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Yohkoh Observations of White-Light Flares

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Abstract. The Aspect Camera on the Soft X-ray Telescope (SXT) on *Yohkoh* has provided a unique database of white-light flares (WLFs). Coincident HXR and SXR observations give a unique opportunity to study the relationship between these different emissions and investigate the origins of the white-light emission. We have found that the spatial and temporal coincidence between impulsive white-light and HXR emission is good but not exact and the case for the gradual white-light emission requires further investigation. Using the a list of *Yohkoh* WLFs observed prior to the failure of the Aspect Camera in 1992 we investigate the spatial and temporal relationship between the gradual white-light emission and both the HXR and SXR emission in an attempt to identify its origins.

1. Introduction

It is widely believed that the energy release in solar flares occurs in the corona and the energy is then transported to the low chromosphere where the optical emission is produced. As a result of this view, attempts to explain the origin of the white-light flare have mostly centred on canonical mechanisms. Thus, the relationship between the hard X-ray flare and white-light emission is one which has received much interest (e.g. Hudson et al. 1992; Neidig & Kane 1996) and indeed in the impulsive phase the spatial and temporal coincidence between WL and HXR emission is often seen to be good (Matthews et al. 1998). However, gradual phase WL emission is also often observed in these events (Hudson et al. 1994) which is not well correlated with HXR emission. Identification of the origin of this emission and its relationship to the impulsive phase emission is important in increasing our understanding of these events.

2. Observations and Analysis

The aspect camera of the Soft X-ray Telescope (SXT) on board *Yohkoh* provided white-light images at 431 nm (the G band) with a bandpass of 3 nm and typical image interval of 10-12 seconds. Simultaneous data from the Hard X-ray Telescope ((HXT), Kosugi et al. 1991) and the Be filter of SXT (Tsuneta et al. 1991) were also used. In this work we consider two flares observed on 26 January 1992 and 14 February 1992. The 26 Jan 92 event occurred in NOAA active region 7012 at S16W66 and had GOES class X1.0 and Hα importance 3B. It has previously been studied by van Driel-Gesztelyi et al. 1994, Hudson et al. 1994. The 14 Feb 92 event occurred in NOAA active region 7056 at S13E02 and was a GOES class M7.0 event with Hα importance 2B.

The preparation of the white-light data involves the subtraction of a preflare image from the series of flare images making use of correlation tracking. HXR images were reconstructed using the MEM algorithm (Sakao 1994; Sato et al. 1999). The standard corrections were applied to the SXT Be filter data.

Light curves of the whole flare show typical relationships between WL, HXR and SXR emission for both events: the HXR emission peaks a few seconds before or simultaneously with the WL, and both of these peak well before the SXR emission. Both of these events showed multiple kernels of WLF emission in the impulsive phase of the flare, with several sites spatially coincident with the HXR emission seen in the M1 channel (23-33 keV) as shown in the top rows of fig.1. WLF emission in the gradual phase is also apparent at a reduced number of sites. This emission is more diffuse and not well correlated with the HXR emission in this phase (fig. 1 bottom rows).

To try to further determine the nature of the WL emission we looked at the temporal behaviour of each kernel in more detail. Light curves were made in WL and in the corresponding sites of HXR and SXR emission. It should be noted that there is some evolution in all of these patches throughout the flare which we have not taken into account in this analysis; future work will consider this. These are plotted for 26 Jan 92 in fig.2 and for 14 Feb 92 in fig.3. Considering the 26 Jan 92 event first it can be seen that all WL kernels have a good temporal correlation with the corresponding HXR emission in these areas. However, the WL emission clearly extends up to several minutes after the HXR burst has ceased. The SXR emission in kernels A,C and E also appears quite impulsive, showing similar temporal behaviour to the WL and HXR in this phase. In kernels B and D the SXR emission is somewhat delayed with respect to the WL and HXR; although we note that D shows a slight bump around the time of the peak in WL and HXR. In the gradual phase, particularly for A, secondary peaks in the WL emission appear to correspond to secondary peaks in the SXR emission, although possibly slightly delayed. The behaviour in B, D and E is less clear cut and in C the secondary peaks appear some 20-40 s before the WL peaks.

