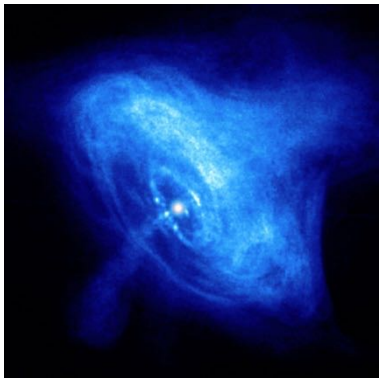
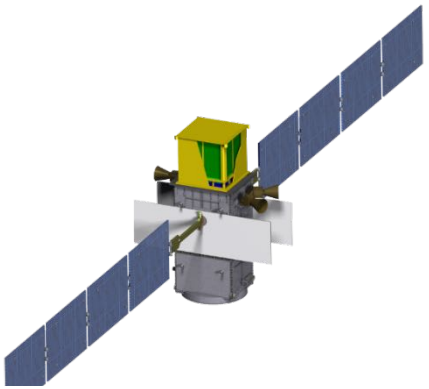
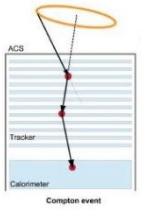
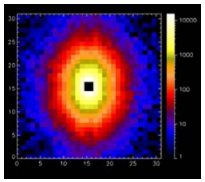
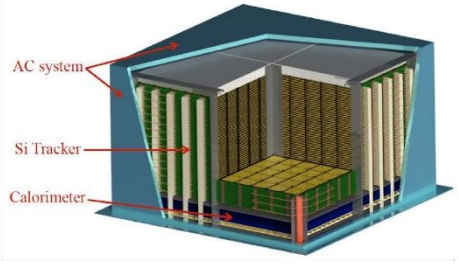
eASTROGAM Compton Polarization











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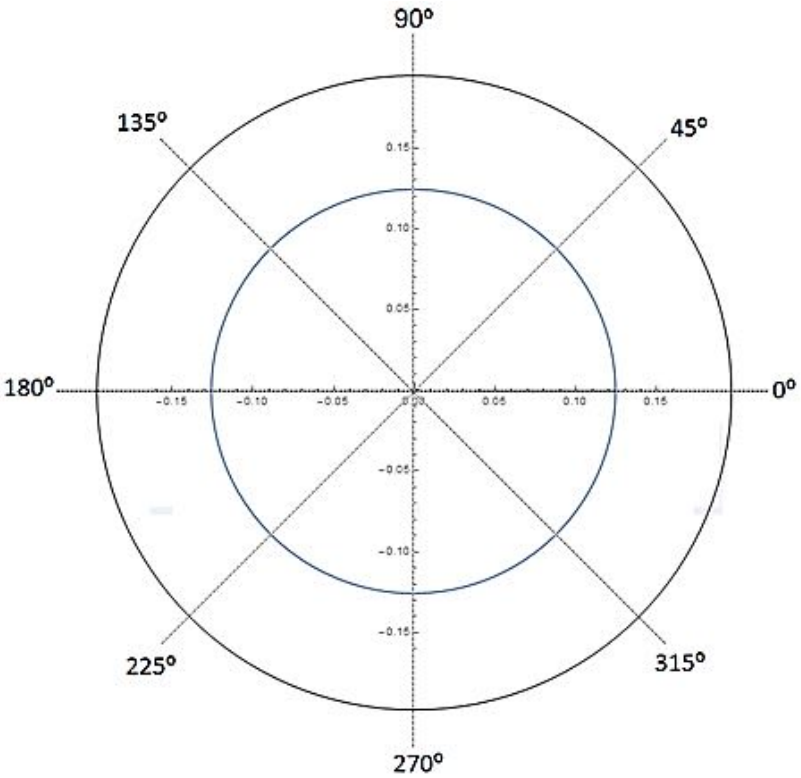
Polarimetry in high-energy astrophysics

- To date in astrophysics, γ-rays have been studied mainly through spectral and timing variability analysis.
- Polarimetry analysis: two extra observational parameters (angle and degree of linear polarization): allows for better distinction between different astrophysical models.
- Polarized γ-rays are produced in a large diversity of emission sites: Sun, compact binaries, pulsars, interstellar medium, AGNs, GRBs, galactic BHs.
- Both Compton scattering and pair creation partially preserve the linear polarization information of incident photons.
- Polarimetric measurements so far: INTEGRAL with IBIS and SPI (not optimized). Sources: Crab, GRBs, Vela Pulsar;

