PROPER MOTIONS OF SUNSPOT GROUPS

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Abstract. Attempts to investigate typical patterns of motions of main spot components
and small pores in complex sunspot groups are described. The data used up to now stem
from observations at Hvar/HR, Tatranská Lomnica/SK, Izaña/E, Debrecen/H and from
the MDI instrument on SoHO. Preliminary results are presented.

Key words: sunspot groups - proper motions

1. Introduction

Besides the well known differential rotation and meridional motion of sunspots a search for systematic motions of pores and sunspots within a sunspot group are important to investigate the dynamics of evolving and dissolving of active regions. It is e.g. interesting to check, whether an irregular local rotation of a sunspot reported by Kucera (1982) can be found in other sunspot groups or if preliminary results of pore motions reported by Mehlitretter (1979) can be improved. The final goal of this investigation is to study the emerging magnetic flux in active regions and especially the emerging of new flux in evolved active regions.

The evolution of sunspots from the observational point of view was summarized by McIntosh (1981). The growth of the larger sunspot groups

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begins with the successive emergence of up to six bipolar sunspot "sets" that appear at approximately 1-day intervals. The axis of a sunspot group starts typically with a high inclination to the solar equator and rotates to a smaller inclination during the addition of new spots. The direction of sunspot-group-axis rotation appears to obey a Coriolis law for the outflowing gas. The rotation of clusters of sunspots in groups obeys a Coriolis law for the inflowing gas.

The angle between the sunspot axis and the solar equator was measured for sunspot groups (Baranyi and Ludmány, 1992) and for sunspots themselves (Khutsishvili et al., 1998). Further, variations and oscillations of these sunspot tilt angles were determined (Kučera, 1982; Antalová, 1983; Khutsishvili et al., 2002) and the morphology of spiral patterns was investigated in some cases (Ding et al. 1987; Negovitsyna and Negovitsyn, 1999).

Since many digital data are now available, it seems worthwhile to investigate systematic motions of sunspots on timescales from minutes up to several days and more. We have selected free available data sets from the Heliophysical Observatory at Debrecen and from the Michelson Doppler Imager (MDI) on the Solar and Heliospheric Observatory (SoHO). We have also collected ourselves images and digital positions of sunspots on the solar disk at the solar observatories in Hvar, Tatranská Lomnica and the Vacuum Tower Telescope (VTT) in Izaña.

2. The Data Sets

2.1. Images Taken at Hvar Observatory

A new system to digitize images from a TV camera and the possibility to record its analog signals on S-VHS video tapes (Klvaňa and Bumba, 1997) at the solar telescope on Hvar (Ambrož et al., 1977) was used. The observed region on the solar disk covers about 350 * 280 arc seconds. In 1999 a first attempt was performed to collect series of images of sunspot groups using this equipment. Since we detected an incompatibility of the digitized images at the observatory with those from the video tapes, we decided to use video sequences only, which made also the collection of data easier. The video records obtained last from a few seconds up to several dozen seconds each, depending on the seeing quality judged by the observer. Since


Table I: Observed video sequences at Hvar

<table>
<thead>
<tr>
<th>Time interval</th>
<th>observing days</th>
<th>observed sunspot groups (different NOAA numbers)</th>
<th>video sequences obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 May</td>
<td>17</td>
<td>14</td>
<td>335</td>
</tr>
<tr>
<td>2001 Jun.</td>
<td>16</td>
<td>20</td>
<td>628</td>
</tr>
<tr>
<td>2001 Jul.</td>
<td>4</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>2001 Aug.</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2001 Sep.</td>
<td>10</td>
<td>9</td>
<td>173</td>
</tr>
<tr>
<td>2002 Mar.</td>
<td>11</td>
<td>13</td>
<td>99</td>
</tr>
<tr>
<td>2002 Apr.</td>
<td>19</td>
<td>24</td>
<td>184</td>
</tr>
<tr>
<td>2002 May</td>
<td>10</td>
<td>33</td>
<td>16</td>
</tr>
<tr>
<td>2002 Jun.</td>
<td>20</td>
<td>50</td>
<td>76</td>
</tr>
<tr>
<td>2002 Jul.</td>
<td>15</td>
<td>37</td>
<td>44</td>
</tr>
<tr>
<td>2002 Aug.</td>
<td>13</td>
<td>36</td>
<td>32</td>
</tr>
<tr>
<td>2002 Sep.</td>
<td>12</td>
<td>34</td>
<td>-</td>
</tr>
<tr>
<td>total</td>
<td>148</td>
<td>279</td>
<td>more than 1606</td>
</tr>
</tbody>
</table>

2001 systematic campaigns to collect data were performed. The presently available data are given in Table I.

