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Simultaneous Observations of Solar Flares with *CGRO*/OSSE and *Yohkoh*/WBS

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Abstract. *Yohkoh* and the *Compton Gamma Ray Observatory (CGRO)* are the only satellites currently measuring of gamma radiation from solar flares. In this paper we present preliminary results of a cross-calibration of the *Yohkoh*/Wide Band Spectrometer (WBS) and the Oriented Scintillation Spectrometer Experiment (OSSE) on *CGRO*. Except for one flare whose spectrum was very hard, total flux measurements by the two instruments agreed. Differences of narrow-line fluxes are probably attributable to the poorer energy resolution of the *Yohkoh*/WBS.

1. Introduction

Yohkoh and *CGRO* are the only satellites providing measurements of γ radiation from solar flares until the launch of *HESSI*. A number of discoveries have resulted from recent analyses of γ-ray flare data from these and similar instruments including: accelerated ions can contain more energy than electrons (Ramaty et al. 1995); the ambient flare plasma on average reflects coronal abundances but shows significant variations both within and among flares (Share & Murphy 1995; Ramaty et al. 1995; Murphy et al. 1997); isotropic or fan-beam distributions of accelerated α particles fit the spectroscopic data (Share & Murphy 1997); temporal variations of $\sim$0.1 s are observed to >10 MeV (Share et al. 1997); the accelerated α/proton ratio can be 0.5 and higher (Share & Murphy 1998); the average accelerated ^{3}He/^{4}He ratio is $\sim$0.1 and ambient ^{4}He may be enhanced (Mandzhavidze et al. 1999). Continued observations of γ-ray flares with these instruments will complement the excellent spectral resolution of *HESSI*.

Having the *Yohkoh* and *CGRO* satellites in orbit simultaneously enhances flare observations in several ways: flare measurements are extended to times when one satellite is either in the radiation belts or behind the Earth; the WBS is less sensitive and so is less likely to be saturated than is OSSE, providing coverage during the most intense portions of flares; the high sensitivity and better spectral resolution of OSSE permits WBS spectral features to be resolved and understood. A first step to a reliable use of data from these instruments is a cross calibration. This has been accomplished for four flares and the results are reported here. We also discuss comparisons of OSSE data with data

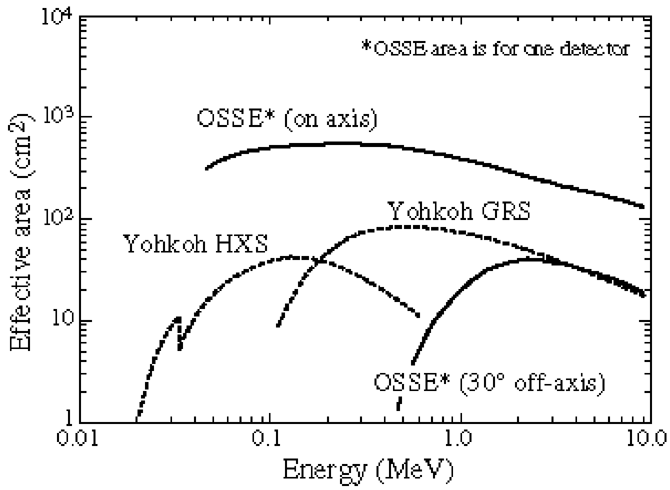

Figure 1. Comparison of *Yohkoh*/WBS and *CGRO*/OSSE sensitivities.

obtained from the *CGRO*/EGRET Total Absorption Shower Counter (TASC) and *GRANAT*/PHEBUS.

2. Comparison of *Yohkoh*/WBS and *CGRO*/OSSE Capabilities

The *Yohkoh* WBS, described by Yoshimori et al. (1991), consists of three instruments covering the range from 2 keV to 100 MeV. Being a dedicated solar instrument, the WBS is always pointed at the Sun. The OSSE instrument, described by Johnson et. al (1993), consists of four detectors and covers the energy range from 0.05 to >150 MeV. Each detector can rotate allowing scanning through 192°. During solar observations the detectors alternately point on and 4.5° off the Sun at 131.1-s intervals. During times when the Sun is not an explicit OSSE target, OSSE can also observe the Sun in response to a BATSE solar trigger if the Sun is accessible along the scan plane. Good observations of strong off-axis flares can still be accomplished by detecting photons penetrating the shields. Because of strong low-energy attenuation, analysis of off-axis data is generally restricted to above ~1 MeV.

