CORRELATION OF SOLAR DECIMETRIC RADIO BURSTS WITH X-RAY FLARES

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Abstract. Several hundred radio bursts in the decimetric wavelength range (300–1000 MHz) have been compared with simultaneous soft and hard X-ray emission. Long lasting (type IV) radio events have been excluded. The association of decimetric emission with hard X-rays has been found to be surprisingly high (48%). The association rate increases with bandwidth, duration, number of structural elements, and maximum frequency. Type III-like bursts are observed up to the upper limit of the observed band. This demonstrates that the corona is transparent up to densities of about $10^{10}$ cm$^{-3}$, contrary to previous assumptions. This can only be explained in an inhomogeneous corona with the radio source being located in a dense structure. The short decimetric bursts generally occur during the impulsive phase, i.e. simultaneously with hard X-rays. The times of maximum flux are well correlated (within 2 s). The HXR emission lasts 4 times longer than the radio emission in the average. This work finds a close relationship between decimetric and HXR emission with sufficient statistics offering additional information on the flare process.

1. Introduction

The decimetric radio bursts are a much neglected range of impulsive flare radiation. Their association with flares has never been systematically investigated. Here we compare them with the simultaneous occurrence of impulsive hard X-rays (HXR), commonly believed to be a signature of the primary energy release, and soft X-rays (SXR), the thermal radiation of the low temperature flare plasma. The aim of this work and future investigations is the understanding of decimetric emissions, their relation to other phenomena of the flare mechanism, and their diagnostic possibilities for the theory of flares.

In the traditional classification the decimetric radio emissions are divided into decimetric type III and type IV events and a broad branch of ‘decimetric pulsations’, called ‘DCIM’. Here we investigate the short-lasting emissions of less than 10 min. This selection excludes the classical decimetric type IV events, which generally last longer by definition. In this study it will be shown that the short decimetric radiation occurs during the impulsive phase, whereas type IV events are generally observed after the impulsive phase. The Zürich group had made attempts to classify the large variety of decimetric phenomena (Benz et al., 1983a; Wiehl et al., 1985). The DCIM type was found to consist of several classes suggesting different emission processes. An additional argument resulting from this study in favour of different classes is the fact that the HXR
association rate varies significantly in different subsets of DCIM events (from 41% to 69%).

In the *metric* wavelength range the association properties with HXR are well known. Noise storms are not associated. Type II and IV events are generally preceded by X-rays. The association of metric type III bursts with HXR is weak and deserves some comments. The occurrence of metric type III bursts in the absence of optical flares (particularly in form of type III storms at low frequency) has cast doubt on their identification as impulsive phase emission of flares. However, Kane (1972), Stewart (1978), and Kosugi (1981) have shown that flare-associated metric type III bursts are associated with hard X-ray events. Kane (1981) has found a rate of association of 3%. The rate increases with increasing starting frequency of the group of type III bursts. His result has encouraged us to anticipate a closer association for decimetric type III bursts. Kahler (1972) compared soft X-ray data (4 keV, 7 keV) with type III bursts at metric wavelength and in a part of the decimetric range. In the metric band (10–300 MHz) 53%, in the decimetric band (300–580 MHz) 82% of the type III bursts were associated with SXR events. Again, the association rate was found higher for bursts observed at higher frequency. However the high association rate between SXR events and flare-associated type III bursts does not imply a close relationship between those two phenomena, a major part of the coincidences may be incidental due to the long duration of the SXR emission.

In the *decimetric* range (300–1000 MHz) narrowband peaks termed ‘blips’ have been found to be well associated with impulsive microwave peaks (Benz et al., 1981) and HXR (Fürst et al., 1982). Benz et al. (1983c) have shown blips to be very similar to type III bursts except for their smaller bandwidth and were found to be accompanied by HXR events in 40% of all cases with simultaneous coverage.

In Section 2 observations and selection are described. The results presented in Section 3 show that the short decimetric bursts, and in particular the DCIM type, have a high probability for association with HXR events. They generally occur in the impulsive phase of flares. The new information is discussed in Section 4 including the role of the different classes of decimetric bursts and their possible diagnostic capabilities for acceleration and injection processes. The results and conclusions are summarized in Section 5.

