DISCRETIZATION EFFECTS ON THE SIZE DISTRIBUTION OF MAGNETIC BRIGHT POINTS

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Abstract. We developed an automated identification algorithm for magnetic bright points to derive the size distribution of MBPs in a quiet region near solar disc centre. For this purpose two different data sets from the Hinode/SOT mission were used. The first data set had a pixel spatial sampling of 0.108 arcsec/pixel, whereas the second data set had the full achievable spatial sampling of 0.54 arcsec/pixel. We found, that the size distribution shifted from a mean value of 218 km in diameter to a smaller value of about 166 km in diameter when the spatial sampling was higher. Therefore, we suggest that discretization effects play a crucial role for the study of small scale features. How the shift of the two distributions could be explained, and how a deeper insight into the discretization problem could be gained, is discussed.

Key words: pattern recognition - magnetic bright points - Hinode/SOT

1. Introduction

Magnetic Bright Points (MBPs) are small scale magnetic features in the solar photosphere. Other names for them are network bright points, as they were called earlier or filigrees if they are in a chain like formation. The size of MBPs is in the range of 100 to 300 km and the magnetic field reaches values of up to 1.2 kG. They are short living features (in the range of minutes) in the photosphere and located in intergranular lanes. MBPs appear at the
merging points of granules and show a complex life. They can merge and form groups but after a while they can split up again. MBPs can be identified hardly in magnetograms (because of their small scale) but it was shown by several authors (e.g. Ishikawa et al., 2007; Mehlretter, 1974 or Dunn and Zirker, 1973) that the magnetic field is correlated with the brightness in the so called G-band. The G-band comprises CH molecule lines centred around 430 nm. The increased brightness in the G-band is due to a decreased opacity (Steiner et al., 2001; Schüssler et al., 2003). In the G-Band there are also non magnetic brightenings i. e. on top of granules. MBPs together with these brightenings are called GBP's (G-band Bright Points).

2. Data

We used data of the SOT (Solar Optical Telescope, see Tsuneta et al., 2008) instrument aboard the Hinode mission (Kosugi et al., 2007). The Hinode spacecraft was designed and is operated by the Japanese Space Authorities in a cooperation with NASA and ESA. The SOT has a 50 cm primary mirror and consists of 3 scientific instruments: a spectropolarimeter, a narrow band instrument for preparation of magnetograms and dopplergrams, and a broad band device. The broad band device uses 6 different filters. Three filters (red/green/blue) are in the continuum range and three are line filters (G/Ca/Fe-band).

The data sets we studied were obtained by the Internet portal of the Hinode mission (for detailed information about the data archive see Matsuzaki et al., 2007). For our analysis run we downloaded 2 data sets of G-band images: The first was from 10th March 2007 from 0:16 to 5:59 UT recorded with a time resolution of about 30 seconds. The data show a region near disc centre (x-pos = −27.0 arcsec, y-pos = 100.6 arcsec). The images have a FOV (field of view) of 55.8 by 111.6 arcsec. The spatial sampling is 0.108 arcsec/pixel, which is not the best pixel resolution the Hinode/SOT instrument can deliver, but with the advantage of a larger field of view, i.e. more bright points should be detectable. The whole time series consists of 645 G-Band images taken by the broadband filter device of the SOT instrument. The second data set from 19th February 2007, 18:19 to 20:39 UT has a spatial sampling of 0.054 arcsec/pixel. It consists of 756 images recorded with a time resolution of 11 seconds. The FOV is smaller with 27.7 by 27.7 arcsec.
SIZE DISTRIBUTION OF MAGNETIC BRIGHT POINTS

Figure 1: On the left hand side, the normalized mean brightness and rms (root mean square) of data set one is plotted. On the right side, the same is plotted for data set two.

Both data sets were fully calibrated and reduced by the Hinode data reduction routines available under SSW (solar software). The normalized mean photospheric intensity and the RMS (root mean square) value for both time series are plotted in Figure 1. For the first data set, the mean photospheric intensity is slightly oscillating, correlated with the 98-min orbital revolution period of the satellite around Earth. The RMS of the image brightness decreases over time. This is most probably caused by a defocusing of the satellite (maybe due to thermal effects). Also in this RMS data, the periodicity of the satellite revolution is reflected. On the right-hand side, the same plots are shown for the second data set. Here the root mean square has no significant trend, but on the other hand the variance is larger. This is due to the fact that the FOV is only one eighth of that of the first data set, and therefore (from the statistical point of view) it should vary with a larger amplitude.


