ASTENA Polarization capabilities

2nd Progress meeting of the SWG, April 18-19, Universidade de Coimbra

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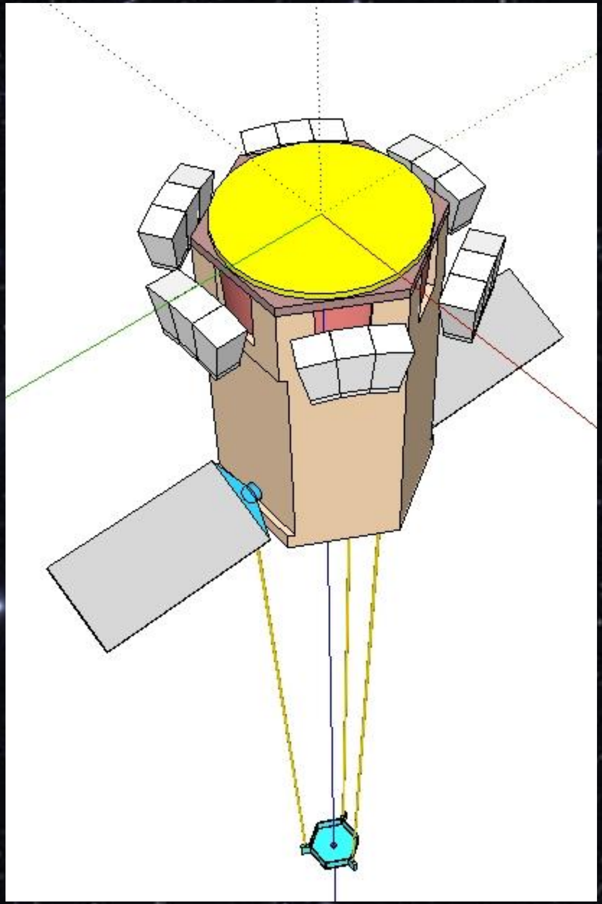
The ASTENA NFT instrument (baseline):

Laue Optics

- Pass-band: 50 - 700 keV
- 20 m focal length
- Si 111 + Ge 220
- Crystal dimensions: 30x10x (optimized thickness) mm^3
- 43 rings
- $R_{in/out}$= 18 cm / 149 cm (3 m diameter)
- Filling Factor 93%
- Total Geometric Area 69800 cm2 ~ 7 m^2 !!



The ASTENA NFT instrument (baseline):

Focal Plane Detector

<u>Main requirements</u>

- Detection efficiency > 80% @ 700 keV
- 3D imaging capability = 400 µm (x, y, z direction)
- Fine spectroscopy response 1 % @ 511 keV

