RHESSI'S FIRST X-CLASS FLARE: APRIL 21, 2002

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ABSTRACT

The X-class flare of April 21, 2002, not only was RHESSI's first X-class event, but also yielded an extraordinary wealth of data from TRACE and SOHO as well as the new results from RHESSI. The flare was a large-scale, two-ribbon, long-decay, CME-associated event and showed (for the first time in TRACE data) the presence of supra-arcade downflows following the dimming signature. RHESSI observed the footpoint development in the flare ribbons in hard X-rays and was able to track the coronal development of high-temperature sources with unprecedented fidelity, for many hours after the impulsive phase. In this paper we review some of the RHESSI and other results in the context of recent flare observations.

INTRODUCTION

The Reuven Ramaty High Energy Spectroscopic Imager (RHESSI; see Lin et al., 2002, for fuller information) began observations in February, but it was not until April 21 that an X-class flare was observed. Due to the "Max Millennium" organization[1], excellent observations were also obtained by TRACE and by SOHO. From the latter there were unprecedented SUMER observations made direction above the flare in a coronal volume that exhibited remarkable properties.

The purpose of this paper is to provide a mini-review of work published thus far on this event, noting that further data reduction and analysis continues. We expect future RHESSI data reductions to improve on all aspects of the results presented here, especially as regards imaging performance and especially "imaging spectroscopy" (Hurford et al., 2002). Unfortunately this X-class flare did not provide strong γ-ray signatures.

[1]*http://solar.physics.montana.edu/max_millennium/*

Table 1. Flare event tabulation (NOAA)

0059	0131	02:51	LEA	FLA	S14, W84	1F, LPS
0043	0151	02:38	GO8	XRA	1-8A	X1.5
0108	0123	0408	LEA	RBR	15,400	1,300
0055	0123	0408	LEA	RBR	8,800	2,700
0057	0124	0408	LEA	RBR	4,995	2,500
0058	0130	0410	LEA	RBR	2,695	1,900
0058	0130	0410	LEA	RBR	1,415	110,000

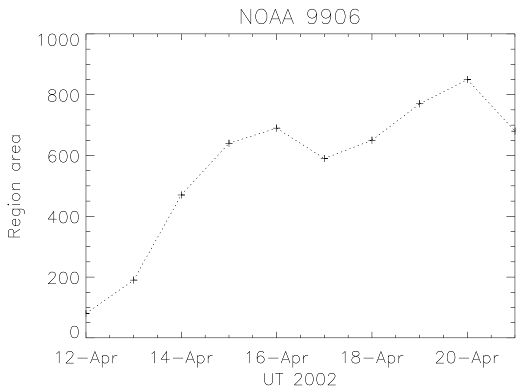

Figure 1. Area growth of NOAA region #9066 in April, 2002. The region was born on the disk, experienced rapid growth, and produced an M-class flare on April 15.

THE FLARE: TEMPORAL DEVELOPMENT

We summarize in Table 1 the relevant information obtained from (the NOAA "events" listing) [2]. The flare occurred in NOAA region #9906 in a $\beta\gamma\delta$ active region just at the west limb (central meridian passage April 15, 2002); Figure 1 shows the region's development. The ribbon alignment was approximately north-south, so that the resulting arcade and loop prominince system was viewed side-on. The flare resulted in a halo CME (first image 01:27 UT, termed "extremely fast" at ∼2500 km/s by the LASCO preliminary CME listing[3]). and a strong proton event at an intensity of 2,520 pfu (Proton Flux Units, the 10 MeV flux at Earth).

We show the RHESSI raw data in an abbreviated format in Figure 2. This format contains several artifacts but gives an excellent overview of the time development of the flare. In particular the hard X-ray emission (see the 30-50 keV band in Figure 2) continues throughout the first orbit of the event, as expected from the long duration of the GOES rise phase, and even into the second orbit as late as about 02:30 UT. The long duration of hard X-radiation would be expected from the Neupert effect (Neupert, 1968; Dennis and Zarro, 1993; Hudson and McKenzie, 2000), but this event also belongs to the category of "extended events" with intense coronal effects (Cliver et al., 1986), as might be suggested by the late hard X-ray excess (∼02:30 UT) more than an hour after event onset. We have examined images of this excess, however, and find it to be at the footpoints of the arcade. Some of the coronal complexity will be revealed in the discussion of RHESSI images below.

