LONG TIME VARIATIONS OF MAGNETIC BRIGHT POINTS OBSERVED BY HINODE/SOT

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Abstract. Magnetic bright points (MBPs) are manifestations of small-scale solar magnetic flux concentrations, best observable due to their high contrast in molecular bands like the G-band. Moreover, they are among the most interesting magnetic features to be studied in high spatial and temporal resolution in the solar photosphere. Their relevance for solar physics is not only given by their contribution to fundamental solar plasma physics on small scales but in addition due to their involvement in processes like the solar atmospheric heating problem (chromosphere and corona), their influence on granulation and hence the convective energy transport, as well as their contribution to the variations in total solar irradiance caused by their higher relative intensity.

In this ongoing study we focus on the long-time evolution of statistical parameters of MBPs over the solar cycle. Are parameters like the mean intensity, average size/diameter, and number of MBPs per unit surface element variable with time? If so, how do these parameters vary and is there a relationship to the solar cycle?

In the actual contribution we will discuss preliminary results regarding the variation of the number of MBPs with time. We saw a decrease in the number of MBPs for the first years of observation (2006 until 2011) with two distinct local minima in the years 2009 and 2011. After 2011 the number of MBPs is increasing again along with an increase in general solar activity (as seen by the number of sunspots, flares, and CMEs).

Key words: solar magnetic field - long-time variations - solar cycle - magnetic bright points (MBPs) - Hinode/SOT
1. Introduction

Among the most conspicuous solar features are sunspots. They have been studied for several centuries with first instrumental observations dating back to the times of Galileo Galilei. A cornerstone discovery was the finding that the number of sunspots varies over time with a period of roughly 11 years—the so-called activity or sunspot cycle. This was first described in the famous paper of Schwabe (1844, for a modern review see Hathaway 2010). In the following years more and more details about the sunspot cycle were revealed which lead to several famous sunspot “rules” such as Hale’s polarity law and Joy’s law about the tilting of sunspot groups (Hale et al., 1919). Furthermore it was established that sunspots are created by strong and extended magnetic fields (see Hale, 1908). Most of the obtained knowledge can be summarized in the form of one famous plot, the so-called butterfly diagram.

These facts give rise to the following questions: If there is a sunspot and activity cycle for large and extended magnetic fields, is there also such a long-time variation for small-scale solar magnetic fields? If so, what is the extent of such a variation and what parameters do vary?

A useful proxy for small-scale magnetic fields are so-called magnetic bright points (MBPs). First discovered and described in the 70’s of the last century (e.g., Dunn and Zirker, 1973), they regained a lot of interest in the recent years due to improved observational and simulational capabilities (e.g., Rieithmüller et al., 2014).

In the current contribution we wish to focus on the variation of the number of MBP’s over a period of almost 10 years, from the beginning of November 2006 until the end of August 2014, by analysing the synoptic data set of the Japanese/US/European Hinode mission (Kosugi et al., 2007). In the following chapter we will outline and describe in detail the used data. This is followed by the description of the analysis process in chapter 3 which leads to the results and a short discussion in chapter 4. The preliminary conclusions and an outlook will be given in chapter 5.

2. Data

The analysed data were taken from the Hinode data centre and comprise images of the G-band filter which is one of the filters of the Broad-band
Filter Imager (BFI) device of the Hinode/SOT instrument (Tsuneta et al., 2008). The data were obtained within the synoptic observation programme which is normally carried out once per day and takes images with all broadband filters close to the disc centre. The programme started after the launch of Hinode at the end of October 2006 and is carried out up to the current day. Until December 2007 the images were taken with full pixel sampling yielding a spatial sampling of 0.054 arcsec/pixel. Later on, due to the failure of the X-band antenna, limiting the downlink bandwidth, the pixel sampling was reduced by a factor of two by performing an onboard binning of the data. Hence we rebinned all the previous data to the lower pixel sampling of 0.108 arcsec/pixel to avoid an influence of the binning on the results. The FOV of the images is about 210 by 105 arcsec$^2$ or 2048 by 1024 pixels$^2$. In total we incorporated 4162 single G-band exposures into this study.

