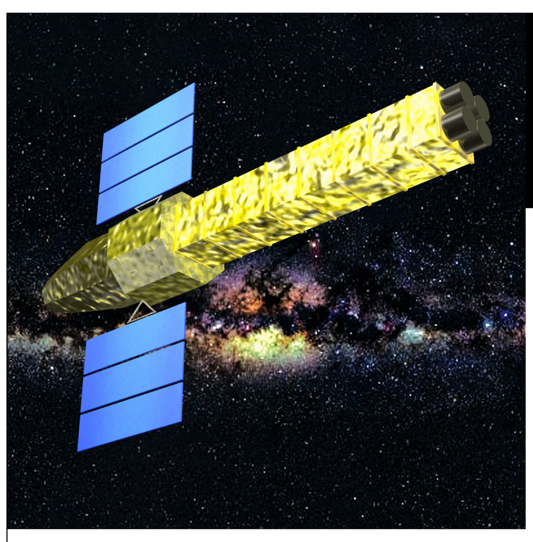

# NeXT/SGD

# EGS4 Monte Carlo Simulation Results for NeXT/SGD Polarization Performance


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## Abstract:

The Soft Gamma-ray Detector (SGD) abroad the New X-ray Telescope (NeXT) proposed at ISAS/JAXA is a narrow field-of-view Compton telescope, which is expected to achieve unprecedented sensitivity in soft gamma-ray band (0.1–1 MeV) by utilizing Compton kinematics. Compton kinematics also enables polarization measurement which will open new windows to study gamma-ray production mechanism in the universe.

CdTe and Si semiconductor technologies are key technologies to realize the SGD. In this presentation, we report EGS4 MC simulation results for expected polarization performance of the SGD.


