

A Modular Hard X-Ray Polarimeter for Solar Flares

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Abstract. We present a modular design for a Compton scatter polarimeter that can be used for studying the polarization of hard X-rays (50-300 keV) from solar flares. A small array of such detectors would be capable of measuring polarization levels of less than 1% in X-class solar flares. Here we shall review the characteristics of this modular design and report on some initial results from a laboratory science model. We will also outline the potential of this design for performing polarization measurements of solar flares.

1. Introduction

An understanding of the acceleration and transport of energetic particles in solar flares requires knowledge about both the angular distribution and the energy distribution of the energetic particles as they interact in the solar material. Most of what we know about solar energetic particles comes from studies of the energy distributions. Relatively little is known about the angular distributions. To date, studies of anisotropies in the energetic electron populations have relied largely on statistical studies of a large sample of solar flare events. Measuring the linear polarization of hard X-rays is a more direct approach to study particle beaming on a flare-by-flare basis. HESSI will be capable of performing polarization measurements at energies below 100 keV, but these data may be somewhat compromised by thermal X-rays (Chanan et al. 1988). Our goal is to perform polarization measurements at higher energies (50–300 keV), where contamination by thermal X-rays becomes negligible.

The basic physical process used to measure linear polarization of hard X-rays (50-300 keV) is Compton scattering. A Compton scatter polarimeter usually consists of two detectors that are used to measure the energies of both the scattered photon and the scattered electron (e.g., Novick 1975; Lei et al. 1997). One detector provides the medium for the Compton interaction to take place. This detector must be designed to maximize the probability of a single Compton interaction with a subsequent escape of the scattered photon. The second detector absorbs the remaining energy of the scattered photon. These measurements also serve to define the scattering geometry. The accuracy with which the scattering geometry can be measured determines the ability to define the modulation pattern and has a direct impact on the polarization sensitivity. The spatial resolution can be improved by using arrays of smaller detector elements, where the element size determines the spatial resolution. Using a large num-

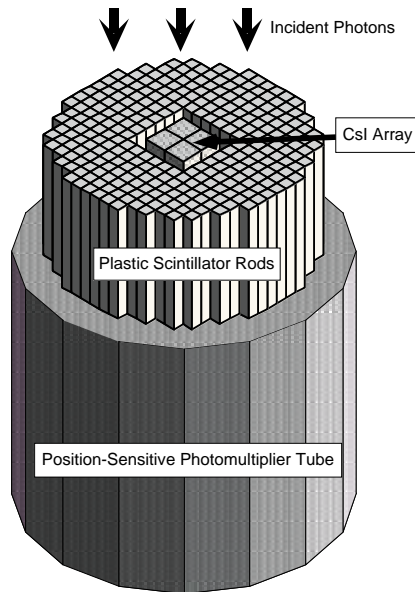


Figure 1. Schematic of the SOLPOL design. (The MAPMT used for readout of the CsI is not shown.)

ber of detection elements, however, typically requires a correspondingly large number of readout channels.

2. A Modular Polarimeter Design

We have developed a compact polarimeter design, incorporating the entire device on the front end of a single 5-inch diameter PSPMT, as shown in Figure 1 (McConnell et al., 1998, 1999a, 1999b). This design, which we call SOLPOL (for SOLAR POLarimeter) incorporates an array of 5 mm square optically-isolated plastic scintillator elements arranged in the form of an annulus having an outside diameter of 10 cm. The PSPMT provides the readout for the plastic array with minimal requirements on the number of electronic channels. The central portion of the annulus is large enough to accommodate a 2×2 array of optically-isolated 1 cm square CsI scintillators. The CsI array is coupled to an independent 4-anode MAPMT for energy measurement and signal timing.

A valid SOLPOL event is one in which the incident photon undergoes a single Compton scatter in one plastic element, with the scattered photon subsequently absorbed in one element of the CsI array. The relatively large mean free path of hard X-ray photons in plastic scintillator (about 6 cm at 100 keV), coupled with the small plastic element size, maximizes the likelihood of a single, well-isolated, Compton scatter in the plastic array.

