Evolution of Photospheric Pores in the Magnetic Field

I. Dorotovič (1), M. Rybanský (1), M. Sobotka (2), M. Lorenc (1), M. Barandas (3), J.M. Fonseca (3)

[1] Slovak Central Observatory, Komárňanská 134, SK-94701 Hurbanovo, Slovak Republic;
E-mail: ivan.dorotovic@suh.sk
[2] Astronomical Institute, ASCR, Fričova 298, 251 65 Ondřejov, Czech Republic
[3] CTS-UNINOVA/CA3, Campus FCT/UNL, Caparica, Portugal

ABSTRACT

We describe conditions of pore formation in relation to the configuration and intensity of magnetic field. We used observations of the SDO/HMI instrument, which observes the photosphere in continuum and simultaneously the magnetic field with a spatial resolution of better than 1" and a temporal resolution of 45 s. We analyze a time-sequence of evolution of area and brightness of pores, their statistics, and in parallel a time-sequence of the line-of-sight magnetic field intensity and its correlation with the area and brightness. Sunspot observations from the Hurbanovo Observatory are used for selection of a suitable area on the solar disc. A pore (small sunspot) observed near the central meridian at the Observatory in Hurbanovo on October 10 and 11, 2013 was selected for analysis. We chose from each SDO image only area with a diameter of 1.05° (35″ as seen from the Earth). Points of the area were transformed into rectangular coordinates (Δl, b) and for alignment of individual images we found from the movement of a pore the synodical rotational speed: ω = 14.35°/24 hours, which is by 1° more than a tabular value. We traced the selected area from 22:01:30 UT (October 10, 2013) to 20:01:30 UT (October 11, 2013) in 83 images with a temporal resolution of 15 minutes. Evolution of the area was analyzed using an animation and quantitative results are derived from data files. At least 6 pores occured in the area during the reported period. Pores are visible if a ratio p (p = intensity in the pore/background intensity) decreases below 0.85. The background noise is at a level of 5% (granulation). Magnetic induction is in the same time at around 600 Gauss (60 mT). The maximum diameter of a pore is about 5″ (1 pixel in the center of the disk is 0.5″), the minimum value of p = 0.49; when B = 1200 Gauss. The course of evolution is presented in a tabular form. Aim of the analysis is demonstrated also using selected images from SDO in cooperation with CTS-UNINOVA/CA3 (Caparica, Portugal).

1. INTRODUCTION

High-resolution observations of the solar photosphere performed using modern ground-based and space-borne telescopes provide important material for investigation of small-scale magnetic features. Helioseismic and Magnetic Imager (HMI; Schou *et al.* 2012) instrument onboard the Solar Dynamic Observatory (SDO; Pesnell et al. 2012) enable us to study tiny pores and magnetic fields in much more details than before the SDO era and brings observational constraints on theoretical models and numerical simulations. Some characteristics of pores are described *e.g.* in Sobotka *et al.* (2012) who focused on magnetic and velocity fields in a large solar pore with a light bridge.

2. INPUT DATA AND METHOD

We used the SDO/HMI images with 4096 x 4096 pixels (px). Diameter of the solar disc covered on that day 1923 px, so that **1 px** in the center of the disc represents **0.03°** in heliographic coordinates, which is 0.5″ when viewed from the Earth. LOS B component of the magnetic field is given in units of Gauss (G) with an accuracy of 10 G, background light intensity of the photosphere is about 61000 in arbitrary units and we determined the intensity around pores for each image separately.

