Comparison of BATSE and COMPTEL spectra for 1991 June 15

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Introduction

Combination of data from the BATSE Large Area Detectors (LAD) and COMPTEL (we use only the telescope mode data) allowes us to construct the solar flare photon spectrum over more than 3 decades in energy: from 25 keV to 30 MeV. While the COMPTEL range is dominated by radiation originating from nucleonic processes, the HXR range of BATSE reflects the electronic bremsstrahlung continuum.
For the flare on 15 June 1991 also data of the GAMMA-1 instrument above 30 MeV are available. The combination of the observations of all three instruments enables us to obtain a photon spectrum spanning a range of more than 5 decades from 25 keV to 5 GeV.

Analysis of BATSE-LAD data

The data files we use in this analysis can be downloaded from the BATSE solar flare server at http://umbra.nascom.nasa.gov/batse/batse_years.html. These data files give information on all eight LADs (Large Area Detectors), sorted by their cosine with the solar position. The information for every detector consists of the following columns:

LAD	cosine	sec rel to base	livetm sec	chan 0	chan 1	chan 2	chan 3	cpd
					counts/sec			

In this format, 'LAD' gives the number of the physical detector, 'sec rel to base' is the timing relative to a certain time basis, 'chan' are the energy channels for the photon measurements and 'cpd' gives the counting rate of the Charged Particle Detector.
The data given for each channel are counting rates (counts s^-1) and have been sampled in 1.024 s intervals. They are corrected for counter overflow, livetime effects and the cosine of each detector with the sun's position. However, the data are not background subtracted.

The energy ranges of the four energy channels are given in table 1. It should be noted, that the highest channel (300-1900 keV) includes the 511 keV annihilation line and nuclear de-excitation lines above $\sim$ 0.8 MeV, while the other three channels are expected to contain electron

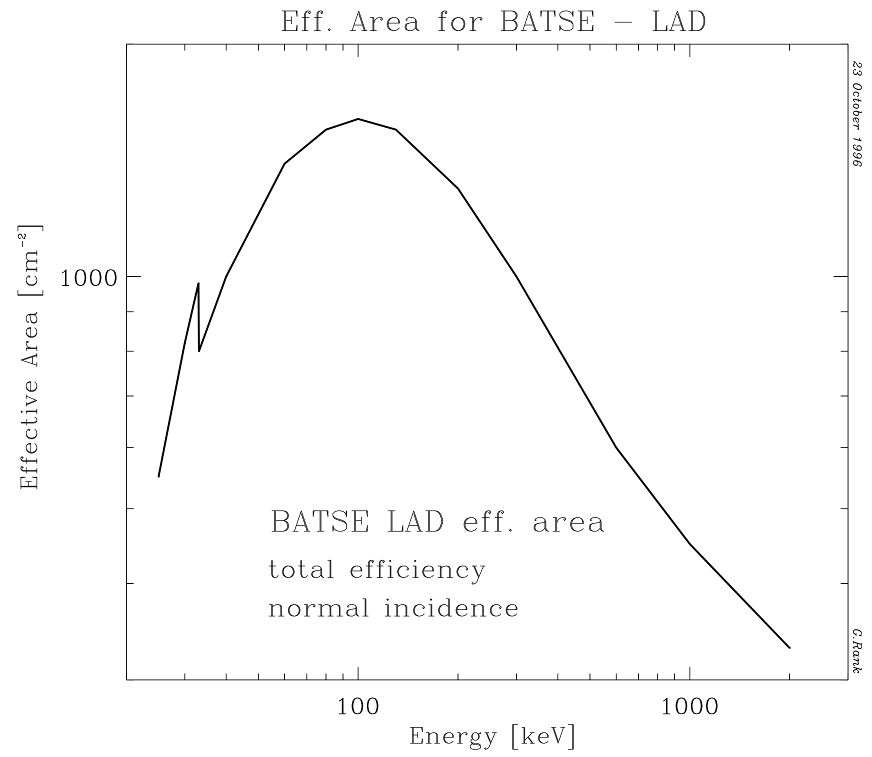

Figure 1: *Effective area for a single BATSE LAD detector.*

bremsstrahlung only. A weighted mean energy for every bin was calculated by integrating a power law spectrum $E^{-3.0}$ and $E^{-3.5}$ within the given energy bins (also incl. in table 1).