## Instrument Description:

(a) 4x4 option of SGD (b) An element of SGD

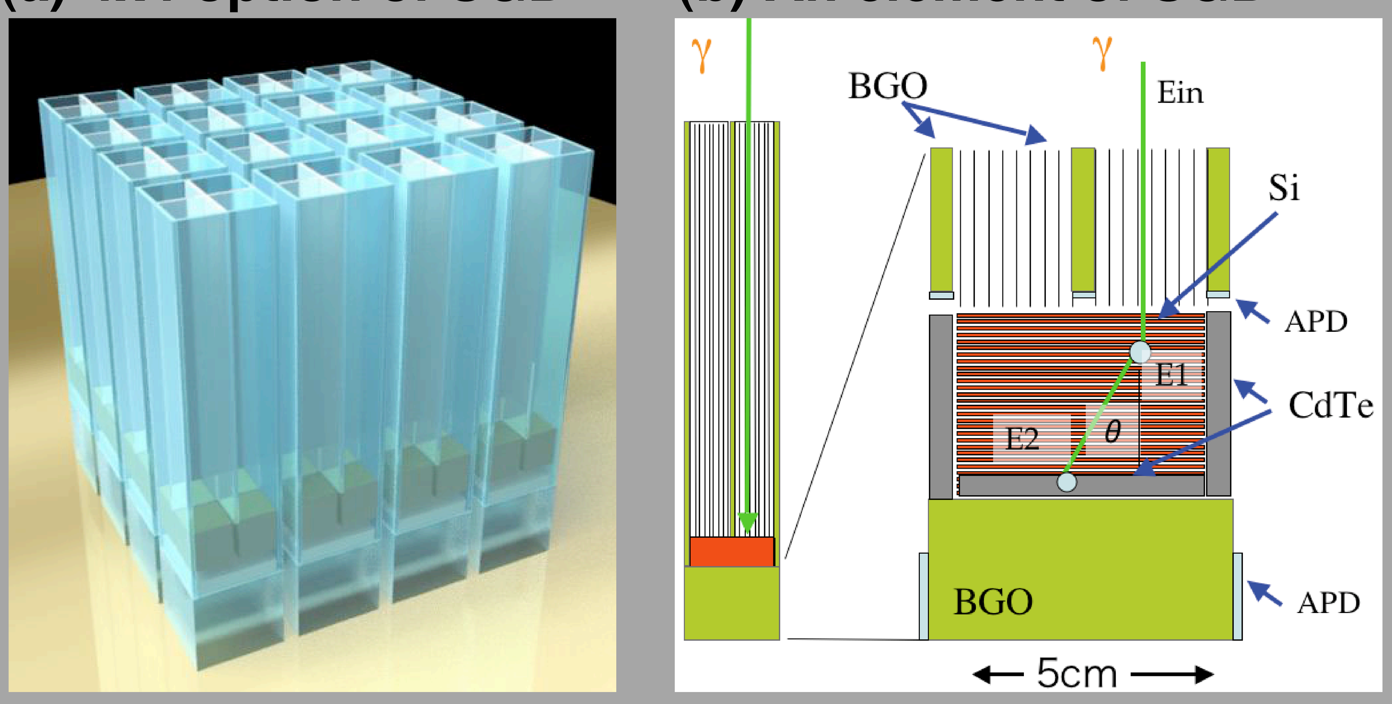


Figure 1: Conceptual view of the NeXT/SGD instrument.

The NeXT/SGD is a hybrid semiconductor gamma-ray detector which consists of silicon and CdTe detectors to detect photons in a wide energy band (0.05–1 MeV); the silicon layers are required to improve the performance at a lower energy band (<0.3 MeV). Figure 1 (a) shows an option with 4 unit x 4-unit. An option with 5 unit x 5 unit is also being considered since it will increase the effective area by 56%.

Figure 1 (b) shows an element of the SGD. It consists of 24 layers of Double-sided Silicon Strips Detectors surrounded by CdTe pixel detectors. The SGD is a Compton telescope with narrow field of view (FOV). The concept of the Compton technique is also illustrated in the figure where E1 is the energy deposited by the recoil electron by a Compton scattering and E2 is that for a photo absorption. The polar angle with respect to the incident photon direction, θ can be related with the observed energies E1 and E2 as

$$\cos\theta = 1 + \frac{m_e c^2}{E1+E2} - \frac{m_e c^2}{E2}$$

θ can also be obtained from the hit positions and FOV providing the over-constraint to facilitate the good background rejection capability.

## Polarization Measurement:

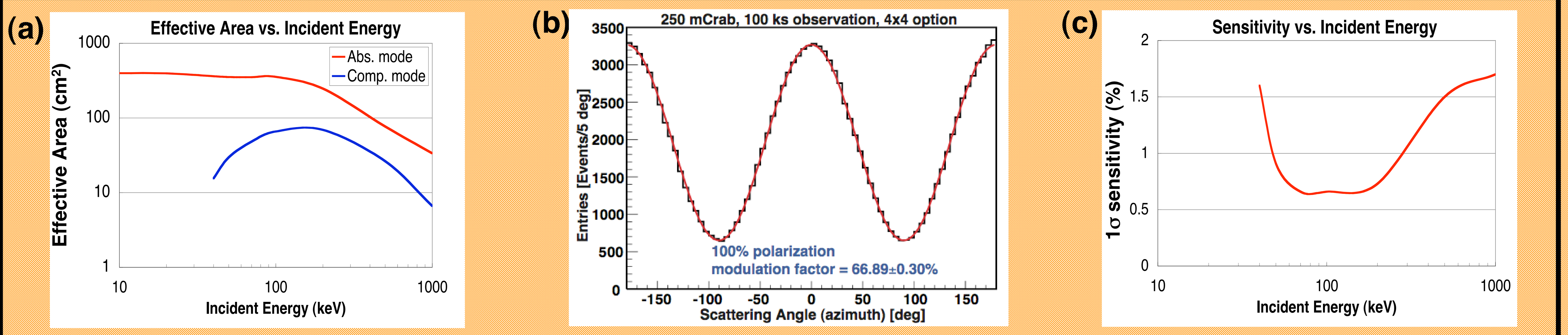


Figure 2: Basic performance of the NeXT/SGD estimated by EGS4.4 MC simulation

Basic performance of the NeXT/SGD is estimated using an EGS4 MC simulation. Energy resolution of 1.5 keV is assumed for Si and CdTe detectors. (The energy resolution of 1.3 keV and 1.6 keV have been achieved for Si and CdTe detectors, respectively.) Figure 2 (a) shows the effective areas for an absorption mode (photo-absorption + Compton) and Compton mode with a 4x4 option as a function the incident photon energy. Figure 2 (b) shows the azimuth angle distribution of the Compton scattering reconstructed in the 4x4 SGD instrument for a 100 ks observation of 250 mCrab source with 100% polarization. A fit to a formula, $AVG \cdot (1 + MF \cdot \sin(2(\phi - \chi)))$, yields the modulation factor (MF) of 66.89% and 1σ polarization sensitivity of 0.45%. Figure 2 (c) shows the 1σ polarization sensitivity for 500k photons as a function of the incident energy. The SGD is most sensitive between 70 and 200 keV for polarization measurements.

