NONTHERMAL AND THERMAL EMISSIONS IN SOLAR FLARES

Nariaki Nitta

Astronomy Program, University of Maryland, College Park, MD 20742, U.S.A.

Abstract

In two major solar flares, we have found evidence for hard X-ray footpoint emission using the X-ray imager on *Hinotori*. Possible factors are discussed as to why we only rarely detect footpoint emissions, which may not always take the form of double sources, depending on magnetic configurations in flares.

1. Introduction

It is often argued that, in a majority of solar flares (so-called "type B" flares), hard X-rays emanate from conjugate footpoints of a sheared loop or loop system, emitted by a symmetric electron beam which precipitates into the chromosphere and interacts with the ambient plasma (see Tanaka 1983; Tsuneta 1984). However, apart from earlier analyses (Hoyng *et al.* 1981; Duijveman *et al.* 1982) with the *Hard X-ray Imaging Spectrometer* (HXIS: the resolution 8") on the *Solar Maximum Mission* (SMM), double hard X-ray sources are far from common (Duijveman and Hoyng 1983). This is more so in observations with the *Solar X-ray Telescope* (SXT: the resolution $\gtrsim$15") on *Hinotori*, where hard X-ray images usually show a single source (Takakura *et al.* 1983, 1984).

However, through further analyses of *Hinotori* flares, we now come to believe that, under favorable conditions, footpoint emission can be detected even with SXT. In this report, we present two of such examples and discuss what are distinct in these flares.

2. Flare on 1982 February 3

This flare is described in detail elsewhere (Nitta *et al.* 1989). Hard X-ray time profiles consist of two major parts (01:05~01:13 UT and 01:14~01:23 UT) separated by a deep valley. In Fig. 1, we show both hard X-ray (dotted lines, 27~54 keV) and soft X-ray (solid lines, approximately 5~10 keV) images on nearly simultaneous H*α* filtergrams. At 01:10:15 UT, corresponding to a peak in the first part, hard X-ray emission comes from two locations whereas soft X-ray emission emanates from in between them. We associate the two hard X-ray emitting regions with footpoints of a loop system (which is similar to H*α* post flare loops seen in Fig. 1(d) well after hard X-rays decay) and the soft X-ray source with the loop top. The small displacement of the hard X-ray sources with respect to the brightest H*α* patches can be attributed to projection effect and/or possible errors ($\lesssim$ 10") in coalignment of the images.

In Fig. 1(b), obtained at a peak of the second part (01:14:40 UT), only one footpoint is seen. About three minutes after the last hard X-ray peak, hard X-ray emission assumes a single source (Fig. 1(c)), nearly cospatial with soft X-ray emission which comes from the loop top all the time during the period covered by in Figs. 1(a)~(c). We believe that the hard X-ray source in this phase is due to thermal emission of temperature $\gtrsim 3\times10^7$ K, similar to the one observed by Lin *et al.* (1981), since the spectrum at low energies is very soft.

https://doi.org/10.1017/S0252921100154089 Published online by Cambridge University Press