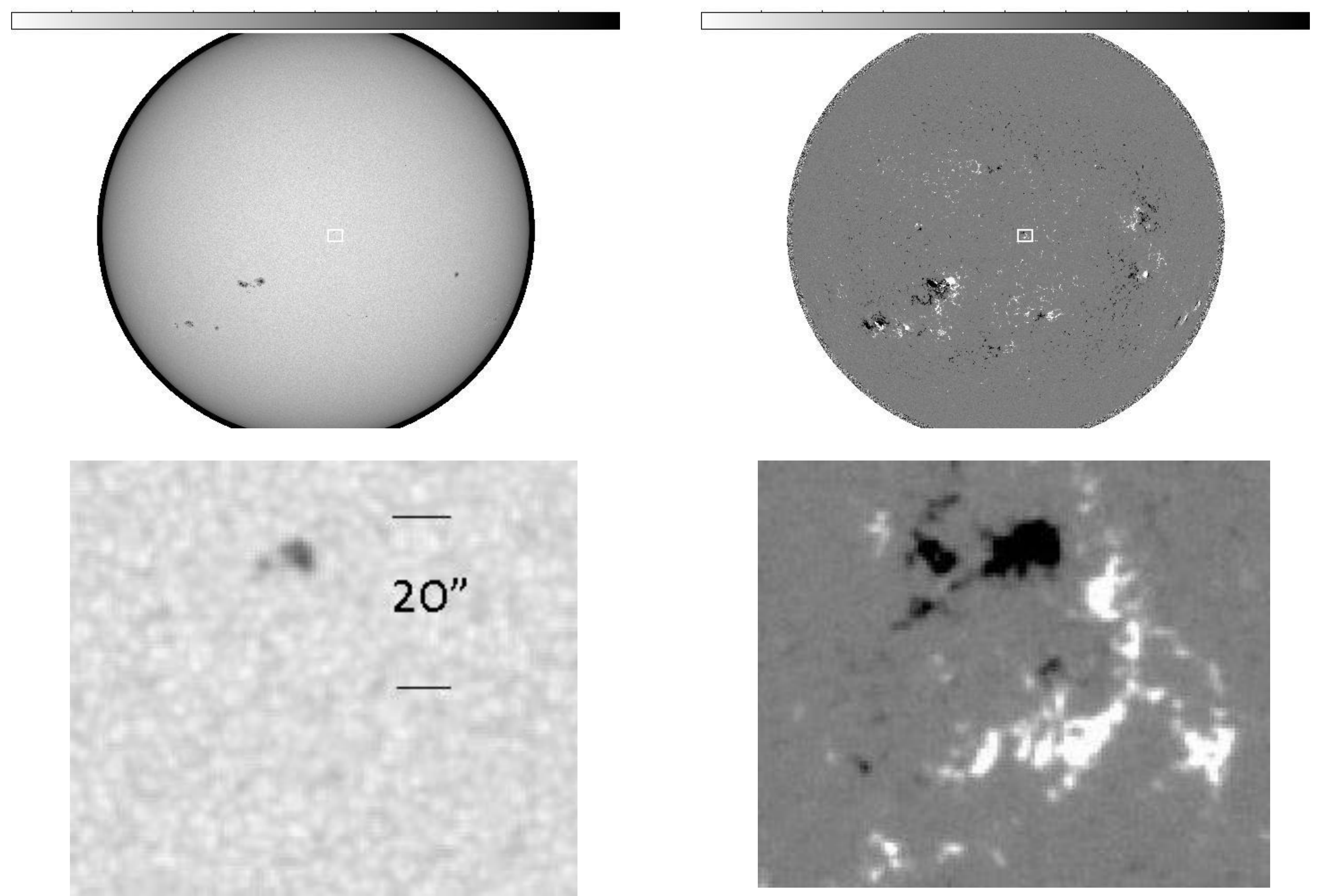


Fig. 1. Studied area on 11 October 2013, the photosphere (left), the magnetic field (right; white - positive polarity).

