SHORT DURATION SOLAR MICROWAVE BURSTS AND ASSOCIATED SOFT X-RAY EMISSION*

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Abstract. During the time period of November 1968 to March 1970, 259 15.4 GHz impulsive microwave bursts have been identified of which 147 had associated 2–12 Å soft X-ray bursts. Average durations, rise times, and decay times for the microwave bursts are 2.9 ± 2.4 min, 0.9 ± 0.8 min, and 2.2 ± 2.1 min, respectively.

Total durations and decay times for the X-ray events display a wide range of values from a few minutes to several hours. Rise times for 50 % of the events fell in the range of 2 to 7 min. A significant fraction (32 %) of the X-ray events may exhibit a flux enhancement prior to the main outburst.

For 85 % of the flare cases, the X-ray event begins simultaneously with or before the microwave event. In 91 % of the cases the X-ray event peaks later than the microwave event. The average delay is 3.0 ± 1.9 min with 50 % of cases in the range of 0 to 4 min.

The X-ray flux increases are significantly correlated with the microwave flux increases, having a correlation coefficient of 0.43 (> 99.9 % confident).

1. Introduction

Using a combination of ground-based and satellite instrumentation, solar flares are being studied over a wide range of wavelengths from radio through optical to X-ray. From the time-intensity relationships of these various emissions a detailed description of the flare process and of the physical parameters in the flare region is evolving (e.g., Švestka, 1970 and 1973; Syrovatskii and Shmeleva, 1972; and Vorpahl, 1972).

The purpose of this report is to further delineate parameters about the association of 2–12 Å soft X-ray bursts with short duration 15 GHz microwave bursts. X-ray data were obtained from Explorers 33 and 35 (Van Allen, 1967) and microwave data from the University of Iowa North Liberty Radio Observatory and AFCRL Sagamore Hill Observatory. In the time period between November 1968 and March 1970, 147 cases of coincident μ-wave and X-ray flares have been examined to determine the relationships of start times, time of maxima, flux, and energy. These parameters are shown to be in general agreement with the studies of Teske and Thomas (1969), Culhane and Phillips (1970), and McKenzie (1970) based on fewer cases which were derived from different instrumentation operating in different wavelength and frequency ranges.

2. Microwave and X-Ray Flare Model

Figure 1 shows a schematic representation of a microwave (μ-wave) and X-ray flare as related to the non-thermal electron acceleration mechanism. In the time

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interval t_0–t_1 some soft X-ray flares exhibit a small enhancement in X-ray activity prior to significant X-ray events (Hudson *et al.*, 1969; Teske and Thomas, 1969; and Culhane and Phillips, 1970). Teske and Thomas (1969) have shown that this pre-burst enhancement (precursor) can start up to 15 min before the earliest reported μ-wave enhancement. Syrovatskii and Shmeleva (1972) and Švestka (1973) suggest that this precursor phase of the X-ray event may be related to turbulent heating of the plasma by a strong electric current in a current layer and that the X-ray emission is from thermal bremsstrahlung from this hot plasma region.

The eruptive phase of the flare in the interval t_1–t_5 is attributed to electrons accelerated by pulsed electric fields by Syrovatskii and Shmeleva (1972) and Švestka (1973).

