AHEAD Coimbra Online Meeting 1-2 October 2020

Task 11.4 - Future missions - beyond the baseline

The ASTENA Mission

Advanced Surveyor of Transient Events and Nuclear Astrophysics

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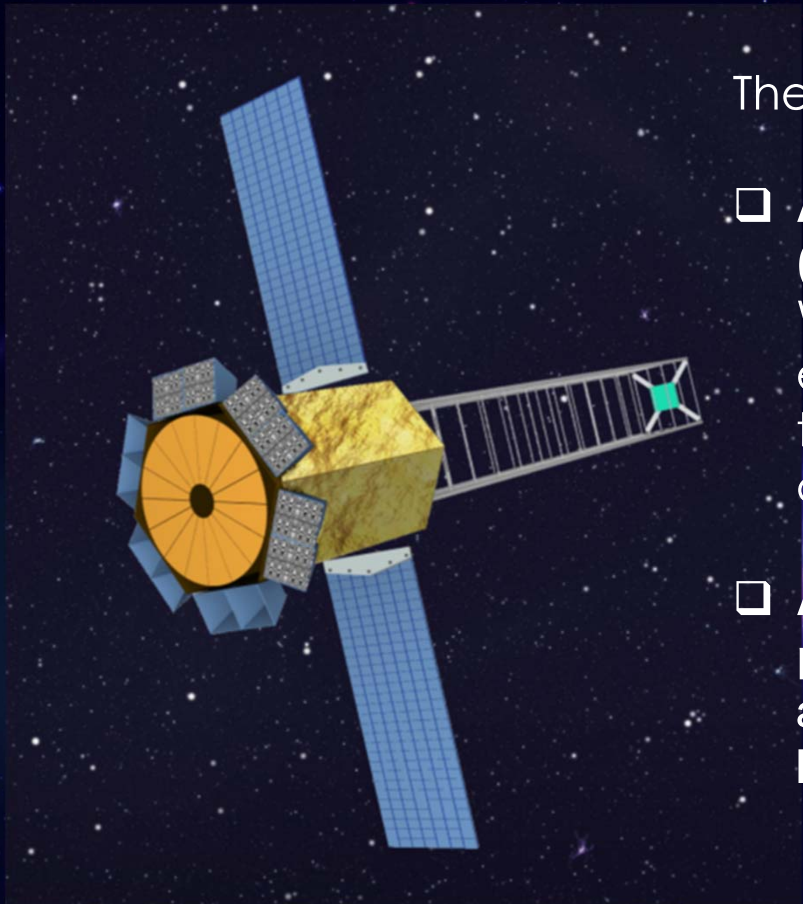
Presentation outline

- The ASTENA mission concept
- AHEAD 2015 – ASTENA study outcome
- AHEAD 2020 – WP 11.4 ASTENA subtasks objectives
  - *Scope and focus of the WFM/S ASTENA sub-task*
  - *Scope and focus of the ASTENA/NFT sub-task*
- ASTENA WFM/S ongoing activities
- ASTENA NFT ongoing activities
- Dissemination & communication activities
- Next steps

The ASTENA mission concept



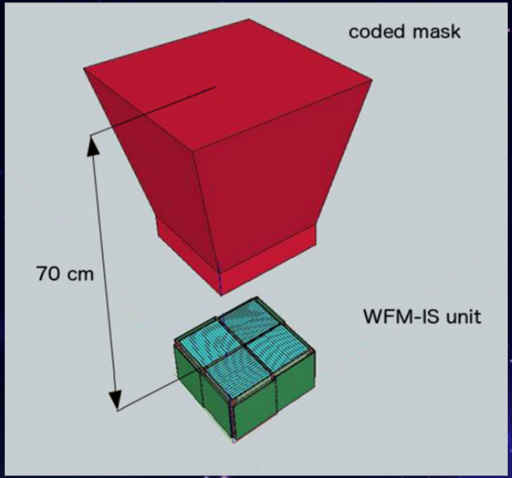
The main ASTENA satellite on-board instruments are:

- **A modular wide field monitor imaging spectrometer (WFM-IS), with a passband from 2 keV to 20 MeV.** The WFM-IS consists of an array of 12 units, two units per each side of the hexagon, that surround the NFT. All the units are offset by 15° with respect to the main axis.

- **A narrow field telescope (NFT), with a 50–600 keV passband**. The NFT is a broad-band Laue lens telescope of about 3 m diameter and 20 m focal length. Part of the focal length (5 m) is inside the spacecraft and 15 m outside.

