The ASTENA mission concept: bringing the hard X-ray/soft gamma-ray sky into focus

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Hard X-/soft Gamma-ray astronomy is a key field for understanding the transient sky and for nuclear astrophysics, however, the sensitivity of the instrumentation beyond 70 keV is strongly limited by the use of no-focusing instrumentation. To overcome this limitation, a mission currently under study called **ASTENA (Advanced Surveyor of Transient Events and Nuclear Astrophysics)** has been proposed in the context of the AHEAD Horizon 2020 program and discussed in two white papers **[1, 2]** submitted to ESA for the "Voyage 2050" long term program. ASTENA (Fig. 1) consists of two complementary instruments: an array of wide-field monitors with imaging, spectroscopic, and polarimetric capabilities in the 2 keV–20 MeV passband (**WFM-IS**) and a Narrow Field Telescope (**NFT**) based on a Laue lens **[3]**, operating in the 50-700 keV range, with unprecedented angular resolution, polarimetric capabilities, and sensitivity (Fig. 5). We also propose a pathfinder of ASTENA, that will be submitted to ASI as an Italian small class mission with an international participation.

Narrow Field Telescope (~150 kg)
energy pass-band 50 – 700 keV

Focusing unit:
- Laue lens with 3 m aperture diameter
- 20-25 m focal length

Focal plane PSD detector:
- builds on CZT 3D position sensitive spectrometers:
  - 0.3 mm spatial resolution in all direction;
  - 1% (FWHM) at 600 keV **[4]**
- 8 x 8 cm^2 cross section
- 8 cm total thickness

Wide Field Monitor-Imaging Spectrometer (~800 kg)
energy pass-band 2 keV – 20 MeV

- builds on **THESEUS/XGIS [5]** detector developments
- 12 detection units equipped with coded mask
- imaging (PSLA = 1' @ E<30 keV; = 5' @ E<150 keV)

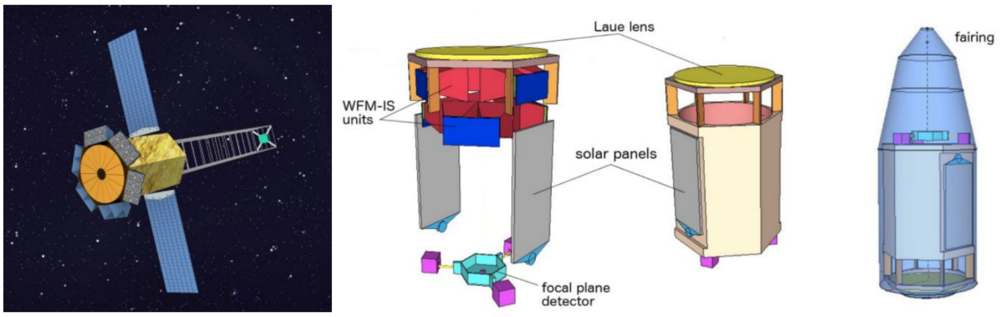

Fig. 1. Left: artistic view of ASTENA in-flight configuration. Right: a view of a possible accommodation of the ASTENA payload before the launch and how the payload could be accommodated in the fairing of the Soyuz or Vega C launchers.

The Narrow Field Telescope – NFT

The **NFT** is based on an **innovative Laue lens** (Fig. 2) based on bent Si(111) crystals working in 50-160 keV and on bent Ge(111) crystals operative for the energy range 160-700 keV. The size of crystal tiles is 30 x 10 mm^2, 2 to 5 mm thick depending on the diffracted energy. Simulations have been performed **[6]** in order to optimize instrument sensitivity, angular resolution and field of view (Fig. 3).

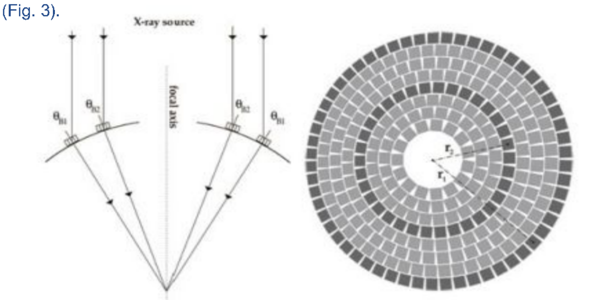

Fig. 2. Working principle of a Laue lens: each ring reflects a given energy passband, depending on the orientation of of the crystal tiles with respect to the incident radiation. According to the adopted geometry, inner rings diffract higher energies and outer rings the lower energies.

