Astronomical and Astrophysical Transactions (*AApTr*), 2016, Vol. 29, Issue 4, pp. 557–566,
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Main parameters and evolution of coronal bright points connected with magnetic bipolar structures in the photosphere

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Received 15 September, 2015

Using coronal images and full-disk magnetograms from AIA (Atmospheric Imaging Assembly) and HMI (Helioseismic and Magnetic Imager) instruments onboard the Solar Dynamics Observatory (SDO), we study evolution, main structure, statistical and physical properties of coronal bright points (CBPs) associated with magnetic bipoles (MBs). A detailed study of interaction of CBPs associated with bipolar structures provides a unique material for understanding of relation between corona and photosphere.

One of the main characteristics of the solar features including CBPs is a maximum intensity and size. The majority of the points have intensity in narrow interval from 300 to 800 DN with maximum at 480 DN. That distribution has quite a steep slope in the region of low intensities. On the other hand, in the region of high intensities the distribution decreases exponentially. That distribution describes the behavior of two types of CBPs.

Keywords: Sun: magnetic fields – Sun: photosphere – Sun: corona – Sun: CBPs

1 Introduction

Point like features in solar corona named coronal bright points have been observed in the X-ray and EUV (extreme ultraviolet) solar images and studied for more than four decades. CBPs are small active regions spread over the whole solar disk and seen during whole cycle – from solar minimum to solar maximum. At the beginning, X-ray bright points were detected by Vaiana et al. (1970) using a soft X-ray telescope (SXT) aboard an Aerobee sounding rocket in April 8, 1969. Later, these coronal small-scale loop like structures were analysed in detail during the Skylab mission. These studies showed that CBPs are distributed all over the solar disk including quiet-Sun regions

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and coronal holes (for details see Golub et al. (1976a)). Afterwards X-ray bright points and coronal bright points were suggested as single structure by Webb et al. (1993) and Sattarov et al. (2010).

Several studies (McIntosh and Gurman 2005; Sattarov et al. 2010) separated CBPs into two types using their brightness: "dim" CBPs are connected to quiet Sun regions and "bright" CBPs related to the active Sun. It was found that the number of "bright" CBPs varies in phase with the solar cycle and the number of "dim" CBPs – in anti-phase (Sattarov et al. 2010; Sherdanov et al. 2013).

CBPs may be due to coronal phenomenon of surface magnetic flow over small bipolar features and, probably, may consist of several loops (Golub et al. 1977; Webb et al. 1993). This process basically takes place at the network boundaries of super granular cells (Habbal et al. 1990; Egamberdiev 1983). CBPs are connected to photospheric bipoles: more than two-thirds of them associated with cancellation of pre-existing magnetic bipolar features, others with emerging bipoles (Harvey 1996).

Magnetic bipoles are small-scale (10–20 arcsec) features with two poles of opposite polarities seen in photospheric magnetograms. They have typical total flux of about 10^{19}–10^{20} Mx with an average lifetime of less than one day (Harvey & Martin 1973; Harvey 1993). Bipoles are found to be associated with bright points (Golub et al. 1974, 1976b). These magnetic bipolar structures were first identified in magnetograms of San Fernando Observatory near to active regions of the Sun. Frazer (1972) described them as the elementary sources of positive and negative flux, and may be supposed as new building blocks of active regions. Later, these small bipolar magnetic features of active regions were studied using videomagnetograms acquired at Big Bear Solar Observatory and were called "elementary bipoles" (Martin 1990).

It is estimated that two opposite-polarity poles of elementary bipole initially emerge very close together and rapidly move in opposite directions or approach one another and disappear with a typical speed of about 3–3.5 km/sec (Harvey 1985; Webb et al. 1993; Guglielmino et al. 2012). Emerging magnetic flux appears as a succession of small-scale bipolar magnetic fields even in very small active regions. Often, these small-scale magnetic bipoles appear as small magnetic regions having some distinct polarity poles, which successively appear in small and compact clusters (Martin and Mkhitaryan 2013).