2. Observations

2.1. Instruments

The radio data were limited to observations carried out between 1980, January 1 and 1981, December 31 with the Zürich analog spectrograph DAEDALUS (Tarnstrom, 1973) in the frequency range 100–1000 MHz, sweeping this range 4 times per second. Between 1980, August 31 and 1980, October 6 the frequency range was changed to 270–1170 MHz. The observations were recorded on film, allowing a maximum resolution of 0.25 s in time and a frequency resolution of approximately 3 MHz.
We selected radio events classified as DCIM in the list of ‘spectral observations of the station BLEIEN’ published in *Solar Geophysical Data*. This selection turned out to include also some decimetric type III bursts, but no type IV events (duration longer than \(\approx 10\) min). The ‘classical’, i.e. drifting decimetric type III bursts have been identified and included in the sample.

### 2.2. Selection

HXR data from the X-ray spectrometer on board the ISEE-3 satellite of 408 radio events and SXR data of 290 events were analyzed (Table I). The ISEE-3 instruments has been described by Kane *et al.* (1982b). The association was usually investigated in the 26–43 keV channel for HXR and in the 5.8–6.9 keV channel for SXR.

In the total sample of 408 events with HXR data 60 were ‘classical’ decimetric type III and 348 of DCIM type. The latter set, however, has been shown to contain 232 ‘type III-like’ bursts which are very likely also caused by streaming electrons (Benz *et al.*, 1983; Wiehl *et al.*, 1984). The rest (116 events) was ‘true DCIM’: i.e. broadband pulsations, grass-like chains, and millisecond spikes, as well as type IV-like patches. The detailed time structures of several events has been studied from digital data with time resolutions of 0.1 to 0.025 s. Since most of the radio bursts were initially classified as DCIM, this term will be used here to refer to all the selected events, so as to avoid possible misunderstanding.

### 2.3. Definition of Association

The terms ‘association’ and ‘correlation’ are used with a variety of meanings in the literature. The published association are more common then the strict correlation. *Association* is defined here as simultaneous enhanced emission in both radio and X-rays. *Correlation* on the other hand, is defined as a correspondence between temporal elements

### Table I

<table>
<thead>
<tr>
<th>DCIM/HXR association statistics</th>
<th>Hard X-rays</th>
<th>Soft X-rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data set</td>
<td>408 events</td>
<td>290 events</td>
</tr>
<tr>
<td>DCIM associated with HXR</td>
<td>195 events</td>
<td>117 events</td>
</tr>
<tr>
<td>Association rate</td>
<td>48 ± 3%</td>
<td>61 ± 5%</td>
</tr>
<tr>
<td>Rise time</td>
<td>110 ± 10 s</td>
<td>&gt; 230 s</td>
</tr>
<tr>
<td>Decay time</td>
<td>210 ± 20 s</td>
<td>&gt; 350 s</td>
</tr>
<tr>
<td>Duration of associated HXR events</td>
<td>320 ± 27 s</td>
<td>&gt; 570 s</td>
</tr>
<tr>
<td>Duration of associated DCIM-radio event</td>
<td>75 ± 5 s</td>
<td>51 ± 4 s</td>
</tr>
<tr>
<td>Delay times ((t_X - t_R))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>−75 ± 10 s</td>
<td>−150 ± 15 s</td>
</tr>
<tr>
<td>Maximum</td>
<td>2 ± 5 s</td>
<td>59 ± 8 s</td>
</tr>
<tr>
<td>End</td>
<td>170 ± 20 s</td>
<td>375 ± 22 s</td>
</tr>
</tbody>
</table>

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(peaks and minimas). *Detailed correlation* is a one-to-one correspondence of single elements. Correlation has been investigated for special subsets of DCIM events (for blips by Benz *et al.*, 1983c; and for decimetric type III bursts by Dennis *et al.*, 1984) and found to be complex in both cases. Detailed correlations are not studied systematically in this work, they will be the focus of future work with higher time resolution. Nevertheless the result was found, that the times of maxima flux in HXR and radio are correlated comparing the statistical average within the accuracy of measurement.

![Radio spectrogram](image1a.png)

**Fig. 1a.** Radio spectrogram (top) observed at ETH Zürich (Bleien) and HXR (26–43 keV) as measured by ISEE-3 on 1981, June 27. The decimetric emission consists of type III-like high drift and some narrowband bursts from 12:54.1 until 12:55.7 UT. A diffuse patch appears at high frequencies from 12:54.2 until at least 12:57 UT. At 12:58.4 UT type II burst starts at metric frequencies.

