Analysis of the Influence of the Magnetic Field on the Plasma Dynamics Around Active Regions

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Abstract

In this work, we studied the relation between photospheric proper motions and the present magnetic field in four sunspots, We used continuum images and magnetic field data from Solar Dynamics Observatory's Helioseismic and Magnetic Imager (SDO/HMI) that show the pass of each sunspot across the solar disk. Before the processing of the data, we employed advanced image processing techniques to coalign and correct limb darkening , projection and p-mode effects. The horizontal proper motions and velocities were obtained applying Local Correlation Tracking techniques in the continuum images. We present the maps of intensity continuum, magnetic field strength and the radial profiles of the velocities obtained with LCT and vertical and horizontal components of magnetic field. We found the first correlations between the velocities, the size of the sunspots and the magnetic field in the sunspots and the surrounding region.

Introduction

The photosphere is the outer shell of the Sun, this region has a 500 km thickness and a temperature about 5000 K in the outer layer. The photosphere has a set of features like the granulation and sunspots. The granulation is the pattern made by the convective motions from the inner zone. Sunpots are zones with intense magnetic field, this causes a lower temperature in the sunspot surface and the brightness is darker than the normal granulation. A sunspot can be divided in a dark umbra where the magnetic field lines are normal to the surface. This umbra is surrounded by a penumbra, in this region the inclination of field lines increases.

One of the main research areas in solar physics are the tracking of the plasma in the photosphere and the influence of the magnetic field in the plasma dynamics. For this purpose, November & Simon [1]developed a technique called Local Correlation Tracking (LCT) to obtain proper motions in a time series of continuum images. This method uses the cross-correlation in a time series of images with a determined cadence for find the apparent motions between the images. An apodization window determines the size of the structures that will be tracked

In this work we used LCT for selected sunspots to derive apparent motions and then we analyzed the correlation of the motions with the local magnetic field.

Methodology

We used images of continuum and magnetic field data of 4 active regions near of the solar disk center. This data were taken from the Helioseismic and Magnetic Imager (HMI) from the Solar Dynamics Observatory (SDO) [2] [3]. The data has a cadence of 720 s, a resolution of 0.504 arcseconds per pixel and a 6 h duration of the time series

The continuum images were cleaned for eliminate limb darkening, differential rotation,and p-modes effects. The proper motions were obtained with LCT algorithm using the cadence, resolution and a 3x3" apodization window as parameters.The LCT algorithm has failures in the umbra, for this reason the results here must be neglected.

The magnetic field data includes the intensity B_r, inclination B_θ and azimuth B_ϕ components. The azimuth data has a 180° ambiguity, this was solved using minimum energy methods [4]. The velocity and magnetic field vector data were de-projected from line-of-sight (LOS) frame to the local frame. For the purpose to compare the velocity of proper motions with the magnetic field vector, we selected a circular region around of each sunspot and divided it in a concentric rings with thickness about 1".In this rings we took the mean of the velocity of the proper motions, and the mean of vertical and horizontal magnetic field. We divided the regions in zones of umbra, penumbra, azimuth and granulation.

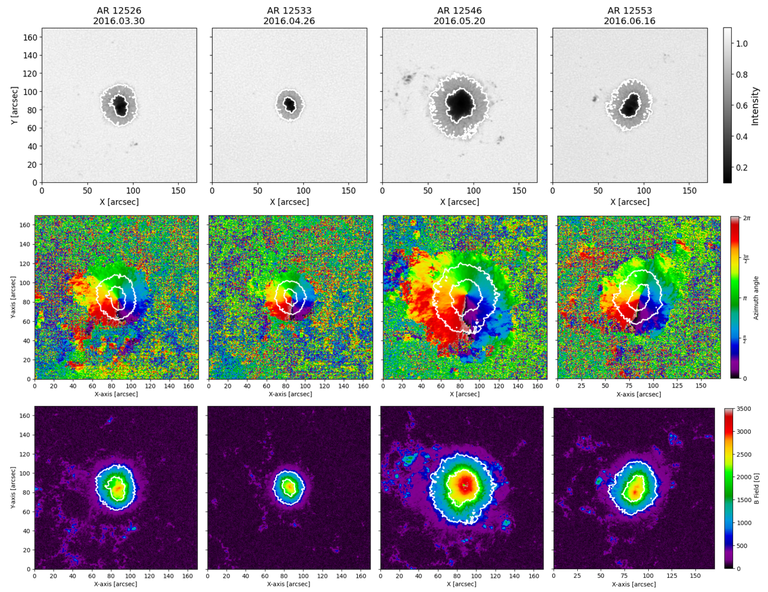
Radial profiles of the mean velocity and magnetic field were constructed for the four sunspots, including their regional divisions. Velocities are given in km/s, and magnetic field strengths in Gauss (G)

