Chapter 4

On the Morphological Relationship Between G-Band and Ca II K Network Bright Points

4.1 Introduction

The solar surface exhibits very high contrast bright points of size $\sim 0.2$ arc sec in short exposure filtergrams obtained with an interference filter of $\sim 10$ Å passband centered at 4305 Å from the best sites under good seeing conditions (Berger et al., 1995; Kitai and Muller, 1984; Muller and Roudier, 1984; Muller, 1985). This wavelength region of the solar spectrum was originally designated by the letter 'G' by Fraunhofer and is currently known as 'G-band'. It is densely populated with absorption lines of the CH radical and a few elements. It is formed in the upper photosphere (Zirin, 1989). It is observed (Berger and Title, 1996) that the bright points occur without exception on the sites of isolated magnetic flux concentrations. It is believed that (Title et al., 1992; Keller, 1992; Yi and Engvold, 1993; Berger et al., 1995) the observed bright points can be associated with 'thin flux tubes' (Spruit, 1976) which have become a standard
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theoretical model for the small scale magnetic flux in the solar photosphere. Berger and Title (2001) have investigated the relationship between the bright points of the G-band and the photospheric magnetic field, using co-temporal observations at G-band, Ca II λ 3933 K line, Fe I 6302 Å magnetograms and 6563 Å Hα and identified a class of G-band bright points that appear on the edges of bright, rapidly expanding granules and are non-magnetic (at the flux limit). Recently, Steiner, Hauschildt and Bruls (2001) compared the theoretical G-band spectrum, computed on the basis of a realistic atmosphere for a magnetic flux tube with that from the quiet Sun surroundings and found that the former has significantly high intensity throughout the spectrum because it is hotter than the quiet Sun and the difference is more pronounced within the range of CH band lines. They attributed the enhanced contrast in the G-band to the reduction in the abundance of the CH radicals through dissociation in the deep photospheric layers of the hotter flux-tube atmospheres compared to the quiet Sun surroundings; this process weakens the CH lines within the flux tube and allows more of the continuum to shine through the thinned forest of CH lines.

The lower (h < 1500 km) and middle (1500 ≤ h ≤ 2250 km) chromosphere of the Sun reveals a conspicuously bright network of cells of size ~ 33000 km when observed in the K line of Ca II (Title, 1966; Foukal, 1990). The walls of the cells are outlined by bright flocculi. The cells are well defined except for occasional gaps in the cell boundaries and are present everywhere in the disk. The cellular pattern is lost near the limb but bright flocculi survive. Near the active region, the cell is completely filled with bright material and the cell forms the part of chromospheric faculae. It is found that the chromospheric network is closely associated with the photospheric network which in turn is highly associated with the distribution of the longitudinal magnetic fields at the photosphere (Chapman and Sheeley, 1968). The origin of the chromospheric network lies in supergranulation, a cellular pattern of horizontal motions in the upper photosphere covering most of the quiet Sun. The supergranulation is closely related to both the chromospheric and the photospheric networks. It is believed
that the horizontal currents associated with each supergranule sweep the magnetic fields to its boundaries and these magnetic fields cause excess heating, which, in turn causes the bright chromospheric network (Bray and Loughhead, 1974). It is also known that supergranular flows do not always fill the cell, as evidenced by incomplete cell boundaries.

The Network Bright Points (NBPs) of the photosphere (Stenflo and Harvey, 1985; Muller, 1985) have been identified to exhibit high contrast in violet band head of CN radical (Chapman, 1970) and in the G-band (Muller, 1985). It is also known that the NBPs are closely associated with the coarser calcium network bright points (Chapman and Sheeley, 1968; Muller, 1985). However, it is puzzling to note that while the G-band bright points are distributed all over the disk (Berger et. al, 1995; Muller, 1985), the chromospheric network bright points are preferentially present along the boundaries of the network cells. In this Chapter, we try to address the following question: What is the physical phenomenon that dictates the preferential heating at the chromospheric levels, though the sources from below - if assumed to be the G-band bright points - are distributed all over the disk? To find an answer to this question, we performed near-simultaneous observations at the G-band and the K line of Ca II at three different regions of the solar surface. In the following Sections, we describe the details of our observations and analyses, and discuss the results in the light of the aforementioned question.

