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Solar X-ray Bursts in Relation to the Microwave Bursts & SIDs

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Solar X-ray bursts recorded by Explorer 37 satellite in the bands 0·5-3, 1-8 and 8-20 Å have been analyzed in relation to their morphological types and peak time attainment at the different wavelength bands. They have also been examined in relation to (i) solar microwave bursts recorded at different frequencies by Sagamore Hill and Manila solar radio observatories and (ii) sudden ionospheric disturbances recorded all over the globe. It has been found from both statistical analysis and actual time profile of X-ray bursts that they are mainly of three different morphological types, namely, (i) impulsive, (ii) gradual rise and fall (grf) and (iii) gradual rise and quick fall (grqf) in contrast to their earlier classification into two types only. Impulsive X-ray bursts were found to be more associated with bright H_α-flares and also with different microwave bursts and SIDs, in comparison to those for the 'grf' and 'grqf' types of X-ray bursts. The peak of the X-ray bursts at a shorter wavelength is attained in most of the cases earlier than that at a longer wavelength, in general, and this time separation ($+\Delta t$) is more prominent with increasing difference between the bands of the X-rays. X-ray bursts having small Δts are more associated with bright H_α-flares, while bursts with large Δts are found to be more associated with H_α-flares having large durations. It has further been observed that the association of the X-ray bursts, in general, with SIDs in the presence of microwave bursts is about double in comparison to that in the absence of microwave bursts.

1. Introduction

THE EARLIEST experiments on solar X-rays during solar flares were made by Byram, Chubb, and Friedman[1] using rockets. Since then various satellite-borne detectors have recorded solar X-ray bursts in several bands and a large amount of data have thus been accumulated. The present state of knowledge on the subject of solar X-rays has been reviewed from time to time by different authors[2-4]. However, results obtained by different investigators either from isolated short duration rocket observations or from prolonged satellite observations often treat the X-ray bursts, in general, without any consideration to their different morphological types, if any. Moreover, there exists some controversy in regard to the time of attainment of peak flux[5,6] of the X-ray bursts at different bands. The purpose of the present investigation has been to analyze the different types of X-ray bursts and also to examine the nature of association of the different types of X-ray bursts with (i) the microwave bursts of different morphological types, (ii) intensity-wise classes of H_α-flares and (iii) different types of sudden ionospheric disturbances (SIDs).

2. Collection of Data

Data from SOLRAD-9 (Explorer 37 satellite) present the peak flux, peak time, duration of the X-ray bursts in the bands 0·5-3, 1-8 and 8-20 Å. The starting time of an X-ray in any band is reported as to be the time (UT) when the flux in the 1-8 Å exceeds 3×10^{-3} erg/cm^2/sec. Hence, in the present analysis much weight is given to the data in the 1-8 Å band. Data of the microwave bursts at different microwave frequencies, viz. 1415, 2695, 4995, 8800 and 15400 MHz recorded by Manila and Sagamore Hill Solar Radio observatories as well as the data of solar H_α-flares and different sudden ionospheric disturbances reported by different stations all over the world have been used in this statistical analysis. An association between an X-ray and a microwave burst was assumed whenever they occurred within ± 2 min of the starting of the X-ray burst, while an association between an X-ray, H_α-flare and SID was assumed when the former occurred within ± 5 min of the occurrence of the other events. All these data as obtained from the Solar Geophysical Data books issued by NOAA, USA, have been examined for the period January 1969—December 1971.

3. Analyses of Data and Results

Solar X-ray bursts at any band when critically examined seem to be of different morphological types. Some typical plots of X-ray bursts recorded in the band 1-8 Å are shown in Fig. 1. This clearly shows the existence of three different types of X-ray bursts, namely, (i) impulsive (ii) gradual rise and fall abbreviated as 'grf' and (iii) gradual rise and quick fall or 'grqf' in contrast to the two definite classes of solar microwave burst, namely, 'impulsive'