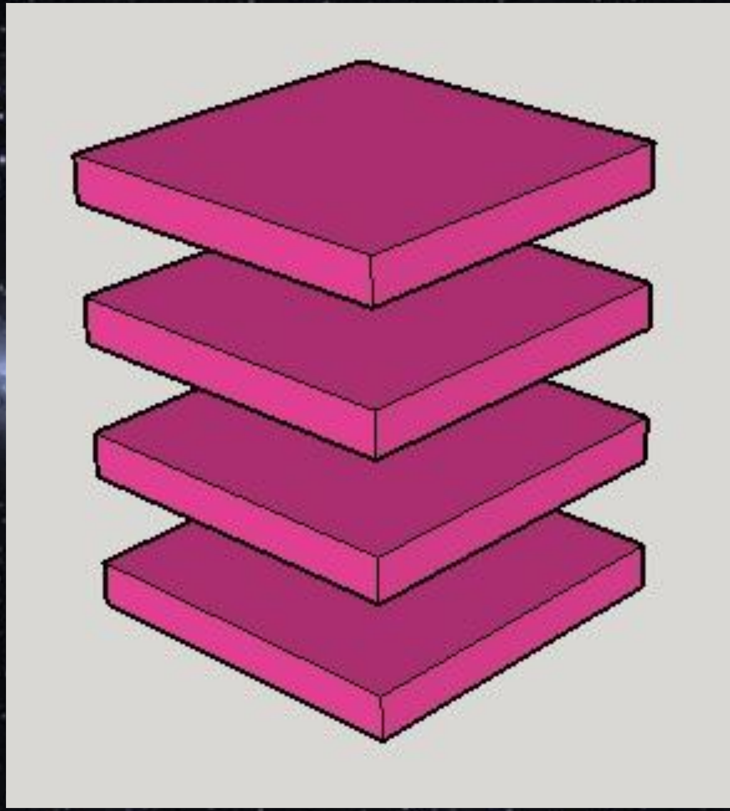
<u>Geometrical characteristics:</u>

❖ Material: CZT

❖ CZT units: Anode drift strip and orthogonally segmented cathode in PTF

❖ 4 layers of 8x8x2 cm^3

❖ Sensitive volume 8x8x8 cm^3

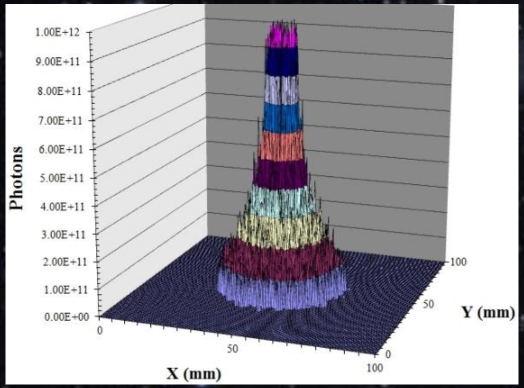


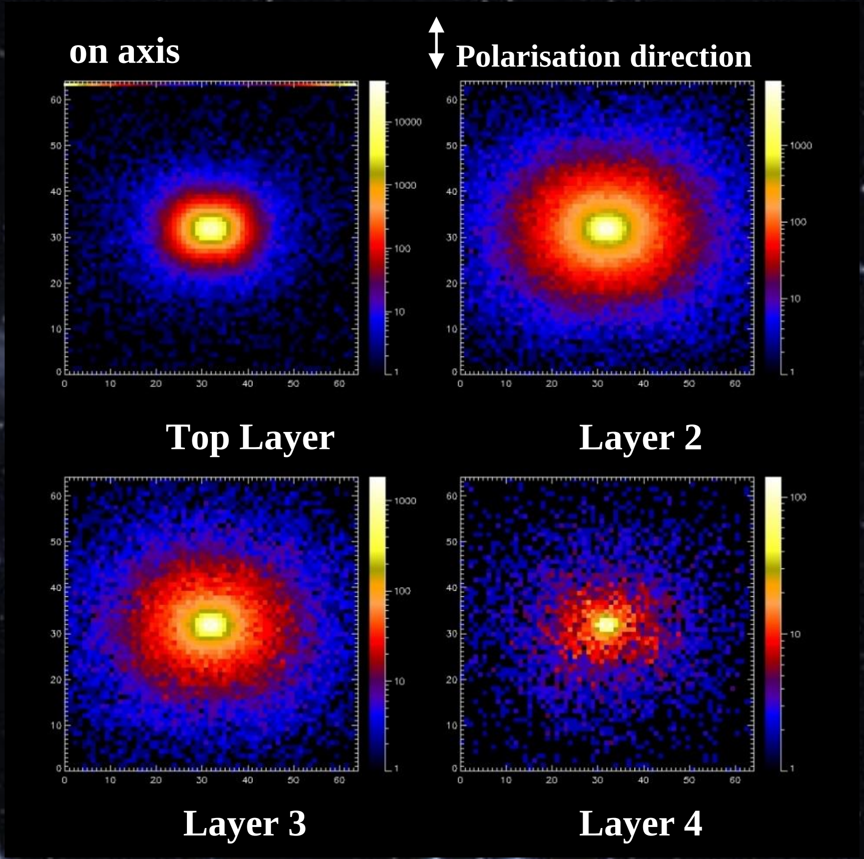
ASTENA-NFT Heritage (GRI) Polarimetry Simulation

Laue Lens	Dimension
Cu Mosaic Crystals	1.5x1.5x0.2 cm^3
Focal Lenght	100 m
Ext. Diameter	2.5 m
Pass band	100-600 keV
Focal Plane	**Dimension**
Top Layer	16x16x0.5 cm^3
N. 3 Bottom Layers	16x16x2 cm^3
Pixel Size	2.5x2.5 mm^2
Layer pixelisation	64x64
Gap between layers	20 mm

GRI like Laue Lens Telescope main characteristics

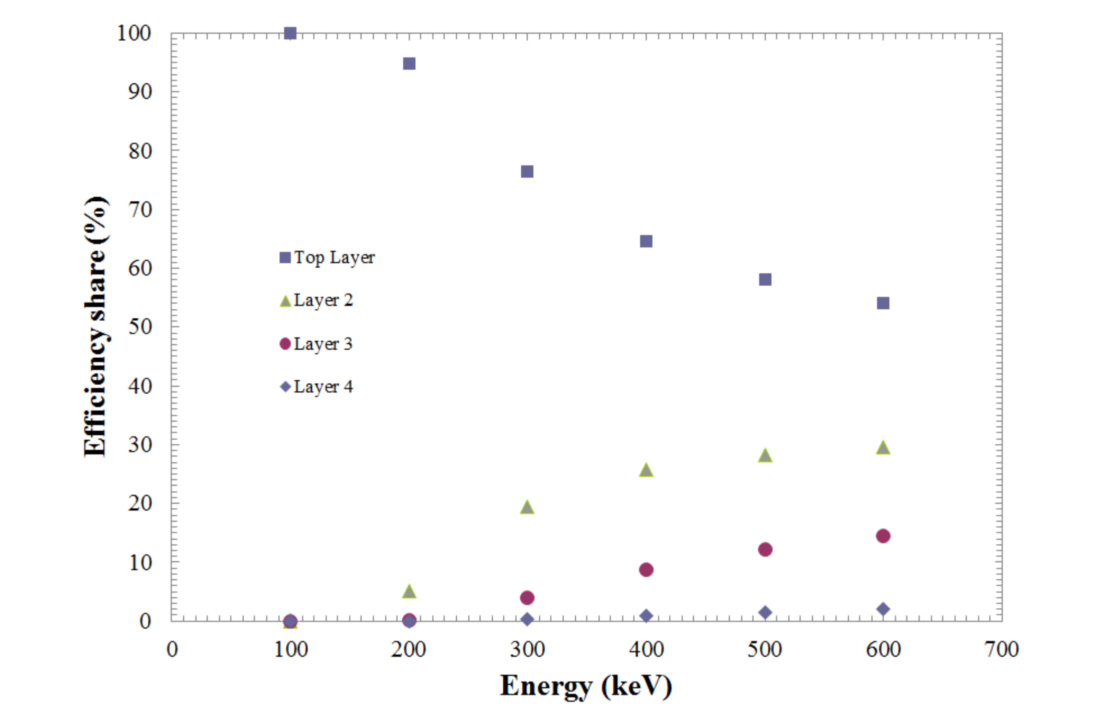
Mosaic Laue lens PSF (∅ ~2 cm FWHM) at 400 keV.





