TIME DELAY BETWEEN Hα AND HARD X-RAY EMISSIONS DURING IMPULSIVE SOLAR FLARES

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Abstract. This investigation shows that statistically there are significant time delays between Hα and hard X-ray (HXR) emissions during solar flares; most impulsive flares produce HXR emissions up to ~1 min before and up to 2 min after the onset of Hα emission. HXR emissions are also found to be peaked up to 2 min before the Hα emissions.

1. Introduction

In large flare events energy is observed both as electromagnetic and mechanical energy (Bruzek, 1967). Electromagnetic flare radiations include almost the whole wavelength range from gamma rays to the decametre wavelengths. In general, solar flares produce a variety of electromagnetic particle radiations (Kane *et al.*, 1980). Energetic solar flare particles are broadly defined as particles with energies greater than 10 keV and their production is intimately related to the flare mechanism itself (Ramaty *et al.*, 1980).

The controversy whether there is a time delay between the Hα emissions, microwave bursts and hard X-ray (HXR) emissions is still not fully resolved. Some authors hold the view that there cannot be a delay, whereas others are of the contrary opinion (Kampfer and Magun, 1983). Many authors studied the relationship between the optical, HXR and microwave data (Zirin *et al.*, 1971; Vorpahl, 1972, 1973). According to Vorpahl (1972, 1973), Hα profiles lagged behind the associated HXR profiles by about 20–30 s in their corresponding onset and peak locations. However, this lag was not found in the observations by Zirin (1978); instead the curves in Hα were found to match the HXR profiles to within the experimental time resolution (± 5 s) during their onset and during the rise of intensity to maximum. Many observers find that the flare kernels observed in Hα, correspond approximately in time with the spikes in HXR emissions and microwave bursts (Vorpahl and Zirin, 1970; Zirin *et al.*, 1971; Vorpahl, 1972, 1973; and Zirin, 1978). According to Švestka (1976), it is important to distinguish between the kernel emissions and the emissions associated with the extended Hα flare. An intense kernel starts brightening up abruptly within 20 s of Hα flare as a whole (Vorpahl, 1973).

In this paper, we present a study of the time delay between Hα emissions and HXR emissions at onset and peak, during solar flares.

2. Observational Data and Analysis

In our study of the time delay between the Hα and HXR emissions during solar flares the source of Hα data is *Solar Geophysical Data* (1981, 1982, 1983, and 1984) and the

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source of HXR data is *Hinotori Satellite Data* (1982, 1983). During 1981–82 Hinotori, a Japanese satellite, recorded 609 flare time profiles (FTP). Data about HXR time profiles during solar flares was published by Hinotori SXT/HXM team in Parts I (1982) and II (1983). Each FTP consists of four frames and the four frames correspond to four energy channels. The first frame counts 17–40 keV photons, the second frame counts 40–67 keV photons, the third frame counts 67–152 keV photons and the fourth frame counts 152–359 keV photons. Details about the photon counting for various energy levels are given in both Parts I (1982) and II (1983).

For elucidating the time delay between the Hα and HXR emissions during solar flares, we followed the time correlation procedure used earlier by Swarup *et al.* (1960) and Zirin (1978). We adopted this method because while the spatial locations of the flares in Hα are known, the spatial locations of flares in HXR are unknown. During 1981–82 (i.e. between 26 February, 1981 to 15 December, 1981 and January, 1982 to 30 September, 1982), Hinotori satellite recorded 609 FTP. Out of these 399 FTP were excluded from our analysis because: (i) for 219 events Hα observations are not reported; (ii) for 65 events there is an uncertainty in either onset or peak intensity times or in both in HXR emission; (iii) for 65 events no flare has been recorded in Hα observations; (iv) for 50 events either onset times or peak intensity times or both are not known with certainty in Hα observations. Finally, we were left with only 210 FTP (HXR) corresponding to which the Hα emission flare data for 210 flare is available in *Solar Geophysical Data*. For this investigation we have limited ourselves only to impulsive flares, whose maximum energy release during the impulsive phase is characterised by short durations of 10–1000 s (Kane *et al.*, 1980).

In the present study we used only the first frame/energy channel for HXR data basically because the frequency of events are maximum in this channel. The lower threshold of the first frame/channel was switched to 30 keV from 17 keV, on 4 August, 1981. We noted the onset and peak times for each flare within 6 s from FTP by using a magnifying eyepiece (magnification = 7) with a millimetre scale having a least count of 0.1 mm. We also noted the corresponding Hα flare onset and peak times from *Solar Geophysical Data* (1981, 1982). The onset delay and the peak delay between the Hα and HXR emissions have been studied separately.