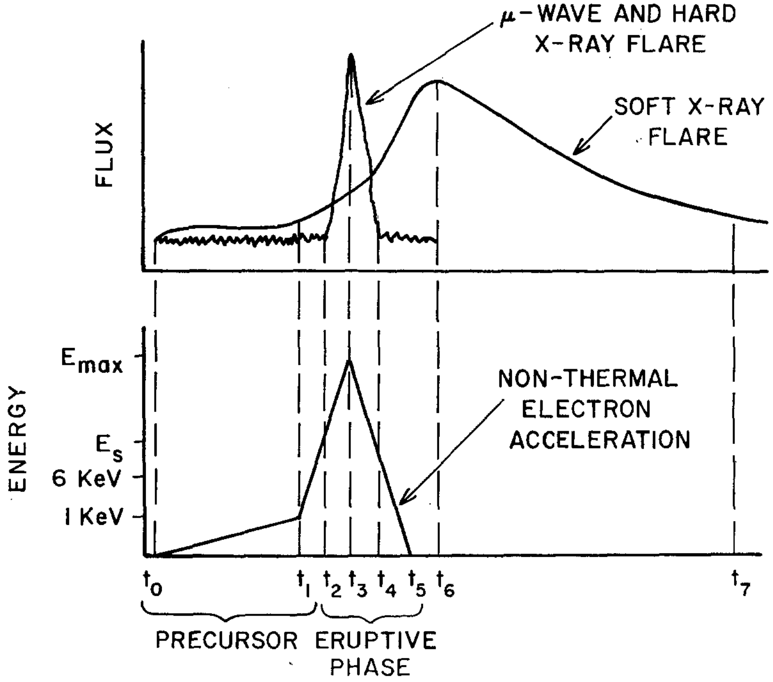

Fig. 1. A schematic time profile of a microwave and soft X-ray flare and the associated electron acceleration mechanism. The time t_0–t_1 indicates a possible precursor stage, in which turbulence and/or compression of the flare region results in heating of the region in advance of the main outburst. The time t_1–t_2 represents the onset of non-thermal electron acceleration. Electrons accelerated during this time are not of sufficient energy to produce significant microwave radiation, but do produce soft X-rays by thermal bremsstrahlung emission. The time t_2–t_4 is the time during which electrons are accelerated to energies greater than the minimum energy (E_s) required to produce significant microwave radiation and to the maximum energy at t_3. This time should correspond to the time of peak intensity of both the microwave and hard X-ray burst. After time t_4 no further microwave radiation should result, although properties of the acceleration mechanism in the time t_4–t_5 may affect the intensity and peak time of the soft X-ray burst. The time t_3–t_6 represents the peak-to-peak time delay between the microwave and soft X-ray bursts. This time depends on the details of the acceleration mechanism and the parameters of the medium which affect the energy transfer from the non-thermal electrons to the surrounding plasma. The time t_6–t_7 represents the decay phase of the soft X-ray burst due to radiative cooling, conduction, or expansion.

As copious numbers of electrons are accelerated through the detectable X-ray energy range (1–6 keV for Explorers 33 and 35) a significant amount of soft X-ray emissions begins (t_1–t_2). At time t_2 the accelerated electrons are sufficiently energetic (of energy E_s) to begin emitting microwave radiation by gyrosynchrotron emission in magnetic fields of a few hundred gauss and non-thermal (or hard) X-ray bursts (>10 keV (de Jager, 1967)) due to non-thermal bremsstrahlung (Hold and Ramaty, 1969; Takakura, 1972). The similarity in the time intensity profiles for μ-wave and hard X-ray flares in the time interval t_2–t_4 is well established (e.g., Kundu, 1965; Arnoldy *et al.*, 1968; Hudson *et al.*, 1969; and Vorpahl, 1972). For a magnetic field of 200 G in the microwave source region, E_s would be in the range 50–100 keV (Holt and Ramaty, 1969).

At the time t_3 the acceleration mechanism is accelerating electrons to the maximum energy which corresponds to the time of maximum μ-wave and hard X-ray emission. Takakura (1969) estimates this maximum energy $E_{\max}$ to be 500–1000 keV; Švestka (1970) argues that $\mathrm{E}_{\max}$ could be even greater than 10 MeV, but that electrons at these energies are not significant in the flare region since they lose energy rapidly by synchrotron emission. The rise time for the hard X-ray and μ-wave burst (t_2–t_3) is on the order of 1 min (Vorpahl, 1972) and seems to be related directly to the rise time of the acceleration mechanism (Švestka, 1970).

Vorpahl [1972] has found a decay time (t_3–t_4) for the hard X-ray burst ranging from 15 to 100 s. The time for the energetic electrons to be de-energized to E_s by synchrotron, bremsstrahlung and collisional losses is probably short compared to the decay time (e.g., Takakura and Kai, 1966; Holt and Ramaty, 1969). Because of the fine structure and multiple peaks in some events, the acceleration is assumed to be continuous during the impulsive burst although non-uniform (Vorpahl, 1972).

At t_5 the acceleration phase is assumed to be completed although the soft X-ray flare may not have reached its peak. For wavelengths from 0.2 Å (McKenzie, 1972) to 12 Å (Teske and Thomas, 1969) the X-ray maximum occurs later than the maximum of the μ-wave emission (0.4 to 6 min). In general these soft X-ray events are thought to be due to thermal bremsstrahlung radiation from a plasma of $15–30 \times 10^6$ K (e.g., Drake, 1971) although there is evidence that for some events a non-thermal component may be present (e.g., Culhane and Phillips, 1970; and Landini *et al.*, 1972). This heating is thought to be due to collisional losses of the accelerated electrons (e.g., Neupert, 1969; Syrovatskii and Shmeleva, 1972). Teske and Thomas (1969) and McKenzie (1972) suggest that the peak-to-peak time delay (t_3–t_6 in Figure 1) between the X-rays and μ-waves is due to the time duration of trapping of the energetic electrons and the precise evolution of the emitting volume. This trapping time could range from a few seconds to a few minutes according to Teske and Thomas (1969) which is in rough agreement with the observed value.

Culhane and Phillips (1970) suggest that the decay phase of the soft X-ray event (t_6–t_7) is due to plasma cooling. Several cooling mechanisms seem possible: radiation, collisions, and conduction.

