2-1994

COMPTEL measurements of the gamma-ray burst GRB 930131

James M. Ryan
University of New Hampshire, James.Ryan@unh.edu

K Bennett
ESTEC

W Collmar
Max-Planck-Institut für extraterrestrische Physik

A Connors
University of New Hampshire - Main Campus

Gerald J. Fishman
NASA Marshall Space Flight Center

See next page for additional authors

Follow this and additional works at: https://scholars.unh.edu/physics_facpub

Part of the Astrophysics and Astronomy Commons

Recommended Citation
Authors
James M. Ryan, K Bennett, W Collmar, A Connors, Gerald J. Fishman, J Greiner, L O. Hanlon, W Hermsen, R M. Kippen, C Kouveliotou, L Kuiper, G G. Lichti, John R. Macri, J. Mattox, Mark L. McConnell, B McNamara, C Meegan, V. Schonfelder, R VanDijk, M Varendorff, W Webber, and C Winkler
COMPTELE MEASUREMENTS OF THE GAMMA-RAY BURST GRB 930131


Received 1993 October 4; accepted 1993 December 2

ABSTRACT

On 1993 January 31 at 1857:12 UT, the Imaging Compton Telescope COMPTEL onboard the Compton Gamma Ray Observatory (CGRO) detected the cosmic $\gamma$-ray burst GRB 930131. COMPTEL's MeV imaging capability was employed to locate the source to better than $2^\circ$ (1 $\sigma$ error radius) within 7 hr of the event, initiating a world-wide search for an optical and radio counterpart. The maximum likelihood position of the burst from the COMPTEL data is $\alpha=12^h18^m$, $\delta=-9^\circ42'$, consistent with independent CGRO-BATSE and EGRET locations as well as with the triangulation annulus constructed using BATSE and Ulysses timing data. The combined COMPTEL and EGRET burst data yield a better estimate of the burst location: $\alpha=12^h12^m$ and $\delta=-10^\circ21'$, with a 1 $\sigma$ error radius of 32'. In COMPTEL's energy range, this burst was short, consisting of two separate spikes occurring within a ~1 s interval with a low intensity tail for ~1 s after the second spike. No statistically significant flux is present for a 30 s period after the main part of the burst. This is consistent with the EGRET data. The COMPTEL telescope events indicate a hard, power-law emission extending to beyond 10 MeV with a spectral index of $-1.8 \pm 0.4$. The rapid fluctuations and high intensities of the $\gamma$-ray flux >10 MeV place the burst object no farther than 250 pc if the burst emission is not beamed.

Subject heading: gamma rays: bursts

1. INTRODUCTION

Given our present level of understanding, a detection of a $\gamma$-ray burst at any other wavelength would greatly enhance our understanding of the burst phenomena (Schaefer et al. 1994). Searchers over a variety of timescales with sensitive instruments are necessary to draw meaningful conclusions about the luminosity of any optical counterpart. Quick, deep searches require precise, accurate, and timely positions for $\gamma$-ray bursts. Interplanetary triangulations are capable of arcminute locations but are generally available only days after the event. Quick searches at other wavelengths, therefore, rely upon wide-FOV instruments operating in real time with the eventual occurrence of a burst within the FOV of the optical instrument. Projects or campaigns of this type have been summarized by e.g., Vandersot, Doty, & Ricker (1992) and Greiner et al. (1993).

The BATSE instrument (Fishman et al. 1989) is capable of obtaining locations on short notice with >4' (radius) error boxes. However, if a burst can be localized with confidence to be within the FOV of a Schmidt camera, then instruments larger than 60 cm can reach sensitivities better than 20th mag in 1 hr exposures. The required precision and accuracy of burst locations that enable the use of these telescopes can be obtained with COMPTEL (Schönfelder et al. 1993).

