ANALYSIS OF THREE *YOHKOH* WHITE–LIGHT FLARES

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Abstract

Three of the nine white–light flares thus far discovered in the *Yohkoh* white–light data were also observed at the Nobeyama Radio Observatory at its 80 GHz polarimeter. Each of the three flares was relatively close to the center of the Sun and had an Hα importance of 2B-3B, but the X–ray classes were quite different: the flares of 27 Oct. 1991, 15 Nov. 1991, and 14 Feb. 1992 had GOES X–ray magnitudes of X6.1, X1.5, and M7.0 respectively. We have analyzed the characteristics of these flares at white–light, X–ray and radio wavelengths in order to find clues for the emission mechanisms of the white–light and millimeter–wave continuum. Each of these three flares had both impulsve and gradual optical emissions. Using the *Yohkoh* soft X–ray images we associate the gradual component of white–light emission in these flares with compact high-temperature loops. We speculate that the white light itself comes from fine structures embedded in these loops, at densities greater than normal photospheric densities.

1. Introduction

Traditionally the solar flares visible in white light have been considered as a separate class of flare events. This distinction may turn out not to be significant, however, since improved instrumentation (Hudson *et al.*, 1992; Neidig *et al.*, 1993; van Driel-Gesztelyi *et al.*, 1994) shows that a large fraction of all flares — and doubtless all flares, given a certain scatter in the relationship — produce continuum emission. Nevertheless the major events remain interesting both because they are the easily detectable. Some of the white–light emission mechanisms remain unclear. These unknown mechanisms, when properly understood, may help us to understand various aspects of the physics of solar flares.

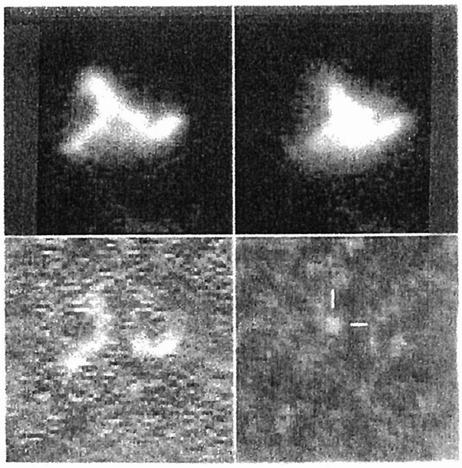

Figure 1. Four panels showing two different phases of the 14 Feb. 1992 flare in soft X-rays as observed by *Yohkoh* SXT. Left/right: impulsive phase (23:07:42 UT) and gradual phase (23:09:42 UT); top/bottom: SXT Be X-ray filter (hν ~2 keV), continuum at 4310Å. The gradual component of white light (lower right, location marked with lines) appears to be concentrated in a loop top as seen also in the 15 Nov. 1991 event. The impulsive–phase images show bright footpoint sourcees.

White–light flares have been known to be associated with powerful mm–wave emission. The radio flux density spectrum for such events may extend virtually unchanging from the microwave band. The summary plots of model spectra in Ohki and Hudson (1975) show this component in relationship to flare continuum in other wave bands. The flatness of the mm–wave spectrum suggests optically thin thermal bremsstrahlung as an emission mechanism, but the level of the emission is far above that expected from the soft X–ray emission measure; it is also far below that of the white–light continuum.

This paper reports an initial search of flare events simultaneously observed with the instruments on board *Yohkoh* and the mm–wave polarimeter at Nobeyama Radio Observatory. We found three events, all of them white–light flares detected by the *Yohkoh* SXT aspect camera.

2. Data and Discussion

The *Yohkoh* white–light data come from the aspect camera of the soft X–ray telescope (Tsuneta *et al.* , 1991; Hudson, 1994). Hudson *et al.* (1992) gave an early report on the SXT optical flare observations, and a fuller study is in preparation (van Driel–Gesztelyi *et al.* , 1994). Because of the brevity of this paper we have selected one event to emphasize, *viz.* that of 14 Feb. 1992 (cf. Ohki *et al.* , 1994); so far as we are aware there are no other published studies of this event except in the present Proceedings. It occurred near disk center (M7 2B; S13E02; in NOAA active region #7056).

The 14 Feb. 1992 event shows the characteristic pattern of soft X–ray brightenings at loop footpoints in the impulsive phase, followed by the evolution of hot plasma trapped in the loops connecting the footpoints. The impulsive white–light emission observed by SXT matches the impulsive soft X–ray in approximately six well–observed locations, as shown in Figure 1. Examination of an overlaid Kitt Peak magnetogram, confirms the appearance gained from the SXT images regarding loop connectivity.