In this paper average values and the range of these different time intervals are reported specifically for 15 GHz microwave impulsive bursts and 2–12 Å X-ray events to facilitate further quantitative studies of the acceleration mechanism, energetic electron spectrum and physical properties of the flare region.

3. Instrumentation and Event Selection Criteria

For the observations of the microwave bursts, data from the 15.375 GHz radiometer of the University of Iowa North Liberty Radio Observatory (NLRO) (Wende, 1968), and from the monthly lists of solar bursts at 15.4 GHz published by the Air Force Cambridge Research Laboratory Sagamore Hill Radio Observatory were used. Due to pointing and calibration uncertainties, dependable values for flare flux changes could not be obtained from the NLRO data (Shawhan *et al.*, 1971). Thus all values of 15.4 GHz flare flux changes were taken from the Sagamore Hill listings.

Soft X-ray data were obtained from the University of Iowa X-ray experiments aboard the spacecraft Explorer 33 and Explorer 35 (Van Allen, 1967). The experiments measured solar X-ray flux in the range 2–12 Å.

All data were taken in the period November 1968 to March 1970.

Using the NLRO data, any flux enhancement which rose three standard deviations above the RMS fluctuations of the background noise and which was of 10 min duration or less was categorized as an event. The start time was defined as that time when the signal rose more than one standard deviation (σ) out of the noise; the peak time as the time when the amplitude reached a maximum, and the end as that time when the declining flux once again reached the 1 σ level. Flare durations were defined as the end-minus-start time. Time was judged to be accurate to better than 0.5 min.

The Sagamore Hill values were obtained from their catalog of solar bursts. The start and peak time of each event, the flare duration, the peak-to-preflare flux change, and the mean or average flux change were recorded for each event. In selecting events all events were chosen whose duration was less than 10 min, and whose morphological profile classified it as a simple 1, simple 2, or simple 3 burst (Kundu, 1965). Other morphological types, such as complex flares or those with post-burst increases were not used. Complex flares possess structure which may indicate multiple injections of energetic electrons. Parameters concerning the energy redistribution effects can not be obtained from the present data analysis method. Post-burst increases are probably due to thermal emission (e.g., Shimabukuro, 1970; Wende, 1968).

Soft X-ray bursts were considered correlated with the microwaves flares if the radio burst occurred during the X-ray flare. For the bursts observed at Sagamore Hill, data were available at more than one frequency.

When the X-ray flare was identified the start time was defined as that time when the X-ray flux rose to a value of 20% above the pre-flare background flux. The end time was similarly defined as being when the soft X-ray flux declined to a value 20% above the background flux. Values of the soft X-ray peak to background flux were determined from the tabulated data. The procedure was to take the mean of the ten data points preceding the flare catalog-determined start time. The peak flux change was then defined as the maximum of the X-ray flux minus the mean pre-flare flux. In a few cases this procedure could not be followed as the soft X-ray burst associated with the microwave flare occurred less than 820 s (time for ten data points) after the end of a previous X-ray event. In these cases as many points as possible were taken which subjectively constituted the pre-flare flux. It is estimated that this process did not result in errors of greater than 10%.

Figure 2 shows the time development of three events observed at the NLRO for which soft X-ray flares are correlated. It is to be noted on events A and C that a