Compton Polarimetry

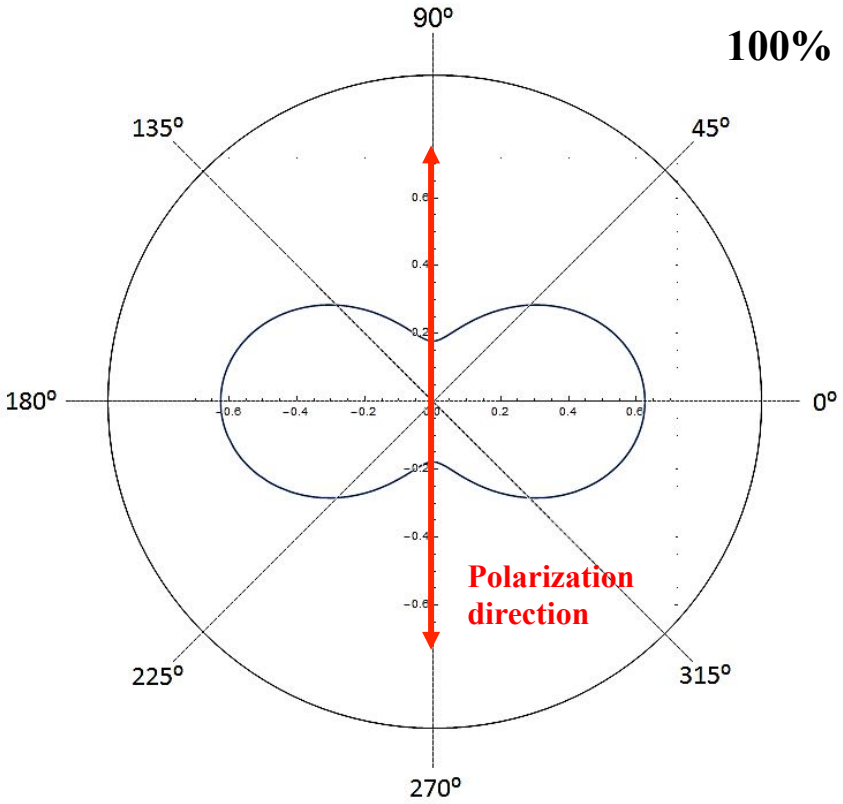
Unpolarized Beam

$$\frac{d\sigma_{KN,U}}{d\Omega} = \frac{1}{2} r_0^2 \varepsilon^2 [\varepsilon + \varepsilon^{-1} - \sin^2\theta]$$



Polarized Beam

$$\frac{d\sigma_{KN,P}}{d\Omega} = \frac{1}{2} r_0^2 \varepsilon^2 [\varepsilon + \varepsilon^{-1} - 2\sin^2\theta \cos^2\eta]$$



Compton Polarimetry

Polarization modulation factor

Klein-Nishina cross-section for linearly polarized photons:

$$\frac{d\sigma}{d\Omega} = \frac{r_0^2}{2}\left(\frac{E'}{E}\right)^2\left[\frac{E'}{E} + \frac{E}{E'} - 2\sin^2\theta\cos^2\varphi\right]$$

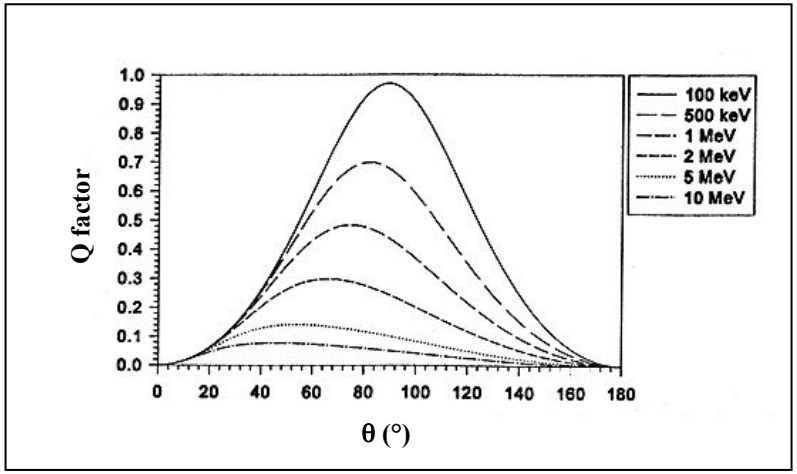
$$Q = \frac{N_\perp - N_\parallel}{N_\perp + N_\parallel} \qquad Q = \frac{d\sigma(\varphi = 90) - d\sigma(\varphi = 0)}{d\sigma(\varphi = 90) + d\sigma(\varphi = 0)}$$

