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Observations at 0.″1 Resolution of the Dynamic Evolution of Magnetic Elements

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Abstract. We present observations of the dynamic evolution of photospheric magnetic elements in the G-band, magnetograms and Dopplergrams. The observations were obtained with the Swedish 1m Solar Telescope on La Palma at close to the diffraction limit of 0.″1. In the most quiet regions we observe individual bright points in the G-band with corresponding magnetic signal in the magnetograms. Where the filling factor of the magnetic field is larger, the bright points interact when advected by the granular and super-granular flow-fields, flux sheets form and fragment. The plage region of the decaying active region is filled with more complex topologies like ribbon structures with darker interior and bright, knotted edges. These change into flower-like shape when small in extent and into micro-pores when the flux region is larger in extent. The magnetic elements in the plage region are associated with upflows with strong downflows in the immediate vicinity in the low-field region.

1. Observations

We used the Swedish 1-meter Solar Telescope (SST) (Scharmer *et al.* 2003).

Narrow-band interference filters were used for imaging in the G-band (430.5 nm). The Solar Optical Universal Polarimeter, SOUP (Title & Rosenberg 1981) was used to obtain magnetograms and Dopplergrams in the Ni I 676.8 nm line.

Seeing effects were reduced using several complementary techniques: image stabilization by a correlation tracker, adaptive optics (Scharmer *et al.* 2003), real-time frame selection, and post-processing using the Multi Frame Blind Deconvolution image reconstruction technique (Löfdahl 2004).

We here report on a 1.5 h time series obtained on 2 June 2003. For details of the data-reduction and calibrations of the magnetograms and dopplergrams, see Berger *et al.* 2004

2. Results

Figure 1 shows the temporal evolution of a plage region in a 4855 s time interval. The region is mostly covered with magnetic structures of almost exclusively positive polarity up to a magnetic flux density of 1300 Mx cm^{-2}. The G-band filtergrams show a very complex pattern of ribbon-like structures with darker central parts surrounded by bright, knotted, features. Where the magnetic flux density covers a large area, the ribbons change appearance to more pore-like structures. When the central area is small, the G-band filtergrams show flower-like structures. There is a continuous change in appearance of these magnetic structures and only small changes to the coverage of the magnetic flux may give large changes to the appearance. In general, the G-band filtergrams show the

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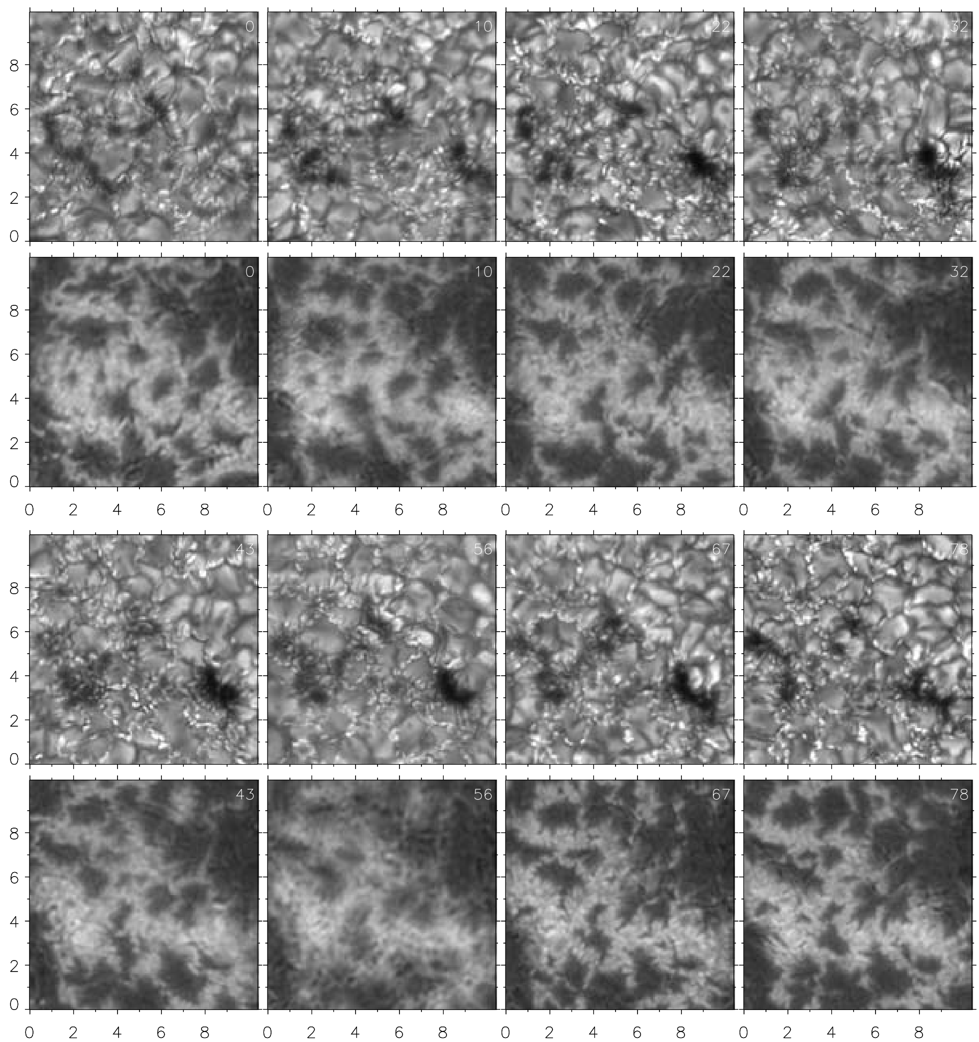

Figure 1. Time evolution of a plage region. G-band 430.5 nm filtergrams in top rows, magnetograms in bottom. Frame numbers in upper right corner. Time between two consecutive frame numbers is 61.5 s giving an average cadence of 694s for the series shown. The range in magnetic flux density is [-229,1312] Mx cm^{-2}

brightest features when there is strong magnetic field with small lateral extent, show a knotted, ribbon-like structure when the magnetic filling factor is larger and a micro-pore appearance for the largest in extent magnetic regions.

