

## Time delay between H-alpha and soft x-ray emissions during solar flares

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**Abstract.** A statistical analysis of time delays between H-alpha and soft x-ray (SXR) emissions at onset and peak respectively during solar flares is presented. We find that at the onset of flares SXR emission starts simultaneously or upto two min earlier than H-alpha emissions. At peak flux the SXR emission is found to be peaked between 2 min before to 3 min after the H-alpha emissions.

*Key words :* H-alpha—soft x-rays—solar flares

### 1. Introduction

Every H-alpha flare is accompanied by a burst of soft x-rays (SXR) ( $1 \text{ \AA} \leq \lambda \leq 100 \text{ \AA}$ ). The spectra of these bursts show that these SXR are emitted by thermal plasma at temperatures of the order of  $10^7 \text{ K}$  (Moore *et al.* 1980). The most intense SXR enhancements are always flare associated, but as one proceeds to weaker events the association becomes worse (Svestka 1981). A typical flare-associated SXR burst has a time profile roughly similar to time development of H-alpha intensity in the brightest point of the flare and similarly is characterized by a fast rise and much slower decay (Svestka 1976). The SXR emission is found to be associated with bright x-ray knots, sometimes located near the ends of the loops (Kahler *et al.* 1975). Some x-ray knots are similar to H-alpha kernels observed in some flares (Kahler *et al.* 1976; Petrasso *et al.* 1979). In other cases, however, the knots are not spatially coincident with the H-alpha kernels and could be the highest parts of the bright end loop structure (*cf.* Svestka 1981). The controversy whether there is a time delay between the H-alpha and SXR emissions is still not fully resolved. Some authors hold the view that there cannot be a delay whereas others hold the contrary opinion. According to Thomas & Teske (1971), the SXR burst precedes the optical H-alpha event (by about 2 min on the average), reaches its peak flux later (the mean difference being about 3 min). On the other hand, Falciani *et al.* (1977) and Zirin *et al.* (1981) report that the SXR starts about 2 min later than H-alpha emission. Datlowe

*et al.* (1974) found the onsets of the H-alpha and the SXR emissions during flares as approximately simultaneous events.

In this paper, we have made an attempt to reinvestigate the time delays between the H-alpha and SXR emissions at onset and peak respectively during solar flares.

## 2. Observational data and analysis

In our study of the time delay between H-alpha and SXR emissions during solar flares we have taken H $\alpha$  data from the Solar Geophysical Data (SGD). SXR data from Donnelly (1981) and Donnelly & Bouwer (1981) are recorded by SMS-GEOS satellites in two channels *i.e.* 0.5–4 Å and 1–8 Å. For most flares both the channels show time coincidences at onset and peak flux emissions respectively. But in some cases we notice that during flares 0.5–4 Å channel of SXR shows enhancement earlier than the 1–8 Å channel at onset and peak respectively.

For the present study we considered only the outstanding events of SXR emissions. For a burst to be outstanding its peak intensity is the usual criterion. However, the duration of a burst or the largeness of the total radiated x-ray energy integrated over time are other important aspects (Donnelly 1981; Donnelly & Bouwer 1981). From the SXR data recorded during 1974 July 1 to 1976 December 31, Donnelly (1981) described only 18 flare time profiles (FTP) as outstanding events. Also, from the SXR data recorded during 1977 January 1 to 1980 December 31, Donnelly & Bouwer (1981) described only 83 FTP as outstanding events. Each FTP is a plot of solar x-ray flux  $W_m^{-2}$  and universal time. Time duration of each plot is 2 hours with a time resolution of about 1 min. In all, during 1974 July 1–1980 December 31 a total number of 101 outstanding solar events were recorded. Out of these, 22 FTP were excluded from our analysis because (i) for 12 events either the onset of the peak flux times or both are not known with certainty in H-alpha observations; (ii) for 2 events no flare has been recorded in H-alpha; (iii) for 4 events H-alpha observations are not reported; (iv) for 1 event there is uncertainty in the onset and peak flux times of SXR data; and (v) for 3 events peak times could not be read due to instrument saturation. Finally, we were left with only 79 FTP (corresponding to 79 H-alpha flares) of SXR emissions for which H-alpha data are available in SGD. All the 79 H-alpha flares are of optical importance greater than 1B.

In the present study we examined both the channels (0.5–4 Å and 1–8 Å) of SXR for onset and peak times during flares. In cases where a difference between the two channels was noticed we noted the 1–8 Å channel times for onset and peak flux times of SXR emissions because the data in this channel have been used more extensively by earlier investigators. For elucidating the time delay between the H-alpha and SXR 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 flares in H-alpha are known, the spatial locations of flares in SXR are not. We noted the onset and peak times for each flare from SXR emissions and H-alpha data respectively.

Separate histograms were plotted between the time differences in minutes at onset and at the peak of H-alpha and SXR emissions respectively against the number of

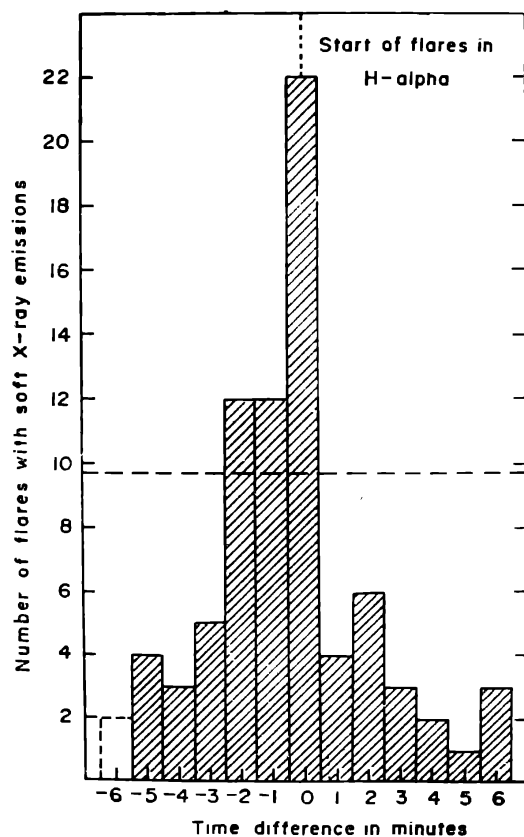


Figure 1. Plot of time difference in minutes between the onset of the H-alpha and SXR emissions during solar flares *versus* the number of H-alpha flares with SXR emissions.

