RHESSI OBSERVATIONS OF THE CORONAL COMPONENT OF SOLAR FLARE HARD X-RAY SOURCES

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ABSTRACT

In flares that occur behind the limb, the intense chromospheric (foot-point) part of the hard X-ray source is occulted, thus permitting good observations of the coronal component. Between 15 and 18 April 2002, RHESSI observed a series of small (GOES Class C) flares produced by the active region NOAA 9905 as it rotated behind the west limb. A preliminary analysis of the observed hard X-ray sources in the 17-18 April 2002 flares has confirmed that flare-associated sources of gradual 12-25 keV X-ray emission can exist in the corona at heights up to 27000 km.

INTRODUCTION

Energetic electrons accelerated during a solar flare interact with the ambient solar plasma to produce hard X-rays through bremsstrahlung. The properties of these electrons can be studied through an analysis of the characteristics of these hard X-ray sources. Multi-spacecraft observations during the last solar cycle have shown that in addition to the relatively intense sources located in the chromosphere at the foot-points of magnetic loops, flare-associated hard X-ray sources exist in the corona at heights in excess of 30000 km (Kane et al. 1982, 1992, 1998). The isolation and detection of coronal hard X-ray emission is difficult because of its relatively low intensity compared to the dominant emission from the low-lying footpoint sources. It is therefore necessary to observe flares which are located few degrees behind the solar limb so that the low lying X-ray sources are occulted by the photosphere but the higher coronal X-ray sources, if present, are visible to the X-ray detecting/imaging instruments.

A question of some importance is whether high coronal sources exist in most solar flares or they are characteristic of only a few unusual intense flares. Observations of a large number of behind-the-limb solar flares are necessary to resolve this question. The high energy spectroscopic imager aboard the RHESSI spacecraft is well suited for such observations. The purpose of this short paper is to report the early results from a recently initiated systematic study of the height of coronal hard X-ray sources made with the RHESSI instrument.

INSTRUMENTATION

The RHESSI spacecraft carries a high energy spectroscopic imager which images the Sun from 3 keV to 15 MeV with high temporal, spectral and spatial resolution (Lin et al. 2002). Here we will be mainly concerned with ~7-arcsecond resolution time-averaged X-ray images in the 12-25 keV range. In order to reduce the low-energy X-ray flux incident at the detectors, either or both of two shutters ("thin" and "thick") can be placed automatically or by command between the incident X-rays and the X-ray detectors. At the time of flares studied here the "thin" shutter was present in the X-ray path.

OBSERVATIONS

Since its launch on 5 February 2002, RHESSI has recorded several hundred flares. For this work, we selected an interval from 15-18 April 2002 in which a series of 8 flares observed by RHESSI occurred in active region NOAA 9905 as it rotated from CMD 60 deg west to behind the west limb of the Sun. This provided an opportunity to look for systematic effects in flare-associated hard X-ray sources as they were partially occulted by the chromosphere. Although the flares were not expected to be identical (homologous), some general similarities in the basic

characteristics of the X-ray flare emission may provide information about coronal X-ray sources and their height above the photosphere.

The occurrence time and soft x-ray flux of each of the eight flares are listed in Table 1 which shows that these were relatively modest events, with observed soft x-ray classes ranging from C3.1 to C9.9. (Of course, in the case of the behind-the-limb events, the total soft x-ray flux is much larger.) The directly observed optical locations for the first four events that occurred on the disk are also given Table 1. Since the number of flares is large and their time-profiles (light curves) are simple and typical for small flares, time-profiles of individual flares are not shown here.

The average X-ray flux for the four unocculted flares (first four flares in Table 1) is comparable to the average flux for the four occulted flares (last four flares in Table 1). Although this is unexpected, it can sometimes happen because the ratio of the occulted to unocculted flux for a given flare depends on the degree of occultation as well as the detailed structure of the flare. All the flares in Table 1 were selected only on the basis of their relationship with the active region NOAA 9905. No other selection criteria were employed.

