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Gamma Ray Measurements of the 1991 November 15 Solar Flare

M.B. Arndt[1], K. Bennett[2], A. Connors[1], M. McConnell[1], G. Rank[3], J.M. Ryan[1],V. Schoenfelder[3], R. Suleiman[1], C.A. Young,[1]

[1] *Space Science Center, University of New Hampshire, Durham, NH 03824, USA*

[2] *Astrophysics Division of ESA/Estec, NL-2200 AG Noordwijk, The Netherlands*

[3] *Max-Plank Institute fur Extraterrestrische Physik, D-8046, Garching Germany*

Abstract

The 1991 November 15 X1.5 flare is a well observed event. Comprehensive data from ground-based observatories and the Yohkoh, PVO, and Ulysses spacecrafts provide the basis for a contextual interpretation of gamma-ray spectra and light-curves from the Compton Observatory. In particular, spectral, spatial, and temporal data at several energies are necessary to understand the particle dynamics and acceleration mechanism(s) within this flare. X-ray images, Ca XIX data and magnetograms provide morphological information on the acceleration region, while gamma-ray spectral data provide information on the photon and particle energy spectra. Furthermore, time profiles in hard X-rays and gamma-rays provide valuable information on temporal characteristics of the energetic particles. We report the preliminary results of our analysis of the evolution of this flare as a function of energy (18.5 keV-2.5 MeV). These preliminary results, together with those from other observations may eventually assist in identifying and understanding the acceleration mechanism(s) taking place in this event.

1 Introduction:

The 15 November 1991 solar X1.5/3B solar flare was fortuitously located near the solar central meridian and equator in NOAA AR 6919 at S13, W19. The event started at ~22:34 UT, and lasted in hard X-rays on the order of 5 minutes. Comparison of a Yohkoh SXT image with a Mees Observatory magnetogram suggests the flaring region is comprised of two bright X-ray kernels that are likely footpoints of a magnetic flux tube or loop. Aschwanden et al. (1996) suggest a loop structure early in the flare with a radius of 13.5 Mm and an acceleration altitude of ~21.5 Mm. Diffuse X-ray emission is present, likely over the neutral line (Culhane et al. 1993). Yohkoh data indicate that during the impulsive phase that harder x-rays originate from regions near the footpoints of the loop structure, while soft X-rays originate from the top of the loop (Sakao et al. 1992). In this soft x-ray source between the two footpoints, Kane et al. (1993) found the temperature to be ~10^7K, and density to be 4×10^{11} cm^{-3}.

Detailed analyses of this flare at several energies begin to shed light on the processes taking place within this event. A positron annihilation line at 511 keV has reported at photospheric densities of 10^{16} cm^{-3} (Kawabata et al. 1994), as well as excited ^{7}Li and ^{7}Be lines from (α,α) reactions (Kotov et al. 1996). Cospatial Ca XIX resonance line blueshifts (v~250 km/s) and Hα redshifts have been measured during, and at least a minute before the onset of the flare. The persistence of these plasma velocities throughout (and before) the flare suggests the shifted emission is *not* due to chromospheric evaporation (Culhane et al. 1993). In the 4-7 MeV range, Kotov et al. (1996) and Kawabata et al. (1994) find strong ^{12}C emission at 4.44 MeV and ^{16}O emission at 6.13 MeV (Kawabata et al. 1994).

We have chosen to concentrate our analysis on prompt nuclear gamma ray lines between 0.6 and 2.5 MeV, and on brehmstrahlung emission between 18.5 and 343.5 keV.

2 Data:

We use data from two experiments on the Compton Observatory to study this flare in the 18.3 keV – 2.5 MeV range. Four BATSE detectors (Fishman et al. 1989) detected the event, with the most solar facing having a 97% exposure. We analyzed data from this detector in four energy channels (0,1,2 and 4) spanning energies 18.5 – 343.5 keV, to provide an estimate of the brehmstrahlung continuum radiation. These data have excellent temporal information with 1.024 second resolution, and were obtained through the public data archive. COMPTEL (Schoenfelder et al. 1993) did not have the event in the telescope field of view (zenith angle 65.87° and azimuth angle 324.9°), and detected the event in burst mode only (Young et al. 1999). These data provide spectral information between 0.6 – 10 MeV.

We used COMPTEL data to define flare phases. The impulsive phase occurred between 2236:40 and 2238:20 UT, with the gradual phase following from 2238:20 to 2241:40 UT (fig. 1). With these start and end times, the flare duration is 300 seconds. In the hard and soft X-ray regimes, Yohkoh observed significant emission starting at flare onset at ~2234 UT (Sakao et al. 1992), however COMPTEL did not detect significant counts during this initial phase.

