GRB Simulations for e-ASTROGAM

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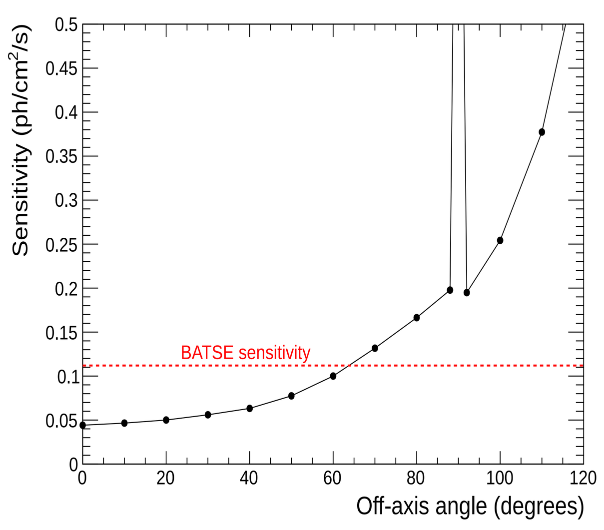
Simulation framework

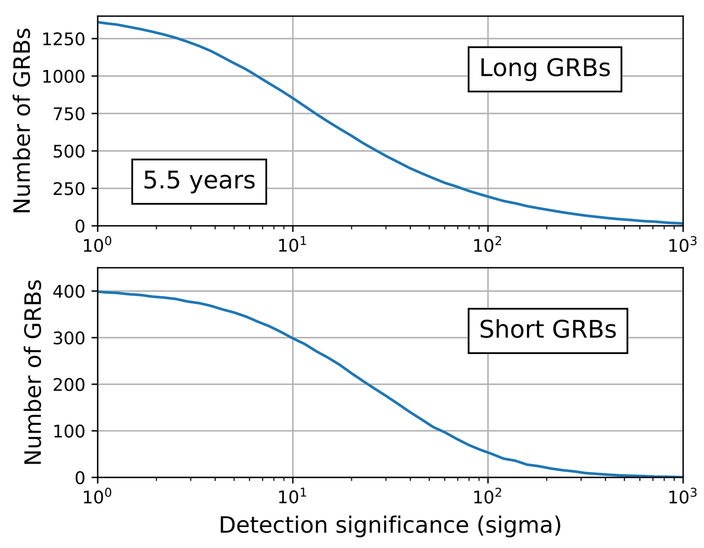
e-ASTROGAM is a high-energy gamma-ray satellite experiment proposed to ESA for a launch slot in ∼2029. It combines a silicon tracker with a CsI calorimeter to function as a Compton and pair-production telescope.

Simulations are performed using the MEGAlib [1] software based on the Geant4 toolkit and a detailed mass model of the telescope. GRBs are simulated as far field point source with a Band function spectrum ($\alpha = -1.1, \beta = -2.3, E_{\rm peak} = 0.3$ MeV in all cases, unless otherwise stated). Two background components are considered: the diffuse cosmic gamma-ray background and atmospheric gamma-rays. The telescope is assumed to be zenith-pointing.

GRB sensitivity

Compton events in the 0.2 – 2 MeV energy range have been used to characterise the sensitivity of e-ASTROGAM to GRBs. A GRB is considered detected if the peak rate of events consistent with the GRB location ($\Delta R < 5°$) exceeds the average background by 6σ. The peak flux is calculated on a 1 s timescale in the energy range above. The sharp drop in sensitivity at an off-axis angle of 90° is caused by the reduced effective area when gamma-rays pass through the tracker in parallel to the silicon plates.





The GRB detection rate has been estimated using the peak fluxes and spectra of BATSE GRBs. Assuming random distribution of the GRBs in the upper hemisphere ($\theta < 90°$), e-ASTROGAM can detect more than half of the BATSE GRBs with a significance of 10 sigma or more. This gives an expected detection rate of ∼200 GRB/year.