For the 14 Feb 92 event we first note that there was no measurable HXR flux in the M1 channel in the region of kernel A. This does not preclude the

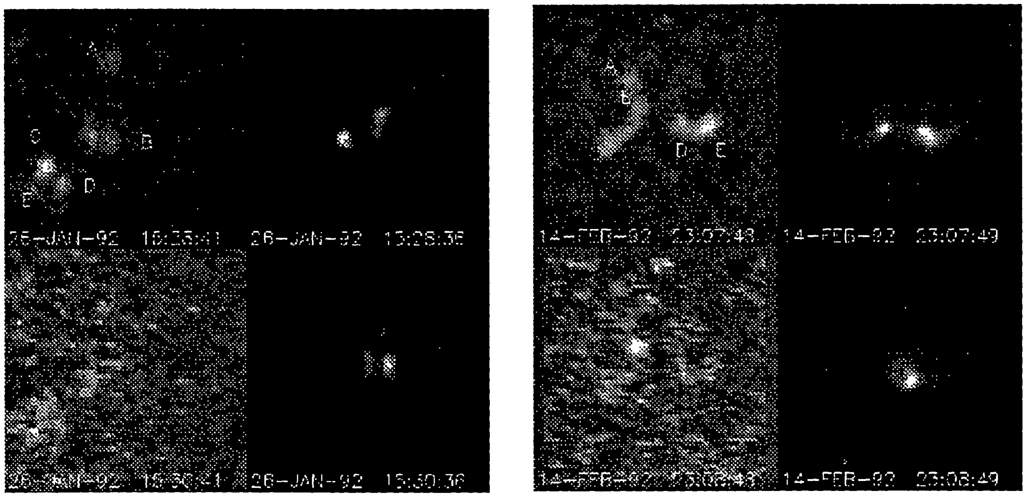

Figure 1. Mosaics showing WLF images (left) and HXR M1 channel images (right) during the impulsive (top) and gradual (bottom) phases of the flares on 26 Jan 92 and 14 Feb 92. WLF kernels are labelled A-E.

existence of HXR emission in this position but any that exists is below the HXT detector threshold limits. In the cases where HXR emission is detectable in the regions of WL emission we again see good temporal correlation in the impulsive phase. For this event we also see quite impulsive behaviour in the SXR emission, particularly for A, C and E, with good correlations between the peaks of all three emissions. The peak in SXR is delayed for B, although by significantly less than for D. Again we see tha the WL emission in all areas extends beyond the end of the HXR burst and is particularly strong in B. Similarly to the 26 Jan 92 event secondary peaks in WL seem to correlate well with secondary peaks in SXR for A, B, C and E.

Using the HXR observations we have also estimated the power associated with a beam of non-thermal electrons assuming that the power-law extends to $E > 50$ keV for each HXR source and compared this with the estimated WL power in this position. Typical values at the peak of the impulsive phase are in the range $10^{27} - 10^{28}$ erg s^{-1} for the electron beam in all cases. The WL power for the 26 Jan 92 event is typically a few 10^{26} erg s^{-1} in the impulsive phase, falling to around 10^{25} erg s^{-1} in the gradual phase. For the 14 Feb 92 event the WL power is a few 10^{27} erg s^{-1} in the impulsive phase in all cases except A, and a few 10^{26} erg s^{-1} in the gradual phase.

3. Discussion

We have presented some very preliminary results in our investigation into the origins of different types of WLF emission using observations from *Yohkoh*. From our analysis so far we have seen that correspondence both spatially and temporally between WL and HXR emission in the impulsive phase of flares is good for some patches of emission, and that the power associated with the electron beam would be sufficient during this phase to account for the WL power observed in

