Characteristics of Two Simple Microwave Bursts

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Abstract. We present simultaneous microwave and X-ray data for two microwave bursts with simple impulsive time profiles. The 17 GHz images show compact sources, and in the one case for which we have simultaneous soft and hard X–ray images, they also show compact sources coincident with the radio source. One of the bursts is barely detected in soft X–rays, yet has a moderate 17 GHz flux.

1 Introduction

In this paper we study the properties of microwave events with simple impulsive time profiles similar to those which we have found to be characteristic of millimeter–wavelength bursts. In recent years we have used the BIMA 3-element interferometer to observe solar flares at 3 mm wavelengths. We have shown that millimeter emission of flares in the impulsive phase is a good diagnostic of the most energetic electrons accelerated in flares. Millimeter emission arises from electrons with energies in excess of 1-MeV – it is unlikely that electrons with energies below 0.5 MeV contribute any significant millimeter emission; such energetic electrons are produced in flares of all sizes, including flares so small that their x-ray signature is barely detectable; and their behavior is not consistent with their energy distribution being a simple extension of the distribution of electrons with energies below 200 keV which produce the observed HXR below 100 keV ([5]; [3]).

A second class of events was detected by us ([6]; [7]). In this class, we found a remarkable similarity in the time profiles of emission associated with the impulsive onset of a flare. In a large fraction of flares, the impulsive phase emission at mm wavelength consists of a rapid rise ($\sim$ 5 seconds) linear in time to a sharp peak, followed by an exponential decay with a decay constant of order 15 seconds.

It seems that for these events the production of MeV-energy electrons follows a very similar pattern. The simplest interpretation of the morphology seems to be that the electrons are accelerated, or somehow injected into a coronal loop, on a timescale of several seconds (the linear rise), but acceleration then ceases abruptly and the number of electrons in the corona decreases exponentially. This linear rise-exponential decay time profile is often not shared by the microwave emission or the hard x-ray emission in the same events. Since we interpret the nonthermal impulsive-phase millimeter emission as a diagnostic of MeV-energy electrons, this means that they have a property not shared by the lower-energy electrons responsible for the hard x-rays (typically 25 - 100 keV) and microwaves (probably 100 - 500 keV). There is also some evidence that the spectral energy distribution of the millimeter-emitting electrons differs from that of the hard x-ray-emitting electrons.

The above results regarding the MeV-electron producing "ordinary" flares and "simple" flares were based upon non-imaging 3 mm interferometer data. It is important to investigate how low in the frequency range these special "simple" flares extend, and what is their spectral and spatial characteristics. So, we selected two "simple" flares observed by the Nobeyama Radio Heliograph operating at 17 GHz. These simple 17 GHz flares were observed as part of an on-going study of 17 GHz active regions and their flare productivity. The spatial and polarization information for these flares comes from NRH, and the spectral information comes from the Toyokawa solar monitoring data at 9.4, 2.0 and 1.0 GHz.

2 Observations

The two simple flares observed on May 25 and May 29 originated in AR 7515 which was followed from May 23 to June 2, 1993, as part of a study of active region evolution and flare productivity. These two flares as observed at 17 GHz were chosen because of the similarity of their time profile to the 3 mm time profiles of a class of 3 mm bursts observed with the BIMA telescope: their sharp and linear rise to maximum followed by an exponential decay, and their short duration. Since these bursts were observed with NRH and Toyokawa patrol telescopes, we were able to study their spatial and spectral characteristics.

3 Event of May 25

Figure 1 shows the time profile of this burst observed at 17 GHz on May 25, 1993. Also shown in the figure are the total power time profiles at 9.4 GHz as well as the Yohkoh HXT and GOES time profiles. Based on the closeness of the 9.4 and 17 GHz fluxes and the lack of detection at 3.8 GHz, we believe that the turnover frequency lies between 9 and 17 GHz. Note that the 17 GHz time profile is the correlated power at the longest base lines, rather than the total power profile which was not sensitive enough to detect this burst.

