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AN APPLICATION OF THE RANDOM WALK MODEL TO PROPER MOTIONS OF CORONAL BRIGHT POINTS FROM SDO DATA

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Abstract. Atmospheric Imaging Assembly (AIA) images from the Solar Dynamics Observatory (SDO) were used to follow the motions of coronal bright points (CBPs) in the period 1 January - 19 May 2011 with a cadence of 10 minutes. This resulted in a data set of 80966 CBPs with measured lifetimes and mean velocities which were used in a random walk model to calculate the diffusion coefficient, D. The results show that D has a value of $\approx$260 km^2 s^{-1} for CBPs with lifetime below 6 hours, decreasing to $\approx$170 km^2 s^{-1} for lifetimes above 12 hours, with a mean value of $\approx$230 km^2 s^{-1}.

Key words: Sun - coronal bright points - random walk - diffusion coefficient - SDO/AIA

1. Introduction

Coronal bright points (CBPs) are small bright structures observed in X-ray and EUV images of the Sun, associated with local magnetic reconnection above the underlying bipolar magnetic features (Golub *et al.*, 1974; Harvey-Angle, 1993). Because of their uniform distribution across the solar disc and typical lifetime of several hours they are frequently used as tracers to study solar velocity field (e.g. Brajša *et al.* 2002; Vršnak *et al.* 2003; Kariyappa 2008; Dorotovič *et al.* 2014).

Diffusion of the magnetic field is an important part of theories modeling the solar dynamo. Leighton (1964) was the first to suggest that random walk model could be used to describe this diffusion process and applied it to the motions of photospheric magnetic concentrations governed by supergranular flows. This idea was followed by Mosher (1977) who derived a value for the diffusion coefficient (D) between 200–400 km^2 s^{-1}. Wang *et al.* (1989) preformed numerical simulations of evolution of the surface magnetic field to find that convective diffusion of 600 km^2 s^{-1} best fits the observations.

In a study of magnetic field concentrations from SOHO magnetograms, Hagenaar *et al.* (1999) found a value of 70–90 km^2 s^{-1} for timescales $<$10 ks and 200–250 km^2 s^{-1} for timescales $>$30 ks. More recently, Utz *et al.* (2010) measured a value of 350$\pm$20 km^2 s^{-1} using magnetic bright points detected in G-band solar images. Abramenko *et al.* (2011) analyzed departures from normal diffusion and found a super-diffusive regime. Iida (2016) reported a super-diffusion at scales smaller than $10^{3.8}$ km and sub-diffusion on larger ones.

In present work, we apply a random walk model to the proper motions of CBPs to estimate the diffusion coefficient.

2. Data and Reduction Method

For the application of the random walk model, we used position measurements of CBPs from the images taken by Atmospheric Imaging Assembly instrument on-board Solar Dynamics Observatory (AIA/SDO; Lemen *et al.* 2012). The data set covers a period of more than 5 months (2011 Jan. 1 – 2011 May 19) with a cadence of 10 minutes. First, a segmentation algorithm was used to identify and track CBPs in subsequent images (a modification of algorithm by Martens *et al.* 2012) and then the data were filtered for outliers, height corrected and finally, residual rotation (Δv_{rot}) and meridional (v_{mer}) velocities were calculated (Sudar *et al.*, 2016).

The same data set was already used to analyze meridional motions and Reynolds stresses by Sudar *et al.* (2016), while similar CBP measurements covering only two days were used to derive differential rotation profile of the Sun (Brajša *et al.*, 2014; Sudar *et al.*, 2015) and calculate diffusion coefficient (Brajša *et al.*, 2015). In this paper, we repeat the analysis of Brajša *et al.* (2015) on a larger 5-month data set.

Within the random walk model, where CBPs are viewed as "particles" that diffuse into the surrounding medium, diffusion coefficient is calculated as:

$$D = \frac{\langle l^2 \rangle}{4\tau}, \tag{1}$$

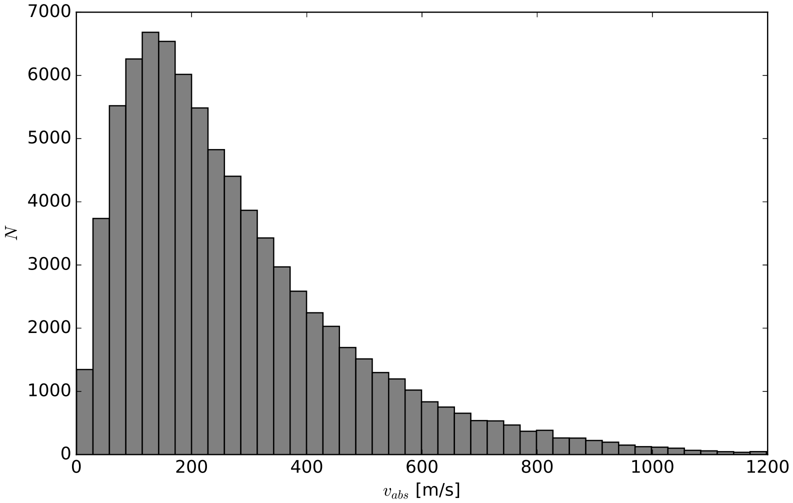

Figure 1: Distribution of absolute velocities of CBPs. N is the number of data points in each bin.

where l is the mean free path, i.e. the distance traveled by CBP during its lifetime τ. The mean free path was calculated for each CBP as:

$$l = v_{abs} \cdot \tau, \tag{2}$$

where the absolute velocity (v_{abs}) was determined using:

$$v_{abs} = \sqrt{\Delta v_{rot}^2 + v_{mer}^2}. \tag{3}$$

3. Results and Discussion

Figure 1 shows the distribution of v_{abs} for the entire data set. Most CBPs have velocities in the range 100–300 m s^{-1}, in line with Brajša *et al.* (2015), but somewhat larger than measured by Brajša *et al.* (2008) on SOHO/EIT images.