GRB polarisation

The determination of linear polarisation in GRB prompt emission is an important diagnostic with the potential to significantly constrain emission mechanisms, magnetic compositions and geometric structures of GRB jets. In the case of synchrotron emission with ordered magnetic fields, the observed GRB polarisation is expected to vary little with viewing angle. However, in the case of synchrotron emission in random magnetic fields and Compton-drag models, the observed polarisation is significant only near the edge of the jet [6]. These types of models can therefore be distinguished with a sample of the size and quality that e-ASTROGAM will collect over its nominal lifetime [7].

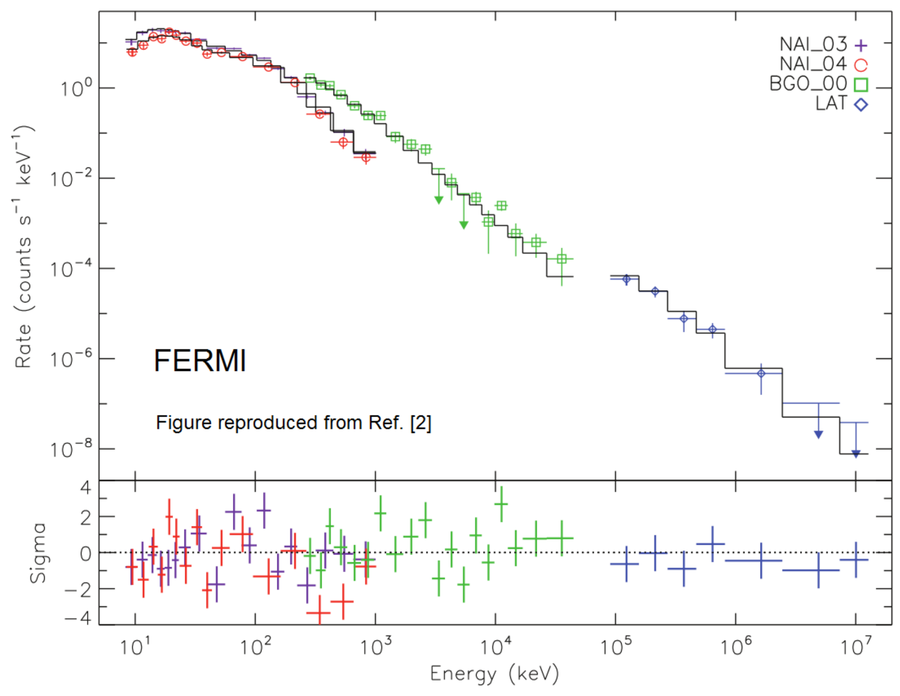
The detection technique relies on the measurement of multiple events scattered into adjacent detectors because the Compton scatter angle depends on the polarisation of the incoming photon.

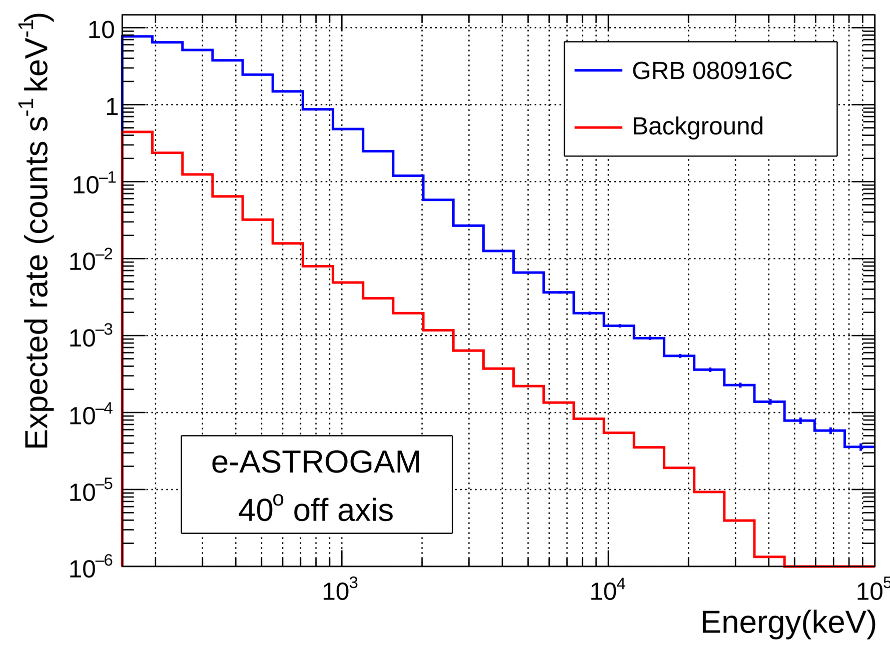
SPI and IBIS on ***INTEGRAL*** have demonstrated the capability to detect the signature of polarised emission in the medium energy gamma-ray range from γ–ray sources, including GRBs. For example, GRB 041219a was an intense burst localised by ***INTEGRAL***, whose degree of linear polarisation in the brightest pulse of duration 66 s was found by SPI to be $63^{+31}_{-30}\%$ at an angle of 70^{+14}_{-11} degrees in the 100–350 keV energy range [4]. The angle and degree of polarisation found using SPI data in different intervals and energy ranges are reasonably consistent with those determined using the IBIS data [8]. However, the relatively low significance of these detections, combined with the lack of on-ground calibration of polarimetric response, limit the scope of what can be achieved with current instruments.