The 25 May burst has a simple source structure. The 17 GHz flux peaks at 01:14:38 UT and is polarized (-8%) during the impulsive phase. The decay phase is unpolarized ($< 1\%$). The HXT time profile agrees reasonably well with the 17 GHz profile; however, its almost equally rapid decay as the rise is followed by a small post-burst increase which does not seem to have a 17 GHz counterpart.

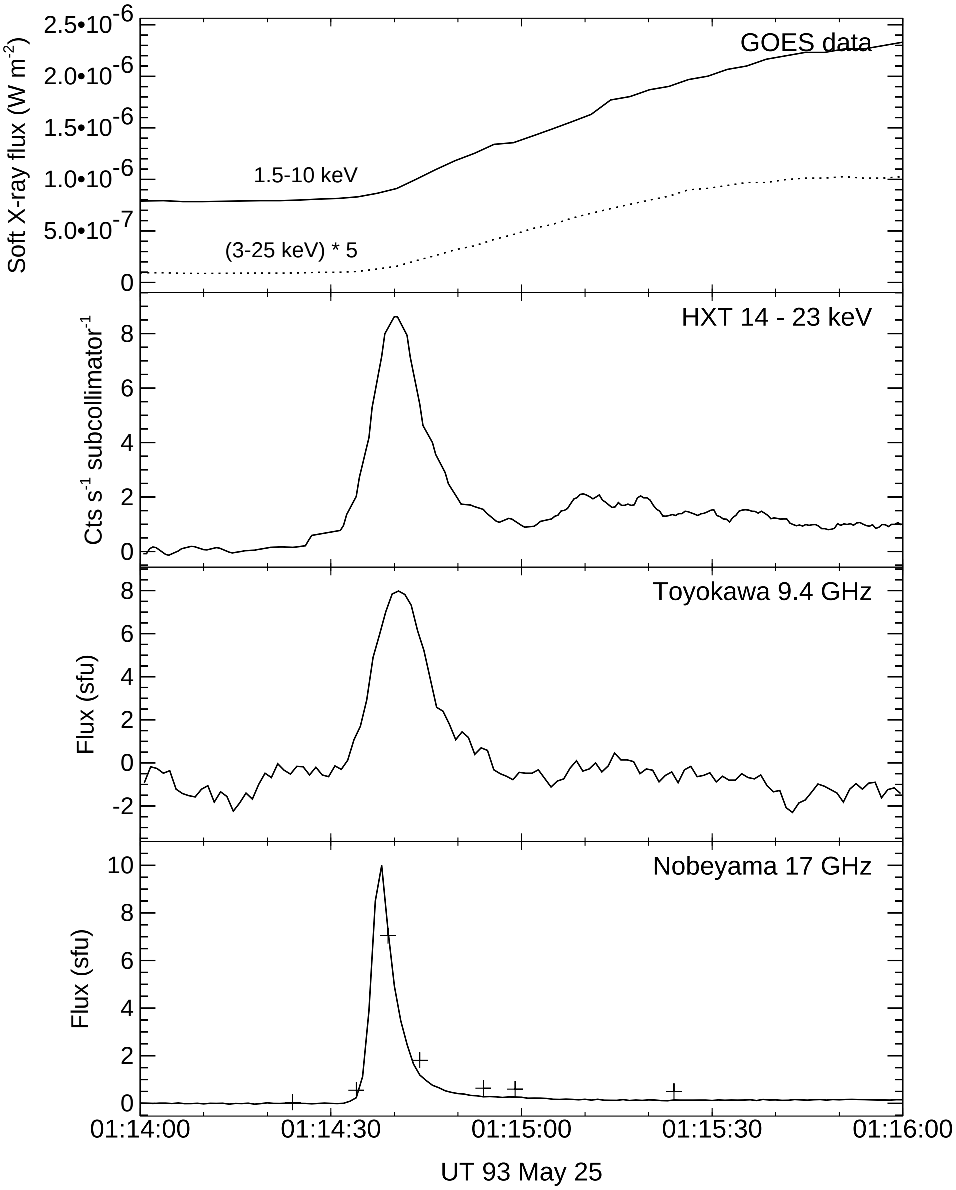

Fig. 1. The time profile of the 1993 May 25 01:14 UT flare in soft X–rays, hard X–rays, at 9.4 GHz and 17 GHz. The crosses in the bottom panel show the times of 17 GHz images used in the analysis; the solid line in the bottom panel is the time profile of the correlated power on the longest baselines of the Nobeyama array, corresponding to the flux in small spatial scales.

