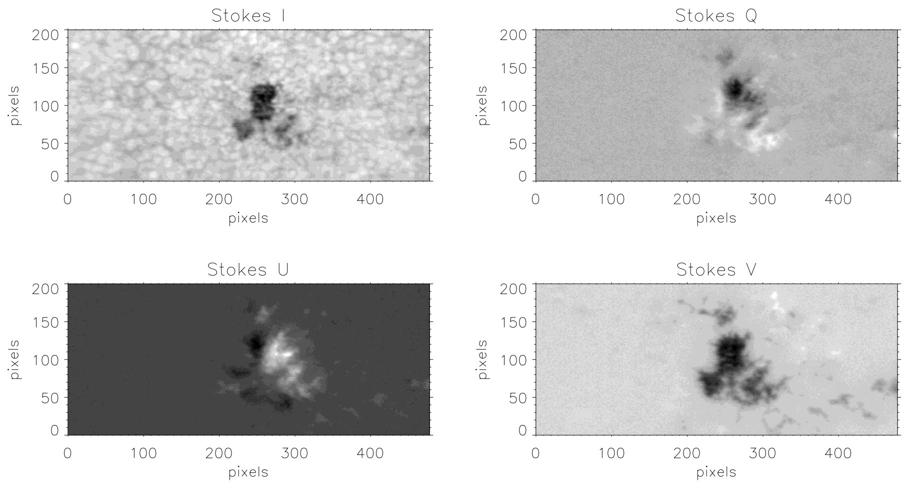

Fig. 1. – Maps of the four Stokes profiles of the preceeding pore of NOAA 12549 on the 29th May 2016 at 11:58 UT.

seems that some magnetic elements, called Moving Magnetic Features (MMFs) can have a central role [15, 16], and some of they are observed in the observed regions. MMFs are small-size magnetic elements seen to stream out from sunspots, especially during the decay phases. These features can appear as isolated features of polarity with the same or opposite sign with respect to the sunspot, or as couples of features of opposite polarity. A dipolar MMF is perfectly visible in the map of the magnetic field inclination in the upper right corner of the pore.

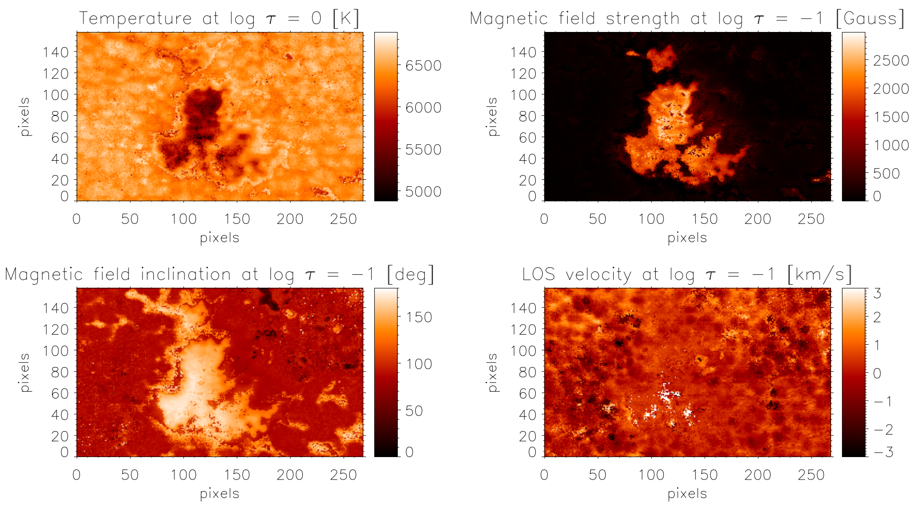

Fig. 2. – Maps of the temperature, magnetic field strenght, magnetic field inclination and LoS velocity of the preceding pore of NOAA 12549 on the 29th May 2016 at 11:58 UT.

4. – Conclusions

High-resolution spectro-polarimetric data are essential to study with high detail the processes of formation, evolution and disappearance of solar active regions. We observed the evolutionary phases of the NOAA 12549 active region using the GREGOR solar telescope and the GRIS instrument. We highlighted the presence of strong downflow motions in the darker region of the preceding pore and the presence of a MMF during the decay phase of the active region. In the next future, large diameter 4m-class solar telescopes, like DKIST or EST, will help the solar physics community to better understand these processes with higher spatial, temporal and spectral resolution.

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REFERENCES

[1] MURABITO M. *et al.*, *The Astrophysical Journal*, **825** (2016) 75
[2] LANDI DEGL’INNOCENTI E. and LANDI DEGL’INNOCENTI M., *Solar Physics*, **97** (1985) 239
[3] LANDI DEGL’INNOCENTI E., *Fisica Solare* (Springer, Milano) 2008
[4] DEL TOTO INIESTA J.C., *Introduction to Spectropolarimetry* (Cambridge University Press, Cambridge) 2003
[5] VIAVATTENE G. *et al.*, *J. Phys.: Conf. Ser.*, **956** (2018) 012006
[6] RUIZ COBO B. and DEL TORO INIESTA J.C., *The Astrophysical Journal*, **398** (1992) 375
[7] RUIZ COBO B. and DEL TORO INIESTA J.C., *Astronomy & astrophysics*, **283** (1994) 129
[8] DEL TOTO INIESTA *et al.*, *Astronomy & astrophysics*, **294** (1995) 855
[9] DEL TORO INIESTA J.C. and RUIZ COBO B., *Solar Physics*, **164** (1996) 169
[10] SCHMIDT W. *et al.*, *Astron. Nachr.*, **333** (2012) 796
[11] SOLTAU D. *et al.*, *Astron. Nachr.*, **333** (2012) 847
[12] COLLADOS VERA M. *et al.*, *Astron. Nachr.*, **333** (2012) 872
[13] GINGERICH O. *et al.*, *Solar Physics*, **18** (1971) 347
[14] COLLADOS VERA M. *et al.*, *Astronomy & Astrophysics*, **291** (1994) 622
[15] ZUCCARELLO F. *et al.*, *Astronomy & Astrophysics*, **500** (2009) 5
[16] CRISCUOLI S. *et al.*, *Astronomy & Astrophysics*, **546** (2012) 26