# Polarimetric prospects of the Narrow Field Telescope aboard the ASTENA mission concept

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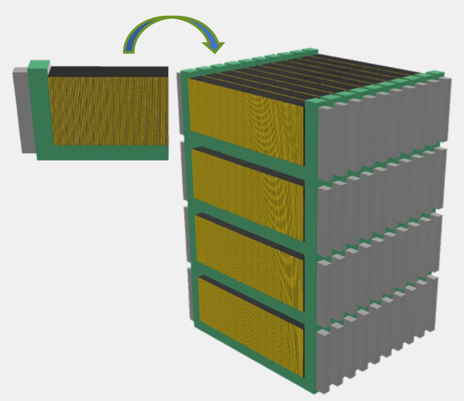
## ABSTRACT

The measurement of the polarization of the high-energy emission (>100 keV) from cosmic gamma-ray sources has now become a key observational parameter for understanding the production mechanisms and the geometry of the regions involved. Therefore, a mandatory requirement for new instrumentation in this energy range will be to get high sensitivity for polarimetric measurements. For several years our group has studied the performance of CdTe/CZT pixel spectrometers as scattering polarimeters. However, in order to achieve the sensitivities required by the next generation of instrumentation at energies higher than 100 keV, a promising solution is now offered by a broadband Laue lens telescope paired to a spectrometer with very good three-dimensional spatial resolution. This configuration is proposed for the narrow field telescope (NFT) of the ASTENA mission concept currently under study also in the framework of the AHEAD European project [1]. In this poster we will report on the results of a Monte Carlo study devoted to evaluate the polarimetric performances of the NFT while presenting two examples in which a next generation hard X-/soft gamma ray mission can provide significant advances.


## ASTENA NFT FOCAL PLANE DETECTOR MASS MODEL

A broadband Laue-based telescope such as the one under study for ASTENA's narrow-field instrument (NFT) [2], which allows focusing photons from 50 to 700 keV, places very stringent requirements on the focal plane detector in term of efficiency, spectroscopy, and imaging capability. We are considering CZT and HPGe (see L. Ferro poster). We assume CZT.

| Focal Plane Requirements | | |
|---|---|---|
| Detection Efficiency | Energy Resolution | Spatial Resolution |
| 80% at 700 keV | 1% FWHM at 511 keV | 0.3 mm in XYZ (3D) |

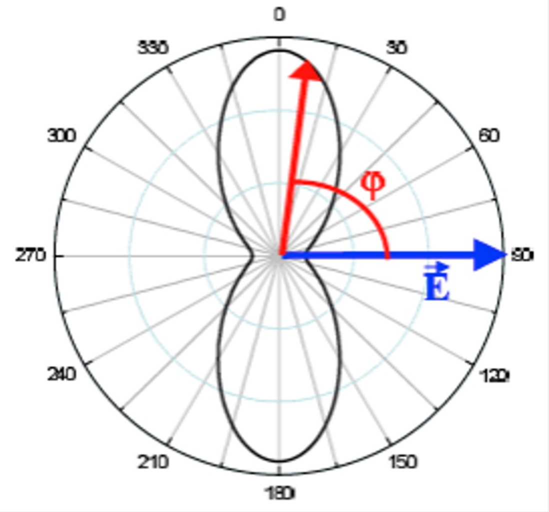


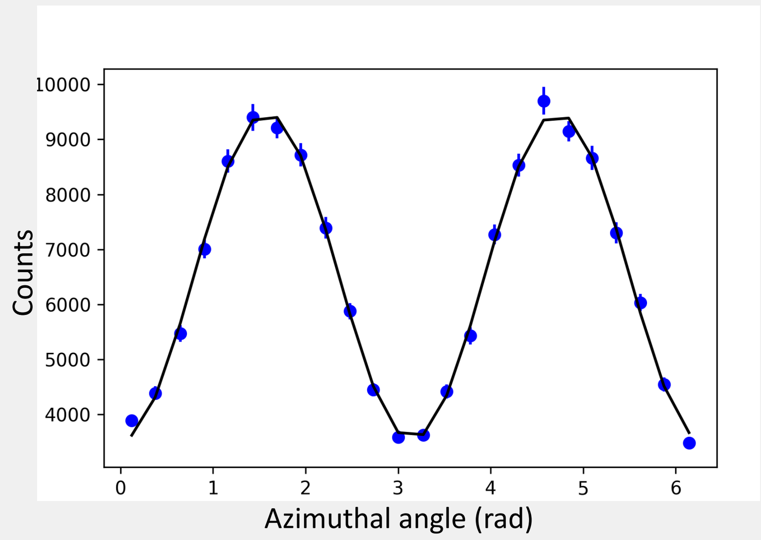
The mass model used for the simulations is based on the latest developments of 3DCZT strip detectors [3] and consist:

- 4 layers of CZT separated by a 10 mm thick layer of PCB;
- Each layer is made by packing a series of two facing 3DCZT unit based on 30/40 mm x 20 mm x 5 mm CZT crystals;
- The number of 3DCZT sensors used for each layer is defined by the required lateral dimension of the focal plane: 8 cm.
- Spectroscopic response is modelled by an analytical relationship, derived from experimental data on CZT spectrometers [3].

## COMPTON Polarimetry

From the Klein-Nishina differential cross-section for linearly polarized photons, the probability distribution of the scattering angle will present a maximum along the direction orthogonal to the polarization plane and a minimum in the parallel [5].



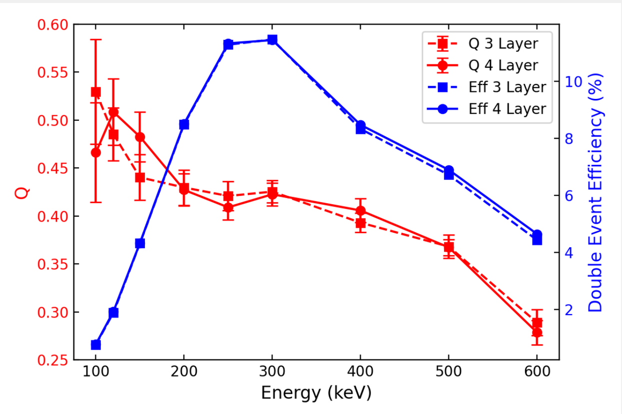




***Minimum Detectable Polarization, MDP, gives*** the confidence that polarization is detected. For a space polarimeter in a background noise environment, MDP, at 99% confidence level, is given by:

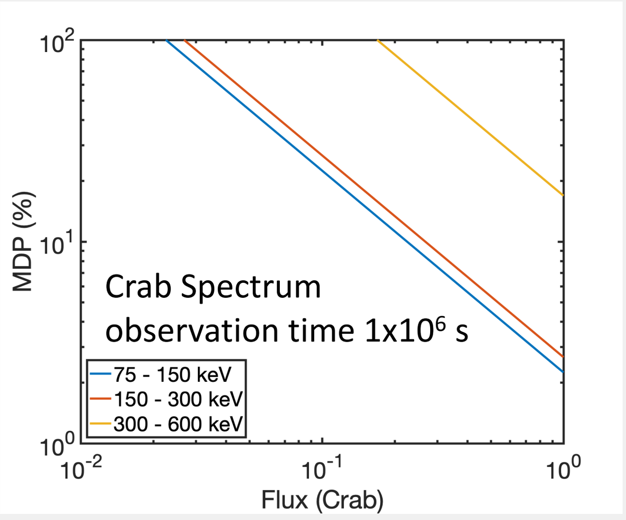
$$\mathrm{MDP} = \frac{4.29}{A \cdot \varepsilon \cdot S_F \cdot Q_{100}} \sqrt{\frac{A \cdot \varepsilon \cdot S_F + B}{\Delta T}}$$

$A_{eff}$ - Effective Area; $Q_{100}$ - Q for 100% pol. Beam
$\varepsilon$ - Event efficiency; $B$ - Background
$S_f$ - Flux; $\Delta T$ - Observation Time

To minimize MDP, it is crucial to maximize $Q_{100}$ and $\varepsilon$. Extensive simulation studies have been conducted to optimize detector geometry and event selection in order to maximize both of these parameters for the NFT energy range.




In the side Figure, we show the expected MDP in a low Earth orbit environment by injecting a Crab-like spectrum on the MEGALib toolkit [6] to obtain the modulation factor, $Q_{100}$, and event efficiency, ε.