Table 1: *BATSE LAD energy channels*

channel	energy range	mean energy	mean eff. area	mean energy	mean eff. area
		index = -3.0		index = -3.5	
0	25 - 50 keV	33.1	795.4	32.5	780.6
1	50 - 100 keV	66.5	1403.8	65.2	1392.9
2	100 - 300 keV	149.8	1440.3	143.7	1463.1
3	300 - 1900 keV	516.0	702.7	471.7	740.7

The effective area of the BATSE LAD is taken from Fishman et al., Proc. of the GRO Science Workshop, GSFC, 1989. Figure 1 shows the total effective area of a single detector facing the sun. To get the effective area that applies to each energy bin, the effective area has been folded with a $E^{-3.0}$ and a $E^{-3.5}$ spectrum, summed into energy bins and then devided by the value of the integrated power law. The results are included in table 1.

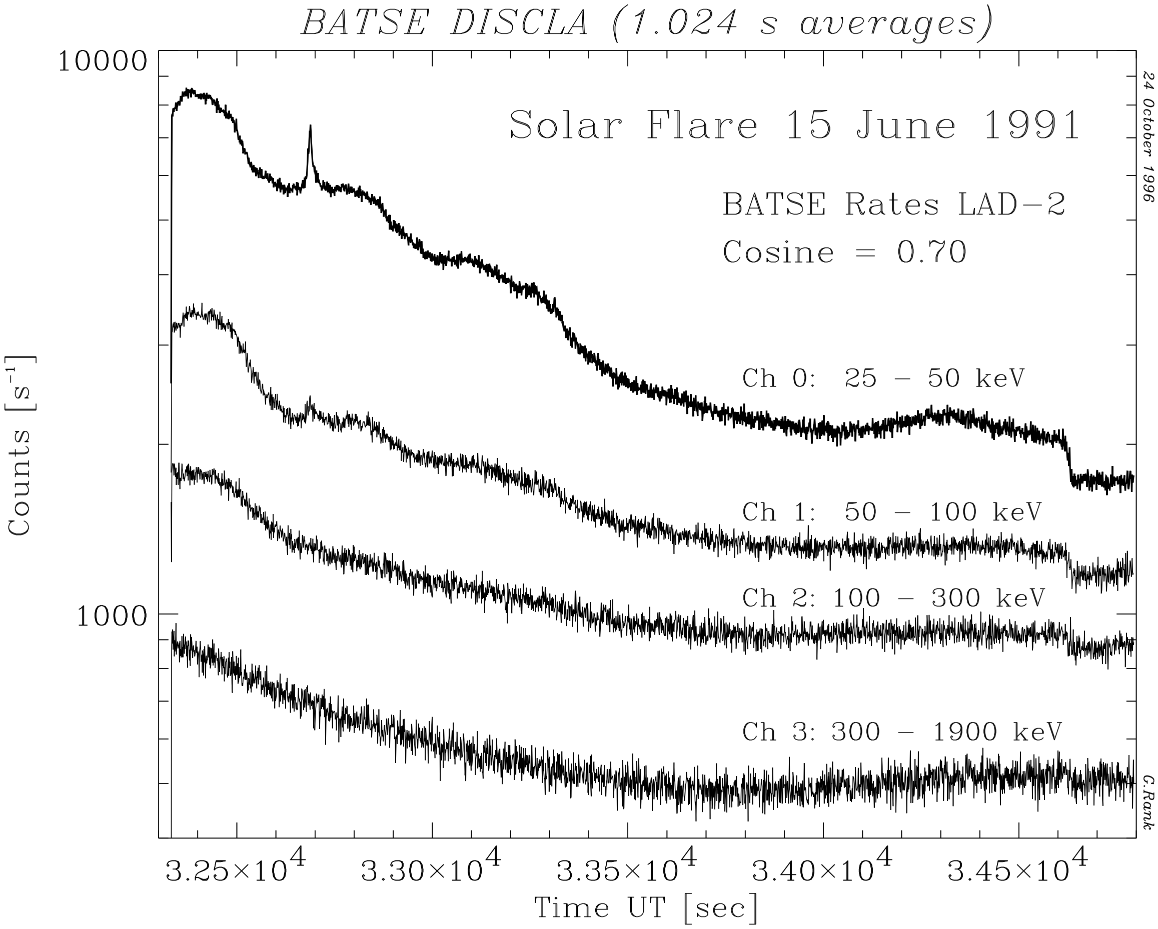

Figure 2: *DISCLA rates for the most sunward pointed detector (physical detector LAD-2) for four energy channels.*

