ASTENA Narrow Field Telescope: focal plane detector simulations

Enrico Virgilli
on behalf of the AHEAD/ASTENA collaboration

University of Ferrara - Italy
INAF-IASF - Bologna - Italy
DTU - Technical University of Denmark - Copenhagen
University of Coimbra/LIP, Portugal
Summary

Astena WFI and NFT main features

Goals of this progress activity

Laue lens sensitivity discussion

New features in the Laue lens optics

NFT detector geometry

MEGAlib simulations
Advanced Surveyor of Transient Events and Nuclear Astrophysics (ASTENA)

Narrow Field Telescope (NFT)
- broad band
- large collection area
- LAUE lens

Wide Field Monitor Spectrometer (WFM/S)
- 6 blocks
- 18 modules
- total detector area \( \sim 18000 \text{ cm}^2 \)
- 1 keV - 20 MeV
- \( >1 \) sr FoV

focal plane detector
- 3D CZT
ASTENA Narrow Field Telescope (NFT)

**optics configuration**
- pass-band 50 - 700 keV
- 20 m focal length
- Si 111 + Ge 220
- crystal dimensions: 30 x 10 x (optimized thickness) mm$^3$
- 43 rings
- Rin/out= 18 cm / 149 cm
- Filling Factor 93%
- Total Geometric Area 69800 cm$^2$ $\sim$ 7 m$^2$ !!

**focal plane detector requirements**
- detection efficiency $> 80\%$ @ 700 keV
- 3D imaging capability = 300 $\mu$m (x, y, z direction)
- fine spectroscopy response 1 % @ 511 keV
Goals of this progress activity

**Laue lens optics**

Definition of:

- optimized crystal size and crystal dimensions
- instrument field of view

**Focal plane detector**

Definition of:

- detector geometry (layers, thickness)
- detector material
- detection area
Laue lens sensitivity

Due to the effect of integration above the Effective area $A_{\text{eff}}$

All mission compared:

$$\Delta E = \frac{E}{2}$$

$$T = 10^5 \text{s}$$

$3 \sigma$
Laue lens optics updates
Laue Lens Library (LLL): SILC (Barriere et al.) geometry implemented

SILC tests in @ LARIX facility - Ferrara (within WP4 AHEAD TransNational Access program)

- flat mosaic
- flat perfect
- bent mosaic
- bent perfect crystal
- stack of flat crystals
- SILC

quite easy inclusion in LLL being it already conceived for modular elements

link between WP4 and WP9
real comparison between simulations and experiments

credits to Cosine measurement systems http://www.cosine.nl/
taken and adapted from Girou et al. (2017) SPIE Optical Engineering + Applications, 2017
Laue Lens Library (LLL): SILC (Barriere et al.) geometry implemented
NFT - field of view

NFT - FoV is limited by aberration effects of the Laue optics. Bent crystals help to reduce this effect with respect to flat crystals.

\[ \text{FoV} = 3.6' \text{ corresponds to a minimum detector size of } 24 \times 24 \text{ mm}^2 \]
Focal plane detector simulations
Starting point

Ideal PSF (only lens focusing contribution)

Focal plane reconstruction and dependance on energy.
MEGAlib simulations

GEOMETRY AND DETECTOR INFORMATION → SIMULATION

EVENT SELECTION AND TRACK RECONSTRUCTION → IMAGE RECONSTRUCTION

20 mm
5-10 cm
20 mm
Detector optimization geometry

4 CdZnTe modules required to complete the NFT - FoV

Single CZT unit 20 x 20 x 5 mm + read out electronics

4 CZT packed units
Detector parameters and optimization

at present a simple detector geometry is considered
no electron tracking selected