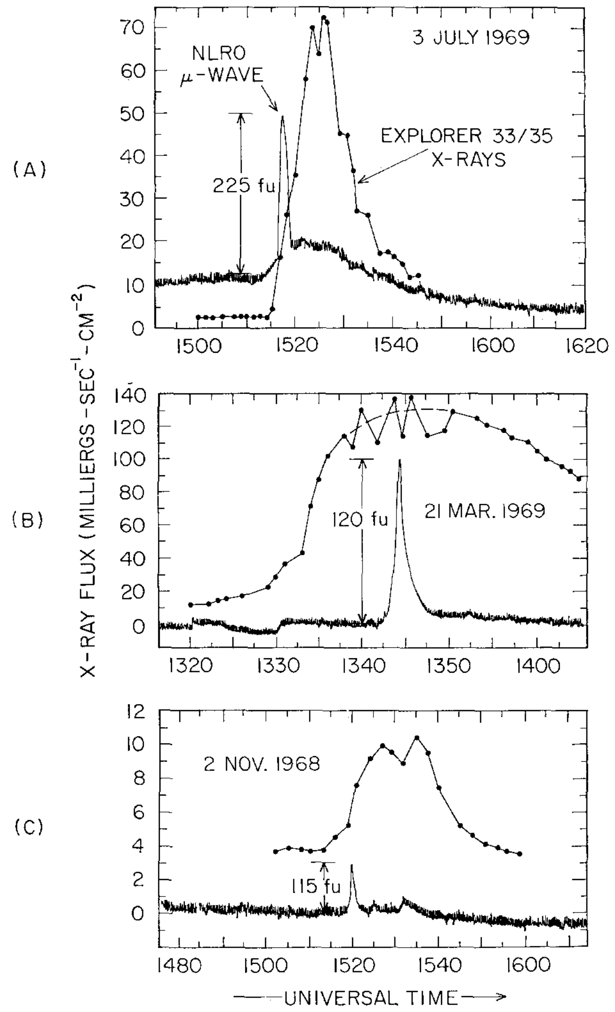

Fig. 2a–c. Time-intensity profiles of the X-ray and microwave flux fort hree events included in this study. In each case the continuous record is a tracing from the NLRO 15.4 GHz radiometer chart record. The individual points represent 82 or 164 second averages from the Explorer 33 or Explorer 35 2–12 Å X-ray detectors. For these cases the X-ray emission begins earlier than the impulsive microwave flare, but peaks later.

lower-lying radio enhancement whose time profile is similar to that of the X-ray burst is observed. These low-profile flares are presumed to be thermal emission. These enhancements comprise the microwave counterpart of the thermal soft X-ray flare. They are to be contrasted with the impulsive bursts which have time profiles which are completely different than the soft X-ray time profile. This is a strong indication that the impulsive bursts are non-thermal in nature.

Further discussion of the data selection and a listing of the events is given by Spangler (1973).

4. Microwave and Soft X-Ray Relationships

4.1. EVENT STATISTICS

Of the observed total of 259 microwave bursts, 147 were found to have associated soft X-ray emission. Of the remaining 112 events 39 occurred during soft X-ray data gaps. Seventy-four were found which were not associated with observable X-ray events. If only those radio flares which occurred during a period of soft X-ray data coverage are considered, 147 out of 220, or 67%, of all such events had accompanying detectable soft X-ray emission. In the studies by Culhane and Phillips (1970), Teske and Thomas (1969), and McKenzie (1972) the X-ray flares rather than radio flares were used as the control group. Culhane and Phillips did correlate X-ray bursts with radio bursts, but they considered flares at any radio frequency. This criterion allows a more general class of radio bursts than centimetric impulsive bursts. In their investigation they found all but 1 of 38 radio flares occurred during periods of X-ray activity, and 26 out of the 38 radio flares had associated X-ray flares.

4.2. IMPULSIVE MICROWAVE BURST CHARACTERISTICS

4.2.1. *Peak Intensity Distribution*

An investigation of the peak intensity distribution of the microwave flares using the Sagamore Hill classification scheme (Castelli and Guidice, 1972) gave the following results. Of 209 bursts for which accurate flux measurements were available, 186, or 89%, were in Class 1 (0–50 flux units); 22, or 11%, were in Class 2 (50–500 flux units); and only one was observed to be of Class 3 (>500 flux units). This would seem to indicate that greater radiometer sensitivity would significantly increase the number of such events observed.

It is worth noting that soft X-ray flares are far more numerous than microwave impulsive bursts with the present radiometer sensitivity. Soft X-ray bursts occur typically several times a day (Drake, 1971), whereas the type of radio event of interest to this study occurred with a frequency of less than one per day.

4.2.2. *Duration, Rise and Decay Time Distribution*

In Figure 3 is shown the distribution of μ-wave flare durations (t_2–t_4 in Figure 1) deduced from the list of 259 events identified by Spangler (1973). These times are

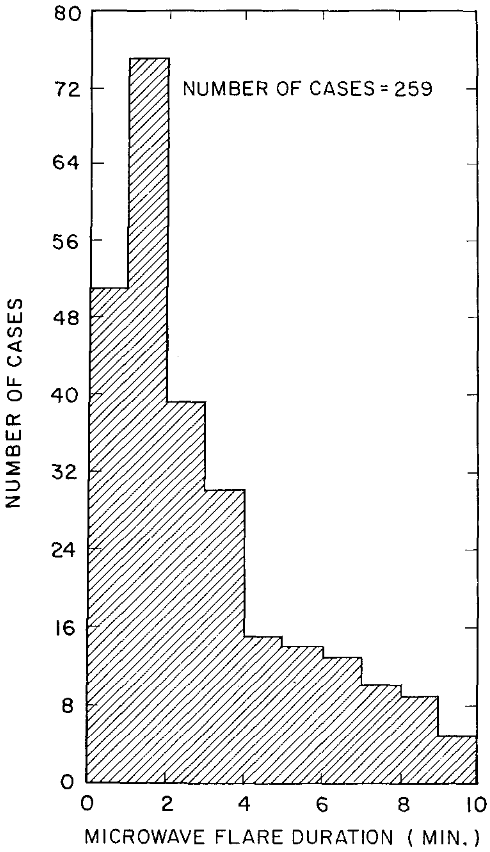

Fig. 3. A histogram of the durations for the 259 microwave bursts observed in this study. The average value of the microwave burst duration is 2.9 ± 2.4 min.

distributed up to the selection cutoff of 10 min. The most probable value for the flare duration is 1 to 2 min for 75 out of 259 flares (26%) and 75% of the cases have a duration of less than 4 min. The average value is 2.9 min with a standard deviation of ±2.4 min. For these same events the average rise time (t_2–t_3 in Figure 1) is 0.9±0.8 min with a minimum value of 0.1 min and a maximum of 5.0 min. Likewise the decay time average is 2.2±2.1 min with extrema of 0.1 and 9.0 minutes. These quantities are summarized in Table I.