From the tapes the best five images of each sequence were digitized using a system available at the KIS. The resulting size of the images is 720 * 576 pixels with a digitizing precision of 8 bits each. An example of a fraction of such an image obtained on June 8, 2001 is given in Figure 1.

2.2. Digital sunspot positions from Tatranská Lomnica

Within a project to investigate the interaction of sunspot motion and the solar plasma motion digital positions of sunspot groups from pencil drawings of sunspots obtained at the solar refractor at Tatranská Lomnica (Ambrož and Kučera, 1992) have been collected with a cadence of about an hour since several years (Wöhl et al., 2000). Using this experience it was possible to obtain the positions of the main sunspot umbrae with a high precision. The available digital data sets given in Table II are already converted from cartesian coordinates to heliographic coordinates.
2.3. Digital images and sunspot positions obtained at the VTT

During an observing campaign in April 2002 at the VTT (see Schröter et al., 1985) it was possible to collect digital sunspot positions using the guiding system of the telescope as well as digital images of the slit-jaws of the Echelle spectrograph. The images have a size of 768 * 576 pixels with a precision of 8 bits; they were mostly taken in 'white light', but also in Hα and Ca II K. The main aim was to have a comparison of position data and images obtained with one telescope as compared with the complementing data sets described in sections 2.1 and 2.2, respectively. Data could be obtained at the VTT on 7 observing days from 12 different sunspot groups. A total of 41 sets of digital positions and about 13000 digital images in JPG format were recorded.

2.4. Sequences of digital images from MDI on SoHO

For a comparison of our collected images we intend to use also free available data from the INTERNET. A first series of images obtained in the high resolution mode of MDI on June 8, 2001 covers about 40 minutes with a cadence of one minute. An example is given in Figure 2.

Figure 1: An example of a fraction of an image obtained at Hvar on June 8, 2001 at 16:06 UT. The East-West direction on the sky is parallel to the horizontal edges of the image. The tilt angle P at the observing time was about -12.4 degrees. This image should be compared with Figure 2, but their different orientation has to be taken into account.
Table II: Observed sunspot groups at Tatranská Lomnica

<table>
<thead>
<tr>
<th>Time interval</th>
<th>observing days</th>
<th>observed sunspot groups (different NOAA numbers)</th>
<th>digital positions obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 May</td>
<td>25</td>
<td>35</td>
<td>123</td>
</tr>
<tr>
<td>2001 Jun.</td>
<td>16</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>2001 Jul.</td>
<td>16</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>2001 Aug.</td>
<td>28</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>2001 Sep.</td>
<td>15</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>2001 Oct.</td>
<td>23</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>2001 Nov.</td>
<td>10</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>2001 Dec.</td>
<td>7</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>2002 Jan.</td>
<td>14</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>2002 Feb.</td>
<td>14</td>
<td>32</td>
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<tr>
<td>2002 Mar.</td>
<td>17</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>2002 Apr.</td>
<td>17</td>
<td>35</td>
<td>48</td>
</tr>
<tr>
<td>2002 May</td>
<td>18</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>2002 Jun.</td>
<td>18</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>2002 Jul.</td>
<td>16</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>2002 Aug.</td>
<td>16</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>2002 Sep.</td>
<td>14</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>284</td>
<td>533</td>
<td>171</td>
</tr>
</tbody>
</table>

2.5. Digital sunspot positions from Debrecen

From the Debrecen Photoheliographic Data series the daily positions of sunspots and sunspot groups are available on CD-ROM for the years 1986 until 1988. Since one of us (Wöhl, 2002) has successfully determined meridional motions of recurrent sunspot groups from these data, they seem to be also useful to analyse single sunspot motions.

2.6. Solar images from (hidden) archives

Besides the well known archives of sunspot positions it is possible to use special solar images collected within the last centuries, but not yet publi-
Figure 2: An example of a fraction of an image obtained by MDI on June 8, 2001 at 16:08 UT. The East-West direction on the sun is parallel to the horizontal edges of the image.

cally available: E.g. an inspection of several thousands of solar photographs on glass plates in the archives of the KIS resulted in several remarkable series of images taken during the strongest solar activity so far observed by mankind around the middle of the last century. These can be used to trace proper motions in extremely large sunspot groups.

3. Reductions performed

The main aim of reductions performed so far, is to compare the qualities of different data sets and the best methods to analyse larger quantities of digital data and images.

