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PRELIMINARY RESULTS ON THE SOLAR ROTATION DETERMINED TRACING SDO/AIA CORONAL BRIGHT POINTS

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Abstract. In this paper we present preliminary results on the solar differential rotation measured tracing coronal bright points in SDO/AIA images. An automatic recognition method was applied to the series of images taken in the test period, 1-2 January 2011. Coronal bright points are suitable tracers for the determination of the solar differential rotation, because they are localized objects which are very well distributed over solar disc. Results presented in this paper show that the SDO/AIA data are very useful for that aim, due to the high spatial and temporal resolution of the images.

Key words: Sun - rotation - corona

1. Introduction

Solar differential rotation and its dependence on latitude, depth/height and time is one of the fundamental properties of the Sun as a star. A high quality solar rotation profile with good reliability can be achieved either by using long term data sets (typically sunspots observed during many decades) or by using solar synoptic images with a high cadence (typically satellite data with a cadence of hours or less). For the latter case a significant progress has been achieved in the last 15 years using especially data from Yohkoh, SOHO and Hinode satellites (Brajša *et al.*, 2000, 2001; Wöhl *et al.*, 2001; Mulec *et al.*, 2007; Brajša *et al.*, 2008; Kariyappa, 2008; Hara, 2009; Wöhl *et al.*, 2010; Jurdana-Šepić *et al.*, 2011). This development could be continued recently when even more precise data from the SDO/AIA satellite became available (Lorenc *et al.*, 2012; Dorotovič *et al.*, 2014; McIntosh *et al.*, 2014).

In this paper we present preliminary results on the solar rotation determined tracing coronal bright points (CBPs) in successive SDO/AIA images.

2. Data set and reduction methods

Preliminary data from the Atmospheric Imaging Assembly (AIA) instrument on board the Solar Dynamics Observatory (SDO) spacecraft (Lemen *et al.*, 2012) were used. The instrument has a high spatial resolution of about 0.6 arcsec per pixel and the analysed images were taken with a cadence of 10 minutes. The reduction method is based on a segmentation algorithm which identifies small structures brighter than the smoothed average background intensity level in the 19.3 nm AIA images (Martens *et al.*, 2012). In this way solar coordinates of more than 13000 identified CBPs from the test period 1-2 January 2011 were measured. In total more than 66000 position measurements were obtained. Synodic solar rotation velocity was then calculated by the linear least square fit of the central meridian distance as a function of time. Sidereal rotation velocity was calculated by applying a time dependent synodic-sidereal transformation (Roša *et al.*, 1995; Skokić *et al.*, 2014).

3. Results

As usually, solar differential rotation is represented by the formula:

$$\omega(b) = A + B\sin^2 b + C\sin^4 b \ , \qquad (1)$$

where ω is the solar sidereal rotation velocity expressed in deg per day, b is the heliographic latitude in degrees and A, B, and C are solar rotation parameters. The parameter A describes the equatorial rotation velocity of the Sun, while B and C are the differential rotation parameters.

In this paper we present results on the solar differential rotation of CBPs for various filters and for different tracing times (expressed by the number of consecutive images in which a CBP was identified). The filters used are explained in Table I. Unfiltered data are denoted by "1", while a rotation velocity filter is denoted by "2": all measured rotation velocities lying outside the given velocity range are excluded from further analysis. For all identified CBPs also the meridional velocities were calculated by least squares fit of the CBP's heliographic latitude positions as a function of time. The next

Table I: Filters used

Filter	Constraints
1	none
2	$8^\circ\ \mathrm{deg}^{-1} < \omega < 19^\circ\ \mathrm{deg}^{-1}$
3	$-4^\circ\ \mathrm{deg}^{-1} < \omega_{mer} < 4^\circ\ \mathrm{deg}^{-1}$
4	$\lvert\Delta\omega\rvert < 2^\circ\ \mathrm{deg}^{-1}$

Table II: Results for minimal number of CBP measurements > 2

Filters	n	A	B	C
1	4681	14.88 ± 0.26	-0.95 ± 1.90	-1.28 ± 2.28
2	3147	14.32 ± 0.08	-1.91 ± 0.60	0.56 ± 0.75
2, 3	2484	14.40 ± 0.08	-1.88 ± 0.64	0.39 ± 0.83
2, 3, 4	1481	14.51 ± 0.04	-2.12 ± 0.37	0.50 ± 0.51

filter, denoted by "3", excludes all rotation velocities for CBPs having extreme values of meridional motions, as written in Table I. Finally, we used a filter shifting in latitude, excluding all rotation velocity values which differ by 2 deg/day or more from the mean differential rotation curve obtained before an application of this filter. Such a filter was used in earlier reductions of SOHO/EIT data, by e.g., Brajša *et al.* (2000); Wöhl *et al.* (2001); Mulec *et al.* (2007); Brajša *et al.* (2008); Wöhl *et al.* (2010). In the present paper it is denoted as Filter "4" in Table I.

Table III: Results for minimal number of CBP measurements > 6

Filters	n	A	B	C
1	2015	14.73 ± 0.17	-0.64 ± 1.31	-1.82 ± 1.56
2	1755	14.46 ± 0.09	-0.97 ± 0.70	-1.12 ± 0.88
2, 3	1618	14.51 ± 0.09	-1.02 ± 0.71	-1.25 ± 0.89
2, 3, 4	1091	14.53 ± 0.05	-0.95 ± 0.42	-1.48 ± 0.56

Table IV: Results for minimal number of CBP measurements > 9

Filters	n	A	B	C
1	1386	14.76 ± 0.16	-2.46 ± 1.19	0.86 ± 1.43
2	1271	14.51 ± 0.10	-0.67 ± 0.76	-1.66 ± 0.94
2, 3	1226	14.53 ± 0.10	-0.85 ± 0.76	-1.53 ± 0.94
2, 3, 4	883	14.53 ± 0.05	-0.59 ± 0.46	-1.95 ± 0.61

Solar differential rotation parameters from Eq. (1) are presented in Tables II, III, and IV for various filters and tracing times. In these three tables results without application of any filter and with application of filters "2", "2" and "3", as well as "2", "3", and "4" are presented together with the number of rotation velocities (n).

4. Discussion and conclusion

We now discuss how an application of various filters influences the deduced solar differential rotation parameters and their respective errors, as presented in tables II, III, and IV. As expected, application of the overall velocity filter ("2") significantly reduces the errors due to exclusion of erroneous velocity values. However, it is interesting that introducing an additional filter for meridional motions ("3") does not change/improve the final results significantly. Finally, the latitude dependent filter ("4") further reduces errors. Longer tracing times surely improve accuracy, but this is not simply reflected in smaller errors, due to the smaller numbers of identified structures.

We conclude that CBPs are suitable tracers for the determination of the solar differential rotation, primarily while they are localized objects which are very well distributed over solar disc. Preliminary results presented in this paper show that the SDO/AIA data are very useful for that aim, due to the high spatial and temporal resolution. Automatic methods for object recognition and data reduction are needed because of huge data sets available.

In a continuation of this work we plan to apply additional filters (especially to exclude the solar limb effects), to analyse solar hemispheres separately and to use orthogonal functions to minimize the crosstalk between differential rotation parameters. An important goal of this study is to investigate the cycle related changes of the solar rotation and to analyse the angular momentum transfer on the Sun by calculating meridional motions, rotation velocity residuals and Reynolds stresses determined by CBPs. Finally, the detailed analysis of proper motions of CBPs will enable to study diffusion of small magnetic elements on the Sun using a random walk model.

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