ON A STRANGE RECURRING TYPE I BURST PATTERN

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Abstract. Two remarkable intensity-time patterns in the 113 and 64 MHz single-frequency radio flux records during a type I noise storm and/or a type IV burst on 31 July, 1983 are studied. A comparison of the patterns at both frequencies reveals a high degree of resemblance and inherent common structure although the 64 MHz pattern was seen 40 min later than the 113 MHz pattern. An interpretation is given assuming a slowly uprising and thereby expanding clumpy plasma-magnetic field configuration which is (via accompanying coronal loops) two times illuminated by energetic electrons coming from the soft X-ray flare precursor source region of the H-alpha flares F1 and F2 (see Figure 1).

1. Introduction

On radio spectrograms different types of bursts and spectral fine structures are sometimes characterized by a phase correlation in the frequency-time plane; the resulting time delays of related phenomena range from fractions of a second up to minutes (Krüger, 1979).

We give an example of correlated intensity variations ('patterns') observed with a very large time delay (40 min) at 113 and 64 MHz. The observation is quantitatively described by analyzing high time-resolution records (0.062 s sampling rate) using statistical methods. In the discussion we present proposals for an interpretation in terms of noise storm chains, coronal mass ejections, and flare precursor phenomena. Additional soft X-ray data support a plausible explanation of the strange observation which invokes a close connection between X-ray and radio source regions.

2. Observations

On 31 July, 1983 the single-frequency patrol records of the Tremsdorf Observatory indicate weak noise storm activity at 234 and 113 MHz (right-handed circularly polarized). At 07:32 UT, a weak type IV burst starts at both frequencies, and in the decimeter-microwave range. Somewhat later, at 07:42 UT, the first of a sequence of three H-alpha flares in the course of the next hour is noted in the active region group NOAA No. 4263, 4267, and 4268 (Solar Geophysical Data, 1983). About 40 min later the radio event is observed at lower frequencies also. Figure 1 gives the meter-wave flux
Fig. 1. The meter wavelength radio flux intensity $I$ and the circular polarization degree $P$ of the 31 July, 1983 event (Tremsdorf Observatory). Intensity scales are given in solar units (1 s.u. = $10^{-22}$ W m$^{-2}$ Hz$^{-1}$). The sense of the circular polarization is indicated. The brackets in the top and the bottom of parts of the 113 and 64 MHz records denote the intervals of special interest. The arrows at the bottom time scale of the figure mark the onset times of the corresponding microwave burst and the H-alpha flares (Solar Geophysical Data, 1983). The table in the upper left corner gives flare coordinates and importances. Note that the saturation occurs at 60 s.u. for the sensitive 234 MHz record.

and polarization records, together with the starting times, heliographic coordinates, and importances of the related H-alpha flares. Below the 113 and 64 MHz records, bars mark the first 20 min intervals of the event. The ends of these intervals are characterized by a steplike flux increase (see the square brackets above the 113 and 64 MHz records in Figure 1).

Using Weissenau spectral records (kindly supplied by H. Urbarz) the discussed flux record intervals have been identified as noise storm continua with drifting chains and (in the late phase of the 64 MHz record) type III storm-like features (Urbarz, 1983, 1985). Near 113 MHz, and at 64 MHz immediately after the onset of the continuum, the emission becomes restricted in bandwidth.

3. Data Analysis

First, using high time-resolution digital 113 and 64 MHz records, the hypothesis has been tested that both intervals marked in Figure 1 represent a highly similar sequence of single bursts. By means of a special cross-correlation analysis (Kurths, 1986) the burst pattern can be divided (after a linear trend removal) into at least four strongly
cross-correlated subintervals $D1$ to $D4$. The subintervals are defined in Table I. The subinterval $D3$ is disturbed by type III bursts at 64 MHz (start of the flares $F2$, $F3$; cf. Figure 1) and is left aside for the further treatment.

