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COMPTEL observations of gamma-ray bursts: imaging and localization

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Abstract. — The COMPTEL experiment on GRO images 0.7–30 MeV celestial gamma-radiation that falls within its 1 steradian field of view. During the first eleven months of orbit, preliminary localizations from BATSE triggers indicated that about 1 in 6 cosmic events could have fallen within COMPTEL's field of view. We present COMPTEL positions for four of the brighter of these gamma-ray bursts.

Key words: gamma rays — gamma ray bursts.

1. Introduction.

For the past two decades, γ -ray burst localization has meant either arcminute error boxes from timing comparisons among widely separated spacecraft; or error boxes $\sim 10^\circ$ wide based on broad, anisotropic instrument response (Hurley *et al.* 1984). Studies of these positions revealed an apparently isotropic distribution on the sky (Pedersen *et al.* 1984; Hurley 1992); and, surprisingly, not a single compelling quiescent counterpart at any wavelength (Schaefer 1992 and references therein), with the well-known exception of GRB 790305 (Cline *et al.* 1980). This drove speculation that the fine error boxes based on timing could be misleading, due either to nearby sources (e.g. < 100 AU, Kuznetsov 1982), at one distance extreme; or to gravitational lensing and beaming effects at the other (McBreen & Metcalfe 1987). Recent BATSE results have dramatically highlighted this distance controversy (Meegan *et al.* 1992).

The COMPTEL experiment can directly image MeV sources, offering a completely independent γ -ray burst localization method. In COMPTEL's "telescope" mode, ideally, a photon Compton-scatters once in one of the seven upper D1 detectors, then is completely photo-absorbed in one of the lower array of fourteen high-Z D2 detectors (see Schönfelder *et al.* 1984; also Winkler *et al.* 1986). In

this simple case the possible γ -ray source positions lie on a circle of radius $\bar{\varphi}$ around the direction of the scattered photon, with

$$\cos \bar{\varphi} = 1 - \frac{1}{\epsilon_2} + \frac{1}{\epsilon_1 + \epsilon_2}, \quad (1)$$

where ϵ_1 and ϵ_2 are the energy deposits measured in the upper (D1) and lower (D2) detectors, respectively, in units of the electron rest-mass. The intersection of these circles produces an image. In practice the full instrument response includes the effect of multiple scatters and partial energy absorption, which smear and broaden this ideal response substantially, as a function of energy and photon scatter-direction measurements (Diehl *et al.* 1991). Comparisons of burst positions measured by COMPTEL with those based on timing have so far been in agreement (Hurley *et al.* these proceedings; Varendorff *et al.* 1992).

2. Data and analysis.

Roughly half of the BATSE burst trigger messages contain preliminary positions, with typical error radii of 10° – 15° . Of these, about 16% had been given BATSE positions within 45° of COMPTEL's telescope zenith, and were potential candidates for imaging. COMPTEL results for one very intense event, GRB 910503, have already

been published (Winkler *et al.* 1992a). In this paper we present position constraints for four more bright events: GRB 910425 (BATSE trigger: 2268 s UT; COMPTEL zenith of 45°); GRB 910601 (BATSE trigger: 69736 s UT; COMPTEL zenith of 8°); GRB 910627 (BATSE trigger: 16159 s UT; COMPTEL zenith of 10°); and GRB 910814 (BATSE trigger: 69275 s UT; COMPTEL zenith of 28°).

For each burst, a time window was selected using the BATSE trigger time and extending over the total burst duration. Only telescope events which satisfied the optimum event selection criteria were used. Spectra and light-curves for these events are described by Collmar *et al.* (these proceedings) and Winkler *et al.* (1992b).

COMPTEL uses several imaging methods, including a maximum entropy technique to estimate the count-rate per angular bin on the sky. This general method is detailed by Strong *et al.* (1991); and its application to imaging γ -ray bursts by Varendorff *et al.* (1992). In this paper we focus on quantitative constraints on source positions, for which a maximum likelihood fitting technique is used (de Boer *et al.* 1991; also Kuiper *et al.* 1992).

One first transforms to the spatial coordinates $\chi, \psi, \bar{\varphi}$, plus E_{TOT} ; where $\bar{\varphi}$ was defined in Equation 1, E_{TOT} is the total energy deposited in both D1 and D2, and (χ, ψ) represent convenient telescope coordinates for the photon scatter-direction. For a single energy interval, COMPTEL's complex instrument response is factored into an instrument geometry and exposure, which depend on the absolute telescope position; and a point spread function, which depends on the relative coordinates $\chi, \psi, \bar{\varphi}$ (Diehl *et al.* 1991 and references therein). This is then integrated over an assumed input energy spectrum.