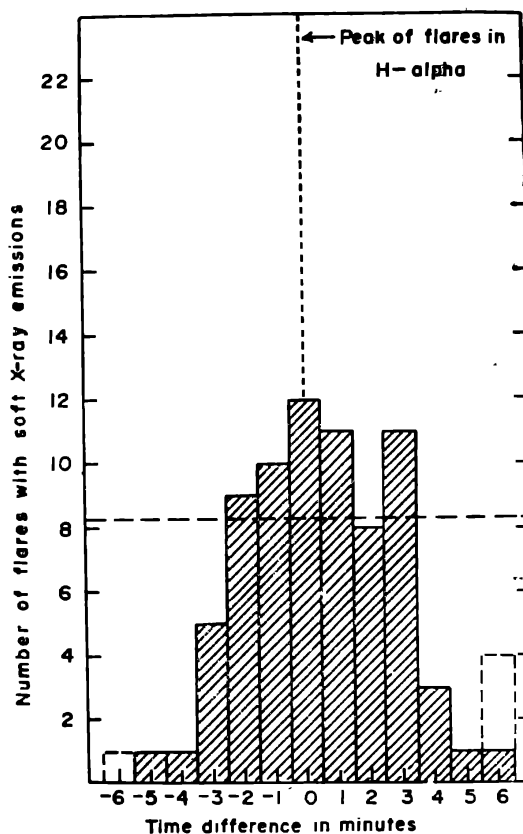


Figure 2. Plot of time difference in minutes between the peaks of the H-alpha and SXR emissions during solar flares *versus* number of H-alpha flares with SXR emissions.

flares with SXR emissions (figures 1 and 2). These histograms are plotted for 1 min interval only. In figures 1 and 2, the small dashed vertical lines mark the moment of simultaneous emissions for H-alpha and SXR radiations during flares. The broad horizontal dashed lines in the said figures delineate 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 show a number of flares with SXR emissions after and before 6 min.

Figure 1 shows that most flares produce simultaneous H-alpha and SXR radiations. From figure 1 it is also clear that a significant number of flares produce SXR emissions nearly upto 2 min before the onset of H-alpha radiations.

Figure 2 shows peak time delay between H-alpha and SXR radiations during flares. From figure 2 it is evident that the SXR emissions peak approximately upto 3 min after the H-alpha emission peaks. During some flares the SXR emissions peak upto 2 min earlier or simultaneous to the H-alpha emissions.

### 3. Discussion

The above results for onset and peak time delays between the H-alpha and SXR emissions during flares are based on a study of 79 outstanding solar flares. The

onset of SXR emissions upto 2 min before H-alpha during flares confirms the findings of Thomas & Teske (1971). From figure 1 it is evident that some flares show simultaneous emissions of H-alpha and SXR radiations at onsets and peaks; this also confirms the results of Datlowe *et al.* (1974). These results do not confirm the findings of Falciani *et al.* (1977) and Zirin *et al.* (1981), based on small data base. According to these authors, SXR emissions start 2 min later than H-alpha emissions. At peak flux during flares, Thomas & Teske (1971) and Zirin *et al.* (1981) found that the SXR emissions peaked about 2 min later than H-alpha emissions, whereas Datlowe *et al.* (1974) found that the SXR and H-alpha emissions peak together. In addition to these results we found that the SXR emissions also peaked upto 2 min earlier than the H-alpha emissions.

The observed time delay between the H-alpha and SXR emissions shows that both the emissions do not emerge from a common height in the solar atmosphere. The H-alpha emissions originate in the lower chromosphere ( $h \sim 1800$  km), while the SXR emissions originate in chromosphere-to-corona ( $h$  ranging from 10000 km to 100000 km, *cf.* Svestka 1976) region of the solar atmosphere, where the electron densities, the temperature and the magnetic field differ by an order of magnitude. Also the H-alpha is produced by fast or thermal electrons (*cf.* Kampfer & Magun 1983) whereas the SXR (1–10 Å) emissions require temperatures of the order of  $10^7$  K and originate in such a hot plasma through bremsstrahlung continuum and lines of heavily stripped ions (Svestka 1981). Thus since the location in the solar atmosphere and also the emission mechanisms and the energies associated for H-alpha and SXR emissions may be quite different, a time delay observed between these two emissions seems quite plausible.

The observations of the SXR emissions before the H-alpha emissions at the onset of the solar flares support the Kopp & Pneuman (1976) model of the solar flares. In this model two-ribbon flare is the visible manifestation (in H-alpha) of magnetic reconnection in the corona above the flare site. In this model the flare is triggered through reconnection of the field lines from the corona; therefore the SXR emission will be observed earlier than the H-alpha emission during the flares.

#### 4. Conclusions

The above investigation of time delay between the H-alpha and the SXR emissions at onset and peak during solar flares can be summarized as follows :

- (i) The SXR emissions start simultaneously with or upto 2 min earlier than the H-alpha emissions.
- (ii) The SXR emissions are peaked upto 2 min before, simultaneously with, and upto 3 min later than, the H-alpha emissions.

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