The WFM-IS and the focal plane position sensitive detector (PSD) are inside the spacecraft at the launch. The ASTENA spacecraft can be accommodated inside the fairing of a Soyuz or Vega C launchers.

The ASTENA WFM-IS instrument



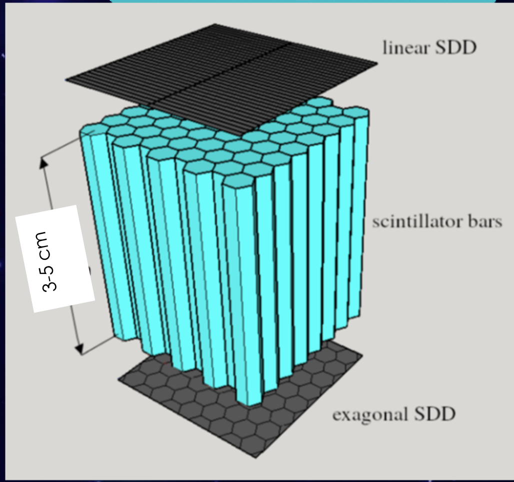
Concept and function principles derived from the THESEUS XGIS instrument.

Each detector module of the WFM-IS is a Position Sensitive Detector (PSD) surmounted by a coded mask at 70 cm distance.

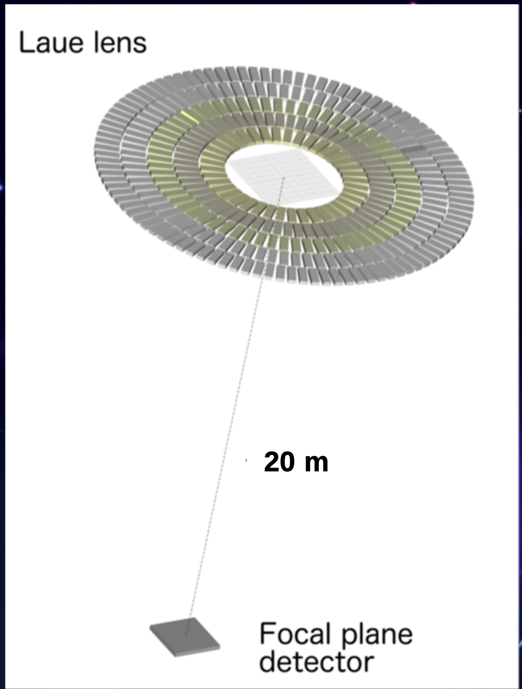
- The imaging Is obtained using a double scale coded mask: one scale for the high energy photons (30-150 keV), and another scale for the low energy photons (< 30 keV). The high energy mask is made of Tungsten 1 mm thick, while the low energy mask is made of stainless steel 0.5 mm thick.

Property	WFM-IS
Energy pass band	2 keV-20 MeV
Total exposed area	5800 cm^2 (< 30 keV) 6700 cm^2 (30–150 keV) 13800 cm^2 (> 200 keV)
FOV	2 sr
Angular resolution	6 acrmin
PSLA	1 arcmin

- The PSD unit consists of an array of 4x8 modules, each of which consists of 10 rows of hexagonal scintillator bars 4.5 mm between flats readout, on the top, by linear multi-anode SDDs 0.4 mm thick, and, on the bottom, by hexagonal single anode SDDs. This configuration has the advantage of a very broad passband (2 keV{20 MeV), a 3D position sensitivity to energy losses in the scintillator bars and a very low intrinsic background, given its similarity to a phoswich system



The ASTENA NFT instrument



The Laue lens is made by bent crystals tiles distributed in concentric circles extending from 0.26 up to 3 m in diameter

- Bent crystals dimensions: 1 cm x 3 cm (along the radius), and thickness 1-2 mm.
- Crystal tile curvature: 40 m
- Crystal material: Si (111) and Ge (111)
- Number of crystal tiles: ~19500

Property	NFT
Energy pass band	50-600 keV
Total exposed area	7 m^2
FOV	4 arcmin
Angular resolution (HPD)	~30 arcsec
PSLA	< 10 arcsec

The focal-plane detector will be based on a semiconductor PSD made of 4 layers, with each layer made of 4x16 3D-CZT sensors. The PSD has a total cross section of 8x8 cm^2 and thickness of 8 cm, to have an efficiency higher than 80% up to 600 keV.