Histograms are plotted with HXR emission for onset and peak times (Figures 1 and 2). In Figures 1 and 2 a delay of less than 6 s is taken as simultaneous emissions, shown by 0 minutes. These histograms are plotted for 30 s interval only. In each case the small dashed vertical line shows time of simultaneous emission for Hα and HXR emissions during flares. The broad horizontal dashed line in each case shows an upper mean level with 95% confidence and only the peaks above this line are considered significant. In Figures 1 and 2 the dashed box above 6 and − 6 min shows number of flares with HXR emissions before or after 6 min.

Figure 1 shows that most flares produce HXR within 30 s of the onset of Hα emission. From Figure 1 it is clear that a sufficient number of flares also produce HXR emissions nearly 1 min before the onset of Hα emissions. Figure 1 also shows that a large number of flares produce HXR emissions upto 2 min 30 s after the onset of flares in Hα.

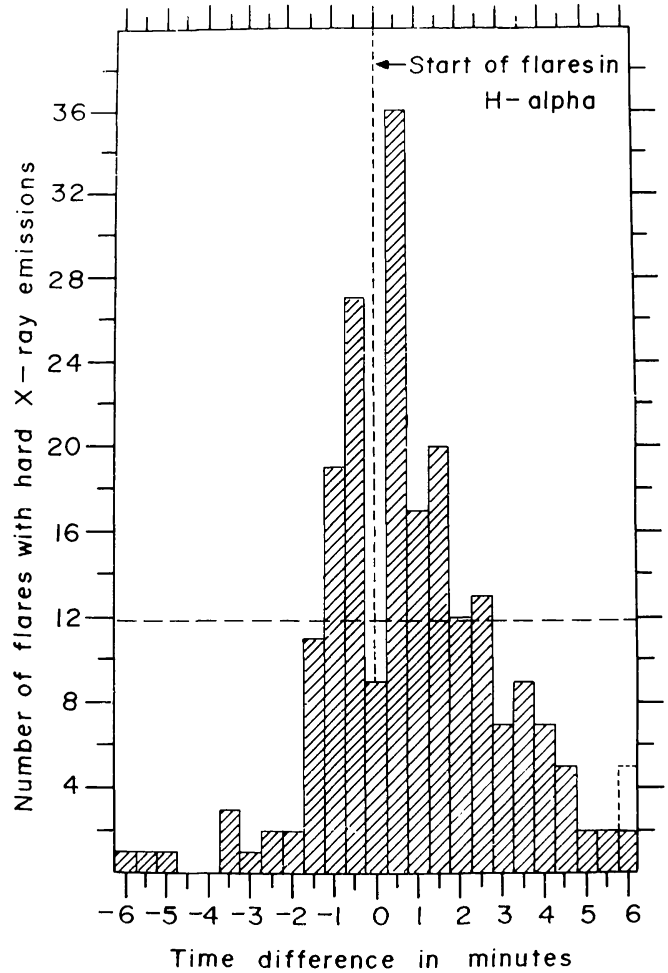

Fig. 1. Plot of time difference in minutes between the onset of the Hα and HXR emissions during solar flares versus the number of Hα flares with HXR emissions.

Furthermore, there are a few flares which show simultaneous emissions (Figure 1).

Figure 2 shows peak time delays between the Hα and HXR emissions during flares. From Figure 2 it is obvious that usually the HXR emission peaks occur approximately 2 min before the Hα emissions. For some flares the HXR and Hα emissions peak together. It is also evident (Figure 2) that appreciable number of flares manifest HXR peaks upto 30 s after the Hα emission peaks.

3. Results and Discussions

The present investigation is based on a study of time delay of the onset and peak times of Hα flares as a whole and not on the kernel brightening onset and peak brightness times. Since the kernel brightening starts in Hα flare region within 20 s of the onset of the flare as a whole (Vorpahl, 1973), therefore, the delay (studies based on the onset times in Hα for the flare as a whole) may be equally significant. Also, since the kernels are intense and represent the brightest parts of the flares, therefore, the peak brightness times of kernels and corresponding flares may be considered as identical.