The burst localization process involves only the double-scatter (or telescope) mode of COMPTEL. In the telescope mode, COMPTEL "focuses" $\gamma$-rays with a nominal source location accuracy, which, depending on source strength, can be as good as 0.5 (e.g., GRB 910503 and GRB 910814; Hanlon et al. 1993) with an energy resolution better than 10% FWHM (at 662 keV).

The observation of GRB 930131 is significant because of the peak flux of the burst, its hard spectrum (extending beyond 10 MeV), its temporal evolution, and the fact that it was located within 7 hr of the event (Ryan, Kippen, & Varendorff 1993). This counterpart search demonstrates the utility of COMPTEL in multiwavelength observations of $\gamma$-ray bursts.

2. DATA AND RESULTS

Figure 1 shows the count rate of the telescope events recorded by COMPTEL and the rates of two individual D2 detectors. As seen in the data, the burst consists of two spikes within a 1 s interval. However, both BATSE, EGRET, and COMPTEL (>600 keV in the "burst mode" spectrometer data) detect $\gamma$-rays beyond this 1 s. The major difficulty in measuring the light curve of an intense burst with COMPTEL is the limited capacity of the telemetry and event processing systems (Schönfelder et al. 1993). High rates of individual detector modules (>10^5 s^-1) also may affect the instrument lifetime.

Because of the complexity of the burst and performance of the instrument during the event, we have subdivided the burst into several intervals as the basis for the following discussion. The moment of the internal BATSE trigger (1857:11.682 UT)
serves as a reference time. The intervals are defined as follows:

A.—1857:11.582–1857:11.682 UT, the onset of the burst as measured by COMPTEL, the time of the most intense γ-ray flux. Livetime fraction ~0%.

B.—1857:11.682–1857:12.0 UT, the 300 ms trailing edge of the main spike.

C.—1857:12.0–1857:12.28 UT, a 300 ms interval between spikes where there is little activity. Livetime fraction ~98%.


E.—1857:12.602–1857:13.0 UT, a 300 ms interval during which COMPTEL can make no measurements. Livetime fraction = 0%.

Average lifetime information is recorded on a 16.4 s basis. The intense 1 s of the burst was fully contained in such a 16.4 s interval. An analysis of the various components of the lifetime indicates that the effective livetime for the intense 1 s of the burst was 12%. The instantaneous livetime fraction was much smaller during the most intense parts of the burst.

The BATSE data indicate that a first intense spike is followed by a weaker one during the main 1 s of the burst (Kouveliotou et al. 1994). The question arises whether the same relationship exists between the two spikes as measured by COMPTEL. Any differences would suggest a spectral change taking place from one spike to the next. The first burst events recorded by COMPTEL occur ~100 ms before the BATSE trigger (Fig. 1, interval A). The exact onset of the burst is uncertain because of the low number of counts.

Individual COMPTEL detector elements assist in determining the relative intensities of the two main spikes. Different D2 detector rates (with an energy threshold of ~450 keV) are recorded every 2.048 s. A 2.048 s time boundary fortuitously occurred near the end of the first spike at 1857:11.810 UT (within interval B). Before this boundary, the excess D2 module count rate is attributed to the first 228 ms of the first spike (A and part of B), while after this boundary the excess is attributed to the remaining 800 ms of the main 1 s. These excess rates in the single detectors are represented by the two-bin histogram superposed on the telescope count rate. Overlying material makes the detectors relatively immune to the time effects caused by the intense γ-ray flux. Modeling of the individual detectors with an $E^{-2}$ spectrum of γ-rays indicates that the relative intensities of the two spikes >450 keV are the same as those measured at lower energies by BATSE. We therefore attribute the low count rate in the first spike as due to unusually large dead-time effects and not to a much softer spectrum. Based on the count rate of a single D2 detector module, for the 128 ms before 1857:11.810 UT we estimate the >450 keV flux to have an average value of ~200 cm$^{-2}$ s$^{-1}$. Another spike starts approximately at 1857:12.1 UT (D) with a structure shorter than 50 ms as seen in the inset of Figure 1. After 1857:11.810 UT (C, D, and part of B) the flux >500 keV is ~16.5 cm$^{-2}$ s$^{-1}$ averaged over the remainder (800 ms) of the 1 s burst. The period between the two spikes (C) is consistent with no signal. During the second spike, the intensity is lower, but still large enough to exhaust the capacity of the telemetry buffer at approximately 1857:12.602 UT. Therefore, for the next ~300 ms (E), no telescope events are recorded. After 1857:13.0 UT all COMPTEL rates are at background levels, and the livetime fraction has returned to ~98%.