Two neighboring flux elements of opposite polarity called ephemeral bipolar regions – short-lived, small (about 20 arcsec in diameter) and appear for one–two years before appearance of a new sunspot activity cycle and can serve the harbinger of the new cycle (Harvey 1993). Basically, small-scale bipoles are designated as ephemeral regions if the opposite-polarity poles meeting the following spatial, temporal, and magnitude criteria (Harvey and Martin 1973): 1) appear close to one another and rapidly move apart, 2) appear at nearly the same time and gradually increase in magnetic flux, 3) have approximately the same quantity of meaning of magnetic flux in the opposite-polarity poles.

Using the area of the bipoles Tlatov et al. (2010) separated them into three types: small quiet-Sun bipoles (QSBs), active regions (ARs) and ephemeral regions (ERs). In addition, they found that in their orientation, ERs and ARs tend to follow Hale-Nicholson polarity rule. However, ERs' orientation in high latitudes is opposite to a current sunspot cycle (Wilson et al. 1988). On the other hand, AR tilts follow Joy's law.

The number of small-scale bipoles existing at each moment on the Sun is several hundred and their lifetime is about several hours. In this case, the combined effect of a large number of ephemeral regions to shaping new poloidal field can be equal to contribution of sunspots in the overall magnetic fields configuration at the Sun. Thereby, the ephemeral regions can greatly change the generally accepted physical model of solar activity. In previous studies ephemeral bipoles were always associated with some various features of solar activity, such as CBPs, small-scales flares, jets, etc.

In recent observations (see discussion in Jiang et al. (2013)) it was reported that some loop-type jets were centered around an emerging small bipole. Earlier Moore et al. (2011) speculated that some coronal jets may be associated with emerging bipoles. Webb et al. (1993) investigated the correspondence between bright points and magnetic features and concluded that the majority of CBPs are associated with cancelling magnetic features (MFs).

2 Data and data reduction

2.1 HMI magnetograms and AIA solar images data set

We employ two data sets: full disk solar images from AIA (spatial resolution about 0.6 arcsec per pixel) and full disk magnetograms from HMI (spatial resolution about 0.5 arcsec per pixel) to study solar phenomena: coronal structures – CBPs and small-scale photospheric magnetic bipoles – MBs.

AIA images were taken at wavelength 195 Å with 45 second intervals and full disk HMI magnetograms – at wavelength 6173.3 Å on January 1, 2013. SDO data allow us to study the properties of small-scale magnetic bipoles and coronal bright points in more detail because HMI and AIA instruments provide a high resolution. Joint Science Operations Center (JSOC) web site (http://jsoc.stanford.edu/HMI/Magnetograms.html) cites the per-pixel noise level for HMI data between 5 and 10 G. Further details may be obtained from the instrument webpage (http://sdo.gsfc.nasa.gov/).

We used the dense data set obtained with AIA and HMI instruments over a period of 100 minutes. AIA and HMI images were taken at level 1.0. The level 1.0 data are then converted to level 1.5. To adapt pixel size of images and their calibrations (rotation, translation, scaling), data were converted using SolarSoft (SSW) routine aia_prep.pro.

2.2 Selection of coronal bright points

To identify coronal bright points, we employ the automatic procedure developed by us.

We implement the following steps in the CBP identification:

- Subtraction of large scale variations in the corona.
- Exclusion of compact brightenings above active regions from the CBP search.
- Identification of potential CBPs.

• Analysis of shape and length of potential CBPs to exclude hot pixels, cosmic ray streaks, and loop-like features not associated with active regions.

At the final step we record coordinates of a CBP and compute several parameters (maximal and average intensity, area, tilt etc.) Detailed description of each step is given in Sattarov et al. (2010).

2.3 Selections of magnetic bipoles

When choosing bipoles, we cut off the areas immediately adjacent to the solar limb and large active regions. Bipole pairs were selected on the basis of proximity and flux balance of two neighboring flux elements of opposite polarity.