![Radio spectrogram](image1b.png)

**Fig. 1b.** A flare on 1980, November 4 observed by the same instruments as in Figure 1a. Broadband decimetric pulsations occurred from 12:46.9 until 12:48.7 UT. Some decimetric type III bursts with clear drifts appeared between 12:45.8 and 12:49.3 UT and a grass-like chain at 12:48.8 until 12:49.5 UT.
We define a decimetric burst to be 'associated with an X-ray event' if the decimetric emission occurred during the X-ray emission or if the time gap between the two kinds of emission was less than approximately one minute. This criterion for association is not very sensitive to the time gap between the two emissions. From the 195 decimetric events which were associated with HXR bursts only 8 exhibited a time gap between the two kinds of emission of greater than 0.1 min. Normally, the associated events occurred during the time of enhanced HXR emission.

In Figure 1 two complementary examples of radio-HXR association are presented: Figure 1a shows decimetric bursts with narrowband elements (blips) occurring well within the rise time of an impulsive HXR burst, during the decay time only a weak patch of continuum emission at \( \approx 1000 \) MHz is present. In contrast, in Figure 1b broadband pulsations are presented with the brightest part emitted during the decay time of the associated HXR burst.

2.4 Measurements

For each associated event we measured the starting time, the time of maximum emission, and the end time in both radio and hard X-ray emissions by reading the hard X-ray times from an intensity-time plot and the radio times from a dynamic spectrum on film. This allows for start and end time an accuracy of at least 0.1 min in both cases. The onset of decimetric emission is generally abrupt, well observed and does not depend much on the sensitivity of the instrument. For the timing of the HXR maximum we considered the highest peak during the radio emission, which was not always the highest peak in extended events. The analogous times of the SXR flare are measured with more uncertainty. Generally the start of SXR bursts is gradual and sometimes during the decay of a previous event. The time of maximum flux is not always well-defined. Sometimes data gaps prohibit an accurate measurement of start or end times. The measured SXR durations are lower limits.

Other parameters have been measured in radio events. We define an 'event' as ensemble of 'single elements'. Two different events must be separated in time at least by 10 min. A decimetric event may consist of up to several hundred elements, which often have not been fully resolved. In particular, this was the case in events consisting of millisecond spikes. We have determined the number of elements, their bandwidth, duration, drift, and diffuseness. Measured parameters of the whole event were: maximum frequency, minimum frequency, center frequency, bandwidth, and duration.

3. Characteristics of DCIM/X-Ray Association

3.1. General results

The analysis of a total of 408 decimetric events in the frequency range of 300–1100 MHz shows an association rate of 48\% with HXR events (Table 1). This is more than an order of magnitude larger than the association rate of metric type III events (Kane, 1981). In earlier studies, even classical type III bursts starting in the decimetric range
Fig. 2. The association rate (in percent) of short decimetric bursts with enhanced hard X-ray emission vs. various parameters of the radio emission (cf. definitions in text). The error bars are derived assuming a Poisson distribution for the number of associated events. The parts of histogram with poor statistics are modified by larger binwidths (at least 5 events per bin).

\( \nu > 300 \text{ MHz} \) were found to be associated only in 14\% of all cases (Benz et al., 1982). The high rate of association with HXR surpasses the expectations and seems to be an intrinsic feature of short-lasting decimetric emission.

Although we limited our study to association some of the decimetric events may in fact be correlated with HXR. There are two indications: (a) 96\% of the associated DCIM events occur during the duration of the associated HXR burst; (b) the maximum decimetric radio flux and the peak of the associated hard X-ray emission often coincide within the accuracy of our measurements (Table I).

Comparing with SXR events, the association rate of decimetric emissions amount to 61\%, similar to the value found by Kahler (1972) for type III bursts starting in the decimetric range. It may be interesting to note here that the associated SXR emissions usually consist of gradual bursts, but sometimes impulsive components at energies down to 5.8 keV have been noted.

