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A comprehensive study on solar X-ray emissions in relation to H_α-flares

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Abstract : A study on the solar X-rays in the 0.5–4 Å and 1–8 Å wavelength bands has been made in relation to the associated H_α-flares. Important results obtained are : (i) Intensity distribution of X-rays follows an exponential law; (ii) The occurrences of X-ray bursts fall with impulsiveness in an exponential way; (iii) X-ray bursts are found to be related with flares that have a single or more brilliant points and several eruptive centres as their visual features, these kinds of flares are found to be more impulsive and burst productive; (iv) X-rays lag behind the associated H_α-flares in respect of their time of onset, although there is no definite one-to-one correspondence for the attainment of their maximum phases; (v) North-South asymmetry increases with latitude, but East-West asymmetry follows no definite pattern; the results conforming with other kinds of solar activity.

Keywords : Sun, X-rays, flares

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1. Introduction

The state of knowledge on the subject of solar X-rays had been reviewed in different articles [1–3] published from time to time. In recent times, various satellite-borne detectors have recorded solar X-ray bursts in several bands and a large amount of data have thus been accumulated, which are still being analysed. Pearce and Harrison [4] undertook a statistical analysis of soft X-ray (3.5–5.5 KeV) profiles of solar flares. They concluded that commonly held views about relationship between flare duration and intensity, profile asymmetries and intensity *etc*, are in error. Kurokawa *et al* [5] found out a close relationship between H_α- and hard X-ray emissions at the impulsive phase of a solar flare. They inferred that a fast electron beam rather than a thermal conduction front is the main heating mechanism of H_α-flare at the impulsive phase of a flare. Pearson [6] discussed about the impulsiveness and energetics in solar flares with and without type II radio bursts by considering hard X-ray characteristics for over 2500 flares. Webb [7] studied in a comprehensive way the coronal X-ray activity preceding solar flares. Koomen [8] showed that the long-duration X-ray bursts tend to ignore the sunspot cycle, this being true for the events with duration of six hours or longer. Bogovalov [9] studied the directivity of hard X-ray emission of solar flares based on data from SNEG–2M2 Instrument. They observed systematic softening of the X-ray emission spectra of flares towards the centre of solar disk in the region of photon energy > 50 KeV; this being due to the angular anisotropy of the accelerated electrons. From the observations of the relative timing of hard X-ray, microwave and lower frequency radio bursts in different phases of flare, Trottet [10] obtained important information concerning the electron acceleration/injection process. The hard X-ray, microwave and lower frequency sources appear to arise from a common injection of electrons continuously undergoing through different phases of flare. Petrosian [11] proposed a model in which it has been assumed that solar X-ray bursts result from interaction of a beam of high energy electrons with solar plasma. This model agrees with the observed polarization of impulsive X-ray bursts, softening of the spectra toward the limb, the frequency distribution across the solar disk and the observed absence of correlation between the ratio of soft-to-hard X-ray fluxes with solar longitude. The following analyses deal with the exposition of more typical features of X-ray bursts in the wavelength ranges 0.5–4 Å and 1–8 Å studied in relation to the H_α-flares and Sudden Ionospheric Disturbances (SIDS).

2. Data collection and method of analysis

Nearly six hundred X-ray events in 0.5–4 Å and 1–8 Å wavelength bands which were observed during the rising phase of 21st Solar Cycle, 1977–80, have been collected from Solar Geophysical data bulletins issued by NOAA, U S Department of Commerce. These data contain the beginning time, peak time, flux values at the starting and peak times of X-ray bursts in the bands 0.5–4 Å and 1–8 Å. The bursts were observed by the Space Environment Monitor (SEM) aboard the Synchronous Meteorological Satellites (SMS) and the Geostationary Operational Environmental Satellites (GOES).

The data of solar H_α-flares and sudden ionospheric disturbances reported by different stations all over the globe have been used in the analysis. An association between an X-ray and H_α-flare as well as SID was assumed when the former occurred within ± 15 min. of the occurrences of the other events.

3. Results

Intensity distribution of X-ray flares :

In order to find out the intensity distribution of X-rays, the peak intensity values have been grouped into different convenient ranges (ΔI) and the occurrences of X-ray bursts (ΔN) in those ranges have been examined. The values of ΔN thus evaluated have been plotted against I, where I represents the mid values of the corresponding adopted ranges of X-ray flux. The same technique has been repeated after grouping the bursts in various ranges of solar latitudes

(0–30°N, 0–30° S) and longitudes (0–30°, 31–60°, 61–90° E or W). Some of the graphs are displayed in Figure 1 for the X-ray events in both 0.5–4 Å and 1–8 Å wavelength ranges.