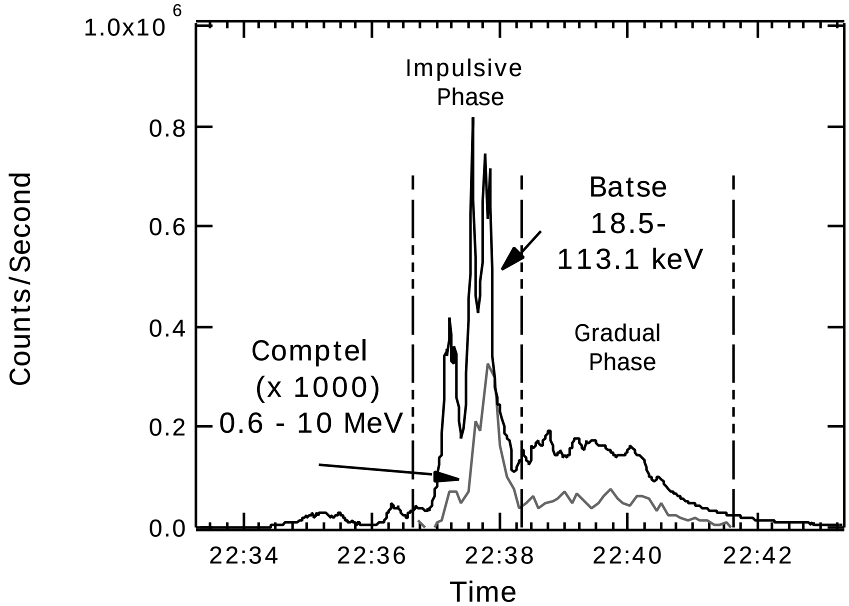

Figure 1: Light curves of the 15 November 1991 event. BATSE data (dark) are from channel 4 (18.5-30.3 keV). COMPTEL counts (grey) are multiplied by 1000, and span 0.6-10 MeV.

3 Analysis:

3.1 COMPTEL Spectrum

COMPTEL spectra of this event are deconvolved using a maximum entropy method (Gull and Skilling, 1991) and an appropriate response to account for instrumental effects (c.f. Young et al. 1999).

Several robust lines are easily identified in the photon spectrum of the whole event, including the ^{2}H neutron capture (2.223 MeV), ^{56}Fe (0.85 MeV) and ^{24}Mg (1.38 MeV) lines. ^{20}Ne contributes to the broad feature near 1.6 MeV.

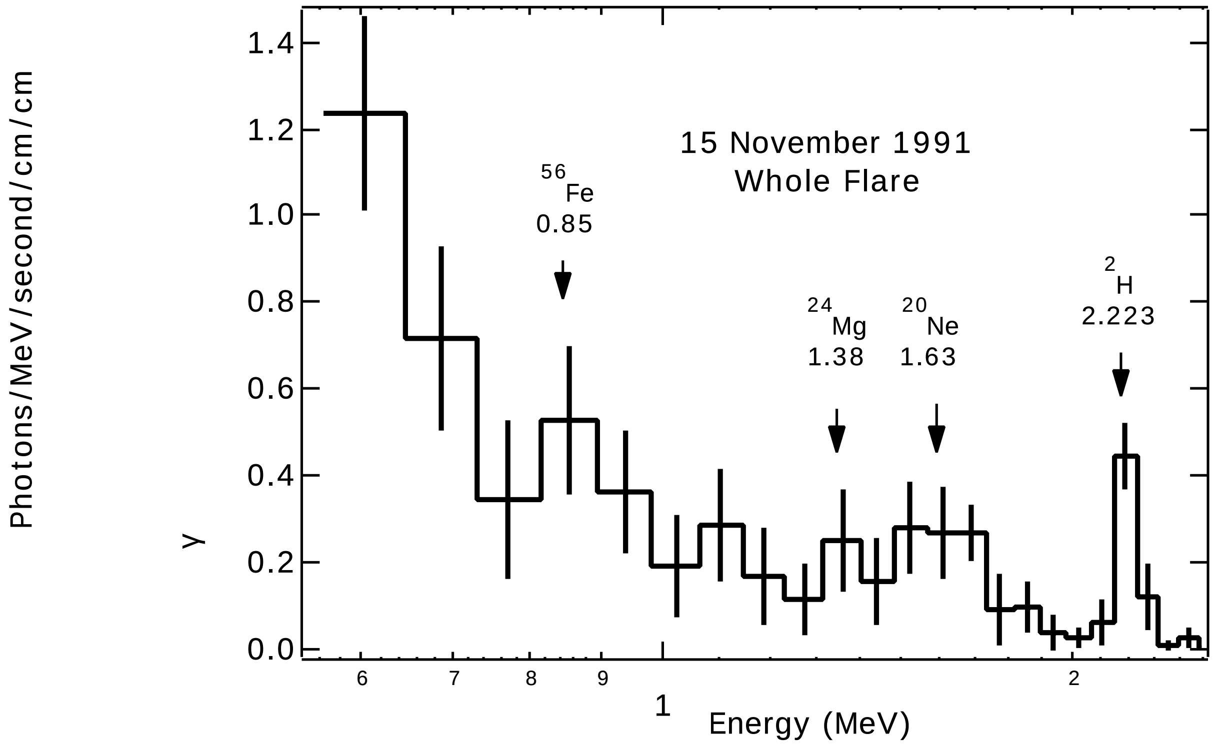

Figure 2: COMPTEL spectrum of the whole 15 November 1991 event. A few clear line features are marked.