4.2 Observations

A quiet Sun region, a plage region and the NOAA AR8923 were observed near simultaneously at the K line of Ca II ($\lambda = 3933$ Å) and at the G-band of CH radical ($\lambda = 4305$ Å) on 24th, 25th and 26th March 2000 respectively. using the 76 cm Dunn Solar Telescope of the Sacramento Peak Observatory (Evans, 1967). Sunspot, New Mexico, USA. The selected region of the primary image was collimated using a telecentric lens
Table 4.1: Characteristics of observations performed at Sacramento Peak. Observations were performed at $\lambda = 430.5 \pm 5$ (G-band) and $\lambda = 393.3 \pm 15$ (Ca II K) near-simultaneously. First column represents different series of data recorded. Second and third columns represent the date and Universal Time of the observations. $\Delta t$ is the exposure time. $\theta$ is the heliocentric position angle of the observed region. $M$ is the number of frames recorded per series. Plate scale for G-band data is 0.07396 arc sec per pixel and for Ca II K data is 0.09343 arc sec per pixel. QR - Quiet Region. RAR - Remnant Active Region (Plage Region), AR8923 - NOAA Active Region 8923.

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of focal length 1500 mm. Another telecentric lens of focal length 1553 mm formed the final image, with a plate scale of 3.89 arc sec per mm. A 50/50 cube beam splitter was placed in the path of the beam immediately after the image forming lens. A G-band filter with 10 Å passband was placed in one beam and a Ca II K filter with 3 Å FWHM was placed in the other. The 16 bit Pixel Vision camera consisting of 512 by 512 square pixels of size 24 micron was used to record a few sequences of images at the K line of Ca II at the rate of one frame per 2.7 s. The 10 bit Thompson camera consisting of 640 by 640 square pixels of size 19 micron was used to record a few sequences of images in the G-band at the rate of one frame per 2.7 s. The field-of-view was 47.8354 by 47.8354 arc sec with 0.09343 arc sec per pixel for the images recorded in the K line and 47.3371 by 47.3371 arc sec with 0.07396 arc sec per pixel for the images recorded in the G-band. The theoretical resolution of the telescope was 0.13 arc sec at the K line of Ca II and 0.14 arc sec at the G-band. Table 4.1 indicates finer details of the observations.

### 4.3 Analysis

Since the exposure time was more than 20 ms, the recorded G-band bright points were smeared in most of the frames. The images were recorded with at the rate of 2.7 s per frame. Assuming the value of sound speed as 10 km per second, the life time of the features is \( \sim 10 \) s. Thus, we could not use more than 3 consecutive frames for speckle reconstructions. Moreover, because of poor seeing conditions, the images were completely blurred on many occasions. Thus, we could not perform analysis of long time sequences. Instead, we selected three consecutive best images using our frame selection method (Section 2.7, Page 29) and obtained a speckle reconstruction for each region (AR8923, plage and quiet Sun regions). Figures 1.1 and 4.2 represent the reconstructed images of a plage region in Ca II K line and G-band respectively. Figures 4.3 and 1.1 represent the reconstructed images of a quiet Sun region in Ca II K
and G-band respectively. Figures 4.5 and 4.6 represent the reconstructed images of the AR8923 in Ca II K and G-band respectively. The images recorded in G-band were rotated, re-sampled and shifted (using `sushift.pro` mentioned in Chapter 3) to match the Ca II K images. The required amount of shifts were estimated up to half a pixel accuracy by cross-correlating the US Air Force target pattern recorded at Ca II K line and G-band.