4.3. SOFT X-RAY BURST CHARACTERISTICS

A wide range of values of X-ray rise times, decay times, and durations were observed. Decay times and durations ranged from a few minutes to several hours. The half of the events with the shortest decay times decayed in 3 to 18 min. The range was 5 to 29 min for the half of the events with the shortest durations.

In Figure 4 is shown the distribution of rise times (t_0–t_6 in Figure 1) for 137 events

TABLE I

Burst characteristics of 15 GHz μ-waves and 2-12 Å soft X-rays (November 1968 to March 1970)

A. *Microwaves (259 events)*

Quantity	Time interval (Figure 1)	Average min.
Duration time	t_2–t_4	2.9 ± 2.4
Rise time	t_2–t_3	0.9 ± 0.8
Decay time	t_3–t_4	2.2 ± 2.1

B. *Soft X-rays (147 events)*

Quantity	Time interval (Figure 1)	Most probable (50 % of events) min.
Duration time	t_0–t_7	5–29
Overall rise time	t_0–t_6	2–7
Precursor duration	t_0–t_1	7–15
Main rise time	t_1–t_6	2–5
Decay time	t_6–t_7	3–18

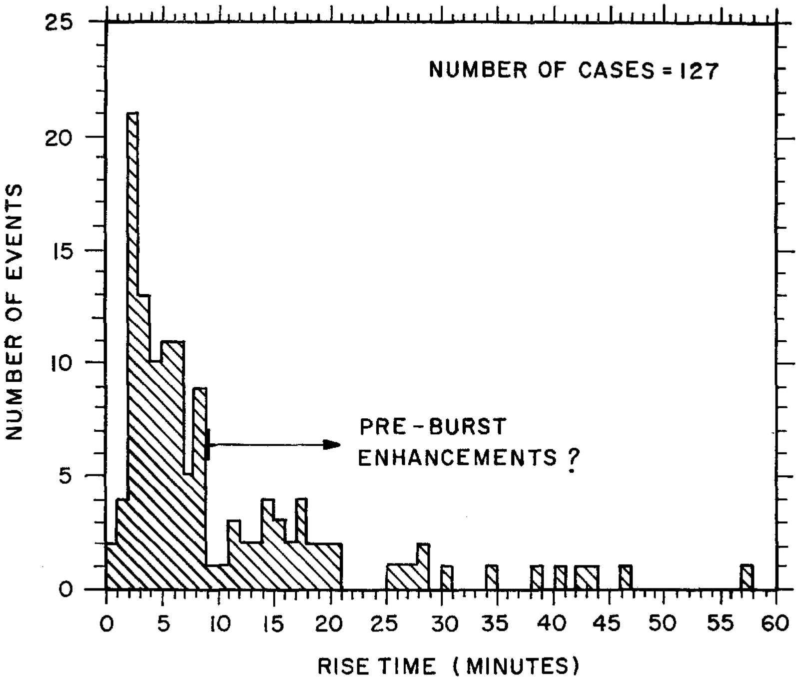

Fig. 4. A histogram of the soft X-ray rise time (t_0–t_6 in Figure 1) for 127 X-ray flares associated with impulsive microwave flares. The distribution shows a pronounced maximum at 2 to 3 min, although observed values range from less than a minute to over one hour. Half of the events fall in the range of 2 to 7 min. The events with rise times greater than 9 min (32 %) may include events with pre-burst flux enhancements.

in which this parameter could be reliably measured. Included are events which probably have pre-burst enhancements. The distribution has a pronounced peak at rise times between 2 and 3 min. Observed values range from 1 min to greater than one hour with 50% of the events in the range of 2–7 min. For times greater than 9 min, the distribution seems to have a discontinuity which may be due to events with pre-burst enhancements. For example, a small enhancement is evident between 1322 and 1333 UT for the event in Figure 2A. However, all the events have not been examined in detail. Breaking the distribution at the 9 min point, the events with rise times between 0 and 9 min have an average rise time of 4.6 ± 1.8 min (t_1–t_6) with 50% of the events falling in the range of 2–5 min. Approximately 41 of 127 events (32%) have rise times greater than 9 min, and thus may exhibit pre-burst enhancements. Considering the 5 min average rise time of the eruptive phase (t_1–t_6 in Figure 1), the most probable