## Expected Performance with Cygnus X-1 Observation:

Polarization measurement of radiation from accreting Galactic black holes such as Cygnus X-1 is essential to understand the photon emission mechanism in the hard X-ray band, and to constrain the source geometry. In the soft state, most models assume that hard X-rays originate from single Compton scattering by very hot, relativistic plasma present near the accretion disk. Since the disk is inclined to the line of sight, large polarization is expected. In the hard state, the hard X-ray emission is also due to Compton upscattering of soft photons, but the plasma has lower temperature, and to produce hard X-ray photons, multiple Compton upscatterings are necessary. Since in multiple-order Compton scatterings the information about the polarization of the original photon is lost, the primary hard X-ray flux is unlikely to be polarized. However, the Compton reflection of the primary radiation from the accretion disk might have some degree of polarization, but the total level of polarization most likely will be lower than for Cygnus X-1 in the soft state. In any case, the electrical vector of scattered photons (*i.e.* polarization phase, χ) that are detected by an observer seeing such an inclined disk is most likely predominantly parallel to the plane of the accretion disk. Therefore, the polarization phase also provides important information to understand the hard X-ray emission mechanism.

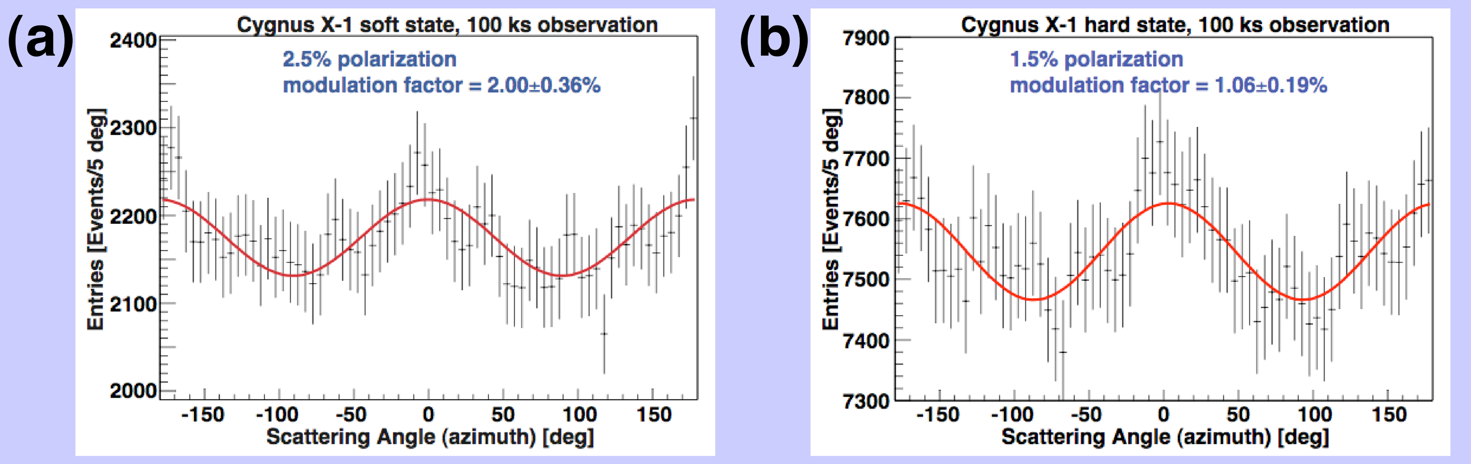


Figure 3: 5σ detection limit for a 100 ks observation of Cygnus X-1.

Figures 3 (a) and (b) shows azimuth Compton scattering angle distribution in the SGD at 5σ detection limit with 100 ks observations of Cygnus X-1. These figures clearly demonstrate that the SGD can detect 2.5% and 1.5% polarization at 5σ in the soft and hard states, respectively.

