Multi-spacecraft observations during a series of three solar energetic particle events in May, 2009

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Abstract: At the end of the prolonged solar minimum of solar cycle 23 a fleet of well-separated spacecraft were monitoring to observe solar energetic particle (SEP) events. In the beginning of May 2009 a series of three SEP events on the first, second and fifth of May were observed by ACE and WIND. Except from the first event, energetic electrons and protons were also detected by STEREO A. The source region of the first two events is clearly identified with the help of SOHO/EIT and STEREO/EUVI to be at the west limb for the Earth. STEREO B EUVI observations together with multi-point radio measurements support an eastern source for the third event. However in-situ particle time-intensity profiles and anisotropies suggest a well-connected source, rather than the eastern AR separated by 100 degrees from the footpoint of STEREO A. Combining 3D propagation simulations with multi-point observations, we discuss the propagation conditions for this series of SEP events.

Keywords: Solar Energetic Particles (SEPs), Propagation, Perpendicular Diffusion

1 Introduction

Large flares and Coronal Mass Ejections (CMEs) are often accompanied by enhanced flux of energetic protons and electrons measured at 1 AU. These so-called solar energetic particle (SEP) events are expected to be observed when the source region at the Sun is close to the magnetic footpoint of the observing spacecraft (s/c). But previous observations have shown that in some cases SEPs are still detected even with separations rising above some tens of degrees up to more than 100 degrees. With multiple spacecraft observing the same event one can determine much more information about the event as with a single observer. Knowing the angular spread, relative intensities and timing of the event it is possible to draw a picture of the distribution and propagation of the energetic particles including information on possible asymmetries.

The sequence of SEP events in the beginning of May 2009 is investigated using measurements from four spacecraft namely STEREO A, STEREO B, ACE, and WIND. While the ACE and WIND spacecraft are located close to the Earth at L1, the STEREOS were separated by more than 40 degrees in longitude from the Earth at that time. While the source region of the two first events on May 1 and May 2, 2009 co-rotates, it moves away from the Earth yielding in a worse magnetic connection for the ACE and WIND s/c. For the third SEP event on May 5, 2009 it is unclear if the associated source region is again this Active Region (AR). Due to a data gap in STEREO A / SECCHI optical observations of this AR are missing. However, STEREO B / EUVI detects a flare in another AR providing a second candidate as source region.

2 Instrumentation

Aboard the twin STEREO spacecraft energetic particles are measured by the IMPACT instrument suite [2] containing among all the Low Energy Telescope (LET, [3]), and the Solar Electron and Proton Telescope (SEPT, [1]). The latter measures electrons in the range of 30-400 keV and nuclei from 60-7000 keV/n. The SECCHI investigation [4] aboard the STEREO spacecraft provides remote sensing observations of the Sun in extreme ultra violet (EUVI, [6]) as well as coronagraphic observations (COR1 and COR2 Instruments), which allow to link in-situ observations with the associated source regions at the Sun. Besides the two STEREOs, the ACE and WIND spacecraft complete a multi-spacecraft fleet allowing multi-point observations of the same events. Energetic electron measurements at ACE and WIND are provided by the EPAM [8] and 3DP [9] experiments, respectively. Radio signatures are detected with the WAVES instrument aboard WIND [5] and the STEREO/WAVES instruments [7].
3 Observations

In the beginning of May 2009 three SEP events were observed on the first, second and fifth of May close to the Earth by the WIND and ACE spacecraft. While the STEREO B observatory did not detect clear electron increases, STEREO A observed enhanced electron flux on May 2 and May 5. Fig. 2 summarizes the electron measurements of the four s/c. With STEREO A / EUVI observ-

![Figure 1: Longitudinal configurations of the AR (arrow) and the spacecraft positions and connecting magnetic field lines.](image)

<table>
<thead>
<tr>
<th>$\Delta \varphi$</th>
<th>May 1</th>
<th>May 2</th>
<th>May 5 (AR 11016)</th>
<th>May 5 (AR 11017)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACE/WIND</td>
<td>2</td>
<td>33</td>
<td>80</td>
<td>163</td>
</tr>
<tr>
<td>STEREO A</td>
<td>-41</td>
<td>33</td>
<td>12</td>
<td>94</td>
</tr>
<tr>
<td>STEREO B</td>
<td>60</td>
<td>90</td>
<td>133</td>
<td>-144</td>
</tr>
</tbody>
</table>

Table 1: Longitudinal separation angles $\Delta \varphi$ between active region and spacecraft magnetic footpoint.