For example, Figure 2(a) shows the high time-resolution records of the subinterval $D1$ (note the different time-scales). This figure can be compared with Figure 2(b) which is a tracing of features on the Weissenau spectra. Those features which are perhaps related to the numbered peaks on the flux records are indicated. The relative amplitude of the peaks is different from event to event at both frequencies. In absolute flux units the pattern is stronger at 64 MHz (see Figure 1), some peak intensities can be compared in Table II. The peaks forming the pattern are more intense in the first subintervals. This is a common property of noise storm chains (Elgarøy and Ugland, 1970). It is also the reason why only the subinterval $D1$ can be recognized near 113 MHz in the Weissenau spectra.

### Table I

Parameters of highly correlated subintervals $D1$ and $D2$.

<table>
<thead>
<tr>
<th>Start (UT)</th>
<th>Dur. (s)</th>
<th>Start (UT)</th>
<th>Dur. (s)</th>
</tr>
</thead>
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<tr>
<td>113 MHz</td>
<td>64 MHz</td>
<td>113 MHz</td>
<td>64 MHz</td>
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<td>07:33:10</td>
<td>08:13:10</td>
<td>07:41:00</td>
<td>08:21:00</td>
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<td>290</td>
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<td>230</td>
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<table>
<thead>
<tr>
<th>Start (UT)</th>
<th>Dur. (s)</th>
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<tbody>
<tr>
<td>113 MHz</td>
<td>64 MHz</td>
</tr>
<tr>
<td>07:45:10</td>
<td>08:25:10</td>
</tr>
<tr>
<td>280</td>
<td></td>
</tr>
</tbody>
</table>

### Table II

Peak intensities of the records shown in Figure 2 (taken before linear trend removal; $\Delta I/I \approx 5\%$).

<table>
<thead>
<tr>
<th>Peak No. (Figure 2)</th>
<th>$I_{113\text{ MHz}}$ (s.u.)</th>
<th>$I_{64\text{ MHz}}$ (s.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>46</td>
<td>140</td>
</tr>
<tr>
<td>2</td>
<td>354</td>
<td>140</td>
</tr>
<tr>
<td>3</td>
<td>104</td>
<td>112</td>
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<td>4</td>
<td>97</td>
<td>315</td>
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<td>5</td>
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<td>248</td>
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<td>6</td>
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<td>8</td>
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<td>226</td>
</tr>
<tr>
<td>9</td>
<td>63</td>
<td>553</td>
</tr>
</tbody>
</table>
Fig. 2a–b. Details of the subinterval $D1$. (a) High time resolution records (sampling rate 0.062 s). (b) Schematic of the burst pattern as seen with the Weissenau spectrograph. The spectrogram was kindly submitted by H. Urbarz.
Some typical parameters of the analyzed pattern are as follows:

- The half-power burst duration is 4 to 10 s at 113 MHz and 5 to 11 s at 64 MHz. This is roughly five times the average single burst duration in a noise storm chain (Elgarøy, 1976; de Groot et al., 1976).
- Individual bursts are associated with an enhanced flux level, indicating that the chains are superposed onto a background emission (see also Elgarøy and Ugland, 1970).
- The patterns are slightly ($\leq 10\%$) left-handed polarized.

The surprising correspondence between the two 40 min delayed patterns at 113 and 64 MHz can be further quantified. A rough inspection of Figure 2 yields the impression that the subinterval $D_{164\text{ MHz}}$ is an expanded version of the subinterval $D_{113\text{ MHz}}$ (see the broken lines in Figure 2). This points towards a nonlinear relation between the subintervals which can not be completely reflected by the cross-correlation function. For testing this supposition we try to define a typical time scale of the subintervals $D_1$, $D_2$, and $D_4$ at both frequencies, separately. An autoregressive approach (linear stochastic difference equations) is used which covers a wide class of stochastic processes. Starting with the fourth-order difference equation the corresponding characteristic polynomials of the subintervals have two complex and two real zeros. Hence, we proceed as follows:

- We fit the parameter model (1) of the autocovariance function to the sample autocovariance function $C_{xx}(\tau)$ of the different subinterval records:

$$C_{xx}(\tau) = u_1 r_1^\tau + u_2 r_2^\tau + u_3 r_3^\tau \cos(2\pi \tau/t_p),$$  \hspace{1cm} (1)

$r_1$, $t_p$, estimated parameters; $u_i$, linear factors; $\tau$, delay time (cf. Box and Jenkins, 1970). The parameter $t_p$ is the typical mean time-scale of the time series variability in the analyzed subinterval.

