POLARIMETRIC SENSITIVITY AND PERFORMANCE OF A GERMANIUM STRIP DETECTOR

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ABSTRACT

The germanium strip detector provides high sensitivity to measure gamma-ray polarization of arbitrary direction and magnitude.

Key to the performance are **energy resolution**, ability to cleanly **detect and locate multiple interactions**, and the **full detector volume is used to detect both the primary Compton scattering, and any secondary interactions.**

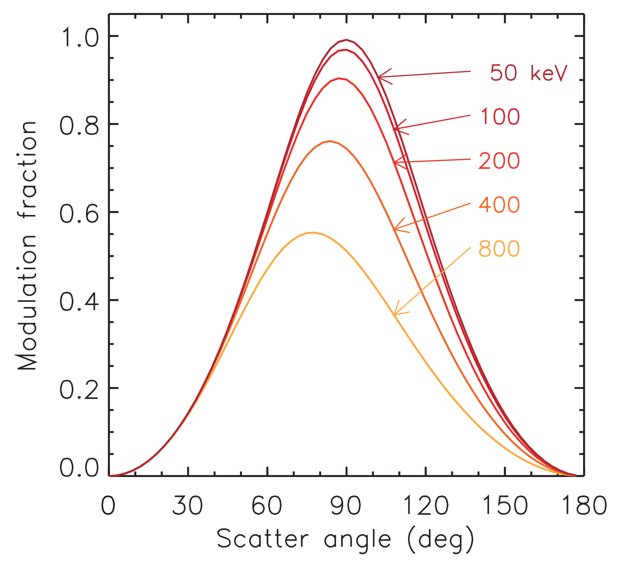
The germanium strip detector has been shown to provide sensitivity approaching the theoretical limits for Compton polarimetry. The principle is to capitalize on the angular dependence of the Compton scattering cross section to polarized gamma rays and measure the distribution of scatter directions within the detector.

Performance measurements of a germanium strip are presented, along with efficiency and sensitivity calculations.

The sensitivity of an astrophysics polarization mission designed to measure polarization in the 70-500 keV energy range is also presented.