Results

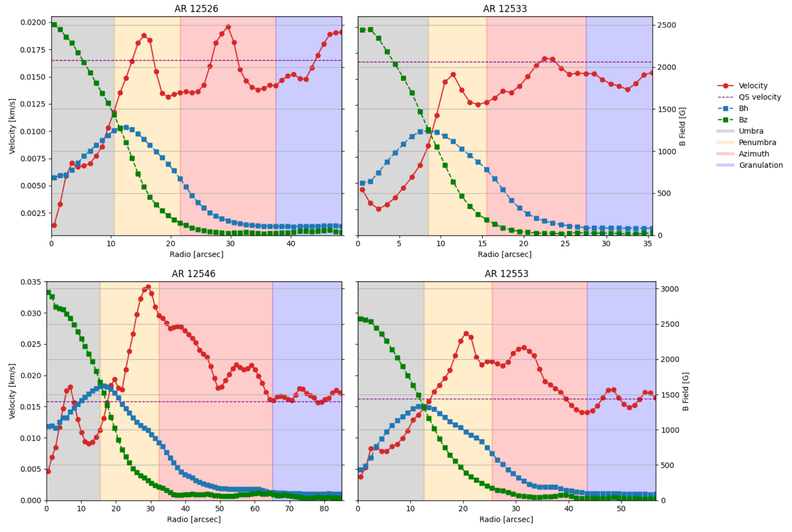
We calculated the sunspots area, for the purpose to find a possible dependence of the velocities and magnetic field intensity with the sunspots sizes:

Active Region	Date	Sunspot area [arcsec^2]
AR 12526	2016-03-30	1419.26
AR 12533	2016-04-26	824.08
AR 12546	2016-05-20	3478.47
AR 12553	2016-06-16	1964.58

The sunspots in active regions AR 12546 and AR 12533 have the largest and smallest sizes respectively. The figures below shows the maps of continuum intensity and the azimuth and strength components of the magnetic fields. All sunspots has a field-of-view (FOV) of $175'' \times 175''$



The azimuth images show a region where the azimuthal direction of the magnetic field is well defined, and it extends several arcseconds beyond the boundary of the sunspots penumbrae. This could be an indicator on the extension of the influence of the magnetic field over the velocities in a larger area than the sunspots. The magnetic field maps shows the greatest intensities in the center of the umbras.The largest sunspot (AR 12546) exhibits a significantly stronger magnetic field compared to the other 3 sunspots.



Discussion

The magnetic radial profiles show the typical structure of magnetic field in a sunspot: The vertical component (green dotted line) has the strongest value in the umbra's center.This strength decreases progressively with radial distance from the umbral center. Meanwhile the horizontal component (blue dotted line) has a maximum in the umbra frontier with the penumbra, in both directions (towards and away from the sunspots centers) the horizontal magnetic field decreases

The behavior of the velocities obtained with LCT can be classified into two types: the velocities associated with the "small" sunspots and those associated with the "large" sunspots. In the small sunspots, the velocities exhibit peaks in magnitude within the regions of "well-defined" azimuth and the penumbra. In AR 12526, the valleys between these peaks show a reduction in velocity compared to the mean "quiet Sun" velocity (purple dashed line), whereas in AR 12553 this reduction is more pronounced. Near the umbral boundary, the rate of decrease in velocity magnitude increases. The small peak in velocity near the center of the umbra in AR 12533 is considered to be an error of the LCT method.

In the other hand,the large sunspots exhibit a stable velocity behavior in the granulation region, with values close to the mean in the quiet Sun. In the region of well-defined azimuth, the velocities show a significant increase towards the center of the umbra, reaching a maximum in the penumbra near the boundary. Beyond this point, the velocity values decrease considerably. Once again, the velocity peaks observed within the umbra are a LCT error.

This profiles shows the change of the apparent velocities in the zones with strong magnetic fields. The diference of the velocities profiles between the small and large sunspots give us the hypothesis of the possible correlation of the sunspots area and the apparent motions.We found that the largest sunspots has greater values of velocities near the sunspot.The same occurs with the magnetic field intensities. However, the QS mean value of velocities are similar for all the active regions. Additionally, the sunspots in regions 125326–12533 and 12546–12553 are considered to be the same sunspot respectively, as they make two passes across the solar disk. In the second pass, the area of the sunspots has decreased due to decay, and consequently, both the magnetic field intensity and the velocities magnitudes have also decreased.

Our future work will focus on the analysis of sunspots with areas comparable to those studied in this work, in order to verify the behavior of proper motion velocities in both small and large sunspots. Additionally, we aim to investigate the alignment between these velocities and the magnetic field azimuth in the regions surrounding the sunspots.

References

[1] L. J. November and G. W. Simon, "Precise Proper-Motion Measurement of Solar Granulation," *The Astrophysical Journal*, vol. 333, p. 427, Oct. 1988.

[2] W. D. Pesnell, B. J. Thompson, and P. C. Chamberlin, "The Solar Dynamics Observatory (SDO)," *Solar Physics*, vol. 275, pp. 3–15, Jan. 2012.

[3] J. T. Hoeksema, Y. Liu, K. Hayashi, X. Sun, J. Schou, S. Couvidat, A. Norton, M. Bobra, R. Centeno, K. D. Leka, G. Barnes, and M. Turmon, "The Helioseismic and Magnetic Imager (HMI) Vector Magnetic Field Pipeline: Overview and Performance," *Solar Physics*, vol. 289, pp. 3483–3530, Sept. 2014.

[4] K. D. Leka, G. Barnes, A. D. Crouch, T. R. Metcalf, G. A. Gary, J. Jing, and Y. Liu, "Resolving the 180° Ambiguity in Solar Vector Magnetic Field Data: Evaluating the Effects of Noise, Spatial Resolution, and Method Assumptions," *Solar Physics*, vol. 260, pp. 83–108, Nov. 2009.