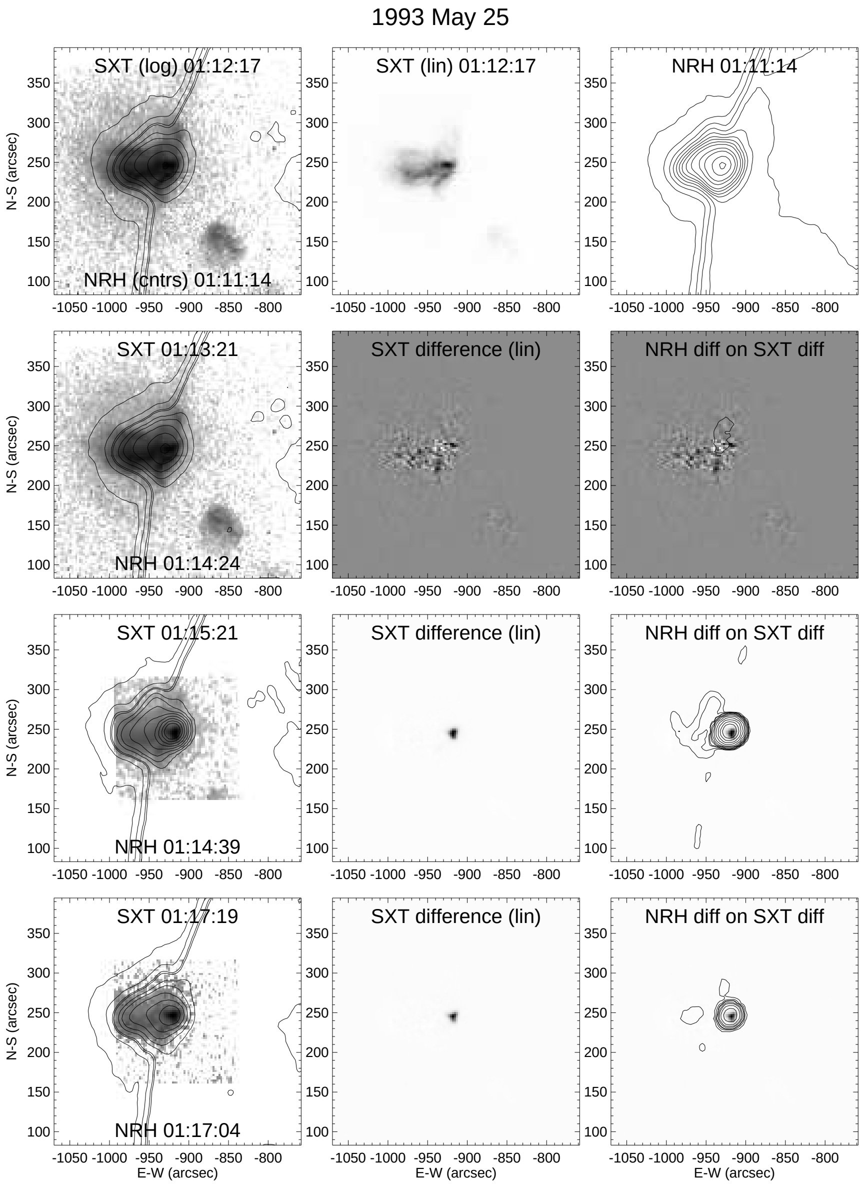

Fig. 2. Images of the 1993 May 25 01:14 UT flare in soft X–rays and at 17 GHz at selected times. The top row of panels shows the preflare 17 GHz images (17 GHz contours on SXT image, log display, left panel; SXT image with linear intensity display, middle panel; 17 GHz contours, right panel). In each subsequent row the left panel shows the 17 GHz contours overlaid on the SXT image at the corresponding time; the middle panel shows the SXT image with the preflare image subtracted; and the right panels show the same preflare–subtracted SXT image with contours of a preflare–subtracted 17 GHz image overlaid.