The following gradual phase of white–light continuum is concentrated in one location, as shown in the lower–right frame of Figure 1. It is this phase that matches best in time with the mm–wave gradual component in this flare. Because this component has been identified with hot plasma in loops (Hudson and Ohki, 1972), we would like to associate the gradual white–light component with this same structure. This identification is problematic, because the longest–lived white–light emission patch in this flare is not located in a symmetrical position above the Kitt Peak magnetic inversion line, suggesting a different morphology for the white–light and soft X–ray loop sources.

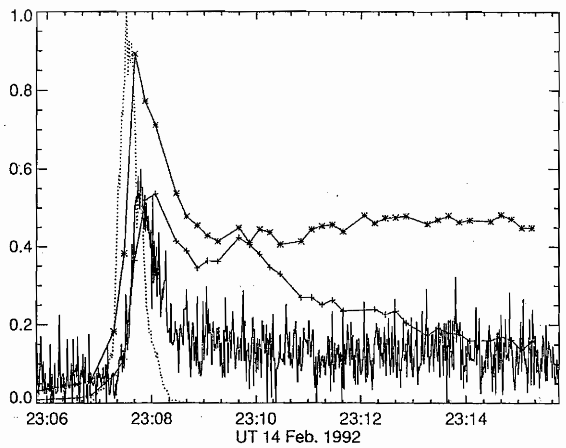

Figure 2. Time history of different radiations in the 14 Feb. 1992 event, showing the impulsive and gradual components. Dotted line, hard X–rays (BATSE high–energy channel); solid line, Nobeyama 80 GHz signal; asterisks, soft X–ray flux from impulsive footpoint; plus signs, soft X–ray flux from gradual source identified in Figure 1. Each plot is linear and to an arbitrary normalization.

We can also compare the emission levels of the sources. At mm–wave and soft X–ray wavelengths, the emission mechanism is optically–thin bremsstrahlung, a theoretically well understood process. The emission measure seen in soft X–radiation has an unknown temperature distribution, but at mm wavelengths the temperature dependence is quite negligible. Thus the mm–wave measurement gives an approximate integral of the differential emission measure distribution. The existence of this integral is important, because this event clearly shows "superhot" thermal behavior in the *Yohkoh* HXT photometry. This means a broader and less–well–defined emission–measure distribution. Our guess was that the superhot phenomenon, also observed in the other two events studied here, is connected with the gradual white–light continuum phenomenon.

We have found by detailed examination of the SXT temperature maps that the superhot source in this event does not coincide with the inferred white–light loop (the source marked in Figure 2). Instead it is diffuse in nature and extends between the array of footpoint sources to the S of the marked point. Each estimate of the temperature and emission measure of an X–ray source can be used to predict a mm–wave flux level. We have used the data available at 23:09 UT to make the estimates shown in Table 1 via a standard formula provided by White (1993).

Table 1. Estimates of 80 GHz Flux Density ("superhot" phase at 23:09 UT)

	T, 10^6K	n^2V, cm^{-3}	Flux, SFU
SXT	13.1	1.1×10^{50}	15.2
GOES	16.6	5.2×10^{49}	8.6
HXT	30	1.2×10^{49}	2
80 GHz			20±6

Following the arguments in Ohki and Hudson (1975), we remark that the gradual white–light source appears to be optically thick at 80 GHz, according to the information in

Table 1. If optically thin, an extrapolation of the optical continuum to mm wavelengths would result in a flux density exceeding 10^3 SFU from free–free emission.

3. Conclusions

The white–light flares detected by *Yohkoh* SXT often exhibit a *gradual* emission component. We have studied the sample of three such events for which Nobeyama 80 GHz polarimeter detections were available, and described one of these in some detail. As expected, the mm–wave fluxes are consistent with that extrapolated to long wavelengths from the soft X–ray band, even though there is a good possibility the gradual phase of each of these events exhibits "superhot" behavior. We suggest that the gradual component comes from high–density plasma trapped in low–lying magnetic loops. The white–light continuum is far in excess of the interpolated continuum connecting the mm–wave and X–ray bands, establishing that optically–thin bremsstrahlung from ordinary flare loops cannot explain it. We can speculate, at this level of analysis, that the gradual white–light sources are in extremely fine filaments of greater than photospheric density, which occur as sub–telescopic inclusions in the macroscopic flux tubes observed by SXT to connect the impulsive footpoint sources seen in these flares.

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