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3. The Algorithm

In this section, we briefly describe our algorithm for the identification of MBPs. For a detailed description we refer to Utz et al. (2009). Our algorithm comprises of three steps:

- Segmentation step:
  The segmentation algorithm is based on the idea of following the contours of the features from their brightest pixels down to their faintest in subsequent steps.

- Clean up step:
  This step is necessary to remove oversegmentation which occurs due to noise.

- Identification and analysis step:
  The right features are determined by a size criterion (Figure 2) and interesting parameters are then calculated.

An algorithm, which is already based on a multi level brightness approach for automated identification and pattern recognition, is the so called MLT algorithm of Bovelet and Wiehr (2001) or their newer MLT 4 version (Bovelet
and Wiehr, 2007). Our algorithm is similar to this algorithm, but differs in some points (see Utz et al., 2009).

4. Results and Discussion

Size Distribution  The size distribution was derived by measuring the area of each identified MBP in pixel. The criterion for size was chosen in such a way that only the brightest elements of the MBPs were counted (selected via a brightness threshold criterion; for details see the size definition paragraph below.). This area was then transformed to an equally sized circle. Therefore, the calculated data bins are not equally distributed in diameter. The size distribution obtained with our algorithm, with data set I, follows a normal distribution with the fit parameters $\sigma = 48$ km (standard deviation: describes the broadness of the distribution), $\mu = 218$ km (mean value of the distribution). It is shown in Figure 3 together with the size distribution for the second data set: $\sigma = 31$ km, $\mu = 166$ km. It is obvious that the increased spatial sampling causes a shift of the distribution to smaller values.

Size Definition  An important factor on the behaviour of the size distribution is the definition of size itself. We thought of at least 4 different ways (all having some pro and cons, see also Figure 4) for such a definition.

1) Cutting the features at an absolute brightness level (for example the mean photospheric brightness): this will have the advantages that it is well defined and easy to apply. On the other hand, it has the big disadvantages that features which are obviously bright point features (with regard to their surrounding) could be missed if they do not reach this absolute brightness level or significantly underestimated if they just exceed this level.

2) Another possibility would be assigning the size by a relative measurement between minimum and maximum brightness of the feature. This has the advantage that every feature gets a size, but the disadvantage that it is depending on the background, or say, surrounding. If a bright feature lies in a very dark intergranular region, it will be assigned a bigger size, than if the same feature would be situated in a brighter surrounding. Thus, the same feature could have different sizes depending on its surrounding.

3) The next possibility would be to assign the size by a threshold relative to the brightness maximum of each feature (e.g. cut every feature

Figure 3: Size distribution of MBPs gained by two data sets from the Hinode/SOT mission recorded with different spatial sampling. The distributions were fitted by Gaussians giving $\mu = 166$ km, $\sigma = 31$ km for data set II sampled with 0.054 arcsec/pixel (dashed histogram), and $\mu = 218$ km, $\sigma = 48$ km for data set I sampled with 0.108 arcsec/pixel (full line histogram), respectively.

at a brightness of 0.35 of the features maximum brightness). This has the disadvantage that the brightness of the features consists of two components. Firstly the brightness of the region if the feature not be there (say the intergranular brightness without magnetic field), and secondly the brightness of the feature which is added to this background level. As the intergranular brightness could change, also the maximum brightness of the feature and therefore the relative threshold could change, causing a change of the size of the feature for same features (with different background).

