COMPTEL Locations and Spectra of Gamma-Ray Bursts

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Abstract

In three years of operation, COMPTEL has measured the locations (mean accuracy $\sim 1^\circ$) and spectra (0.75–30 MeV) of 18 gamma-ray bursts and continues to observe new events every 1–2 months. The existing COMPTEL bursts have been analyzed as a group to study the small-scale angular distribution and MeV emission properties. Furthermore, measurements of individual strong bursts like GRB 930131 and GRB 940217 provide unique insight into the physics of burst sources. We review recent analyses of COMPTEL burst locations and spectra and give an update on recent observations, including the on-going search for fading low-energy counterparts using rapidly-determined COMPTEL burst locations.

1 Introduction

The COMPTEL instrument aboard the *Compton* Gamma Ray Observatory measures the locations and spectra of several cosmic gamma-ray bursts per year. Strong, hard bursts that occur inside the ~ 1 sr field-of-view of the main instrument ("telescope") are localized through direct imaging and are measured in the energy range 0.75–30 MeV with 125 μs time resolution [1]. Here we present results from the analysis of 18 bursts measured in the telescope during the three year period from April 1991 through April 1994. The ability of COMPTEL to quickly and accurately localize bursts within *hours* of detection has allowed deep counterpart searches to be performed in record time—highlighting the value of the COMPTEL observations.

2 Burst Directions

COMPTEL gamma-ray bursts are localized using a maximum-likelihood imaging technique [2] that provides quantitative constraints on the source directions and fluxes. Location accuracy depends on *both* the intrinsic angular resolution

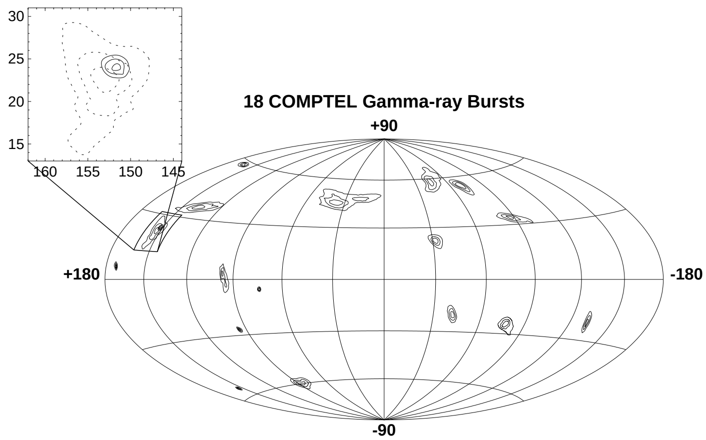

Figure 1: *COMPTEL localization coutours (1, 2 and 3σ confidence) of 18 gamma-ray bursts in Galactic coordinates. Enlarged at left is the region containing spatially coincident bursts GRB 930704 (dashed coutours) and GRB 940301 (solid contours).*

of the instrument ($\sim$1°) and the total number of photons detected. Localizations of all 18 bursts in Galactic coordinates are shown in Figure 1. The mean statistical accuracy (i.e., average of all 18 bursts) is about 1° (1σ), with a possible systematic error estimated to be $\lesssim$0.°5. The COMPTEL burst localizations are consistent with those obtained from the *Compton*–BATSE and EGRET instruments as well as with the accurate timing annuli provided by the Interplanetary Network (IPN [3]).

The COMPTEL burst localizations are consistent with an isotropic angular distribution of sources in either Galactic or celestial coordinate systems (e.g., in Galactic coordinates the dipole moment $\langle \cos\theta \rangle = -0.13 \pm 0.14$ and the quadrupole moment $\langle \sin^2 b - \frac{1}{3} \rangle = +0.01 \pm 0.07$). This is an independent confirmation of the well known result that the directions of strong bursts are isotropically distributed on the sky [4]. Two of the COMPTEL bursts, however, originate from the same direction within the statistical location errors—indicating the *possibility* of burst recurrence (see Figure 1). The probability of such a coincidence occurring by chance given an isotropic distribution of 18 sources has been estimated using Monte Carlo simulation to be $\lesssim$3% [5]. Independent localizations of GRB 930704 and GRB 940301 provided by BATSE, EGRET and IPN measurements can neither confirm, nor deny that the two bursts originated from a single source. Combination of COMPTEL and IPN localizations of these two bursts reduces the probability of a random spatial coincidence to $\sim$1.5%. The possibility of gravitational lensing has been ruled out since the lightcurves and spectra of the bursts differ significantly [6].

