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Physical Conditions in Coronal Structures About to Flare

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Abstract. We use *Hinode* observations to study coronal structures about to flare, based on their apparent footpoints as a guide to identification. The high resolution and excellent stability of the *Hinode* observations makes the identifications much more precise than those done with the soft X-ray telescope (SXT) on board *Yohkoh*. The physical conditions in the coronal structure about to flare are important in understanding the nature of the plasma processes leading to the eruption. We find examples of soft X-ray microflares that agree with the SXT conclusions: the structure is essentially invisible prior to the flare in most cases. We present a estimation of preflare temperature and density and find that in these cases, the flare appears to happen in flux tubes with undetectably low electron density, less than $\sim 10^8$ cm^{-3}. A similar program with the full instrument set of *Hinode* would be extremely powerful, owing to the broad temperature coverage available.

1. Introduction

A solar flare typically takes place in an active region near a sunspot group. In soft X-rays it appears as a set of loop-like structures in the solar corona apparently tracing out magnetic flux tubes, and filled with gas hot and dense enough to produce the X-ray emission via normal collisional excitation of thermal lines and continua. Sensitive observations with high resolution can in principle characterize the physical conditions in the corona prior to the event. Because of the short timescale of flare brightenings, we can identify preflare and flare structures by determining their footpoints in the chromosphere. This was attempted previously with the Soft X-ray Telescope on board *Yohkoh* by Fárník et al. (1996) and by Fárník & Savy (1998), with the general result that in most cases a bright preflare structure had not been visible with the footpoint pattern of the flare loops that subsequently appeared. This result implicates coronal volumes with low plasma beta, $\beta = 2nkT/(B^2/8\pi)$, in the flare process.

In contrast, recent RHESSI data have suggested the existence of "coronal thick targets" in some events (Veronig & Brown, 2004), in which the electron acceleration underlying flare radiations appears to have taken place in a loop already having an appreciable gas pressure. This finding appears to confirm the pattern originally reported by Strong et al. (1984) that suggested successive independent energy releases in the same coronal flux tube. We thus have somewhat contradictory results in the literature. The *Hinode* observations, with their unprecedented sensitivity and spectral coverage, should produce decisive results regarding preflare conditions. In this paper we describe a first look at data from the *Hinode* X-ray telescope XRT and sketch out a new analysis technique. Our findings confirm those of Fárník et al (1996) in most of the cases we examined. We point out that a far more definitive study can be made by combining data from all three of the *Hinode* telescopes, and we encourage such a study in the future.

2. Data and Analysis

For each event studied, we made a difference image from the level-0 data, allowing for the pedestal and exposure time, and compared its morphology with that of the preflare active region. To identify flux tubes in two distinct images requires (a) accurate coalignment, and (b) sufficient angular resolution to be able to match the footpoint regions. We have checked the coalignment by cross-correlating the images in the microflare data cube from November 11, 2006, but have not tried to identify footpoints quantitatively for this analysis. In the full use of *Hinode* data it would be ideal to be able to do the footpoint identification with the highest-resolution images, e.g. by using SOT to image the H line (or RHESSI hard X-rays) in the impulsive phase.

An example of the difference-image technique for a microflare is shown in Figure 1. The flare consists of loops that brighten up near previously existing active-region loops, but do not coincide with them. At this resolution it is clear that the flaring and non-flaring loops do not, in general, share footpoints, and therefore must represent distinct flux tubes.

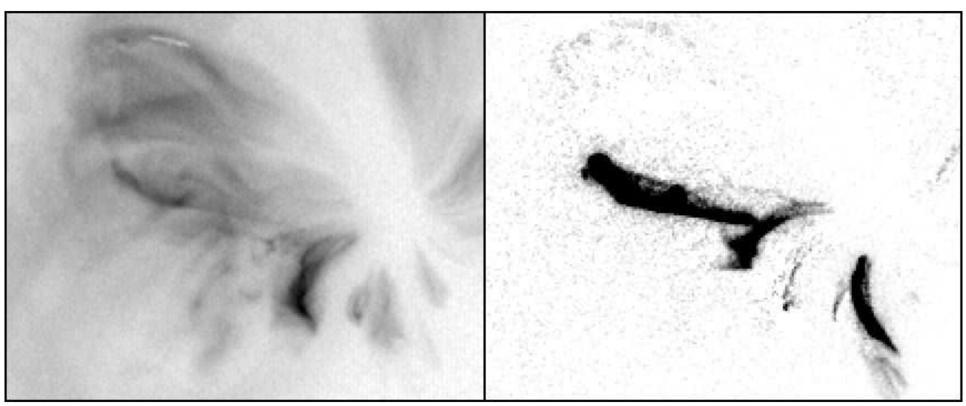

Figure 1. Images from a microflare observed in soft X-rays by *Hinode*/XRT. *Left*, pre-event image, 2006 11 Oct. 11:20:57, compressed; *right*, the difference between a flare image at 11:25:59 and this reference, scaled linearly to the preflare image range. This figure illustrates the appearance of new loops during such an event. Image size $220'' \times 175''$, filter Al-Poly.

