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Mark L. McConnell
University of New Hampshire - Main Campus, mark.mcconnell@unh.edu

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Future Prospects for High Energy Polarimetry of Gamma-Ray Bursts

M. L. McConnell

Space Science Center, University of New Hampshire, Durham, NH 03824

Abstract. The recent detection of linear polarization from GRB120206 has piqued the interest of the community in this relatively unexplored avenue of research. Here, we review the current status and prospects for GRB polarimetry at hard X-ray and soft γ-ray energies. After reviewing the most recent results, we present a brief survey of current and planned experiments that are capable of making GRB polarization measurements in the energy range between 30 keV and 30 MeV.

INTRODUCTION

For many years, astronomers have generally been slow to accept the idea that polarimetry could be a useful tool for γ-ray astronomy. This has been both because of the experimental difficulty in making such a measurement and because the levels of polarization were expected to be quite low. Even at lower energies (1–10 keV), where source fluxes are considerably greater, the astronomical community has been slow to embrace the potential value of polarimetry. All this may have changed, however, with the recent detection of γ-ray polarization from GRB021206. This paper provides a brief overview of the experimental status and future prospects of GRB polarimetry at energies above ~ 30 keV.

POLARIMETRY TECHNIQUES

At these energies, there are three physical processes that can be exploited to measure linear polarization. These are: the photoelectric effect, Compton scattering (and its low-energy equivalent, Thomson scattering), and electron-positron pair production. In each case, the byproducts of the initial photon interaction (photoelectron, scattered photon, or electron-positron pair) have angular distributions that go as $\cos^2\theta$. A measurement of the angular distribution of these secondaries provides a measure of not only the direction but also the magnitude of the linear polarization of the incident flux. The phase of the distribution is directly related to the direction of the incident polarization. The amplitude of the modulation in the angular distribution is directly related to the magnitude of the incident polarization. Much of the technical challenge for experimentalists arises from the difficulty in measuring these distributions.

CP727, *Gamma-Ray Bursts: 30 Years of Discovery*, edited by E. E. Fenimore and M. Galassi

RECENT RESULTS FROM RHESSI

Although originally designed as a hard X-ray solar imager, the Ramaty High Energy Solar Spectroscopic Imager [RHESSI; 1] has proven itself to be a valuable polarimeter. Two recent results demonstrate how RHESSI can do polarimetry utilizing two different techniques. Both techniques make use of RHESSI's 9-element Ge spectrometer array [2]. For polarization measurements at low energies (20 – 100 keV), a small block of passive Be (strategically located within the Ge array) is used to scatter photons into the rear segments of adjacent Ge detectors [3]. The polarization of a transient event (such as a solar flare) can be determined by a careful analysis of the counting rates in the Ge detectors that are closest to the Be scattering block. This mode is limited to a small FoV ($\sim 1^\circ$) by the collimation of the Be scattering element through the front of the telescope assembly. At higher energies, scattering events between the Ge detectors within the spectrometer array can be used to measure polarization. The lack of significant amounts of shielding surrounding the Ge array means that this mode is sensitive to events over a much larger area of the sky. In both cases, the rotation of the RHESSI spacecraft (required for imaging with RHESSI's rotation modulation collimators) greatly facilitates effective polarization measurements by reducing systematic uncertainties and providing a more uniform sampling in the azimuthal direction.

A preliminary result from the low energy polarimetry mode has indicated a 20–40 keV polarization of $\sim$ 27% from the solar flare of 23-July-2002 [4]. The high energy polarimetry mode of RHESSI has been dramatically demonstrated with a result from GRB 021206 that indicates polarization at a level of $80(\pm 20)$% in the 150 keV – 2 MeV energy range [5] .

FUTURE PROSPECTS FOR GRB POLARIMETRY

One of the most important requirements of a GRB polarimeter is a large FoV. For most (if not all) other polarization studies, a large FoV can be detrimental in terms of increase background, etc . It may therefore be necessary, especially at lower energies, to consider dedicated GRB polarimeters.

