Solar Polarization 4
ASP Conference Series, Vol. 358, 2006
R. Casini and B. W. Lites

Polarimetric Observations of the Formation of a G-Band Bright Point

C. Beck,[a] W. Schmidt,[a] L. R. Bellot Rubio,[b] R. Schlichenmaier,[a] P. Sütterlin,[c] and B. W. Lites[d]

[a]*Kiepenheuer-Institut für Sonnenphysik, Schöneckstrasse 6, D-79104 Freiburg, Germany*

[b]*Instituto Astrofísica de Andalucía (CSIC), Apdo. 3004, E-18080 Granada, Spain*

[c]*Sterrekundig Instituut, P.O. Box 80000, NL-3508 TA Utrecht, The Netherlands*

[d]*High Altitude Observatory, National Center for Atmospheric Research,*[1] *P.O. Box 3000 Boulder, CO 80307-3000, U.S.A.*

Abstract. We investigate the kinematic and magnetic properties of G-band bright points in the moat of a regular sunspot. The analysis is based on vector polarimetric measurements made at the German Vacuum Tower Telescope in visible (630 nm) and infrared (1565 nm) spectral lines, complemented by high-resolution filtergrams in the G-band at 430.6 nm and the core of the Ca II H line at 396.7 nm from the Dutch Open Telescope. The spectro-polarimetric data has been inverted to derive the magnetic field properties of the observed region. We witness the formation of a G-band bright point from a patch of diffuse flux with an initial field strength of 0.4 kG. The magnetic field strength increases to 0.9 kG in the course of several minutes, accompanied by a downflow of magnetized plasma. A few minutes after the field intensification, a G-band bright point is seen at the location of the flux concentration. The formation of the bright point shows the signatures of convective collapse.

1. Introduction

Imaged through a narrow-band filter in the G-band (around 430 nm), the solar surface shows many small-scale isolated brightenings called *G-band bright points* (GBPs). It is commonly believed that these features indicate the presence of strong magnetic fields. The lower density inside magnetic elements allows to see deeper layers of the solar atmosphere, where the temperature is higher. At those temperatures, CH molecules dissociate, leading to reduced absorption (i.e., a brightening) in the G-band. However, only strong magnetic field concentrations ($B > 0.5$ kG) show up as GBPs.

The formation of flux concentrations is due to two processes. The converging flows of supergranules accumulate flux at the edges of supergranular cells. This so-called flux expulsion intensifies the magnetic field up to equipartition values. A second process is needed to reach kG fields, namely convective collapse (Spruit 1979). A fast evacuation of a flux concentration by accelerated

[1]National Center for Atmospheric Research is sponsored by the National Science Foundation.

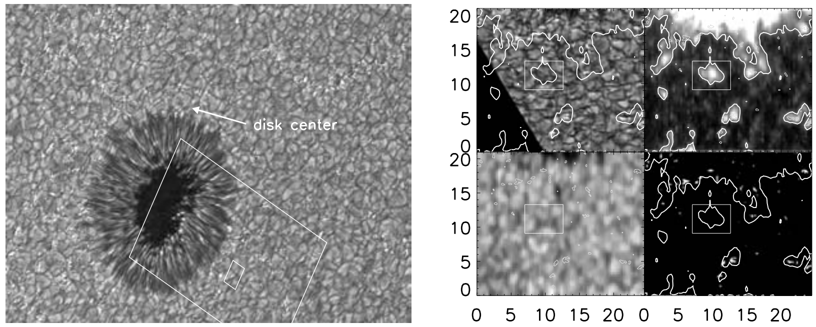

Figure 1. *Left:* G-band image from the DOT displaying the sunspot and the surrounding moat. The large rectangle outlines the FOV of the instruments at the VTT, the small inlet the area examined. *Right:* Lower part of the FOV at the VTT. Clockwise, starting from upper right: circular polarization signal, difference intensity, continuum intensity at 1565 nm, G-band intensity.

downflows reduces the internal pressure. An increase in B ensues to maintain mechanical equilibrium. The convective collapse has been found to happen in 2D simulations (Grossmann-Doerth, Schüssler, & Steiner 1998), but it remains an elusive observational target because of the short time scale of the process. Indeed, only few instances of observed convective collapse have been reported up to now (Sigwarth et al. 1999; Bellot Rubio et al. 2001). Here we present spectro-polarimetric measurements of the formation of a GBP associated with an intensification of the field up to 0.9 kG and strong downflows.