For each gamma-ray burst, a point source was convolved with the instrument response, and added to a simple background. This model was compared to the data-counts in each $\chi, \psi, \bar{\varphi}$ -bin, using the standard maximum-likelihood statistic appropriate for Poisson counts per bin (de Boer *et al.* 1991). The source flux and background level (consistent with zero) were allowed to vary, as contours of constant probability were mapped out in (χ, ψ) space, at the equivalent of 1, 2, and 3σ significance for the case of two parameters (Lampton *et al.* 1976; Cash 1976).

3. Results.

We display these maximum-likelihood ratio contours, which incorporate statistical errors only, in Figures 1 through 4, for GRB 910425, GRB 910601, GRB 910627, and GRB 910814. The varying widths of the contours reflect the number of telescope events available for imaging, which ranged from ~ 30 to ~ 200 .

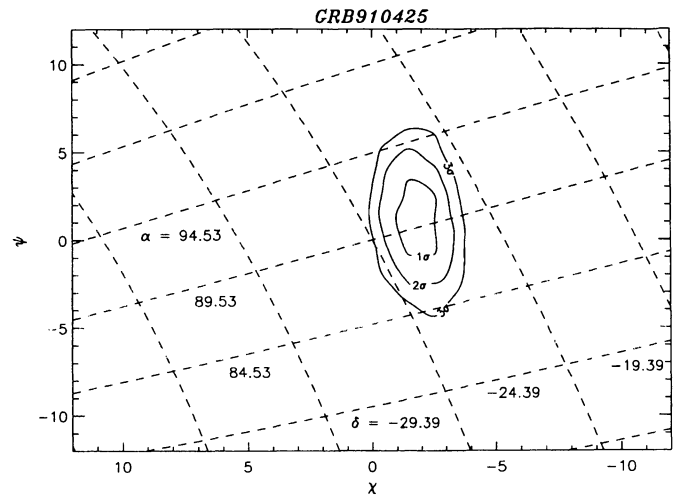


FIGURE 1. GRB 910425: maximum likelihood ratio map, with $\alpha_{2000}, \delta_{2000}$ grid superposed.

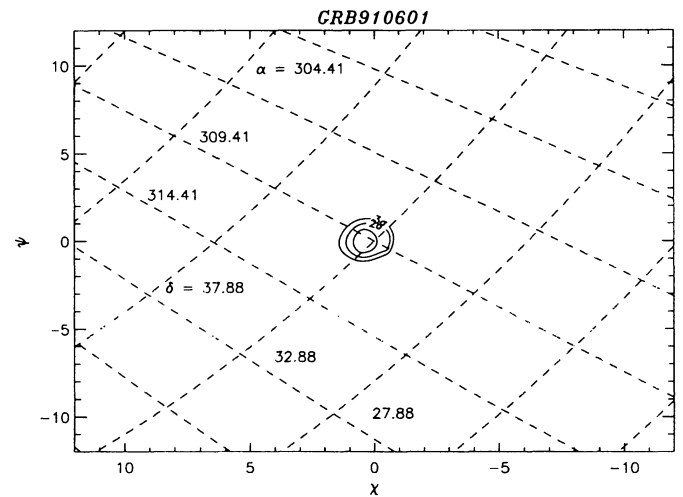


FIGURE 2. GRB 910601: maximum likelihood ratio map, with $\alpha_{2000}, \delta_{2000}$ grid superposed.

TABLE 1. Summary of COMPTEL burst positions.

GRB ID (date)	Equatorial $\alpha_{2000} \pm \sigma$	Coordinates $\delta_{2000} \pm \sigma$
910425	$5^h 59^m \pm 10.^m$	$-22.4^\circ \pm 1.3^\circ$
910601	$20^h 39^m \pm 4.8^m$	$33.2^\circ \pm 1.2^\circ$
910627	$13^h 15^m \pm 11.^m$	$-4.0^\circ \pm 2.9^\circ$
910814	$22^h 50^m \pm 4.4^m$	$30.0^\circ \pm 1.3^\circ$

Ten years ago, time delays from four or more widely separated spacecraft were used to show that position constraints derived from cosine law detector response could be in error by $\geq 5^\circ$ (Hurley 1982 and references therein). Recently, BATSE results have demonstrated the significant impact of atmospheric backscatter when solving for