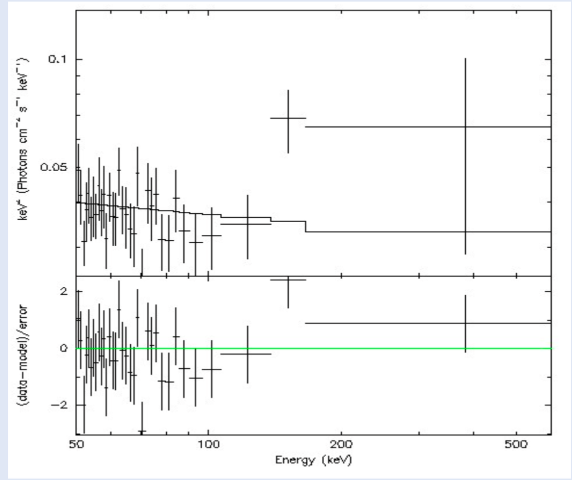



The background components were modelled in detail also using the MEGAlib tollkit and the effective area is calculated analytically as the product of the geometrical area of the instrument and the reflection efficiency of the lens.

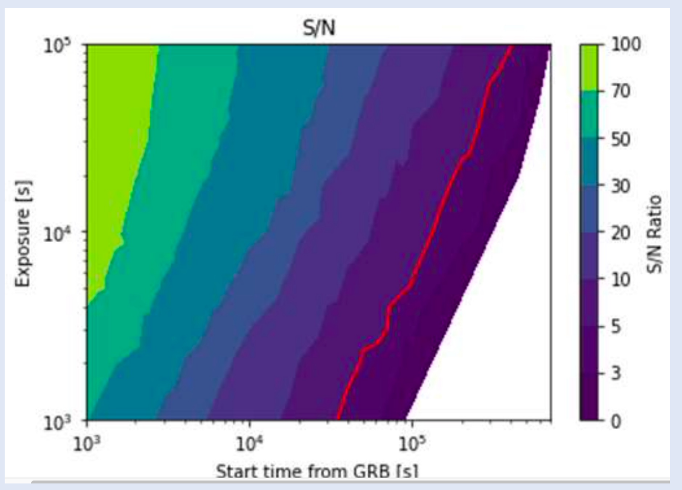
## GRB AFTERGLOW

Due to the high sensitivity of the NFT, one of the fundamental questions that it could answer is what mechanism powers the transient, long-lived hard X/soft γ–ray emission that characterises GRB afterglows [6]. Thanks to the BeppoSAX and Swift missions we have a very consolidated knowledge of the temporal and spectral behaviour of the low energy (< 10 keV) afterglow. However, due to the limited sensitivity of the current instrumentation, at higher energies the afterglow temporal and spectral behaviour is an almost uncharted territory. Only a few hard X-ray measurements have been obtained by BeppoSAX, NuSTAR, or INTEGRAL.

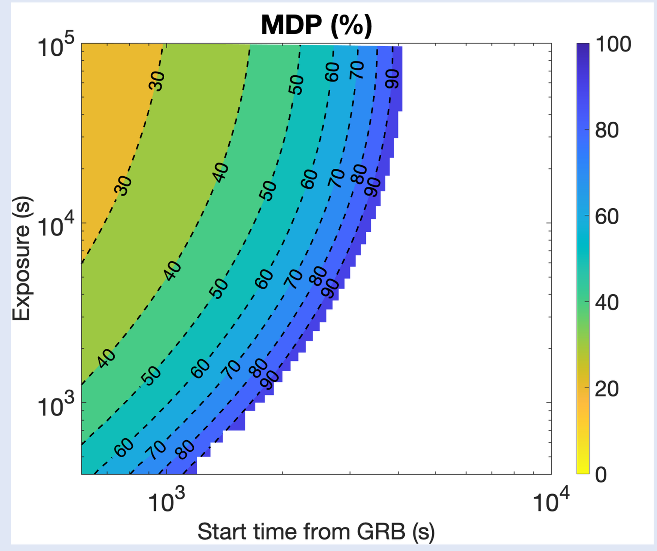
As an example, GRB 130427A was detected in April 2013 and occurred in a relatively nearby galaxy. Its prompt emission had the largest GRB fluence ever recorded at that time, and the afterglow was bright enough for *NuSTAR* to observe it in the 3 – 79 keV energy range for a long time after its prompt emission (~1.5 and 5 days) [7]. Using a broken power law with indices -1.67 e -2.17, and a break energy of 70 keV, from the flux decay as a power law with index -1.30, we first performed XSPEC simulations to obtain the expected afterglow spectra by NFT as a function of the starting time of observation and exposure time. Then we derived the corresponding expected MDP shown in the Figure below.



