COMPTEL Measurements of MeV Gamma-Ray Burst Spectra

R.M. Kippen*, J. Ryan*, A. Connors*, M. McConnell*,
C. Winkler†, L.O. Hanlon†, V. Schönfelder‡, J. Greiner‡,
M. Varendorff‡, W. Collmar‡, W. Hermsen§ and L. Kuiper§

**Space Science Center, University of New Hampshire, Durham, NH 03824*
†*Astrophysics Division, ESA/ESTEC, NL-2200 AG Noordwijk, NL*
‡*Max-Planck-Institut für Extraterrestrische Physik, D-85748 Garching, FRG*
§*SRON-Utrecht, Sorbonnelaan 2, 3584 CA Utrecht, NL*

We present results from the on-going spectral analysis of gamma-ray bursts measured by the COMPTEL instrument in its main Compton "Telescope" observing mode (0.75–30 MeV). Thus far, 18 bursts have been analyzed from three years (April 1991 – April 1994) of observations. The time-averaged spectra of these events above 1 MeV are all consistent with a simple power law model with spectral index in the range 1.5–3.5. Exponential, thermal bremsstrahlung and thermal synchrotron models are statistically inconsistent with the burst sample, although they can adequately describe some of the individual burst spectra. We find good agreement between burst spectra measured simultaneously by BATSE, COMPTEL and EGRET, which typically show a spectral transition or "break" in the BATSE energy range around a few hundred keV followed by simple power law emission extending to hundreds of MeV. However, the temporal relation between MeV and GeV (e.g., as measured by EGRET) burst emission is still unclear. Measurement of rapid variability at MeV energies in the stronger bursts provides evidence that either the sources are nearby (within the Galaxy) or the gamma-ray emission is relativistically beamed.

INTRODUCTION

With relatively few exceptions, most detailed measurements of gamma-ray burst (GRB) spectra have been made in the energy range around a few hundred keV. Several experiments have shown that burst spectra in this range can be well described by a combination of two variable power laws connected by a smooth (but variable) transition (1). Unfortunately, our present knowledge of the characteristics of burst emission below ~10 keV and above ~1 MeV is limited. In this study, we use the COMPTEL instrument aboard the *Compton* Gamma Ray Observatory to characterize the properties of burst emission at the high-energy end of the spectrum. Data from 18 GRBs (2) detected

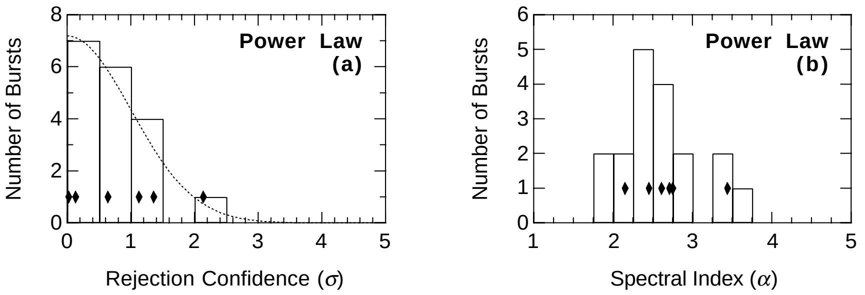

FIG. 1. The distribution of power law goodness-of-fit estimates (**a**) and best-fit spectral indices (**b**) for 18 COMPTEL bursts. Diamonds represent values for the six largest bursts and the dotted curve shows the average distribution expected from random statistical fluctuations.

TABLE 1. The acceptability of different simple spectral models based on the full sample of COMPTEL time-averaged burst measurements.

Model	Differential Spectrum	Q^{a}
Power Law	$N_E(E) \propto E^{-\alpha}$	9.1×10^{-1}
Thermal Synchrotron	$N_E(E) \propto e^{-(4.5E/E_c)^{1/3}}$	1.1×10^{-2}
Thermal Bremsstrahlung	$N_E(E) \propto E^{-1}e^{-E/kT}$	$< 10^{-6}$
Exponential	$N_E(E) \propto e^{-E/E_o}$	$< 10^{-6}$

[a] Probability that the distribution of 18 COMPTEL model fits can be explained simply by random statistical fluctuations of the model.

in the main COMPTEL "telescope" observing mode (0.75–30 MeV) are used to supplement earlier MeV burst measurements of *SMM* and to complement contemporaneous *Compton*– BATSE and EGRET observations.

