MEASUREMENTS OF SOLAR ROTATION USING EUV BRIGHT POINTS - PRELIMINARY RESULTS

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Abstract. Full-disc solar images in the extreme ultraviolet part of the spectrum from the SOHO spacecraft (instrument EIT, data in the spectral line of Fe XV at the wavelength of 28.4 nm) are used to identify visually various small-scale coronal structures appropriate for the determination of the solar rotation. From the time differences in tracer positions, approximately six hours, the solar rotation velocity is determined tracing coronal bright points in the period June 4–14, 1998 by four observers. The resulting rotational profiles are mutually compared and the reduction methods are discussed.

Key words: solar rotation - coronal bright points - SOHO-EIT

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1. Introduction

Coronal bright points are small, isolated areas of bright X-ray and extreme ultraviolet (EUV) emission with lifetimes in the range of 2–48 hours and diameters in the range of 5 – 20 × 10^4 km (e.g., Benz, 1993; Harvey-Angle, 1993; Golub and Pasachoff, 1997). The lower limit to the lifetime and diameter was found to be instrument dependent, while the upper limit was arbitrarily chosen to separate X-ray bright points from active regions. Bright points are widely distributed in latitudes from the equator to the poles and appear more frequently in the active region belts and at the equatorial latitudes. All X-ray bright points can be identified on photospheric magnetograms as small magnetic bipoles, but the correlation in the opposite sense is not so strong. Coronal bright points belong to the lower corona of the Sun (Golub et al., 1974) and consist of several, small loops (Sheeley and Golub, 1979).

Dupree and Henze (1972) and Simon and Noyes (1972) have traced the brightest points in active regions in Mg X (62.5 nm) spectroheliograms from OSO-4. A higher equatorial and a more pronounced differential rotation velocity in comparison with long-lived sunspots was obtained. The sidereal rotation velocity at the solar equator deduced from EUV bright points amounted to 14.65 ± 0.2 deg/day, in a good agreement with the equatorial sidereal rotation velocity determined tracing X-ray bright points in the Skylab photographs, which was found to be 14.6 ± 0.3 deg/day (Golub et al., 1974).

So, coronal bright points may represent appropriate tracers for the solar rotation determination, primarily because of their large number, broad coverage of latitudes and small, well-defined shapes. However, because of their relatively short lifetime, time differences between the successive images should be in the order of hours rather than days.

2. The Data Set

The data from the Extreme Ultraviolet Imaging Telescope (EIT) on board the SOHO (Solar and Heliospheric Observatory) are used. In the frame of the SOHO-EIT Proposal Brajsa 206: ”An analysis of
the solar rotation velocity by tracing coronal features” (proposers: R. Brajša, B. Vršnak, V. Ruždjak, D. Roša, H. Wöhl, and F. Clette) full-disc filtergrams in Fe XV at the wavelength of 28.4 nm in FITS and GIF formats were made available. Among the four EIT channels (Moses et al., 1997) the wavelength of 28.4 nm was selected, since the bright points seem to be most discernible at this wavelength. Further, at 28.4 nm the Fe XV line is formed at a temperature of $2.0 \times 10^6$ K and is thus the hottest of the four lines detected by EIT (Moses et al., 1997). The temperature of coronal bright points is also approximately $2.0 \times 10^6$ K (Golub and Pasachoff, 1997). However, it is planned to extend the analysis with the data obtained in the 17.1 nm and 19.5 nm bandpasses later on.

Our data set consists of 602 full-disc solar images obtained with the EIT at 28.4 nm with the regular cadence of 4 images per day, i.e., one image every 6 hours. Sometimes, there is a gap in the sequence, so that there are 12 hours between the successive images. Further, there are some periods of missing data. All images were preprocessed by correcting defects (grid, CCD flat field) and the CCD offset. The 602 images mentioned above were taken in the time interval from June 4, 1998 to May 22, 1999. In the present paper, preliminary results from the tracing of coronal bright points in the first 40 images from our data set, performed by four different observers independently, are presented and mutually compared. Let us stress that this work is still in progress, and that extended results will be published subsequently.

3. Reduction Methods

Four different observers:

- Mladen Kasabašić (MK)
- Jens Rodmann (JR)
- Hubertus Wöhl (HW)
- Roman Brajša (RB)

have traced coronal bright points in the first 40 images (June 4–14, 1998) with slightly different procedures. MK selected all bright points
Table I: Solar sidereal rotation velocity parameters (deg/day) from the equation (1) obtained by four different observers. In the left-hand (right-hand) part of the Table the parameters from all (filtered) data are presented, as explained in the text. \( n \) – the number of traced bright points, Ob. – observer, \( M \) – the standard error

<table>
<thead>
<tr>
<th></th>
<th>( A \pm M_A )</th>
<th>( B \pm M_B )</th>
<th>( n )</th>
<th>Ob.</th>
<th>( A \pm M_A )</th>
<th>( B \pm M_B )</th>
<th>( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14.40 ± 0.17</td>
<td>3.37 ± 0.62</td>
<td>66</td>
<td>MK</td>
<td>14.49 ± 0.13</td>
<td>3.15 ± 0.58</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>14.40 ± 0.17</td>
<td>3.34 ± 0.59</td>
<td>74</td>
<td>JR</td>
<td>14.32 ± 0.10</td>
<td>2.91 ± 0.37</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>14.44 ± 0.13</td>
<td>3.30 ± 0.46</td>
<td>67</td>
<td>HW</td>
<td>14.45 ± 0.10</td>
<td>3.17 ± 0.36</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>14.39 ± 0.10</td>
<td>3.07 ± 0.38</td>
<td>208</td>
<td>RB</td>
<td>14.36 ± 0.07</td>
<td>2.93 ± 0.27</td>
<td>180</td>
</tr>
</tbody>
</table>