2. Observations and Data Analysis

The sunspot NOAA 10425 was observed on August 9, 2003 between 9:36 and 10:34 UT with the two spectro-polarimeters of the German Vacuum Tower Telescope (VTT) at the Observatorio del Teide: the Tenerife Infrared Polarimeter (TIP; Martínez Pillet et al. 1999) and the Polarimetric Littrow Spectrograph (POLIS; Beck et al. 2005). Both instruments were operated simultaneously. The same sunspot, located at an heliocentric angle of 27°, was observed from 8:25 to 11:58 UT with the Dutch Open Telescope (DOT) at the Observatorio del Roque de los Muchachos. TIP and POLIS were used to measure the Stokes profiles of near-infrared and visible spectral lines with different magnetic sensitivities (Fe I 1564.741 nm, Fe I 1564.852 nm, Fe I 1565.287 nm, Fe I 630.150 nm, Fe I 630.249 nm, Fe I 630.346 nm, Ti I 630.375 nm). Scanning in steps of 0.″35 was performed using the tip-tilt mirror of the correlation tracker system. The integration time per step was 6 s. Repeated raster scans covering 24.5 arcs (70 steps) were taken at a cadence of about 7 minutes.

DOT's data consist of speckle-reconstructed filtergrams in the G-band at 430.5 ± 0.5 nm, blue continuum at 432.0 ± 0.3 nm, and Ca II H at 396.8 ± 0.06 nm, with a cadence of 1 min. Information on the image processing can be found in Sütterlin, Bellot Rubio, & Schlichenmaier (2004). Figure 1 displays the fields of view (FOV) at the DOT and the VTT, for the first repetition of the scan.

To have co-spatial and co-temporal maps, the data from the VTT and the DOT have been aligned carefully by a multiple-step procedure. The maximum

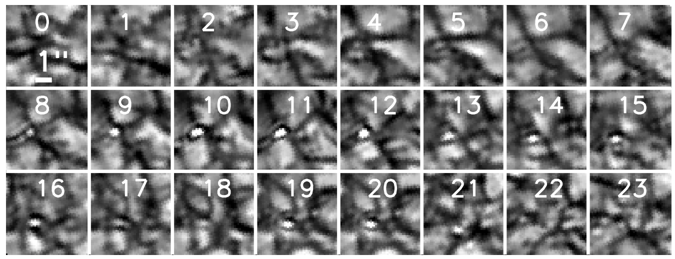

Figure 2. Temporal evolution in the G-band images from the DOT with 1 min cadence. The sides of each square are 5.″3. The BP appears at $t = 8$ min.

time difference between co-spatial points is 30 s, the maximum spatial displacement is estimated to be about 0.″35. In order to identify bright points, the G-band and blue continuum images are normalized in mean intensity and subtracted. GBPs are then identified as regions that exceed a certain threshold in the difference images (cf. Fig. 1).

The VTT measurements have been used to compute the average total polarization signal, $p = \int (Q^2 + U^2 + V^2)^{1/2} \, d\lambda$, of the four strongest lines (630.15 nm, 630.25 nm, 1564.85 nm and 1565.29 nm). Additionally, the Stokes profiles have been inverted simultaneously using the SIR code (Ruiz Cobo & del Toro Iniesta 1992), if the polarization level was above a given threshold. A model atmosphere consisting of a magnetic and a field-free component was used to determine the magnetic field vector and the line-of-sight (LOS) velocity.

The area of interest for the BP formation is located half-way between the outer penumbral boundary and the moat edge (cf. the small rectangle in Fig. 1).

3. Formation of a Bright Point

Figure 2 shows the evolution of the G-band intensity in the area marked with small rectangles in Fig. 1. The cadence is 1 min. The BP appears abruptly at $t = 8$ min, with no trace of it in the previous image, and remains visible for around 13 min afterwards. According to the inversion of the polarimetric data from the VTT (cf. Fig. 3), with 7 min cadence, the BP formation is the result of a longer concentration process. At $t = 0$ min, a relatively large polarization patch is seen with only weak fields (0.4 kG), but no associated G-band BP. At the lower border of the patch, downflows of up to 2 kms^{-1} are detected, both at $t = 0$ min and, more localized, at $t = 7$ min. The field strength at the position of the downflows increases to around 0.8 kG. At $t = 14$ min, a BP is visible in the DOT data. At its location, a small field concentration with 0.9 kG and high magnetic flux is seen. The remainder of the initial flux patch in the upper part of the area stays diffuse with low field strength and no G-band enhancement.

