ASTENA

Advanced Surveyor of Transient Events and Nuclear Astrophysics

Simulation Working Group Meeting

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The ASTENA payoload: two complementary high performance instruments covering the 1-20000 keV range.

- **A modular wide field monitor/spectrometer (WFM/S),** with a passband from 1 keV to 20 MeV. Each detector module is coupled to a light coded mask, for GRB localization accuracy of order of ~1' between 1 and 50/100 keV. The number of modules is sufficient to achieve the sensitivity for GRB science requirements. The total isotropic detection area will be ~ **1.8 m^2** with a FOV of at least 1 sr. The
- **A narrow field telescope (NFT),** made of a broad-band Laue lens (50 – 600/700 keV) of a 15-20 m focal length, with a FOV= 2-3 arcmin, and an angular resolution of ≈20". The NFT is coupled to a high efficiency (>80% above 600 keV) focal plane position sensitive detector, with 3D spatial resolution of ~300 μm in the (X,Y) plane, fine spectroscopic response (1% @511 keV) and with polarization sensitivity.

ASTENA Hot scientific points (1): Gamma-Ray Bursts

- Unprecedented performances of the **WFM/S** for the detection, characterization and localization within few arcmin of all classes of GRBs: high-z (**-> GRB cosmology**), soft/weak (**GRB-SN connection**), short (-> **GW and multi-messenger astrophysics**), ultra-long (-> **pop III stars**)

- **WFM/S** measurements of GRB spectra, light curves and polarization over an unprecedented energy band (1 keV – 20 MeV) with large effective area and excellent energy and time resolution (-> **GRB physics, fundamental physics with GRBs**)

- Investigation of the poorly unexplored X-ray afterglow emission above 10 keV and of the totally unexplored soft gamma-ray afterglow emission with the **NFT** (-> **GRB and shock-emission physics, GRB jet structure and energetics**)

ASTENA Hot scientific points (2): Nuclear Astrophysics

- **NFT** Measurements with unprecedented sensitivity and angular resolution of the 511 keV annihilation line from the GC with the: **origin** (diffuse vs. discrete sources), **hints of dark matter**, **physics of galactic sources**.

- **NFT** measurements of the intensity and time behavior of the expected lines emitted by the heavy elements produced in supernova explosions: **nuclear burning processes in Type-1a supernovae** (impact on SNe-Ia cosmology) and from hypernovae associated to GW events after-glow

- MORE…………………… (see scientific case)

ASTENA Hot scientific point: Hard X-ray polarization studies

- **Target for ASTENA NFT: MDP < 1% for a mCrab source**
- **Target for ASTENA WFM/S: MDP ~10% for a mCrab source**

- **Polarimetry for prompt GRB emission (from 10 keV up 10/20 MeV) with WFM/S**
- **Polarimetry for high energy follow-up (60-600 keV) with NFT**