Definition of modulation fraction

$$\frac{\sigma(\phi) - \sigma(\phi+90)}{\sigma(\phi) + \sigma(\phi+90)}$$

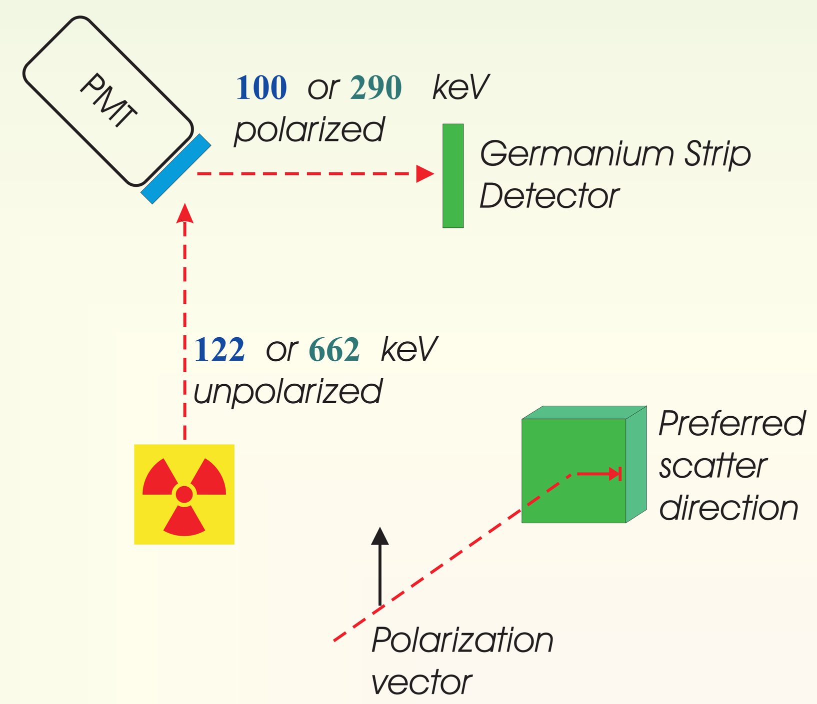


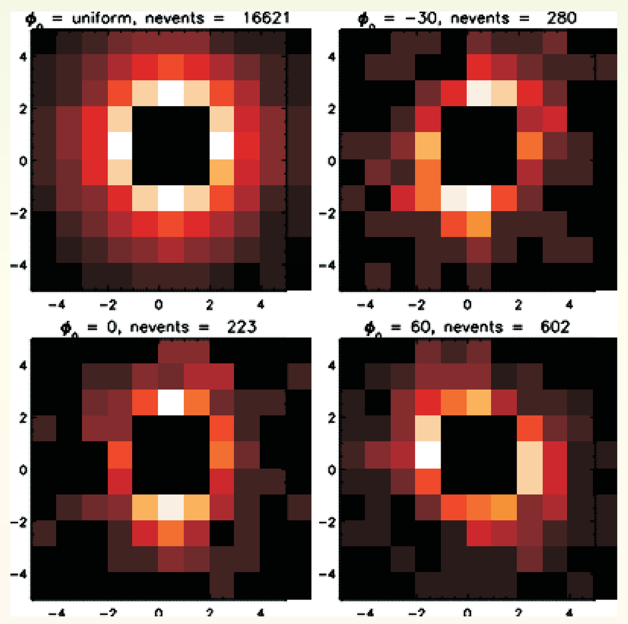
$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_e^2 \beta^2 \left[\beta + \beta^{-1} - 2\sin^2\theta\cos^2\phi\right]$$

Compton scatter formula

where β is the ratio of scattered to incident energy

Experiment

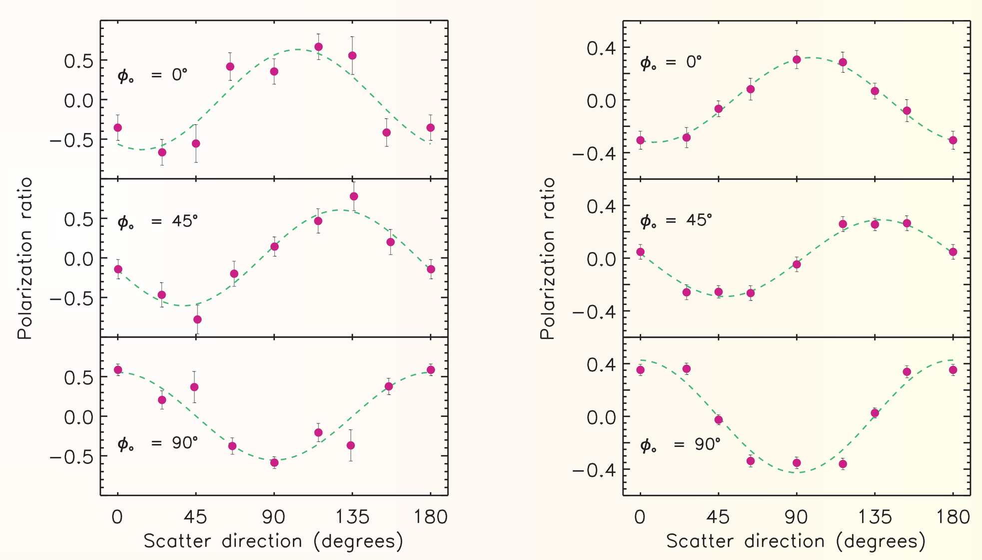




Direction of polarization is clearly visible in each of these four experiments.