We determined: in the studied area (**Figure 1, bottom**):
1. position in *px* with the **minimum intensity** of the photosphere and the **maximum** absolute value of the **magnetic field induction**;
2. the centroid position of "**intensity and magnetic volume**" around these extreme value pixels. Volume (V) is defined by the value of:

$$V = S_{px} \sum_i y_i \; , \qquad (1)$$

where y_i is the value of darkening in the photosphere in a particular pixel:
$y_i = y_0 - I_i$, y_0 is the basic level of darkening volume - the average intensity of the surrounding photosphere reduced by **2σ** (at a level of 5% of the average intensity of the photosphere) and I_i is the intensity at a given pixel;
3. corresponding **extreme of the magnetic fields** and average **diameter** of the area occupied by the pore (d_f for the pore and d_m for the magnetic field). For d (in arc seconds) then we get:

$$d = 0.5\sqrt{\frac{8V}{\pi y_m}} \; [''] \; . \qquad (2)$$

3. RESULTS

Six pores were observed in the selected area during the period from October 10, 2013, 22:01:30 UT to October 11, 2013, 20:01:30 UT (**Figure 2**). Already from a rough examination it was clear that the position of the pore is almost identical with the position of the absolute maximum value of the magnetic field, although, as it is shown below (**Figure 3**), small differences in position exist.