Figure 2 shows the rates of the four energy channels for the most sunward pointed detector. At the beginning of the observation interval, which started some 40 min after the onset of the flare, the spacecraft came out of the SAA passage. After about 34620 s the spacecraft entered orbital night and the rates drop to a lower level.

One problem that has to be solved, is the proper subtraction of background. In the case of a short duration flare the background can be fitted from data before and after the flare, assuming that all systematic variations in the background happen on much longer time scales than the duration of the flare event. For long events, however, the background variations can not be neglected during the flare.

By comparing the rates of the detectors facing away from the Sun it can be seen that they are variing largely. Therefore, these detectors cannot be used for the determination of the background level.

As a first approach to estimate the background, we use the lower counting rate levels, that occur at the end of the daylight period, shortly before sunset. This level for each energy channel was taken as a constant background through the whole orbit. However, it is obvious from figure 2 that for the high energy channel this might not be an approppriate assumption.

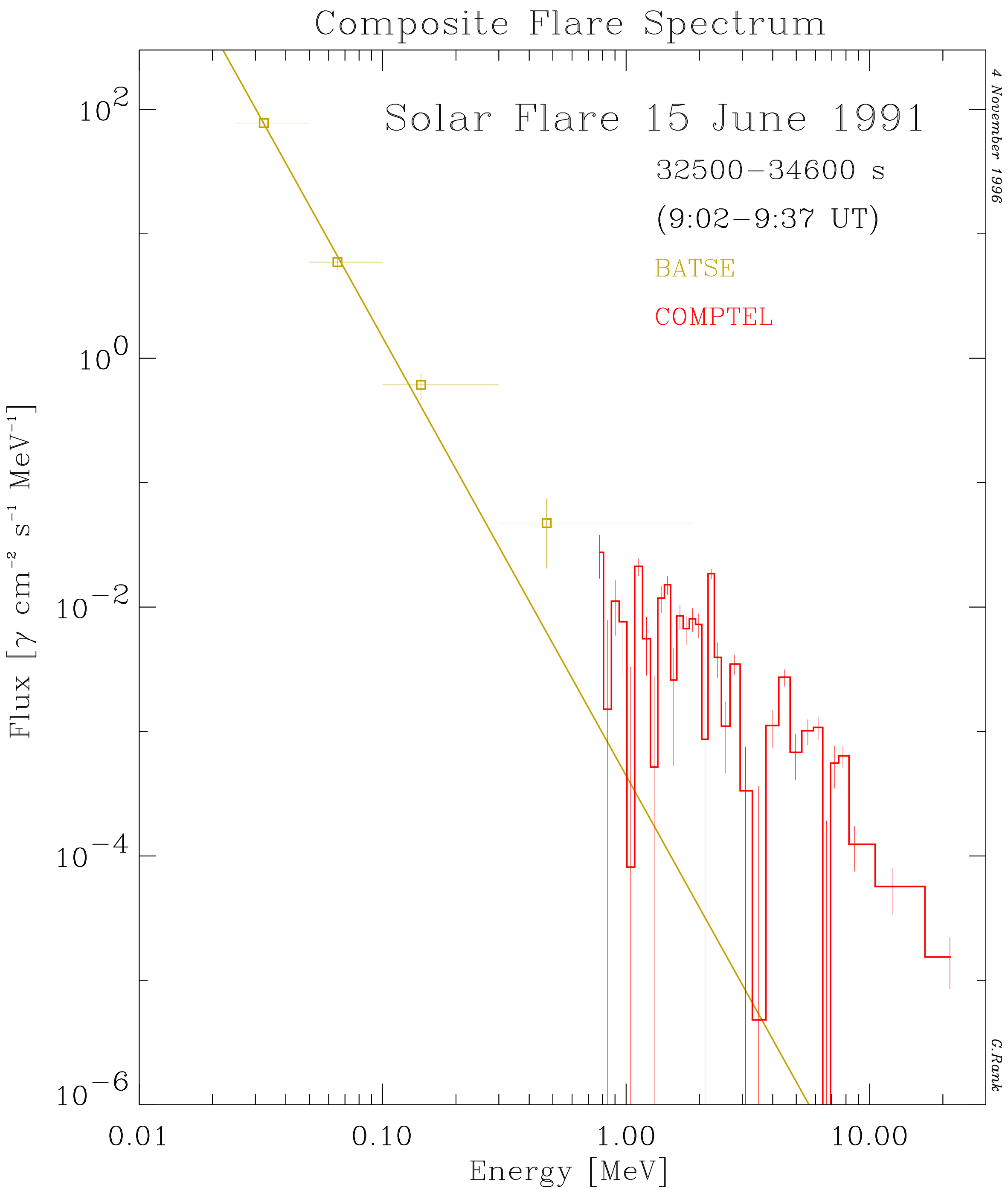

Figure 3: *Composite spectrum of BATSE and COMPTEL for the June 15 flare. Horiontal bars indicate no statistical errors but only the energy range.*

As a second approach we apply the orbit method that has been used successfully for COMPTEL data. We try to construct a background model from the observation periods 15 and 16 orbits before and after the flare. However, the BATSE rates (as high-level products) are only available during flares or bursts. For the two possible background periods we get no full coverage, but three overlapping data sets. From these data we see that the first order background is well justified for the three lower energy channels. As we use these for the determination of the HXR bremsstrahlung spectrum, we use constant background in the following analysis.