Hard X/soft γ-ray Polarimetry will become a standard observing mode

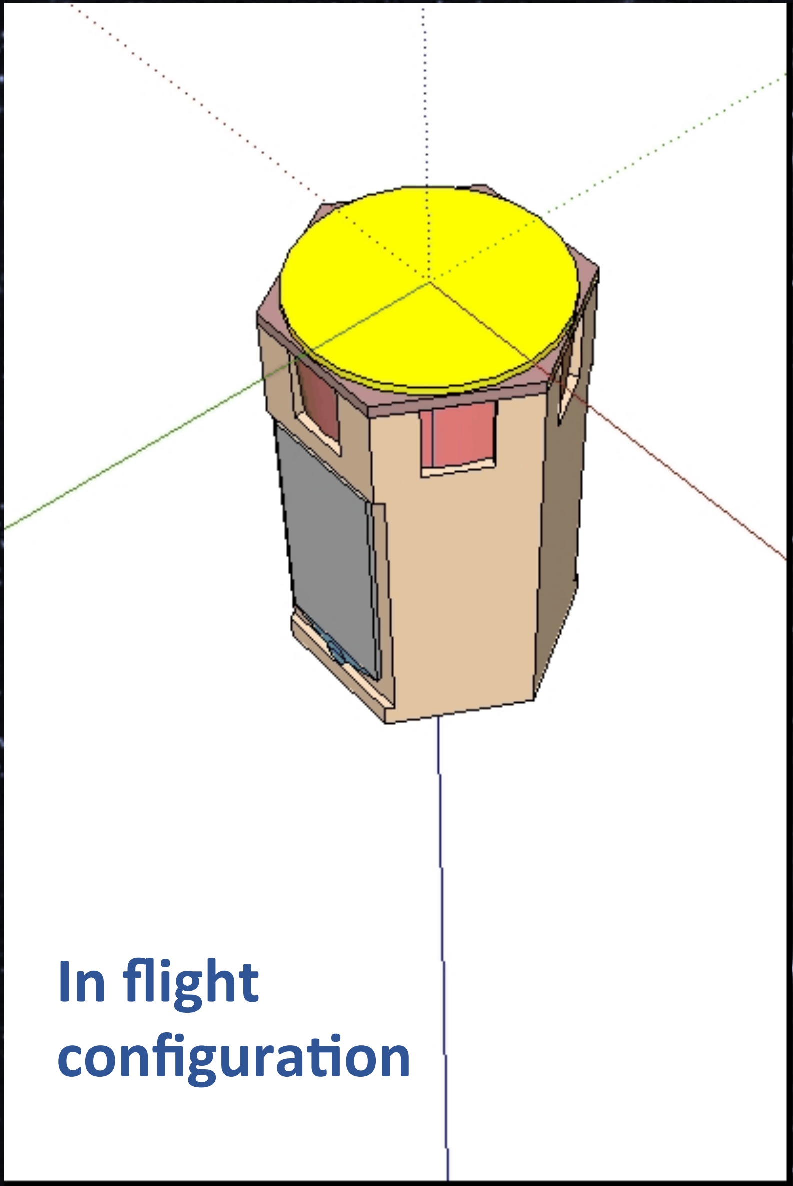
ASTENA main configuration (updated)

- One of the scientific main target of ASTENA is the high energy follow-up of GRBs;
- This will be achieved by the ASTENA NFT with two order of magnitude jump in sensitivity, up to 600 keV;

WFM/S modules and NFT are partially coaxial.

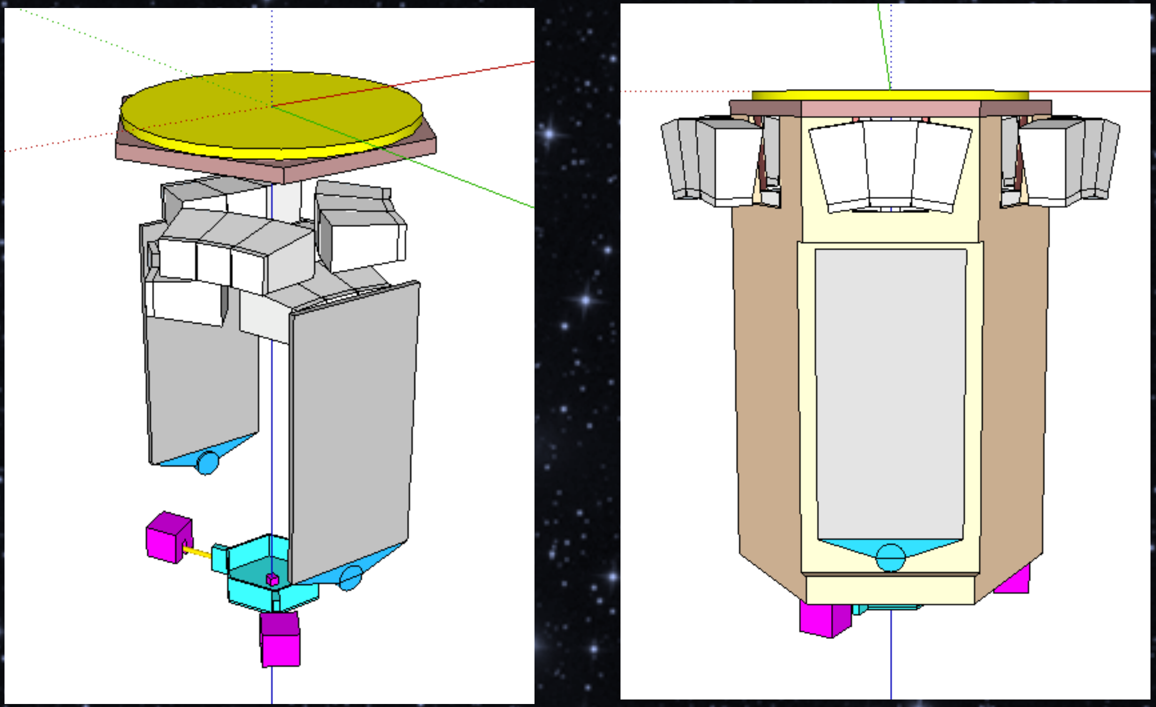
This configuration guarantees that the NFT field of view is centred in the WFM FOV.