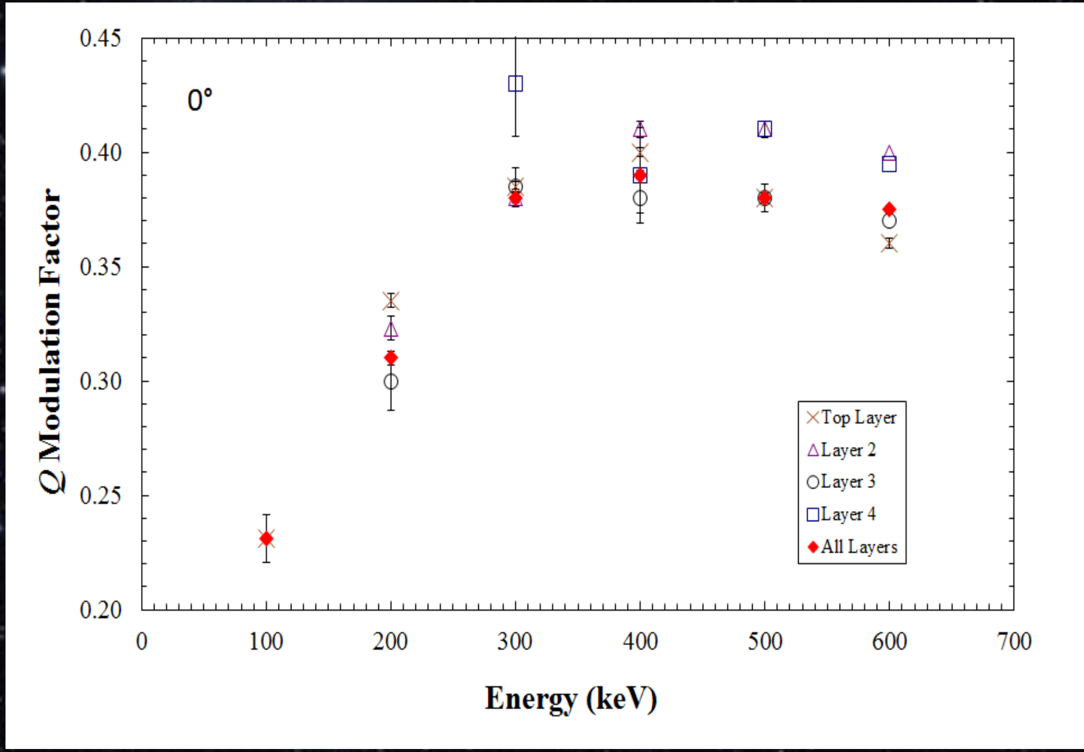
Double event distribution maps obtained for each CZT stack layer when irradiated by a 400 keV Laue lens PSF fully polarized source in axis. The polarization direction is indicated.

ASTENA-NFT Heritage (GRI) Polarimetry Simulation Results



Relative efficiency of double events generated by a fully polarized Laue lens PSF source distribution for each stack detector layer.