4. Discussion and Conclusions

The formation of this particular BP is characterized by two phases: a gradual increase of field strength over several minutes (at least 8 min), followed by the rapid appearance of the BP in less than 1 minute. Our results support the concept of convective collapse as the process that produces strong magnetic fields

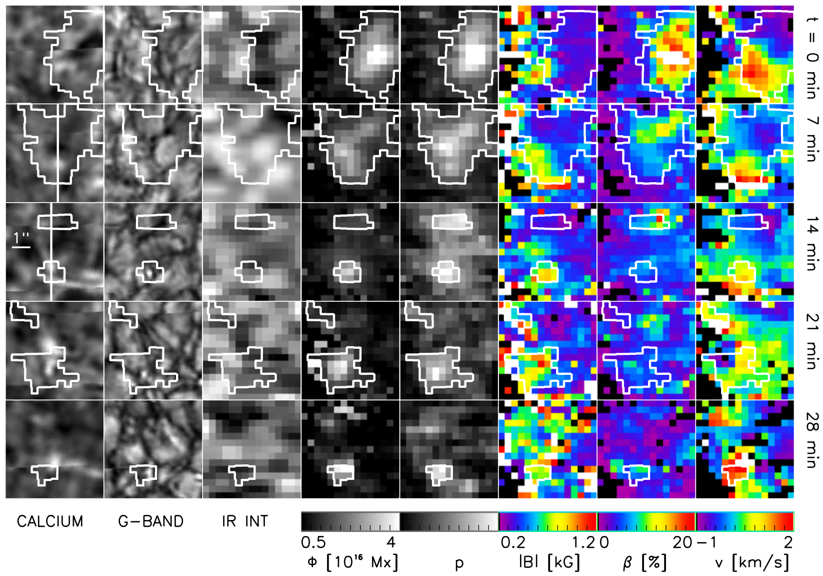

Figure 3. *Left to right*: DOT Ca line-core, DOT G-band, IR intensity, unsigned magnetic flux (Φ), average total polarization (p), field strength (B), fill fraction (β), and LOS velocity in the magnetic component (v; positive values represent downflows), with a cadence of 7 min. White contours outline areas where p is larger than 0.021. Each box has a size of 5.″3 square. The IR intensity map at $t = 7$ min is smoothed to show the accuracy of the alignment.

in the solar photosphere from an already formed concentration, in agreement with Bellot Rubio et al. (2001) or the numerical simulations of Grossmann-Doerth et al. (1998).

Acknowledgments. Part of this work is funded by the Deutsche Forschungsgemeinschaft (Schl 514/2-3), and by the Spanish Ministerio de Educación y Ciencia (Programa Ramón y Cajal and ESP2003-07735-C04-03). The VTT is operated at the Observatorio del Teide (Tenerife) by the Kiepenheuer-Institut für Sonnenphysik. The DOT is funded by Utrecht University, The Netherlands (NL) Graduate School for Astronomy, and the NL Organization for Scientific Research, NWO. P. Sütterlin's research is supported by NWO.

References

Beck, C., Schmidt, W., Kentischer, T., & Elmore, D. 2005, A&A, 437, 1159

Bellot Rubio, L. R., Rodríguez Hidalgo, I., Collados, M., Khomenko, E., & Ruiz Cobo, B. 2001, ApJ, 560, 1010

Grossmann-Doerth, U., Schüssler, M., & Steiner, O. 1998, A&A, 337, 928

Martínez Pillet, V., Collados, M., Sánchez Almeida, J., et al. 1999, in ASP Conf. Ser. Vol. 183, High Resolution Solar Physics: Theory, Observations, and Techniques, ed. T. R. Rimmele, K. S. Balasubramaniam & R. R. Radick (San Francisco: ASP), 264

Ruiz Cobo, B., & del Toro Iniesta, J. C. 1992, ApJ, 398, 375

Sütterlin, P., Bellot Rubio, L. R., & Schlichenmaier, R. 2004, A&A, 424, 1049

Sigwarth, M., Balasubramaniam, K., Knölker, M., & Schmidt, W. 1999, A&A, 349, 941

Spruit, H. C. 1979, Solar Phys., 61, 363