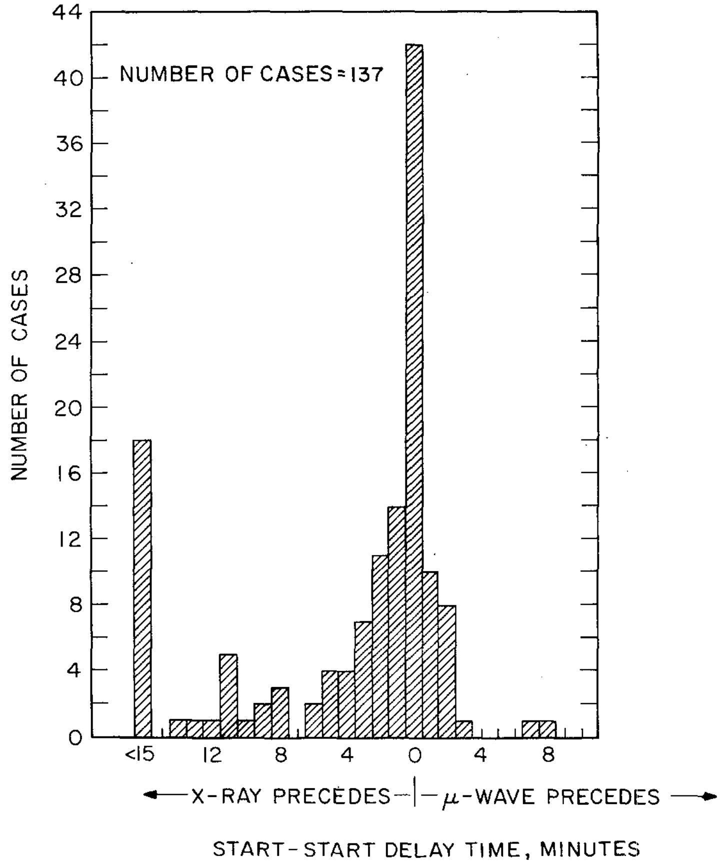

Fig. 5. A histogram for the time delay between the start of the X-ray flare and the start of the microwave flare (time t_1–t_2 in Figure 1) for the 137 cases in which this parameter could be determined. Half of the events have simultaneous start times ± 1.5 min and 85 % of the events occur simultaneously or with the X-rays starting earlier. In 23 % of the flares the X-ray emission began 8 min or more before the impulsive microwave burst which may be further evidence of pre-burst enhancements.

duration (t_0–t_1) for 50% of the events with possible pre-burst enhancements range from 7 to 15 min. These values are also summarized in Table I.

Although the results of the durations and decay times of the X-ray bursts are in general agreement with the values obtained by Drake (1971) in treating an ensemble of more than 4000 events, the most frequently occurring rise time for X-ray flares accompanying impulsive microwave bursts (2–3 min) is shorter than that found by Drake for soft X-ray bursts in general (4–5 min). A possible explanation is that the great number of non-thermal electrons present during a microwave burst heat up the soft X-ray flare region more quickly than is the case when they are absent.

4.4. START-TO-START DELAY TIMES

Figure 5 gives the frequency histogram for the time delay between the start of the microwave and X-ray flares. The start-to-start delay time is defined as the difference in time between the onset of the microwave burst and the onset of the X-ray burst (t_1–t_2 in Figure 1).

Half of the events had simultaneous start times to within ±1.5 min. In 85% of the cases observed the X-ray burst began simultaneously with or previous to the micro-