$$Q = \frac{\sin^2\theta}{\frac{E'}{E} + \frac{E}{E'} - \sin^2\theta}$$

Minimum Detectable Polarization 3σ

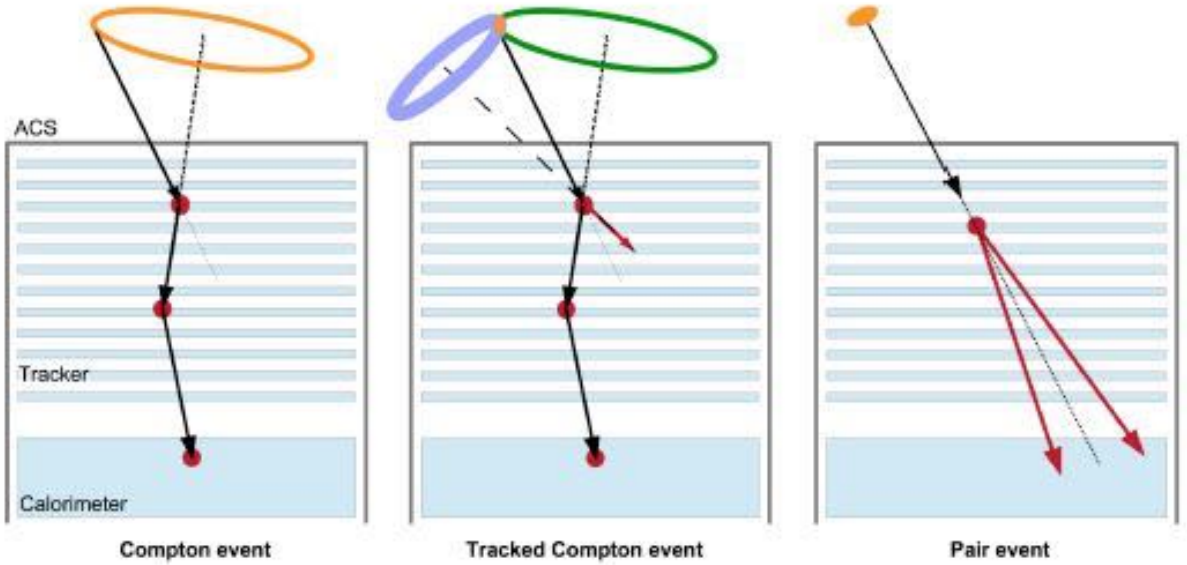
$$MDP = \frac{4.29}{A.\varepsilon.\phi_s.Q_{100}}\sqrt{\frac{A.\varepsilon.(\phi_s + \phi_B)}{T}}$$

φ_s – source flux
φ_B – background flux
Q_{100} – polarimetric modulation factor for 100% radiation
ε – detector double event efficiency
A – detector area
T – observation time



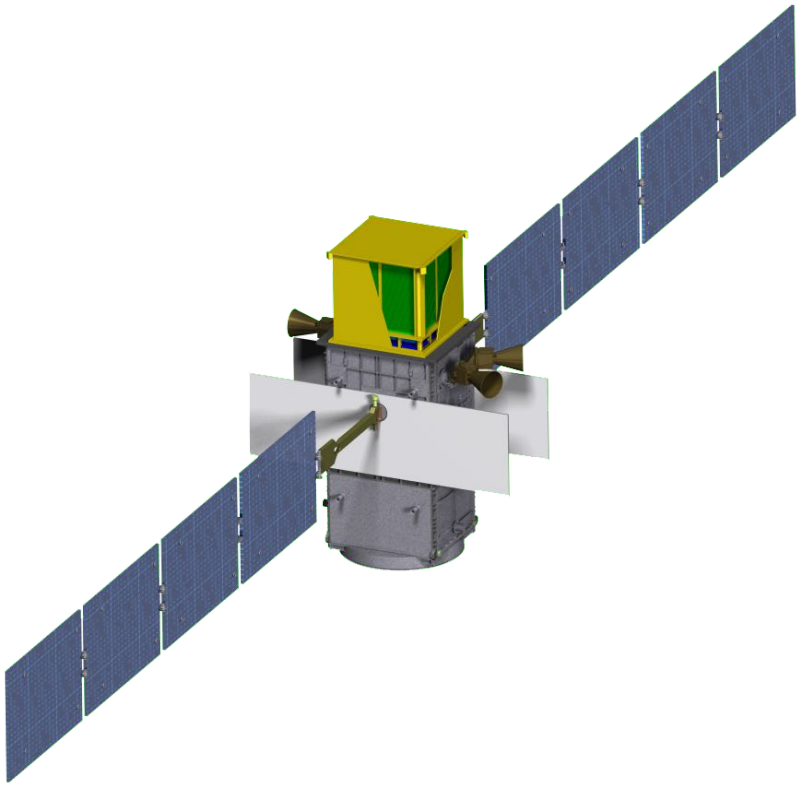
Compton Polarimetry

- A pixel/voxel detector is a good candidate to perform measurements on all the standard observable parameters (spectroscopy, timing, imaging).
- Efficient use of the detector: each unit acts both as a scattering and as detection elements.

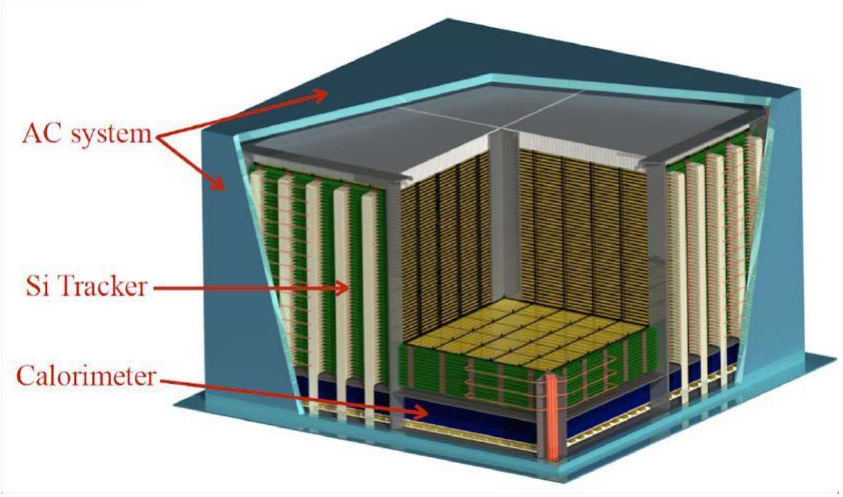


e-ASTROGAM telescope proposal

Parameter	Value
Energy bands:	0.3 MeV – 3 GeV (Gamma-ray imager: Tracker + Calorimeter) 30 keV – 200 MeV (Calorimeter burst search)