In the absence of continuum images, we adopted the following procedure to extract the G-band bright points from the reconstructed images:

- We used a 'blob finding' algorithm (Tomaita, 1990; Berger et al., 1995) to extract bright blobs from the reconstructed image.

- We then performed an un-sharp masking to sharpen the edges of the blobs.

- We then obtained a binary image by setting the intensity values of all the pixels above a 'hard' threshold to unity and the rest to zero. We selected the threshold using the following criteria: We obtained an histogram of the un-sharp masked image and empherically selected a value (1.25 for plage region, 0.4 for quiet Sun region, and 0.5 for the AR8923) at the right side of the peak. We found the average intensity of of all the pixels having value greater than the selected value minus one standard deviation as the threshold value.

- We then 'opened' (Haralick, Sternberg and Zhuang, 1987) one copy of the binary image using dilation and erosion processing with 5 pixel kernel to reduce the large residual granulation noise. We subjected another copy of the binary image to a median filter to reduce the noise due to isolated peaks (salt and pepper noise).

- Finally we created a binary bright point map by performing a Boolean 'OR' operation of the two copies of the binary images. Figures 4.7, 4.8 and 4.9 show the binary bright point maps of the plage region, quiet Sun region and the AR8923 overlaid on the corresponding G-band images.
4.4 Results and Discussion

In what follows, we present a detailed comparison of the processed image of Ca II K and the G-band image for the three different regions. We refer to the features in the Figures by their co-ordinates. For example, [0,0] represents lower left corner of the image; [45,45] represents upper right corner of the image. A feature covering more than a single point in the image is represented by the coordinates of its lower left corner and the upper right corner. We use the term GBP to denote G-band bright points. The Ca II K images (Figures 4.1, 4.3, and 4.5) printed on tracing sheets, have been placed on top of the binary bright point maps overlaid on the corresponding G-band images (Figures 4.7, 4.8 and 4.9), to help the readers to clearly see the points mentioned below.

*Plage region* (Figures 4.1 and 4.2):

1. At the outset, we find a striking correlation between the large scale distribution of the GBPs and the bright network of the Ca II K line.

2. The GBPs seem to be shifted horizontally by 0.5 arc sec with respect to the Ca II K network bright points. Since we have aligned the images as accurately as possible, we can not attribute this offset (∼ 5 pixels) to alignment errors. However, as mentioned in Section 4.2, the field-of-view of the G-band images is less than that of Ca II K images by 0.5 arc sec. This could perhaps be the reason for the spatial mismatch. At the same time, we also find a GBP aligned with an isolated brightening in Ca II K image ([1,3] in Ca II K image). This implies that the error due to the difference in the field-of-view is distributed throughout the image.

3. In a majority of the cases, for a brightening in Ca II K image, there is an associated GBP.

4. There are a few brightenings in Ca II K images, for which there are no associated GBPs. For example, brightenings in Ca II K images at [9.35], [10.37], [15.37], [4.5.13: 6.5.13] do not have associated GBPs that can be clearly identified.
Figure 4.1: Image reconstructed from three best frames of a plage region in Ca II K line.
Figure 4.2: Image reconstructed from three best frames of a plage region in G-band.
Figure 4.3: Image reconstructed from three best frames of a quiet Sun region in Ca II K line.
Figure 4.4: Image reconstructed from three best frames of a quiet Sun region in G-band.
Figure 4.5: Image reconstructed from three best frames of NOAA AR8923 in Ca II K line.
Figure 4.6: Image reconstructed from three best frames of NOAA AR8923 in G-band.
Figure 4.1: Image reconstructed from the final transmitted image region. H-K deconvoluted G-band image.
Figure 4.7: G-band binary map of a plage region overlaid on the corresponding reconstructed G-band image.
Figure 4.3: Image reconstructed from three best frames of a quiet Sun region in Ca II.