THE FLARE: IMAGE MORPHOLOGY

The two images shown in Figure 3 do not begin to do justice to the complicated evolution of the RHESSI and TRACE data. This requires a movie, and we refer the reader to a version viewable on the Internet[4]. Both RHESSI and TRACE evidently have sufficient sensitivity to study the very earliest stages of flare development, but with quite different diagnostic capabilities. In this movie one can identify several phenomena:

- The early compact brightening appears first in the RHESSI contours, rather than in the TRACE 195Å images.
- The TRACE data show a diffuse coronal feature, which we attribute to the Fe XXIV response at 192 Å as studied by Warren et al. (1999).
- The RHESSI higher-energy emissions clearly reveal the footpoints of the loop system seen by TRACE at low temperatures (see Figure 4).
- The TRACE later stages show a clear coronal dimming above the arcade (Hudson and Webb, 1997) indicative of a CME (as observed); they also show supra-arcade downflows (McKenzie and Hudson, 1999).

We elaborate on some of these observations next. First, one should note that the general outlines of each of the observations noted above appear in earlier data, especially the flare observations from *Yohkoh* in soft and hard X-ray images. Here the superior resolution and sensitivity of RHESSI shows us new features. The growth of the soft X-ray loop system, as shown in Figure 4 (from Gallagher et al., 2002), is a particular case. Here we see a rising set of postflare loops, a phenomenon long recognized as potentially the signature of a progressive reconnection of open field lines. This picture may be over-simple, though, since the upward apparent motion begins long before the field lines inferred from the TRACE images actually have opened. The abrupt change in slope at about 03:00 UT has not been reported before; it brings into question the distinction between Švestka's "giant arches" (Švestka et al.,) and ordinary post-flare arcade systems, since in these observations a single post-flare structure appears to evolve continuously while exhibiting the linear motion noted for the giant arches.

[2] *http://www.sel.noaa.gov/ftpdir/indices*
[3] *ftp://lasco6.nascom.nasa.gov/pub/lasco/status/LASCO_CME_List_2002*
[4] *http://hesperia.gsfc.nasa.gov/∼ptg/hessi/20020421/eit-trace-hessi-large.mpg*

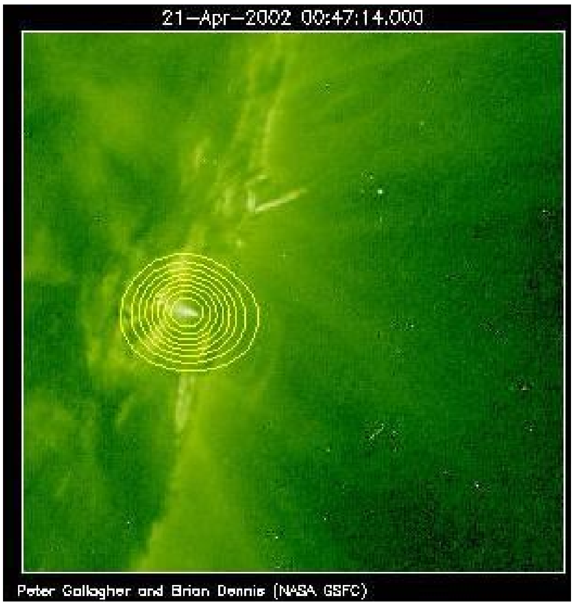

Figure 3(a). Initial stage of flare, as shown by TRACE with RHESSI contours (12-20 keV) overlaid. At this quite early moment in the flare, 00:47:14 UT, the TRACE and RHESSI sources are close to one another; however the RHESSI signal appears to precede the TRACE signal.

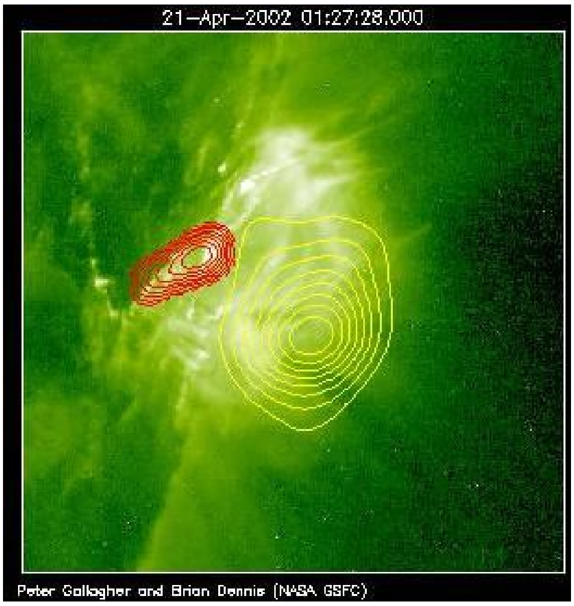

Figure 3(b). Main phase, with two RHESSI contour sets overlaid on the TRACE image at 01:27:26 UT. The yellow contours matching the TRACE coronal structure (right side of image) represent a 12-25 keV band; the red contours at the footpoints (ribbons) show 50-100 keV.

