TYPE III RADIO BURST PROLIFIC MAGNETIC FIELD CONFIGURATIONS

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Abstract. The occurrence of metre-wave type III radio bursts was investigated in relation to the location of the associated flare in the magnetic field configuration for two periods of low solar activity in 1975–1977 and 1985–1987. In a statistical analysis it was found that for subflares the probability to produce a type III burst is higher by about one order of magnitude if the flare occurs at the boundary compared to a position elsewhere inside the general bipolar pattern of the related active region. The 3-D-topology of the magnetic field was calculated by extrapolation of the observed magnetic field for selected active regions and events. The locations at the border where the Hα-patches of flares associated with type III bursts were observed are close to open field lines extending high into the corona.

Key words: flares - type III bursts - magnetic field topology

1. Introduction

Spectral type III radio emission is a fascinating phenomenon in solar physics and has stimulated substantial observational and theoretical interest since it was first observed about 6 decades ago. The consensus that has been reached is that the observed fast frequency drift events are caused by accelerated electrons moving at 0.2–0.6c outward through the solar corona into the interplanetary space where they can also be directly detected in situ at 1 AU. Spatially the electron streams follow the Archimedean spiral of open magnetic field lines (Nitta et al., 2006). Observations show that type III bursts are clearly associated both in time and location with flares and solar active regions.

The association of metre-wave type III radio emission with solar flares and active regions has been studied by numerous authors (see, e.g. Po-
quérusse and McIntosh, 1990 and references therein). It was found that the probability of type III burst occurrence increases (i) to a lesser extent with the flare importance (area) than with brightness within the same importance class and (ii) with proximity to sunspots.

Using VLA, Nançay Radioheliograph and Yohkoh data Kundu et al. (1995) and Raulin et al. (1996) investigated the association of type III bursts with X-ray bright points and soft X-ray jets and demonstrated that strong particle acceleration accompanies reconnection in these events. Efficient particle acceleration at high coronal altitudes by multiple reconnection sites connected by common field lines was discussed by Aurass et al. (1998) and Benz et al. (2005). Observations indicate that metric type III bursts are produced by accelerated electrons and that open field lines must be present at the energy release site. Based on logical conclusions from different observations a lot of cartoons and schematic drawings for magnetic field configurations for the generation of flare associated type III bursts were developed in the past, but systematic calculations of the 3-D-topology based on observed magnetic fields have not been accomplished yet.

To find specifics of type III radio burst prolific magnetic field configurations we investigate the occurrence of type III bursts in relation to the location of the associated flare in the magnetic field pattern of the involved active region. We considered a sample of about 3000 compact flares during two periods of low solar activity to join a statistical analysis about the location of the flares associated with type III bursts to extrapolations of the observed longitudinal magnetic fields.

2. Association between Flares and Type III Bursts

The investigation of the flare – type III burst association was based on timing. A type III burst was assumed to be associated with a flare if it started during the impulsive phase, i.e. between the beginning and maximum of the Hα flare. To minimize the risk of random associations we investigated selected time intervals for periods of low activity in 1975-1977 and 1985-1987 when only one active region was present on the solar disk. Information on 2737 Hα flares and 3392 type III bursts reported during these intervals were taken from the event lists published in Solar-Geophysical Data (Prompt or Comprehensive reports, respectively). The patrol films taken at Kanzelhöhe Solar Observatory (KSO) and maps presented in Solnechnye Dannye have
Table I: Flares for which the location within the general bipolar pattern could be established listed according to importance and brightness categories. i-flares: flares inside the bipolar pattern, o-flares: flares outside the bipolar pattern. N denotes the number of flares, NA the number of associated flares.

<table>
<thead>
<tr>
<th>Importance</th>
<th>i-flares</th>
<th>o-flares</th>
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<tbody>
<tr>
<td></td>
<td>N</td>
<td>NA</td>
</tr>
<tr>
<td>SF</td>
<td>954</td>
<td>20</td>
</tr>
<tr>
<td>SN</td>
<td>496</td>
<td>33</td>
</tr>
<tr>
<td>SB</td>
<td>61</td>
<td>8</td>
</tr>
<tr>
<td>All subflares</td>
<td>1511</td>
<td>61</td>
</tr>
<tr>
<td>1F</td>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>1N</td>
<td>53</td>
<td>7</td>
</tr>
<tr>
<td>1B</td>
<td>29</td>
<td>6</td>
</tr>
<tr>
<td>All flares Imp. 1</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>All flares</td>
<td>1611</td>
<td>75</td>
</tr>
</tbody>
</table>

been used to find the position of the Hα flares in the active regions.

