GRB Polarization Measurements with CGRO/COMPTEL

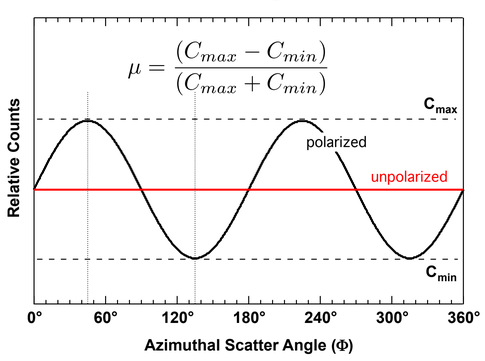
Mark L. McConnell – *Space Science Center, University of New Hampshire, Durham, NH, USA*
Werner Collmar – *Max Planck Institute (MPE), Garching, Germany*

We have embarked on a program to analyze CGRO/COMPTEL data in search for evidence of polarization in both transient sources and in brighter steady sources. We are pursuing this work because of the heightened interest in high energy polarimetry, the recognition that some high energy sources may be highly polarized (thus improving our chances of a making useful measurements), and the ready availability of modern computing resources that provide the ability to carry out more comprehensive simulations in support of the analysis. The only significant work done to date with regards to COMPTEL polarimetry was published almost 20 years ago and used a simplified mass model of COMPTEL for simulating the instrument response. Estimates of the minimum detectable polarization (MDP) near 1 MeV included 30% for a two-week observation of the Crab, as low as 10% for bright GRBs, and as low as 10% for bright solar flares. The data analysis performed at the time led to inconclusive results and suggested some unknown systematic error. We contend that a self-consistent analysis will be feasible with high fidelity simulations, simulations that were not easily generated 20 years ago. Our analysis utilizes the latest GEANT4 simulation tools in conjunction with a high-fidelity mass model of the COMPTEL instrument, and updated analysis tools originally developed by the COMPTEL collaboration. Given the nine years of COMPTEL data, we expect that this work will likely add to our understanding of the polarization properties of transient sources, such as GRBs and solar flares, as well as brighter steady sources, such as the Crab and Cyg X-1. Here we present results from simulations of the COMPTEL polarization response and examine prospects for studying GRB polarization.

Compton Polarimetry

In Compton scattering, the incident photon tends to scatter at right angles to the incident electric field vector. For a 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 detected

Polarization Signature



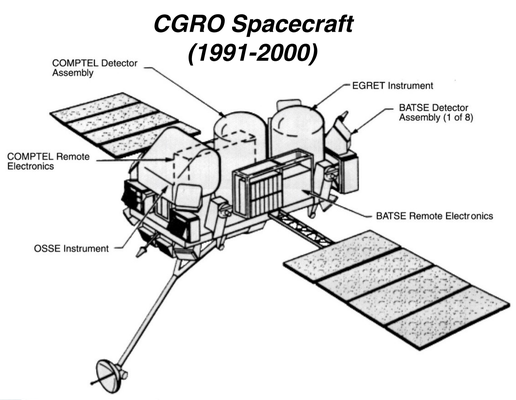
At the 99% confidence level, the MDP associated with an observation is given by,

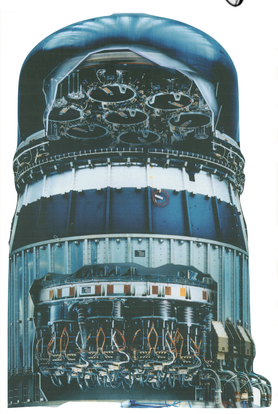
$$MDP = \frac{4.29}{\mu_{100}\, C_{src}} \sqrt{C_{src} + C_{bgd}}$$

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

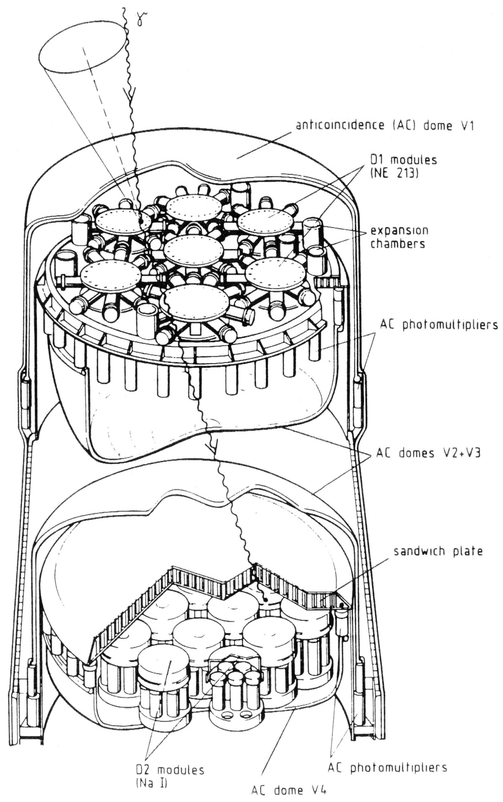
CGRO/COMPTEL

CGRO Spacecraft (1991-2000)



