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Energetic Proton Spectra in the 11 June 1991 and 24 October 1991 Solar Flares

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Abstract

The solar flares on 11 June 1991 and 24 October 1991 as observed by the gamma-ray telescope of COMPTEL indicate that part or all of the flares respectively contain a soft proton spectrum. In order to further investigate this we have examined the same flares with the independent burst mode of COMPTEL. Initial work indicated a need to further understand the instrument response and energy resolution in order to produce robust, stable photon spectra with the burst mode. In this paper we discuss the necessary steps to take before we can analyze and interpret the data.

1 Introduction:

Flares and intervals within flares have been observed to have of soft proton spectra. Share and Murphy (1997) have found evidence of soft proton spectra in several flares. During 1991 COMPTEL was used to measure the spectra of several flares including some indicating soft proton spectral features.

COMPTEL has two modes that operated simultaneously. The telescope mode is a Compton imaging telescope that operates in the energy range of 0.75 MeV – 30 MeV. It consists of two detector planes. The top is a low-Z liquid scintillator that Compton scatters an incident photon to the bottom detector plane that is a set of high-Z NaI detectors. The second mode is the burst spectrometer and operates in 0.1-1.1 MeV and 0.6-10 MeV. It is one of the NaI detectors in the lower (D2) modules.

The 11 June 1991 flare observed with the COMPTEL instrument aboard CGRO shows several indicators of a soft proton spectrum. During a middle phase of the flare (Dunphy et al. 1999), there is minimal 4-7 MeV emission, no emission above 10 MeV and a very strong 2.2 MeV line (Rank et al. 1997). In addition the 2.2 MeV line has a long (> 300 s) decay time. These two facts together favor lower energy neutrons and thus a softer proton spectrum (Ryan et al. 1996). Similarly, the 24 October 1991 flare shows a paucity of 4-7 emission. There is a strong 2.2 MeV line and an even stronger ^{20}Ne line (Suleiman 199). This ^{20}Ne line and other low threshold lines seen along with the 2.2 MeV line indicate low energy neutrons and thus a soft proton spectrum. The 11 June measurements were performed in COMPTEL's telescope mode, whereas the 24 October measurements were performed with preliminary data from the burst mode. An ideal analysis of the flares should include both data sets. The telescope mode provides spectral and imaging data so it has a high signal to noise ratio but a low effective area. The burst mode provides spectral information in a completely overlapping energy band with lower signal to noise ratio but a much higher effective area. This provides two data sets that contain comparable information but with different systematic errors.

2 The Response:

In order to be confident of photon spectra we must be demonstrate the uniqueness and robustness of our deconvolution algorithm. The deconvolution used here is performed with the Bayesian Maximum Entropy package of Gull and Skilling, MEMSYS5. The instrumental response of COMPTEL is simulated using GEANT.

To test a deconvolution method we must start with a theoretical spectrum, apply the response to obtain a count spectrum, then deconvolve this count spectrum with the response and compare the output with the theoretical spectrum. The response and deconvolution methods are tested with a theoretically calculated spectrum from the April 27, 1981 (Murphy et al. 1990) solar flare. An initial starting spectrum must be chosen for the deconvolution process such as a power law or a set of lines or a combination of the two. This serves as a starting place; the final result is very robust and could be found even by starting with a constant. The maximum entropy method uses the information in the response to simply map the counts at an energy into photons at that or a lower energy, minimizing χ^2 while maximizing entropy or the smoothness of the spectrum. Figure 1 shows the count spectrum with the theoretical photon spectrum superimposed upon it. The lines in the original spectrum do not show up in count space strictly as lines. Instead they consist of photopeaks and the partial absorption of energy due to Compton scattering at the line energy and below. This tends to wash out the lines in a continuum.