Lifetimes of CBPs can be seen in Figure 2 (note the logarithmic ordinate axis). There is an exponential decay in number of CBPs with longer lifetimes which is also observed in other studies (e.g. McIntosh and Gurman 2005).

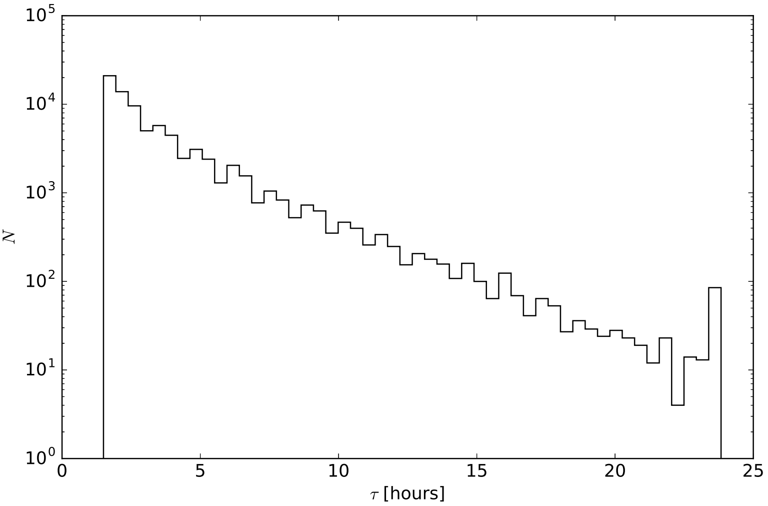

Figure 2: Number of CBPs with different lifetimes.

The least squares fit gives a typical decay time of 3.2 hours, a value close to the mean value of CBP lifetime of 3.7 hours (see Table I). The lifetime histogram is sharply limited on both sides, at 1.5 hours because only CBPs that were visible on 10 or more subsequent images were used, and at 24 hours because the used algorithm tracked CBPs over one day and then resets for the next day, treating the same long living CBP as two independent ones. This fact also explains the bump in the tail of the lifetime distribution.

Table I: Average values of lifetime (τ), absolute velocity (v_{abs}), mean free path (l) and diffusion constant (D) for the complete data set and several subsets of lifetime.

	N	$\bar{\tau}$ [h]	$\bar{v}_{abs}$ [m s^{-1}]	$\bar{l}$ [km]	D [km^2 s^{-1}]
$0 < \tau \leq 6$ h	69603	2.78	298	2700	263
$6 < \tau \leq 12$ h	9475	8.13	140	4020	193
$12 < \tau \leq 18$ h	1551	14.35	100	5110	167
$18 < \tau \leq 24$ h	337	21.05	81	6160	170
all	80966	3.70	275	2910	235

The results are presented in Table I, for all data points and over several subsets of various lifetime. The mean free path is ≈3000 km with values increasing to 6000 km for the longer living CBPs. The opposite trend is seen in absolute velocity with values going from 300 m s^{-1} down to 100 m s^{-1}. Finally, the mean diffusion coefficient is 235 km^2 s^{-1} with a somewhat larger value for short living CBPs, but settling to $\approx$170 km^2 s^{-1} for the longer living ones.

Measured values of diffusion coefficient are lower than required by simulations (600 ± 200 km^2 s^{-1}, Wang *et al.* 1989) but very similar to other results obtained by tracking CBPs (Brajša *et al.*, 2008, 2015), magnetic concentrations (Mosher, 1977; Hagenaar *et al.*, 1999) and magnetic bright points in G-band images (Berger *et al.*, 1998; Utz *et al.*, 2010). The variation of D with lifetime suggests a sub-diffusive regime, also found by Lawrence and Schrijver (1993), but in contrast with super-diffusive results of Abramenko *et al.* (2011). Iida (2016) found that super-diffusion changes to sub-diffusion at $10^{3.8}$ km, roughly corresponding to the mean free path of longer living CBPs in our data set, which could explain the difference between various observations.

4. Conclusion

In this work, we used motions of CBPs to estimate diffusion coefficient. While some part of the observed motions can be due to magnetic reconnection processes associated with CBPs, the main part should come from the underlying motions of solar plasma because the overall velocity field measured from CBPs corresponds well to those derived from Doppler measurements (Sudar *et al.*, 2016). The motions of CBPs suggest a diffusion coefficient of 170–270 km^2 s^{-1} with a possible sub-diffusive regime on longer timescales. In further work, we plan to analyze this anomalous diffusive behavior in more detail.

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