The strength of e-ASTROGAM regarding GRB polarimetry will be in its determination of polarization ($\mathrm{MDP}_{99} \leq 20\%$) for an unprecedented sample size, of order 40 GRBs per year.

Polarisation measurements as a function of energy can also be used to distinguish between synchrotron and photospheric emission mechanisms. Furthermore, jets that produce broken power-law spectra also produce highly polarised emission for most observers (> 10's%), while jets that produce a Planck-type spectrum produce emission with lower degrees of polarisation for most observers (max. 10%) [5]. e-ASTROGAM's broad spectral coverage in combination with its polarimetric response and large sample size will be able to test these predictions.

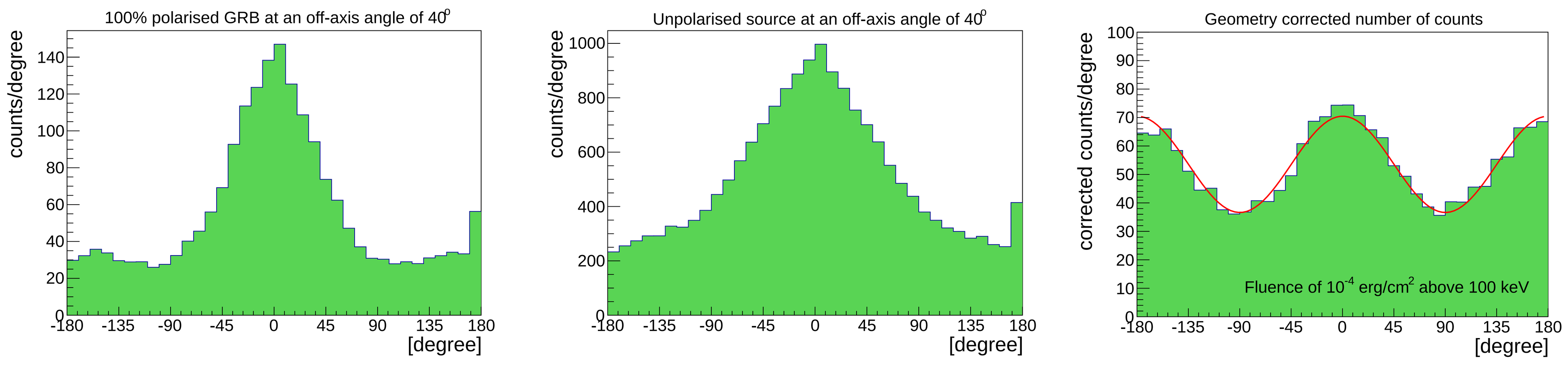
GRB spectral measurements



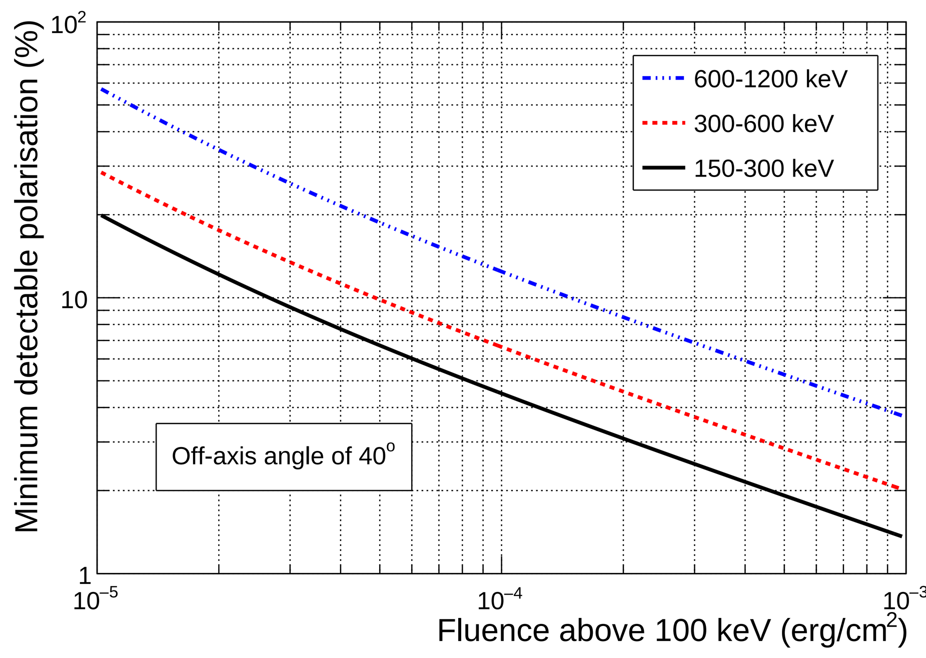


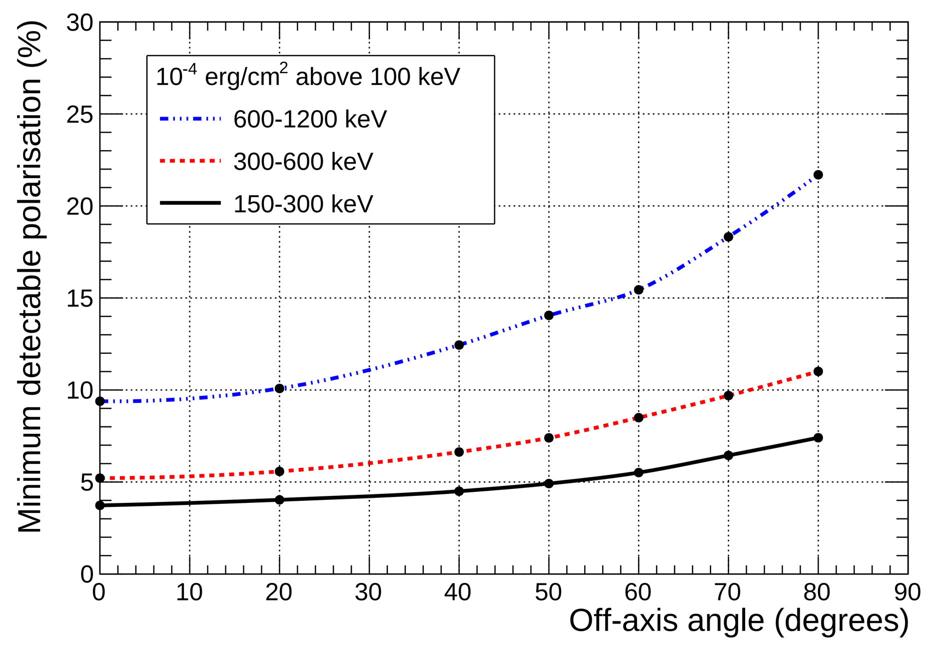
To demonstrate e-ASTROGAMs GRB spectral capability, time slice "b" of GRB 080916C [2] has been simulated with a duration of 4.1 s, flux of 5.63 photons/cm^2/s in the 50 - 300 keV band, and spectrum fit with Band function parameters α = -1.02, β = -2.21, $E_{\rm peak}$ = 1170 keV.