Simulated modulation *Q* factor obtained for each layer and the *Q* factor obtained integrating the contribution of all layers, for an on-axis



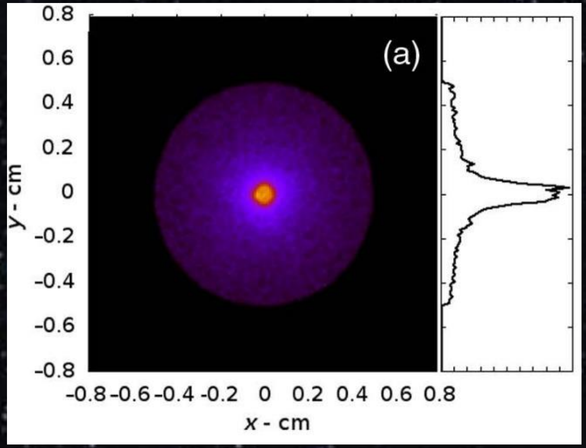
ASTENA-NFT: Improving Hard X ray Polarimetry

Determinant characteristics for improved polarimetric performance of the ASTENA NFT:

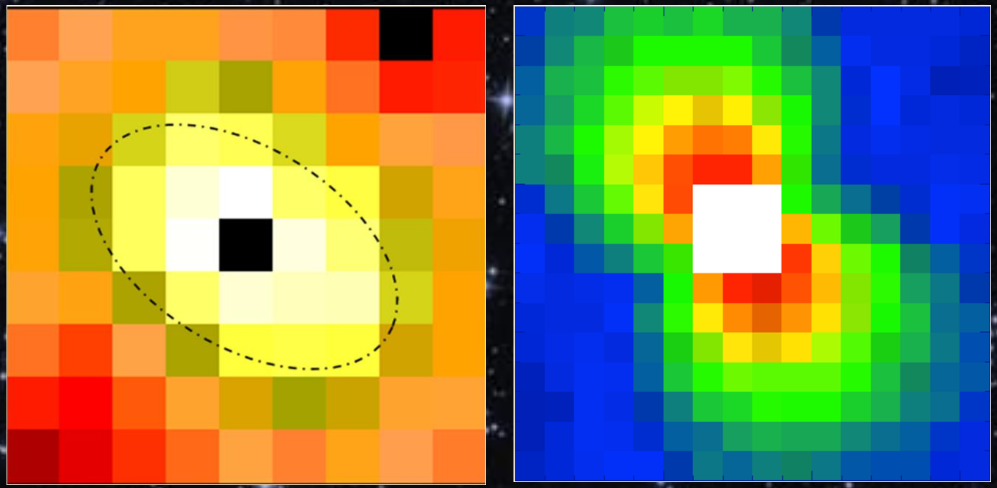
1. Laue lens using curved crystal tiles (Ge, Si): PSF ∅ = 2 mm (*figure*)
2. CZT focal plane with fine spatial resolution: voxel size = 0.4x0.4x0.4 mm^3
3. CZT focal plane with fine spectroscopy: 1% FWHM @ 511 keV

Advantages for polarimetry measurements sensitivity:

1. Small amount of background
2. High modulation factor of the detector
3. Reliable Compton event selection and filtering