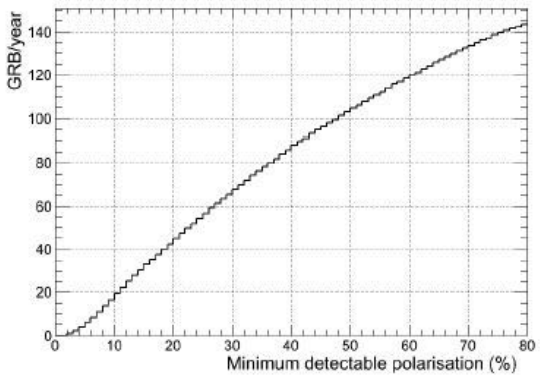
Size 110x110x80 cm, mass 820 kg.
Three detection system: **silicon tracker** where cosmic γ-rays undergo Compton scattering or pair conversion; **calorimeter** to absorb and measure the energy of secondary particles, and **anticoincidence system** to veto the prompt-reaction background induced by charged particles.



e-ASTROGAM Polarimetric Potential

- The addition of polarimetric information will be crucial for a variety of investigations, including accreting black-hole (BH) systems, magnetic field structures in jets, and the emission mechanisms of GRBs. Polarization will provide definitive insight into the presence of hadrons in extragalactic jets and the origin of ultrahigh-energy cosmic rays

- Bright GRBs polarization in the MeV range, Tracker down to (150-200) keV, also for polarization measurements. About 42 GRBs/year 20% polarized and about 16 GRBs/ year 10% polarized. 50 pulsars, magnetars, and black hole systems in the Galaxy.



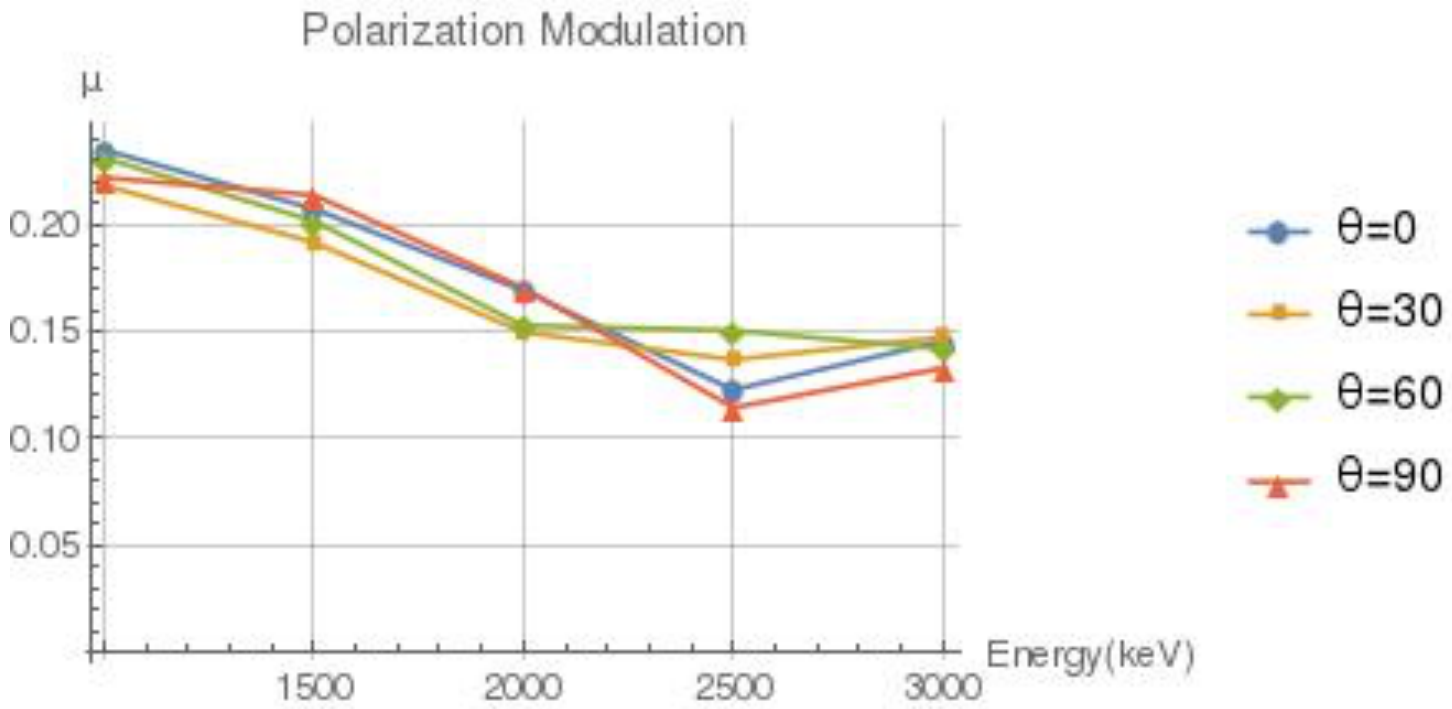
- e-ASTROGAM will also be able to study the polarimetric properties of more than 50 pulsars, magnetars, and black hole systems in the Galaxy.