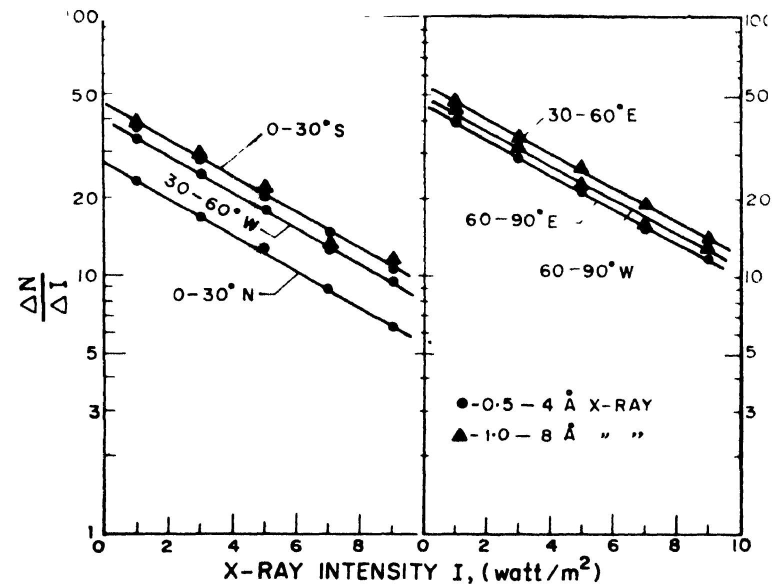

Figure 1. Occurrence frequency distribution of X-ray bursts as a function of their peak intensity. The bursts are grouped according to the longitude or latitude ranges. Some of the graphs are shown for 0.5–4 Å and 1–8 Å wavelength X-ray events.

The intensity distribution of X-rays has been found to obey the following exponential law

$$\frac{\Delta N}{\Delta I} = \exp(-1.336\, I)$$

which is independent of the positions of X-ray bursts in the solar atmosphere. Here I has been expressed in watt/m^2.

Impulsiveness of X-ray events :

The ratio of X-ray intensity at the time of maximum to that at the time of beginning gives a measure of the impulsiveness of the event. It will be misleading to assume that the intensity of an X-ray burst is zero at the time of the burst-onset. This is because a flare was not listed unless the flux remained above the 3×10^{-3} ergs cm^{-2} sec^{-1} level for four minutes or more. The starting and ending times are determined when the 1–8 Å flux first rises above and subsequently drops below the aforesaid level. Figure 2 shows the variation of the relative percentage of occurrences of X-ray events for 0.5–4 Å and 1–8 Å wavelength ranges with intensity ratio. The relative percentage of occurrences decrease with the increase of intensity ratio almost in an exponential manner. The Figure further reveals that the occurrences of 1–8 Å band X-ray bursts are greater than that of 0.5–4 Å band in higher intensity ratio values.

It may be concluded from the above analysis that the occurrences of highly impulsive X-ray bursts in the solar atmosphere are fewer in number; the number decreases exponentially with the increase of impulsiveness.

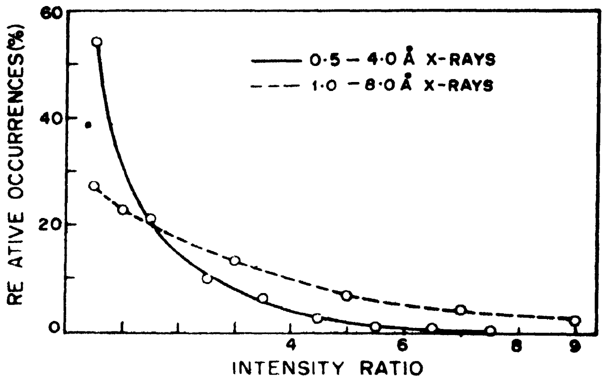

Figure 2. Curves showing the variation of relative percentage of occurrences of X-ray events with the intensity ratio at the time of maximum to that of the time of beginning.

Visual features of X-ray associated H_α-flares :

The X-ray events in both 0.5–4 Å and 1–8 Å wavelength ranges have been associated with H_α-flares. Visual features of the experimental observations of these flares are indicated by different alphabetical letters. The results of the said association obtained are being displayed in Figure 3. From the histograms it may be concluded that X-ray events are mostly associated with *D*, *E*, *F*, *J*, and *U* types of H_α-flares, where

D : One brilliant point,

E : Two or more brilliant points,

F : Several eruptive centres,

J : Distinct variation of plage intensity before or after the flare,

U : Two bright branches, parallel and converging.

The explanation on other types of visual indications of H_α-flares can be found in the Descriptive text of Solar Geophysical Data bulletins. It is to be mentioned further that about 41% of total X-ray events are related with H_α-flares having two or more brilliant points.