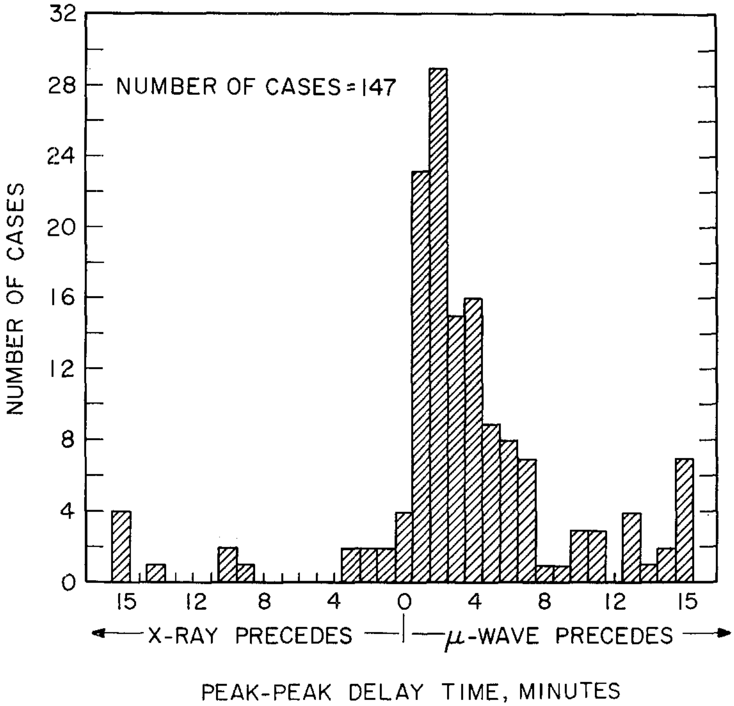

Fig. 6. A histogram for the time delay between the microwave flare peak and the soft X-ray flare peak (time t_3–t_6 in Figure 1) for the 147 events for which this parameter could be determined. In 133 out of 147, or 91 %, of the cases the microwave burst peaks simultaneously (±0.5 min) or before the X-ray burst. In 50 % of the cases the delay time is in the range 0–4 min. The most probable delay time is 2 ± 0.5 min, and the average value of the distribution is 3.0 ± 1.9 min.

wave flare. Of the 21 events (15% of total) in which the microwave burst onset was previous to the X-ray burst onset, all but 3 were in the time delay range 0.5–2.5 min. The significant number of events (32 of 137 for 23%) where the X-ray event precedes the microwave flare by 8 min or more is probably due to the X-ray pre-burst enhancements.

4.5. PEAK-TO-PEAK DELAY TIMES

Figure 6 is in agreement with the findings of Teske and Thomas (1969) and Culhane and Phillips (1970) concerning the microwave and X-ray peak delay times. Although in most cases X-ray emission precedes the onset of the microwave burst, in 133 out of 147, or 91%, of the cases the microwave burst peaks simultaneously (±0.5 min) or before the X-ray peak (t_3–t_6 in Figure 1). In 50% of the cases the delay time is in the range of 0 to 4 min. As is clear from Figure 6, the most probable delay time is 2±0.5 minutes. The average for this distribution is 3.0±1.9 min.

4.6. FLUX-FLUX RELATIONSHIP

One of the most important experimental relationships in terms of identifying mechanisms responsible for observed emission is a comparison of the intensity in different spectral regions.

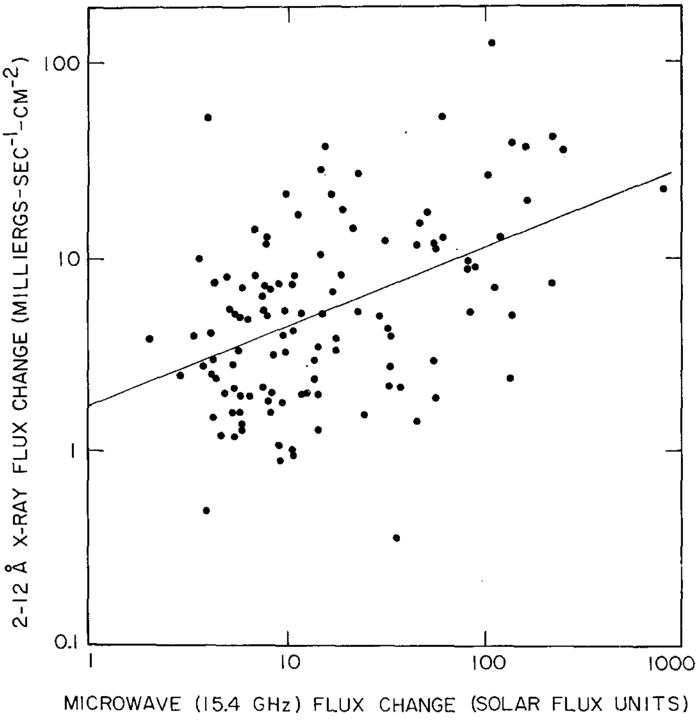

Fig. 7. A plot of peak flux change of the microwave burst versus peak flux change of soft X-ray flare. A least squares fit to the data gives an intercept of 1.7±0.4 mergs s^{-1} cm^{-2} and a slope of 0.39±0.08. The correlation coefficient for this relationship is 0.43 with a confidence of >99.9%. The relationship is similar to that found by Teske and Thomas (1969).