- The required resolution in the (X,Y) plane is 0.3 mm. It has already been demontrated that this value can be achieved with the proposed configuration for single sensors of CZT.
- The PSD, because of its high segmentation (~40000 "virtual" voxel for each sensor) and fine spectroscopy, operate as a high performant Compton scattering polarimeter.

AHEAD 2015 - ASTENA study outcome

ESA VOYAGE 2050
LONG-TERM PLANNING OF THE ESA SCIENCE PROGRAMME

CALL FOR THEMES

COVID-19 Pandemic impact: "The original timeline was for the Senior Committee's recommendation to be delivered to the SPC in November, but this is now anticipated to be more a draft recommendation rather than a formal recommendation as originally planned.
Accordingly, the release of the Voyage 2050 public report will also be delayed into 2021.

Two white papers relying on the ASTENA concept as reference mission

- **A Deep Study of the High–Energy Transient Sky - Deeper & Broader: Future Observations in the X–/Gamma–Ray Band of Known and Unknown Explosion Transients** (Coordinator C. Guidorzi, University of Ferrara, supported by a team from 21 institutions from Europe and USA), selected for presentation at the ESA Voyage 2050 Workshop, 29 – 31 October 2019, Madrid, Spain. www.cosmos.esa.int/GuidorziC_WP_ESA_Voyage_2050.pdf, *in publication on Exp. Astronomy (2020).*
- **Understanding the origin of the positron annihilation line and the physics of the supernova explosions Contact** (Coordinator F. Frontera, University of Ferrara, supported by a team from 12 institutions from Europe and USA). www.cosmos.esa.int/FronteraF_White_Paper_FFrontera-ESA-voyage2050.pdf, *in publication on Exp. Astronomy (2020).*

Scope and focus of the WFM/S ASTENA sub-task

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- Implementation of hexagonal section scintillator bars for the high-energy detector, mainly to improve its performance as a scattering polarimeter
- Use of linear SDDs in the top plane to bring the spatial resolution to 1 mm, as required for obtaining a localization error of the order of the minute of arc. This requirement is fundamental to enable the follow-up of GRB and other transient events by the NFT telescope.
- Design optimisation of a two scale coded mask to achieve the required point source location accuracy of 1 minute of arc by the SSD low energy detector.

The above targets will be accomplished:

- Mainly with the development of a flexible numerical model of the WFM/S detector modules for the optimisation of their operating parameters and the design.
- By using a detection systems prototype currently under construction as a THESEUS' XGIS demonstrator: a 8×8 module of CsI square section bars coupled to two SDD arrays (produced within one year by OHB). The test results on this detector will be used to validate and tune the numerical model of the WFM/S.

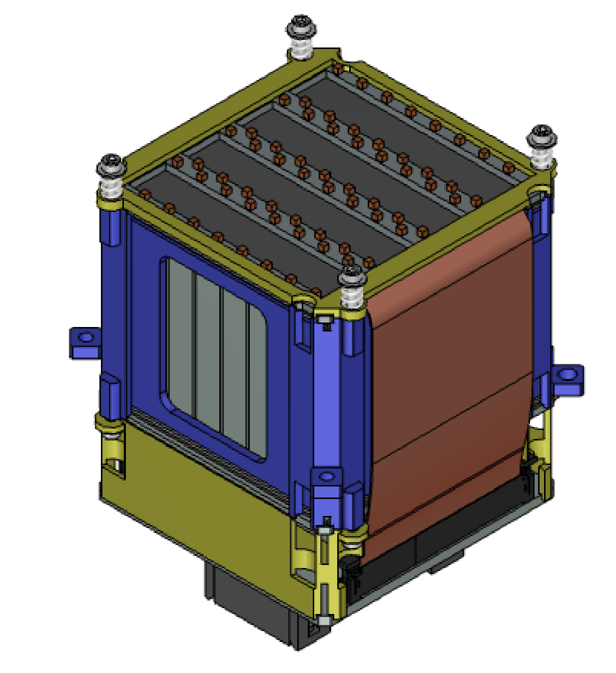
Scope and focus of the ASTENA/NFT sub-task

- Optimization of the configuration of the focal plane based on spectroscopic sensors with 3D spatial resolution, to maximize their performance according to the characteristics of the Laue lens, in terms of spectroscopy, imaging and sensitivity to polarization.
- Optimization of the lens configuration to maximize the effective area in the operating band (50-600 keV), in terms of the type and material of the crystals and their distribution.