The "burst mode" data (Schönfelder et al. 1993) show that in the 2 s following the burst there is residual emission >600 keV at a level consistent with the measurements reported by Kouveliotou et al. (1994) and also consistent with the lack of events in the COMPTEL telescope data.

We employ a maximum-likelihood technique to determine the position of the burst (de Boer et al. 1992) using telescope data. Twenty-eight events from 0.75 to 30 MeV were selected from the most intense part of the burst (A through D) (Fig. 2) and used to produce an image. Although GRB 930131 was intense, the low instrument livetime and the short duration resulted in fewer recorded events than other bursts observed during the mission (Winkler et al. 1992; Hanlon et al. 1993). This manifests itself in a relatively large statistical error box (±1:5 in both directions at the 1σ confidence level) around $\delta_{2000} = 12^h18^m$, $\delta_{2000} = -9^\circ42'$. We have compared the COMPTEL burst location map to other independent locations by overlaying: the BATSE burst position; the EGRET location contours (Sommer et al. 1994) and the Interplanetary Network annulus (Hurley 1993; Cline, Barthelmy, & Palmer 1993). Good agreement is obtained between the COMPTEL position and all other locations at the 2σ confidence level. Based on COMPTEL data alone, the best location along the triangulation annulus is $\delta_{2000} = 12^h15^m$, $\delta_{2000} = -9^\circ41'$ (±1' along the annulus). The best location from an image using the combined COMPTEL/EGRET data (Fig. 2) is $\delta_{2000} = 12^h12^m$ and $\delta_{2000} = -10^\circ21'$ (±32' in both directions at the 1σ confidence level).

To construct an energy spectrum we selected 26 events originating within 10° of the burst position from the first ~1 s after 1857:11.582 UT (A through D). These events were restricted to a minimum energy of 0.75 MeV and a maximum energy of near 30 MeV. Three measured events >10 MeV compared to a predicted background of 0.1 event establishes the presence of high-energy emission from this burst. The data fit a power-law photon spectrum of $(7.5 \pm 3.1) \times (E/1$ MeV$)^{-1.8 \pm 0.4}$ cm$^{-2}$ s$^{-1}$ MeV$^{-1}$ (Fig. 3). The largest uncertainty in the spectrum arises from the underrepresentation of the intense part of the
burst due to livetime effects, affecting only the shape and not the intensity. The spectrum normalization is handled correctly since the instrument integrates the livetime effect over the whole event. The spectra of the two separate pulses within the limits of the statistics show no spectral difference. A preliminary analysis of the high-range “burst mode” data integrated over 1 s, starting at the BATSE trigger, yields a best-fit power-law spectrum with an index of $2.2 \pm 0.2$, consistent with the telescope data for the corresponding time interval.