TABLE II

Summary of impulsive microwave and associated soft X-ray characteristics

Source	Number of cases	X-ray wavelength (energy)	μ-wave frequency	X-rays start before μ-waves	X-rays peak after μ-waves	F_x versus F_μ
Teske and Thomas (1969) March 9, 1967–December 31, 1967 OSO III	42	8–12 Å (1–1.5 keV)	2800 MHz	0–1 min[a]	3–6 min	0.63 correlation $> 99.9\,\%$ confidence
Culhane and Phillips (1970) October 27, 1967–May 8, 1968 OSO 4	34	3–4 Å (3–4.5 keV)	> 1000 MHz	up to 15 min[b]	2 min	
This study November 1968–March 1970 Explorer 35 and 33	147	2–12 Å (1–6 keV)	15 GHz	0 ± 1.5 ($23\,\% > 8$ min)	3.0 ± 1.9	0.43 correlation $> 99.9\,\%$ confidence
McKenzie (1972) March 9, 1967–June 30, 1968 OSO III	81	1–1.5 Å (8–12 keV) < 0.6 Å (> 22 keV)	'μ-wave'	0.04 min	0.87 min ± 0.16 0.40 min ± 0.14	$\int F_\mu$ versus F_x significant

[a] Low sensitivity. High sensitivity gives 5 to 23 min which includes precursors.

[b] Including precursor events.

Two previous studies have considered the relationship between the μ-wave and X-ray flux changes. Culhane and Phillips (1970) found no relationship between the two fluxes while Teske and Thomas (1969), with a smaller number of cases, found evidence for a positive correlation between the two intensities. The results of the present study are shown in Figure 7.

The least squares fit to Figure 7 gives an intercept of 1.7 ± 0.4 merg s^{-1} cm^{-2} and a slope of 0.39 ± 0.08. The correlation coefficient for this relationship was 0.43 which has a confidence factor of >99.9% that the correlation is real (Young, 1962).

For comparison, the flux-flux data of Teske and Thomas (1969) was subjected to the same analysis. This was done by scaling data from Figure 3 of their paper. The least squares fit to their data gave an intercept of 4.3 ± 0.6 merg s^{-1} cm^{-2} and a slope of 0.45 ± 0.08. The correlation coefficient for the relationship was 0.63 which also gives a confidence factor >99.9%. Within the statistical error limits both sets of data give basically the same significant relationship between the μ-wave and X-ray fluxes.

4.7. ENERGY-ENERGY RELATIONSHIP

A comparison of total X-ray energy between 2–12 Å and radio energy at 15.4 GHz released during the flare showed no statistically significant relationship.

The results of this study concerning the start-start and peak-peak times and the flux-flux relationships are tabulated in Table II with comparison results from previous studies.

5. Discussion

The parameters for the 15 GHz microwave bursts and 2–12 Å X-ray bursts listed in Table I are generally consistent with the results of previous studies and consequently with the schematic model presented in Figure 1 as discussed in Section 2.

The entries in Table II are ordered in decreasing X-ray wavelength (increasing energy) to exhibit the significant change in peak times found from several studies. The X-rays peak after the μ-waves by 0.4 min at <0.6 Å but by up to 6 min at 8–12 Å. This quantitative relationship provides a test for detailed models of the flare processes.

Based on the model in Figure 1, a good correlation would be expected between the maximum microwave flux change and the maximum X-ray flux change. Decorrelation, however, can result because of microwave absorption, the emission of microwaves and X-rays from different volumes and the escape of energetic electrons from the flare volume.

6. Conclusions

(a) 67% of impulsive microwave events (15.4 GHz) identified between November 1968 and March 1970 have accompanying 2–12 Å soft X-ray emission.

(b) Average durations, rise time, and decay time of 2.9 ± 2.4, 0.9 ± 0.8, and 2.2 ± 2.1 min, respectively, have been deduced from 259 μ-wave events.

(c) For 147 X-ray flares the most probable (50% of events) duration, rise time, and decay times for the main event are 5–29, 2–7, and 3–18 min, respectively. The early enhancement of X-ray emission in 32% of the cases may be significant. The duration of this pre-burst enhancement is in the range of 7–15 min for 50% of the events. The average main flare rise time is 4.6 ± 1.8 min.

(d) For 85% of the cases observed the X-ray event begins simultaneously with or previous to the μ-wave flare. Half of the events had simultaneous start times ± 1.5 min.

(e) For 91% of the cases observed the X-ray event peaks simultaneously with or after the μ-wave flare. For 50% of cases this delay is in the range of 0 to 4 min. The average delay value is 3.0 ± 1.9 min. In comparison with results at different X-ray wavelengths (Table II), a significant dependence on wavelength is confirmed – the longer the wavelength, the longer the peak delay time.

(f) A peak flux relationship has been fitted to the data:

$$F_x = F_\mu^{(0.39 \pm 0.08)} + 1.7 \pm 0.4 \text{ merg cm}^{-2} \text{ s}^{-1}$$

where F_μ is in 10^{-22} W m^{-2} Hz^{-1}. For this expression, the correlation is 0.43 with a confidence of >99.9%.

(g) X-ray flares associated with impulsive microwave events show a tendency to rise to peak intensity more rapidly than do X-ray flares in general. A significant fraction of such X-ray flares may manifest a pre-burst enhancement.

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