Table I shows an interesting detail in the durations of associated DCIM bursts. The duration is smaller if associated with SXR than with HXR. This effect is caused by the larger number of short (mainly type III-like) DCIM events which become associated with decreasing X-ray energies.
3.2. Dependence of Association on Radio Parameters

Among the parameters that were measured from dynamic radio spectra we found 5 parameters on which the DCIM/X-ray association rate depends to a statistically significant degree (cf. Figure 2). The significance was established by the Student T-test

Fig. 3. Timing comparison of decimetric events relative to associated hard X-ray burst (top) and relative to associated soft X-ray burst (bottom).
of the linear regression coefficient at a significance level of 95%. The association rate for HXR events with respect to radio bursts varies as a function of the radio parameters. Figure 2 demonstrates that the association rate increases with increasing value of the following parameters in the radio event:
- number of elements;
- bandwidth of the event and of single elements;
- duration;
- maximum frequency.

Other parameters such as center frequency, drift, single element duration, and minimum frequency did not show any relation.

For SXR the dependence of the association rate on the same parameters is very similar. The higher rate of the SXR association (61%) causes saturation above certain limits: All decimetric events with a single element bandwidth > 600 MHz, or with event duration > 100 s, or with number of elements > 30 have been accompanied by SXR mission.

3.3 Occurrence of DCIM Bursts in Relation to HXR Event

The occurrence of radio bursts has been analyzed in relation to the X-ray flare. The delay times of start, maximum and end of the DCIM emission in relation to the associated HXR and SXR events is histogrammed in Figure 3 and summarized in Table I. The main results are:

1. The HXR onset starts predominantly before the DCIM emission, the average delay amounts to 75 s.

2. The times of maximum flux shows a striking coincidence within precision of measurements, \((t_X - t_R) = 2 \pm 5\) s. This average delay is less than the standard deviation and is therefore statistically not significant. In the most cases the correspondent HXR and DCIM peaks are really correlated.

3. The HXR emission endures much longer than the associated DCIM events, in the average the gradual tail of the HXR emission ends 170 s after the abrupt stop of the radio counterpart.

To determine the timing of the decimetric bursts in the history of the HXR flare, we normalized the radio delays by the time scale of the X-ray event. In the following we call the time from background to maximum (maximum time minus start time) shortly the ‘risetime’ and the time from maximum to background (end time minus maximum time) the ‘decay time’. Intervals before the X-ray maximum have been normalized by the X-ray rise time, intervals after the maximum have been normalized by the decay time. This phasing of the DCIM emission is shown in Figure 4. The probabilities of decimetric burst to occur before, during the rise time, during the decay time or after the HXR emission are given in Table II. From this phase analysis it is found that:

1. Most DCIM and type III events (68%) start in the rise time of the HXR emission. Only 12% of the events start before the HXR emission. Some such cases in connection with preflash HXR emission have been studied by Benz et al. (1983b).

2. The time of maximum radio flux is well synchronized with the associated maxima
Fig. 4. The phase of decimetric emission in relation to hard X-rays: (phase = −1: start of HXR; phase = 0: maximum HXR; phase = 1: end of HXR). The histograms represent the number of starts, maxima, and ends observed relative to a time scale normalized by HXR rise time (before maximum) resp. HXR decay time (after maximum).

TABLE II

Occurrence (percentage) of decimetric radio emission in relation to hard X-ray emission

<table>
<thead>
<tr>
<th></th>
<th>Before HXR</th>
<th>During rise time HXR</th>
<th>During decay time HXR</th>
<th>After HXR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start DCIM</td>
<td>12%</td>
<td>68%</td>
<td>18%</td>
<td>1%</td>
</tr>
<tr>
<td>Maximum DCIM</td>
<td>5%</td>
<td>43%</td>
<td>49%</td>
<td>2%</td>
</tr>
<tr>
<td>End DCIM</td>
<td>4%</td>
<td>9%</td>
<td>74%</td>
<td>12%</td>
</tr>
</tbody>
</table>

of the HXR flux. The phase of maximum flux fits a Gaussian distribution with an average $\Phi_m = -0.06 \pm 0.09$ (in units of HXR rise time). The delay of the time of maximum flux of the radio emission in relation to HXR emission is statistically not significant.

(3) The end of the radio emission occurs mostly during the decay time of the HXR emission. A large part of the decimetric emissions stop close to the time of maximum HXR emission. Long enduring radio emission bursts were not selected (but are anticipated among decimetric type IV bursts).

(4) The radio emission occurs generally during the HXR emission, i.e. enhanced HXR emission is present during most of the decimetric burst. The HXR emission
generally last longer (average HXR duration: 320 s) than the decimetric emission (average DCIM duration: 75 s, cf. Table I).