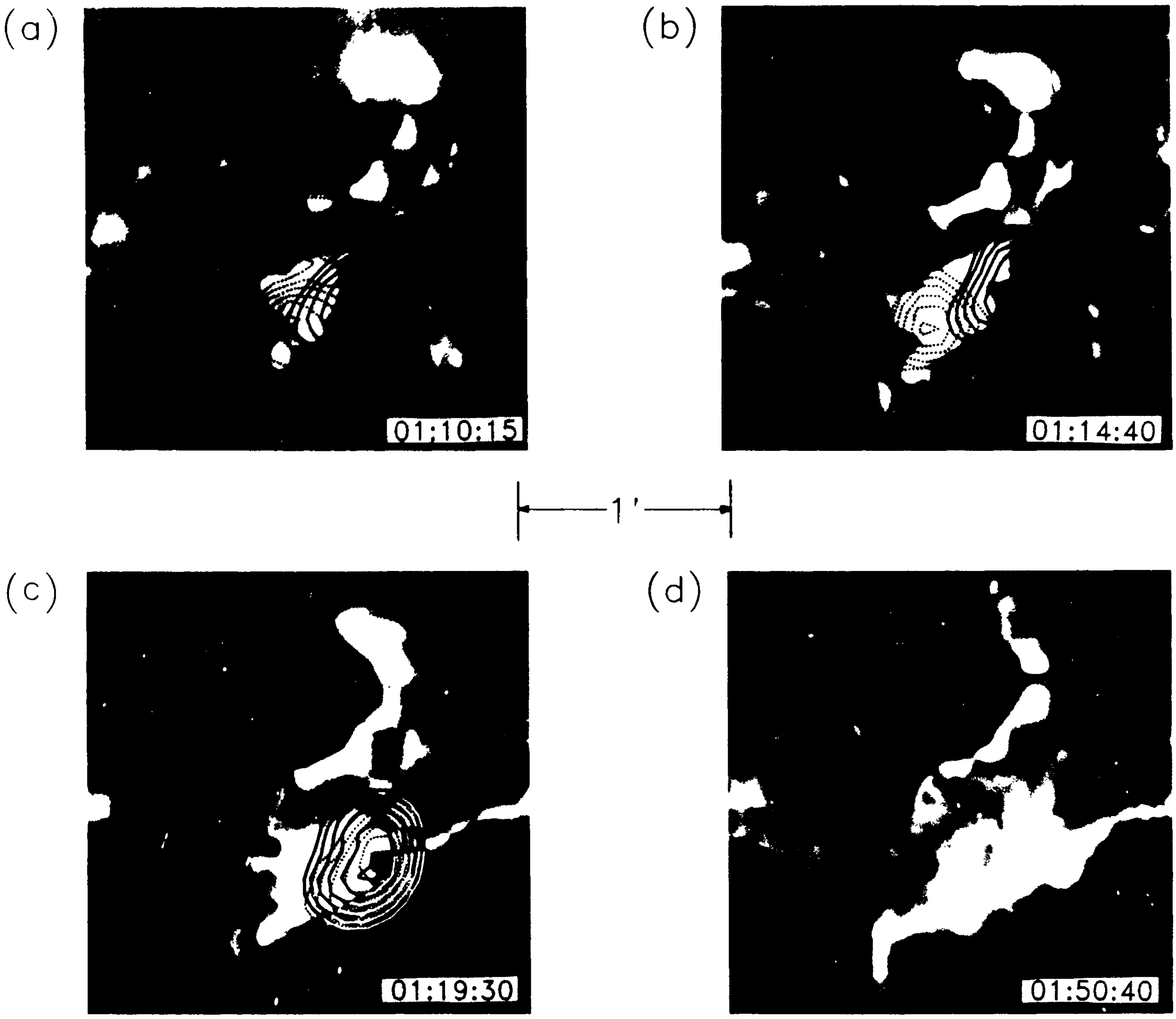

Fig. 1- Overlay of hard X-ray (dotted lines) and soft X-ray (solid lines) images on Hα filtergrams at peaks ((a) and (b)) and in the decay phase ((c)). Contour levels are 15.9%, 22.5%, 31.8%, 45 %, 63.6% and 90% of the peak intensity in each image. North is at the top and west is to the right. An Hα filtergram in the post flare period is shown in (d).

3. Flare on 1981 October 15

There is again evidence for footpoint emission for this flare. Hard X-ray (approximately 25~50 keV) images (Figs. 2(a)~(c)) change significantly in about 1 min. At first only one footpoint (A_1) is seen. Just after the first peak at 04:44:07 UT, a second source (B) appears, as A_1 moves southward (or rather, a new footpoint A_2 emerges). Then another footpoint A_3 dominates. In Fig. 2(d), the Kitt Peak magnetogram (with potential field lines) at 16:33 UT on the same day is shown. Magnetic features are shifted unforshortened to allow for the rotation of the Sun. The SXT field of view is drawn for reference. Comparison with hard X-ray images suggests that footpoints A_1, A_2 and A_3 are all of positive polarity while the footpoint B is of negative polarity.

This flare is unusual in the sense that soft X-ray emission is very weak with respect to hard X-ray emission (Fig. 3). Soft X-ray images are not available. Since the spectrum in 10~30 keV ranges is not affected much by thermal emission of temperatures (1.5~2.5)x10^7 K which is commonly observed in solar flares, this flare offers a rare chance to study the extension of nonthermal spectrum to low energies (Nitta and Dennis 1988).

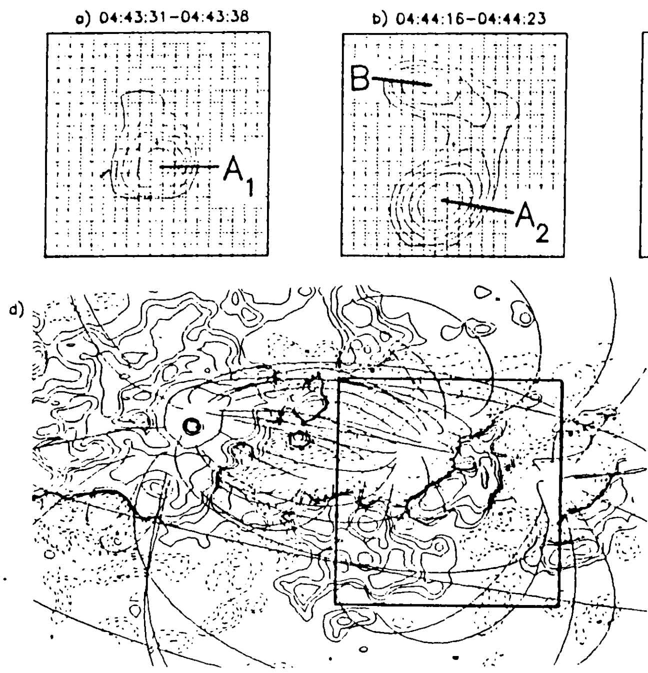

Fig. 2- (a)~(c) Hard X-ray images for the flare on 1981 October 15 at three representative times. Contour levels are 15.9%, 22.5%, 31.8%, 45% and 63.6% of the peak intensity in each image. (d) Kitt Peak magnetogram at 16:33 UT on the same day (solid lines for positive polarity and dashed lines for negative polarity), with potential field lines. The SXT field of view is drawn for reference.