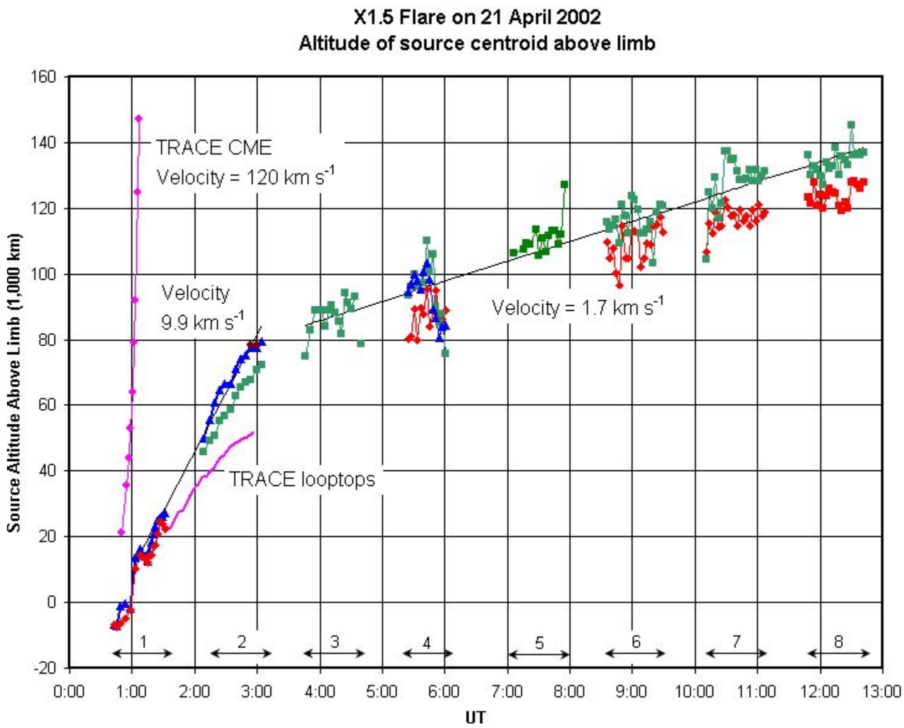

Figure 4. Growth of the coronal X-ray loop system as observed by RHESSI in different energy bands (diamonds, 3-6 keV; squares, 6-12 keV; triangles, 25-50 keV; the lower set of squares at the latest time is also 3-6 keV). The feature labeled "TRACE CME" is at most a component of the CME (because of its low speed) and may represent prominence material. RHESSI tracks the loop system for many hours and follow its cooling; note that the much cooler TRACE looptops lie will below the RHESSI loops, consistent with the theory (Forbes and Acton, 1996) of "shrinkage."

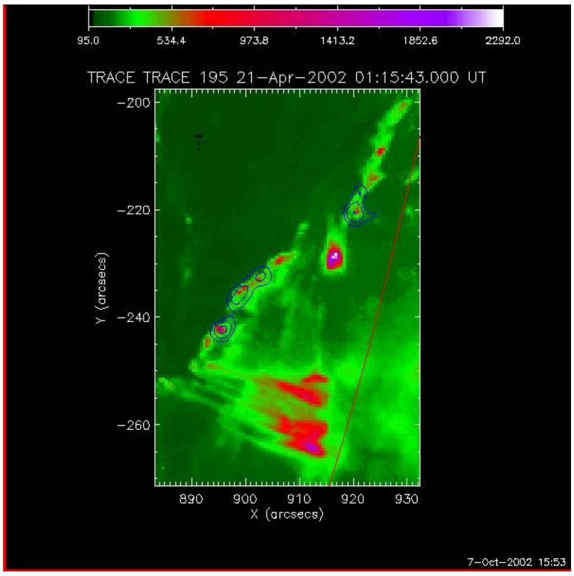

Figure 5(a). The hard X-ray footpoints overlaid on the TRACE image at 01:15:43 UT, showing the presence of simultaneous multiple footpoints, matching closely between the EUV and hard X-rays. Note that the brightnesses of the footpoints do not necessarily correlate well.