Results

Flux values are obtained by integrating the background subtracted counting rate for each energy channel over a given time interval, devide by the integration time, by the energy bin width and by the effective area. The data are already corrected for the cosine of the detector. The weighted mean values according to a -3.5 power law (see table 1) have been used, as the resulting slope of the power law is closest to this case.
A power law was fitted to the resulting datapoints. Only channels 0,1,2 are used for this purpose, as channel 3 (300keV-1900keV) already includes a substantial portion of nucleonic emission and therefore should exceed the value expected from a bremsstrahlung power law.
The combined spectrum of BATSE and COMPTEL for the time interval of 32500 - 34600 s UT is shown in figure 3. The best power law fit to the BATSE spectrum is $4.4 \cdot 10^{-4} E^{-3.5}$ as shown in the figure. The power law extrapolation is in quite good agreement with the low energy COMPTEL points. According to the COMPTEL spectrum in the region 3-4 MeV we do not expect much bremsstrahlung contribution. But the high energy BATSE data point seems to exceed the COMPTEL values too much.

The flux in channel 3 is used to test the compatibility of both data sets, as it overlaps both energy ranges. For this purpose, the best fit power law obtained from the other three BATSE data points and the COMPTEL contribution in the 300 - 1900 keV band (from a fit to the 750-1900 keV data, extended to lower energies) are integrated and added. This gives an upper limit to the expected value, because the COMPTEL spectrum already includes a small contribution from bremsstrahlung. Figure 4 shows the same data as figure 3, but now including the 'expected' value for channel 3 (large square symbol).