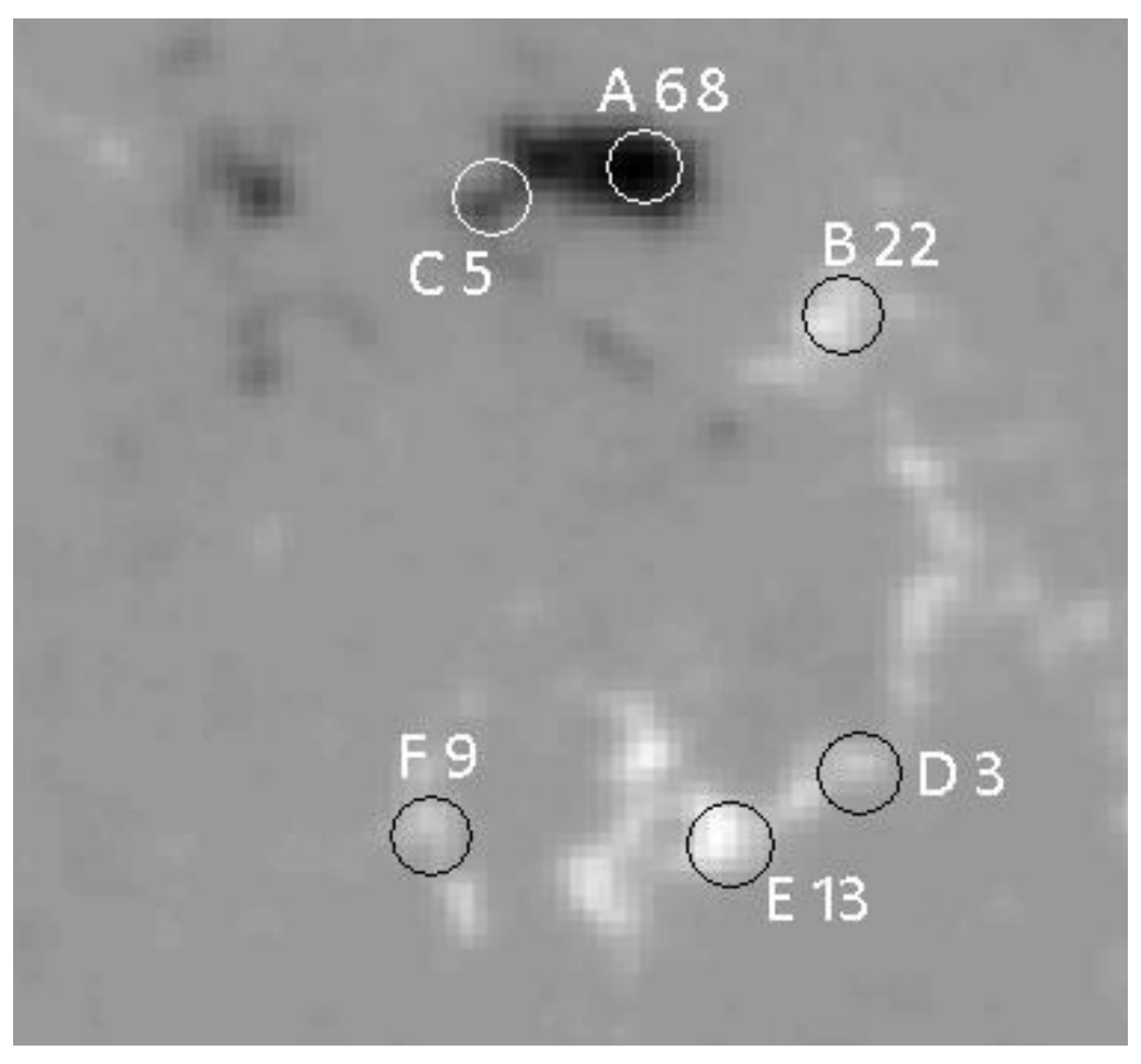


Fig. 2. Circles indicate an approximate position of the observed pores, number is a count of images where the pores are visible.