Unpolarized
ϕ=-30 deg
ϕ= 0 deg
ϕ= 60 deg

Plot of the sectored rates (derived modulation ratio) for three polarization

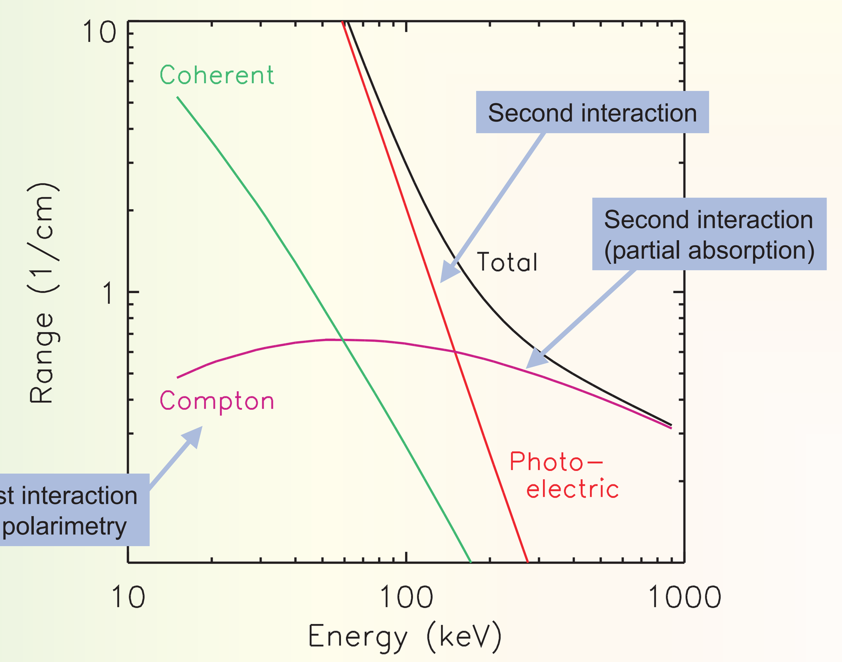


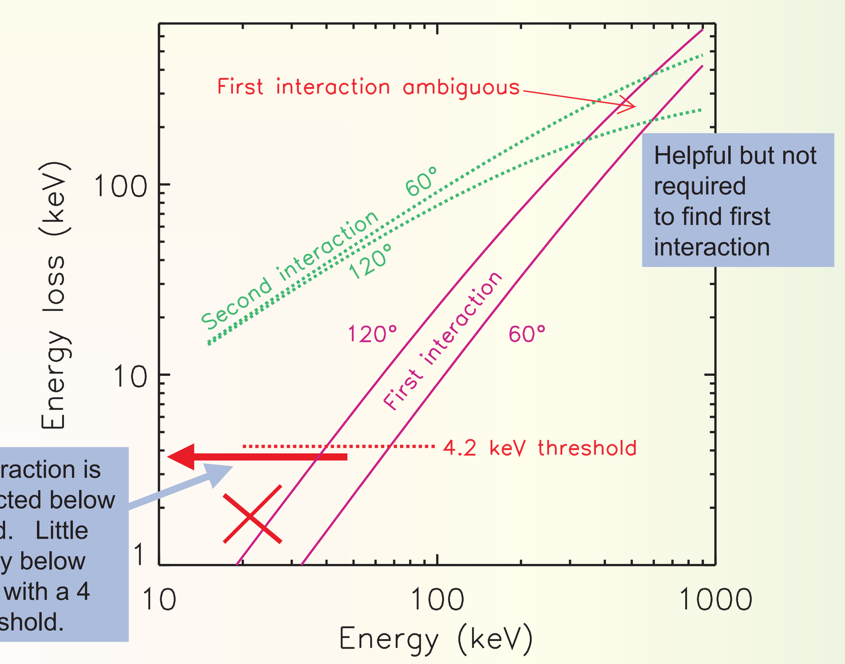
	100	290
Beam Energy (keV)	100	290
Beam Polarization	0.96	0.58
Polarization Ratio Amplitude	0.60	0.35
Meas. Modulation Fraction	0.62	0.60
Calc. Modulation Fraction 60-120° scatter range	0.82	0.71

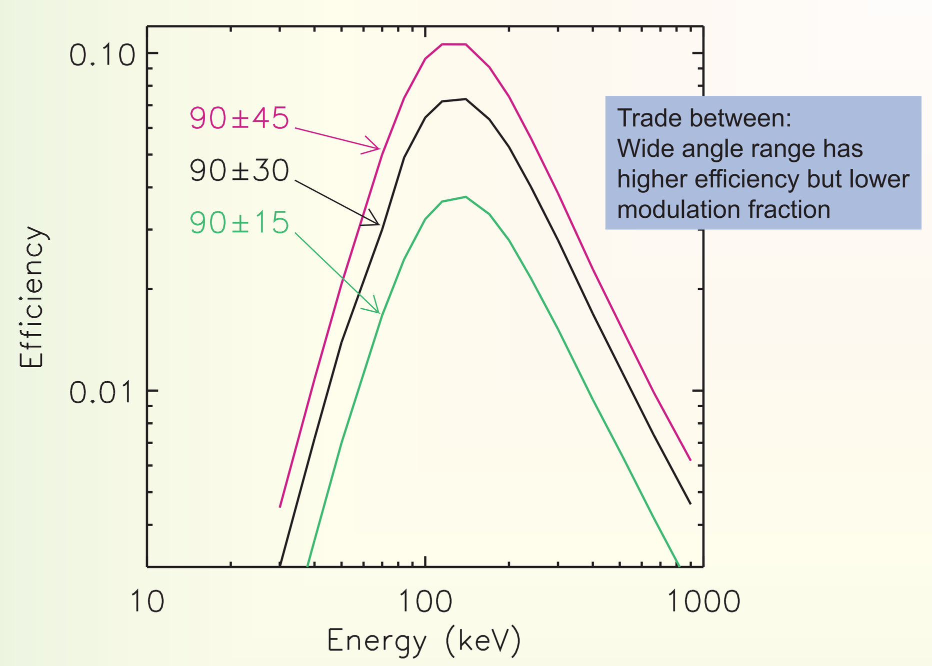
Large portion of the difference is attributable to the geometry factor of nearby pixels adding error in the azimuth angle determination. Finer spatial resolution should close the gap, approaching the theoretical limits.