The measurement of polarization is based on the fact that polarized photons have a tendency to Compton scatter at angles perpendicular to the incident electric field vector. For each event, the azimuthal scattering angle is derived from measurements of the interaction site in the plastic array and in the CsI

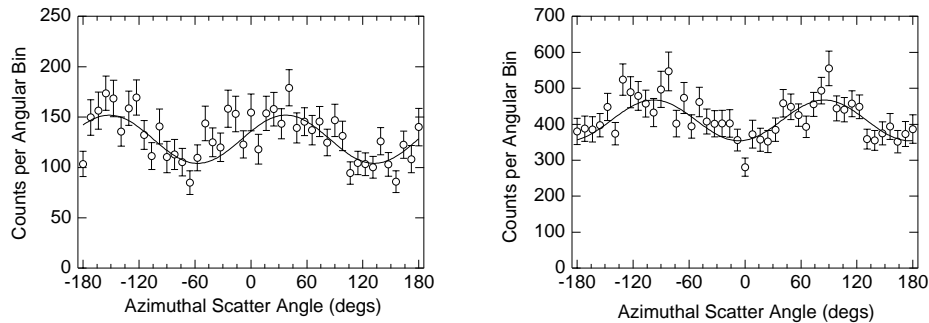


Figure 2. Laboratory results from the SOLPOL science model taken at two different polarization angles, showing a polarization signature.

array. For an unpolarized incident beam, the distribution of azimuthal scattering angles (corrected for detector geometry effects) will be uniform. For a polarized beam, the corresponding distribution will exhibit a $\cos 2\theta$ modulation pattern. The amplitude of the modulation indicates the degree of polarization. The phase of the modulation indicates the plane of polarization. Monte Carlo simulations indicate that one such module, with a scintillator thickness of 12.7 cm, has a peak effective area of almost 3.5 cm^2 at 200 keV and a polarization modulation factor in excess of 50% from 50 keV up to 250 keV.

3. Recent Laboratory Testing

We have performed laboratory testing of a SOLPOL science model (McConnell et al. 1999b). The initial tests made use of a charge division network for the PSPMT (Hamamatsu R3292) that provides a weighted average of the spatial distribution of the measured light output using only four anode signals. Improved spatial resolution in the plastic array could be achieved by more effective use of all, or some fraction, of the 56 (28-x plus 28-y) anode signals from the PSPMT.

A source of polarized photons was generated by Compton scattering photons from a radioactive source (e.g., McConnell et al. 1998). The exact level of polarization of such a scattered photon beam is dependent on both the initial photon energy and the photon scatter angle. The scattering of photons from a ^{137}Cs source, for example, generates 288 keV photons with a polarization fraction of $\sim 55\text{--}60\%$. The use of plastic scintillator as a scattering block permits the electronic tagging of the scattered (polarized) photons which is useful in identifying the interaction of the polarized photons in the polarimeter.

Figure 2 shows the distribution of azimuthal scattering angles derived from data collected with the incident beam at two different angles of polarization offset by $\sim 45^\circ$. Not only does the modulation pattern indicate the presence of a polarization signal (of roughly the expected magnitude), the change in phase between the two sets of data is consistent with the change in polarization angle.

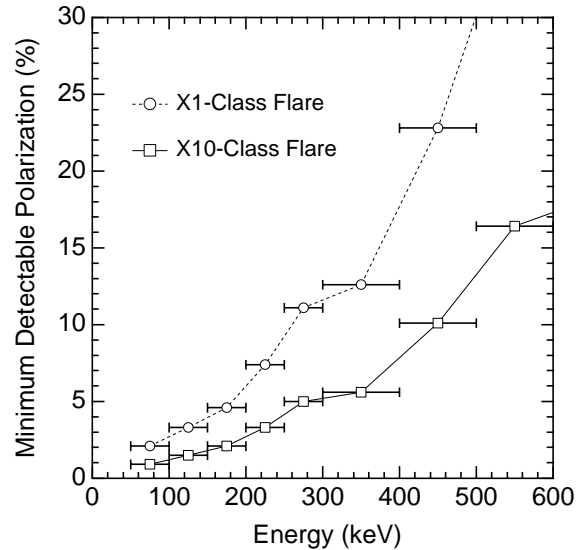


Figure 3. Solar flare polarization sensitivity of a 16-element SOLPOL array.

4. Solar Flare Polarimetry

We anticipate that this design will be used in the context of an array of polarimeter modules. An array of 4 modules, for example, would be capable of measuring sensitivity levels in the integrated 50-300 keV range of less than 1% in all X-class flares. Figure 3 shows the polarization sensitivity for a larger array of 16 SOLPOL-type modules, where the sensitivity levels in this case are given for smaller discrete energy bands. A SOLPOL element or array of elements could also be used with a rotation modulation collimator to achieve arc-second angular resolution. Imaging polarimetry with arc-second spatial resolution would open up the exciting possibility of measuring time-dependent polarization at various locations within the flare region.

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