COMPTEL Observations of Gamma-ray Bursts[a]

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INTRODUCTION

The origin of cosmic γ-ray bursts is as mysterious today as it was when they were discovered more than 25 years ago. Despite a wealth of new observational data obtained with the BATSE instrument on board the *Compton* Gamma Ray Observatory, many of the fundamental questions remain unanswered. For instance, although BATSE has provided a tremendous statistical advantage (allowing the most accurate measurement of the spatial isotropy and inhomogeneity of burst sources[1]), its limited angular resolution and spectral range have given us an incomplete picture of the small-scale angular source distribution and high energy emission properties.[2,3] Furthermore, the limited angular resolution has also made it difficult to search for burst counterparts at other wavelengths.

The COMPTEL instrument on board *Compton* measures the locations and spectra (0.75-30 MeV) of several strong γ-ray bursts per year which occur within the ~1 sr field-of-view of the main ("telescope") instrument. A secondary ("burst") observing mode provides supplementary spectral data at lower energies (0.3-10 MeV). The statistics of COMPTEL burst observations are modest, but good location accuracy and spectral coverage at higher energies make them a valuable source of information which may help to understand the nature of bursts in those areas where BATSE is most limited. Many of the COMPTEL burst observations have been reported elsewhere.[4] Here, we present an overview of results from recent spatial and spectral analyses and report on the ongoing campaign using COMPTEL burst localizations to quickly search for fading low-energy counterparts.

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ANGULAR DISTRIBUTION AND BURST RECURRENCE

In its first three years of operation from April 1991 through April 1994, COMPTEL detected 18 significant ($\gtrsim 4\sigma$) γ-ray bursts in the main instrument. These bursts are localized through direct imaging using a maximum-likelihood technique.[4] Statistical location accuracy (1σ) ranges from better than 0.5° for strong bursts to ~2° for weak detections, with a mean of ~1°. Systematic location errors are estimated to be $\lesssim 0.5°$.

The COMPTEL burst locations (FIGURE 1) are consistent with an isotropic distribution of sources within the large statistical uncertainty produced by the small sample size (errors caused by location uncertainty are negligible). The Galactic dipole and quadrupole moment statistics[5] corrected for non-uniform COMPTEL sky exposure are $\langle \cos \Theta \rangle = (-0.13 \pm 0.14)$ and $\langle \sin^2 b - \frac{1}{3} \rangle = (+0.01 \pm 0.07)$, respectively. Because all COMPTEL bursts are also observed by BATSE, these results provide an important, independent confirmation that a subset of some of the strongest BATSE bursts are consistent with isotropy. The full BATSE sample, which now incorporates more than 1000 bursts, clearly provides the most constraining measure of the large-scale angular distribution by merit of its overwhelming statistical advantage.[6]

In the COMPTEL sample of source locations, two bursts coincide spatially within instrumental uncertainties.[7] GRB 930704 and GRB 940301 occurred ~8 months apart and are completely consistent with the same position on the sky within the statistical location errors (see FIGURE 1). The probability of such a coincidence occurring by chance in an isotropic distribution has been estimated using Monte Carlo simulations to be $\lesssim 3\%$ — suggesting the *possibility* that these two events are related to a single source.[8] Independent localizations determined by BATSE, EGRET and the Interplanetary Network (using BATSE, *Ulysses* and *Mars Observer* arrival time analysis) cannot rule out this possibility. Gravitational lensing has been excluded since the lightcurves and

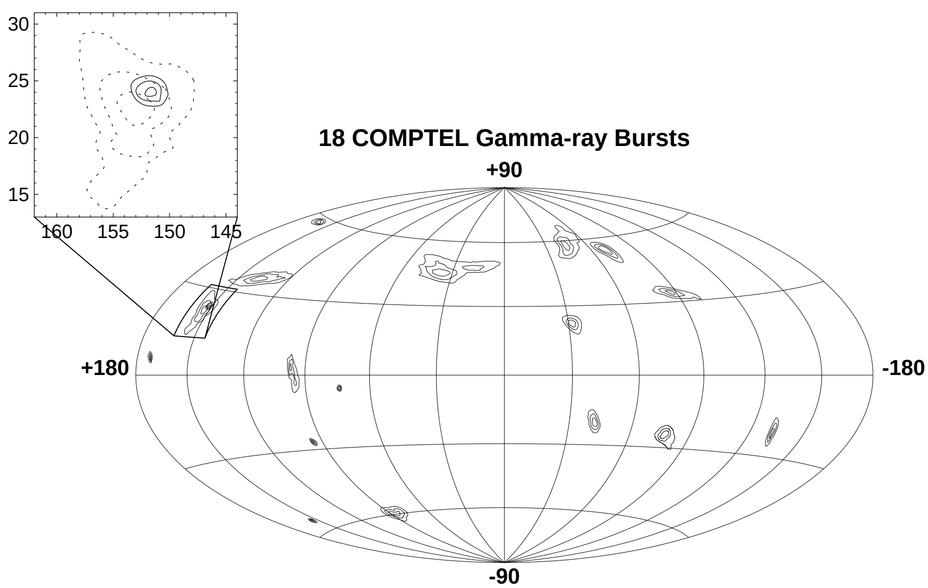

FIGURE 1. The Galactic distribution of 18 γ-ray bursts localized by COMPTEL. For each burst, 1σ, 2σ and 3σ statistical location uncertainty contours are shown. The enlarged region at left shows localizations of the spatially coincident bursts GRB 930704 (dashed contours) and GRB 940301 (solid contours).