Table 1. Hard X-ray flares from solar active region NOAA 9905

2002	GOES		OPTICAL	HXR	HXR	HXR LOCATION			RADIAL	OCCULT.	TOTAL
DATE	MAX	CLASS	LOCATION	INTERVAL	COUNTS	West	North	heliocentric	OFFSET	HEIGHT	HEIGHT
	UT			UT	x10^3	arcsec		degrees	arcsec**	arcsec	km
15-Apr	1736	C3.1	S16 W60	1738-1745	10.6	798.5	-206.5	S15.3 W59.7	-131.7		
17-Apr	0040	C9.9	S13 W83	0038-0042	421	918.0	-232.5	S14.8 W83.0	-9.1		
17-Apr	0237	C2.3	S13 W84	0235-0237	6.8	922.5	-233.5	S14.6 W85.4	-4.5		
17-Apr	1342	C6.9	S11 W90	1336-1346	33.4	939.0	-222.5	S13.3	9.1	0.0	6600
17-Apr	1658	C9.8	W93*	1654-1700	242	929.5	-244.5	S14.7	5.2	0.5	4200
17-Apr	2304	C4.4	W96*	2301-2305	94.6	928.5	-240.0	S13.9	3.2	3.3	4700
17-Apr	2319	C4.4	W96*	2313-2320	62.8	928.5	-247.5	S14.3	5.1	3.2	6100
18-Apr	1612	C3.0	W106*	1513-1520	43.2	926.5	-260.0	S13.7	6.7	30.1	26800
	* Longitude inferred from time of occurrence.										
	** Relative to the optical limb.										

Using normal RHESSI imaging procedures (Hurford et al 2002), hard X-ray maps were made of each flare over an interval that included its peak. The CLEAN algorithm was used with subcollimators 3 through 9 to produce images with ~7 arcseconds angular resolution in the 12-25 keV energy range. The absolute locations are good to ~1 arcsecond. The images obtained for the eight flares are shown in Figure 1. These images correspond to "gradual" X-ray emission. In the first three flares the X-ray sources are located on the solar disk. In the remaining five flares, however, the X-ray sources are located above the solar limb with essentially no emission sources on the solar disk. The time intervals, total counts and the observed centroid location for each image are given in Table 1. Physical dimensions or shape of the X-ray sources could not be determined because the sources were not "resolved" by the instrument. Linear dimension of the observed X-ray sources seems to be $\leq$ 5000 km.

For each flare a composite photon spectrum (thermal + double power law) was fit to the observed photon flux averaged over the same time interval as the images of the X-ray sources. The power law exponents obtained for the 12-25 keV photons varied from 7.1 to 10.5. In the 12-25 keV range, the relative contribution from the "thermal" emission was found to be very small. The observations are therefore consistent with a "non-thermal" spectrum. However, in most cases the photon spectra are very steep. Moreover the observed photon spectrum covers only a small energy range because photons with energy >30 keV were not detectable above the detector background. It was therefore not possible to make a reliable determination as to whether the photon spectrum was thermal or non-thermal.