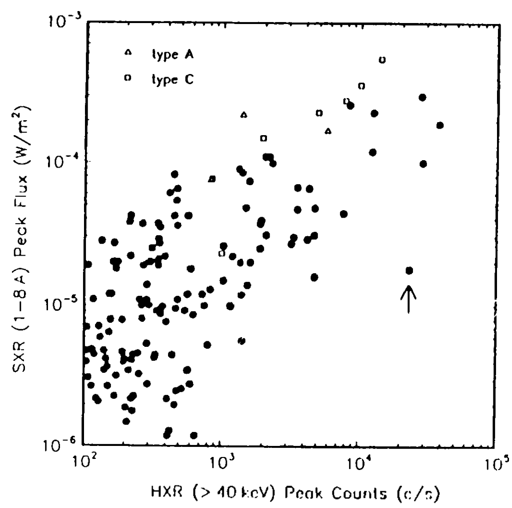

Fig. 3- Peak soft X-ray flux vs peak hard X-ray flux for 147 *Hinotori* flares. The 1981 October 15 flare is indicated by an arrow. Those flares showing clear spectral hardening over the peaks are classified as "type C" (7), while those with an extremely steep spectrum and small source size are classified as "type A" (3).

https://doi.org/10.1017/S0252921100154089 Published online by Cambridge University Press

4. Discussion

Unlike previous analyses, we have been able to see footpoint emission with the *Hinotori* imager, which has a spatial resolution of only $\gtrsim$15''. Wide separation of footpoints (50''~70''), commonly observed in both of the two flares, is certainly a key factor for detection of footpoint emission, although it is not well known how separated footpoints of flare loops generally are. Without comparisons of X-ray images with optical informaion such as Hα pictures and manetograms, which have not been made systematically in other flares, the fact that hard X-ray images show a single source cannot rule out the possibility of footpoint emission, since footpoint emission often takes the form of a single source as Figs. 1(b), 2(a) and 2(c) indicate. We consider that flare loops are more or less asymmetric (see Maetzler 1976; Kundu and Vlahos 1979), letting electrons precipitate nearly freely at the footpoint of weaker magnetic field, while mirroring them back above the footpoint of stronger magnetic field. Both examples shown here have stronger (weaker) hard X-ray emission on plage (sunspot) regions.

For the 1982 February 3 flare, although coalignment of X-ray images on Hα filtergrams leaves some uncertainty, simultaneous soft X-ray images, which are dominated by thermal emission of temperatures ~2×10^7 K have been useful in associating hard X-ray emission with footpoints. For the 1981 October 15 flare, exceptionally small soft X-ray flux (Fig. 3) may lead us to observe footpoint emissions. In fact the low energy ($\lesssim$40 keV) hard X-ray spectrum shows a clear flattening toward low energies (Nitta and Dennis 1988). This in turn suggests that what is observed to be a power-law spectrum may be decomposed into a flattening nonthermal spectrum superposed by thermal emission (whose temperature should be considerably higher than 2×10^7 K). If this is the case, some, if not all, of the hard X-ray images so far obtained at $\lesssim$35 keV) may be affected significantly by the thermal components.

The author acknowledges support from NSF grant ATM 87-17157, NASA contract NAG 5-969 and NASA grant NGR 21-002-199 to the University of Maryland.

References

Duijveman, A., Hoyng, P., and Machado, M.E. 1982, *Solar Phys.*, **81**, 137.

Duijveman, A. and Hoyng, P. 1983, *Solar Phys.*, **86**, 279.

Hoyng, P., Duijveman, A., Machado, M.E., Rust, D.M., and Svestka, Z. 1981, *Ap.J.(Letters)*, **268**, L155.

Kundu, M.R. and Vlahos, L. 1979, *Ap.J.*, **232**, 595.

Lin, R.P., Schwartz, R.A., Pelling, R.M., and Hurley, K.C. 1981, *Ap.J.(Letters)*,**251**,L109.

Maetzler, C. 1976, *Solar Phys.*, **49**, 117.

Nitta, N., Kiplinger, A.L., and Kai, K. 1989, *Ap.J.*, in press.

Nitta, N. and Dennis, B.R. 1988, in preparation.

Takakura, T., Ohki, K., Tsuneta, S., and Nitta, N. 1983, *Solar Phys.*, **86**, 323.

Takakura, T., Tanaka, K., and Hiei, E. 1984, *Adv. Space Res.*, **4**, 143.

Tanaka, K. 1983, in *IAU Colloq. 71, Activity in Red Dwarf Stars*, eds. P.B. Byrne and M. Rodono, (Dordrecht: Reidel), p.307.

Tsuneta, S. 1984, in *Proc. Japan-France Joint Seminar on Active Phenomena in the Outer Atmosphere of the Sun and Stars*, ed. J.C. Pecker and Y. Uchida (Paris: CNRS and L'Observation de Paris).