- We calculate the relative time-scale expansion $\Delta t_p/t_p$ of the subintervals, defined as

$$\frac{\Delta t_p}{t_p} = 2 \frac{t_p 64\text{ MHz} - t_p 113\text{ MHz}}{t_p 64\text{ MHz} + t_p 113\text{ MHz}}.$$ \hspace{1cm} (2)

Table III gives the results of this treatment confirming our idea of a nonlinear relation between corresponding subinterval time series at both frequencies. The estimated time-scales $t_p 64\text{ MHz}$ and $t_p 113\text{ MHz}$ are different, and the difference growths with the

<table>
<thead>
<tr>
<th>Sub-interval</th>
<th>$r_1$ $64\text{ MHz}$</th>
<th>$r_2$ $113\text{ MHz}$</th>
<th>$r_3$ $64\text{ MHz}$</th>
<th>$r_3$ $113\text{ MHz}$</th>
<th>$t_p (s)$</th>
<th>$\Delta t_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>0.875</td>
<td>0.871</td>
<td>-0.133</td>
<td>-0.170</td>
<td>0.404</td>
<td>0.508</td>
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<tr>
<td>D2</td>
<td>0.817</td>
<td>0.858</td>
<td>0.259</td>
<td>0.086</td>
<td>0.395</td>
<td>0.287</td>
</tr>
<tr>
<td>D4</td>
<td>0.692</td>
<td>0.912</td>
<td>0.382</td>
<td>0.169</td>
<td>0.451</td>
<td>0.271</td>
</tr>
</tbody>
</table>

TABLE III
Results of model fitting according to formulae (1) and (2)

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subinterval number (this means from the start to the end of the 20 min pattern). The relative time-scale expansion according to formula (2) underlines this statement surprisingly clearly (Figure 3).

We note that analyzing later time intervals of the same event using the described method does not yield significant cross-correlations which adds credence to our results for the chosen correlated subintervals.

![Graph showing relative time scale expansion](image)

**Fig. 3.** The relative time scale expansion $\Delta t_p/\tau_p$ (formula (2)) of the subintervals $D1$, $D2$, and $D4$; drawn according to the position of the center of the subintervals in the time scale of the pattern. The second ordinate scale gives the corresponding expansion velocities with respect to the assumed pattern propagation velocity of 90 km s$^{-1}$.

4. Discussion

The strong resemblance of two 20 min duration noise storm continuum intervals observed with a time delay of 40 min at different frequencies (the equivalent plasma levels have a distance of 0.3 $R_\odot$ in a five-fold Newkirk (1961) density model which is generally applied in the present paper) is an unexpected result. As an explanation we need a model including a stable, slowly rising structure with at least one hour lifetime which is able to induce the recurring pattern by emitting a typical radio signature during the passage of the 113 MHz and (40 min later) the 64 MHz plasma levels, respectively. We adopt for this structure the term 'plasma-magnetic field configuration' (e.g., Spicer et al., 1981). Figure 4 illustrates such an approach with respect to our data. Some consequences follow:

- The partition of the radiation pattern in cross-correlated subintervals indicates clumpiness of the propagating coronal structure.

- The relative time-scale expansion of the subintervals (Table III, Figure 3) can be understood as a hint to a slowly changing internal structure of the propagating disturbance (expansion in an inhomogeneous medium, yielding the head structure $D1$
with $v_{exp} \approx 8 \text{ km s}^{-1}$ followed by faster expanding tail features, e.g., $D_4$ with $v_{exp} \approx 35 \text{ km s}^{-1}$.