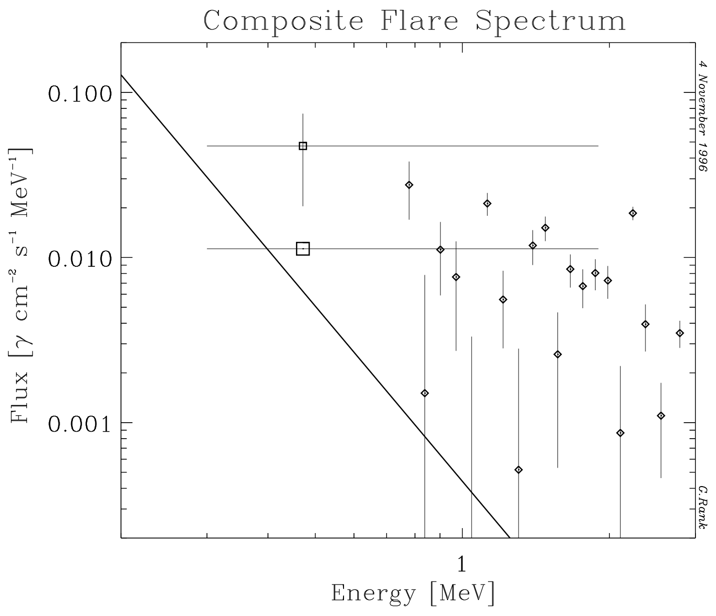

Figure 4: *Test of channel3 flux (see text).*

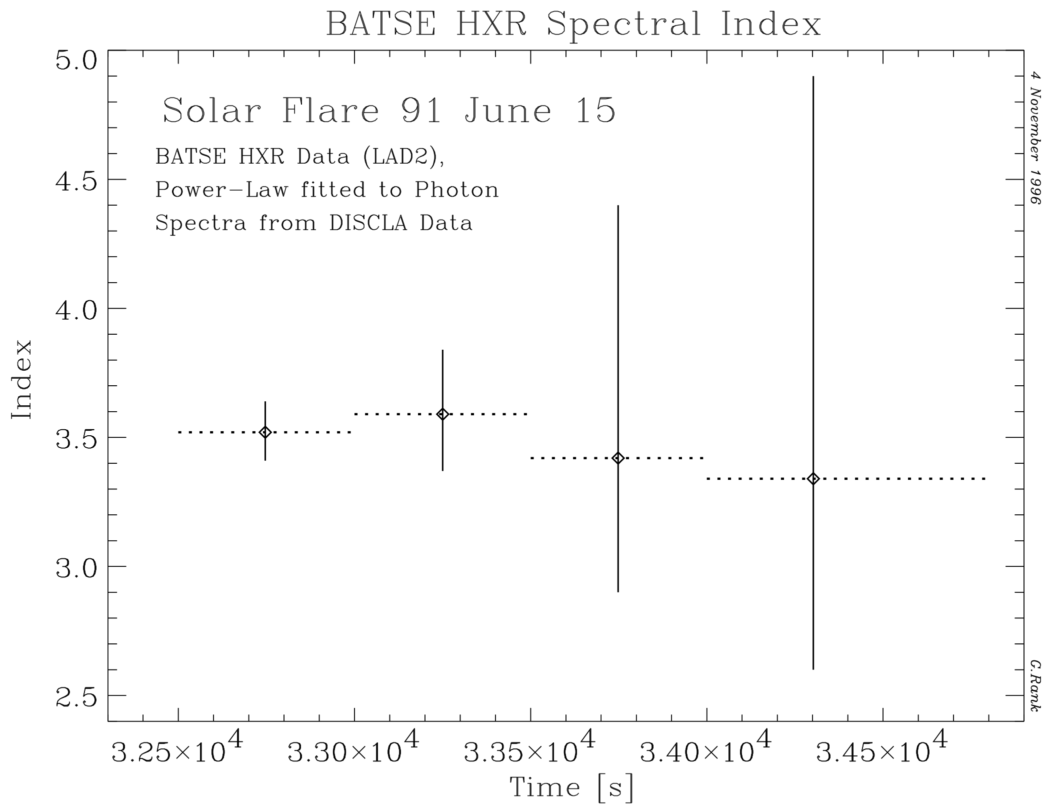

Figure 5: *Power law index in the energy range 25 - 300 keV for the June 15 flare.*

The expected value is located about 1.5 σ below the measured data point. This result indicates that either the deconvolved data points for BATSE (or at least channel 3) are somewhat high or the COMPTEL data points are somewhat low. Another possibility would be that secondary electron bremsstrahlung accounts for the difference.
The power law indices have also been derived for four time periods separately. The resulting curve (see figure 5) shows no variations through the period. Due to the decrease of the counting rate, the statistical errors grow quite large for the last time period.

Summary

- We study BASTE-LAD data for the extended phase of the 15 June 1991 solar flare in four energy channels ranging from 35 keV to 1.9 MeV.
- The obtained BASTE spectrum can be fitted by a power law. Energy channel 3 is not used for the fit and its flux exceeds that of the extrapolated power law.
- The comparison with COMPTEL data results in a spectrum that extends from 25 keV to 30 MeV. To first order, the alignment of both spectra is quite smooth. Closer examination shows that some inconsistency of the flux in channel 3 is still remaining.
- The power law index that is fitted to the BASTE flux values shows no indication of variability during the studied time period.