4) Finally, there is a fourth possibility, which we have chosen for our algorithm. We estimate the size by an absolute threshold down from the maximum brightness of the feature. This is relative to the background. So if the background intensity increases, the maximum brightness of the feature, and therefore the cutting level, will increase too. Thus, this definition does not rely on the background brightness, but only on the feature itself. The estimated size depends on two facts: firstly on the size of the brightness plateau, and secondly on the value of the brightness gradient. We believe that our definition could be applied quite optimally on perfect flux tubes in
Figure 4: This sketch illustrates 4 different ways of size definition. From top to bottom: size determination by 1) an absolute value, 2) a relative assignment between brightest and faintest, 3) a relative value down from the maximum brightness and 4) an absolute threshold down from the maximum brightness.
the sense that they have a diameter not much depending on the cutting level, because of their sharp brightness gradient. Therefore, it does not matter if we cut the flux tube at a certain brightness or a little bit above or below that level. On the other hand, if the features look like Gaussian distributions (say, have no constant diameter but a rather small brightness gradient) fainter features would be estimated larger. So the key question is now how the spatial intensity distribution of single features looks like. We think that today this can not be figured out with the achievable telescope resolutions. On the other hand, the telescope point spread function smears out features and degrades brightness slopes. Therefore, the true brightness slopes should be steeper and we think that the method is appropriate when compared to the pros and cons of the other methods.

**Discretization Effects** Figure 3 clearly shows that the size distribution is different for different spatial sampling. This behaviour is unusual, as one would expect the same distribution for oversampled images, if both exceed the telescope's limiting resolution. Hinode/SOT has a diffraction limit of about 0.2 arcsec. Therefore a sampling of 0.1 arcsec per pixel should be sufficient. But then an increase of the spatial sampling to 0.054 arcsec should not change the final result. Instead it can be seen that increasing the spatial sampling by a factor of two changes the distribution but does not yield smallest features of half size. We think the change of the distribution is mainly due to two effects.

The brightness of a pixel corresponds always to the averaged brightness of the underlying real feature. So if the resolution is decreased, the area over which the features got averaged, increases. Therefore, features, which are both small and faint, will not be detectable any more.

The broadness of the distribution could be explained by the fact that there will be always some wrongly mapping of the real sizes into a corresponding measured sizes. But as we have no uniform size distribution but more likely a Gaussian distribution, more features would be mapped wrongly from the centre to the wings of the distribution than vice versa. In the case of a lower resolution these mapping errors play even a more important role, and therefore this effect of broadening the distribution is increased.

How could we get more insight into this problem? A possible way would be to do Monte Carlo computer simulations by placing circles (MBPs) by
random with a given brightness on a black grid. Then calculate the averaged pixel values on this grid. Last but not least count the pixels which exceed a certain brightness threshold to measure the size of the circle. If one does this for different grids and different distributions of circle diameters, one could get a better insight into discretization effects in the analysis of small scale features in solar images.

Other Effects  The most important other effect which influences the size distribution is the instrument itself. Due to diffraction effects a telescope is acting like a low pass filter in the Fourier domain. Therefore, higher frequencies are damped more strongly than lower frequencies which causes smaller structures to be smeared out. A similar effect happens if the telescope is defocussed. The consequences are lower contrast and bigger sizes derived for small features. The influence of the telescope can be seen in Figure 3, where the size distribution, for the higher sampled data, starts to drop down at sizes of 160 km (This corresponds to the theoretical diffraction limit for Hinode/SOT G-band images). One could try to reconstruct the ”true” image before being altered by the modulation transfer function (point spread function in the Fourier domain). The problem is to derive the correct modulation transfer function. A second problem is, that the noise in the image gets amplified by reconstruction procedures. Another effect, which alters the image, and therefore the derived information, is stray light. Not only photons coming directly from the Sun, but also photons which were reflected on the inner side of the telescope, are counted by the CCD and contribute to the image (mainly to the image background, which is therefore not constant).

5. Conclusion

In this paper we shortly described our automated identification algorithm for small scale magnetic brightenings (MBPs). From the considerations above it is clear that there are many effects which contribute to the derived size distribution of small scale features. Such effects could and will falsify the outcome of every measurement. An interesting result is that more detailed information about small features could be gained by oversampling (the obtained distributions should be closer to the real distributions). Overall, the derived distributions agree in the range of uncertainties with earlier found
distributions. Berger et al. (1995) found (for a log-normal fit through their distribution) a modal value of 220 km with a SVST (48 cm Swedish Solar Vacuum Telescope/La Palma) data set. Bovelet and Wiehr (2003) found a value of 220 ± 25 km (45 cm Dutch Open Telescope data set) and in a newer research Wiehr et al. (2004) measured a value of 160 ± 20 km (1 m Swedish Solar Telescope) for their distribution.

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