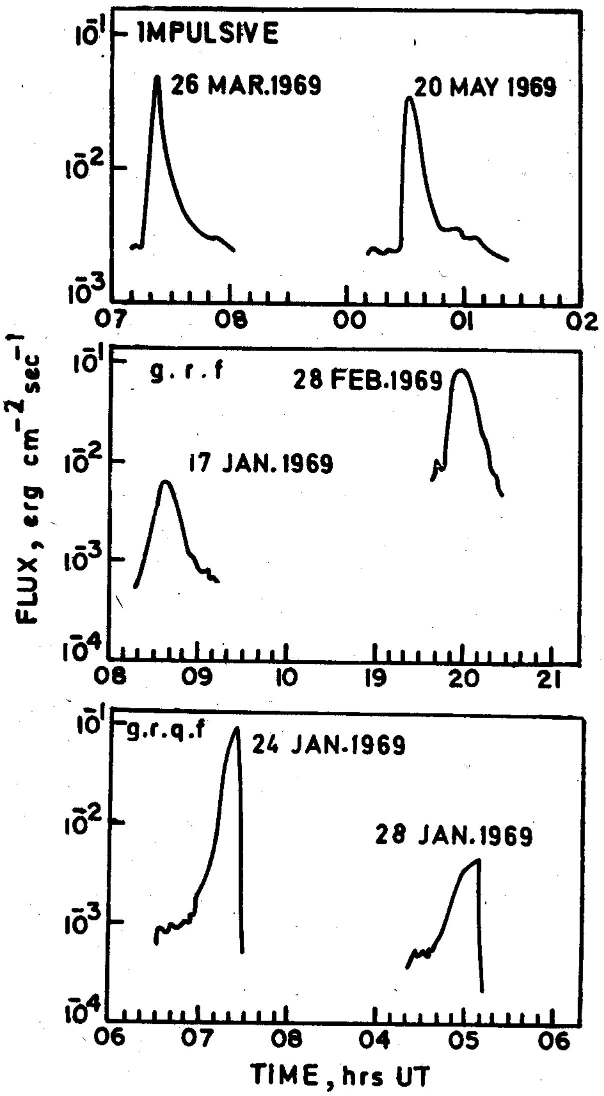

Fig. 1—Some typical plots of impulsive, gradual rise and fall (grf) and gradual rise and quick fall (grqf) X-ray bursts in the 1-8 Å band with the date of occurrence of each burst indicated therein

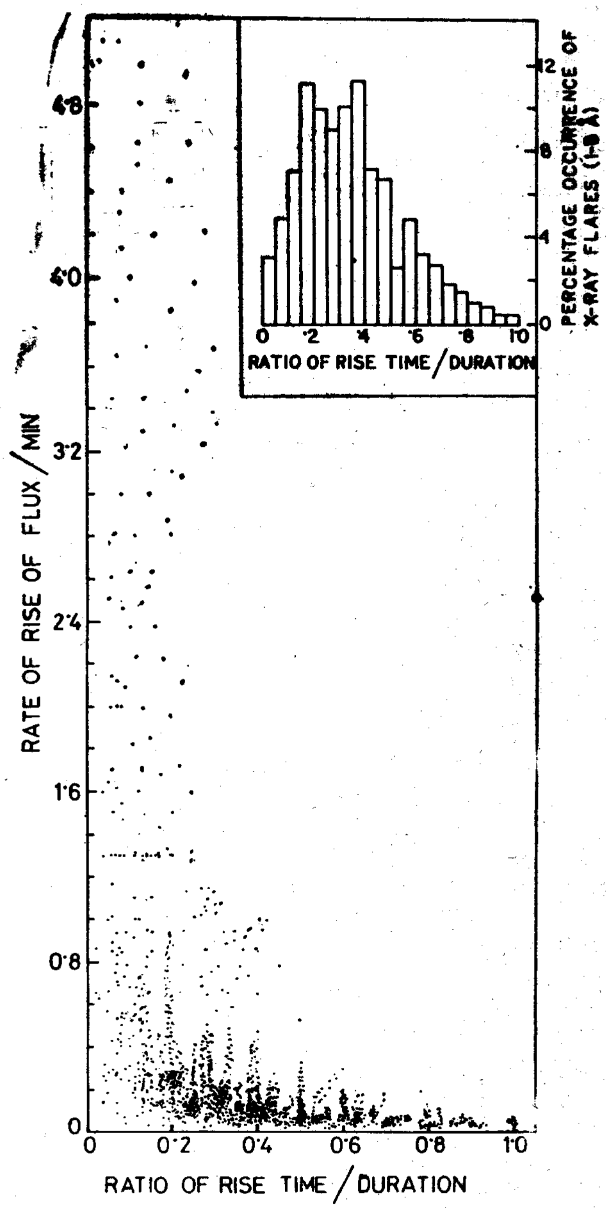

Fig. 2—Scatter diagram showing rate of rise of peak flux (per minute) against the corresponding ratio of rise time to duration of the X-ray bursts in the 1-8 Å band (Histogram at the corner shows the percentage occurrences of X-ray flares for different values of the ratio of rise time to duration)