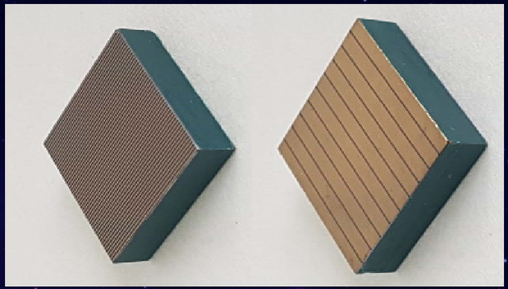
The above targets will be accomplished:

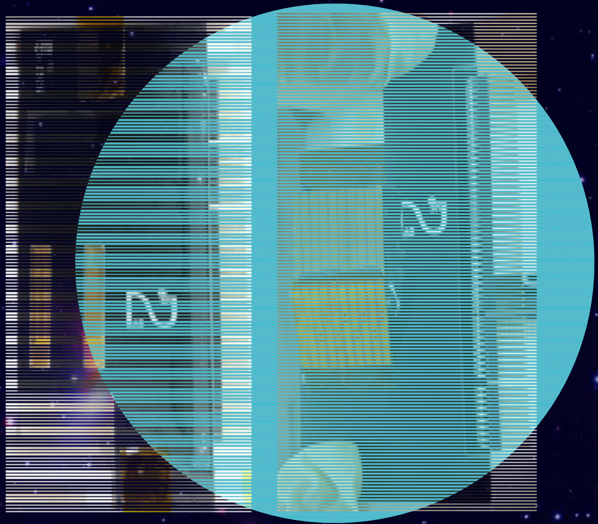
- Mainly with the development of numerical models of the ASTENA detectors and optics that allow the reliable evaluation of the performances and allow optimizing their operating parameters and the design.
- By using the 3D CZT sensor module which is under development in the framework of an INAF/ASI project (available within a year). With this device, tests will be carried out at facilities within the collaboration (e.g. LARIX, Ferrara), and externally (e.g. ESRF). A balloon flight in 2022 is foreseen for a small payload based on the same sensor type supported by the HEMERA program. The results from these measurements will be used to validate the Monte Carlo models for ASTENA NFT performance simulation.
- By prosecuting the technological activity on Laue Lens crystals assembling at LARIX (Ferrara).

Detector prototypes elements



Overview of the the 8x8 CsI-SDD module with its ASIC AFEE under realisation as THESEUS XGIS demonstrator. The CsI bars are 3 cm long and 0.5x0.5 cm^2 section.



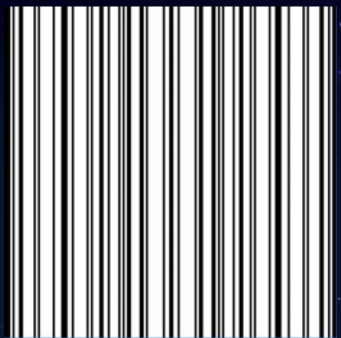
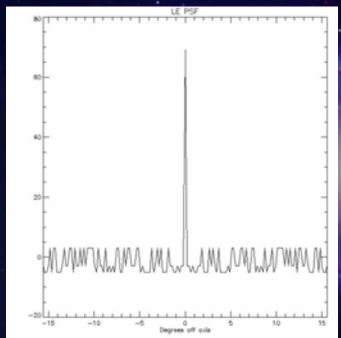


(right) The 3D CZT sensor: 20x20x5 mm^3;
Anode side: 12 collecting anodes,
3 strips drift strips between each anode couple.
Cathode side: 10 gold strips (2 mm pitch).
(left) The sensor mounted and bonded on the mechanical/electrical interface

WFM-IS Actvity up to now

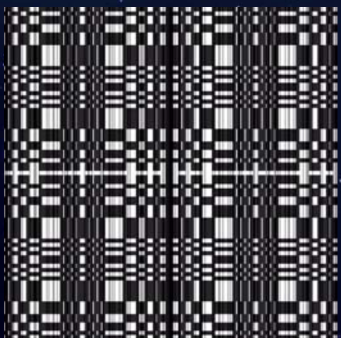
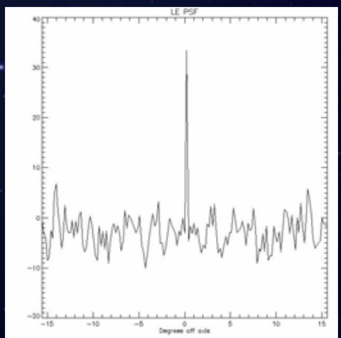
Studies were performed to estimate, the performance of ASTENA's WFM-IS modules in terms of imaging and polarimetry.

