Interaction of Convective Structures with the Magnetic Field of Solar Pores

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Abstract. Time series of high-resolution white-light images of solar pores are analyzed. Granular motions in the vicinity of pores are driven by mesogranular flows: Motions toward the pore dominate in the 2" zone around the pore boundary, while at larger distances the granules move away from the pore. Triggered by these motions, small granules and granular fragments located close to the pore border penetrate into the pore, where they move inwards as short-lived bright features very similar to umbral dots. The formation of a transitory penumbra-like structure at the border of a large pore was observed simultaneously with a temporary reorganization of adjacent granular field to expanding elongated granules separated by dark filaments.

1. Introduction

Solar pores are sunspots lacking penumbrae and constitute the first stage of sunspot evolution. Due to the absence of the perturbing penumbra, pores are a virtually ideal laboratory in which to study the interaction between the vertical magnetic field, forming the umbra, and the surrounding convective motions. Muller & Mena (1987) found that facular points and granules move away from a sunspot. In contrast to the sunspot observations, Wang & Zirin (1992) reported converging flows around pores. Penumbral grains have been observed to move toward the umbra (Muller 1973). Some of them cross the umbral border and continue to move as UDIs. Is there any analogous process taking place at the pore boundary? Another problem is how the granulation is affected by the emergence of new magnetic flux or by the formation of a horizontal magnetic field inside the active region. An alignment of granules and intergranular lanes is observed in this case. According to Wang & Zirin (1992), dark alignments either connect magnetic elements of opposite polarity or correspond to unipolar fields.
2. Observations and Data Analysis

Two time series of white-light images of pore groups in the central zone of solar disk were obtained at the 0.5 m Swedish Vacuum Solar Telescope, Observatorio Roque de los Muchachos, La Palma. A very small active region, Ramy 174, consisting of two pores (P1, P2) was observed on 18 June 1993 ($\lambda = 5257\text{Å}$), duration of the series was 85 min. A group of 10–11 rapidly developing pores, NOAA 7886, was observed on 30 June 1995 ($\lambda = 5257\text{Å}$), duration of the series was 67 min. Four pores of this group (P3–P6) were studied in more detail, including a very large one (P4), with a diameter of 8.9″, rich of fine bright structures (umbral dots, light bridges). The temporal resolution of both time series was 20 s and the spatial resolution was near to the diffraction limit of the telescope (0.27″). In 1995, G-band frames ($\lambda = 4308 \pm 5 \text{ Å}$) were taken simultaneously with the white-light images. Magnetic maps of the active region NOAA 7886 were obtained on 30 June 1995 at the photoelectric scanning magnetograph of the Ondřejov Observatory.

The series of frames were corrected for the instrumental profile of the telescope, de-stretched, and filtered to remove acoustic waves and the residual jitter induced by seeing. Photospheric flows and divergence were derived from the motion of granules using the standard method of local correlation tracking (LCT, November & Simon 1988, IDL routines written by Molowny-Horas & Yi). The FWHM of the Gaussian window used in the tracking was 0.8″ and the averaging time was equal to the length of the series. The systematic and random errors of derived horizontal velocities were $-25\%$ and $\pm 15\%$, respectively. Motions of granules and small-scale features near the pore border were measured using manual feature tracking in segmented frames, where the objects under investigation were separated from the background by an edge-enhancement algorithm.

3. Mesogranular Pattern and Bright Network Points

Flow maps were computed for the regions with pores and for a field of quiet granulation. The spatial resolution of the tracking was high enough to detect motions of small granules, granular fragments, and collective motions inside the pores. In all flow maps we see the typical “rosetta” velocity patterns characteristic of mesogranulation. The nearest-neighbor (center-to-center) distance of the mesogranules in the region of quiet granulation is 4.1″ on average. The largest velocities in the granular flow field are of 1 km s$^{-1}$, and the spatial average is 0.4 km s$^{-1}$, in accordance to previous measurements (e.g. Strous et al. 1996).

The flow maps computed for pores and their surroundings show maximum velocities between 0.8 and 1.1 km s$^{-1}$ and the spatial average of 0.3–0.4 km s$^{-1}$, that is, the velocity magnitudes are similar to those in quiet granulation. The maximum and average velocities of umbral features inside P4 are 0.2 and 0.1 km s$^{-1}$, respectively. The emergence of small pores with diameters $\leq 3″$ seems to distort the mesogranular structure only slightly. The mean nearest-neighbor distance of 4″ between the centers of mesogranules located around the pore is almost equal to that in quiet granulation. The situation is different in case of P4 (diameter 8.9″). The large pore re-organizes the flow pattern, pushing the mesogranules away from each other and making them encircle the pore boundary.
Figure 1. Gray-scale maps of divergence (white—positive, black—negative) for the pores P4–P6. Black contours outline the borders of the pores, white contours show time-averaged positions of brightenings in the G-band. The coordinate unit is 1 pixel = 0.062".