ASTENA Satellite configuration (updated)



Laue Lens (∅ 3 m)

WFM/S (18 modules)



(left) WFM/S closed configuration;
(right) open configuration.

ASTENA: Optimisation & Performance evaluation

ASTENA Simulation Working Teams:

- **WFM/S configuration optimisation**
  INAF/IASF-Bologna (Italy): M. Orlandini, Fabio Fuschino, R. Campana
- **WFM/S Performance Simulation:**
  INAF/IASF (Italy), CEA/Irfu-Saclay.: E. Caroli, C. Labanti, G. De Cesare, P. Laurent
- **NFT Optimisation and Simulation:**
  UniFe, INAF/IASF (Italy), DTU-Space (Denmark), LIP-Coimbra (Portugal): E. Virgilli, Rui M. Curado da Silva, Irfan Kuvvetli

ASTENA-NFT: Optimisation & Performance evaluation

- **Broad band Laue Lens configuration optimisation and simulation**:

Development of a ray tracing program to optimise mainly the PSF, the efficiency, and the FOV of the Laue Lens optics.

- Produce the impinging focal spot (position, direction and energy of each photon focused on the top focal plane surface) for different observations.

- **Focal Plane detector optimisation and simulation:**

Development of a GEANT4/MEGALIB model of the CZT 3D spectro-imager focal plane and subsystems (shield, baffle, electronics volumes):

- Evaluate the sensitivity and MDP as function of configuration and operating parameters (e.g. 3D spatial and energy resolution, background, etc.) and for different types of observation defined by the Laue Lens photon list outputs

ASTENA-WFM/S: Optimisation & Performance evaluation

➢ **Overall WFM/S configuration optimisation**:

❖ Development of a ray tracing program to optimise the FOV and the exposed sensitive area of the WFM/S instrument.

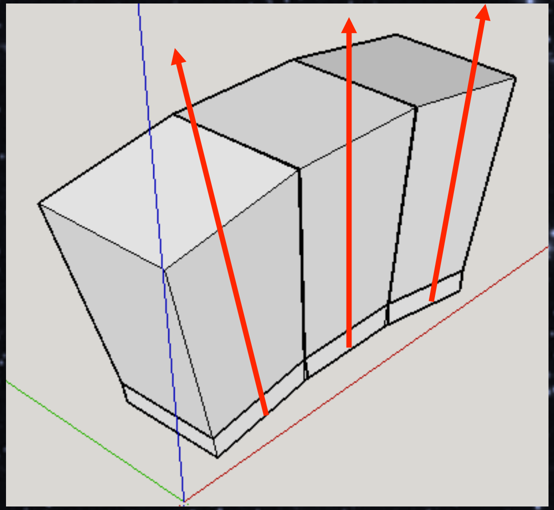
❖ These tools will be used to decide the best trade-off between the number of modules per block, their respective axis of orientation with respect to the NFT optical axis

➢ **WFM/S Performance evaluation:**

❖ Development of a GEANT4/MEGALIB model of one WFM/S block (i.e. 3 coded mask telescopes/block);

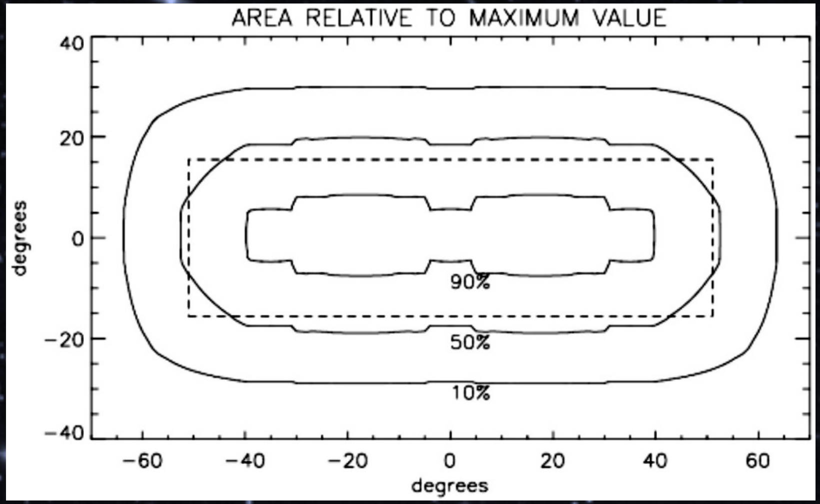
❖ To evaluate WFM/S Block performance (sensitivity and MDP) as function of relevant configuration (e.g. shape of sensitive elements and mask design) and operating parameters (e.g. spatial and energy resolution, background) and for different types of observation (e.g. source spectra and direction);