- Optimisation of the **double scale design of the mask** of the WFM modules to achieve the 1 arcmin target of point source location accuracy; The high energy mask is made of Tungsten 1 mm thick, while the low energy mask is made of stainless steel 0.5 mm thick.

The low energy (< 30 keV) mono-dimensional mask of length 157 and throughput of ~66% together with the its psf.
The mask sequence is based on triadic residues.

The low energy mask high throughput (around 60-70%) allow a combined fine/course mask pattern to have a throughput of 50% at high energy, and therefore 30-35% at low energy.

The complete mask (high +low energy) with the low energy psf for the fullmask.

The high energy mask is based on a URA design.

WFM-IS Actvity up to now

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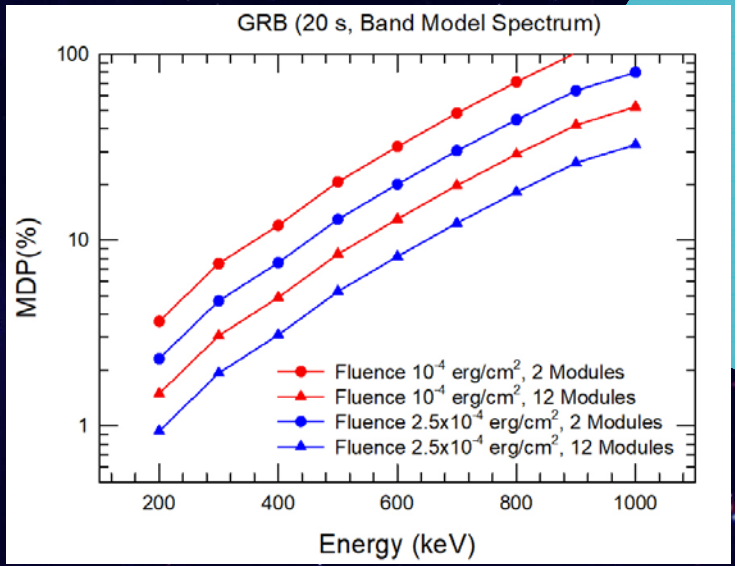
- Estimation of the ability to localize the position of a source by means of Compton kinematics.

Assuming 5 cm length of the CsI bars, and exploiting the 3D spatial resolution of the bars (5 mm in each direction) for double events generated by Compton interaction of 1 MeV incident photons, a simple semi-analytical estimate of the source location accuracy gives:

	ΔE/E=5%,	ΔE/E=10%
phot att	~8°	~18°
tot att	~30°	~35°

The results depending on counts statistics and scattering distance distribution.

- Preliminary evaluation of the performance as scattering polarimeter of the CsI bar detector (still assuming square section)



Minimum Detectable Polarization at 3 level for a GRB of 20 s duration and 2 different fluences.

The assumed spectrum is a Band law with low-energy photon index = 1,0, high energy photon index = 2,3 and peak energy of the EF(E) spectrum = 300 keV.

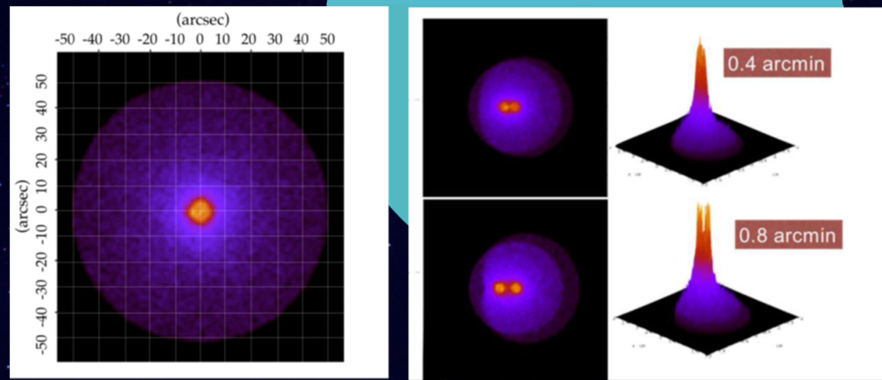
NTF Activity up to now

Concerning ASTENA's NFT instruments, the activity has focused on the evaluation of the expected performance in terms of sensitivity and polarimetric capabilities.