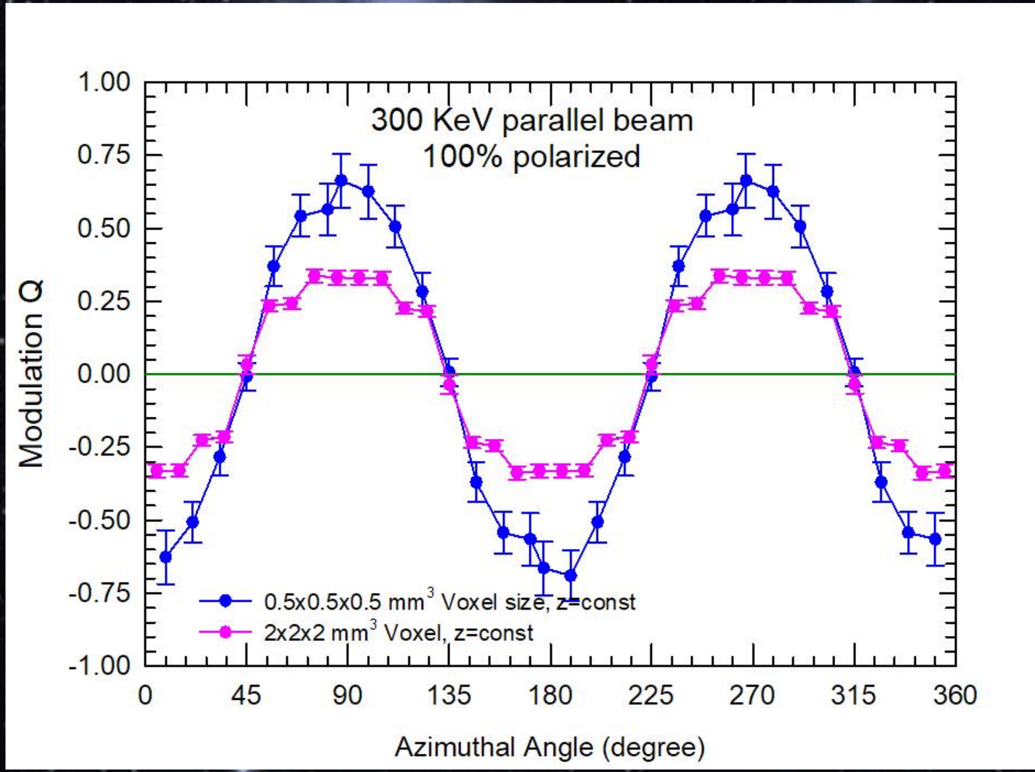


ASTENA-NFT: Polarimetry vs Focal plane spatial resolution

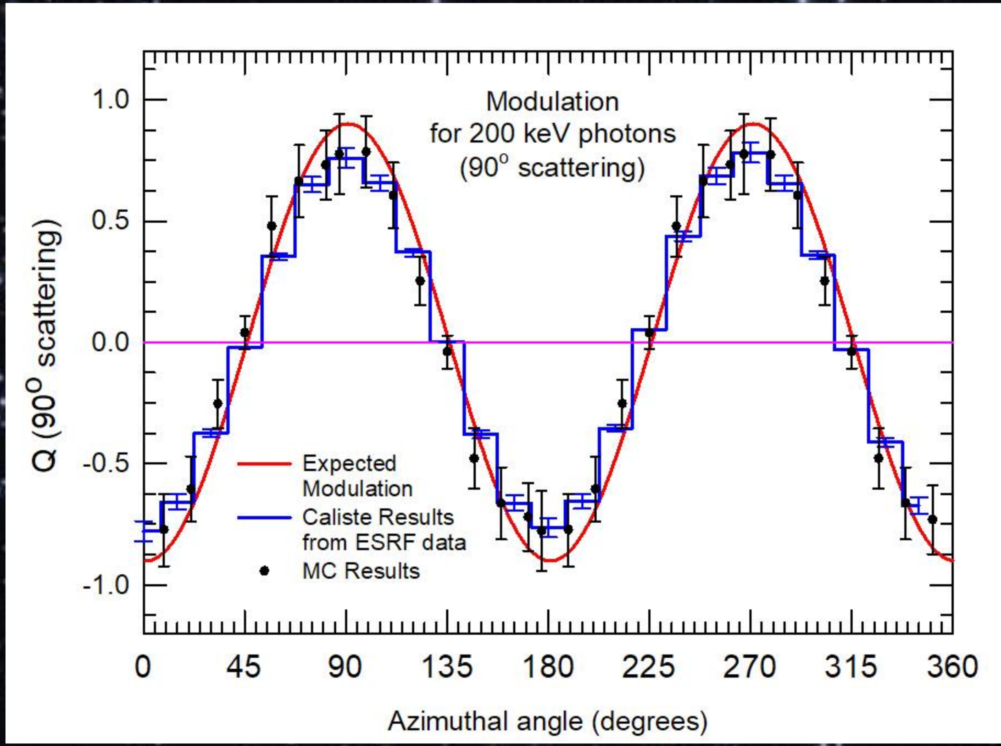


Two scattering maps at 200 keV and with polarisation axis 30° inclined with respect
to the detector ones:
(left) Imarad CZT with 2.5 pixel pitch, 5 mm thick, 2.75x2.75 mm^2;
(right) Caliste CZT module with 0.58 mm pixel pitch, 2 mm thick, 9.3x9.3 mm^2

MC Modulation curve for **two different discretisation in voxel** of the same volume obtained by selecting scattered events for which the two hits have the same coordinate in z (along the detector thickness)



ASTENA-NFT: Polarimetry vs Energy resolution



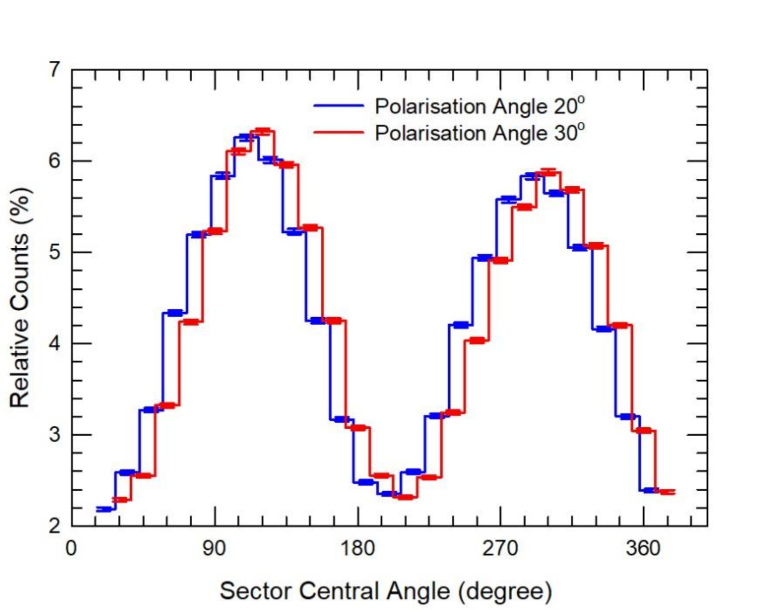
The experimental Caliste modulation curve at 200 keV (**blue line**).

