Modern Solar Facilities – Advanced Solar Science, 1–4
F. Kneer, K. G. Puschmann, A. D. Wittmann (eds.)

Magnetic properties of G-band bright points

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Abstract. Bright points (BPs) visible in the G band at 430 nm are commonly used as tracers of magnetic fields, indicating the location of kG flux concentrations. To study the actual magnetic properties of G-band BPs, we took observations in 2003 and 2005, employing simultaneously a speckle setup in the G band and vector spectropolarimetry to derive the magnetic field vector. From the analysis of the co-aligned polarimetric data we find that the BPs show a broad range of field strengths, magnetic fluxes, and field inclinations. Many G-band BPs are not co-spatial with the central part of the nearby flux concentrations. Even at the small heliocentric angle of only 12 degrees, the BPs appear projected on adjacent granules, whereas the magnetic field is concentrated in the intergranular lanes. Our findings support the view that the G-band BPs are a result of the "hot wall effect". The downward shift of the optical depth scale in the presence of magnetic fields allows to see deeper and hotter layers in the hot granules *next* to the field concentrations, where CH dissociates. Thus, information drawn from imaging observations of BPs has limited use for an investigation of the actual variation of the magnetic field structure, when the BPs are not co-spatial with the central part of the flux concentrations.

1 Introduction

The solar spectrum around 430 nm shows numerous spectral lines. Many of them are due to absorption by the CH molecule, which forms at low temperature. Images of the photosphere taken with a broadband interference filter in the G band show isolated brightenings located inside and near the intergranular lanes with high contrast to their surroundings. It was found that these bright points (BPs) are caused by the presence of strong magnetic field concentrations. Several authors found the BPs to be co-spatial with the flux concentrations, e.g., Berger & Title (2001). However, BPs are only indirect tracers of the field. The presence of the field leads to a downward shift of the optical depth scale due to the evacuation of the flux concentration. In the deeper layers with higher temperature CH dissociates, and hence, the intensity in the G band increases due to the disappearance of the molecular spectral lines. Similar effects take place in the CN band at 388 nm (Zakharov et al. 2005), whereas the BPs visible in chromospheric lines like Hα or Ca II H and K also indicate magnetic fields (Leenaarts et al. 2006), although their origin is probably different. At present, there is an ongoing discussion on which tracer is best suited for the detection of magnetic fields (Zakharov et al. 2005; Leenaarts et al. 2006; Uitenbroek & Tritschler 2006), with Sánchez Almeida (2000) even claiming that indirect tracers are to be preferred over the direct measurements of the field via the Zeeman effect. However, none of the observational studies

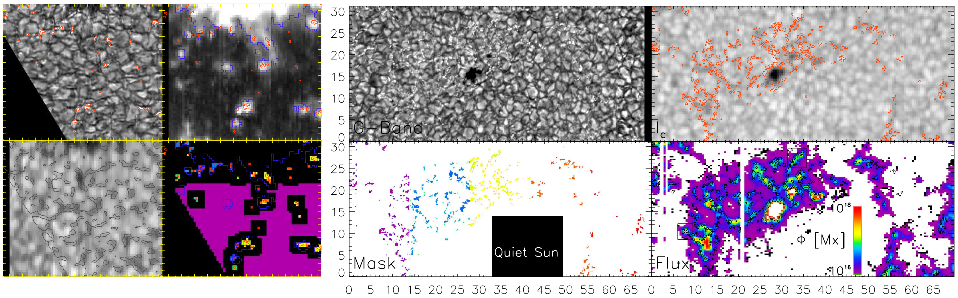

Figure 1. *Left, counterclockwise*: intensity in G-band, intensity at 1.5 μm, mask, polarization degree; 2003. *Right, counterclockwise*: intensity in G-band, mask, magnetic flux, intensity at 1.5 μm; 2005. Tickmarks are in arcsec.

carried out so far combined the simultaneous measurement of G-band intensities (as a proxy of magnetic fields) and vector Stokes polarimetry (for a direct measurement). In this contribution, we present the results of simultaneous G-band proxy magnetometry and vector spectropolarimetry to investigate the relation between G-band BPs and magnetic fields in the solar photosphere.

2 Observations & data analysis

For the present study we employ two data sets, taken in 2003 and 2005. On August, 9, 2003, we observed a region close to the sunspot NOAA 10425 from 09:36 to 10:34 UT with the Tenerife Infrared Polarimeter (TIP, Martínez Pillet et al. 1999) at 1.5 μm and the POlarimetric LIttrow Spectrograph (POLIS, Beck et al. 2005) at 630 nm attached to the Vacuum Tower Telescope (VTT) on Tenerife. The same area, located at a heliocentric angle of 27 degrees, was observed by the Dutch Open Telescope (DOT) on La Palma. The section shown in the left panel of Fig. 1 was scanned in total 8 times. On 11 October 2005 between UT 10:35 and 10:58, we used TIP together with a speckle channel in the G band at the VTT to observe a network region close to a pore at a heliocentric angle of 12 degrees south-west of the disc center. In both cases the same data analysis was performed: the G-band data were speckle reconstructed and spatially aligned to the polarimetric data; a mask with locations of BPs was derived from the G-band intensities by hard thresholding ($I > 1.2 \cdot I_c$), and the polarization profiles were inverted with the SIR code (cf. Bellot Rubio & Beck 2005).