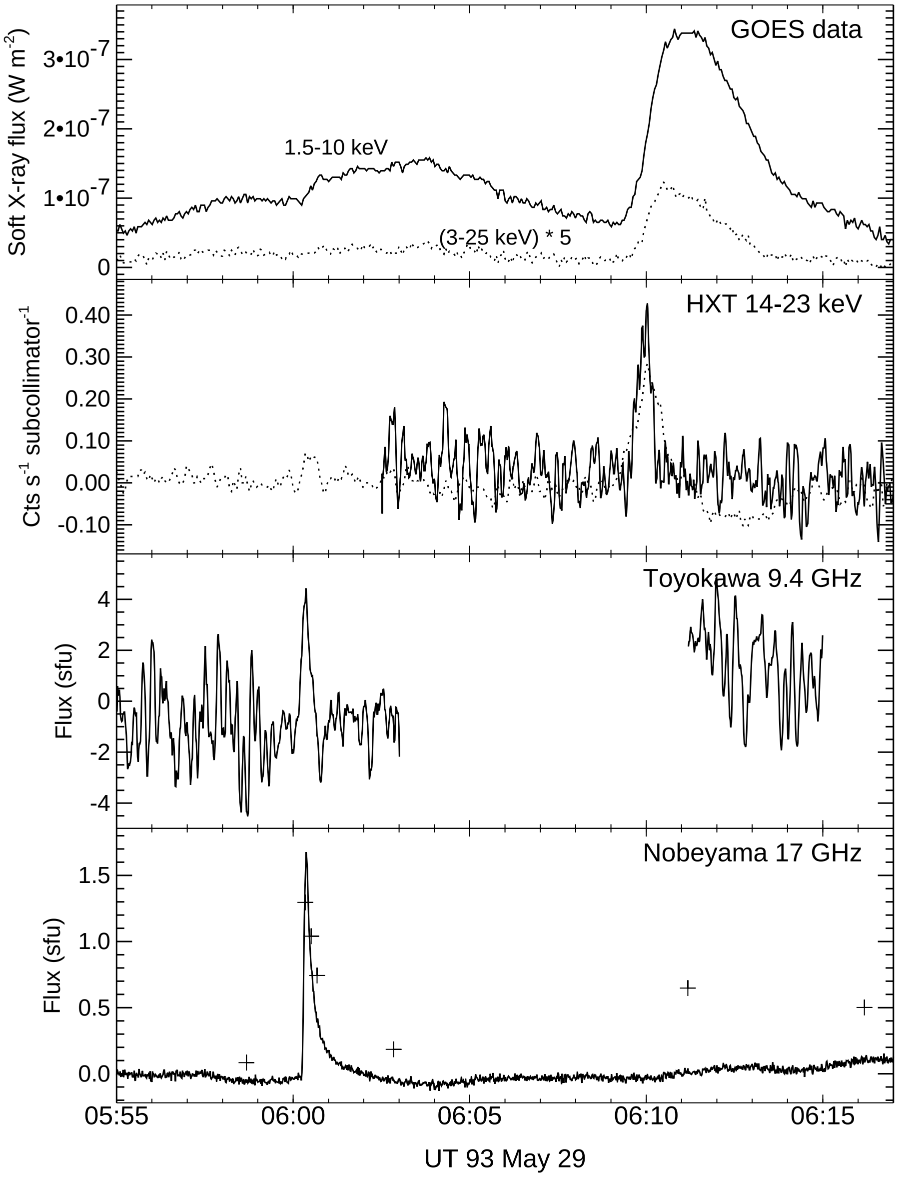

Fig. 3. The time profile of the 1993 May 29 06:00 UT flare in soft X–rays, hard X–rays, at 9.4 GHz and 17 GHz. The broken line in the second panel is the derivative of the GOES 1.5-10 keV profile, a proxy for the hard X-rays during the first flare when no hard X-ray data were available.

Figure 2 shows the 17 GHz and SXT images of the pre–flare and flare emission and their coalignment. The first and second row of panels are preflare times, except that the second row has been preflare–subtracted to show the noise level associated with the subtraction process. The source structure of 17 GHz emission is simple and compact (i.e., unresolved at less than 15″). The SXT source (although at a later time) is aligned almost perfectly with the 17 GHz source. A hard X–ray image made with photons accumulated over the whole flare (not shown) is also perfectly coincident with the 17 GHz and soft X–ray sources. The soft x-ray source is remarkable for its very small size and the fact that it shows no expansion as it evolves.