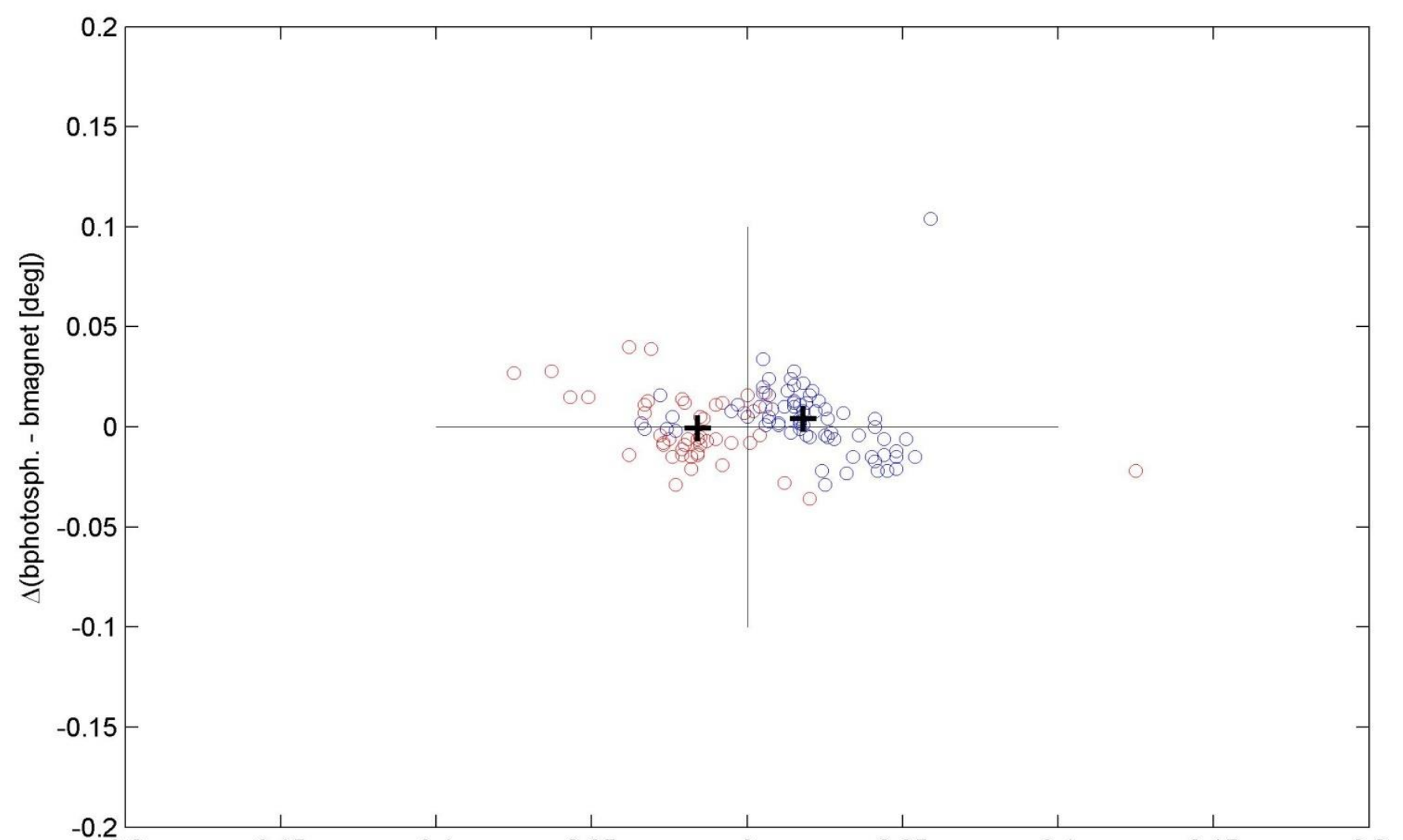


Fig. 3. Relative position of magnetic field maximum and a pore. For positive polarity the magnetic field maximum leads the pore position and *vice versa*.

