COMPTEL Search for Gamma-Ray Polarization in GRBs and Solar Flares

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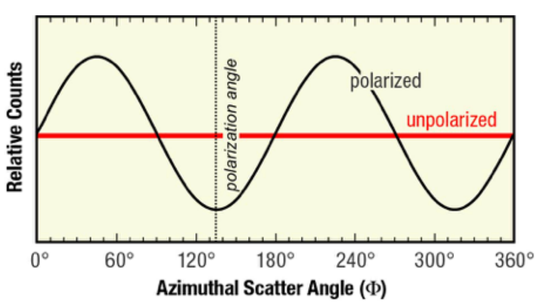
The Imaging Compton Telescope (COMPTEL) operated on orbit from 1991 to 2000. COMPTEL was a Compton imaging telescope that operated from 0.75 - 30 MeV. Although the COMPTEL design was not optimized for polarization measurements, it did retain soime level of polarization sensitivity. We have analyzed COMPTEL data in search of gamma ray polarization in solar flares and gamma-ray bursts (GRBs). Solar flare candidates were GOES X-ray flares of class C or larger that occurred within the COMPTEL field of view (<30° from the pointing direction). GRB candidates included all those from the BATSE 4B catalog that occurred within the COMPTEL field of view (<30° from the pointing direction). For each event we defined source and background periods and determined the net source counts. For those events showing a positive excess of source counts, we calculated the minimum detectable polarization (MDP) for COMPTEL. The MDP was estimated using the traditional formulation based on histograms of photon scatter angles. There were no cases in which the MDP was estimated to be less than 100%, meaning that COMPTEL measurements did not have the necessary sensitivity to constrain the polarization for any of these events.

Compton Polarimetry

In Compton scattering, the incident photon tends to scatter at right angles to the incident electric field vector. For an unpolarized flux of Compton scattered photons, the distribution of the azimuthal scatter angles (the scatter angle distribution in the plane of the detector) will be uniform. For a polarized flux of Compton scattered photons, the distribution of azimuthal scatter angles will be non-uniform and be sinusoidally distributed. This polarization signature can be used to determine the fractional polarization and the polarization angle of the incident flux. The energy-dependent *modulation factor* (μ) characterizes the polarization signature and can be used to estimate the *minimum detectable polarization* (MDP). This represents the minimum level of polarization that can be measured in a given observation.

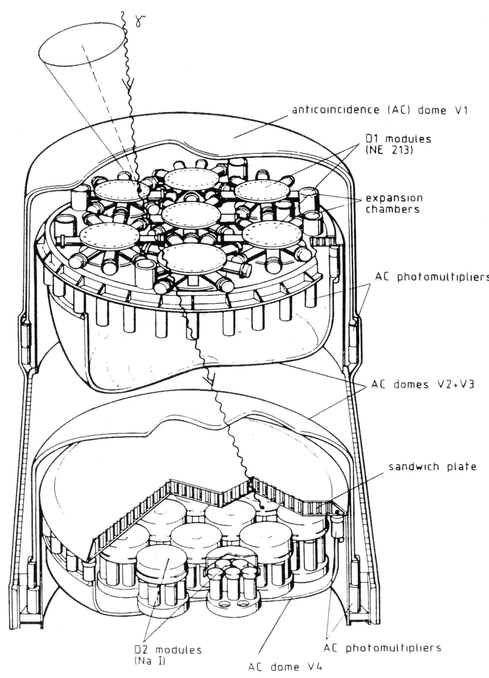


At the 99% confidence level, the MDP associated with an observation is given by,

$$MDP = \frac{4.29}{\mu_{100}\, C_{src}} \sqrt{C_{src} + C_{bgd}}$$

where μ_{100} is the modulation factor corresponding to fully polarized radiation, C_{src} is the total number of measured source counts, and C_{bgd} is the total number of measured background.