4 Event of May 29

The May 29 burst at 17 GHz occurred at 06:00 UT when no HXT data are available (Fig. 3). The only data available are a single long-exposure full-disk SXT through the Dagwood filter at 06:00:50. All active regions are saturated in this and other similar images, but it shows one very narrow vertical saturation spike which could be coincidental with the Nobeyama radio source. The 3-25 keV GOES data show no rise in SXR emission at all at this time. There is a suggestion of a small rise in the 1.5 - 10 keV soft x-rays but it is superimposed on a gradual rise which started much earlier. Both SXT and HXT had impulsive emission at 06:09 UT when there was no obvious 17 GHz emission in the correlation plot (Fig. 3). However, the images do show that there is 17 GHz emission at 06:09 UT corresponding to the impulsive HXR and SXR emission: it appears clearly on 17 GHz contour plots (Fig. 4). Other sources present are steady, and are associated with the fact that subtraction was carried out with an image made almost 1 hr earlier, and there has been some evolution in the region. Like the 25 May event, this burst at 06:00 UT is also polarized (-20%) during the implusive phase. The burst source is simple and compact at its impulsive phase (Fig. 4). The SXR source at 06:09 UT is more complex, having several component sources, of which one component has an impulsive rise and decay in correspondence with the HXR time profile. The radio data for the second burst do not show an impulsive profile, and are only very weakly polarized (-2%).

5 Discussion

The 17 GHz event of 1993 May 29 (06:00 UT) is remarkable for the apparent lack of associated x-ray emission (Figure 3). In the absence of SXT or HXT data, we can attempt to estimate the hard x-ray profile associated with this event by differentiating the soft x- ray time profile and invoking the x-ray "Neupert effect" (e.g., Dennis & Zarro [1]). Clearly, differentiating the 3 - 25 keV soft x-ray light curve implies a very low level of hard x-ray emission. The small event at 06:09 UT, by contrast, shows a significant enhancement in soft x-rays but negligible radio emission.

Kosugi, Dennis & Kai ([2]) have shown that the ratio of the peak hard x-ray flux to the peak 17 GHz flux varies by only a factor of 3 over a very large sample of flares. The low microwave flux observed in the 06:09 UT event is consistent