e-ASTROGAM Polarization Requirements

- MDP < 20%
  - 99% confidence level
  - 10 mCrab source
  - 0.3-2 MeV
  - T_{obs} = 1 year

- Detection of a polarization level ≥ 20% in more than 20 GRBs per year

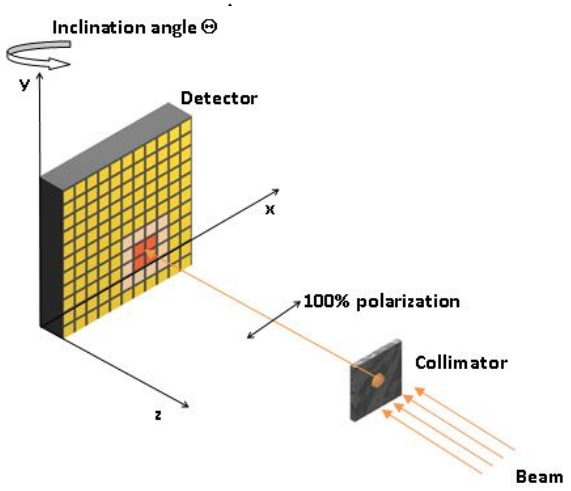
eASTROGAM Mass Model Polarization Modulation

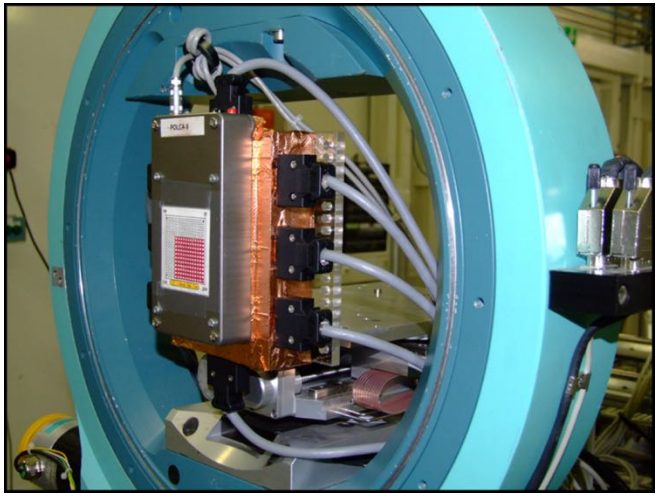


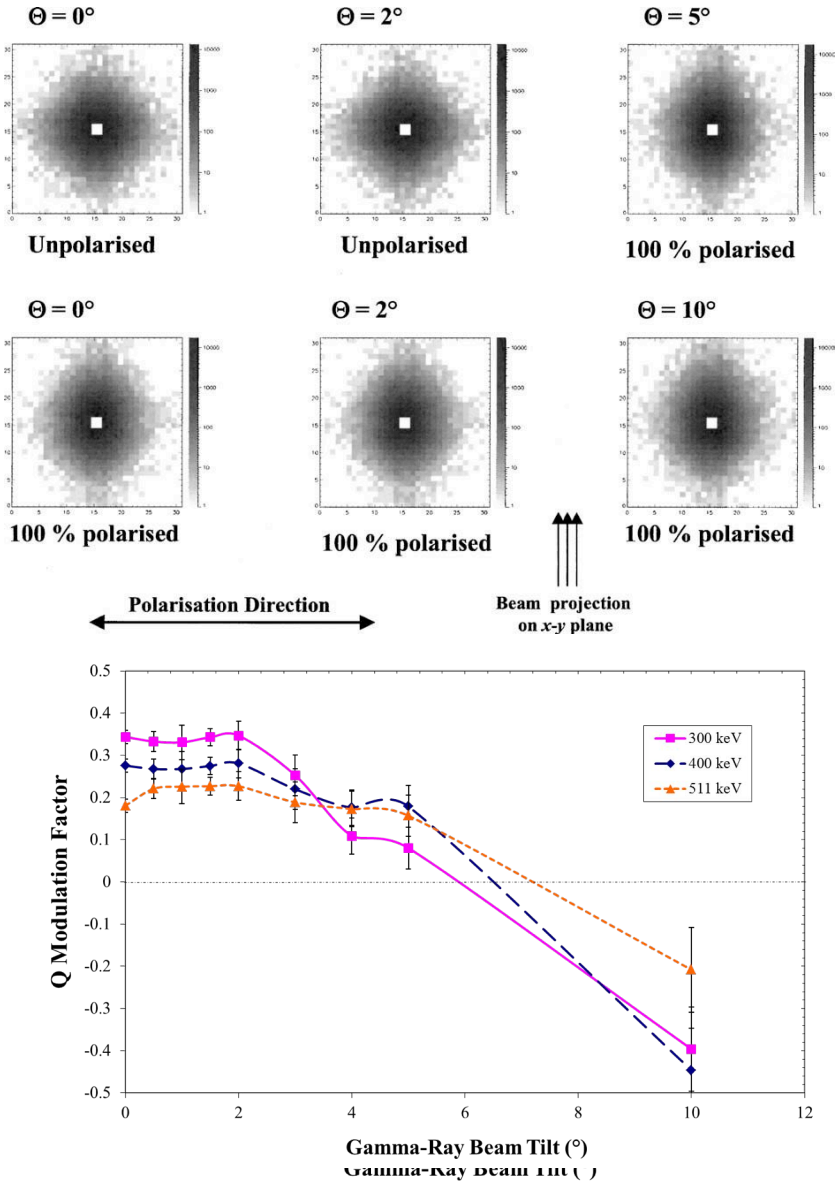
Source:
Monochromatic; far-field; variable angle of incidence θ