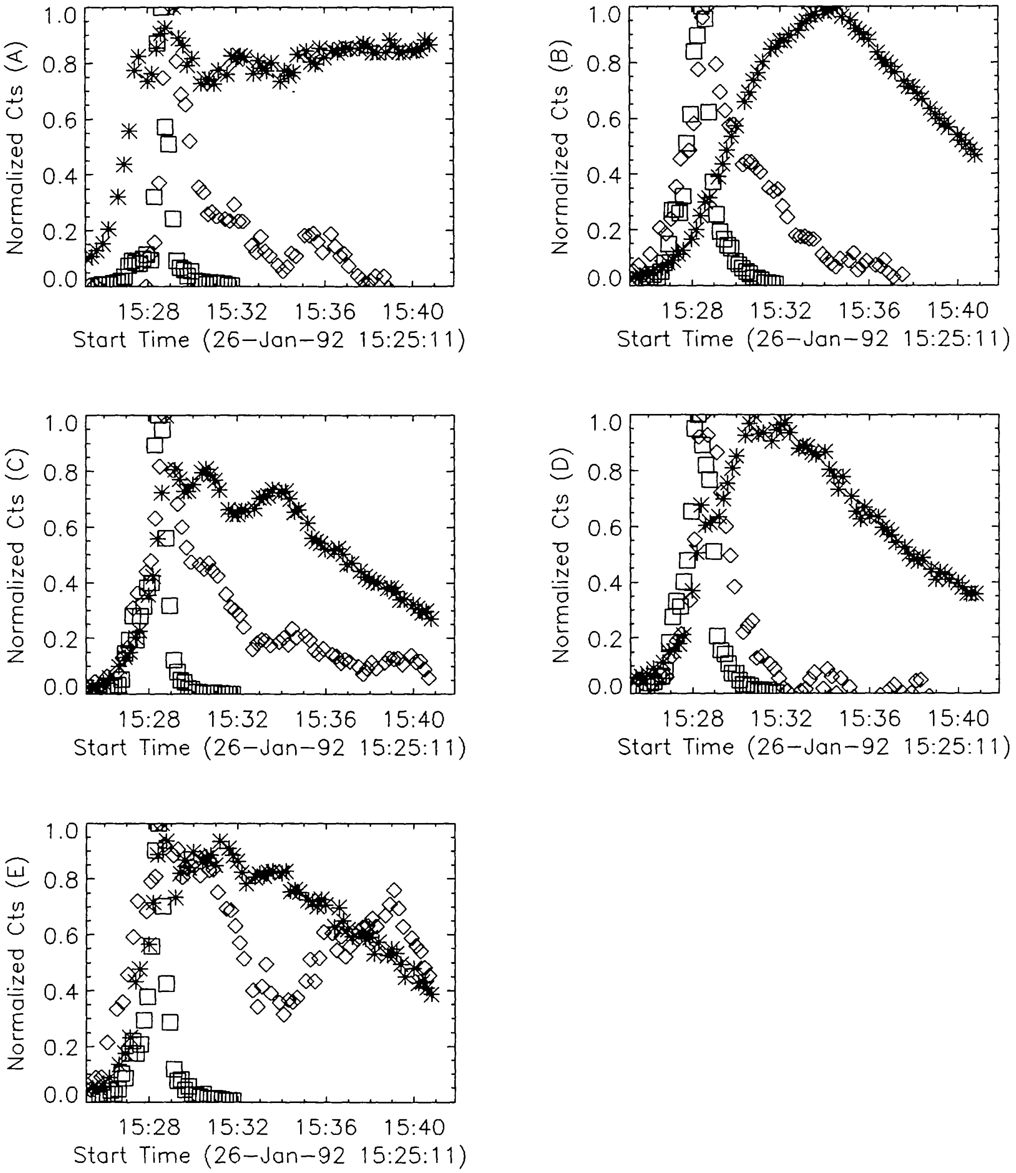

Figure 2. Normalised light curves in SXR (*), white-light (◇) and HXR M1 channel (△) for 26 Jan 92.