Time lag between X-ray and H_α-flare events :

The time lag between onset of X-rays and H_α-flares have been plotted in Figure 4 against the relative percentage of occurrences of X-rays. As the absolute time differs from observatory to observatory, we have taken the data corresponding to the Group Reports of the H_α-flare observations, thus minimising the error that may be intruded in the reported time. Moreover, although the events were said to be associated when they occurred within ± 15 min. of the starting times, there was no event which occurred after ± 8 min. time interval. When the X-ray event starts before the H_α-flare, the time interval is designated as positive and when it

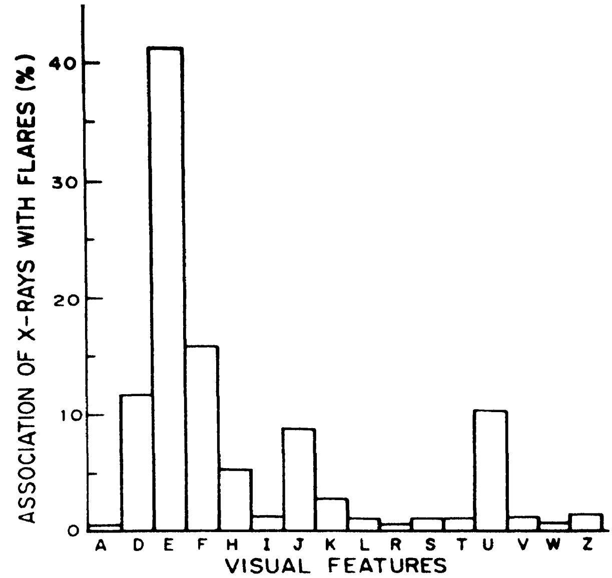

Figure 3. Histogram showing the percentage occurrences of X-ray associated flares classified according to their visual features.

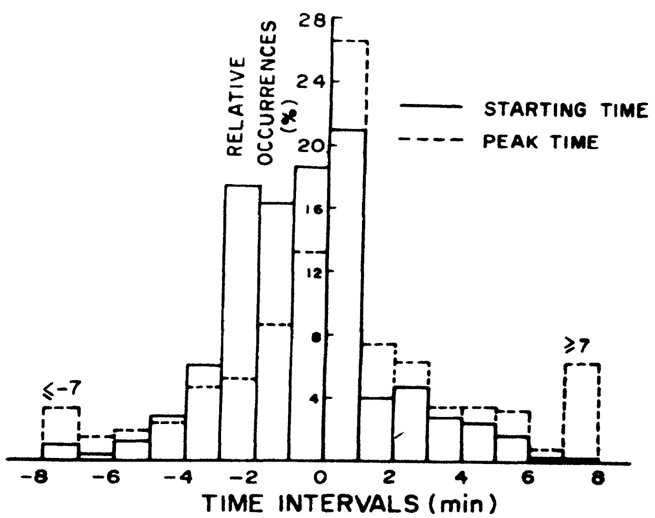

Figure 4. Histogram showing the relative percentage of occurrences of X-ray events in different ranges of time intervals.

occurs after the flare the same is treated as negative. From the Figure 4 it may be concluded that in about 75% of the cases, the X-ray event either starts after or coincides with the onset of H_α-flare.

Following the above procedure, the time intervals between the maximum phases of H_α-flares and that of X-ray bursts have also been plotted in Figure 4. The occurrences of X-ray bursts before or after the attainment of maximum phase of the associated H_α-flares are found equally probable, which holds true barring the coincident events. In this connection, it is to be mentioned that only in 9% cases, this time interval exceeds ± 8 min.

Frequency distribution of rise times of X-ray associated events :

The histogram in Figure 5 gives the percentage occurrences of (i) X-ray events, (ii) X-ray associated H_α-flares, (iii) X-ray related Sudden Ionospheric Disturbances (S.I.D.) in various

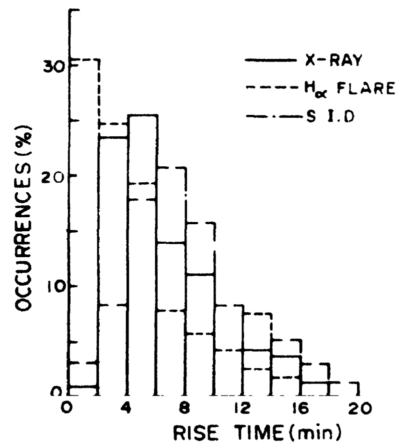

Figure 5. Histogram showing the percentage occurrences of X-ray, H_α-flare and sudden ionospheric disturbances in different ranges of respective rise times.