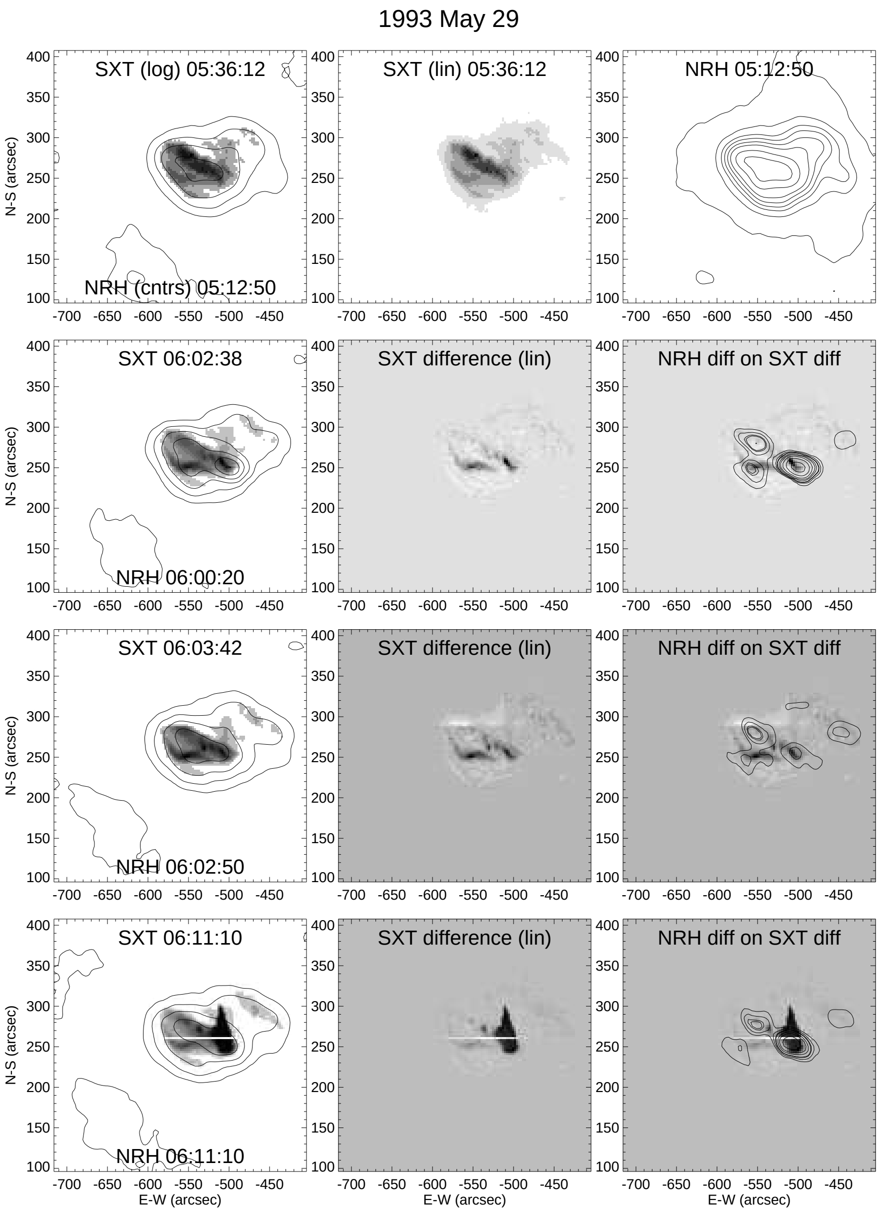

Fig. 4. Images of the 1993 May 29 06:00 UT flare in soft X–rays and at 17 GHz at selected times. In each row the left panel shows the 17 GHz contours overlaid on the SXT image at the corresponding time. The middle panels show the SXT images with a preflare image subtracted, while the right panels show the same preflare–subtracted SXT image with contours of a preflare–subtracted 17 GHz image overlaid.

with this relationship, and with the small size of the event in x-rays (GOES class B7). However, the 06:00 UT radio burst is clearly not consistent with this relationship.

Remarkably, we know of one other event which seems to be inconsistent with the Kosugi et al. relationship, and it shares several other properties consistent with the 06:00 UT event presented here. The previous event (from 1989 June 23) was analyzed by White et al. [4]: it showed a linear rise to a sharp peak in 6 seconds (for this event, 6-7 seconds), followed by an exponential decay with an e-folding decay time of 18 seconds ($\sim$ 14 seconds for this event). It reached a peak flux of 1.7 sfu at 8 GHz, 15 GHz and 86 GHz (coincidentally the May 29 burst has a similar flux at 17 GHz). The GOES data showed no enhancement in soft x-rays in the 1989 event. The earlier event showed some other peculiarities not necessarily shared by this event: in that case, the event was not detected at 5 GHz with an upper limit of order 0.1 sfu implying a very sharp low frequency cut-off as well as a flat spectrum above 8 GHz. On 1993 May 29 the 3.8 GHz microwave patrol data unfortunately have a data gap at the time of the event, so we do not have other information on its spectrum. The impulsive nature and weak or absent thermal signatures leave little doubt that it represents acceleration of energetic electrons without the usual conversion of a significant amount of energy to hot thermal plasma as is usual in a flare. Such radio–rich events are not yet understood: White et al. [4] discussed a number of models for the earlier events.

In the case of the 93 May 25 flare, this event was mostly remarkable for the short rise and fall of the 17 GHz emission: a rise time of 4 seconds and a decay time of about 6 seconds. It has a time profile similar to those observed by White [6] at 3mm. It has a very simple source structure: compact and coincident in position in SXR, HXR and 17 GHz radio. It is polarized around its peak. However, unlike the May 29 event, it is a simple but ordinary flare in the sense that it has SXR associated with it.

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