Figure 2 shows a blowup of the upper left region during the last part of the time sequence shown in Figure 1. The cadence is now 61.5s and the figure shows the temporal evolution over a 16 min interval. The region contains a wide magnetic ribbon just above the middle and a curved, very narrow (down to the resolution limit of 70 km in the G-band and 100 km in the magnetograms), magnetic flux sheet in the lower part. The dopplergrams show that there is an upflow (dark in the figure) associated with the magnetic flux concentrations and that the downflow (bright in the figure) is maximum in the low-flux region just next to the flux concentrations. The gradient may be very sharp, from an upflow of 400 m s^{-1} in the flux concentration to a downflow of 360 m s^{-1} just

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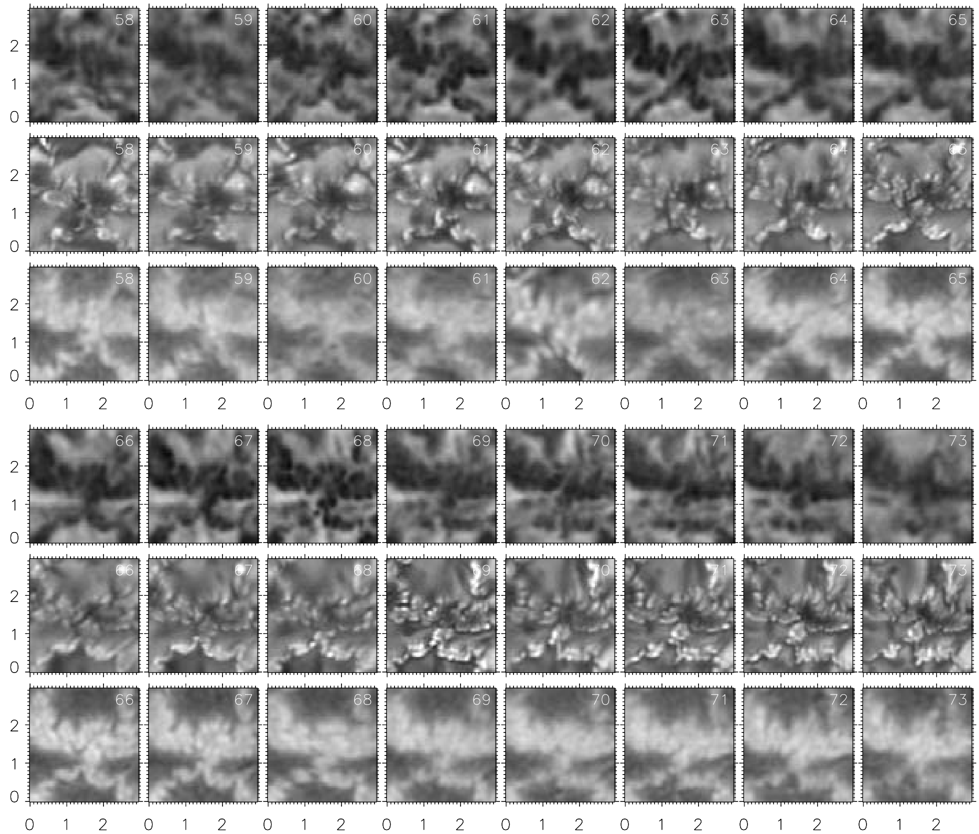

Figure 2. Time evolution of the upper left corner of Figure 1. Dopplergrams in top rows, G-band filtergrams in middle and magnetograms in bottom rows. Frame numbers in upper right corner. The cadence is 61.5 s. The range in dopplershift is [-575,364] m s^{-1}. The range in magnetic flux density is [-65,1076] Mx cm^{-2}

outside. The G-band appearance of the flux concentrations is that of a ribbon for the wide band above the middle of the region. This ribbon-structure changes continuously in time, appearing as a micro-pore in the first half of the time-series and a ribbon with flower-like structures (e.g. frame 69) in the second half. The forms continuously change with the life-time of the knotted structures on the order of 3-5 minutes.

The various appearances in the G-band of the magnetic regions are consistent with results from magneto-convection simulations Carlsson *et al.* 2004; The magnetic elements are cooler than the surroundings at a given geometrical depth. This is because the strong magnetic fields prevent convective energy transport from deeper layers. One would thus expect the magnetic elements to be darker than the non-magnetic areas. There is, however, an effect in the opposite direction: because of the lower density in the magnetic elements compared with the surrounding intergranular medium one sees deeper layers. With the temperature increasing inwards in the photosphere this effect will give a higher intensity. Which effect is the more important depends on the temperature gradient in the flux concentration. If the flux concentration is small in extent, the interior is radiatively heated by the surrounding hotter, non-magnetic plasma and the net effect is a higher temperature at optical depth unity than in the intergranular lane and thus higher intensity in the G-band. For more extended flux-concentrations, the temperature at optical

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depth unity is lower than in the surroundings and we get a low intensity except at the edges where the radiation from the sides may penetrate and heat the plasma enough.

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