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NHXM: a New Hard X-ray Imaging and Polarimetric Mission

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NHXM is a new hard X-ray imaging and polarimetric satellite mission characterized by a high spatial and energy resolution over a very broad energy band, from 0.3 to 80(120) keV, together with a sensitive X-ray imaging polarimetric capability. It is based on four identical mirror modules that, for the first time, will extend up to 80(120) keV the fine imaging capability today available only at E<10 keV. At the focus of three telescopes there will be three identical spectro-imaging cameras, at the focus of the fourth an X-ray polarimeter. The addition of a Wide Field X-Ray Monitor, sensitive in the 2-50 keV band, will also permit to detect transient phenomena. NHXM will provide a real breakthrough on a number of hot astrophysical topics, including: i) Black hole census, cosmic evolution and accretion physics; ii) Acceleration mechanism and non-thermal emission; iii) Physics of matter under extreme conditions.
A NHXM proposal has been submitted to the ESA 2010 Call for a Cosmic Vision M3 mission.

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1. Introduction

The exploration of the X-ray sky with simultaneous and deep observations in the soft and hard X-ray energy bands allows a detailed investigation of the physics of a variety of objects whose X-ray emission is often linked to the accretion and/or acceleration processes. However, while our knowledge of the sky below 10 keV has increased dramatically (∼8 orders of magnitude) by using grazing incidence optics, the same is not true above 10 keV, where to date only collimated instruments or coded mask telescopes are used, whose sensitivity and spatial resolution are order of magnitudes worse than those achieved below 10 keV. In addition, an almost totally unexplored field that can provide breakthrough insights in the physics of a variety of object classes is X-ray polarimetric astronomy. However, the lack of an efficient measurement tool has so far limited X-ray polarization observations only to one very bright and highly polarized source, the Crab Nebula. With the advent of a new generation of X-ray polarimeters time is now ripe for the exploration of this field. The relevance of these scientific topics has already prompted the approval of three missions, aimed at their investigation, that will provide first important answers to these topics. However, because of intrinsic (design) limits, several major goals lie beyond their capability. They are: NuSTAR (USA, due for launch in 2012), with prominent differences in band (7-80 keV) and angular resolution (about 45” HEW at 30 keV); Astro-H (Japan, 2014), with a much worse angular resolution (about 100” at 30 keV); GEMS (USA, 2014), a non-imaging polarimeter mission which must be rotated to average systematic effects (for a constant source). To fully uncover BH cosmic evolution, accretion physics, acceleration mechanisms and the physics of matter under extreme conditions a more significant leap forward is essential.

Following on the above considerations we propose the New Hard X-ray Mission (NHXM) that will achieve for the first time simultaneous high-sensitivity broad band (0.3-80 keV, with the goal to go up to 120 keV) X-ray imaging and spectroscopy and polarimetry in the 2-35 keV band. NHXM will host four identical telescopes with a focal length of 10 m, achieved after launch by means of a deployable structure (see Fig. 1). Thanks to the multilayer coating technology, the mirror modules will extend up to 80 (120) keV the fine imaging capability achievable by grazing incidence reflection. At the focus of three telescopes there will be three identical spectro-imaging cameras while the fourth telescope will focus on two polarimetric cameras. The addition of a Wide Field X-Ray Monitor, sensitive in the band 2-50 keV, will allow a continuous monitoring of the sky permitting the detection of highly variable sources and enabling the repointing of the narrow fields intruments within 1 hr.

NHXM will provide significant improvements on the study of many class of objects and scientific topics that are dominating the high-energy astrophysics and it will perform groundbreaking science in the following large areas of astrophysics and cosmology:

- **Black hole census, cosmic evolution and accretion physics**. The cosmic history of accretion (the dominant source of X-rays in the Universe) is encoded in the Cosmic X-ray Background (CXB). Resolving the CXB at its peak (30 keV) will provide invaluable insight into the interplay between the Super Massive Black Hole growth and the evolution of their host galaxies. Polarimetry and broad-band X-ray spectroscopy will provide information on the nature of the AGN primary component and the hard reflection component from circum-nuclear matter.