K-patterned G-band image
Figure 4.8: G-band binary map of a quiet Sun region overlaid on the corresponding reconstructed G-band image.
Figure 4.5: Image reconstructed from three best frames of NOAA AR8923 in Ca II K line. Constructed G-band image.
Figure 4.9: G-band binary map of the NOAA AR8923 overlaid on the corresponding reconstructed G-band image.
5. Relatively darker regions in Ca II K images have associated GBPs that are either co-spatial or offset by 3-6 pixels.

Quiet Sun Region (Figures 4.3 and 4.4):
1. The conspicuous network pattern in the Ca II K image ([7,16; 17.5,27]) has associated GBPs; but these GBPs are spread diffusely (unlike the dense clustering in plage region).
2. The brightening in the lower right corner of the Ca II K image ([41,3.5; 43.7]) does not have an associated GBP; The brightening at [43,32; 45,34] has got a tiny associated GBP at its edge; that is, at [45,32] in G-band image. In general, the brightenings on the right hand side edge of Ca II K image do not have associated GBPs.
3. Not all the brightenings in Ca II K image have associated GBPs.
4. Relatively darker regions of Ca II K image have associated bright points which are clearly evident; but in a few cases, this tendency is not clear.

AR8923 (Figures 4.5 and 4.6):
1. All the brightenings in Ca II K image have associated GBPs. The spatial density (the number of bright points per square cm) appears to be proportional to the degree of brightenings; that is, the higher the intensity in Ca II K image, the denser the distribution of bright points.
2. Here again, GBPs occur near the edges of Ca II K brightenings: at a few places GBPs are co-spatial with the Ca II K brightenings.
3. Relatively darker regions of Ca II image have got associated GBPs.
4. There is an isolated brightening in Ca II K image ([25.5,17.5]) for which there is no associated GBP.

In general, we find that the GBPs are densely clustered in the plage region than in quiet and the AR8923. However, since our exposure time was large, most of the GBPs could have been washed out and this could be one of the reasons for the absence of GBPs for some brightenings in Ca II K. This also implies that only those GBPs that are relatively larger in size and withstood the atmospheric blurring have been identified.
Our G-band binary map also contains bright points that are relatively bigger. These could be residuals of granulation. It should also be remembered that our bright point maps are vulnerable to the threshold value. The relatively higher density of GBPs at the locations of brightenings in Ca II K images implies that these GBPs must be of magnetic origin (as the Ca II network has been popularly known as poor man's magnetogram; Bray and Loughhead, 1974). Thus, there could be two varieties of GBPs: those closely associated with the photospheric magnetic field distribution and those present everywhere. Even these intra-network bright points could be associated with the intra-network Ca II K bright points (Sivaraman and Livingston, 1982), not resolved in the present data. The bright points which are present everywhere are swept by the horizontal motions in the supergranulation to the boundaries and hence there is clustering. At the same time, GBPs are continuously formed at all locations and hence at any given time we get to see the GBPs everywhere.

4.5 Summary

We performed speckle observations of a quiet Sun region, a plage region (remnant active region) and the NOAA AR8923 near-simultaneously at G-band and Ca II K with an exposure time of 50-70 ms and a frame rate of one frame per 2.7 seconds. We selected three consecutive best images from the sequences of images of the aforementioned regions using our frame selection scheme and obtained a reconstruction in each case. We obtained a binary map of the GBPs from the reconstructed G-band images using image segmentation techniques and then studied the morphology of the Ca II K and GBPs. We suggest that perhaps there could be two varieties of the GBPs: those present everywhere and those closely associated with the magnetic field distribution in the photosphere; the former are swept by supergranular horizontal motions to the boundaries and cause heating at the upper layers; continuous formation of GBPs at all locations is responsible for their uniform distribution at any given time. The intra-network GBPs are perhaps associated with the Ca II K bright points, not resolved in the present data.