Voxel 3d 300 x 300 x 300 μm³

Number of layers: 2 - 20

layers distance: 0.5, 0.75, 1.0 cm
MEGAlib simulations

GEOMETRY AND DETECTOR INFORMATION  \rightarrow  SIMULATION  \rightarrow  EVENT SELECTION/TRACK RECONSTRUCTION USING THE BEST QUALITY FACTOR  \leftarrow  IMAGE RECONSTRUCTION

COSIMA setup

- Triggered events = $10^4$
- Single lines: 90, 250, 511, 650 keV
- Polychromatic spectrum: 90 — 600 keV
- only on axis source
On axis source

Using only first interaction

Number of layers: 10

Layers distance: 0.5 cm

Using all interactions
Different effects act in opposite manner

1. **Low energy** photons are photoelectrically absorbed at outward layers

2. **Low energy** photons come from outer radii (large diffraction angles)

~2° —> if the interaction occur at:

- 10 mm depth: —> ~ 4”
- 20 mm depth: —> ~ 7”
Next steps

- Complete the NFT geometric model (to be defined in DTU next July)
- Continuum sensitivity with real detector efficiency (until now used 0.9)
- Move to the science case (e.g. diffuse 511 keV emission, blazars spectra)
The advanced surveyor of transient events and nuclear astrophysics (ASTENA) mission within the AHEAD project

P. Rosati\textsuperscript{1}, E. Virgilli\textsuperscript{1}, F. Frontera\textsuperscript{4}, C. Guidorzi\textsuperscript{1}, E. Caroli\textsuperscript{2}, J. B. Stephen\textsuperscript{2}, N. Auricchio\textsuperscript{2}, L. Amati\textsuperscript{2}, M. Orlandini\textsuperscript{2}, F. Fuschino\textsuperscript{2}, L. Bassani\textsuperscript{2}, R. Campana\textsuperscript{2}, C. Labanti\textsuperscript{2}, A. Malizia\textsuperscript{2}, I. Kuvvetli\textsuperscript{3}, C. Budtz-Jørgensen\textsuperscript{3}, S. K. Brandt\textsuperscript{3}, G. Ghirlanda\textsuperscript{4}, R. Gilli\textsuperscript{2}, R. M. Curado da Silva\textsuperscript{5}

\textsuperscript{1} University of Ferrara (Italy);
\textsuperscript{2} INAF - IASF Bologna (Italy);
\textsuperscript{3} Technical University of Denmark (Denmark);
\textsuperscript{4} INAF - Osservatorio Astronomico di Brera;
\textsuperscript{5} Universidade de Coimbra (Portugal);

Abstract

Within the AHEAD consortium a mission concept named ASTENA (Advanced Surveyor of Transient Events and Nuclear Astrophysics) is proposed to address the top-priority themes identified by the AHEAD Science Advisory Group: Gamma-Ray Bursts and Nuclear Astrophysics. With the wide field monitor/spectrometer (WFM/S, 1 keV - 20 MeV) we expect to accurately determine the energy spectrum of all type of Gamma Ray Bursts (GRBs) prompt emission in the broadest band ever achieved with a single instrument, to measure the gamma-ray polarization of, at least, the brightest GRBs and to search for electromagnetic counterparts of Gravitational Waves triggers. With the narrow field telescope based on Laue lenses (NFT, 50 – 700 keV), which is at least 100 times more sensitive at a few hundred keV than any other past or planned mission, we can carry out for the first time a long-sought study of the afterglow spectrum of GRBs up to high energies (600/700 keV), including its polarization level.
The Narrow Field Telescope on board the ASTENA mission

E. Virgilli¹, P. Rosati¹, F. Frontera¹, E. Caroli², L. Amati², J. B. Stephen², N. Auricchio², Cr. Guidorzi¹, M. Orlandini², L. Bassani², A. Malizia², S. Silvestri², A. Basili², I. Kuvvetli³, C. Budtz-Jørgensen³, R. M. Curado da Silva⁴, C. Labanti², F. Fuschino², R. Campana², S. K. Brandt⁵