In Figure 1 we compare the sensitivities of the WBS and one OSSE detector. In addition to the OSSE sensitivity to an on-axis source, we also show the sensitivity to a source located 30° off-axis. Even for such an off-axis source, the OSSE and *Yohkoh* sensitivities are comparable above a few MeV.

3. Description of Flare Data

Four X-class flares have been identified that were simultaneously observed by *Yohkoh* and OSSE. Table 1 lists the four flares, their dates, GOES classifications, times of the soft X-ray peak, the *Yohkoh* accumulation times, the corresponding OSSE accumulation times, and the angles of the Sun from the OSSE detector

Table 1. Flares Simultaneously Observed by *Yohkoh* and OSSE

Date	GOES class	GOES peak time	Yohkoh accumulation interval	OSSE accumulation interval	OSSE off-axis angle
1991 Oct 24	X2.1	2:40	2:38:38–2:38:42	2:37:36–2:38:41	30°
1991 Oct 27	X6.1	5:48	5:40:06–5:41:30	5:40:07–5:41:29	31°
1991 Nov 15	X1.5	22:39	22:37:10–22:37:58	22:37:02–22:38:08	32°
1998 Nov 22	X3.7	6:42	6:37:30–6:40:18	6:37:26–6:40:10	42°

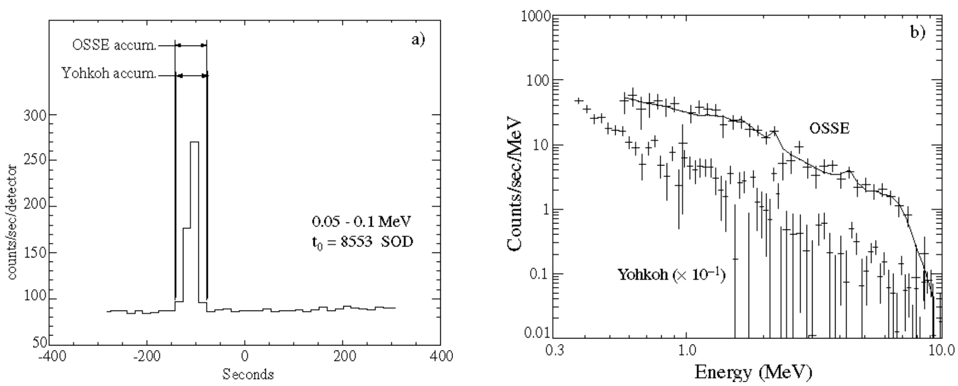

Figure 2. OSSE 50-100 keV count rate time profile (a) and OSSE and *Yohkoh* count spectra (b) of the 1991 October 24 flare.

axis. All times are UT. We note that OSSE has more extensive observations of these flares but here we only accumulate data over the *Yohkoh* intervals. None of the flares were observed with the Sun within the OSSE field of view. Because of severe attenuation of low-energy photons at these large off-set angles, the OSSE data were fit only above 0.55 MeV.

The spectra were fit with a model including components representing the electron bremsstrahlung (a power law), the narrow 2.223 MeV neutron-capture line, and narrow and broad nuclear deexcitation lines. Because the 1998 November 22 spectrum showed no evidence of nuclear-line emission, the OSSE data from this flare were fit only with a power law. Since the OSSE data were fit only above 0.55 MeV, the power law component is not well determined and, consequently, the broad component is also uncertain. We note that because the *Yohkoh* accumulation times are short, only a fraction of the delayed 2.223 MeV line emission from the flares has been measured.

Figures 2a and 2b through 5a and 5b show 50-100 keV OSSE count-rate time profiles and OSSE and *Yohkoh* count spectra of the 4 flares. In each figure, the spectrum from one of the two instruments has been shifted as indicated for display purposes. The best-fitting model resulting from the OSSE fit is also shown overplotting the OSSE data.