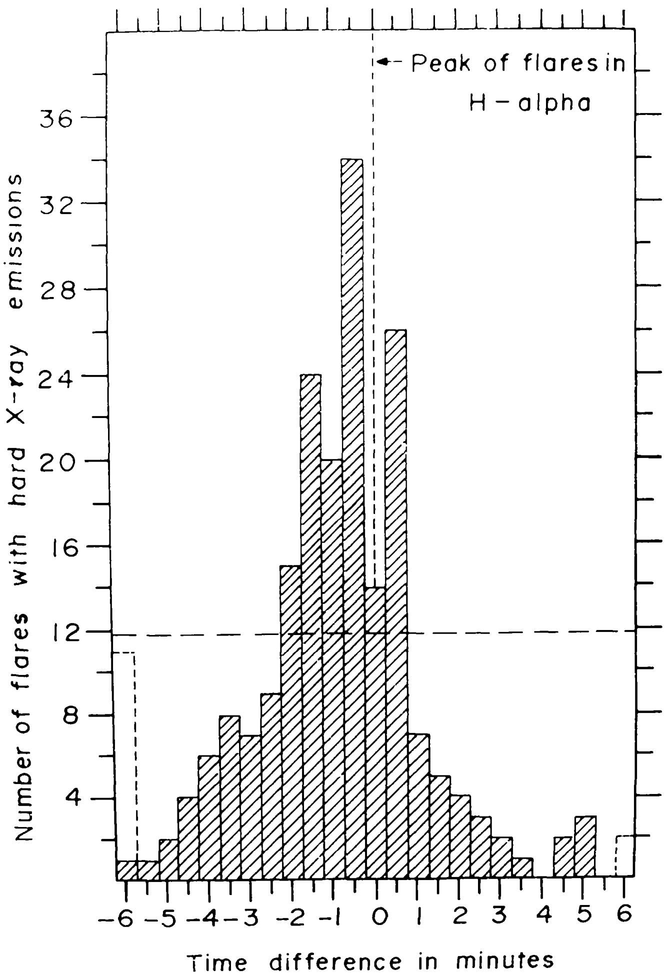

Fig. 2. Plot of time difference in minutes between the peaks of the Hα and HXR emissions during solar flares versus number of Hα flares with HXR emissions.

The information about Hα emission is obtained from *Solar Geophysical Data* where the onset and time of maximum are given in hours and minutes. Hence, the onset and peak times of our Hα flare are known to an accuracy of ~1 min. Under these circumstances peak of 30 s may not be justified.

The salient features of the present investigation are as under:

(1) Most flares produce HXR emissions up to ≥2 min after the onset of Hα emissions. Also, some flares produce HXR emissions up to ~1 min before the onset of Hα emissions and inappreciable number of flares produce Hα and HXR emissions simultaneously (Figure 1).

(2) For most flares HXR emission peaks up to 2 min before the Hα peak. For some flares, Hα and HXR emissions peak simultaneously.

The above results for onset and peak delays between the Hα and HXR emissions are somewhat different from those obtained by earlier investigators. For onset we find that the flares may produce HXR emissions up to ≥2 min after the Hα emission. Earlier Vorpahl (1972, 1973) found that the Hα emission lagged behind the HXR emission time profiles by about 20–30 s in their onset and peak locations, but Zirin (1978) found no lag for the onset and peak locations. The present investigation also shows that the HXR emission may peak up to 2 min earlier than the Hα peak emission, a finding similar to that made by others also (cf. Švestka, 1976). For some flares we found that the HXR and Hα emissions peak simultaneously.

From Figure 1 it is evident that the HXR emissions are usually observed, before and after the onset of Hα emissions and that only an inappreciable number of flares may show simultaneous emissions. The observed time delays between the Hα and HXR emissions show that both the emissions do not emerge from a common height in the solar atmosphere. Based on high-time correlation Dulk and Dennis (1982) pointed out that the HXR and microwave emissions emanate from a common source. The Hα emissions originate in the lower chromosphere, while the HXR emissions originate in the chromosphere to corona transition region of the solar atmosphere where the electron densities, the temperature, and the magnetic fields differ by an order of magnitude as compared with these parameters in the lower chromosphere (Kampfer and Magun, 1983). According to these authors the Hα emission originates through excitation by fast or thermal electrons. The authors have not cited any reference in this regard. However, Švestka (1976) is of the view that the chromospheric emission must be predominantly due to heat conduction from corona and that heating by particles must be considered as an additional effect only. In addition, flare models have been constructed in which the transfer of energy from corona into chromosphere through conduction and accelerated particles has been incorporated. Therefore, one may accept the view expressed by Kampfer and Magun. On the other hand, the HXR emission is produced through bremsstrahlung. Thus, since the location in the solar atmosphere and also the emission mechanisms and the associated mechanisms for Hα and HXR emissions may be quite different, a time delay between these two emissions seems quite plausible.

The observations of HXR emissions before and after the Hα emissions during the onset of solar flares imply that there may be two types of flares originating through different mechanisms and triggered at different altitudes. To confirm this, very high spatio-temporal resolution observations for the Hα and HXR emissions for a large number of flares are required.

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