Spectrum simulated in XPEC using NFT response matrix as it was observing the GRB 130427A afterglow.




S/N as function of the starting time and duration of the observation for the GRB130427A .



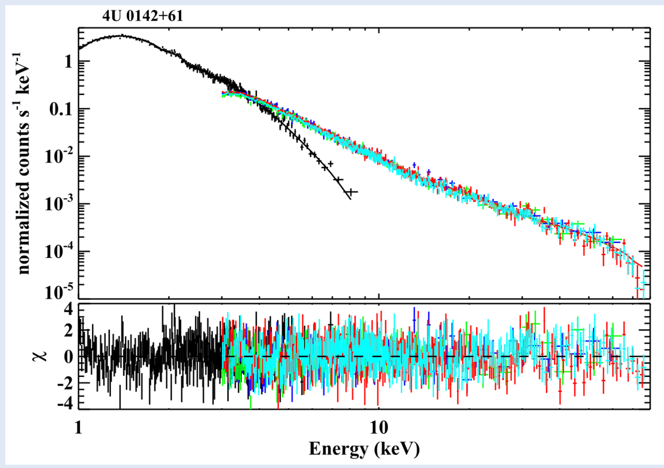

MDP as function of the starting time and duration of the observation for the GRB130427A .

## MAGNETARS

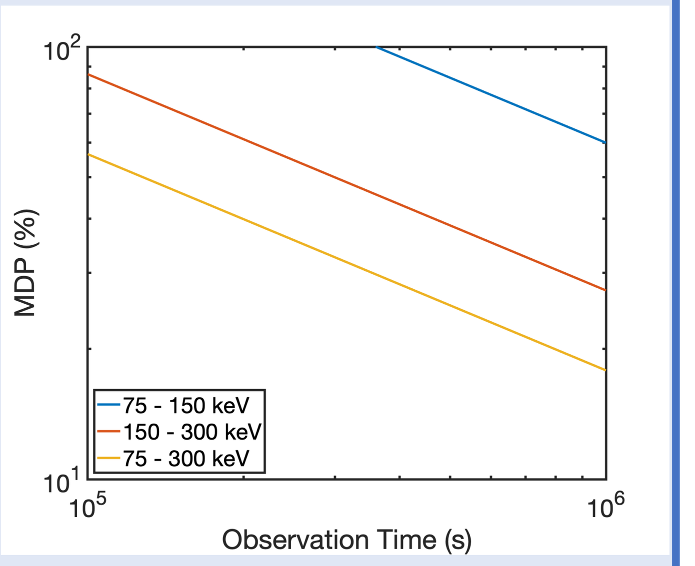
Magnetars are neutron stars with ultra-strong magnetic fields, which can be observed in X-/gamma-rays. There are about 30 confirmed magnetars known (*2*), many of which are detectable only during periods of enhanced activity. At present, hard X-ray emission has been reported in about one-third of magnetars. However, our understanding of magnetar energetics is still incomplete: there is no clear evidence of the energy beyond which the hard X-ray emission would decline rapidly and only a sensitive soft γ-ray instrument like NFT would ultimately uncover the peak energy of the magnetar high energy spectral distribution and, possibly, its polarization that could provide information on their magnetic fields and surface properties.

As an example, we consider the magnetar 4U 0142+61, an AXP well investigated in the soft and hard X X-ray bands with INTEGRAL, NuSTAR and Swift [8], and recently with IXPE [9], that measured its linear polarization properties at low energies, finding a strange polarization degree with energy: 15.0 ± 1.0% at 2-4 keV, no significant polarization in 4-5 keV, and 35.2 ± 7.1% @ 5.5-8 keV.

Using the spectrum obtained with NuSTAR extrapolated to higher energies and we have obtained the expected MDP achievable with NFT, assuming CZT as focal plane detector. We expect a better sensitivity with HPGe (work in progress).




X-ray count spectra of 4U 0142+61 observed by NuSTAR [8].




MDP as function of the observation time when NFT observe the 4U 0142+61.

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