3.4. Occurrence of DCIM bursts in relation to SXR

The associated SXR emissions last about twice as long as the HXR. The delay times $t_{\text{SXR}} - t_{\text{DCIM}}$ spread over a larger time range. In the average the SXR emission starts $\approx 150$ s before the decimetric burst and stops $\approx 375$ s after the radio emission. We found that the SXR events generally are delayed in their maximum time relative to the HXR maximum, which is a well-known property. The peak SXR flux is on the average about 1 min after the well synchronized peak of the DCIM and HXR emissions. The decimetric radio emission is clearly better related to the HXR, i.e. the impulsive phase, than to the SXR flare.

4. Discussion

4.1. Coronal transparency

A very striking result is the fact that decimetric type III radiation has been noticed in this study up to the limit of the observed band at 1100 MHz. The minimal optical depth in a static, isothermal atmosphere ($T = 2 \times 10^6$) at 1000 MHz is calculated to be $\tau \geq 130$ for the fundamental emission, and $\tau \geq 3$ for the harmonic. Hence no fundamental plasma emission can be expected at 1000 MHz from a homogeneous atmosphere, at best a weak harmonic component. The most likely interpretation is that the radio emission originates in high density structures, which are embedded in a relatively low density atmosphere. The radio waves are then refracted to the low density region where absorption is reduced. The high density region may be a dense loop. The scale length in transverse direction can be much smaller than in a non-magnetized, isothermal atmosphere. The optical depth depends linearly on the scale height $\lambda$. The transverse density profile of a magnetic loop can be described approximately by a $e$-folding curve with a scale length of the loop radius. A scale length of 1000 km as derived from observations (e.g. Strong et al., 1984), would reduce the optical depth by two orders of magnitude making plasma emissions at 1000 MHz possible even for the fundamental.

In the metric range at 169 MHz the origin of radio emission in overdense structures has been establised from coronograph and radio observations (Trottet et al., 1982).

The high density structure source model for decimetric type III bursts does not exclude electron beams in ambient density regions. They will just not be observable in radio waves. The occasional complete absence of any decimetric emission in some large HXR flares may then be interpreted by a lack of inhomogeneity in the source.

4.2. Association rate and maximum frequency

A most remarkable result of our analysis is the further increase of the association rate with HXR at high frequencies (average for decimetric type III-like events: 45%). In contrast, the great majority of metric type III bursts is not associated with any detectable
HXR enhancements. The observations suggest a physical relation between the maximum frequency (resp. starting frequency) and the DCIM-HXR association rate. In the following we consider three different physical explanations.

The simplest interpretation assumes a unique relation between electron density and altitude (e.g. barometer equation). A higher maximum frequency indicates a higher source density and hence lower altitude of the deepest part of the type III source. An increase in the type III-HXR association with the increase in maximum frequency is to be expected since it implies smaller separation between the radio and HXR sources (Kane, 1981). The proximity of the two sources is confirmed from SXR and HXR density observations. Strong et al. (1984) measured densities of $4 \times 10^9 \text{cm}^{-3}$ at a typical flare region and of $3 \times 10^{11} \text{cm}^{-3}$ for a preheated region correspond to plasma frequencies between 500 and 5000 MHz.

A second consideration results from an empirical point of view. A close relationship between the HXR intensity and the starting frequency during a single event has been observed on several occasions (Kane and Raoult, 1979; Rust et al., 1981; Kane et al., 1982a). Furthermore a correlation between HXR peak flux and the starting frequency of the associated radio events (blips) has been established (Benz et al., 1983). The higher association rate with increasing maximum frequency is obviously related with higher HXR peak flux and is therefore a threshold effect of HXR sensitivity.

A third reason in favour of a better association rate is a theoretical argument. The optical depth $\tau$ increases quadratically with the frequency. Hence the high frequency radio waves are stronger attenuated by collisional damping of the ambient plasma than the lower frequencies. Therefore the high frequency radio bursts require statistically higher intensities to escape than the low frequency bursts. Assuming that the emission in the radio frequency range is proportional to the HXR flux, the high frequency radio bursts are associated with greater HXR flare importance. As a consequence, the increasing maximum frequency of the decimetric emissions would imply a selection of great HXR flares, and a better correlation is expected.

The second argument is not proved with sufficient statistics. The third reason assumes a proportionality between HXR flux and the energy release in the radio source. Therefore the first argument seems to be the most likely interpretation of the better association rate with increasing maximum frequency.