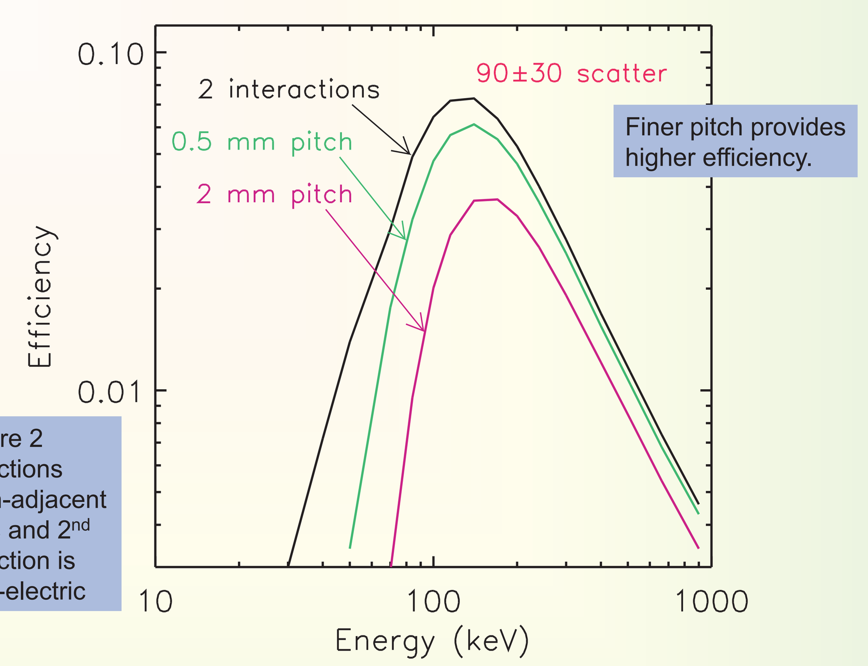
"Gamma ray polarimetry using a position sensitive germanium detector," R.A. Kroeger, W.N. Johnson, J.D. Kurfess, B.F. Philips, NIM A 436 (1999) 165-169.

Polarization Detection Efficiency









Calculationsin lower figures are for a 1 cm thick germanium strip detector

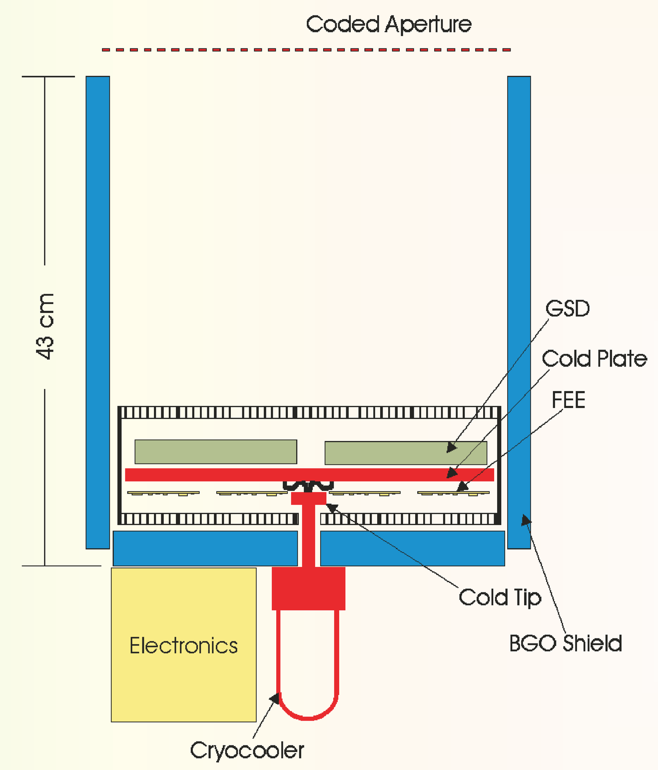
GIPSI
Gamma-ray Instrument for Polarimetry, Spectroscopy and Imaging