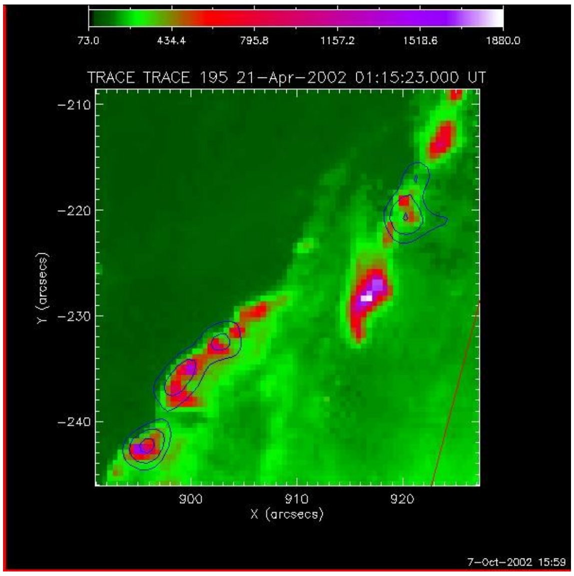

Figure 5(b). The hard X-ray footpoints overlaid on the TRACE image at 01:15:23 UT, again showing the presence of X-ray and EUV footpoint sources, but at a larger scale. Although the brightnesses of the footpoints do correlate well the positions of the EUV and hard X-ray sources match quite well.

One key question to be answered by the RHESSI imaging spectroscopy, when it is complete for this flare, will be the role of non-thermal electrons within the loops as they develop. We know from the footpoint brightening, which can be imaged at high energies right through RHESSI's second orbit of observation (the excess noted earlier at ∼02:30 UT), that particle acceleration continues well past the time the supra-arcade downflows appear in the TRACE movie. How are these phenomena, suggested earlier to have a relationship based upon occurrence statistics (Hudson and McKenzie, 2000), physically related? Most importantly, how is the impulsive-phase electron acceleration related to the restructuring during magnetic reconnection? Several competing scenarios exist for this process, which has fundamental importance for understanding how flares work.

Although this flare, at W81, does not provide a good view of the ribbons, the RHESSI data confirm the finding of Masuda et al. (2001) regarding the hard X-ray illumination of the ribbons (see also Fletcher and Hudson, 2001) for a view of the EUV ribbons in the context of the hard X-rays; both of these papers deal with the "Bastille Day" flare of July 14, 2000). Figure 5 shows RHESSI's view of the ribbons, making use of the full resolution of the instrument.

THE FLARE: TRACE AND SOHO

We have already shown some of the TRACE data. At the time of writing no detailed analysis has appeared in the literature, even among the RHESSI "first papers" compendium in *Solar Physics*. However Wang et al. (2002) have described the SUMER (Solar Ultraviolet Observations of Emitted Radiation) data from this event. As a result of the Max Millennium planning the SUMER slit was placed exactly above the flaring arcade, in perfect alignment to measure the activity in the arcade and above it. Because the supra-arcade downflows probably represent the most direct signature of the large-scale magnetic reconnection process in an eruptive flare, the measurement of plasma parameters via EUV spectroscopy is extraordinarily nice.

The Wang et al. (2002) description of the event does not take RHESSI data into account, and emphasizes jets seen to begin as early as 00:39:39 UT at a position to the north of the initial hard X-ray brightening (Gallagher et al., 2001). By their appearance the jets originates or near the region of the western ribbon (the north end) that will develop as the flare proceeds. Because of the lack of an X-ray signature we speculate that this initial jet is an accidental coincidence, not related to the full development of the flare, although Wang et al. (2002) stress the significance of the jet in a model they have developed for a similar event, also seen at the limb (Wang et al. 2001).

CONCLUSIONS

This paper should have at most a brief period of utility, since research should proceed on this remarkably well-observed event. In the case of RHESSI, a learning process is still continuing and we can expect quantitative changes as well as new discoveries. For SUMER too, there is little literature on flare observations, and certainly none of a flare as powerful and well-disposed as this one. We therefore expect abundant further information from SUMER as well as the other SOHO instruments that were in use.

The RHESSI instrument has shown its capability to track faint early-phase flare developments, which should enable us to identify the energetically significant participants in preflare activity. In this flare too, for the first time, we have RHESSI images making use of the full resolution of its finest collimator ($2.26''$ resolution, full width at half maximum) during the main development phase. This has confirmed that multiple footpoints along the flare ribbons can be illuminated by hard X-rays approximately simultaneously. This information in the context of models of the coronal magnetic field during its restructuring should help us to understand the main flare energy release. As argued by Fletcher and Hudson (2001), the hard X-rays guide us to the coronal sources of the electrons that carry a large fraction of the flare energy. Finally, we see from Figure 4 that the RHESSI low-energy capability will also help us to understand the aftermath of the eruption, a matter of great importance because of the unknown physics of the magnetic flux newly opened by a CME (Gold, 1962).