Photonic background:
cosmic and atmospheric γ-ray background; galactic center annihilation line

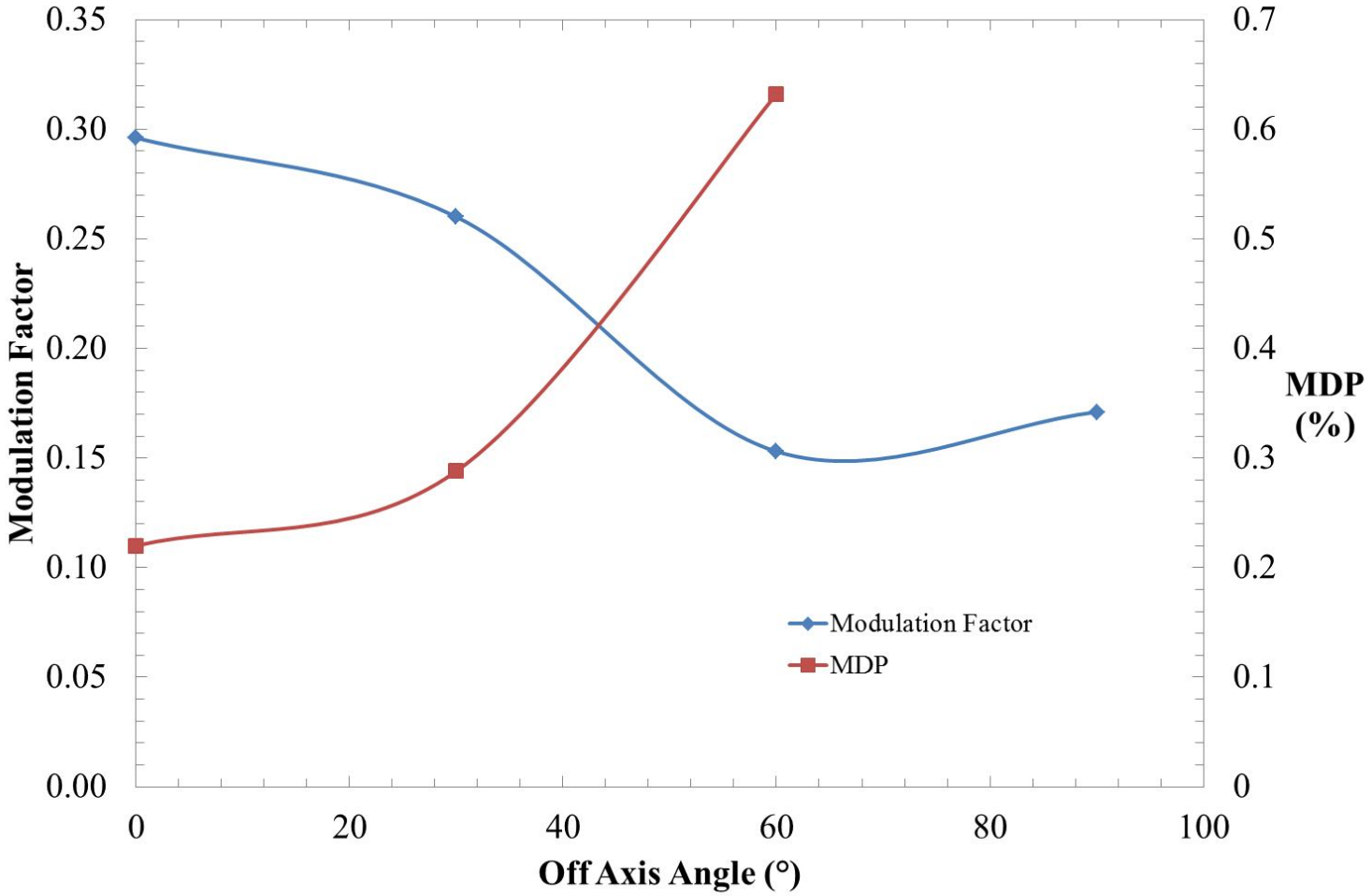
Off-axis Effects on Polarimetry







Crab Simulation (800-5000 keV)