The modulation factor Q measured with Caliste, selecting double events with energy in the 139–148 keV window, was ~0.78, i.e. very close to the theoretical expected values of 0.9 (**red line**).

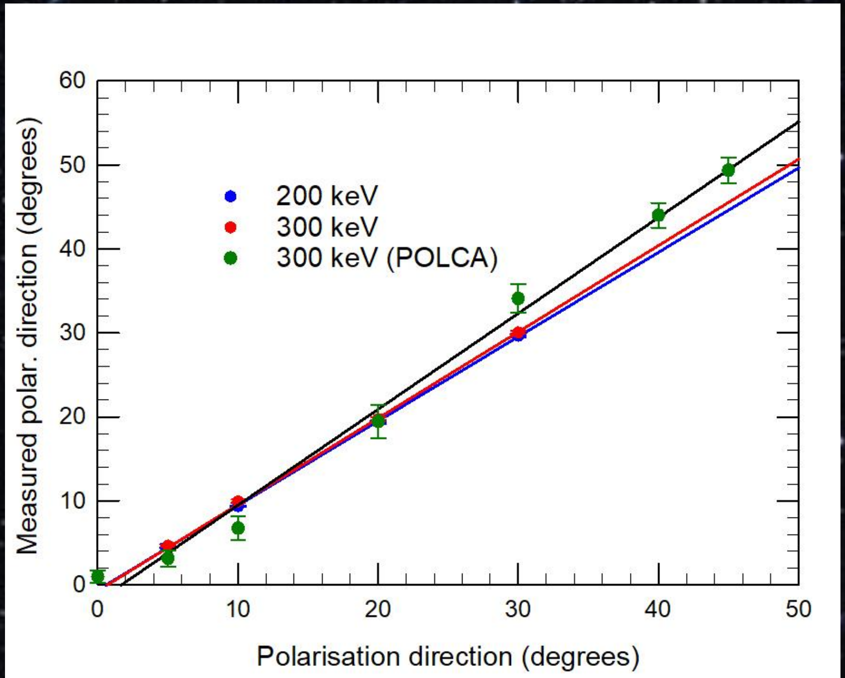
In **black**, the data obtained by a simple Caliste Monte Carlo model results are statistically consistent with the experimental results.

The selection correspond to events that scatter at 90° : i.e. the optimal condition for polarimetry

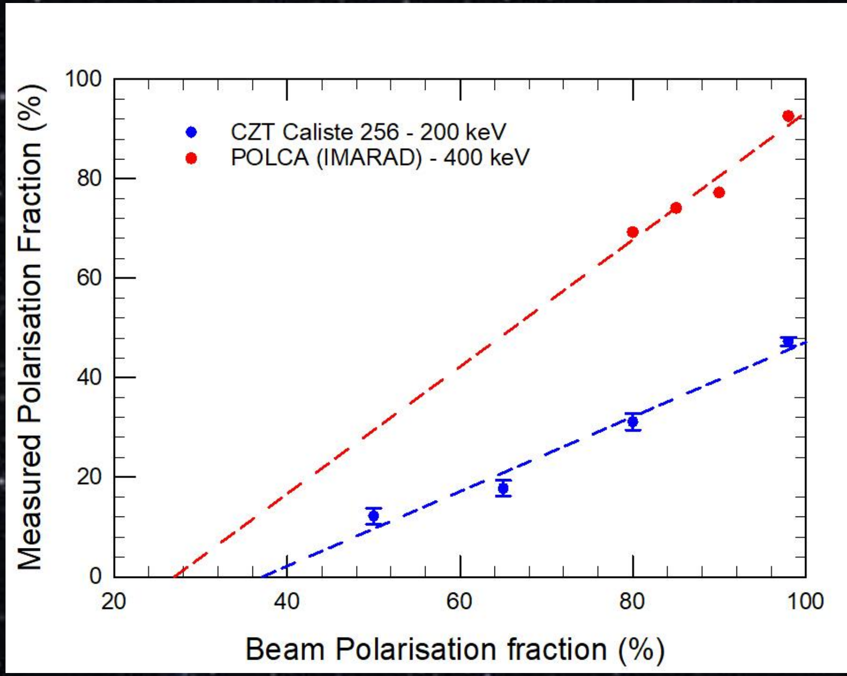
The modulation curve obtained with CZT Caliste 256 at 300 keV (98% linearly polarized) for different polarisation plane orientation; Double events selection within 181–197 keV.