- ❑ The improvement of the simulation tool used to evaluate the effective area of the Laue lens in the 50-600 keV pass band and its response function, with the implementation:

- ➢ of a more realistic numerical model to estimate the first order Laue crystal reflectivity, plus
- ➢ the inclusion of the higher order diffraction to improve efficiency at higher energies

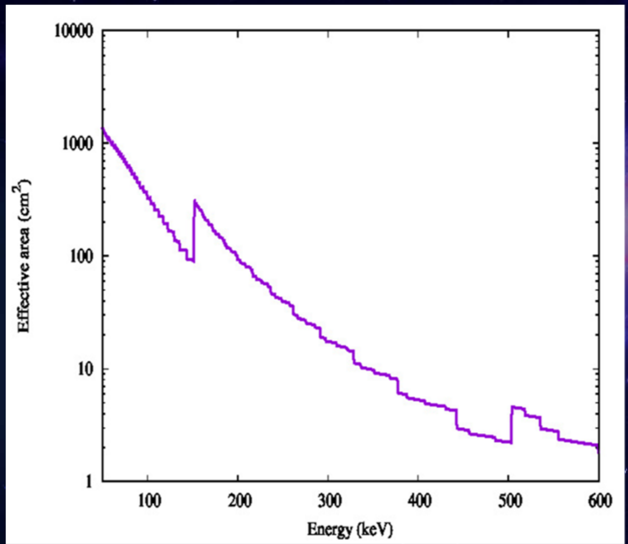
Best choice: Si(111) for 50– 70 keV; Ge (111) from E >170 keV



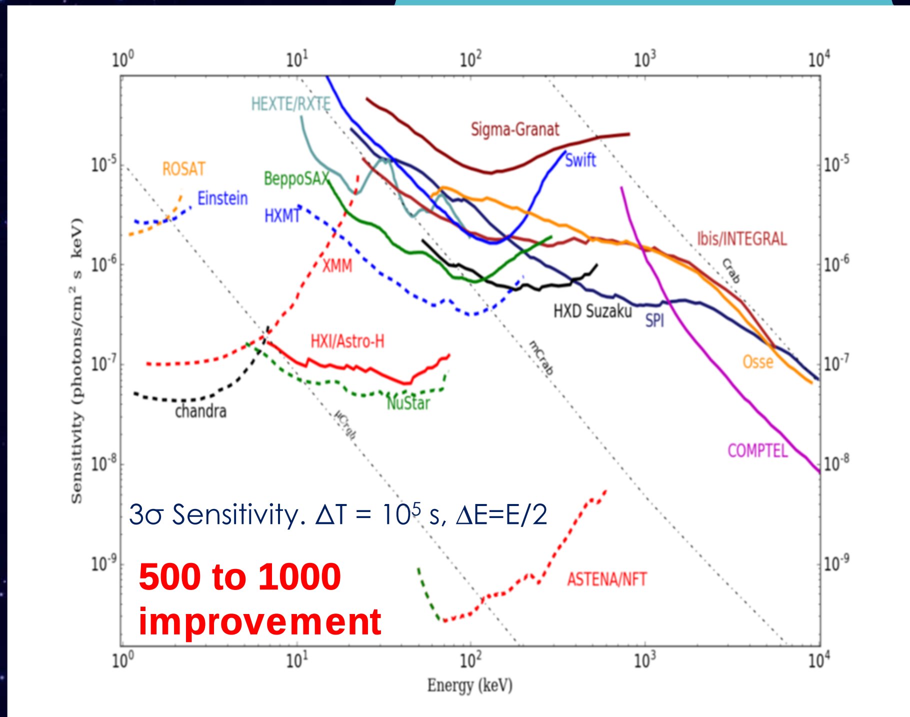
The Laue lens PSF simulated using the new SW tools for the case of a on-axis point source and two source a different angular distance in the Lens FOV.

NTF Activity up to now

- Development of a new user interface for the software tool (based on Laue Lens Library) to simulate the spectro-imaging capabilities of the Laue lens with Si and Ge crystals.
  - this now includes new functionalities and allows the access the full set of parameters (crystals properties, geometrical configuration, input source).