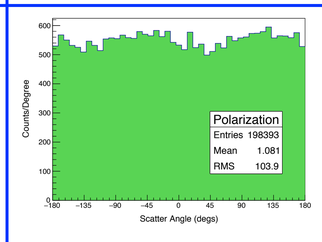
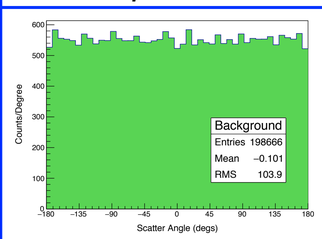
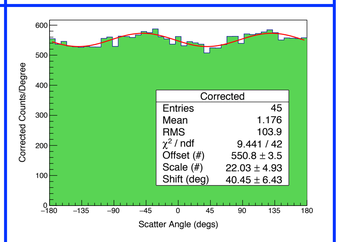
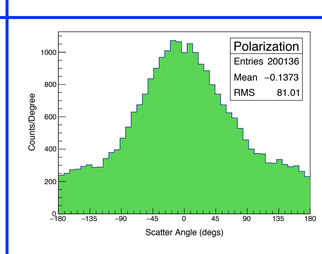
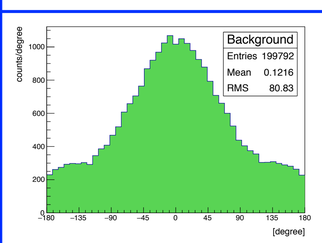
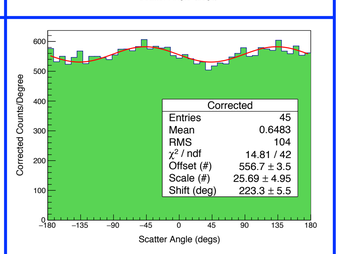
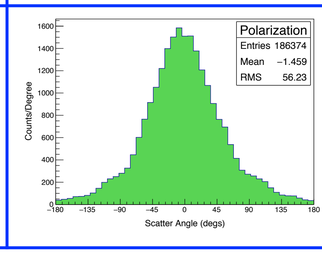
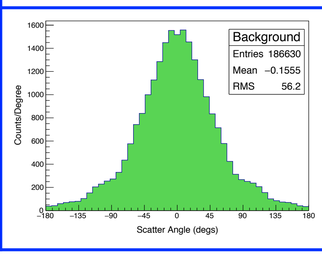
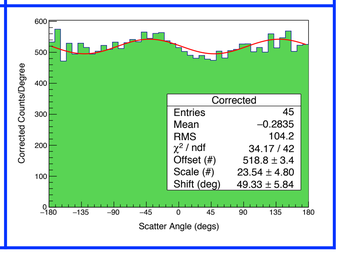


The COMPTEL instrument on the Compton Gamma Ray Observatory (CGRO) was a double-scatter instrument (D1 - liquid scintillator / D2 - NaI(Tl)) capable of imaging 0.75-30 MeV gamma rays. With a D1-D2 separation of 1.5 m, it relied on pulse shape discrimination (PSD), Time-of-Flight (ToF) and scatter angle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

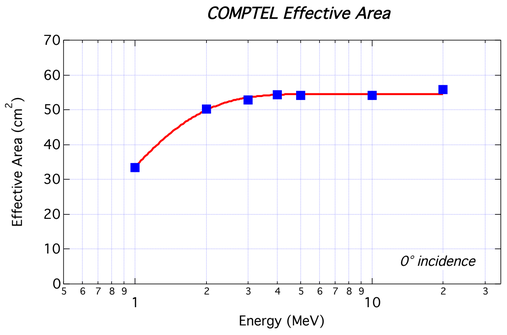


Simulation Results

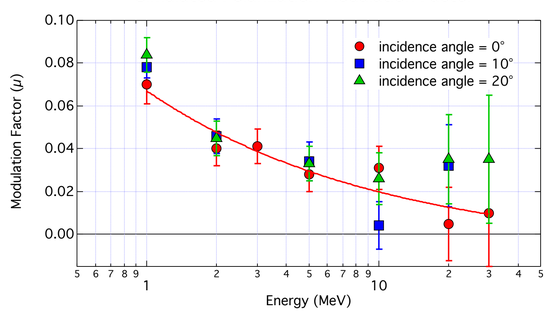
A series of mono-energetic simulations at various incidence angles have been generated using the MEGAlib software package. The azimuthal scatter angle distribution of the polarized simulation must be corrected for geometrical effects using a corresponding unpolarized simulation. Results are shown here for various cases. Geometrical effects are more pronounced for off-axis sources.