and 'grf' (Covington and Harves[7]) and to the earlier classification of X-ray bursts into 'impulsive' and 'gradual rise and fall' type by Culhane and Phillips[8]. However, as we did not have at our disposal all the records obtained during the period under investigation, we examined this point further on statistical grounds. The rate of rise of peak flux against the respective ratio of rise time to duration (t_r/t_d) of the X-ray bursts in the band 1-8 Å have been plotted as shown in Fig. 2. The percentage distribution of the bursts in the different ranges of t_r/t_d has also been shown by the heights of the histograms placed at the top of Fig. 2, which shows statistically the existence of three different types of X-ray bursts. These are (i) impulsive bursts showing low ratio of rise time to duration (t_r/t_d) but large rate of rise of peak flux (p_f/t_r), (ii) gradual rise and fall or 'grf' which shows comparatively large ratio of t_r/t_d but smaller rate of rise of peak flux and (iii) 'gradual rise and quick fall' or 'grqf' which shows the value of t_r/t_d nearly equal to unity but low value of p_f/t_r.

On the other hand, the peaks of the X-ray bursts have been found to occur at different times. The time difference between their peaks is represented in the present analysis by Δt which is reckoned as positive whenever the harder X-ray attained its peak flux at an earlier time. The relative percentage

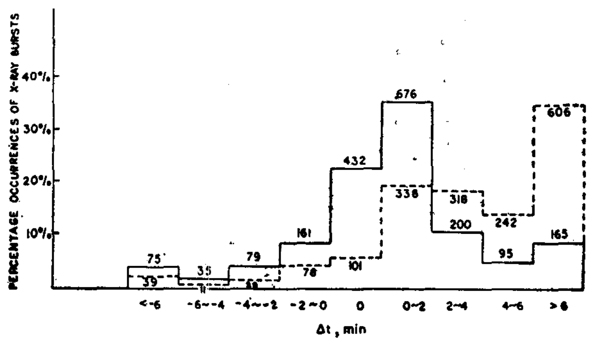

Fig. 3—Heights showing the occurrences of X-ray bursts for different values of Δ*t*s in the bands 0·5-3 Å and 1-8 Å (solid line) and 0·5-3 Å and 8-20 Å (dotted line) (The figures on the heights show the number of occurrences of X-ray bursts in that range)

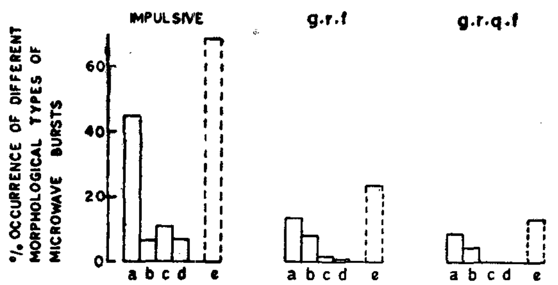

Fig. 4—Heights of the histograms for impulsive, grf and grqf, X-ray bursts show the percentage occurrences of X-ray associated microwave bursts of different types. [The types of microwave bursts in each case are represented by block from left to right as impulsive (a), gradual rise and fall (b), complex (c), and the rest (d). The overall association is indicated by the dotted block (e)]

occurrence of the X-ray bursts in the different ranges of positive and negative Δ*t*s are shown in Fig. 3, which shows that progressively more and more X-ray bursts attain positive Δ*t* values with increasing difference between the two X-ray bands.

X-ray bursts can thus be classified either according to their morphological types at any single band or according to their Δ*t* values at any two bands. Of the three X-ray bands mentioned here, namely, 0.5-3, 1-8 and 8-20 Å, the records of the extreme two bands 0·5-3 and 8-20 Å) can be suitably utilized as regards their Δ*t* values are concerned, since the overlapping between the bands is avoided. The nature of X-ray burst-associated microwave burst of different types and different SIDs has been examined in relation to (i) the different morphological types and (ii) the different Δ*t* values of X-ray bursts mentioned above.

3·1 Analyses in relation to the different morphological types of X-ray bursts

'Impulsive', 'grf' and 'grqf' types of X-ray bursts have in the present analysis been grouped by specific values of t_r/t_d and p_f/t_r. These values are 0-0·2 and