in each image independently, determined their positions and put them into synoptic charts describing the solar latitude vs. central meridian distance (one synoptic chart for every 13 images). Then he has recognized which positions belong to the same objects and calculated their rotation velocities. In this way bright points could have been followed in up to 14 successive images, i.e., as long as 85 hours. The other three observers, JR, HW, and RB, identified bright points in solar images and determined positions only of those objects, which could have been traced in at least 3 subsequent images. JR and HW have traced an object in up to 25 and 24 successive images respectively (6–7 days), and RB has intentionally confined the upper limit to 4 images. Two dozens of consecutive images can be taken in about 150 hours and in these cases small active regions were traced. All four observers inspected the function of central meridian distance vs. time, for each identified tracer, to exclude wrong identifications. These lines were in most cases very straight, implying that coronal bright points are good tracers for the solar rotation determination. From each identified bright point one rotation velocity value was calculated, regardless of the tracing time. In Table I the numbers of coronal structures determined by the four observers are given.

4. Preliminary Results

As usually, the solar differential rotation velocity is represented by
\[ \omega(b) = A + B \sin^2 b, \]  

where \( \omega \) is the sidereal angular rotation velocity in deg/day, \( b \) the heliographic latitude, and \( A, B \) the solar differential rotation velocity parameters. Both solar hemispheres were treated together and the results are presented in Table I and in Figures 1–4.

\textbf{Figure 1:} Solar sidereal rotation velocity values obtained tracing coronal bright points in both solar hemispheres during June 4–14, 1998 by the observer MK. The solid line represents the fit to all data points and the dotted lines border the filter. 13.6\% of the data were filtered out.

The exclusion of the extreme rotation velocity values was performed in the following way. Firstly, rotation velocity parameters from equation (1) were found for all data points for each observer. These parameters are presented in the left-hand part of Table I and the solar rotation curves are represented by solid lines in Figures 1–4. Then, a filter shifting in latitude, excluding all velocity values which differ by 1.5 deg/day or more from the mean curve, was imposed on the data.
Figure 2: The same as in Figure 1, for the observer JR, 9.5% of the data were filtered out.

and new parameters were found. These parameters are presented in the right-hand part of Table I. The thresholds of the filter are represented by the dotted lines in Figures 1–4.

5. Discussion

When filtering out, the number of measured solar rotation velocity values is reduced by about 14% in the case of the observers MK and RB, and by less than 10% in the case of the other two observers, JR and HW (Table I, Figures 1–4). The solar rotation velocity parameters have not been changed significantly (Table I) and their errors became smaller, as expected. As a hint for future data reductions, we can recommend the application of a slightly broader filter, since many data points lie just outside the borders (e.g., Figure 4).

Let us now compare the results obtained by the four observers, who used the same data set, but applied slightly different procedures,
as earlier described. Concerning the number of identified bright points (Table I, Figures 1–4), each of the first three observers, MK, JR, and HW, have used about 70 tracers. On the other hand, the fourth observer, RB, identified more than 200 bright points and this is partly due to the shorter tracing time (up to only 4 successive images) used by this observer. So, in this last case, occasionally the same objects were probably identified and counted more than once; whereas the same objects were identified and counted only once by the other three observers. Furthermore, the observer RB extended his analysis also to fainter and less discernible features. The most important conclusion from the comparison of the solar rotation parameters obtained by the four observers is that the differences between the parameters are in most cases very small (Table I). This holds for both the raw and filtered data, and the differences between the parameters are in all cases below the 1σ level (Table I). The similarity of the four solar differential rotation profiles (Figures 1–4) also indicates that all four
observers obtained essentially the same results. This is important for the continuation of this work, since the results seem to be independent from the subjective differences between observers and even from some small alternations in the applied visual tracer method.

The latitudinal distribution of identified bright points (Figures 1–4) reveals that latitudes between the solar equator and almost 70 deg are covered. There is a maximum in the distribution in the active region belts (at the latitude of about 20 deg), especially discernible in Figure 4, in accordance to earlier results. On the other hand, a gap in the data was found at latitudes of about 50 deg by the observers MK and JR (Figures 1 and 2, respectively). This gap was not reported by the other two observers, HW and RB (Figures 3 and 4, respectively).

Finally, let us mention that we applied the method for the simultaneous determination of the true solar synodic rotation velocity and the height of the tracers (Roša et al., 1998; Vršnak et al., 1999). Equations (17b) and (33)–(35) from the paper by Roša et al. (1998) were
applied to the results of the first observer, MK (data from June 4–14, 1998). The solar radius (in EIT pixels) and the coordinates of the position of the SOHO spacecraft in space respectively to the Sun (in kilometers) were taken from the headers of the images. From the solar radius in pixels, the solar radius in arcsec was calculated knowing that 1 pixel corresponds to 2.62 arcsec. From the coordinates of the spacecraft, the distance from the spacecraft to the Sun was calculated and used to convert the solar radius in arcsec to the one in kilometers. In this way a solar radius which approximately corresponds to $704 \times 10^3$ km was found for the considered time interval and used in the coordinate transformation. The result of the calculation implies that the bright points have no significant height above this solar radius, which is about $8 \times 10^3$ km larger than the radius of the solar photosphere. So, the traced coronal bright points are located in the lower corona, as expected, but more data are needed for a more precise height determination using the above mentioned method.

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References

MJERENJA ROTACIJE SUNCA POMOĆU SVIJETLIH TOČAKA OPAŽANIH U DALEKOM ULTRALJUBIČASTOM DIJELU SPEKTRA - PREHODNI REZULTATI

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