ASTENA-NFT: Polarimteric status measurements



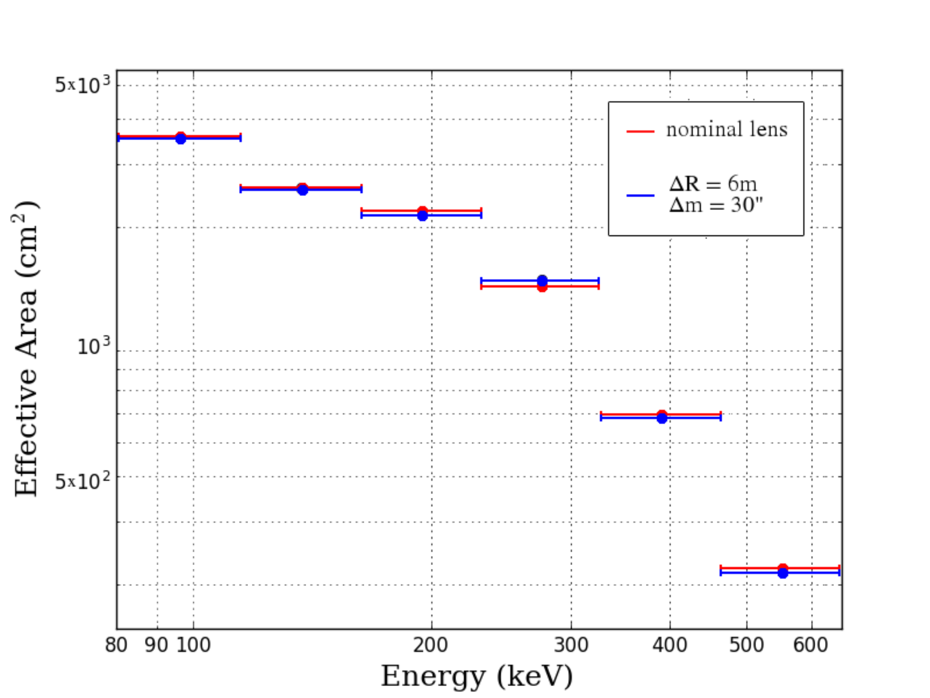
The reconstructed polarisation plane direction versus the real beam polarisation plane direction for two energies;



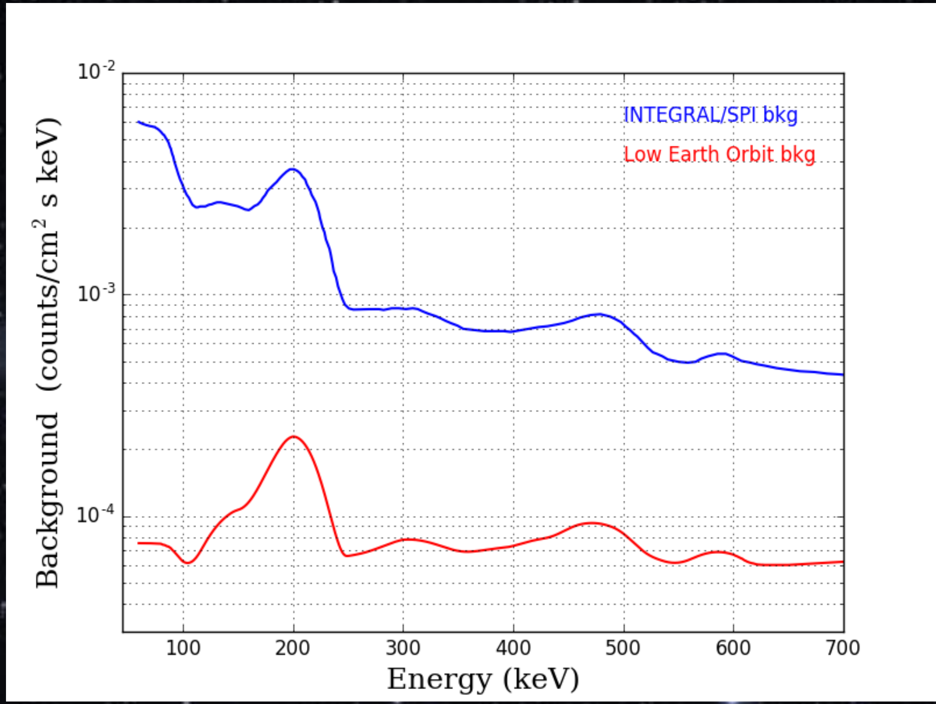
Comparison between the sensitivity to polarisation degree evaluated from ESRF data for the POLCA (IMARAD) and the CZT Caliste detectors.

The large difference between the two results is a further confirmation of the modulation factor improvement achievable with a fine spatial resolution coupled with fine spectroscopic performance.