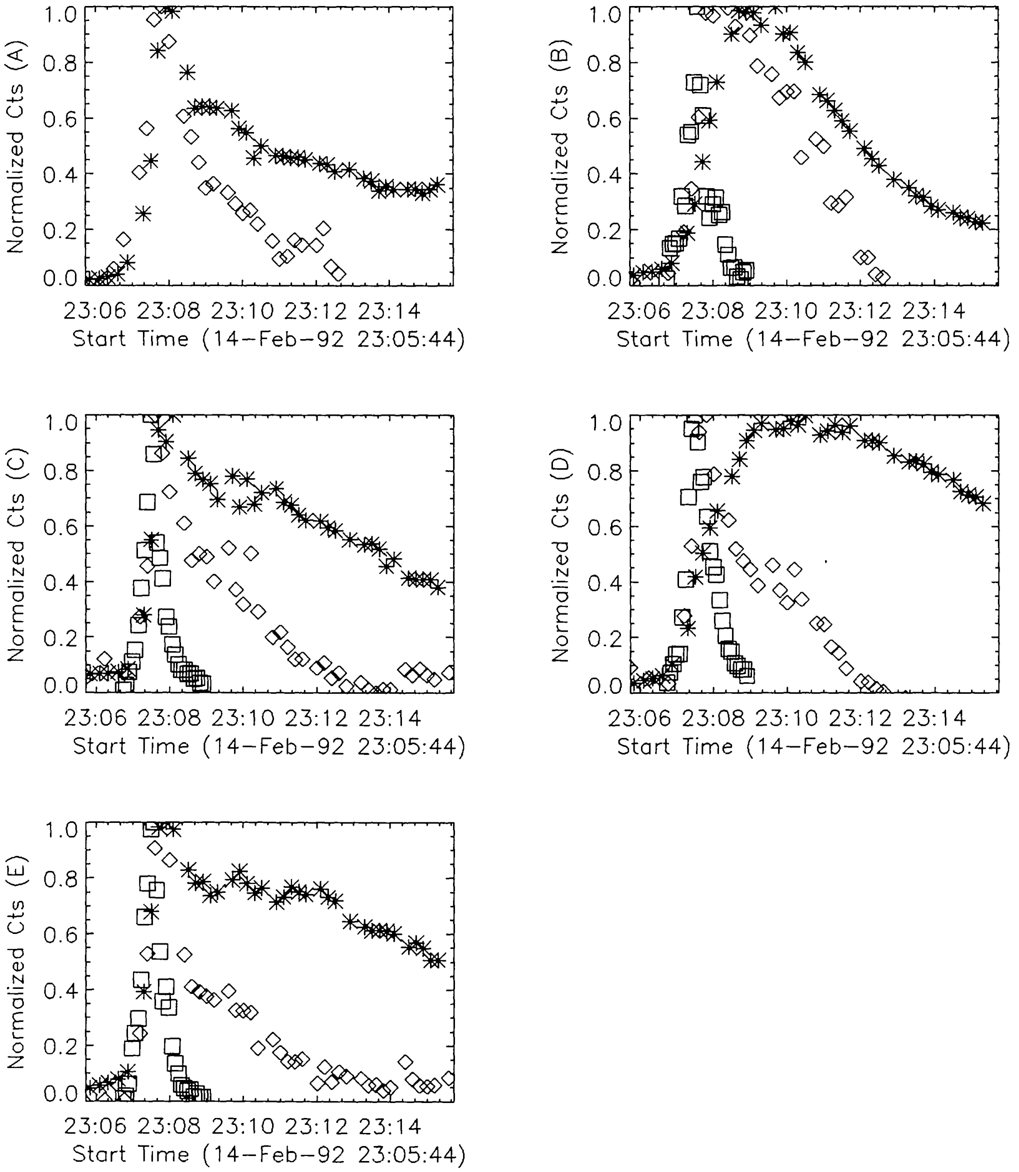

Figure 3. Normalised light curves in SXR (*), white-light (◇) and HXR M1 channel (□) for 14 Feb 92.

this wavelength band. However, there are cases where the WL and HXR emission are mis-matched during this phase, and the electron power is clearly not capable of accounting for the gradual component of the WL emission. By comparing light curves in SXR, HXR and WL we have seen that in several areas the SXR shows quite impulsive behaviour and that secondary peaks in WL during the gradual phase appear to correspond to peaks in the SXR with a slight time delay. This suggests a possible relationship between the origins of these two types of emission. One of these events (14 Feb 92) has previously been studied by Hudson et al. 1994. They speculated that the gradual WL sources come from high density plasma trapped in low-lying magnetic loops.

It seems clear that while the possibility of an electron beam origin for the WLF emission is supported by the observations in some regions, other mechanisms must also be contributing both during the impulsive and gradual phases. Other possible mechanisms include chromospheric condensations and nonthermal ionization (e.g. Gan et al. 2000; Aboudarham & Hénoux 1986; Hudson 1972). In particular Gan et al. 2000 have suggested that the continuum enhancement originates in the photosphere which is radiatively heated by the existence of a chromopsheric condensation and nonthermal ionization. Another possible contribution to WL emission seen by *Yohkoh* that should be considered is that of the H_γ line which is contained within this passband. Before we can with confidence comment on the origins of the WLF emission in these events we must address this issue.

4. Acknowlegements

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