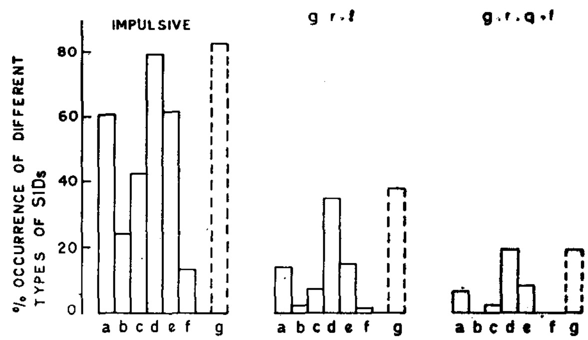

Fig. 5—Heights of the histograms for impulsive, grf and grqf X-ray bursts show the percentage occurrences of X-ray associated SIDs of different types. [The types of SIDs in each case are represented by blocks from left to right as SWF (a), SCNA (b), SEA, (c) SPA (d), SES (e) and SFD (f). The overall association is indicatad by the dotted block (g)]

>0·5 unit/min for impulsive bursts; 0·4-0·7 and 0-0·2 unit/min for the 'grf' bursts; >0·8 and 0-0·2 unit/min for the 'grqf' type of X-ray bursts where 1 (one) unit is taken to be = 1 erg/cm²/sec. Association of the impulsive, grf, grqf X-ray bursts with microwave bursts and also with SIDs have been examined categorically. The percentage association of the impulsive grf, and grqf X-ray bursts with microwave bursts, in general, have been found to be 68·8%, 23·1%, and 2·8 %, respectively, and the percentage association with different types of microwave bursts are shown in Fig. 4.

The percentage association of the above three types of X-ray bursts with SIDs, in general, have been found to be 82·2%, 37·3% and 19·1 %, respectively, and their association with individual types of SIDs are shown in Fig. 5.

The percentage association of the impulsive, grf, and grqf type of X-ray bursts with intensity classes of H_α-flares have also been examined. The results are shown in Table 1.

It is evident from the contents of the above that impulsive X-ray bursts are comparatively more associated with bright H_α flares and also with different types of microwave bursts and SIDs than the grf and grqf types of X-ray bursts.

3·2 Analyses in relation to the Δ*t* values of the X-ray bursts

X-ray bursts at 0·5-3 Å and 8-20 Å having positive Δ*t*s both small and large have been analyzed

Table 1—Percentage association of X-ray bursts with bright, normal and faint flares

Types of X-ray burst	Percentage association with flare type		
	bright	normal	faint
Impulsive	34·7	27·8	3·4
grf	6·0	25·9	3·9
grqf	2·1	14·9	6·4

Table 2—Distribution of the X-ray associated microwave bursts and SIDs in relation to small and large values of positive Δts

Associated events	Type of the event (code types)	Occurrence at different Δt value	
		Δt 0-2 min (385 events)	10>Δt>6 min (280 events)
Microwave bursts	impulsive (1, 2, 3, 4)	96	80
	gradual rise & fall (20, 22)	18	45
	complex (45, 46)	19	—
	others	5	7
SIDs	SWF	161	104
	SCNA	40	21
	SEA	93	53
	SPA	239	156
	SES	155	100
	SFD	39	6

in relation to the microwave bursts (4995 MHz) of different morphological types and with different sudden ionospheric disturbances. Results obtained are shown in Table 2. No such analysis could, however, be made for the X-ray bursts with negative Δts due to their small number in all the ranges.

It is evident from Table 2 that X-ray bursts have greater affinity for impulsive microwave bursts irrespective of their Δt values. Moreover, X-ray bursts with small Δt have considerable association with the complex microwave bursts while those having large Δt have comparatively larger association with the gradual rise and fall type of microwave bursts. As regards their association with SIDs as shown in Table 2, it can be said that sudden frequency deviation (SFD) has a remote chance to occur when the X-ray bursts attain their peak at a wider time difference. It is now fairly known that "radiation at wavelengths longer than 100Å are required to explain most SFDs" (Donnelly[9]) while radiation at wavelengths less than 10 Å are mainly responsible for other SIDs. Hence, from the results obtained here it can be said that simultaneous X-ray burst attaining peak at wide time difference is comparatively less associated with euv radiations.

X-ray bursts of different Δt values have also been examined in relation to the different classes of H_α-flares. The percentage association of the X-ray bursts ($\Delta t \sim$0-2 min and $\Delta t \sim$6-10 min) with intensity-wise classes of H_α-flares have been shown in Fig. 6 (top) while the percentage distribution of the X-ray associated H_α-flares have been shown at the bottom of Fig. 6. Of the two categories of X-ray bursts considered, bursts with smaller Δts are relatively more associated with bright flares in comparison to