We found 366 metre-wave type III bursts to be associated with flares. About 95% of them were subflares. For 2203 flares of our sample the position of the flare with respect to the general bipolar pattern of the active region could be exactly determined. We denote as i-flares all flares occurring between the preceding and following spot and as o-flares all flares occurring east of the following or west of the preceding spot as well as flares located at the northern or southern boundary of the related active region.

In Table I we list the flare – type III association with respect to the position of the flare in the bipolar pattern of the active region. The majority, 1611/2203 ~ 73% of all flares, occurs inside the bipolar pattern of the active regions. The inverse situation is found regarding the association with type III bursts: 207/282 ~ 73% of the flares associated with type III bursts occur at the border of active regions. For subflares the association rate of o-flares exceeds that of i-flares by nearly one order of magnitude. Axisa (1974) found a similar relation investigating the flare – type III burst association for a sample of four active regions. These results show that the location of the energy release site in the magnetic environment of an active region is highly
Table II: Flares outside the bipolar pattern (o-flares) listed according to the location where they occur: at the leading edge ($F_l$), at the following edge ($F_f$), and north or south of the general bipolar pattern ($F_{n/s}$), respectively. $N$ denotes the total number of flares and $NA$ the number of flares associated with type III bursts.

<table>
<thead>
<tr>
<th></th>
<th>$F_l$</th>
<th>$F_f$</th>
<th>$F_{n/s}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>346</td>
<td>146</td>
<td>102</td>
</tr>
<tr>
<td>$NA$</td>
<td>143</td>
<td>48</td>
<td>17</td>
</tr>
<tr>
<td>$NA%$</td>
<td>41</td>
<td>33</td>
<td>17</td>
</tr>
</tbody>
</table>

important for the generation of type III bursts, i.e. the access to open field lines.

The o-flares were investigated in more detail with regard to their location, i.e. if they occurred at the leading edge (denoted as $F_l$), at the following edge ($F_f$), or north or south ($F_{n/s}$) of the general bipolar pattern of the active region, respectively. The numbers are given in Table II. We found a clear preference for o-flares occurring at the leading edge. This concerns not only the rate for type III association (about 41%) but also the total number of flares (346/594 ~ 58%) at this location.

3. Flare Locations and 3-D Magnetic Field Structure

3.1. Data and Methods

For a selected set of subflares we investigated systematically the 3-D-topology of the magnetic field by extrapolation of the measured longitudinal field. Subflares show highly concentrated, point-like Hα-patches which enable to identify exactly the location of the involved fields and for which the field remains relatively preserved, opposite to dynamic flares which undergo an eruptive restructuring of the pre-flare magnetic field. The extrapolations were done by using the procedure described by Seehafer (1978) assuming a potential field. In general, the magnetic field at the photosphere and in the flaring area deviates from the potential state, but not so much as conventionally assumed (Moon et al., 2002) so that the potential field can be regarded as a good approach for the overall 3-D-topology.

We used the following main criteria in our selection of active regions for
which we performed the magnetic field extrapolation:

- Availability of National Solar Observatory/Kitt Peak (NSO/KP) data and patrol flare observations at Kanzelhöhe Solar Observatory (KSO) at the same day.

- Location of the active region within $\pm 30^\circ$ Central Meridian Distance to ensure that the vertical component of the magnetic field does not differ too much from the observed longitudinal one, thus supporting reliable results of the extrapolation.

- Several associated flares at the same location during the day under study to exclude further the possibility of random associations.

3.2. SELECTED EXAMPLES

Two typical examples from our sample selected for investigation of the 3-D-topology by extrapolation of the observed longitudinal field are the active regions McMath 14756 and 13738.