Comparison with requirements and other simulations

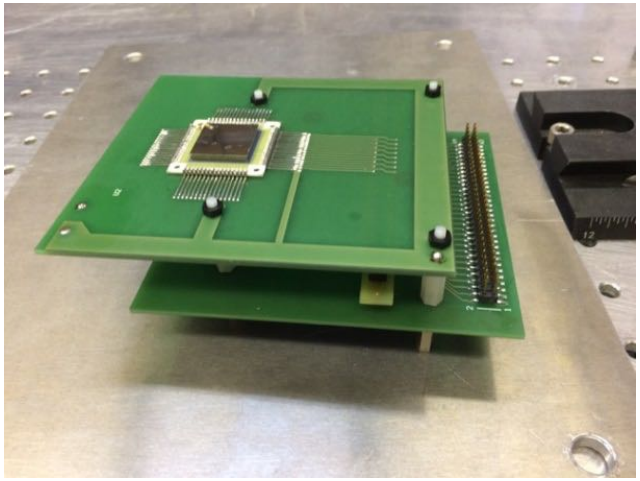
MDP Requirements	EASTROGAM paper MDP	Simulated MDP
< 20 %	0.70% Crab, 0.2-2.0 MeV, 1 Ms obs. time	0.3 -0.7 % Crab, 0.8-5.0 MeV, 1Ms obs. time
10 mCrab, 0.3-2.0 MeV, 1 year obs. time	10% 10 mCrab, 0.2-2.0 MeV, 1 Ms obs.	0.7-1.5 % Crab, 0.8-5.0 MeV, 1Ms obs. time

- Simulate and tune requirements and publications conditions for eASTROGAM;
- Study exhaustively off-axis, all-sky observations on polarimetry;
- Simulations with and without calorimeter deliver slight different results;
- Study other geometries and possibly material solutions.

Experimental Polarimetry

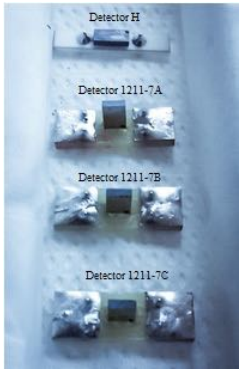
ESRF - Dual Plane Polarimeter

2 planar CdTe ACRORAD
18x18 mm², 2 mm thick
8x8 pixels with 2 mm pitch



Proton radiation damage and activation

EURORAD CdTe detectors tested at ICNAS, Coimbra, cyclotron proton beamline.



Conclusions and Future Steps

- e-ASTROGAM mass model polarization response simulation showed modulation factors (~0.2 to 0.4) and MDP levels (0.3 to 1.5%) in fairly in accordance with eASTROGAM requirements and published estimations;

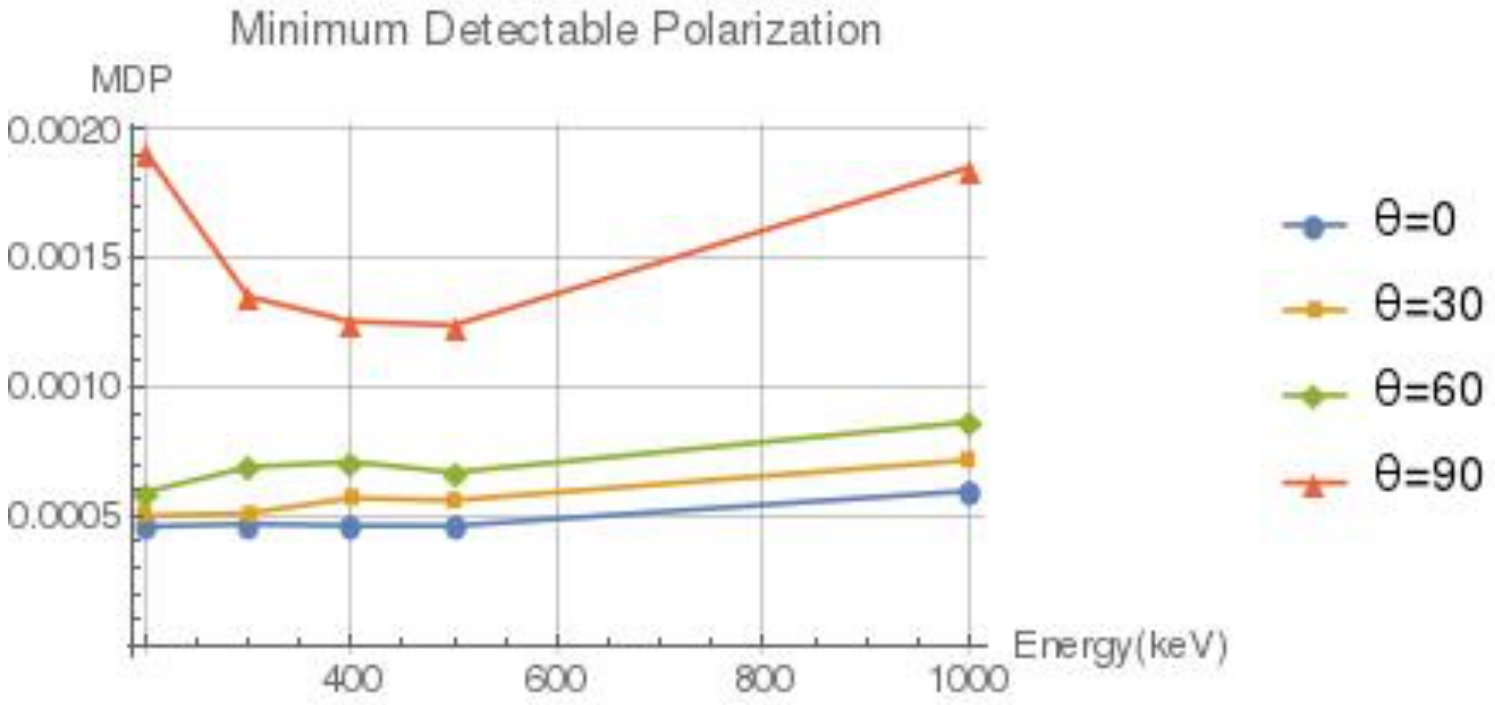
- Improve and tune polarization simulations: MEGAlib internal parameters (general and for polarimetry) explore off-axis and all sky, polarization orientation and level, background and source types (GRBs, other strong gamma emitters), etc.