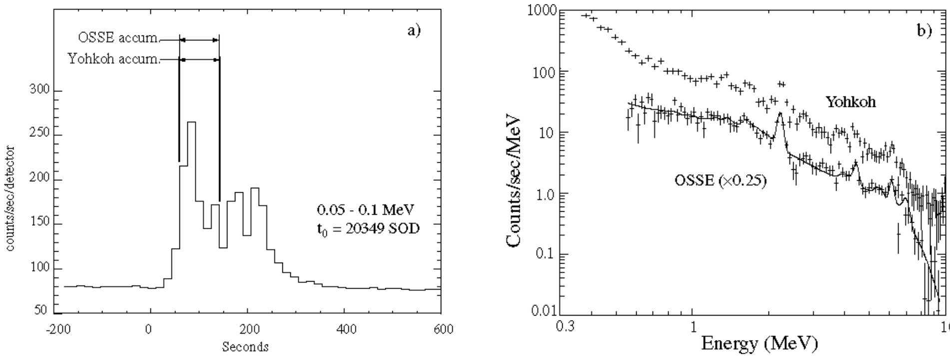

Figure 3. OSSE 50-100 keV count rate time profile (a) and OSSE and *Yohkoh* count spectra (b) of the 1991 October 27 flare.

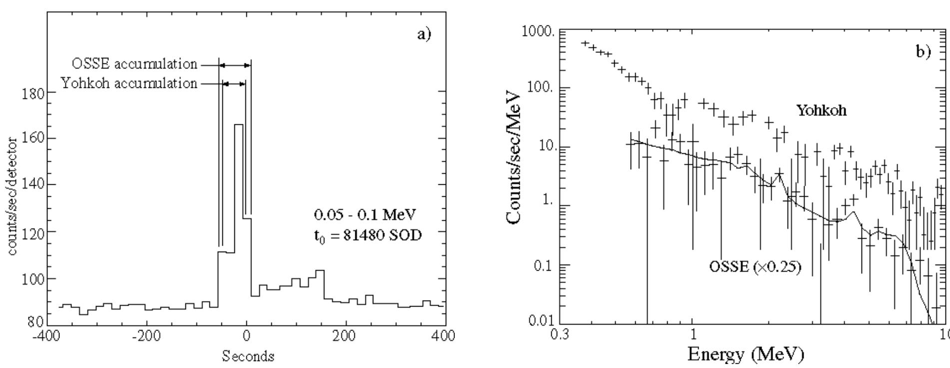

Figure 4. OSSE 50-100 keV count rate time profile (a) and OSSE and *Yohkoh* count spectra (b) of the 1991 November 15 flare.

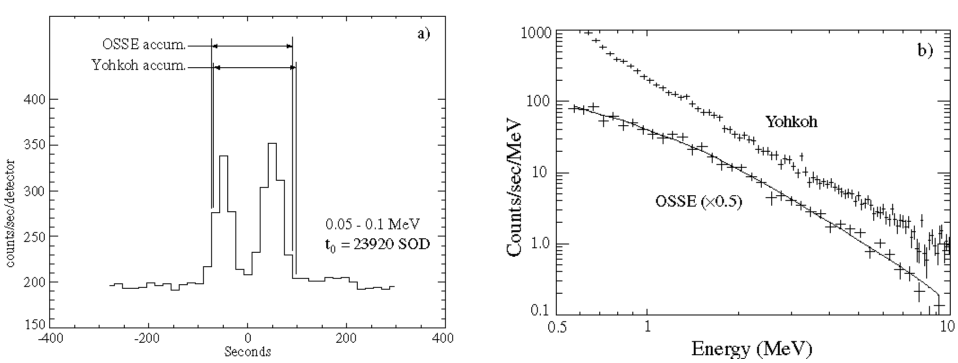

Figure 5. OSSE 50-100 keV count rate time profile (a) and OSSE and *Yohkoh* count spectra (b) of the 1998 November 22 flare.

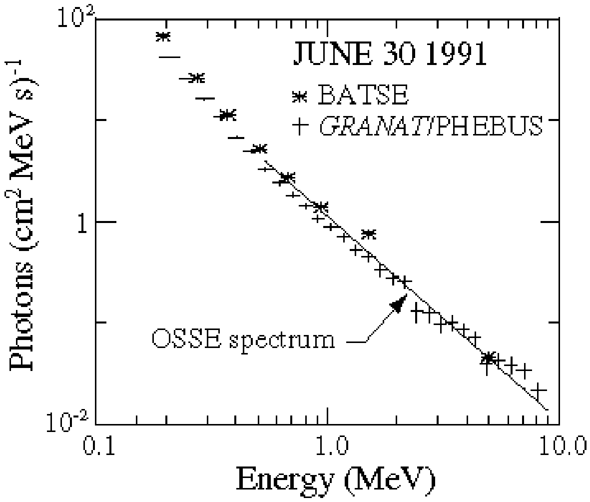

Figure 6. *GRANAT*/PHEBUS, BATSE, and OSSE derived photon spectra for the 1991 June 30 solar flare (from Vilmer, et al. 1999)