Polarisation sensitivity



For linearly polarised gamma-rays, the differential probability of Compton scattering depends on the azimuthal scatter angle with respect to the polarisation vector, which results in a modulated azimuthal distribution of scattered photons. As shown above, the reconstructed azimuthal scatter angle distributions (ASAD) require corrections for non-uniformity of the detector acceptance, which is particularly large for sources at high off-axis angles. The required corrections are estimated using the ASAD simulated for an unpolarised source with the same spectrum and position. Corrected distributions for the polarised sources show clear modulations in several energy bands.

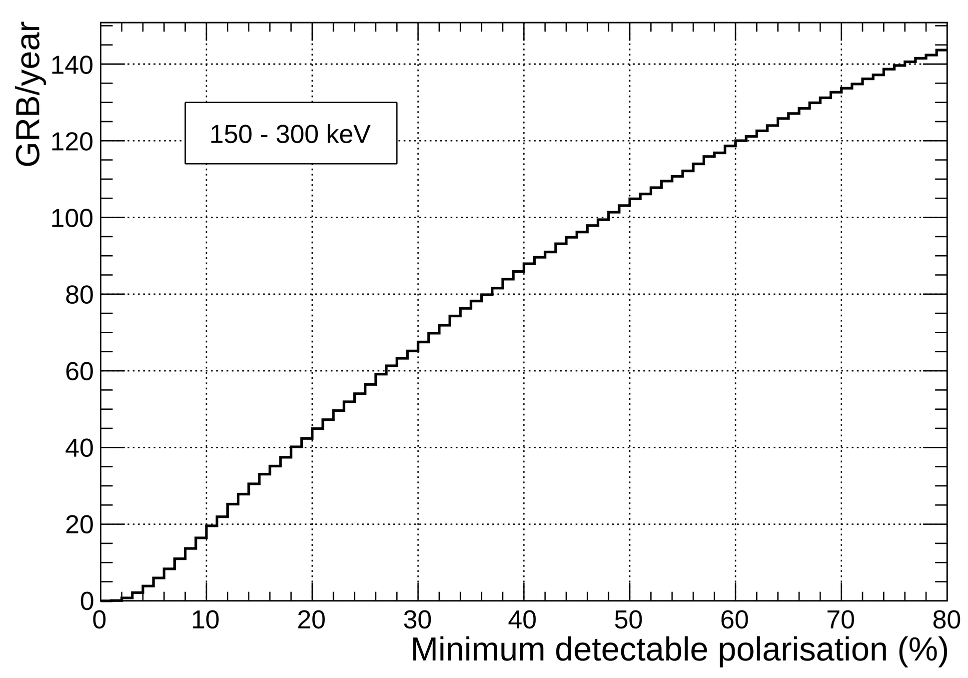




The minimum polarisation fraction detectable at the 99% confidence level is given by

$$\mathrm{MDP}_{99} = \frac{4.29}{\mu_{100} S}\sqrt{S+B},$$

where μ_{100} is the modulation amplitude for a 100% polarised source, S and B are the number of source and background counts, respectively [3]. A time interval of 50 s is used in this study to estimate the number of background events for the GRBs. To calculate the minimum detectable polarisation, the analysed data sample includes both events where the first interaction occurs in tracker and events with the first interaction in the calorimeter. The latter events are found to be very important for polarisation measurements in the high energy bands, as they significantly increase the number of events in the sample and also produce a higher modulation amplitude. For bright GRBs, the polarisation sensitivity is limited by the number of reconstructed photons, but background events become important near 10^{-5} erg/cm^2.



The cumulative GRB rate as a function of MDP_{99} has been estimated using the 100-300 keV fluences (translated to the 150-300 keV band) and T_{90} durations of BATSE GRBs. e-ASTROGAM is expected to detect about 40 GRBs per year with $\mathrm{MDP}_{99} < 20\%$.

References

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Acknowledgements

This work is being supported under ESA's Strategic Initiative AO/1-6418/10/NL/Cbi. LH acknowledges support from Science Foundation Ireland (SFI/RFP/AST/11/3188)