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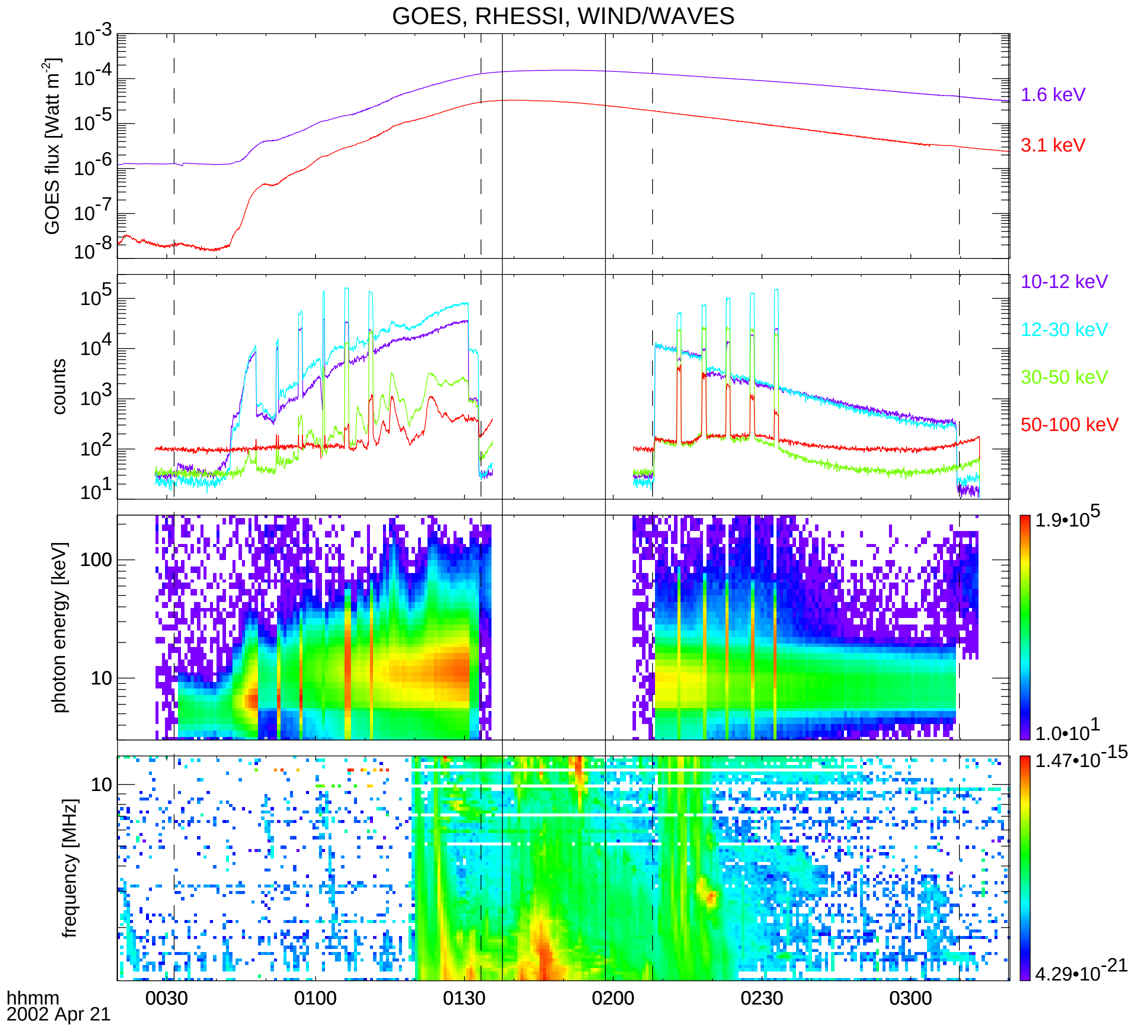

Figure 2. Overview plot of the GOES (upper panel) and RHESSI counting rates (second panel), with a dynamic spectral representation of the latter in the third panel and a similar representation of the WIND/WAVES radio observations at the bottom. The plots cover a time range of three hours, starting at 00:00 UT April 21, 2002; the vertical dark zones show eclipse intervals (orbit nights) for RHESSI. The RHESSI observations show the raw data in a rather schematic way; the automated operation of the shutters strongly affects the presentation, producing vertical artifacts in the dynamic spectrum. The upper envelope of the dynamic spectrum shows the spiky hard X-ray variability to extend throughout most of the first orbit of observations. The WIND/WAVES data shows that disturbances in the outer corona did not begin immediately with the onset of the flare.