McMath 14756 (Figure 1) was a bipolar active region with a well-developed sunspot in the leading polarity and a small, already fragmented spot in the following polarity. The dominating sunspot is observable as the black patch in the H$\alpha$-filtergram or as concentrated leading polarity (white patch) in the magnetogram, respectively. The white bar marks the location of two homologous subflares associated with type III bursts. The position of the H$\alpha$-flares is also marked by a small white cross in the magnetogram. It is situated in the southwest of the spot, between the spot and an intrusion of opposite polarity (faint black patch in the west of the cross). The extrapolation shows that one part of the spot is connected with the following polarity by closed loops bridging over the arcade between the leading and following polarity. Field lines starting in the west and southwest of the spot leave the box used for the extrapolation at the top as open field lines. Some of them start in the spot and run toward southwest, partly over the local loop system of the intrusion before leaving the volume at the top. They are in close contact to the local field of the intrusion where the flares associated with type III bursts occur.

McMath 13738 (Figure 2) was a bipolar group with a dominating sunspot in the leading polarity. The sunspot is marked by the upper black
Figure 1: Active region McMath 14756 on June 09, 1977. Upper panel: KSO Hα-filtergram at 1237 UT (right) and Kitt Peak Magnetogram (left) at 1325 UT (same field of view). The white bar or cross mark the location of two flares, respectively. Lower panel: 3-D-magnetic field configuration obtained from extrapolation of the Kitt Peak Magnetogram. The isolines represent the measured longitudinal field at the photospheric level where the field lines start toward the upper atmosphere.
Figure 2: Active region McMath 13738 of July 02 and 03, 1975. Upper panel: KSO Hα-filtergrams of July 02 at 1536 UT (left hand side) and of July 03 at 1616 UT (right hand side). The lower (white) bars denote the location of flares and the upper (black) bars mark the dominating sunspot in the leading polarity. Lower panel: 3-D-magnetic field configurations obtained from extrapolation of the Kitt Peak Magnetogram of July 02, 1975 at 1541 UT. Selected field lines showing the 3-D-Structure of the magnetic field east (left hand side) and west (right hand side) of the sunspot.

bars in the Hα-filtergrams. There are two locations of repeated flaring denoted by the lower white bars. One (left hand side filtergram) is in the east of the spot, i.e. inside the active region. The three flares observed at this position were not associated with type III bursts. The extrapolation at the left hand side of the lower panel shows that a dense arcade of closed loops between the following and leading polarity is situated at this place.

The other flare location (right hand side filtergram) is in the west of the sunspot at the leading edge of the active region. A total of 11 flares were...
observed at that location on July 2 and 3, seven of them were associated with type III bursts. For this location the extrapolation at the right hand side of the lower panel shows a field topology similar to the situation found for active region McMath 14756. An intrusion of opposite polarity is situated in the west of the spot – cf. isolines of the photospheric magnetic field in the extrapolation at the left hand side. A system of low lying loops between this intrusion and the surrounding field is in close contact with open field lines starting in the sunspot, running somewhat to the west, and growing to coronal heights.

4. Summary and Discussion

A large sample of flares, mostly subflares occurring during two periods of low solar activity, is investigated by a statistical analysis about their location and association with type III bursts and by extrapolations of the observed longitudinal field to find out specifics of the 3-D-topology of the involved magnetic fields.

As the main result of our statistical analysis we found that the probability for a flare to be associated with a type III burst is higher by about one order of magnitude if the flare occurs at the boundary compared to a position elsewhere inside the active region. This is in good agreement with the results of the extrapolations. There we find field lines open to coronal heights at the locations of associated flares occurring close to the boundary of active regions. This indicates that electrons can find access to open field lines much easier at the periphery than inside an (typically bipolar) active region where the field is mostly shielded up to coronal heights by dense arcades between the leading and following polarity as shown in the example of not associated flares.

A further result is a strong preference of the leading edge, where about 58% of o-flares occur and the highest rate (41%) for type III association was found. This hints at the importance of the magnetic field strengths involved. In general, the leading polarity develops more compact whereas the following polarity has the tendency to spread. The correlation can be explained by the fact, that stronger fields and tight patterns with stronger magnetic gradients are required to accelerate electrons to high velocities. This result corresponds with the findings of Zlobec et al (1990) who found an increase of the flare-type III burst association rate with the magnetic
field strength of the spots covered by a flare ribbon.

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References


Solar Geophysical Data

Solnechnye Dannye