Polarimetry in the 30–300 energy band requires low-Z scattering elements (coupled with high-Z photon absorbers) for achieving the best result. Unfortunately, instruments that operate in this energy band are usually not constructed using position sensitive *low-Z* material, but rather they are designed with *high-Z* materials to maximize photon absorption. Consequently, there is a need in this regime for dedicated instrumentation. One dedicated design, referred to as GRAPE, has been developed [6]. Based on Compton scattering from a low-Z plastic scintillator into a high-Z inorganic scintillator (CsI or $LaBr_3$), an early GRAPE design has been demonstrated in the laboratory (Figure 1a). Its very wide FoV also makes it ideal for studying the polarization of γ-ray bursts. A more recent version of the GRAPE concept (Figure 1b) permits tiled arrays, to serve as either a large area, wide FoV detector or as a detection plane for a coded mask imaging polarimeter.

At higher energies (300 keV – 10 MeV), Compton polarimeters based on the use

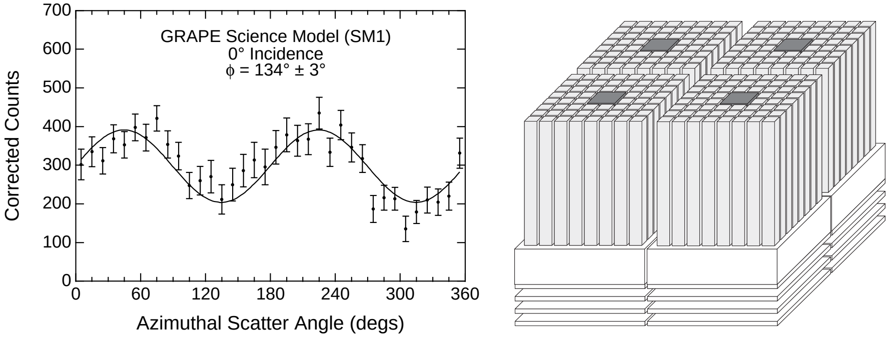

FIGURE 1. a) Laboratory results for a GRAPE prototype at 290 keV. b) A more recent GRAPE concept utilizes a flat-panel MAPMT for readout, shown here in a tiled configuration.

of high-Z scattering elements (coupled with high-Z absorbers) becomes viable. For example, the Ge double scatter approach used by RHESSI becomes most effective at energies above $\sim$ 300 keV. Multiple scatter events in high-Z coded mask detection planes also offer possibilities for polarimetry. The use of a Ge strip detector has been demonstrated in this energy range [7]. An imaging polarimeter based on the use of CdTe is also being developed [8]. In principle, both the IBIS and SPI instruments on INTEGRAL are capable of polarimetry in this energy band [9]. Unfortunately, the lack of rotation makes the polarization analysis of these data difficult and telemetry limitations may limit the capabilities of IBIS. In principle, the CdZnTe detection plane of the Swift BAT instrument [10] might make for a good polarimeter, but the packaging design of the detectors and the design of the signal processing electronics results in a loss of the necessary multiple scatter event information.

This energy range is also the domain of Compton telescopes. A properly configured Compton telescope can serve as a very powerful polarimeter. The one Compton telescope that has flown in orbit, the COMPTEL instrument on CGRO [11], was very limited in its ability to do polarimetry. This was due both to its inability to precisely measure the interaction sites and also to a very poor Compton scattering geometry that required scatter angles $< 90°$. Although some efforts have been made to study polarization with COMPTEL data, no successful results have so far been obtained [12].

Compton telescope designs that are currently being studied offer a much more favorable geometry for polarization measurements. With the elimination of time-of-flight measurements, recent designs are much more compact. This results in significantly improved detection efficiency and a significantly larger FoV. It also provides a far more optimized well-type geometry for Compton polarimetry. The next generation of Compton telescopes will offer substantial improvements in polarization sensitivity. Recent Compton telescope designs can be characterized as those that attempt to track the scattered electron, such as TIGRE [13] and MEGA [14], and those that don't, such as LXeGRIT [15] and NCT [16]. One concept for the Advanced Compton Telescope (ACT) involves a large (1 m^2) stack of Si strip detectors that is used to track multiple Compton intertactions [17].

The potential utility of pair production for measuring polarization at energies above 2 MeV has been recognized for some time [e.g., 18]. Unfortunately, effective polarization measurements with pair production telescopes are limited by the effects of multiple coulomb scattering, which makes it difficult to define the plane of pair production. Efforts to measure polarization both with COS-B [19] and with CGRO/EGRET [20] have been unsuccessful, largely for this reason. It also appears that both GLAST and AGILE will suffer from similar difficulties, making polarization measurements with those instruments unlikely. One recent design for an effective pair production polarimeter involves the use of gas micro-well detectors for tracking the electron-positron pair with minimal scattering [21].

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