To select small-scale bipolar pairs we follow Longcope et al. (2001) and Sattarov et al. (2002) bipole identification with additional criterions of flux balance ($R_{\min}$, $R_{\max}$, $S_{\min}$, $S_{\max}$) and correction for limb shortening. The correction of configuration is set up for 0.75% zone of limb only.

First, we selected the magnetic flux elements of positive and negative polarity with the fixed threshold about 10 G (Gauss) and total flux of about 10^{18}–10^{20} Mx on the basis of an error analysis of HMI magnetograms published by Liu et al. (2012). For each magnetogram, using automatic procedure, we identified magnetic poles of negative and positive polarity, whose cross section was between $R_{\min} = 5$ arcsec (size lower limit of magnetic concentration) in diameter (to cut off sunspots or active regions, for instance) and $R_{\max} = 55.2$ arcsec (size upper limit of magnetic concentration).

Next, we searched for the closest pairs of opposite polarity poles with separations between $S_{\min} = 5.5$ arcsec, $S_{\max} = 48.3$ arcsec. A detailed description of automatic procedure for the identification of magnetic bipoles can be found in Minenko et al. (2013).

3 Elements of evolution and main characteristics of CBPs and MBs

A model supporting the magnetic reconnection as a possible mechanism for the origin of CBPs was presented in recent studies (Kariyappa et al. 2011). They showed that a small bipolar magnetic region forms a loop-like structure in the coronal layer. Figure 1 demonstrates a complex relation between bipolar magnetic flux concentrations and typical CBP. Here we refer to CBP and small-scale N-S polarity magnetic fluxes closely associated with them outlined by a single contour situated near the center of each frame in Fig. 1.

In Fig. 1 an elongated CBP lays almost parallel to the line connecting two major poles of opposite polarity. At first glance, this CBP also appears as being oriented parallel to a line connecting two opposite polarity poles. One could make a plausible speculation that there could be loop-like form of CBPs within white contour outlining. However, upon a closer examination, the CBP seems to connect the main pole of the small bipole and a strong negative polarity below the negative pole. Maybe this "single" CBP had two formations: one is point-like (upper part of the structure) and the other is loop-like formation. Nevertheless, the magnetic footpoints for this CBP are unclear.



Figure 1 Example of a CBP in the AIA image (left) with the corresponding region with N-S polarity on the HMI magnetogram (right).

In this section we focus our attention on the main characteristics of CBPs and MBs. One of the main characteristics of solar features, including CBPs, is a maximum intensity. To explore intensity of elementary bright points we calculate averaged distribution of all coronal bright points by their maximal intensity.

Figure 2 demonstrates obtained distribution. X-axis shows maximal intensity of CBPs in DN (DataNumber), and y-axis shows number of points with corresponding intensity.

As may be seen from Fig. 2, the majority of the points have intensity in narrow intervals from 300 to 800 DN with maximum at 480 DN.