4.3. Association and Other Decimetric Parameters

The analyzed observations exhibit furthermore a significant increase of the DCIM/HXR association rate with the increase of the following radio parameters: large bandwidth, long duration, number of elements.

Why does a large bandwidth lead to a better association rate? The bandwidth is defined as difference of maximum and minimum frequency. In terms of an isothermal coronal model, a large bandwidth corresponds to a large size of the radio emission source in altitude. Since the density decrease rawly exponentially with altitude, a constant height interval correspond to less frequency variation in high altitudes. We have analyzed the association rate in dependence of the minimum frequency and no signifi-
cant relation has been found. For these reasons we can neglect the variations of the minimum frequency. Therefore the better HXR/DCIM association rate with increasing bandwidth is related to better association rate with increasing maximum frequency. This similar behaviour is indicated in Figure 2. Not all decimetric emissions can be explained with the type III model, but the same argument holds for any plasma emission model.

How is the better association rate related with the number of elements of the radio event? The many single peaks of a complex decimetric event indicate frequent injections of energetic electrons. If an observed radio burst needs a minimal number of energetic electrons, this threshold determines the number of single bursts observed on Earth. Hence a large number of single elements in the radio event indicates greater flare importance and the better association rate is due to the selection effect of big HXR flares.

Since duration and number of elements have been found to be correlated, the same explanation may also hold for the observed correlation of association rate and radio duration.

We divide the decimetric emissions into type III-like and 'true DCIM'. The former group is represented predominantly in the decimetric range (73% of all cases), the latter group contains no homogeneous characteristics (see Section 2.2). The two groups are disticted in the DCIM-HXR association behaviour as well: In the set of type III-like DCIMs only 45% are accompanied by simultaneous HXR emission, in the rest group of 'true DCIMs' the same association rate improves to 69%. Why are streams of energetic electrons emitting type III-like decimetric radiation less associated with HXR than other classes of DCIM events? Provided that absorption is low (i.e. emission in high density structure, cf. Section 4.1) only few electrons (order of $10^{30}$) are necessary to produce a radio signature. This is 4 orders of magnitude lower than the detection threshold of HXR at ISEE-3. Under favorable conditions radio observations can be much more sensitive than HXR leading to a relatively low association rate.

5. Conclusions

The comparison of 408 short duration decimetric events (DCIM) with HXR and SXR data shows the following results:

1. The association rate of decimetric bursts is comparatively high: 51% are associated with HXR, 61% with SXR. Metric bursts have a much lower rate (particularly when compared with HXR) presumably since their sources are at a much higher altitude than the energetic flares seen in X-rays.

2. The decimetric events start usually (in 68% of all associated cases) during the rise time of the HXR emission and stop (in 74%) during the decay time. They are clearly a phenomenon of the impulsive phase of flares. The comparison with SXR is much less favorable. The maximum emission of decimetric and HXR radiation agrees in the average within the limits of our measurements. We can call this behaviour DCIM/HXR correlation. This again demonstrates the intimate relation between energetic electrons causing HXR and decimetric bursts.
(3) The association rate improves with higher starting frequency and larger bandwidth. This behaviour can be interpreted in the simplest way by the decreasing distance between the HXR source and the source of the associated ratio burst.

(4) The association rate of decimetric bursts increases with duration and number of elements. These parameters roughly express the importance of the radio event and are related to the importance of the HXR flare.

(5) The association rate varies in different DCIM subgroups. The type III-like group is associated with HXR emission in 45%, the rest group of ‘true DCIMs’, such as broadband pulsations, grass-like chains, millisecond spikes and type IV-like patches, in 69%.

(6) The appearance of decimetric radiation during an HXR flare is determined by the following two conditions:

   (i) the exciter of the emission (e.g. beam or losscone distributions) must exist at a sufficient strength;

   (ii) the source must be located (at least partially) in a high density structure to overcome free-free absorption in the corona.

(7) The most popular acceleration mechanisms, shockwaves and plasma turbulence, may both produce plasma emission. The start of all classes of decimetric emissions is usually delayed in relation to the start of HXR emission. The acceleration process of the HXR emitting electrons apparently is not visible at decimetric wavelengths, at least not in the beginning of the impulsive phase. It is unclear how such an energetic process can avoid producing radio emission unless it is generally situated at ambient electron densities exceeding $10^{10}$ cm$^{-3}$.

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