	Polarized	***Unpolarized***	***Corrected Result***
2 MeV 0° Incidence			
2 MeV 10° Incidence			
2 MeV 20° Incidence			

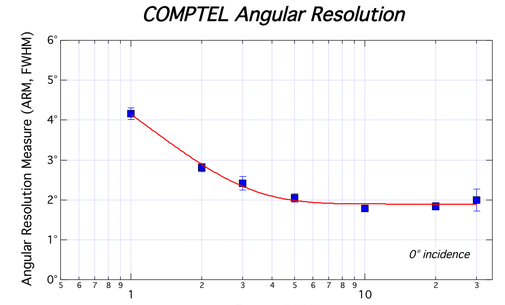
COMPTEL Effective Area



Simulated Polarization Modulation Factor



COMPTEL Angular Resolution

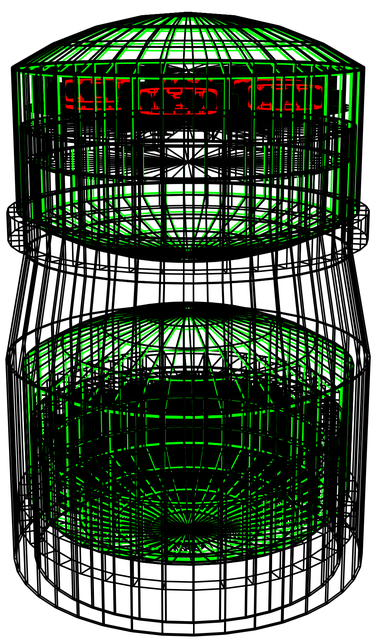


Due to its relatively poor geometry for polarimetry (favoring Compton scatter angles > 90°), COMPTEL's performance as a polarimeter is limited. Hence, the relatively small modulation factor. (Good polarimeters typically have $\mu \approx 0.5$.) However, the relatively low background (resulting in a high S/B) make COMPTEL a potentially useful tool for transient polarimetry.

COMPTEL Simulations

Since the time of the CGRO mission, computer software and computer hardware have dramatically improved. The initial simulations of COMPTEL were conducted using GEANT3, which is no longer under development. Early studies of COMPTEL polarimetry made use of GEANT3, with code modifications to handle the polarization physics (Lei et al. 1996, Astron. Astrophys. Suppl. 120, 695). The GEANT4 simulation software now provides significantly improved handling of the physics, including the polarization physics.

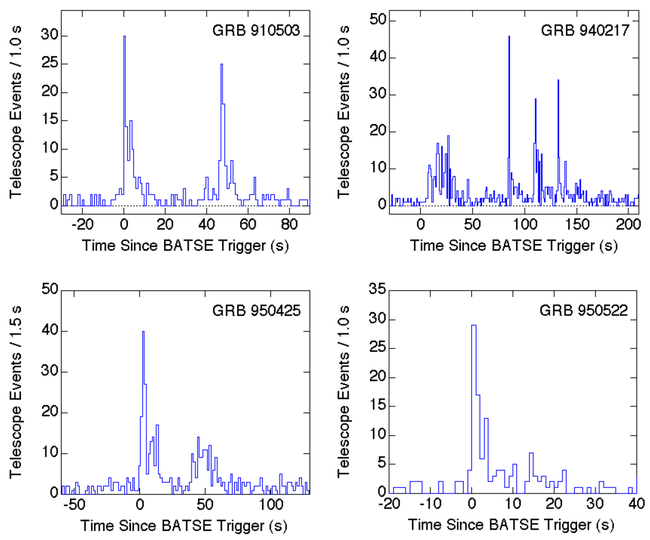
Our work employs the MEGAlib software package (Zoglauer et al. 2006, New Astronomy Reviews. 50, 629). MEGAlib provides a more user friendly interface to the GEANT4 software. One of the advantages of using this package was the ready availability of a detailed COMPTEL mass model (seen here).



COMPTEL GRB Data

During the 9 year mission of CGRO, there were about 60 GRBs detected by COMPTEL within its FoV using the so-called telescope mode data. The S/B is quite high for many GRBs, but the data are sometimes constrained by the limited throughput of the instrument and associated telemetry.

Our plan is to determine the polarization sensitivity (MDP) for every GRB detected by in the COMPTEL telescope mode. In each case we will simulate a GRB at the given location, using the spectrum as measured by COMPTEL. From these simulations, we will determine the modulation factor (μ_{100}) and then use the measured source and background counts (C_{src} and C_{bgd}) to determine the MDP. For those cases where there is significant polarization sensitivity, we will conduct a more detailed analysis to determine the level of polarization or to place constraints on the level of polarization.



Background-subtracted time histories for some of the GRBs detected by COMPTEL within its FoV.

For more information, please contact Mark McConnell - Mark.McConnell@unh.edu

University of New Hampshire