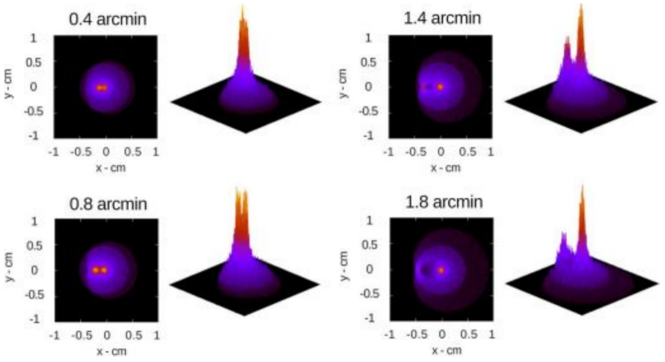

Fig. 3. As a single reflection device, off-axis sources are affected by coma aberrations. Within a limited field of view of 4 arcmin the instrument provides an unprecedented angular resolution of about 30 arcsec.

The Wide Field Monitor – WFM-IS

The **WFM-IS** is a Position Sensitive Detector (PSD) surmounted by a coded mask at 70 cm distance. The mask is supported by 4 Aluminum slabs with, inside, a Tungsten layer about 500 μm thick. Each PSD unit consists of an array of 4×8 modules, each module includes an array of 10x20 hexagonal scintillator bars (Fig. 4, center).

Hexagonal scintillator bars are read out **[7]**:
- **on the top** by linear multi-anode Silicon Drift Detectors (SDDs)
- **on the bottom** by hexagonal single anode SDDs

Imaging capabilities of the WFM-IS are obtained by means of a **double scale coded mask**, one for the high energy photons (30–150 keV) and one for the low energy photons (< 30 keV).

Fig. 4. Left: Schematic view of a WFM-IS unit. Center: portion of a detection module of a WFM-IS unit. Right: working principle of a SDD coupled with a CsI scintillator crystal. Soft X–rays interact directly in the SDD while gamma-rays are absorbed in the scintillator. Secondary photons are then detected with the SDD.

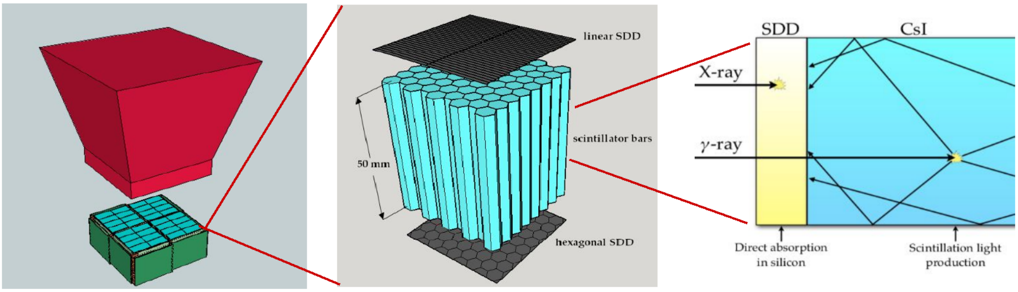

Table 1. The main properties of the two instrument foreseen in the ASTENA mission

	WFM-IS	NFT
Energy pass-band	2 keV – 20 MeV	50 – 700 keV
Total useful area$^{(a)}$	~ 5800 cm^2 (< 30 keV)	
	~ 6700 cm^2 (30–150 keV)	7 m^2 (projected)
	~ 13800 cm^2 (>200 keV)	
Field of View	2 sr	4 arcmin
Angular resolution	6 arcmin	~ 30 arcsec HPD
Point source localization accuracy	1 arcmin	< 10 arcsec

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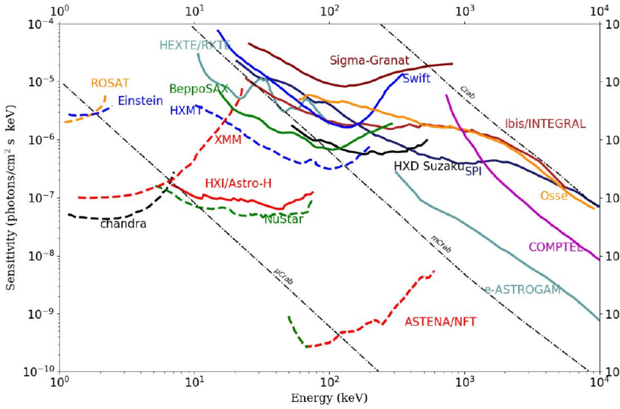

Fig. 5 Three sigma continuum sensitivity of the ASTENA/NFT telescope for 10^5 seconds and ΔE=E/2 compared with that of several no-focusing (continuum lines) and focusing (dashed lines) past, proposed, and still operating instruments. An ASTENA pathfinder we intend to propose to the Italian Space Agency has only the ASTENA NFT on board (with the sensitivity shown). A test of a small prototype of the NFT with lower focal length (around 8 m) is planned to be carried earlier with a balloon experiment.

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