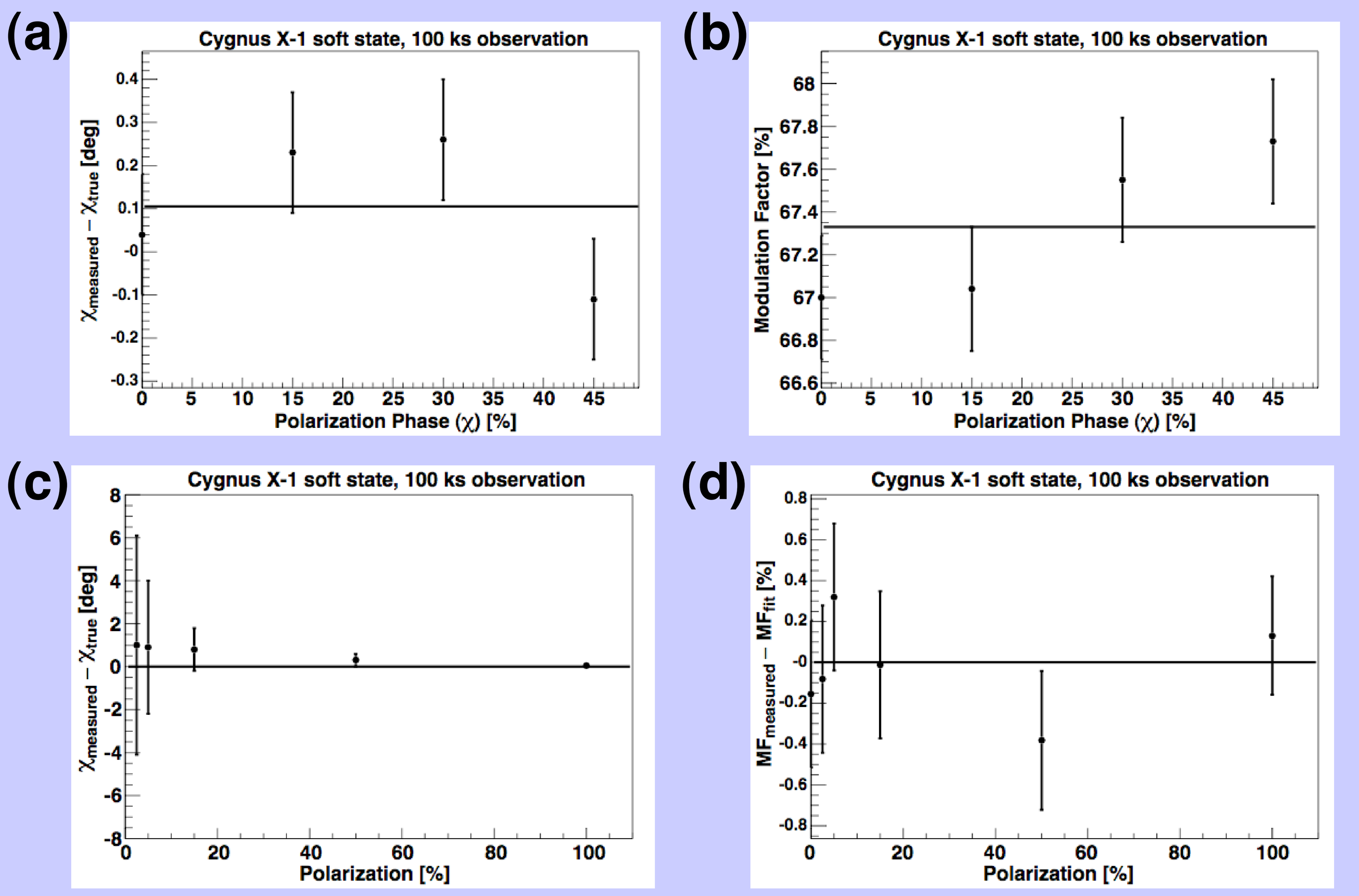


Figure 4: Systematic check of polarization measurement by SGD.

Possible biases in polarization measurements due to detector geometry are also studied. Figures 4 (a) and (b) show the phase bias (observed phase minus true phase) and the modulation factor (MF) as a function of the polarization phase with 100% polarization . It appears the phase bias is negligible while the MF bias could be in the order of 1%. The MF seems to be maximum when the polarization phase is 45°, *i.e.* diagonal to the instrument. Figure 4 (c) shows the phase bias as a function of the polarization of the incident photons. Slight bias can be noticed at low polarization, however it is much smaller than the statistical error. It also shows that the error of the phase measurement is 5° at the 5σ detection limit, *i.e.* 2.5% polarization. Figure 4 (d) shows the difference between the observed MF and that from the linear fit of MF vs polarization. It indicates that the MF linearity is better than 1%.