The event illustrated in Figure 1 is a microflare (magnitude ∼B2). We have checked several (∼10) microflares in the interval 2006 Nov. 11 10:30-12:00 UT, for which XRT had suitable coverage, and obtained similar results. An example of a C-class flare (2007 June 25 04:20) also showed that new structures appeared. The overall impression is similar to that from *Yohkoh*: based upon the footpoint positions, the loops that flare up are usually distinct from those present in the active region prior to the event.

As described above, we often see nothing in the preflare image that can be identified with a flare loop observed by XRT. This implies upper limits on density and temperature, given the general relationship that the soft X-ray intensity $I_{h\nu} = \int n^2 f(T) dl$, with the integral taken along the line of sight. Here f(T) is the model spectral response of XRT considering the detailed properties of the instrument, and based on the Chianti (Dere et al. 1997) spectroscopic model to relate the spectrum to the temperature. A given (n, T) distribution along the line of sight then determines the signal detected in a given XRT pixel. An upper limit on the flux, the most interesting case reported above, therefore implies either an upper limit on density or on temperature.

The physical parameters (n, T) are linked theoretically via the gas pressure in the loop, which can be determined for a steadily heated plasma via the RTV scaling law (Rosner et al. 1978; Craig et al. 1978) if one knows the geometry ($T \sim (pL)^{1/3}$). As a first approximation, in this paper, we make a simplifying assumption about the geometry: we assume that the preflare flux tube has the same geometry as a nearby and morphologically similar flare loop. For this case we find that the ratio of intensity of a flaring loop and a nearby similar (but non-flaring) reference loop to be $I/I_{ref} = (T/T_{ref})^4 \times [f(T)/f(T_{ref})]$. Figure 2 shows typical XRT response functions in the particular form required by this analysis method. The strong temperature dependence implied by conductive equilibrium means that the XRT data are actually not too sensitive to the preflare conditions.

Not all flare loops have such morphologically similar preflare counterparts, unfortunately. For other flare loops one could make other plausible simplifying assumptions, but probably it would be more productive to actually detect preflare structures by use other wavelengths (e.g., EIS) in a future study.

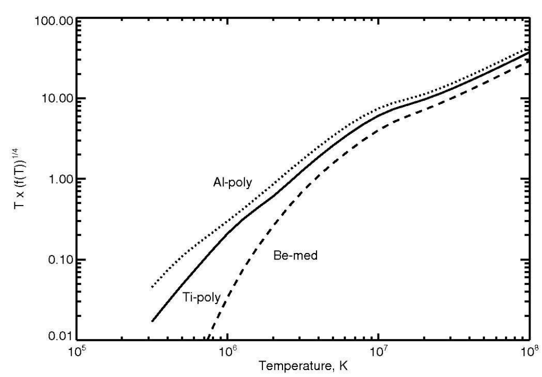

Figure 2. The XRT response functions for three filters as indicated, plotted following $T^4 f(T)$ (an appropriate weighting for RTV equilibrium; see text).

We have used the method described above to provide estimates for a typical microflare loop, finding T $\lesssim$ 1 MK, n $\lesssim 1 \times 10^8$ gm cm^{-3}, plasma beta $\lesssim 1 \times 10^{-4}$, and Alfvén speed $\gtrsim$ 0.1 c. These results are just illustrative and can be substantially improved. To obtain them we simply assumed a reference loop temperature of 3 MK and a loop magnetic field strength of 100 G. Corresponding limits for more complicated situations will depend upon the background intensity provided by the preflare structure that is visible where the flare loops are to appear. Projection effects will frequently confuse the identifications.

3. Conclusions

We have made a first comparison of *Hinode*/XRT images before and after a flare occur, and find that it is difficult to identify the flaring magnetic structure in the preflare images. This means that we have set upper limits on the density and/or temperature of the preflare structure, or its pressure. Making use of the RTV scaling laws, we have derived upper limits on both density and temperature in regions about to flare, finding them to be (undetectably) tenuous and cool.

The study by Fárník & Savy (1998), based on a sample of 32 events well-observed in the preflare phase by *Yohkoh*/SXT, concluded that in only 1/4 of the cases "the flare structure is active in soft X-rays several minutes or more before the flare begins." This result depends upon the resolution of observations, and we believe that the fraction with an active preflare structure can only decrease with the improved XRT resolution. For most of the *Yohkoh* flares the preflare structure of the flaring loops was in fact not identifiable, a result consistent with our observations here. Nothing in the literature, therefore, suggests that we know much about physical conditions in the preflare state of a flare flux tube. The preflare conditions of the coronal plasma must be such as to permit the flare instability to proceed and to extract coronal magnetic energy. We note that this happens at low plasma beta, so the gas pressure (hence X-ray detectability) in a preflare structure might have very little to do with the flare process itself (heating, motion, or particle acceleration).

Finally we note that eruptive flares often seem to show the outward motion of previously existing filamentary material (e.g, Moore et al. 2001). In such cases the conclusion here about a tenuous preflare state may not apply. These cases will be difficult to study by these techniques, because they involve long, low-lying field structures for which it will be hard to locate the footpoints exactly.

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