3 Results

3.1 Statistics of bright point properties

A statistical analysis of the magnetic properties of BPs in the 2003 data (see also Beck et al. 2006) allows us to support the magnetic nature of BPs: more than 90% of the BPs are co-spatial with significant polarization signal within 1″, which corresponds to the spatial resolution of the polarimetric data of 2003. In the data taken in 2003, the BPs show redshifts of ~ 400 m/s inside the magnetic flux. The G-band intensity increases slightly with field strength and slightly decreases for large fluxes. The BP intensity scales strongly with the inclination

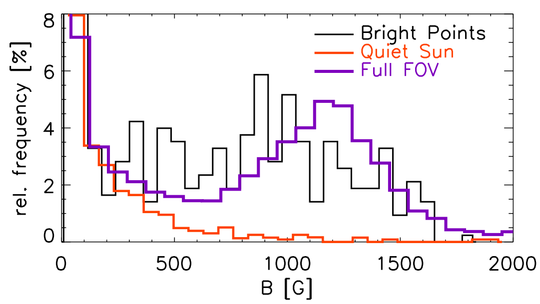

Figure 2. Histogram of field strength of quiet Sun, BPs, and the remaining FOV in the 2005 data.

of the field with respect to the line of sight. For the 2005 data, the field strength associated with BPs ranges from 0 to about 1.5 kG with a uniform distribution and no preferred value (cf. Fig. 2). The BP fields below ~0.5 kG are presumably due to the erroneous inclusion of the hot centers of granules into the BP mask; the BP field distribution is identical to that of the quiet Sun within that range. The very conspicuous peak at 1.3 kG in the distribution of the full field of view (FOV), which is due to the network fields, is completely absent for the BPs. This indicates an intrinsic difference between the network and the BP fields. Together with the large range of variation of BP parameters in the 2003 data, this casts some doubt on the general view that every BP corresponds to a stable kG flux tube.

3.2 Single cases

The G-band data of 2005 were taken at the VTT, whose 70-cm primary mirror is a factor 1.55 larger than that of the DOT. The spatial resolution thus is significantly better than that of the 2003 observations. A closer inspection of the three examples shown in Fig. 3 reveals the reason why the field strength distributions of BPs and network regions differ: there is a slight offset in the locations of BPs and flux concentrations. One finds that the intergranular lanes (IGLs) in the G-band and infrared continuum intensity are co-spatial within the alignment accuracy of about $0\farcs5$, and that the magnetic flux is concentrated in the IGLs. The BPs however are not co-spatial with the flux concentrations, but flank them on either one (3rd example) or two (2nd example) of their sides. In the 3rd example it can also be clearly seen that the brightening appears projected onto the center side of a granule, even at the small heliocentric angle of 12 degrees.

4 Conclusions

G-band BPs are widely used as tracers of magnetic fields and are generally assumed to indicate strong concentrations of magnetic flux with kG fields. In Beck et al. (2006) we demonstrated that at the locations co-spatial with BPs various field configurations are found. Here we have only used the field strength distribution as an example. Even if nearby network fields show preferentially field strengths of kG or more, the BPs show a uniform field strength

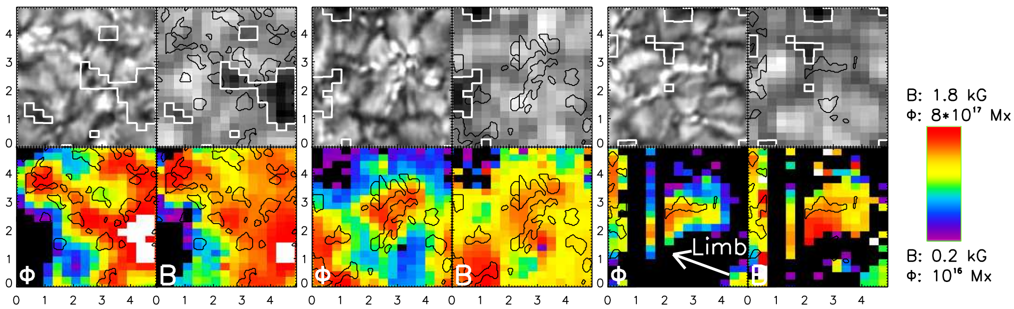

Figure 3. Enlarged sections of the data of 2005. *Clockwise*: intensity in G band, intensity at 1.5 μm, field strength, magnetic flux. White contours outline the darkest intergranular lanes in the infrared intensity, black contours BPs in the G band. Scales are in Mm.

distribution ranging from 0 to 1.5 kG. We suggest that the reason for this discrepancy is the actual location of the BPs relative to the fields: the BPs are not co-spatial with the nearby flux concentrations, but are in many cases slightly displaced.

We suggest that the generation of BPs by the magnetic field strongly depends on geometrical effects. The line of sight has to penetrate to deep *and* hot layers through a shift of the optical depth scale, to reach plasma, where enough CH molecules are dissociated to produce a significant line weakening. An accurate treatment of BPs and their relation with magnetic fields thus requires at least a two-dimensional model of flux concentrations inside IGLs. The multitude of different types of spatial structures ("ribbons", "crinkles", or "flowers") found in recent high-resolution observations by Berger et al. (2004) may well be due to the same mechanism: the structure of the magnetic fields (topology, field strength, flux) and their appearance when viewed from different directions. We conclude that BPs in the G band have a limited use as tracers, as they miss weaker flux concentrations and only indirectly reflect the properties or temporal evolution of the central part of the flux concentrations.

Acknowledgements. This work was supported by the DFG under grant SCHL 514/2–3, and by the Spanish MEC under *Programa Ramón y Cajal* and project ESP2003-07735-C04-03. The DOT is operated by Utrecht University at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias (IAC). The VTT is operated by the Kiepenheuer-Institut für Sonnenphysik at the Spanish Observatorio del Teide of the IAC.

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