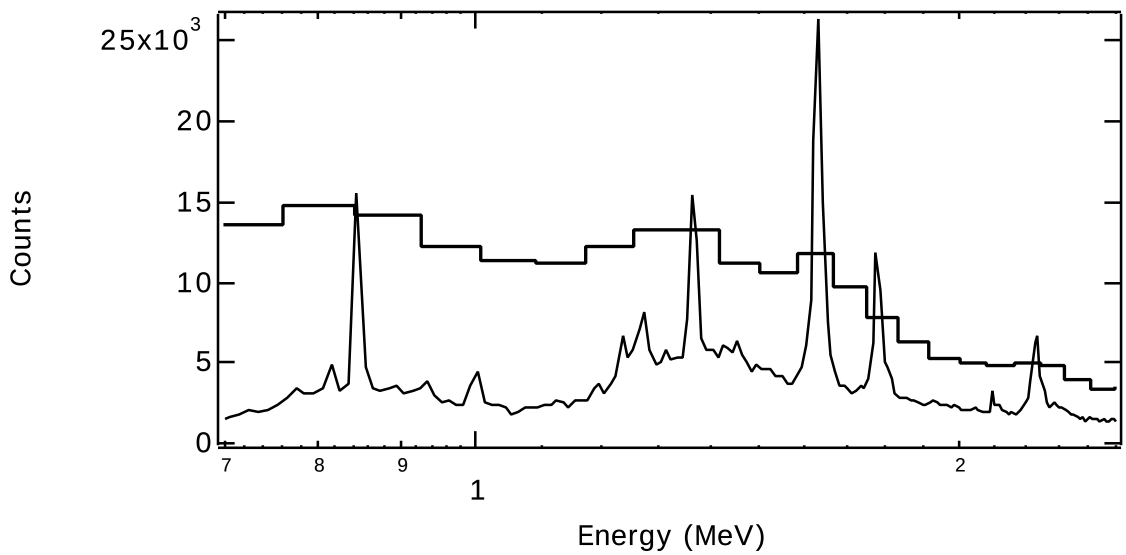

Figure 1: Energy loss spectrum by the response of the instrument to a theoretical spectrum with the theoretical spectrum superimposed over it.

Figure 2 shows the deconvolved photon spectrum with the theoretical spectrum superimposed upon it.

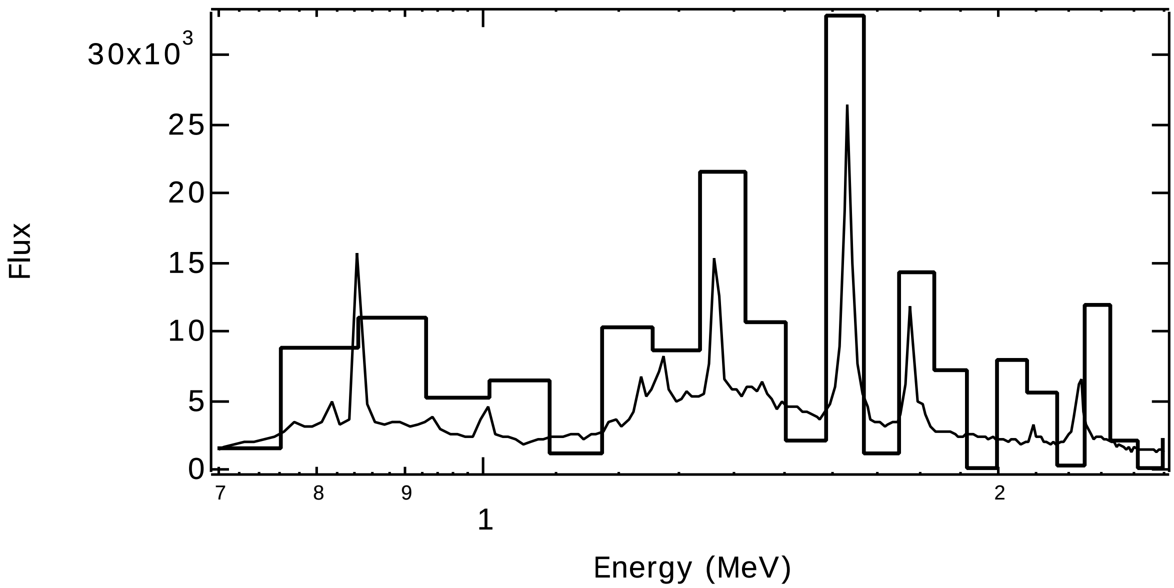

Figure 2: The deconvolved photon spectrum with the theoretical spectrum superimposed over it.

Both plots show, within the limitations of the instrument, the count spectrum and deconvolved spectrum match the theoretical spectrum quite well. The original energy resolution obtained empirically during calibration (Schönfelder 1991) was found to underestimate the instrumental energy resolution at the 2.2 MeV line by about 3%. This was adjusted in the response but this then means the energy bins assigned track the resolution of the instrument only under 3 MeV. Therefore, we have restricted our comparison to energies < 3 MeV.

3 The Science:

Using this recalculated response we will then be able to compare photon spectra from both the telescope and burst mode. This provides two independent measurements in the same energy band. The proton spectrum can then be analyzed along with the associated low energy neutrons (Young and Ryan 1997).

Acknowledgments

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