ANALYSIS AND MODELING OF TIME-AVERAGED SPECTRA

To examine the global properties of burst emission at MeV energies, COMPTEL telescope data have been selected from each of the 18 bursts forming individual time-averaged count spectra. These raw spectra, combined with background, instrument response and livetime information are studied through fitting to model analytic functions. Small numbers of counts make the standard χ^2 model fitting method inapplicable. Hence, the spectra are fitted using a "forward-folding" maximum likelihood technique and model acceptability is evaluated through Monte Carlo simulation. In this analysis, empirical background models based on data from similar orbital conditions as during each burst are employed and detector response functions are obtained through Monte Carlo simulation of the instrument (3).

Each of the 18 time-averaged burst spectra were fit with several simple model functions (Table 1). Due to typically low count-rates in the individual burst spectra, particular models can be rejected on statistical grounds only for the strongest and hardest bursts. However, by examining the *distribution* of goodness-of-fit estimates from the full burst sample we can characterize global properties of MeV emission with enhanced sensitivity. For instance, the distribution of power law model fits is statistically consistent with random deviations, indicating that the power law model adequately describes time-averaged MeV burst emission (Figure 1a; Table 1). While the simple thermal models can adequately describe many of the individual burst spectra, they are statistically inconsistent with the full COMPTEL burst sample. These findings agree with the earlier results of *SMM* (4). The distribution of best-fit power law spectral indices (Figure 1b) is consistent with that of the *SMM* bursts and with extrapolations of BATSE spectra into the MeV energy range (1).

Most of the bursts detected by COMPTEL have been observed simultaneously by other *Compton* instruments, thus wide-band spectral comparisons are possible. COMPTEL spectra for particular strong bursts have been recomputed to match the accumulation times of these other observations. In most cases we find good agreement between BATSE, COMPTEL, OSSE and EGRET in overlapping regions of the spectra (5–8). These wide-band comparisons show that above a variable turnover (typically lying in the BATSE energy range around a few hundred keV), time-averaged burst spectra can be well described by a single power law "tail" out to $\gtrsim$100 MeV.

EXTENDED MEV EMISSION?

In at least two bright bursts detected by COMPTEL (GRB 930131 and GRB 940217), the EGRET spark chamber (SC) observed GeV photons well after the main impulsive parts of the bursts at keV energies subsided (9,10). Power law spectral indices based on fits of the EGRET data are consistent (within large uncertainties) between the impulsive and extended portions of the bursts. However, the temporal and spectral relation between GeV and keV burst emission is unclear due to the limitations of the EGRET SC (severe deadtime and few counts). The observed GeV emission is either a low-intensity *extension* of that present during the main burst (i.e., little or no change in the spectral shape) or a distinctly harder spectral component that has a *delayed* turn-on. Spectral measurements in the MeV energy range can, in principle, solve this important question.

We have examined COMPTEL data during the extended/delayed emission intervals of GRB 930131 and GRB 940217 where EGRET observed GeV photons in an attempt to identify any change in the spectrum from that of the impulsive burst. No significant MeV burst emission has been detected in these intervals. The COMPTEL upper limits are compared with the extrapolated EGRET SC spectra and TASC measurements in Figure 2. The COMPTEL sensitivity cannot to rule out the possibility of *extended* MeV burst emission

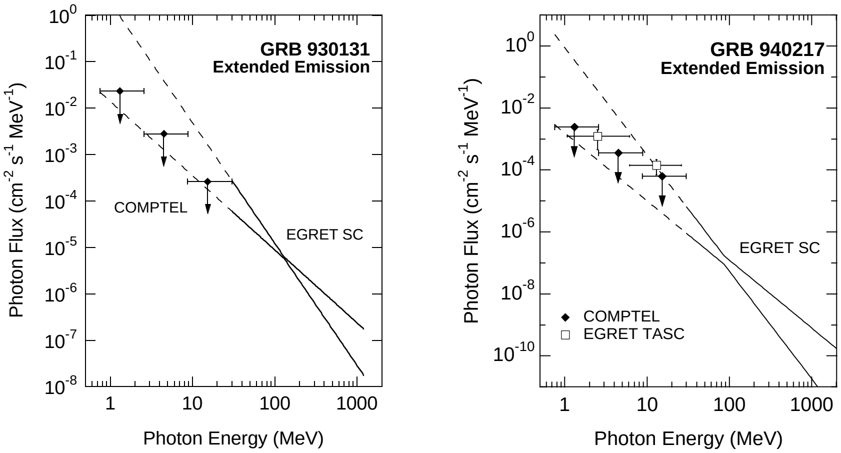

FIG. 2. Extended emission spectra of two bursts comparing COMPTEL upper limits (2σ confidence) with EGRET measurements (9,10).

with the same spectral shape as measured by EGRET (i.e., the COMPTEL upper limits are not inconsistent with the EGRET SC extrapolations). Thus, we can find no evidence that there is significant spectral change at MeV energies in the post-impulsive intervals of these bursts.