3. Analysis

After downloading all the data for the complete time span, starting with the first complete month of observations (November 2006) in the beginning of the mission until the most recent observations (end of August 2014), we applied the SSW reduction routines to these data (dark current, flat field calibration). In addition we rebinned the images of the first couple of months, obtained previously to the downlink antenna failure, by a factor of two to be in accordance with the data obtained later on during the mission. For the identification of the interesting features we employed the algorithm described in Utz et al. (2009, 2010). As an output of the identification routine we obtained the number of MBPs identified in every single image as well as characteristic parameters such as intensity or size of the MBPs. A first plot of the evolution of the number of MBPs versus time is given by Fig. 1. Here we can clearly see a huge variation of the number of detected MBPs. On the one hand this is due to several undesired effects and influences such as: sunspot images, outliers clearly above the bulk of measurements with values as high as 3000; and faulty or defocused images, outliers clearly below the bulk of measurements with values around 500 and even below. On the other hand the bulk of measurements concentrates in the range between 500 to 1000 detected features and a first trend is visible with a decreasing number of MBPs from about 1000 in early 2007 to roughly 600 to 700 around 2011. Later on a slight increase in the number of MBPs up
The number of MBPs per synoptic image versus time is shown for all synoptic G-band images obtained between first of November 2006 and end of August 2014. This first results illustrate the necessity of applying a pre-selection on the data set, i.e. avoiding images with sunspots as well as faulty and defocused exposures. The necessity of applying such a pre-selection on the data was already found in the paper of Muller et al. (2011), who investigated the evolution of characteristic parameters of the granulation over the time period of the extended last solar cycle minimum. To obtain an improved understanding of the data as well as to start the selection process, we plotted the evolution of the mean intensity of the data versus time (see Fig. 2, left panel). In this plot one can identify a trend of decreasing mean image intensities from the year 2007 up to 2011 which might be related to a blinding of the filters of the space instrument by UV radiation. In addition we see that about the year 2011 the mean intensity becomes quite stable. A possible explanation would be that the exposure time has been corrected for the lower filter throughput. Finally, we are able to recognize outliers above and below the trendline. The outliers below the trendline are due to faulty images when a part of the image information gets lost during the transfer process from the satellite to the ground station showing up as black stripes (missing columns) in the images. Such images clearly need to be excluded from the...
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Figure 2: Left: Evolution of the mean image intensity versus time is depicted for all synoptic images (crosses). The smoothed evolution (smoothing over 20 neighbours) is illustrated by a solid line and selection boundaries are given as dashed lines (±5% of the smoothed value). Right: Image contrast of selected synoptic images versus time is shown, i.e. images featuring a mean intensity within the intensity selection criterion. A linear fit is illustrated by a solid line and further selection boundaries are given by dashed lines (±1% of the fitting trend).

analysis. Therefore we came up with the following selection scheme:

We smoothed the evolution of the mean intensity by applying a running smooth window over 20 neighbouring measurement points (images). The width of the smoothing window was obtained empirically with the restrictions that a too small value would not create a sufficiently smooth line while a too large value would mask long-time effects. The smoothed data create the trend shown as solid line in the figure. Next we calculated a ±5% boundary around this threshold (shown as two dash-dotted lines). Every image, having a mean intensity within these intensity boundaries, is selected for further treatment.

In the next step we analysed the contrast of the selected images. This leaves us with the following plot as depicted in Fig. 2, right panel. Here we see again a trend of weakly decreasing image contrasts starting in the year 2007 at around 11.5% and ending in 2014 with contrasts of about 11%. The contrast was defined as standard deviation of the image divided by the mean image intensity. Interestingly we can still identify outliers above as well as below the trendline. The ones below are clearly coming from images which were out of focus while the ones lying above the trendline are either from faulty images which overcame the last selection process or, the ones being closer to the trendline, from images exhibiting active regions. Thus we performed another selection process by creating a linear fit for the contrast.
Figure 3: Number of MBPs versus time for the selected images after the intensity and contrast selection. A linear trend line is shown (solid line) together with a further selection boundary depicted by two dash-dotted lines ($\pm 30\%$ of the trend line value).

Figure 3 illustrates the result of the selection steps: the number of MBPs detected in the previously selected images. A linear fit is depicted in solid line and selection boundaries of $\pm 30\%$ are shown as dash-dotted lines. A few outliers with values as high as 1300 isolated MBP measurements can be seen. These outliers are most likely from a few erroneous selected sunspot images and excluded now in this final selection process. The chosen thresholds for the selection process were obtained empirically by the requirement of not losing too many images and thus information, but still excluding faulty data.