spectra of the two bursts were shown to differ significantly using *Compton*-OSSE and BATSE data.[9] The remaining explanation is that the coincidence is a result of two distinct bursts from a single source. However, without arc-minute localization, the only way to confirm that this is a repeating burst source (i.e., $\gtrsim 4\sigma$ detection) and not an accidental coincidence would be the observation of a third outburst within the next few years.

SPECTRAL RESULTS & GRB 940217

The time-averaged energy spectra of most of the bursts observed by COMPTEL are well described by a single power-law model with spectral index in the range 1.5 to 3.5 — consistent with earlier results obtained with *SMM*.[10] However, at least two bursts show significant evidence of a "break" or transition in their spectra at MeV energies. This behavior agrees with BATSE findings that indicate most bursts have a smooth break in their spectra with turnover energies ranging from below 100 keV to above 1 MeV.[3] Attempts to supplement the keV-range BATSE data with the MeV spectra of COMPTEL have shown that spectral modeling is very sensitive to the high energy end of the spectrum and that simple models are insufficient to describe the wide-band spectra.[11]

The extraordinary γ-ray burst of 17 February 1994 was the strongest event yet observed by COMPTEL with fluence $S(> 0.3\ \mathrm{MeV}) = 2 \times 10^{-4}\ \mathrm{erg/cm^2}$. It exhibited complex, multi-peaked emission throughout the COMPTEL energy range lasting for more than 160 s. Rapid intensity fluctuations and spectral variations were observed throughout this event and during several of the individual pulses — including hard-to-soft evolution both within and between the pulses. Preliminary integrated photon spectra from the independent COMPTEL burst and telescope modes indicate a "break" in the spectral slope from ~2.1 to ~2.6 near 1 MeV.[12]

During the most intense pulse, measurement of significant (3σ) power-law emission up to 4.4 MeV coincident with rapid (100 ms) variability indicates that the source must be closer than 1.3 kpc in order to avoid the opacity of γ–γ interactions (assuming the emission is isotropic at the source).[13] If the source of this burst lies at cosmological distances (> 1 Gpc) significant relativistic beaming is required. This makes γ–γ opacity an unlikely cause of the observed break at ~1 MeV because the required relativistic motion would naturally force the break to be above the COMPTEL energy range.[14]

The *Compton*-EGRET instrument observed high energy photons (up to 18 GeV) from this burst for a period of ~120 minutes following the main 160 s interval — suggesting that high energy emission is extended in time beyond that at lower energies.[15] During the same post-burst interval, COMPTEL did not measure (due to its lower sensitivity) any significant emission from the direction of GRB 940217. The COMPTEL upper limits are consistent with the flux level observed by EGRET.

RAPID BURST RESPONSE

Several of the COMPTEL bursts have been localized within *hours* of their occurrence following timely notification from BATSE. The locations of such rapidly localized events are promptly distributed to a world-wide network of multiwavelength observatories. This "Rapid Burst Response" campaign[16] was initiated in July 1992 to take advantage of COMPTEL's good angular resolution, which allows relatively deep searches to be performed. Since then, continuous improvements have allowed deep searches for fading GRB counterpart emission in record time.

No *obvious* fading counterparts at any wavelength have yet been identified. The most constraining measurements were for GRB 940301,[17] where the absence of an optical counterpart in deep searches ($m_v \approx 16$) seven hours after the burst places an upper limit on the ratio of optical to γ-ray flux of 2.5×10^{-6}. This upper limit is more than three orders-of-magnitude lower than the best previous measurements. The lack of radio counterparts in a comprehensive follow-up study places significant constraints on currently favored cosmological models, which predict transient radio emission.[18]

COMPTEL observes new bursts at a rate of ~1/month and localization response-times continue to improve using automated burst notification via BACODINE.[19] In the near future COMPTEL locations of strong bursts (location accuracy ~0.5°) will be distributed to observers automatically in as little as ~10-15 min. For future bursts like GRB 940217, this capability will allow observations in optical and radio while GeV γ-rays are still being detected (e.g., by EGRET).

CONCLUSIONS

We have shown that COMPTEL γ-ray burst observations are providing information in areas where there are fundamental gaps in our knowledge. Unique measurements of individual bursts like GRB 940217 and GRB 940301 have given us a glimpse of the MeV emission process as well as providing important limits on low energy fading counterparts. Continued observations insure that in the near future COMPTEL measurements of the small-scale distribution of burst sources will provide constraining limits on recurrence.

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