The GIPSI instrument will provide exciting polarization observations in the important hard X-ray range. This range is dominated by non-thermal emissions where significant polarization effects are expected. Compton reflection in this range provides near maximum polarization from the source, but also near maximum sensitivity in the polarimeter itself.

The significantly higher flux in the hard X-ray band *vs.* the higher energy gamma-ray band permit GISPI to be a SMEX-class instrument, and provide a wide selection of candidate source observations.

Nominally, GIPSI will also image with a ~60x40 degree field of view, permitting the observation of transients and gamma-ray bursts.

A strawman GIPSI concept has 4 germanium strip detectors on a common cold plate. Each detector measures 8.5 x 14 x 2 cm in active volume, with 1 mm pitch strips providing position resolution.

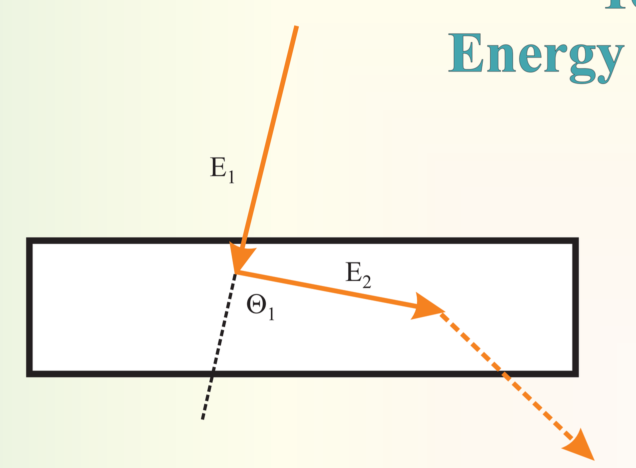


Source	Exposure (weeks)	MSP (%) 70-300 keV
Crab nebula	2	1.4
Crab pulsar	2	5.2
Cen A	2	8.7
Cyg X-1	2	1.6
1A0535+262	2	2.9
GRO J1655-40	2	3.5
NGC 4151	2	14.1
3C 273	2	16.0
X2.5 flare	200 sec	5.3
GRB	~10 sec	~10

	Mass (kg)	Power (W)
Detector subsystem	20	10
Cooling	10	50
Shield	120	5
Electronics	15	25
Aperture	10	
Harness	10	
Mechanical	26	
Heaters		20
TOTAL	211	110

"Gamma-Ray Instrument for Poalrimetry, Spectroscopy and Imaging (GIPSI)," R.A. Kroeger, et al., SPIE Vol 2806, p52, 1996

Total or Partial Energy Loss Determination



Compton kinematic analysis of the positions and energy losses of the two interactions can be applied to **determine if the gamma-ray is totally or partially absorbed** in the detector, and to **reconstruct the full energy of the gamma-ray.**

With only two interactions, the analysis assumes a source location. Thus the scatter angle of the first Compton interaction is determined the positions of the two interactions. The full energy of the gamma ray is given by the equation above. A coded aperture camera or collimated instrument will typically determined flux for a sources or image pixel as if all of the events are from the candidate source direction.

$$E_1 = \frac{L_1 + \left[L_1^2 + \dfrac{4 m_e c^2 L_1}{1 - \cos\Theta_1}\right]^2}{2}$$

where L_1 is the measured energy loss in the first interaction

A single detector also acts as a Compton camera. Those events that are totally absorbed by the detector can be analyszed to produce a wide field-of-view image. The Compton analysis can also be applied to reject background events.

"Depth Measurement in a Germanium Strip Detector," E.A. Wulf, et al, IEEE Trans on Nucl. Sci, Vol 49, No 4, 1876, 2002.