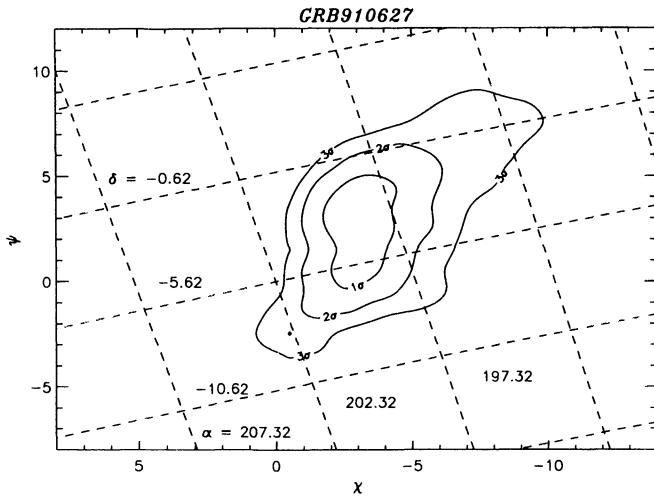


FIGURE 3. GRB 910627: maximum likelihood ratio map, with α_{2000} , δ_{2000} grid superposed.

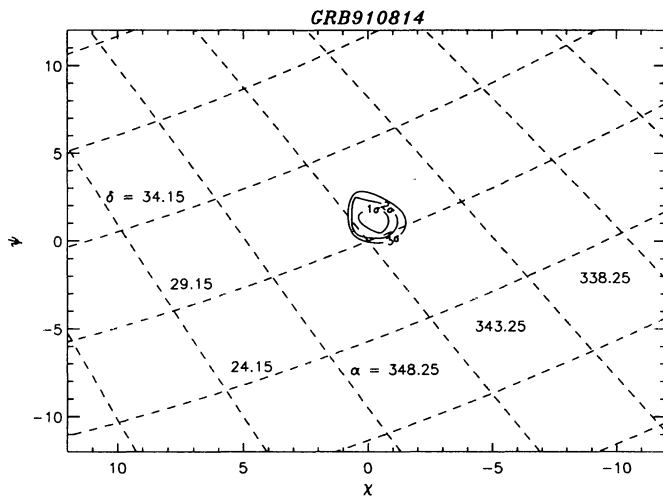


FIGURE 4. GRB 910814: maximum likelihood ratio map, with α_{2000} , δ_{2000} grid superposed.

burst positions (Brock *et al.* 1992). Although COMPTEL's higher energy range renders it less sensitive to this particular effect, it is clearly important to set quantitative limits on any systematic errors in burst locations.

For COMPTEL locations of strong γ -ray bursts, since the background is negligible, the form assumed for the point-spread function is the dominant source of systematic uncertainty. We used solar flares which had a similarly high signal-to-noise ratio to investigate this. Preliminary location studies of the June 9 and June 11, 1991 solar flares indicated systematic uncertainties no larger than $\sim 1^\circ$. The localization of a strong source like the Crab pulsar for different observations rendered positions within 0.5 – 1° from the known position. We expect additional work will allow us to constrain these systematic uncertainties further.

We summarize our results in Table 1. To the 1σ statistical errors, we have added $\sim 1^\circ$ systematic uncertainties in quadrature.

4. Discussion.

COMPTEL's telescope locations and location arcs based on Ulysses–GRO burst arrival times are independent measurements of γ -ray burst source positions that can be combined into error boxes a few arcminutes wide by a few degrees long. This allows searches for counterparts at other wavelengths (Boer *et al.* these proceedings; Hurley *et al.* these proceedings).

It is also interesting to calculate how seriously one can constrain theories that predict that a γ -ray burst should not have the plane-wave signature of a distant point source. As one simple example, consider a nearby γ -ray burst source located at a position \mathbf{P} with respect to the Earth (which we take to be the origin), observed by two satellites, one in Earth orbit and the second some distance away at position \mathbf{S} . Let δt represent the delay in burst arrival time at the second and first spacecraft. For convenience, define the dimensionless parameters $\tau = c\delta t/|\mathbf{S}|$ and $\lambda = |\mathbf{P}|/|\mathbf{S}|$. If θ is the angle to the γ -ray burster from the Earth–spacecraft line, then:

$$\cos \theta = \tau + \frac{1 - \tau^2}{2\lambda}. \quad (2)$$

That is, if the source were nearby, the directional cosine inferred from the time-delay would be too small by a term that is inversely proportional to distance. As a specific example, suppose the second spacecraft were at $|\mathbf{S}| = 4\text{AU}$, and the relative time delay τ were measured to be 0.5. Then for the ideal case when uncertainties in burst arrival times are negligible, the γ -ray burst source would have to be more distant than $\sim 40\text{AU}$ in order for the arc derived from timing to fall within 2° (i.e. $1 - 2\sigma$) of the COMPTEL position.

5. Conclusions.

In telescope mode, COMPTEL measures burst locations to within 1 – 2° . These can be combined with positions derived from burst arrival times at the GRO and Ulysses spacecraft, to provide a narrow window for the search for counterparts at other wavelengths.

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