CGRO/COMPTEL

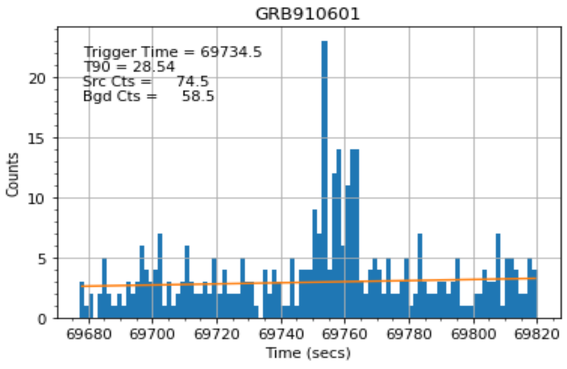


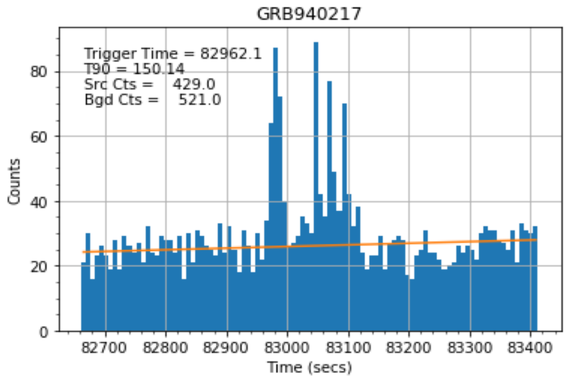
The COMPTEL instrument on the Compton Gamma Ray Observatory (CGRO)[1] was a double-scatter instrument (D1 - liquid scintillator / D2 - NaI(Tl)) capable of imaging 0.75-30 MeV gamma rays. With a D1-D2 separation of 1.5 m, it relied on pulse shape discrimination (PSD), Time-of-Flight (ToF) and scatter angle constraints to identify and reject various background components (e.g., neutrons and activation of passive materials).

For simulating the polarization response, our work employed the GEANT4-based MEGAlib software package [2]. One of the advantages of using this package was the ready availability of a detailed COMPTEL mass model (seen here).

COMPTEL GRB Data

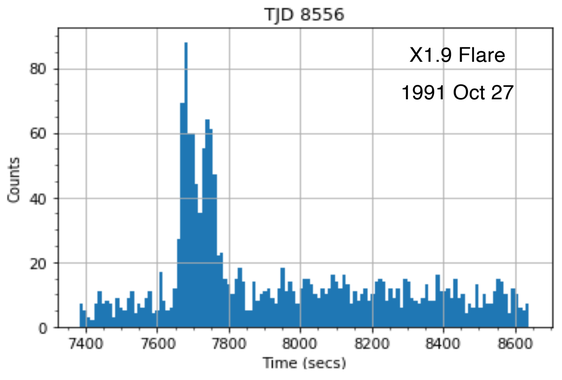
During the 9-year mission of CGRO, about 60 GRBs took place within 30° of the COMPTEL pointing direction. We have conducted a systematic analysis of these GRBs using COMPTEL telescope mode (imaging) data. The goal of our analysis was to estimate the polarization sensitivity (MDP) for each GRB. The number of source and background counts were estimated over the energy range from 750 keV to 3 MeV. Several GRBs showed significant signal, two of which are shown here. In many cases, the S/B is quite large, but the data are sometimes constrained by the limited throughput of the instrument data stream.

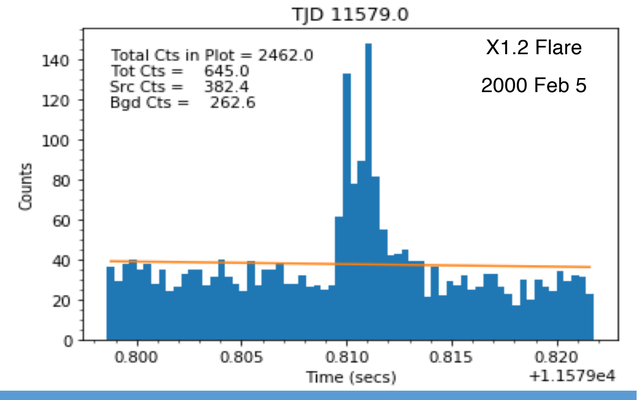




COMPTEL Solar Flare Data

During the 9 year mission of CGRO, numerous solar flares took place within 30° of the COMPTEL pointing direction. Our study of these flares included 6 X-class flares, 141 M-class flares, and 310 C-class flares (> C4.0). The goal of our analysis was to estimate the polarization sensitivity (MDP) for each flare. The number of source and background counts were estimated over the energy range from 750 keV to 3 MeV. Several flares showed significant signal, two of which are shown here. In many cases, the S/B is quite large, but the data are sometimes constrained by the limited throughput of the instrument data stream.