The 20 min duration of the pattern reveals a linear extension of the propagating configuration of about $10^5 \text{ km}$. Assuming spherical symmetry an estimate of the brightness is possible. For the strongest peaks we get $T_{S_{113 \text{ MHz}}} \approx 2 \times 10^{10} \text{ K}$ and $T_{S_{64 \text{ MHz}}} \approx 5 \times 10^{10} \text{ K}$ (peak 6, respectively, peak 9, Table II). $T_{S_{64 \text{ MHz}}}$ is given taking into account the source expansion.

On the plasma hypothesis, the concept of a travelling disturbance is often used in explaining drifting noise storm chains (Wild and Tlamicha, 1965; Hanasz, 1966; Elgarøy and Ugland, 1970). These authors note the relation between the drift velocities of chains and type II bursts. Spicer et al. (1981) and Wentzel (1982) invoke a random series of weak shocks and slowly uprising plasma-magnetic field configurations driven by randomly emerging magnetic flux to explain the typical noise storm type I burst pattern.

The interpretation of the patterns studied in the present paper as being two snapshots of the same disturbance taken with a time-delay of 40 min yields a drift rate of $f^{-1}(\Delta f/\Delta t) = -0.014 \text{ min}^{-1}$ belonging to the most frequently observed class of chain drift rates (cf. Hanasz, 1966). Further, Wild and Tlamicha (1965) as well as Hanasz (1966) note the phenomenon of pairs of chains (defined as chains appearing parallel at different frequencies but overlapping at least partly in time). In both papers some cases are reported with repeating intensity variations in both bands of a pair of chains. De Groot et al. (1976) did not find pairs nor corresponding intensity patterns.
Thus, accepting the recurring pattern in the present observation as drifting noise storm chains, we have described for the first time corresponding intensity patterns in nonoverlapping groups of drifting noise storm chains having a time separation as large as 40 min.

Kerdraon et al. (1983) found a correlation between noise storm enhancements and slowly uprising stable and massive structures in coronal visible light observations. But we feel that some strange characteristics of our observation—the low degree of circular polarization, the exclusively long burst durations, and the nonlinear recurrence relation between the patterns at the different plasma levels do not fit well in the general noise storm picture.

Going back to Figure 4 one should ask why there were two relatively small-band (≈20 MHz according to the Weissenau spectra) 'snapshots' of the uprising structure. Definitely, in the spectra we could not find any indication of a slowly drifting feature at the right frequencies between 113 MHz and 64 MHz during the 40 min interval (assuming radial propagation with a constant frequency drift of \(-1.225\) MHz min\(^{-1}\) respectively a mean velocity of about 90 km s\(^{-1}\)). What kind of 'flashes' lightened the snapshots of Figure 4?

Possibly, an answer can be found comparing the gross evolution of the radio burst complex (cf. Figure 1) with PROGNOZ-9 X-ray data (Figure 5). The PROGNOZ-9 data (Fárník, 1985) reveal an isolated soft X-ray event between about 07:30 UT and 10:30 UT reaching an intensity maximum near 08:45 UT. The event sets on

![Figure 5](image-url)
gradually and can be divided into a first, intermittently gradual growing phase (07:28–08:23 UT) and a stronger second phase (08:23–10:30 UT) being definitely correlated with the H-alpha flare F2. We see during the gradual phase in X-rays a general growth of radio continuum emission (clearly expressed, for instance, at 234 and 113 MHz in Figure 1) which can be already identified in the decimeter range (e.g., at a very sensitive 755 MHz record) (Loćans, 1985). Further, we note that the start of the recurring patterns at 113 and 64 MHz is in time with phases of X-ray enhancement especially in the 4–8 keV channel. The end of the 113 MHz pattern corresponds with the onset of a plateau in the soft X-ray curve. For the 64 MHz pattern we can not judge about this phenomenon because of the superposition with the strong F2 X-ray emission.