![Figure 2: Electron measurements, from top to bottom: STEREO B, STEREO A, ACE, and WIND.](image)

The source region of the first two events is clearly identified as AR 11016, which is located at S07 W90 as seen from Earth on May 1, 20UT and is about 70 degrees behind the limb on May 5. On May 5 AR 11016 is still located at the visible disk as seen from STEREO A but STEREO A / SECCHI data are compromised by a data gap from 8 UT on due to an unexpected SECCHI reset resulting in a lack of visual observations of AR 11016 during the SEP event on that day. However, STEREO B / EUVI observes a flare in the 171 Å band at 8:11 UT in AR 11017 (see Fig. 4). An EIT wave propagating into north-eastern direction is also observed (not shown). The onset time of the flare is in coincidence with a type III radio burst observed by the three observer locations. The radio spectra measured by the STEREO/WAVES experiments are presented in Fig. 3 and show a less prominent radio burst in the STEREO A observations, which is slightly occulted in the high frequency range. Due to the SECCHI data gap it is not possible to proof if AR 11016 also produces a flare on May 5 around the type III onset time. Thus for the third SEP event there are two candidates as possible source region.

Fig. 1 shows the configuration of the Earth and STEREO s/c with respect to the source region for the three events. Longitudinal s/c positions are given as dotted lines, the spirals represent the magnetic field lines connecting the s/c with the Sun taking into account the measured solar wind speed. The black arrow indicates the co-rotating position of AR 11016, while the blue arrow in the right hand figure represents AR 11017. Table 1 summarizes the longitudinal separations between the source regions and the magnetic footpoints of the two STEREO and ACE/WIND s/c for the three SEP events. For the May 5 event both AR 11016 and AR 11017 are taken into account as possible source regions.

Fig. 5 shows energetic proton measurements by

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STEREO A / LET in blue and the anisotropy in red for the May 5 SEP event. Especially during the onset of the protons, the anisotropy is quite strong.

4 Discussion and Conclusions

While AR 11016 moves from the West limb as seen from Earth at May 1, 2009 behind the limb on May 2 and May 5, the longitudinal separation between the Earth magnetic footpoint and the active region grows from 2 degrees on May 1 over 33 degrees on May 2 up to 80 degrees on May 5. The energetic electron increases observed by the close to Earth spacecraft ACE and WIND become successively lower and less prompt (see Fig. 2). This is exactly what one would expect from a source region rotating away from the observer. From the viewpoint of STEREO A the AR moves towards its magnetic footpoint with separations of -41 degree on May 1, -22 degree on May 2, and 12 degrees on May 5. STEREO A only observes energetic electrons from the second and third event. For STEREO B the AR is far behind the limb with separations of 60 degrees on May 1, 90 degrees on May 2, and 133 degrees on May 5 resulting in no clear electron observations of these SEP events.

Although the proton anisotropy measured by

Figure 4: Difference image of STEREO B / EUVI 171 Å showing a flare at 8:11 UT in AR 11017

STEREO A / LET on May 5 fits very well to a well connected source region as AR 11016 on May 5, the radio measurements in combination with the flare observed by STEREO B in AR 11017 suggest this AR as source region for the event. Furthermore Earth based Nancay radio observations (not shown) detect a radio source, which is located at the North/East fitting the position of AR 11017. For several hours around the observed type III radio burst there are no further radio signatures which could be associated to the SEP event. Assuming AR 11017 as source region of the May 5 SEP event, this would demand a process distributing the solar energetic particles

Figure 5: STEREO A LET proton flux and anisotropy on May 5, 2009.

in a very asymmetric way. One candidate for that could be the EIT wave, which propagates into north-eastern direction, meaning the direction of STEREO A. Indeed the electron measurements by STEREO A / SEPT show a clear anisotropy in the North telescope.

To make a concluding remark about the source region of the May 5, 2009 SEP event further analysis has to be done.

References

Figure 3: STEREO/WAVES radio spectrograms on May 5, 2009.