¹ University of Ferrara (Italy);  
² INAF - IASF Bologna (Italy);  
³ Technical University of Denmark (Denmark);  
⁴ Universidade de Coimbra (Portugal);

Abstract

The ASTENA mission, conceived in the AHEAD framework, consists of two coaligned instruments, a broad band Wide Field Monitor/Spectrometer WFM/S and a broad band Narrow Field Telescope (NFT). In the NFT a large geometric area Laue lens (3 m diameter, 20 m focal length) allows to focus the radiation of the 50 - 700 keV energy pass-band. Differently from other proposed Laue lenses in the past, the NFT is made of optimised thickness bent crystal tiles, made with Silicon and Germanium. With these assumption we have optimised the instrument Field of View (FoV) to 3.5 arcmin with the angular resolution of 20”. The Laue lens is coupled with a high efficiency (>80% above 600 keV) focal plane position sensitive detector, with 3D spatial resolution of at least 300 µm in the (X,Y) plane and fine spectroscopic response (1% @511 keV) and with polarization sensitivity. In this SPIE contribution we will discuss the NFI geometry and its simulated performances.
The wide field monitor and spectrometer instrument on board the ASTENA satellite mission concept

F. Fuschino², L. Amati², R. Campana², E. Caroli², G. De Cesare², F. Frontera¹, C. Labanti², M. Orlandini², P. Rosati¹, E. Virgilli¹

¹ INAF - IASF Bologna (Italy);
² University of Ferrara (Italy);

Abstract

The ASTENA mission concept under study in the framework of the H2020 AHEAD project includes a wide field monitor (WFM), mainly dedicated to GRBs. The instrument is sensitive in the range 1 keV - 20 MeV. The total isotropic detection area of the will be ~ 1.8 m² with a FOV of at least 1 sr. The WFM will allow the detection, both spectroscopic and polarimetric characterization of all classes of GRBs. Each module is a coded mask telescope that will allow the source localization within few arcmin up to 50/100 keV. The detector core is based on the coupling of low-noise, solid-state Silicon Drift Detectors (SDDs) with CsI(Tl) scintillating bars. Low-energy and high-energy photons are discriminated using the on-board electronics. The instrument design and preliminary experimental characterizations are reported and discussed.
Laue lenses made with bent mosaic crystals: comparison between simulations and experimental results

E. Virgilli¹, L. Ferro¹, et al.

¹ Department of Physics, University of Ferrara, Via Saragat 1/c, 44122 Ferrara, Italy
² IMEM Institute, CNR, Parco Area delle Scienze 37/A, Parma 43124, Italy e-mail: virgilli@fe.infn.it

Received, accepted

ABSTRACT

Context. Laue lenses made with bent crystals represents a challenging way to focus the radiation from the Gamma ray sky. Investigate the possibility of using bent crystals represents a new window that only recently started to be a real possibility.

Aims. It is shown that the crystals curvature radii represent a very important parameter to be carefully investigated, given that is capable to minimize the psf. The distortion of the photon distribution on the focal plane detector due to the effects of crystal misalignment and radial distortion with respect to the nominal curvature are discussed.

Methods. A software named laue lens library lli has been developed for the purposes. In the Monte Carlo code, all the main parameters have been taken into account. The ray tracer

Results. We have found that a radial distortion of 5-10% with respect to the nominal curvature radius can be accepted to turn into a worsening of the on-axis psf of about 10%. In this paper we have shown our method to realize a prototype with an unprecedented accuracy and stability in long time monitoring.

Conclusions.

Key words. Focusing telescopes; X-ray diffraction; Laue lens; Experimental astronomy; High energy instrumentation
\[ \Delta E = \frac{E}{2} \]
we are performing simulations

coupling simulations with experimental activity (e.g. SILCS)

we are matching simulations of the detector with the state-of-art detectors for focusing instruments

300 x 300 x 300 is the goal of DTU activity