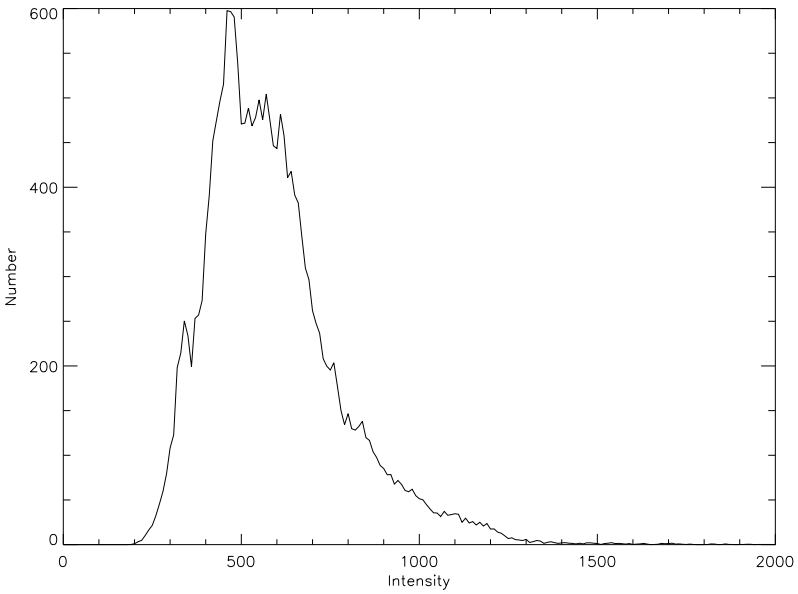


Figure 2 Distributions of CBPs number with intensity.

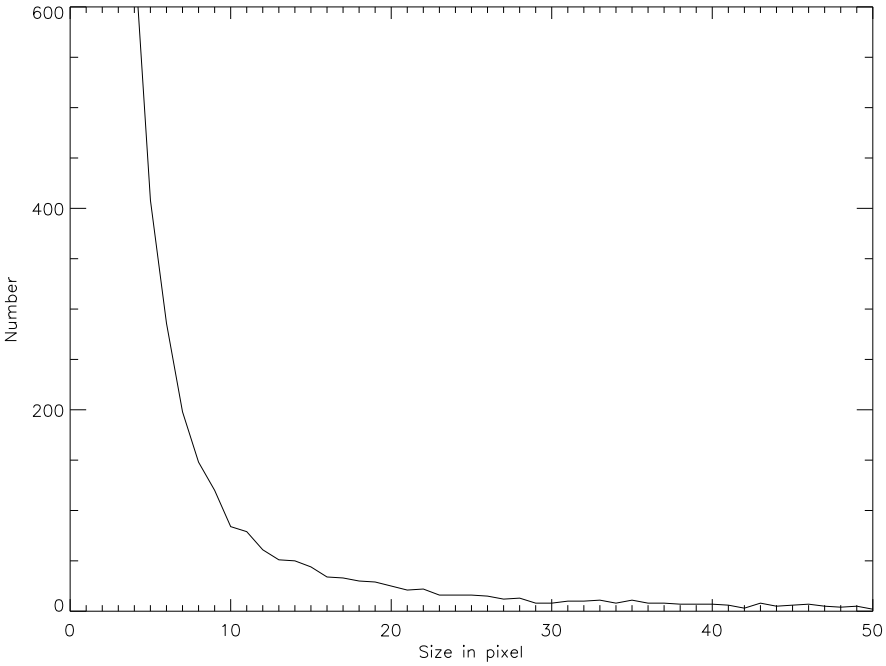


Figure 3 Distribution of CBPs number with size.

The distribution has quite a steep slope in the region of low intensities. It could easily be explained since the main criteria for CBPs detection is intensity. The intensity could not be less than certain value (in this case 200 DN). Otherwise a CBP won't be bright relative to the background, and won't be detected by the automatic program used to find them. In the region of high intensities the distribution decreases exponentially.

One more important parameter of any solar formation is its size. Figure 3 illustrates part of CBPs' size distribution. The size is in pixels where 1 pixel ≈0.6". From the figure one can see that the number of formations is decreasing exponentially with size increase. The main part of all detected CBPs refers to quite small formations with the size about 10 pixels or less. In recent studies a "bright" CBP has been presented as a group of elementary bright points that flare up sequentially (Minenko et al. 2014). That is why it's important to research exactly the smallest elementary point like features. It was suggested that small-scale features in the quiet Sun such as coronal bright points, can provide almost all the heat needed to maintain the coronal temperatures (Parnell et al. 2000). This suggests that most of CBPs were likely play an important role in the local heating of the plasma. CBPs heating of the quiet corona is well supported by the noted investigations on total energy input and the relatively steep slope of the maximal intensity distribution.