The ASTENA Laue Lens efficient area evaluation as a function of energy obtained with the improved sw tool



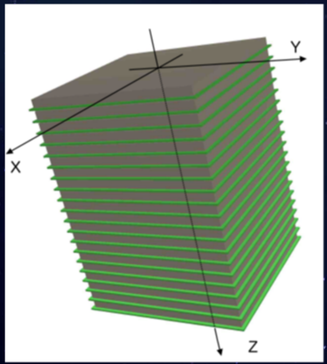
The «new» sensitivity of the ASTENA telescope with the improved efficient area evaluation. Focusing instruments (dotted lines); Non focusing instrument (continuous lines)

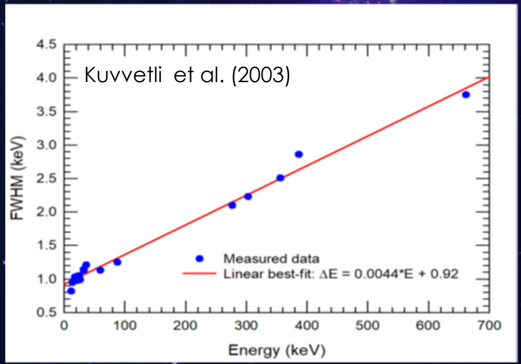
NTF Activity up to now

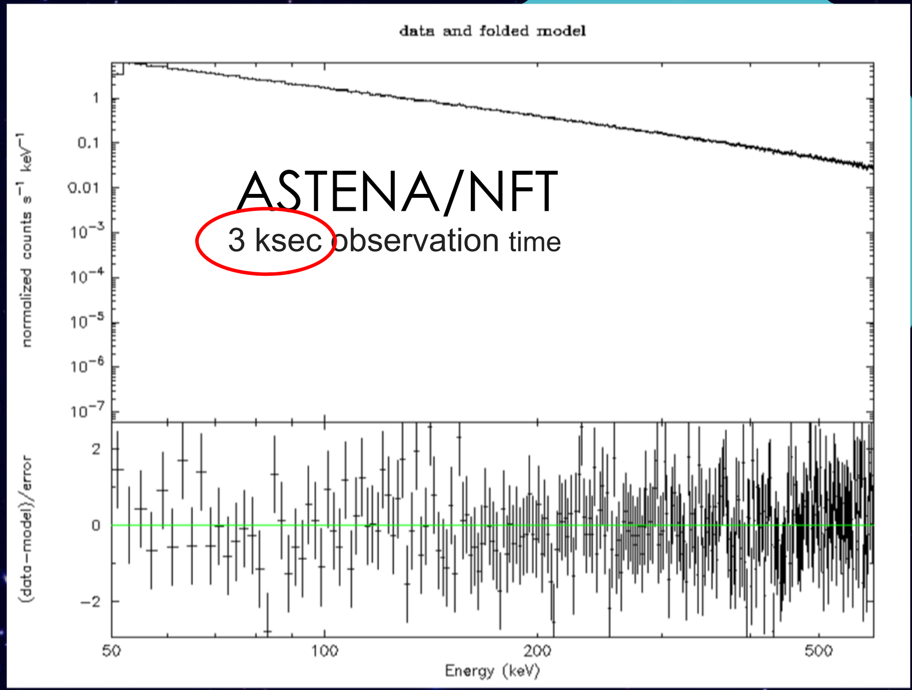
- Implementation of a simple, but flexible, numerical model of the 3D CZT spectro-imager for the NFT focal plane using the MEGAlib package to simulate the response of the entire telescope using as input the output of the Laue Lens sw tool.

These new developments have allowed us to:

- Build a first version of the NFT response matrix in FITS format (RMF and ARF files), which can now be used in XSPEC to verify the NFT performance and assess specific science cases, both for continuum and line sources.