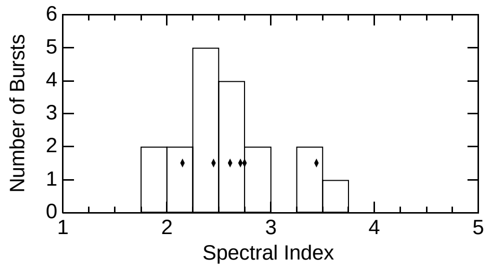

Figure 2: *Distribution of best-fit time-averaged power law spectral indices for 18 COMPTEL bursts. Diamonds indicate values from the six largest bursts.*

3 MeV Burst Spectra

The COMPTEL measurements of time-averaged burst spectra confirm the earlier results of *SMM* [7] that above ∼1 MeV, the spectra are well-described by a single power law model with no indication of a significant turnover at higher energies. Although thermal bremsstrahlung, thermal synchrotron and exponential models can also adequately describe the spectra of many individual bursts, these models are statistically inconsistent with the full COMPTEL burst sample. The distribution of power law spectral indices measured by COMPTEL (Figure 2) is consistent with that observed by *SMM* as well as with the high-energy spectra observed by BATSE [8].

The intensity of MeV burst emission measured by COMPTEL is in many cases observed to vary rapidly on short time-scales. The most striking examples are the strong bursts GRB 910503 and GRB 930131, which exhibited short ($\lesssim$50 ms), high-intensity pulses of emission that were observed up to several MeV. The lack of a high-energy cutoff, *combined* with the observations of high-intensity and rapid variability at high energies implies that two-photon pair production is inefficient at the burst emission sites. The COMPTEL measurements constrain sources emitting isotropically to lie well within ∼1 kpc. If the sources are at cosmological distances (∼1 Gpc), significant relativistic motion [9] is required to overcome the two-photon attenuation (bulk Lorentz factors , $_{\rm B} > 10^2$).

4 Rapid Counterpart Search

The elusive nature of low-energy burst counterparts indicates that if they exist at all they are dim and/or short lived. A "Rapid Burst Response" network exploiting COMPTEL's ability to provide quick and accurate burst positions has attempted to address this point by searching for *faint* fading optical and radio emission soon after bursts. No new or peculiar objects have been identified in deep observations of COMPTEL burst localizations obtained with delays of *hours*. The most constraining measurements so far were for the strong burst GRB 940301, where deep optical ($m_{\rm v} \approx 16$) and radio ($\sim$80 mJy at 8.42 GHz) observations were obtained within 7 hours of the burst onset [10]. The resulting upper limits on fading low-energy counterpart emission are *orders-of-magnitude* lower than previous short-delay results—indicating that future search efforts must concentrate on obtaining deep exposures well within a few hours. Improved rapid response capabilities now allow COMPTEL burst localizations to be distributed to observers in tens of minutes. We believe these capabilities provide one of the best opportunities of identifying a low-energy burst counterpart.

Acknowledgments

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References

[1] Schönfelder, V., et al., ApJS **86**(1993)657.

[2] de Boer, H., et al., in *Data Analysis in Astronomy IV* - Plenum Press New York (1992)241.

[3] Hurley, K., in *Gamma-Ray Bursts* - AIP Press 307 New York (1994)27.

[4] Hartmann, D. & Epstein, R.I., ApJ **346**(1989)960.

[5] Kippen, R.M., et al., A&A **293**(1995)L5.

[6] Hanlon, L.O., et al., A&A (1995) in press.

[7] Matz, S.M., et al., ApJ **288**(1985)L37.

[8] Band, D., et al., ApJ **413**(1993)281.

[9] Baring, M.G., et al., ApJ **418**(1993)391.

[10] Harrison, T.E., et al., A&A (1995) in press.