3.1. Geometrical parameters of the Hvar images

A first task was to determine the size of the pixels in the images digitized from the video tapes recorded at Hvar: From the distance between the leading and the following sunspot of the group NOAA 9454 on May 14, 2001 observed at Hvar and Tatranská Lomnica a pixel size of 0.47 arc seconds was determined. Using the inclination of the two parts of the sunspot group
an error of less than one degree in the East-West-direction of the images from Hvar was estimated.

3.2. Positions of sunspots from Tatranská Lomnica and the VTT

The sunspot group positions obtained on April 4 and 5, 2002 at the VTT and at the solar telescope at Tatranská Lomnica were compared: Linear fits of latitude and central meridian distances (CMD) vs. time were fitted and interpolated for midnight of April 5th. There was one position obviously not useful, because the difference in CMD was about 10 degrees: An elongated sunspot group was cut at different positions. For the other five positions a rms difference in latitude of 0.43 degrees and in CMD of 0.87 degrees was found. Since the range in latitude was only from $-12$ to $+18$ degrees, while the range in CMD was from $-60$ to $+46$ degrees, such a behaviour of the differences was expected.

3.3. Automatic determination of pore positions in MDI images

A program code in the Interactive Data Language (IDL), which was already used to automatically determine the positions of small bright structures in EIT images by Brajša et al. (2001), was adopted to find the positions of pores in the series of MDI images mentioned earlier. An example of an image at the begin of the series is given in Figure 2. Pores were detected in three images with 20 minutes time distances. Those which could be traced in all three sub-images are given in Figure 3. The main motion visible is of course caused by the solar rotation. For details of the problem of guiding errors see the similar investigation by Didkovsky (2000).

3.4. Sunspot motions from Debrecen Photoheliographic Data

Program codes in IDL were used to select sunspot groups and spots of the given NOAA numbers from the CD-ROM of the Debrecen Photoheliographic Data and show their positions in heliographic coordinates and their relative positions to the center of their group. An example of NOAA group number 4710 observed on January 13–15, 1986 is given in Figure 4. Already small groups with less than a dozen spots show a complexity of motions
Figure 5. Positions of pores in the lower left part of three images of a series of MDI images in 'high resolution mode' obtained on June 8, 2001, 16:12, 16:32, and 16:52 UT. The size of a quadratic pixel equals to 0.605°0.605 arc seconds. The three observing times are indicated by crosses, stars and diamonds, respectively. See Figure 2 for a larger section of the image.

and emerging and decaying of spots within about 24 hours. To trace these spots additional information is needed.

4. Results and discussion

The comparison of the data reductions performed so far gives an idea about applicable methods and precision - but also an idea about the amount of work to be done. The main tasks will be very time consuming:

a) To compare series of available data and to trace individual sunspot pores in long time series with a cadence of about one hour.

b) To continue further parallel observing campaigns, e.g. between Hvar and Tatranská Lomnica and/or the VTT.

c) To develop automatic routines for the tracing of pores.

A special attention will be paid to the motion and evolution of δ-
sunspots (opposite polarity umbrae within the same penumbra). The two umbrae can rotate about each other during the evolution of a δ-sunspot, which was observed by, e.g., Kučera (1982) and Wang (1992). Multi-mode kink instability of magnetic flux tubes was considered as a possible explanation for the formation of δ-sunspots and in particular for the above mentioned rotation of their parts (Linton, 2001 and references therein).

5. Conclusions

Data have been collected for a detailed analysis of proper motions within several dozen sunspot groups. The detailed reduction still has to be done. The digital data available in the INTERNET or from Debrecen are easier to use, but do not fit optimal into the cadence of about one hour one would prefer. Therefore the reduction of the own data seems to be worthwhile.
Additional data - plasma velocity fields, magnetic fields etc. - are important and have to be used in the interpretation of the sunspot motions too. An example to be followed is given by Kosovichev (2002) - hopefully with higher cadence of data and better spatial resolution.

Acknowledgements

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References

VLASTITA GIBANJA GRUPA SUNČEVIH PJEGA

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Izlaganje sa znanstvenog skupa

Sažetak. Opisani su pokušaji istraživanja ustrojstava gibanja glavnih pjega i malih pora u kompleksnim grupama Sunčevih pjega. Podaci koji su korišteni do sada potječu s opsevatorija Hvar/HR, Tatranská Lomnica/SK, Izaña/E, Debrecen/H i s instrumenta MDI sa satelita SoHO. Prikazuju se prethodni rezultati.

Ključne riječi: grupe Sunčevih pjega - vlastita gibanja

*Stipendist Zaklade Alexander von Humboldt u KIS-u