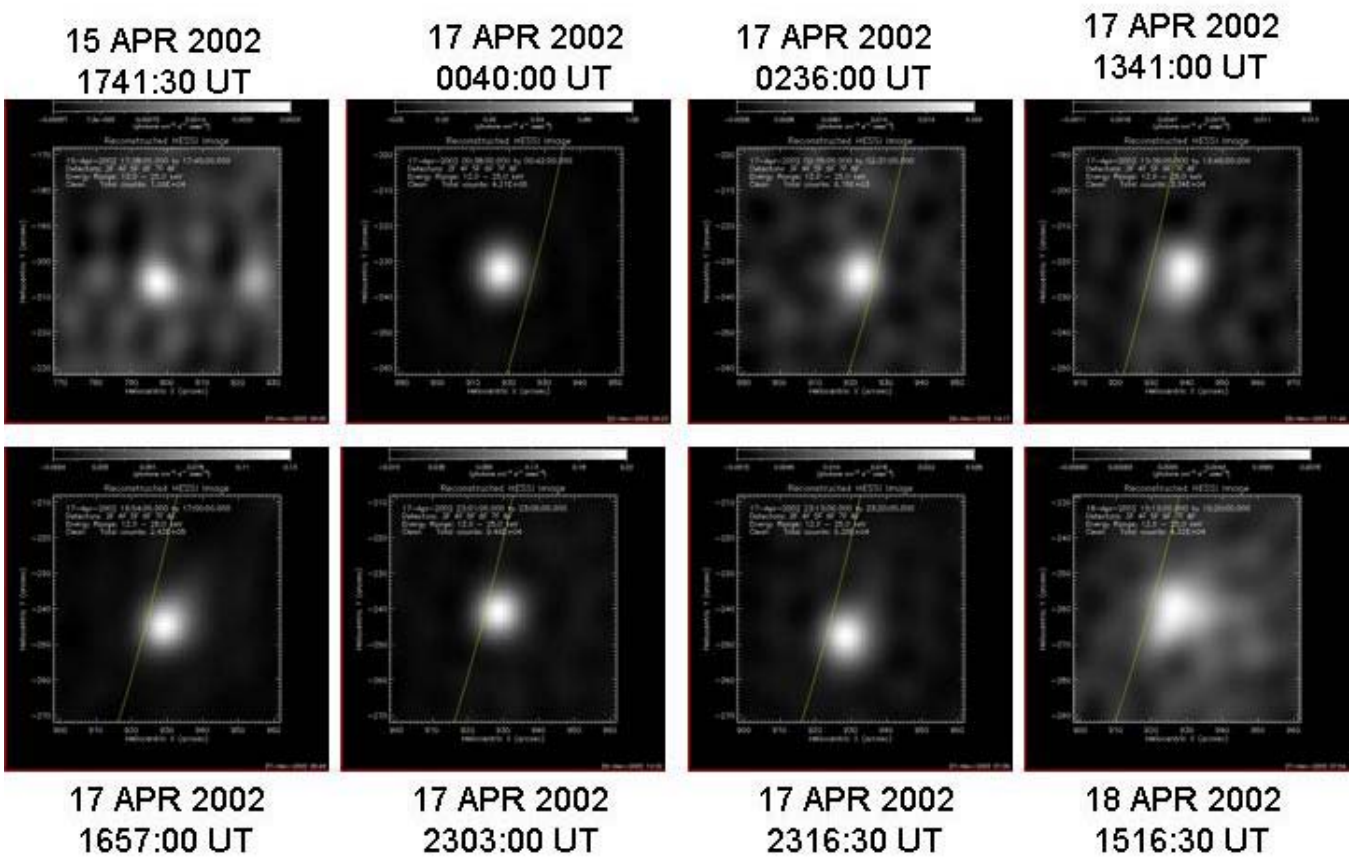

Fig.1. Images of the 12-25 keV X-ray sources as observed by RHESSI for the 8 flares associated with the active region NOAA 9905 are shown with respect to the photospheric limb. In the first (left) image in top row, the solar limb is outside the field of view to the right. The field of view in each case is 64 x 64 arcseconds. See Table 1 for details.

DISCUSSION

To determine the height of the x-ray emission above the active region, optical data from NOAA were used to determine location of the active region as it approached the west limb. These longitudes and latitudes are plotted in Figure 2. Also plotted in Figure 2 are the observed optical and X-ray longitudes of the first 4 flares. Both the active regions and flare longitudes follow the expected trend due to solar rotation. Extrapolating the linear fit to the longitude vs. time trend enables us to estimate the longitude of the last 4 flares that occurred behind the west limb. Assuming this longitude, the observed X-ray location of the 4 behind-the-limb flares can be used to estimate their latitude as well. The results, shown in Table 1 and Figure 2, show that the latitudes of the behind-the-limb events are very consistent with that of the other flares and the active region observations.