ASTENA : WFM/S Ray-tracing tool for configuration optimisation

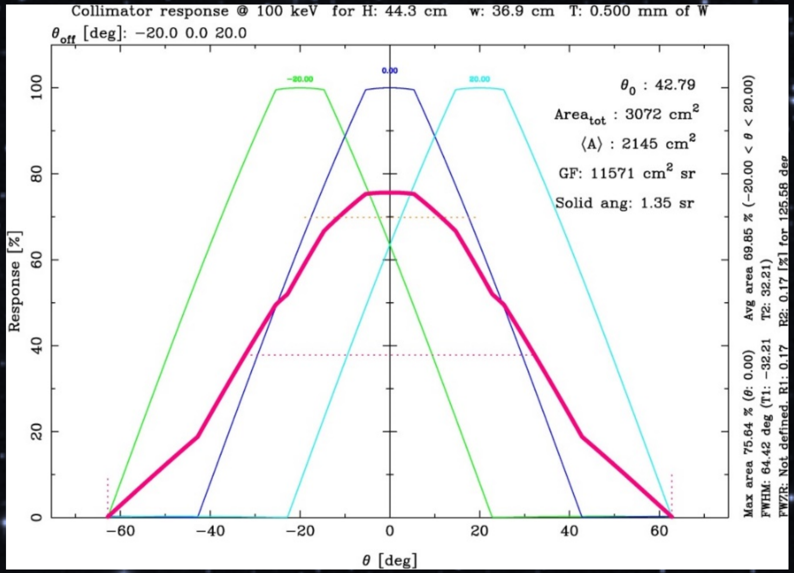


The BLOCK WFM/S assembly.

The red arrows represent the optical axis of each telescope module



The map of one WFM Block FOV at 100 keV with ± 20° offset of the module optical axes



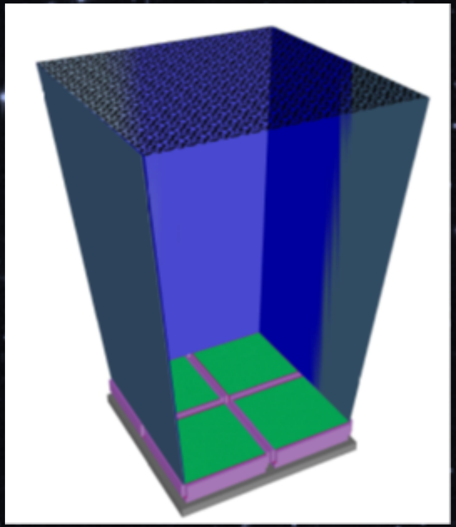
Profile of the FOV at 100 keV of one Block in the direction that crosses the three telescope modules

The total exposed area is ~3000 cm^2.

The FOV is 1.35 sr.

The Total field of View of the WFM/S (6 Blocks) will be the superimposition of the single Block «elliptic» FOV with each major axis rotated by 60°.

ASTENA : WFM/S GEANT4/MEGALIB Monte Carlo Model



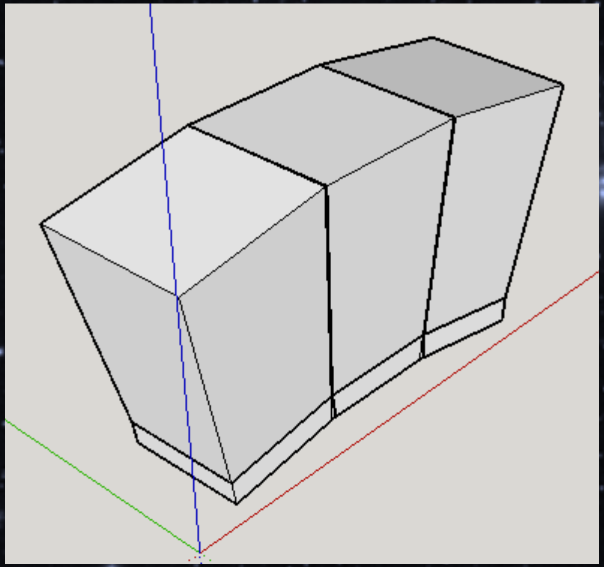
Single coded mask telecope.