- Simulate mass model alternative geometric, design and possibly material solutions

- Assess pros and cons of polarimetric optimal design with other eASTROGAM scientific objectives

- Always compare with available experimental measurements.

Minimum detectable polarization (200-1000 keV)

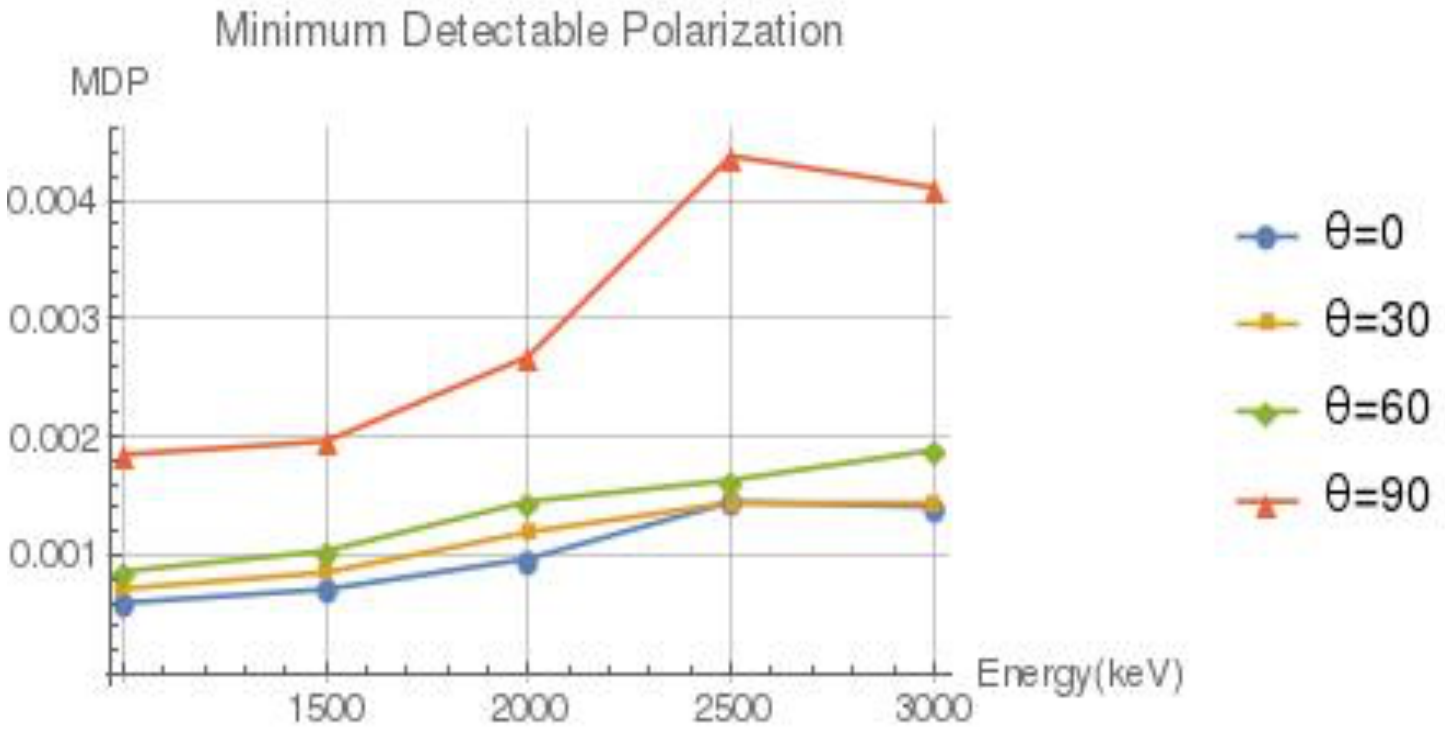


Obs. Time:10^6 s, 99% confidence level

Source: monochromatic, far-field, variable angle of incidence θ

Photonic background: includes cosmic and atmospheric γ-ray background, and the galactic center annihilation line

Minimum detectable polarization (1-3 MeV)



Simulation results for Crab, 800-5000 keV:

θ=0 − MDP (1Ms) = 0.220
θ=30 − MDP (1Ms) = 0.288
θ=60 − MDP (1Ms) = 0.632

Simulation results for Crab, 800-5000 keV:

θ=0 − μ = 0.296
θ=30 − μ = 0.260
θ=60 − μ= 0.153
θ=90 − μ= 0.171