RAPID VARIABILITY AT MEV ENERGIES

The intensity of MeV burst emission measured by COMPTEL is in many cases observed to vary on short time scales. Several of the stronger bursts contain short, high-intensity pulses of emission that are observed up to several MeV (see Figure 3). Poor statistics, electronics deadtime and telemetry gaps limit the ability of COMPTEL to measure such pulses. However, using the available measurements we are able to put conservative limits on the variability time-scale ($\delta t \lesssim$ 50–100 ms), the instantaneous peak flux ($F_{\rm p} \gtrsim$ 10–20 photons cm^{-2} s^{-1} MeV^{-1}) and the maximum energy at which the pulses are observed ($E_{\rm max} \gtrsim$ 2–5 MeV).

If the density of photons at burst emission sites is great enough, γ–γ pair production will attenuate the spectrum above ~1 MeV. The lack of a spectral cutoff in the COMPTEL data (power law spectral index $\alpha \sim$ 2.0–2.5), combined with intense and rapid variability measured simultaneously *at high energies* suggests that γ–γ pair production is an inefficient attenuation mechanism for GRBs. If the MeV burst emission is isotropic, the COMPTEL observations indicate that the sources must be well within a distance of $D_{\rm max} \lesssim$ 1 kpc in order to avoid γ–γ attenuation (11). If the burst sources are at extragalactic distances, significant anisotropic beaming of the photons is required (e.g., due to bulk relativistic motion of the emitting plasma; (12)). For

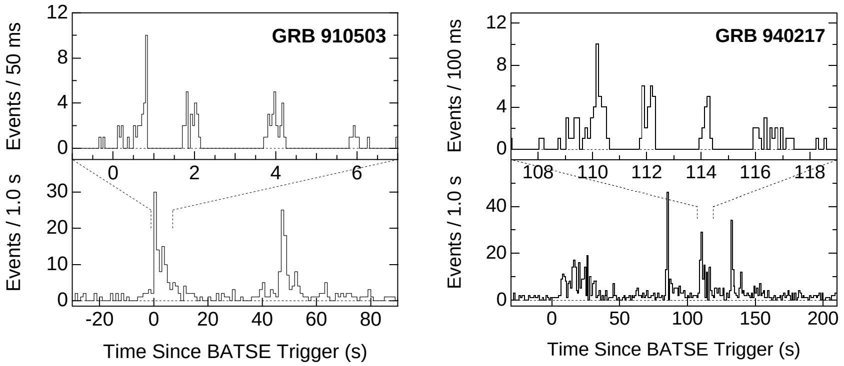

FIG. 3. COMPTEL intensity–time profiles (>1 MeV) of two bursts showing rapid intensity variations. Gaps in the profiles are due to the limited capacity of on-board telemetry buffers.

instance, bulk Lorentz factors $\Gamma_{\rm min} \gtrsim 100$ are required if the sources are at cosmological distances ~1 Gpc and moderate beaming ($\Gamma_{\rm min} \gtrsim 3$) is required even if the sources are within 100 kpc. It should be emphasized that the mere existence of high-energy gamma rays (such as measured by EGRET) does not constrain severely the source distance or the amount of beaming. Rapid variability of the high-energy flux such as shown here is required (13).

Acknowledgements: COMPTEL is supported by NASA under contract NAS5-26645, by the German government through DARA grant 50 QV 90968 and by the Netherlands Organization for Scientific Research (NWO). JG acknowledges the support of DARA under contract FKZ 50 OR 9201.

REFERENCES

1. D. Band et al., ApJ **413**, 281 (1993).
2. R.M. Kippen et al., ApSS **231**, 231 (1995).
3. R.M. Kippen et al., ApJ in preparation.
4. S.M. Matz et al., ApJ **288**, L37 (1985).
5. J. Greiner et al., A&A **302**, 121 (1995).
6. C. Winkler et al., A&A **302**, 765 (1995).
7. B.E. Schaefer et al., in *Gamma-Ray Bursts*, ed. G.J. Fishman, J.J. Brainerd & K. Hurley (AIP 307, New York, 1994), p. 280.
8. G.H. Share et al., in *Gamma-Ray Bursts*, ed. G.J. Fishman, J.J. Brainerd & K. Hurley (AIP 307, New York, 1994), p. 283.
9. M. Sommer et al., ApJ **422**, L63 (1994).
10. K. Hurley et al., *Nature* **372**, 652 (1995).
11. W.K.H. Schmidt, *Nature* **271**, 525 (1978).
12. M.G. Baring, ApJ **418**, 391 (1993).
13. J.M. Ryan et al., ApJ **422**, L67 (1994).