3.2 Composite Spectrum:.

We have generated a composite spectrum of the impulsive phase spanning 18.5 keV to 2.5 MeV using BATSE, COMPTEL, PVO (McTiernan et al. 1994), Ulysses and Yohkoh HXT and HXS data (Kane, 1998). The BATSE, PVO, Yohkoh, and Ulysses data provide an estimate of the brehmstrahlung continuum radiation. We have omitted (small) error bars in the interest of keeping the plot legible. $E^{-3.5}$ is plotted for reference (fig. 3). We have omitted the BATSE channel 3 (>343.5 keV) since nuclear line contributions contaminate the continuum emission, making it difficult to isolate the contribution of accelerated electrons. Yohkoh and Ulysses fluxes are slightly higher in magnitude since they are integrated over 14 seconds near flare maximum, while BATSE and COMPTEL data are integrated for 97 seconds over the entire impulsive phase as defined above. PVO data were integrated for 20 seconds soon after the onset of the flare. Ulysses spectra were fit with $E^{-3.08}$ for $0.02<E<0.15$ MeV, and Yohkoh data were fit with power laws of $E^{-3.20}$ (HXS) and $E^{-3.39}$ (HXT) for $\sim.014<E<0.09$ MeV. Discrepancies between the Yohkoh and Ulysses data are discussed in detail by Kane et al (1998).

4 Conclusions:.

In the composite spectrum, we see an extension up to 2.5 MeV of the brehmstrahlung spectrum measured by other instruments. Furthermore, we see a strong nuclear component above 1 MeV from heavy nuclei (e.g. ^{24}Mg and ^{20}Ne) with low thresholds. These lines have relatively strong intensities compared to that of the neutron capture line, indicating a reasonably soft proton spectrum.

The work presented here is a preliminary analysis of the COMPTEL and BATSE data. Future work will include extending data analysis to 10 MeV, computing flux ratios, and deconvolving other flare components (e.g. the gradual phase).

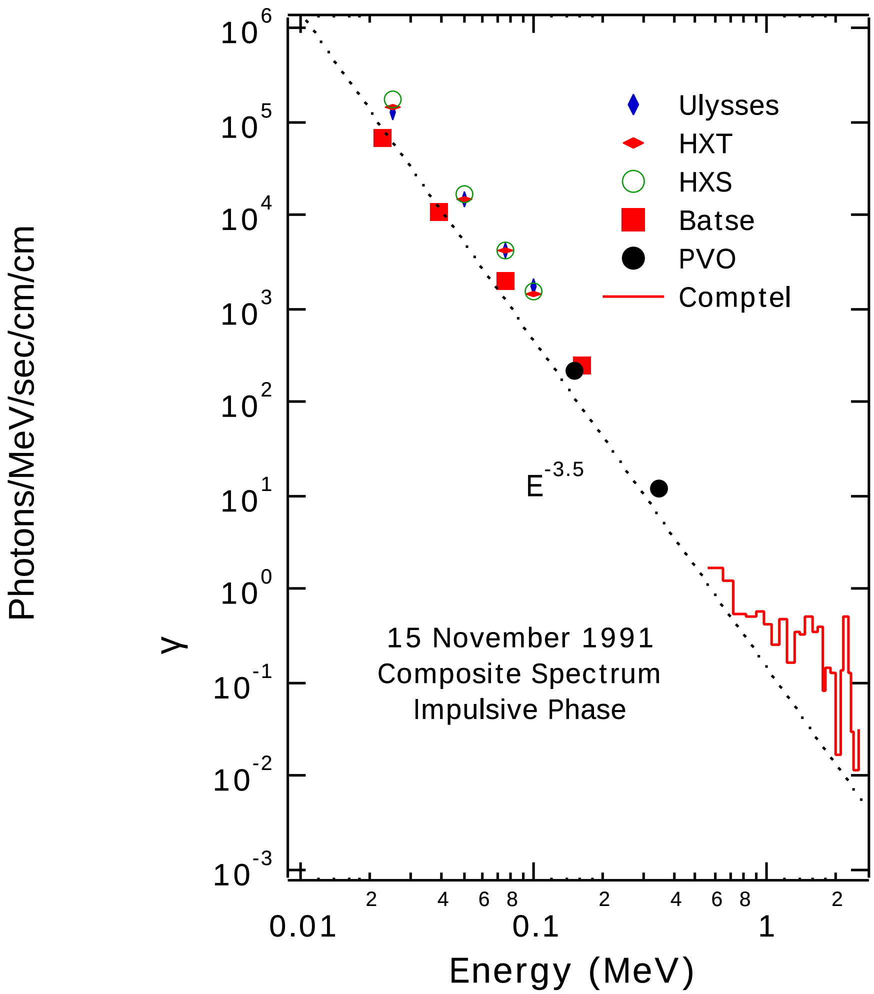

Figure 3: Composite spectrum of the impulsive phase of the 15 November 1991 flare using data from Yohkoh and Ulysses (Kane et al. 1998), PVO (McTiernan et al. 1994), BATSE and COMPTEL.

5 Acknowledgements:

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