The mean nearest-neighbor distance between the centers of mesogranules around the perimeter of P4 is 5.1". Motions of granules in the vicinity of pores are driven by mesogranular flows. Motions toward the pore dominate in a zone out to a distance of 2" from the pore border. The centers of mesogranules are mostly located at this distance. They form a ring-like structure with positive divergence, clearly seen in the gray-scale divergence maps displayed in Figure 1. At larger distances the granules move away from the pore.

The G-band brightenings (clusters of facular points) appear recurrently at locations which surround the pores and which are related to the mesogranular flow pattern. The G-band brightenings are mostly located at the downdrafts, areas with negatively divergent horizontal motions, as demonstrated in Fig. 1.
4. Interaction of Surrounding Granules with the Pores

In the previous section we mentioned the 2″ zone around the pores where the motions toward the pore dominate. These motions sometimes result in a penetration of bright features from the photosphere into the pore. Two morphological types of this effect can be observed: (i) Small granules located at the pore border shrink, separate from the edge, and move inwards. (ii) Large granules split into several pieces and the fragments located close to the border then move into the pore. Once penetrated inside, the fragments or shrunk granules cannot be distinguished from UD's. They continue to move inwards and their brightness and size decrease until they disappear. The examples of both types are shown in a series of frames displayed in Figure 2. The penetrations occur around the whole perimeter of the pore. They are often accompanied by the presence of elongated bright features located near the pore edge (see frame 8 in Fig. 2), which may indicate a local tilt in the magnetic field.

We tracked the evolution and proper motions of 14 randomly selected bright granules and fragments which penetrated into the pore P4. The duration of penetration, measured from the moment when the feature becomes completely separated from the pore border, ranges from 3 to 14 min and its mean value is 6.4 min. The depth of penetration, i.e. the distance between the pore border and the position where the feature disappears, is relatively small: 0.4″ on average and 1″ as a maximum. The velocities of proper motions, averaged over the whole period when the feature is observed, are in the range 0.56–1.82 km s⁻¹. They are anticorrelated with the duration of penetration.

Different processes were proposed to explain the decay of sunspots. Simon & Leighton (1964) first suggested that sunspot decay may be produced by the “gnawing” action of supergranular motions at the edges of the spot. Recently, Petrovay, & Moreno Insertis (1997) developed a model of sunspot decay, called turbulent erosion, based on the action of small-scale adjacent granular motions. We believe that the observed penetration of bright features into the pores constitute the micro-scale manifestation of turbulent erosion, based on the action of all the known spatial scales of photospheric convection (granulation, meso-granulation, and supergranulation).
5. Changes in Intensity and Flow Patterns Due to Magnetic Field

Two interesting phenomena took place in the region of the pores P3 and P4 (NOAA 7886). The first one was a transformation of a bright photospheric granule located at the border of P4 to a system of 2–3 narrow bright penumbra-like filaments which appeared as small elongated features and increased their length by expansion at both ends. After 6–9 min the filaments reached the maximum length of about 2.7″ and decayed, being replaced at locations similar to the previous ones. The total duration of the filamentary system was 22 min. The phenomenon was preceded by a strong and organized horizontal flow from the photosphere toward the pore border with average speed of 1.5 km s$^{-1}$ and duration of 10 min.

Simultaneously with the onset of the horizontal flow toward P4, two elongated granules emerged in the photospheric region between the pores P3 and P4 and expanded with velocities of 2.7 km s$^{-1}$ toward P4 and of 3.0 km s$^{-1}$ toward P3. The granules were separated by a dark filament with maximum length of 3.8″. Close to the ends of expanding elongated granules appeared two bright facular points in the G-band moving away from each other with relative speed of 1.4 km s$^{-1}$. After 34 min, simultaneously with the decay of the penumbra-like filamentary system at the P4 border, the elongated granules disappeared and usual intensity and motion structures corresponding to undisturbed granulation were re-established.

Both phenomena described above indicate the emergence (or local formation) of a nearly horizontal magnetic field. Since they were observed at the same time, we can expect that a common physical process is behind them. The pores P3 and P4 had equal magnetic polarity. However, the observations at the Ondřejov magnetograph have shown that a temporary intrusion of opposite magnetic polarity was located close to the region where the phenomena took place. This intrusion gave rise to a transient, nearly horizontal magnetic field. The penumbra-like filaments and the expanding elongated granules appeared when this horizontal magnetic field emerged through the photospheric layer.

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References

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