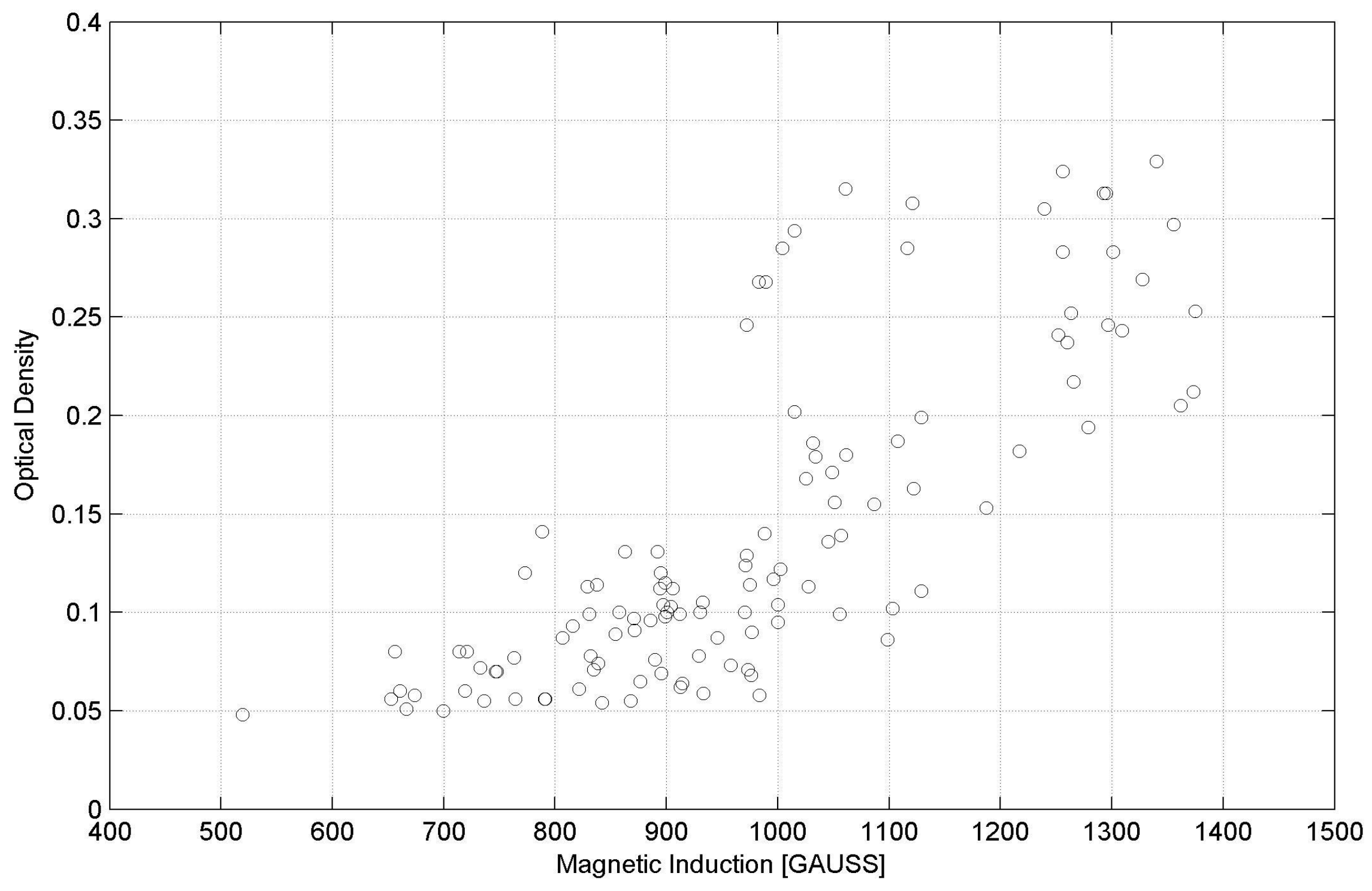


Fig. 4. Relation between optical density (D) of a pore and line-of-sight magnetic field (*D* = – *log(p)*, where *p* = intensity in the pore/background intensity).

The pores become visible at approximately B = 650 G. Until around B = 1000 G optical density slowly increases proportionally, further it changes irregularly.

We calculated synodic rotational velocities of individual pores from the determined positions. Results are in Table 1.

Table 1:
Synodic rotational velocities of individual pores ($\omega_{sider.} = \omega_{synod.} + 0{,}986$).

Pore	*n*	*polarity*	ω_f *[°/day]*	ω_m *[°/day]*	*Δv [m/s]*	*range of b [°]*
A	68	–	14.424 ± 0.005	14.370 ± 0.004	0.148	5.180 – 5.480
B	22	+	13.938 ± 0.009	13.875 ± 0.008	0.080	4.954 – 5.117
C	5	–	14.703 ± 0.019	14.673 ± 0.022	0.187	5.179 – 5.289
D	3	+	15.556 ± 0.024	14.884 ± 0.021	0.307	4.218 – 4.222
E	13	+	13.784 ± 0.011	13.893 ± 0.013	0.058	3.892 – 3.928
F	9	+	16.206 ± 0.014	15.692 ± 0.010	0.399	3.813 – 3.817

where ω_f is angular velocity calcuted from movement of the pore
ω_m is angular velocity calcuted from movement of the maximum B value
Δv is proper velocity of a pore.

Method of determination of the rotational velocity and the possible deviation is described in Lorenc *et al.* (2012).

