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GRB Polarimetry with POET

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Abstract. POET (Polarimeters for Energetic Transients) represents a concept for a Small Explorer (SMEX) satellite mission, whose principal scientific goal is to understand the structure of GRB sources through sensitive X-ray and γ-ray polarization measurements. The payload consists of two wide field-of-view (FoV) instruments: a Low Energy Polarimeter (LEP) capable of polarization measurements in the energy range from 2-15 keV and a high energy polarimeter (Gamma-Ray Polarimeter Experiment or GRAPE) that would measure polarization in the 60-500 keV energy range. The POET spacecraft provides a zenith-pointed platform for maximizing the exposure to deep space. Spacecraft rotation provides a means of effectively dealing with any residual systematic effects in the polarization response. POET provides sufficient sensitivity and sky coverage to measure statistically significant polarization (for polarization levels in excess of 20%) for ~ 80 GRBs in a two-year mission. High energy polarization data would also be obtained for SGRs, solar flares, pulsars and other sources of astronomical interest.

Keywords: Gamma-ray Bursts, Polarimetry, X-ray, Gamma-ray
PACS: 95.55.Ka

INTRODUCTION

Gamma-ray bursts (GRBs) are the most energetic events in the universe, and have stimulated intense observational and theoretical research. Theoretical models indicate that a refined understanding of the inner structure of GRBs, including the geometry and physical processes close to the central engine, requires the exploitation of high energy X-ray and γ-ray polarimetry. To date, observations have been of limited sensitivity and subject to poorly understood systematics. POlarimeters for Energetic Transients (POET) is a SMEX mission concept that is capable of measuring the high energy polarization of GRBs and other sources of astronomical interest [1]. POET obtains measurements with two different polarimeters (both with wide fields of view) to provide observations over a broad energy range: LEP (Low Energy Polarimeter) covers 2–15 keV and GRAPE (Gamma-RAy Polarimeter Experiment) covers 60–500 keV. In the context of studying GRBs, POET would address the following questions : What is the magnetic structure of the jets? What is the geometric structure of the jets? What is the prompt emission mechanism? Where does the emission originate? For

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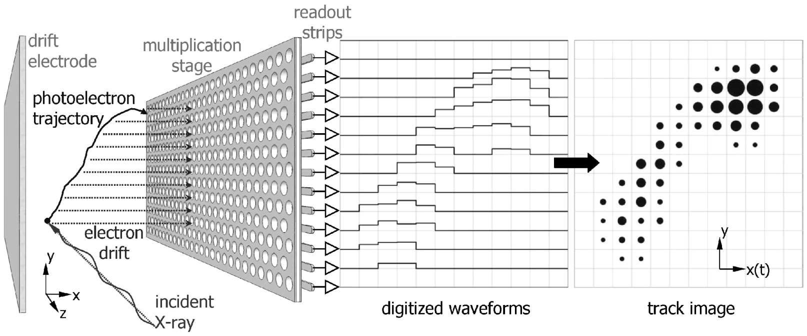


FIGURE 1. The LEP TPC polarimeter uses a simple strip readout and time of arrival to form a pixelized image of a photoelectron track. The TPC polarimeter forms an image by digitizing the signal on each readout strip. The signal from a 6 keV X-ray shows the interaction point, emission angle and end of the photoelectron track. The size of each circle is proportional to the deposited charge in each virtual (132 μm) pixel.

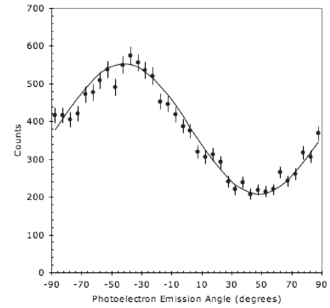


FIGURE 2. A histogram of reconstructed polarized 6.4 keV photoelectron tracks demonstrates a modulation of 45%.

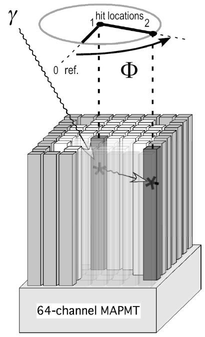
example, by measuring a distribution of GRB polarizations, POET could distinguish between jet models with ordered magnetic fields and those with random magnetic fields, each of which predicts different distributions of polarization values [2, 3].

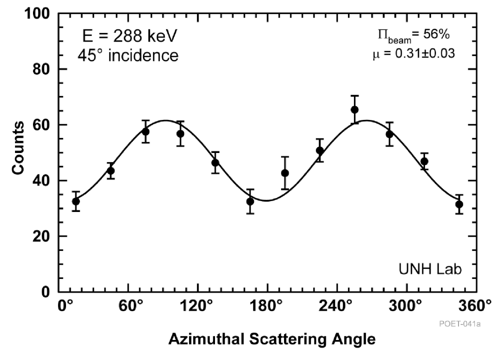
LOW ENERGY POLARIMETER (LEP)