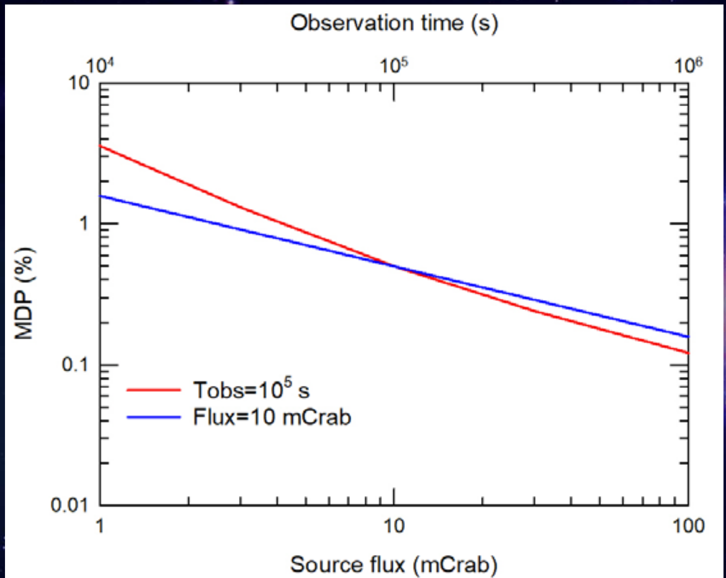




First simulated spectral response of a Laue lens based instrument: Crab Nebula spectrum (Power Law of index -2.1, normalization = 9.7)

NTF Activity up to now

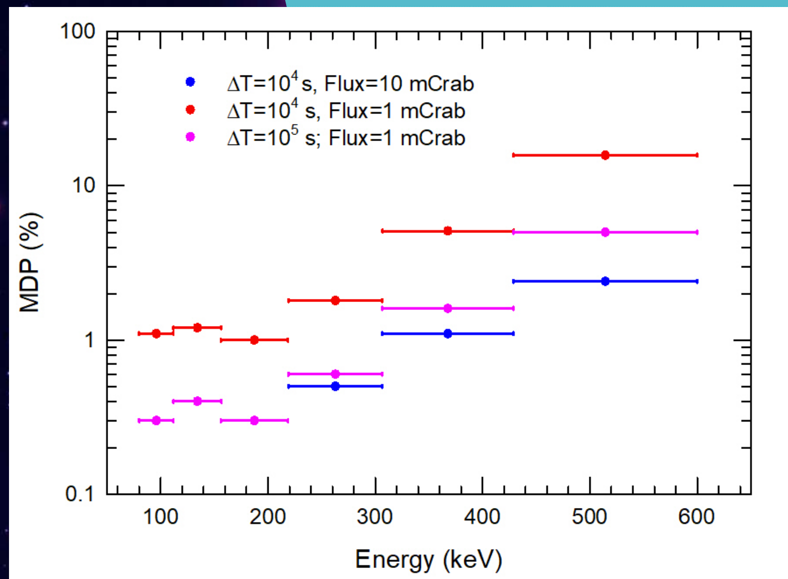
- Refine the evaluation of the polarimetric performance of the ASTENA NFT telescope in different energy bands and for different source fluxes based on the new efficient area figure and detector numerical model.



Minimum Detectable Polarization (MDP) in the full (50-600 keV) Laue lens passband, in 10^5 s, as a function of the polarized source intensity (red line) and, for a 10 mCrab source, as a function of the observation time (blue line).

In both cases, we assumed a modulation factor of the detector of Q_{100} = 0:6 Background derived with scaling from INTEGAL/SPI

MDP in different energy ranges and observation times.



Dissemination and communication activities
(on going and carried out)

- The results of the described activities will be reported in a paper for Astronomy and Astrophysics currently in preparation by the international collaboration team
- The matrix response of the NFT will be made available through the LARIX portal to the science community for observations simulations and studies of relevant science cases.
- A significant fraction of this NFT design improvement has been the subject of a Master Thesis by Lisa Ferro (defended on Sept 17, 2020), entitled "*Simulations and experimental activity in support of the ASTENA concept mission proposed to ESA*".

Next steps

- MonteCarlo model improvements for both the WFM-IS module and the NFT based on the Megalib suite and the new tools for Laue lens transfer function evaluation.
- Measurements at laboratories of the collaboration and at external facilities (e.g ESRF, Grenoble) on both the mentioned detector prototypes (CsI-SSD module, and 3D CZT sensor) to asses the achievable performance in term of spatial resolution, spectroscopy, and polarimetry capability.
- Developments of algorithms based on neural network and self-learning for events treatment and reconstructions to be applied both on experimental data obtained by measurements on detector prototypes.
- Continue the feasibility study to implement double focusing to correct coma aberration of Laue lenses in the current configuration.
- Continuous updating of the response matrix of both the WFM and the NFT to allow scientists to perform increasingly reliable simulations to study predicted scientific cases and new observational scenarios. This updating is of course a direct product of the previously mentioned activities