3. DISCUSSION

The COMPTEL data indicate no significant evolution of the $\gamma$-ray flux during the first 1 s of the burst. The count rate between the two spikes (C) is consistent with no emission. Although EGRET measures the majority of its high-energy photons between 1 and 30 s after interval D, this is a result of the EGRET instrumental livetime rather than of spectral hardening (Sommer et al. 1994). The flux measured by EGRET following the intense 1 s is consistent with the time-integrated COMPTEL spectrum, i.e., $E^{-2}$ (Sommer et al. 1994) but reduced in intensity. This trailing flux folded through the COMPTEL instrument response predicts $\sim 10$ events in the 29 s after the main burst. Our 2 $\sigma$ upper limit on detected “late” events is 12.2 above the background level. Therefore, we find no evidence for spectral hardening in the “delayed” phase of the burst. The EGRET detection at these times presumably results from its greater signal-to-noise ratio compared to that of COMPTEL. Based upon the COMPTEL data above 0.75 MeV, the burst appears to modulate its intensity over a large dynamic range without any significant spectral evolution over the full 30 s duration of the burst. There is no evidence that the emission $> 50$ MeV as seen by EGRET is delayed with respect to that at COMPTEL energies.

The intensity $> 1$ MeV can be used to compute a maximum distance to the burst. Photon-photon interactions attenuate the high-energy ($> 1$ MeV) flux at the source (Schmidt 1978). A maximum diameter ($2c\Delta t$) of 30,000 km can be placed on the burst photosphere (optical thickness $\tau = 1$ at 10 MeV) based on the $\sim 50$ ms structure measured by the COMPTEL instrument within interval D of the main burst (Fig. 1). At that moment, $\gamma$-rays $> 10$ MeV were measured by COMPTEL with an instantaneous flux of $\sim 42E^{-1.8}$ cm$^{-2}$ s$^{-1}$ MeV$^{-1}$. This is based upon the measured flux $> 450$ keV during the last 800 ms of the intense 1 s, half of which occurred in one 50 ms
The instantaneous $\gamma$-ray luminosity for this object at 250 pc, emitting isotropically and integrated from 0.45 to 30 MeV within the 50 ms spike in interval D is $3 \times 10^{39}$ ergs s$^{-1}$. (Integrating to 1 GeV, based on the EGRET measurements, increases this luminosity by only a factor of 2.) Placing the object at 30 kpc and at $10^9$ Mpc with appropriate beaming solid angles implies intrinsic luminosities of $1 \times 10^{41}$ and $1.5 \times 10^{45}$ ergs s$^{-1}$, respectively. Of course, the instantaneous luminosities during interval A could be much larger, perhaps by an order of magnitude. The integrated energy flux for the entire burst from 1 to 30 MeV is $6 \times 10^{-5}$ ergs cm$^{-2}$.

4. CONCLUSIONS

The intense, short-duration $\gamma$-ray burst GRB 930131 was imaged in the MeV range by COMPTEL within 7 hr of its occurrence. The COMPTEL localization was found to be consistent with independent BATSE and EGRET locations, as well as the triangulation annulus obtained from BATSE and Ulysses timing data. Multiwavelength observations of the COMPTEL source region have been performed in record time. Spectral analysis indicates that GRB 930131 is a hard event with power-law emission throughout the COMPTEL energy range. The rapid fluctuations of the $>10$ MeV flux and its great intensity allow us to constrain the source to be nearby within the Galaxy if we assume that the radiation is not beamed due to relativistic motion. A lower distance limit using an upper limit on the parallax does not conflict with any current models for $\gamma$-ray bursts.

We would like to acknowledge the cooperation of the CGRO Project Staff, the Flight Operations Team, and the BATSE and COMPTEL operations teams for assisting in this Rapid Response Campaign. We also thank Brenda Dingus for her assistance and fruitful discussions. This work was supported in part by NASA contract NAS 5-26645 and the Deutsche Agentur für Raumfahrtangelegenheiten (DARA) under the grant 50 QV 90968.

REFERENCES

B. de B. H., et al. 1992, in Workshop on Data Analysis in Astronomy IV, ed. V. DeCesari et al. (New York : Plenum), 241
Cline, T. L., Barthelmy, S., & Palmer, D. 1993, IAU Circ., No. 5703
Hurley, K. 1993, private communication
Ryan, J., Kippen, R. M., & Varendorff, M. 1993, IAU Circ., No. 5702

© American Astronomical Society • Provided by the NASA Astrophysics Data System