The number of CBPs obtained by us over each solar image is much higher than mentioned in previous papers. This could be referred to better spatial resolution

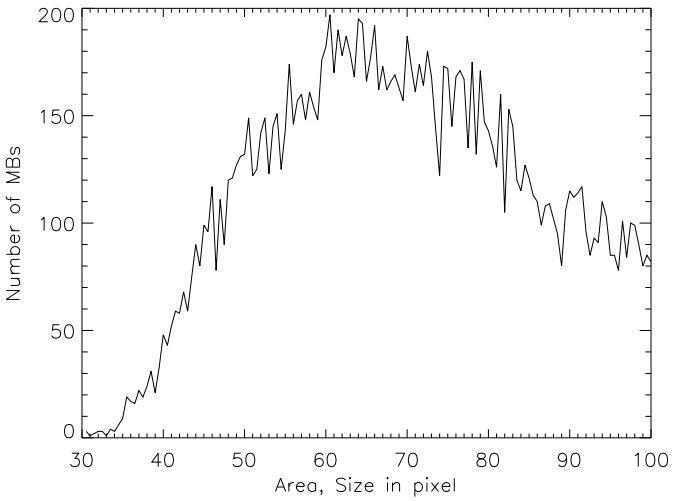


Figure 4 Distribution of MBs number with area

of SDO instruments. Thanks to that we can observe more of the smallest solar formations. Thus, AIA/SDO images used in the current research have resolution $\approx 0.6''$/pixel, while, e.g., EIT/SOHO – $2.629''$/pixel and XRT/Hinode – $1.032''$/pixel. This suggestion is confirmed by Fig. 2, from which we can see how rapidly the number of solar formations is increasing with the size reduction.

On the other hand, in the case of magnetic bipolar structures the main important parameter is its size or area. Figure 4 illustrates part of distribution of MBs area. The size is in pixels where 1 pixel $\approx$ 0.6 arcsec.

From the figure one can see that the number of formations is increasing with size increase. One could make a plausible speculation that the main part of all detected MBs refers to formations with the size of about 30 pixels or more. This distribution is easy to explain by the typical selection criteria, used for MBs detection. In the case of MBs, the area is a sum of areas of opposite polarity poles. This suggests that most of MBs are likely to have the bigger size and play an important role in the local formation of CBPs. In most cases of observed CBPs, a cluster – not a simple bipolar structure (only one opposite and negative polarity fluxes) – of opposite polarity fluxes was revealed.

4 Conclusion

In previous studies, when seen by instruments with lower resolution, bright points were believed to be a simple point or a loop-like system. Other images (for example, SOHO, Hinode etc.) with lower than AIA/SDO resolution also can give this impression. However, AIA and HMI images show more of the finer structure and multiple

connectivity. In fact, the CBPs and opposite polarity magnetic fluxes closely associated with them, as seen on the AIA and HMI images look like a miniature active region with multiple magnetic poles with several connectivities.

As reviewed above, the distribution of total number of CBPs decreases with growth of their maximal intensity. That distribution describes the behavior of two types CBPs, where the number of "dim" CBPs (their intensity less than 500 DN) is more than the number of "bright" CBPs (intensity more than 450–480 DN). Moreover, depending on the emergence and cancellation of the magnetic polarities, different types of CBPs besides variations in morphology evolve differently with time. The majority of all detected CBPs are elementary small-scale structures with an average lifetime of less than one hour. "Bright" CBPs of active Sun are associated with magnetic cancellation which exhibits as magnetic flux disappearance in photospheric observations. "Dim" CBPs (consist of elementary bright points) are associated with emerging small-scale magnetic bipoles in photosphere.

Our results are in a good agreement with previous researches on evolution of bright points (Chandrashekhar 2013) and two types of CBPs associated with MBs (Minenko et al. 2014; Karachik et al. 2014).

Acknowledgements

This work was supported by the Fundamental Research Support Fund of the Uzbekistan Academy of Sciences (FRSF of AS, grant F.6-14)

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