ASTENA-NFT: Effective Collecting Area and Background

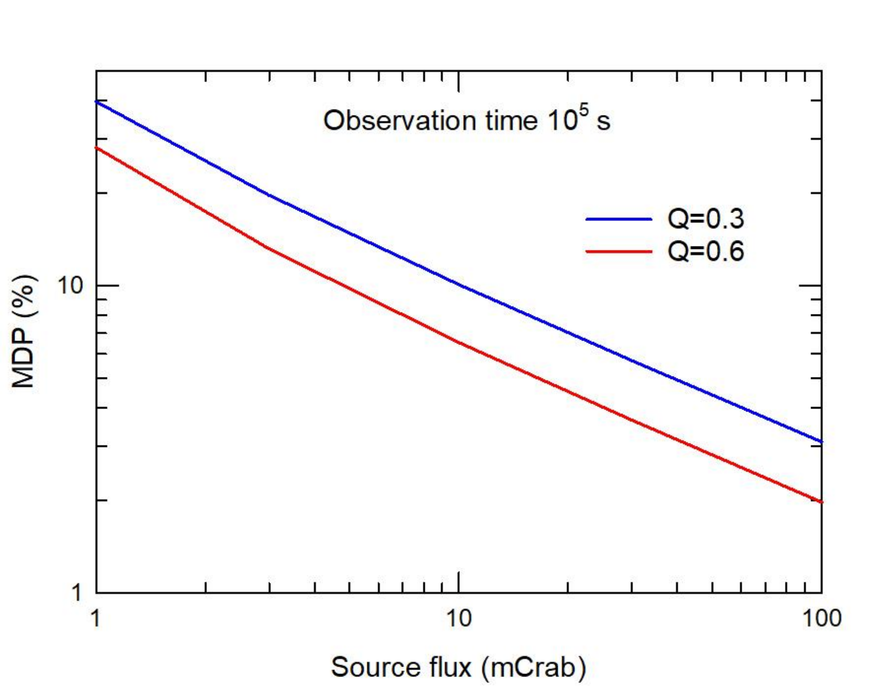


Expected effective area with energy of a Laue lens made with bent Ge(111) tiles, 90 -600 keV passband, and focal length of 20 m.
(red) nominally bent and perfectly arranged tiles;
(blue) crystals radially distorted in the range ±6 m with respect to nominal value of 40 m and uniformly misaligned in the range ±30 arcsec

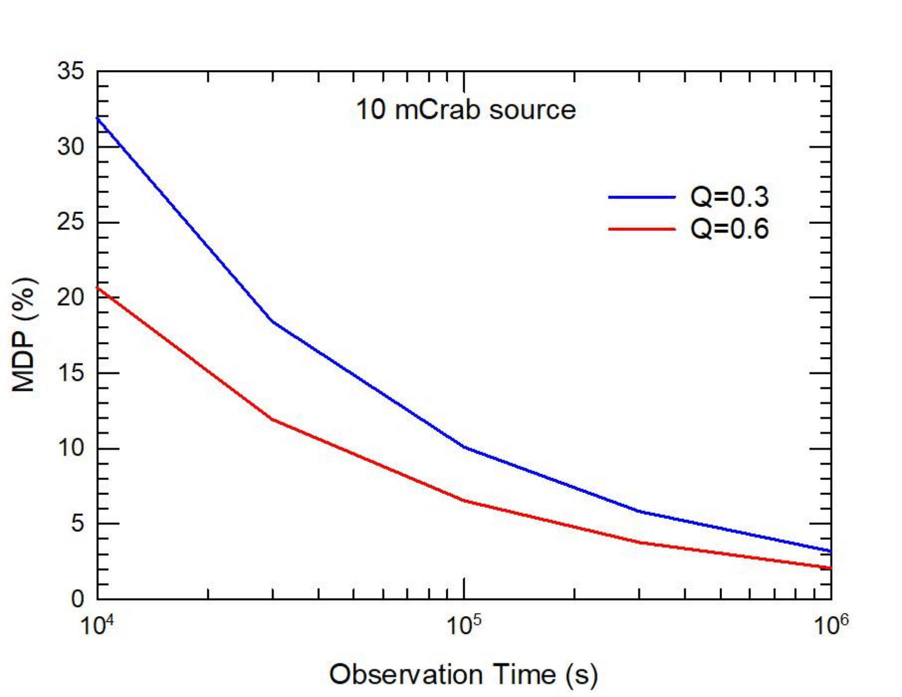


The expected lens background at LEO, compared with the INTEGRAL SPI measured background, for a CZT focal plane with previous given main characteristics.

ASTENA-NFT: MDP preliminary evaluation



Polarimetric performance achievable by a 20 m focal length broadband (90-600 keV) Laue lens telescope with a fine (0.4 mm) spatial resolution focal plane in a LEO orbit.



(top) MDP vs observation time for a 10 mCrab source and two representative (an conservative) modulation factors (Q=0.3 all double events, Q=0.6 double events selected using both hit's energy and coordinates);

(right) MDP vs source intensity (100% polarized) for a 10^5 s observation.

ASTENA-NFT: Next step for Polarimetric performance study

The next steps to evaluate a realiable figure of merit for polarisation capabilities of the ASTENA NFT instrument will foresee:

- ❑ Finalizing the focal plane detector mass model design.
- ❑ Performing simulation of polarized different sources by using the avalailable and verified ray-tracing tools to obtain the photon spatial and energy distribution on the focal plane detector (PSF files)
- ❑ Performing the GEANT4/MEGALIB simulation of the focal plane detector using the PSF files.
- ❑ Analysing MC data obtained with un-polarised source to study pixel geometry systematics.