Coded mask imaging up to 50/100 keV

Hopper FOV delimiter up to 150 keV

- The mask has a self-support pattern in order to guarantee the maximum transparency of the open elements
- The Hopper walls have graded thickness profile to optimize opacity and weight.

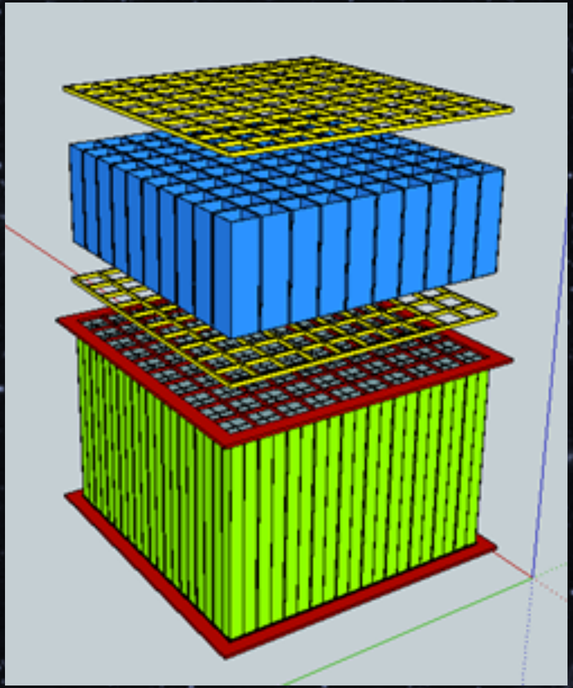
WFM/S module characteristics	
Mask Pattern	Random
Element size	5x5 mm
Pattern Open fraction	30%
Dimension	50 cm xn50 cm
Mask-Detector Dist.	70 cm
Mask Material	Steel
Mask Thickness	0.5-1 mm
Hopper Material	W
Hopper thickness	**0.1-0.5 mm**



WFM/S Block Unit

The relative inclination (offset) between the optical axis of each module shall be optimized to maximize total FOV, but taking into account satellite bus constraints.

ASTENA : WFM/S GEANT4/MEGALIB Monte Carlo Model 1/2



Details of the volumes that are defined in the WFM/S detector array model

WFM/S detector module characteristics	
Energy band	2 keV – 20 MeV
# detection plane arrays	4
# of detector pixels/ array	32x32
pixel size/shape	3-5 mm/ Square/Hex
Low-energy detector (2-30 keV)	SDD 450 µm thick
High energy detector (20 keV-20 MeV)	CsI(Tl)/ (3-5 cm thick)
CsI bar element shape	Square/Hex

Material Definition in the MC model

- SSD Top: Silicon layer on a ceramic l layer
- Scintillator bar detector: CsI(Tl)
- SSD Bottom same as SSD top
- FEE: Silicon and FR4 material mixture.

ASTENA : WFM/S GEANT4/MEGALIB Monte Carlo Model 2/2

The MC model implements:

- ❑ Analytical model of spectral resolution of the SSD layers as function of energy
- ❑ Analytical model of spectral resolution of CsI bar elements as function of energy and interaction position along CsI bar axis (z)
- ❑ Analytical model of spatial resolution of CsI bar sensitive elements along axis.

The CsI bars detector is a 3D spectrometer, in which the position along the longest axis is given by:

$$z = 1/2 \, ? \, \ln(S_1/S_2)$$

Geometric shape SSD and CsI senstive elements:

Square/Hexagonal (preferred)

- ❖ This will have impact on the WFM/S module design (under evaluation)
- ❖ **Improvement** in the polarimetric performance (decreasing the square diagonal effect) and the Compton kinematic reconstruction that can be used for GRB localisation.

For the SWG discussion: Remarks for final results comparison

To help a correct comparison of the final results obtained for each mission concept proposals under study I think we shall define some common figure of merits:

- Define how the sensitivity (both in flux and polarimetry) shall be reported: observation time, number of sigmas, Energy delta (the classical $\Delta E=E/2$ or Energy bands)
- Define some reference observation for simulation: e.g. type of source (GRB and point source), spectrum, duration in time and/or variability.
- Define the reference background model (LEO Orbit)