4. Results

We first wish to establish the reliability of OSSE off-axis data by comparing simultaneous on- and off-axis OSSE data and by comparing OSSE off-axis data with data from the EGRET/TASC and from *GRANAT*/PHEBUS. During the last 10 minutes of first-orbit observations of the 1991 June 4 +X12 flare, the flare intensity had dropped sufficiently so that on-axis OSSE detectors were no longer saturated. This allows comparison of on-axis data with data from detectors pointed 4.5° off-axis. The fitted 2.223 MeV line fluences from on- and off-axis data were 86.6 ± 0.6 and 89 ± 3 photons cm^{-2}. This good agreement implies that the relative OSSE off-axis calibration is quite good at 4.5°.

The EGRET/TASC also observed the June 4 flare. During the interval 3:42:32–4:04:22 UT, the fitted TASC 2.223 line MeV fluence was 678 ± 20 photons cm^{-2} (Schneid, priv. comm.). The corresponding OSSE fluence from 4.5° off-axis data was 622 ± 28 photons cm^{-2}. These values agree to within ∼10%.

OSSE observed the 1991 June 30 M5 solar flare at ∼55° off-axis. It was also observed by *GRANAT*/PHEBUS and Vilmer et al. (1999) found that the PHEBUS data could be reasonably fit with a broken power law. Figure 6 shows the derived PHEBUS photon spectrum and the spectrum derived from simultaneous BATSE data. The derived OSSE >0.55 MeV photon spectrum is also shown as the curve in Figure 6. The agreement of the OSSE off-axis results with both the PHEBUS and BATSE results is quite good.

Turning to the OSSE-*Yohkoh* comparison, Table 2 compares the 2.223 MeV line, >1 MeV narrow nuclear line and total >1 MeV fluences for the four flares of Table 1. (We do not compare the power law and broad-component results because they are so poorly determined with the off-axis OSSE data as mentioned above.) Table 2 shows that the derived *Yohkoh* 2.223 MeV fluences consistently exceed the OSSE values. This may result from the poorer energy resolution of the WBS. For a narrow line such as the 2.223 MeV line, the better energy resolution of OSSE should result in a more reliable determination of the fluence.

Table 2. 2.223 MeV Line, >1 MeV Narrow Nuclear Line & Total >1 MeV Fluences

	2.223 MeV Line (photons cm^{-2})		Narrow-Line (photons cm^{-2})		>1 MeV fluence (photons cm^{-2})	
Flare	*Yohkoh*	OSSE	*Yohkoh*	OSSE	*Yohkoh*	OSSE
Oct 24	11.7±4.0	2.5±0.5	4.3±2.5	6.0±1.3	81.3±21.3	55.6±7.4
Oct 27	33.3±3.5	19.8±1.0	45.8±8.4	28.5±2.3	219±37	183±16
Nov 15	3.1±1.6	2.1±0.9	2.1±1.6	7.7±2.3	33.6±7.2	41.1±15.6
Nov 22	–	–	–	–	624±41	314±12

Table 2 also shows considerable variation between the *Yohkoh* and OSSE narrow nuclear line fluences, although the values differ at most by only 2.1 σ. Again, the better energy resolution of OSSE should produce a better determination of the fluences of such narrow lines. COMPTEL data are also available for the October 24 and November 15 flares and analysis of these data may help to understand these discrepancies.

Except for the November 22 flare, all of the total >1 MeV fluences listed in Table 2 are consistent to within $\sim$1 σ. The fluences of the November 22 flare are significantly different but are still within a factor of two. We have no definitive explanation for the discrepancy although it may have to do with the relative steepness of the spectra near 1 MeV.

During the next year we will continue conducting simultaneous OSSE and *Yohkoh* observations, especially when the Sun is within the OSSE FoV. The Sun has received high observing priority during the current *CGRO* observing cycle, with the Sun observable $\sim$80% of the time through April 2001.

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