LEP measures the direction of photoelectrons that are ejected after the photoelectric absorption of an incident photon. Photoelectrons tend to be ejected in a direction parallel to the electric field vector of the incident photon. The photoelectron tracks are measured with the innovative operation of a Time Projection Chamber (TPC), a proven technology used in high-energy particle physics. The design provides unmatched polarization sensitivity over the 2–15 keV band-pass [4, 5]. The LEP polarimeter enclosure consists of four dual-readout detector modules each with an isolated gas volume contained by a Be X-ray window. Each detector module contains two $6 \times 12 \times 24$ cm^3 TPCs. Each TPC is comprised of a micropattern proportional counter, consisting of a shared drift electrode and a high-field gas electron multiplier (GEM) positioned 1 mm from a strip readout plane. When an X-ray is absorbed in the gas between the drift electrode and the GEM, a photoelectron is ejected in a preferential direction with a $\cos^2 \phi$ distribution, where ϕ is the azimuthal angle measured from the X-ray polarization vector. As the photoelectron travels through the gas it creates a path of ionization that drifts in a moderate, uniform field to the GEM where an avalanche occurs. Figure 1 illustrates how a track image projected onto the x-y plane is formed by digitizing the charge pulse waveforms. The coordinates are defined by strip location in one dimension, and arrival time multiplied by the drift velocity in the orthogonal dimension. The strips are smaller than the mean free path of the photoelectron and therefore an image of the track can be reconstructed and the initial direction of the photoelectron determined. The magnitude and orientation of the source polarization can be determined from a histogram of the emission angles (Figure 2), where the polarization angle corresponds to the maximum in the modulation pattern. LEP is sensitive to GRB emissions at off-axis angles up to at least 45°.

GAMMA-RAY POLARIMETER EXPERIMENT (GRAPE)

GRAPE [6, 7, 8, 9] is designed to measure polarization from 60-500 keV and to provide spectroscopy over a broad energy range from 15 keV to 1 MeV. It relies on the fact that a Compton scattered photon tends to scatter at right angles to the electric field vector of the incident photon. The GRAPE instrument is composed of 64 independent detector modules arranged in two identical assemblies that provide the associated electronics and the required mechanical and thermal support. Each polarimeter module incorporates an array of optically independent $5 \times 5 \times 50$ mm^3 scintillator elements aligned with and optically coupled to the 8×8 scintillation light sensors of a 64-channel MAPMT. Two types of scintillators are employed. Low-Z plastic scintillator is used as an effective medium for Compton scattering. High-Z inorganic scintillator (Bismuth Germanate, BGO) is used as a calorimeter, for absorbing the full energy of the





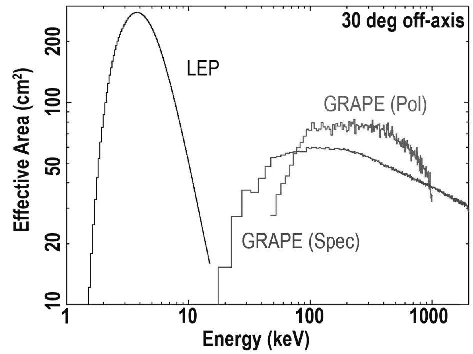


FIGURE 3. GRAPE measures photons that scatter from a plastic element to a BGO element.

FIGURE 4. A histogram of azimuthal scatter angles at a incident photon energy of 288 keV, as measured in the lab. The modulation provides a measure of both the polarization fraction and the polarization angle of the incident radiation.

FIGURE 5. The effective area of the POET instruments for a GRB that is 30° off-axis, illustrating the wide FoV. For GRAPE, the sensitivity to both polarization and spectroscopy are shown.

scattered photon. Valid polarimeter events are those in which a photon Compton scatters in one of the plastic elements and is subsequently absorbed in one of the BGO elements (Figure 3). The azimuthal scatter angle is determined for each valid event by the relative locations of hit scintillator elements. To facilitate spectral measurements over a broader energy range (15 keV–1 MeV), GRAPE also includes 2 independent NaI(Tl) spectrometer modules. The magnitude and orientation of the source polarization can be determined from a histogram of the emission angles (Figure 4), where the polarization angle corresponds to the minimum in the modulation pattern. GRAPE will be sensitive to GRB emissions at off-axis angles up to at least 60°.

THE POET MISSION

The mission concept involves a standard SMEX launch into a circular 600 km orbit. A zenith-pointed spacecraft provides continuous exposure to deep space. Coupled with the wide FoV of both instruments (Figure 5), this maximizes the probability of prompt GRB detection. Spacecraft rotation mitigates the effects of any residual systematic effects in the polarization response. The combined capabilities of LEP and GRAPE will allow us to measure the polarization over a broad energy range (2–500 keV) and also to measure E_p for a large number of GRBs. Simulations based on realistic GRB distributions indicate that both LEP and GRAPE will both be capable of detecting about 40 GRBs per year with a polarization sensitivity of about 20% [1] in their respective energy bands. During a nominal two-year mission, POET would provide statistically significant polarization measurements for $\sim$100 GRBs, providing diagnostic information on the GRB emission mechanism that cannot be obtained from currently-available data [3].

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