Polarization Sensitivity for GRBs

From our survey of all GRBs within 30° of the COMPTEL pointing direction, we selected a total of 6 GRBs that showed significant signal. In each case, we simulated the polarization response of COMPTEL for a source at that specific location within the FoV and with a power-law spectrum corresponding to the measured spectrum for that event. The polarization sensitivity (MDP) derived from our analysis showed that none of these GRBs were measured with enough sensitivity to enable a more detailed study to search for polarization. We therefore conclude that CGRO was not able to measure polarization in any GRB during its 9-year mission.

GRB	θ	φ	α	μ_{100}	Src Cts	Bgd Cts	Polarization Sensitivity
GRB910601	8.3	70.9	3.3	0.066	74.50	58.50	>100%
GRB910627	8.2	217.3	2.3	0.060	19.50	55.50	>100%
GRB920830	16.5	354.1	2.5	0.079	16.00	29.00	>100%
GRB940217	10.3	317.1	2.6	0.067	429.00	521.00	>100%
GRB940314	14.2	54.4	2.7	0.083	57.00	161.00	>100%
GRB960808	16.6	240.8	2.7	0.087	28.50	13.50	>100%

Polarization Sensitivity for Solar Flares

Solar Flare	Class	μ_{100}	Src Cts	Bgd Cts	Polarization Sensitivity
FLR000120	C4.1	0.05	66.3	122.7	>100%
FLR000523	C9.5	0.05	65.7	64.3	>100%
FLR911215	M1.4	0.05	72.7	43.3	>100%
FLR911214	M1.6	0.05	24.2	40.8	>100%
FLR911214	M2.0	0.05	190.9	138.1	>100%
FLR000324	M2.6	0.05	194.7	543.3	>100%
FLR000112	M2.8	0.05	107.2	257.8	>100%
FLR910529	M4.3	0.05	78.5	104.5	>100%
FLR911216	M4.6	0.05	96.2	49.8	>100%
FLR911216	M6.9	0.05	162.3	128.7	>100%
FLR910614	M7.3	0.05	406	187	>100%
FLR910530	M8.2	0.05	119	75	>100%
FLR000205	X1.2	0.05	382.4	262.6	>100%
FLR911027	X1.9	0.05	566.8	167.2	>100%
FLR911024	X2.1	0.05	45.5	15.5	>100%
FLR911027	X6.1	0.05	419.7	167.3	>100%

From our sample of solar flares, we found a total of 16 solar flares with significant signal. The response for each of these flares has not yet been simulated, so we assumed a value for μ_{100} in each case. The polarization sensitivity estimates (MDP values) resulting from our analysis showed that none of these solar flares were measured with enough sensitivity to enable a more detailed analysis. We therefore conclude that CGRO was not able to measure polarization in any solar flare during its 9-year mission.

Summary

COMPTEL was an instrument capable of making polarization measurements of gamma-ray sources, although its response was not optimized for polarization sensitivity. Nonetheless, we have undertaken a systematic effort to look at GRBs and solar flares to see if the polarization sensitivity was enough for a more detailed study. Despite measurements with relatively large S/B, COMPTEL measurements proved to be insensitive to polarization for GRBs and solar flares, using traditional analysis techniques. We are looking at the application of other analysis techniques (for example, using a Stokes parameter analysis [3] and a Maximum Likelihood analysis [4]), but preliminary results indicate no significant sensitivity improvement. This is consistent with the expectation that a few thousand events would have been required for a sensitive measurement, given the relatively low modulation factors ($\mu_{100} < 0.1$) of COMPTEL.

References

[1]Schöenfelder et al. Astrophys. J. Suppl., 86, 657.
[2]Zoglauer et al. 2006, New Astronomy Reviews, 50, 629.
[3]Kislat et al. 2015, Astroparticle Physics, 68, 45.
[4]Lowell et al. 2017, Astrophys. J., 848, 120.

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