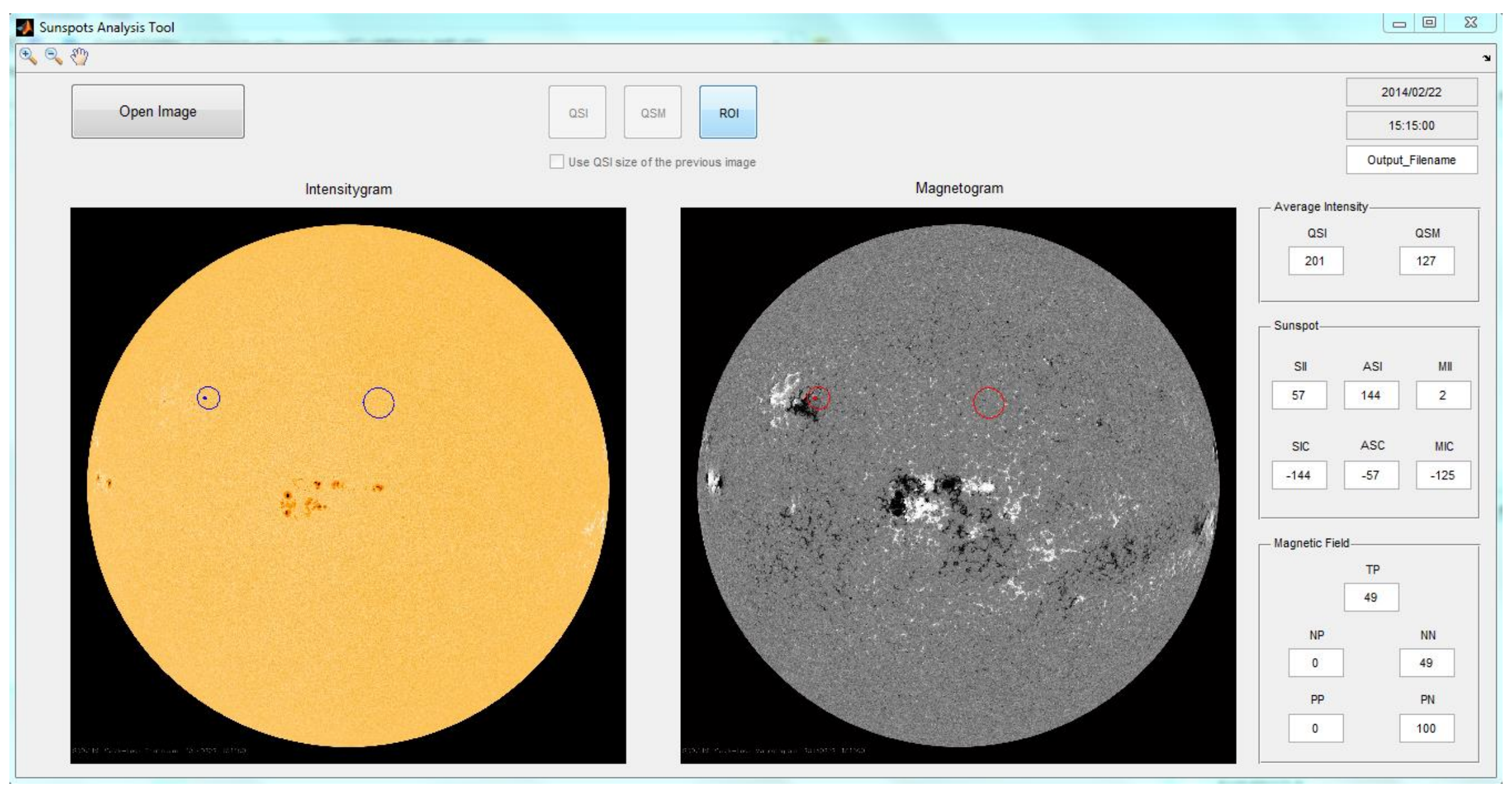
4. DISCUSSION AND CONCLUSIONS

There is rather large **variance of rotational velocities** for individual pores. Mean value of sideric rotational velocity for a given latitude, estimated from movement of sunspots is 14.35°/day (Brajša et al.,2002) and thus we have for mean synodic rotational velocity a value of 13.37°/day.
Difference of mean velocities and the average velocity yields a **larger proper velocity of pores** in the direction of solar rotation, from which follows that pores are not appropriate tracers for determination of rotation of the photosphere.
Note: *This conclusion follows from an assumption that the surrounding photosphere rotates with an average velocity. In fact, we do not really know the actual speed of rotation of the surrounding photosphere.*

Changes in heliographic latitudes are relatively small, at a level of tenths and hundredths of a heliographic degree (last column of Table 1). The rotational speed of a pore, as determined from the magnetic field, is everywhere except the pore E slightly less than the rotation speed determined from the movement of the pore.

Position of maximum magnetic field **leads** the position of the pore in the direction of rotation for the positive polarity and lags behind it for the negative polarity (**Figure 3)**.

An interactive program for „photometry" of sunspots and determining the distribution of the magnetic field polarity in the area of sunspots developed by M. Barandas and J. M. Fonseca in cooperation with the CTS-UNINOVA/CA3 research group (Caparica, Portugal) has been tested using selected SDO/HMI images.



2014/02/22
15:15:00
Output_Filename

Average Intensity
QSI: 201
QSM: 127

Sunspot
SII: 57
ASI: 144
MII: 2
SIC: -144
ASC: -57
MIC: -125

Magnetic Field
TP: 49
NP: 0
NN: 49
PP: 0
PN: 100

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