When a flare is located behind the limb, that part of the X-ray source below the "occultation height" is occulted by the photosphere, with an occultation height depending on how far behind the limb the relevant flare occurred. In these behind-the-limb flares the foot-point hard X-ray sources, presumably located in the chromosphere, are not visible to RHESSI. The heights above the photosphere for the hard X-ray sources in flares 5, 6, 7 and 8 are given in Table 1 and range from ~4000 to ~27000 km. These numbers are determined from the occultation height and the observed radial offset of the hard X-ray source relative to the optical limb.

The RHESSI observations are consistent with the multi-spacecraft observations of coronal hard X-ray sources in large solar flares made during the last solar activity cycle (Kane et al 1982, 1992, 1998; Trottet et al. 2003).The present study shows that, even in relatively small solar flares (as observed from the earth), the gradual hard X-ray emission occurs at heights up to ~ 27000 km. These heights are much larger than those observed earlier in relatively large flares by hard X-ray imaging instruments aboard Hinotori (Takakura et al. 1986) and Yohkoh (Masuda et al. 1995) satellites. RHESSI observations show that gradual hard X-ray emission in solar flares extends

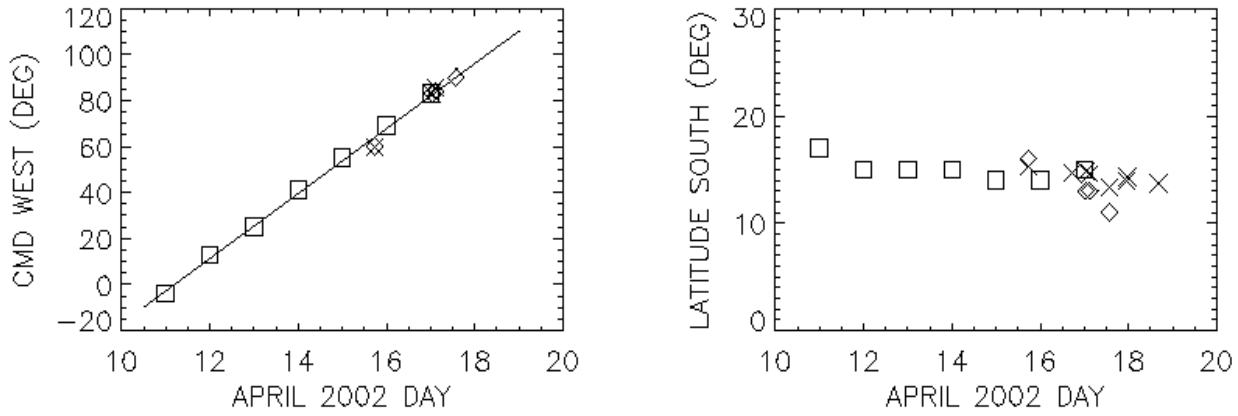

Fig. 2. Variation of the Central Meridian Distance (CMD) and latitude with time for the Active Region NOAA 9905 during its passage on the solar disk. Squares and diamonds show the optical location of the active region and flares respectively. The X's show the observed locations of the HXR sources.

to heights much higher than the heights of relatively low lying magnetic loops associated with hard X-ray sources in most solar flare models.

SUMMARY AND CONCLUSIONS

During the period 17-18 April, 2002 the active region NOAA 9905 produced four small (GOES Class C) solar flares with locations behind the west limb of the Sun. RHESSI observations show that the sources of gradual 12-25 keV X-ray emission in these flares were located at heights up to ~27000 km above the photosphere. These heights appear to be much larger than those expected from most models of solar flares.

RHESSI has extended the previous observations in two important aspects: (1) imaging of the coronal X-ray source and (2) high sensitivity to observe small flares. In case of relatively large behind-the-limb flares, detailed studies of the spatial and spectral structure of the coronal sources are possible with the RHESSI instrument. In this short paper we have presented the early results on the height of gradual 12-25 keV X-ray sources in the corona associated with small (GOES Class C) solar flares produced by one active region. Analysis of RHESSI observations involving (1) several active regions, (2) impulsive and gradual hard X-ray sources in large solar flares, and (3) correlated other emission sources, such as radio and EUV, are in progress. The results will be reported in future communications.

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