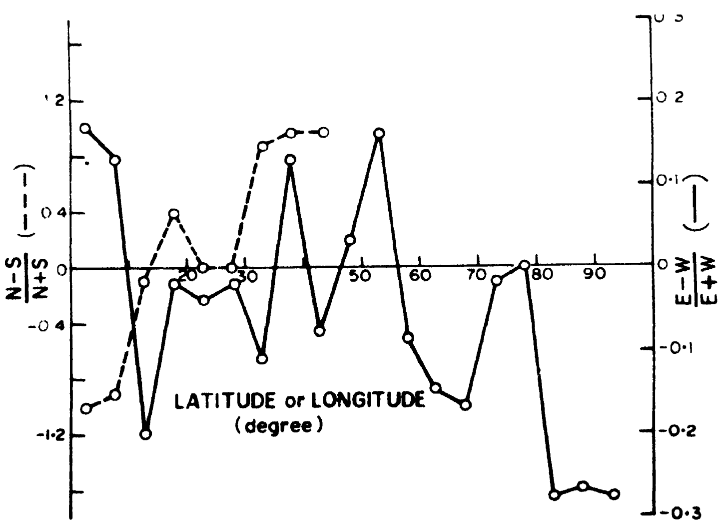

Figure 6. North–South (N–S) and East–West (E–W) asymmetries have been drawn against the positions according to the latitudes and longitudes respectively of X-ray bursts.

ranges of rise times of X-rays, H_α-flares and S.I.DS respectively. It is seen that most of the X-ray events have rise times in between 2–8 mins, X-ray associated H_α-flares have rise times 0–6 mins. and that of S.I.DS 4–10 mins.

Asymmetry in the occurrences of X-ray events :

The North-South and East-West asymmetries are shown in Figure 6 for the X-ray events occurring simultaneously in both wavelength ranges. The N–S asymmetry has been found to be negative upto 12° latitude above which it remains positive, maintaining the increasing tendency with latitude having a slight dip in between 18–27°. The East–West asymmetry fluctuates in an irregular manner with longitude. In the ranges of longitudes 0 to 10° and 35–55° the eastern hemisphere, and in the ranges of 10–35° and 55–90° longitudes the Western hemisphere predominates in respect of the positions of X-ray events on the solar disk.

4. Summary of the results

1) Intensity distribution of X-rays has been found to follow an exponential law, the exponent being independent of the positions of X-ray events on the solar disk.
2) The relative percentage of occurrences of X-ray bursts decreases with the increase of intensity ratio almost in an exponential manner.
3) X-ray events have been mostly found to be associated with H_α-flares which have two or more brilliant points or have several eruptive centres as their visual features.
4) Most of the X-rays start after the onset of H_α-flares, but all of them do not attain maximum after the attainment of maximum phase of H_α-flares. Similar conclusion can be drawn from the results of the study on rise times of the respective events.
5) North-South asymmetry has been found to increase with latitude, whereas the East-West asymmetry fluctuates in an irregular way with longitude.

5. Discussion

The distribution law of X-ray peak intensities has been found to obey exponential law rather than power law as obtained by Drake [12]. The occurrences of X-ray bursts in the 1–8 Å wavelength band compared to that of 0.5–4 Å band in the higher intensity ratio values clearly indicate that softer the X-rays, greater is the chance of occurrences of more impulsive X-ray bursts. Moreover, the present study shows that in most of the cases X-rays are associated with those H_α-flares which possess single or more brilliant points (*D* and *E* types) and have several eruptive centres (*F* type). In earlier studies [13,14], it has been reported that impulsiveness and burst productivities of *E, F, D, J* and *U* types of flares are greater compared to other types of flares classified according to their visual indications. Further, according to the present study, X-ray bursts start after the onset of H_α-flares, but they reach their maximum phases either before or after the attainment of maximum phases of the respective H_α-flares. So during the flash or impulsive phase of a flare, the electrons are energised and they collide with low-density ions to produce X-ray photons as a result of bremsstrahlung process. The emission produced in this manner is called 'thin target'. The time variation of X-ray flux is almost similar to that of the accompanying H_α-flares as observed from the study of the frequency distribution of rise times of X-rays and X-ray associated events. From these studies it can be concluded that the primary sites of H_α-flares with brilliant points or eruptive centres and of impulsive X-ray bursts are located at the same region in the solar atmosphere.

The North–South asymmetry is reflected in various kinds of solar activity, such as, sunspots, flares, coronal holes, faculae, prominences and radio bursts. Most of the authors who studied the 19th and 20th solar cycles reported a northern excess of various kinds of solar activity [15–17]. According to the present study, similar conclusion can be drawn about X-ray bursts also. But in case of East-West asymmetry, no definite conclusion can be drawn as in earlier reports.

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