For the final calibration step we investigated the correlation between the detected number of MBP features and the actual image contrast. This is shown in Fig. 4. The scatter clearly outlines a linear trend which can be expected and explained easily. As the detection algorithm makes use of the brightness gradient of features it is sensitive to the achieved image contrast, i.e. the higher the achieved contrast as a result of a better adjusted focus, the higher the detection rate of the algorithm. Hence we fitted the scatter by a linear curve, assuming implicitly that the detection quality of the algorithm...
Figure 4: Final number to contrast calibration. The number of detected MBPs is shown versus the image contrast. The scatter cloud is fitted by a linear trend line giving the contrast re-calibration line.

Figure 5: Number of MBPs versus time after final calibration and selection. The solid line shows a two component sine fit while the dashed lines mark the one sigma boundary of the data.
varies linearly with the achieved image contrast. This fit can now be used to recalculate the detected MBP numbers to the mean contrast.

4. Results

The last step in the analysis, the recalibration of the images to a common contrast value, gives us our final plot which is depicted in Fig. 5. Having in mind that the small-scale magnetic fields, identified as MBPs, might be related to a local dynamo, and/or a global dynamo, and be influenced by the yearly movement of the satellite around the Sun, we tried to fit the variation of MBPs by the following equation:

\[ N(t) = N_0 + N_y \cdot \sin(\omega_y \cdot t + \phi_y) + N_c \cdot \sin(\omega_c \cdot t + \phi_c), \]  

(1)

where \( N(t) \) is the number of MBPs depending on time \( t \), and \( N_0 \) is the background number of MBPs which is constant (related to a surface dynamo and it does not vary). Furthermore there are two time dependent sine components. One - with the index \( y \) - yielding a yearly variation related to the orbit of the Earth and hence the satellite around the Sun, and a second one - with the index \( c \), related to the solar cycle - oscillating with a roughly 11 year period. The interesting fitting parameters are \( N_0 \) obtained with a value of 700, \( N_y \) with a value of 17, and \( N_c \) with a value of about 30. While the absolute values are of no great importance as they are influenced by the absolute detection quality of the algorithm, the relative values are of interest. Expressed now as relative quantities we obtain a relative change over the year of about 2.5% and a relative change over the 11 year period of about 5%. Unfortunately both changes are of such a small value that they are still within the possible natural fluctuations, as given by the standard deviation \( \sigma \). In the shown case we estimated \( \sigma \) to be in the order of 80 depicted in the plot by the dashed lines.

5. Summary and Outlook

In this proceeding we presented our preliminary results of an ongoing study on the variation of small-scale magnetic fields over longer time periods. We used MBPs as proxies for small-scale magnetic fields and the available G-band synoptic Hinode images as input data. After a careful selection process, in which we tried to exclude active sunspot regions, faulty images and/or
out-of-focus images, and a final correction for the varying image contrasts, we applied a two component sine fit to the available data. Unfortunately, even after the careful selection process, the data scatter was larger than the fitted variation of the MBP number. Therefore we cannot draw to strict conclusions from our current work at the moment. A few remarks and preliminary results can nevertheless be formulated. First, the activity of MBPs around sunspots is generally much larger than in “normal” quiet Sun regions with values exceeding 3 times the values for the quiet Sun. When such active-region images are excluded, the average activity in terms of MBPs is more or less constant within the natural fluctuations of the magnetic network. These fluctuations seem to be quite large as witnessed by the huge scatter of the number of MBPs per image. At the moment the deduced systematic variations of the number of MBPs may be caused to a significant fraction by the orbit of the Earth, and hence the satellite, around the Sun and to a smaller amount by a ‘true’ cycle for small-scale magnetic fields.

For the future we suggest to concentrate on estimating an activity number per month (e.g. median value of the single measurements) instead of incorporating all data values. By doing so we hope to reduce the large scatter in the data significantly, which is right now probably hiding a true physical variation in the MBP activity. Moreover, the influence of the achieved image contrast on the detection quality of the employed algorithm has to be investigated in more detail. Finally, it is questionable if the solar disc centre is the best place to observe a possible changing small-scale magnetic field activity as, e.g., sunspots generally avoid the equator and hence the influence of the changing Sun might be less pronounced in the disc centre.

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