Evidently, the gradual soft X-ray intensity rise starts in the case of F1 as well as in the case of F2 about 10 to 15 min prior to the reported H-alpha flare start. This suits with the timing of soft X-ray precursors and flare starts described by Harrison et al. (1985). Because of the above mentioned time coincidence between the pre-flare soft X-ray enhancement of the flares F1 and F2 and the onset of the recurrent radio emission pattern at 113 and 64 MHz, respectively, our observation also supports the idea of the illumination of large coronal arches by X-ray flare precursors, this means the interrelation of X-ray and coronal loops (Lantos et al., 1981; Harrison, 1985). As already remarked the radio event seems to consist of at least two components in the time between F1 and F2:

1. A broad-band (dm-m) continuum rise indicating a generally enhanced Langmuir turbulence level in the coronal structures above the X-ray loops.

This component is perhaps identical with the broad-band continuum observed by Lantos et al. (1981).

2. The recurring intensity-time pattern which is observed in small frequency bands only, and which perhaps could be the radio signature of a transient forerunner structure (it is already observed near 0.5 \( R_\odot \) at 07:32 UT).

This slowly outward moving configuration is two times illuminated by energetic electrons accelerated near the soft X-ray flare precursor source region and propagating via large coronal loops to the radio source region.

So, the recurring fine structure pattern at 113 and 64 MHz is explained under similar assumptions like in Lantos et al. (1981) a simultaneous fine structure evolution in soft X-rays and 169 MHz radio data. In other words, the sudden appearance of the recurring 'noise storm chains' is independently switched on by the flare sequence F1, F2.

The discussed X-ray data are only the first part of a three hours duration event (Valčiček et al., 1985). According to Sheeley et al. (1983) such events are accompanied by a coronal mass ejection in somewhat more than 50% of all cases. Some features of the present event yield independent hints to the possible presence of a coronal mass ejection (CME) event:

- In NOAA No. 4263 there were an extremely distorted and nonpotential magnetic field configuration, strong proper motions of sunspots, and an activated, large filament system (see the vector magnetic field and H-alpha data presented by Hofmann et al., 1986).
– The H-alpha patrol observations of the Catania Astrophysical Observatory (Blanco, 1986) reveal intense structural changes in the filament system before the start of the flare $F1$ (e.g., between 06:45 and 07:35 UT, the onset time of the recurring pattern at 113 MHz!).

– The stability and clumpiness of the postulated propagating structure are reminiscent of visible light CME forerunners (cf. Jackson and Hildner, 1978).

– The estimated source dimension of $10^5$ km is in accordance with the thickness of the faint arc in front of a CME described by Gary et al. (1984), with the measured extension of the CME-related noise storm source studied by Lantos et al. (1981), and with the radio forerunner source diameter in the CME event discussed by Dulk et al. (1976).

Indeed, Dulk et al.'s (1976) observation of a stationary radio source during the passage of white light sources fits the picture assumed in our model (Figure 4). But in contrast to Dulk et al. (1976) we have not been able to trace a drifting from high- to low-frequencies continuum emission in spectrograph data, although we found comparatively high flux densities in the single frequency records. Possibly, this can be explained with the above mentioned triggering of the source illumination by the soft X-ray flare precursors of the flare sequence $F1$ and $F2$.

5. Conclusions

The described data confront us with the following essential facts:

1. The observation of the repeated, 40 min delayed appearance of a characteristic time sequence of type I-like bursts at 113 and 64 MHz (corresponding plasma levels are separated by about 0.2 to 0.35 $R_\odot$).

2. From an analysis and comparison of the fine structure of the two patterns some indications follow for an expansion of the postulated stable and radially outwards propagating plasma-magnetic field configuration which seems to proceed in an inhomogeneous background medium (remind of the slowly expanding head and the faster expanding tail).

Both approaches presented in the discussion – the interpretation of the pattern as noise storm chains or the explanation in terms of coronal transient forerunners and soft X-ray flare precursors – invoke the slowly propagating (about 90 km s$^{-1}$) disturbance (plasma-magnetic field structure). The flare precursor triggered illumination of accompanying coronal loop structures by energetic electrons more or less conclusively explains the existence of the recurring radio burst pattern.

Nevertheless, some strange characteristics of the observed radiation (burst duration, polarization) remain unexplained.

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