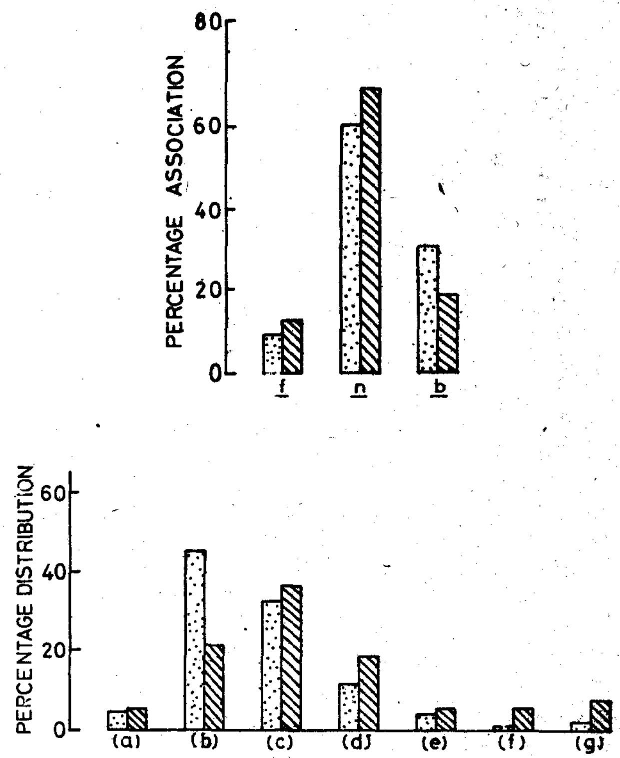

Fig. 6—Histograms (in the upper set) showing the percentage association of X-ray bursts of small and large Δts with faint (*f*), normal (*n*), and bright (*b*) H_α-flares; and histograms (in the lower set) showing the percentage distribution of the X-ray associated H_α-flares of different durations, (a) 0-10; (b) 10-20 min; (c) 20.30 min; (d) 30-40 min; (e) 40-50 min; (f) 50-60 min; and (g) >60 min. [The dotted bars stand for the small Δt cases (0-2 min) while the hatched bars are for large Δt cases (6-10 min)]

that for the bursts having large Δts, while the reverse is true for the normal and faint flares. Moreover, X-rays with large Δts are, in general, progressively more associated with Hα-flares having durations greater than 20 min.

The percentage association of the X-ray bursts, in general, (i.e. without their sub-classification as mentioned above) with different types of SIDs in the presence or absence of the microwave bursts, have also been examined and the results are shown in Fig. 7, which shows that the X-ray bursts associated with microwave bursts are highly responsible for the production of different types of SIDs. This result may be explained in accordance with the conclusion of Donnelly[9] that "many believe that the initial centimetre radio burst is caused by synchrotron emission from a stream of energetic electrons in the flare region and that the corresponding hard X-ray burst is produced by bremsstrahlung emission when these electrons collide with the atoms of the solar atmosphere", while the X-ray burst generated by any alternative process without accompanying centimetre

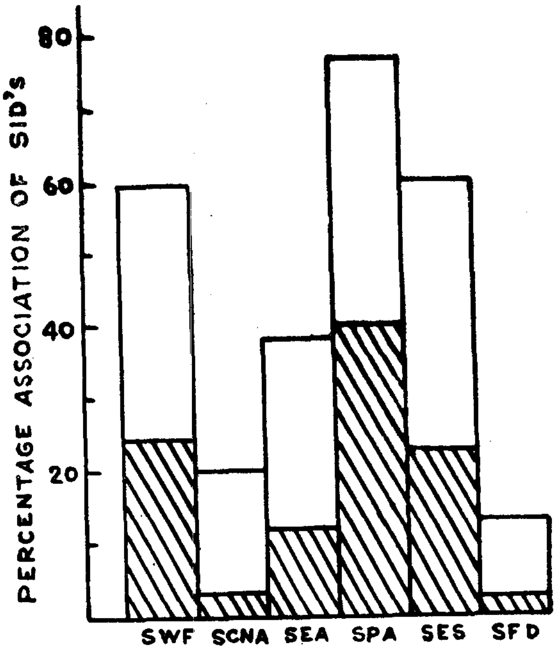

Fig. 7—Histograms showing the percentage association of X-ray bursts with different types of SIDs in the absence and presence of microwave bursts [The height of the hatched bars corresponds to the values in the absence of microwave bursts while the total height of the bars stand for in the presence of microwave bursts)

burst is less important in producing SIDs. Conclusion may thus be drawn that the simultaneous presence of X-ray and centimetre bursts can only ascertain the subsequent occurrences of SIDs.

Results show that the percentage association of the X-ray bursts, in general, with SIDs is about double in the presence of microwave bursts, in comparison to the percentage association in the absence of microwave bursts.

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