- **Acceleration mechanism and non-thermal emission**. The physics behind the formation

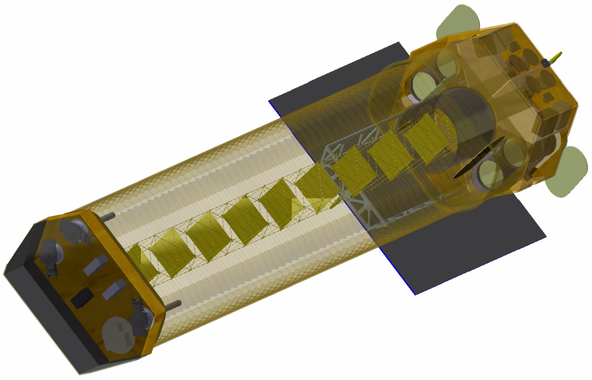

Figure 1: The NHXM satellite in its current configuration. The four mirror modules are on the satellite platform (top right corner in this figure) and the focal plane cameras on the detector platform at the end of the deployable truss (lover left corner). Note that a deployable blanket is foreseen to control the thermal-elastic deformation of the truss and protect the detectors from direct exposure to space environment.

of jets and their emission mechanisms, as well as the details of shock development and cosmic ray production remain quite poorly understood. Sensitive broadband imaging, spectroscopy and polarimetry can provide breakthroughs in all these phenomena, which can be responsible for significant energy injection into the interstellar matter in galaxies and intra-cluster gas.

- **Physics of matter under extreme conditions**. General relativistic effects on emission line profiles, on the continuum shape and on the polarization properties of the radiation emitted by the accretion disk can be used to estimate the BH spin, a key parameter for black hole birth and growth. The line and continuum methods already provide precise (in statistical terms) results. These are, however, often in disagreement each other, indicating insufficient control of systematics. This is likely due to poor knowledge of the underlying continuum. This can be overcome only by broadband, high throughput observations. The study of the polarization angle of the disk emission provides a third method to measure the BH spin.

A NHXM proposal has been submitted to the ESA 2010 Call for a Cosmic Vision M3 mission by a strong international team including institutions from: Australia, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Israel, Italy, Poland, Spain, The Netherlands, UK, USA (a full list of supporters can be found at http://www.brera.inaf.it/NHXM/supportingteam/).

2. The scientific payload configuration

Some of the most relevant scientific requirements of NHXM are listed in Table 1; while below we briefly describe the NHXM payload.

2.1 The mirror modules

The MMs will be based on nested electroformed Nickel-Cobalt alloy (NiCo) shells with Wolter I profile. There are a few improvements with respect to the mirrors realized with the same technology for other X-ray telescopes (e.g. Beppo-SAX, Jet-X/Swift and XMM-Newton): the NiCo

Table 1: some of the NHXM top-level scientific requirements.

Parameter	**Value**
Energy band	0.3–80 keV (goal 0.3–120 keV)
Field of view	$\geq$ 12’ (diameter)
On-axis effective area	$\geq$ 300 cm^2 at 0.5 keV; $\geq$ 1000 cm^2 at 2–8 keV $\geq$350 cm^2 at 30 keV $\geq$ 100 cm^2 at 70 keV
Detector background	$< 2 \times 10^{-4}$ ($< 2 \times 10^{-3}$) cts s^{-1} cm^{-2} keV $^{-1}$ HED (LED)
Angular resolution (HEW)	$\leq$20” (15" goal) at E <30 keV; $\leq$ 40” (goal) at E= 60 keV
Polarization sensitivity (100 ks)	10% MDP for 1 mCrab source (2–10 keV) 10% MDP for 1.8 mCrab source (6–35 keV)
Wide Field X-Ray Monitor	sensitivity of 2 mCrab in 50 ks at 5σ (2-50 keV); 1s trigger on a 0.5 Crab source providing the position in < 1 min; FOV= 2.9 sr partially coded, 0.5 sr fully coded

alloy instead of pure Nikel (Ni) offers a better stiffness and superior yield properties allowing a reduction in the thickness of the mirrors (2 times thinner than the XMM Ni shells); the use of a Pt/C multilayer, as X-ray reflecting coating, allows a larger FOV and an operating range from 0.3 keV up to 80 keV and beyond. The multilayer coating will be sputtered on to the internal surface of the gold-coated NiCo mirror shells that are built via replication from mandrels. The angular resolution requirement is of a Half Energy Width (HEW)$\leq$20" for energies lower than 30 keV and $\leq$40" at 60 keV. Several engineering models with Ni and NiCo integrated shells coated with W/Si and Pt/C multilayer films (up to 200 bilayers) have already been developed and tested at the Panter-MPE X–ray calibration facility, demonstrating the feasibility of mirrors with the quality requested by the NHXM [1, 2] . In the baseline configuration each MM is equipped with 70 Wolter-I Mirror Shells (parabola + hyperbola) with a focal length of 10 m and interface diameters in the range $\sim$390 to $\sim$150 mm. This shell configuration can already be produced with the current technological set-up at MLT. In the goal configuration the mirror sensitivity is extended up to 120 keV. This will be achieved by filling the internal hole of each MM with additional 20 mirror shells (to a minimum shell diameter of 110 mm) These additional shells will be fabricated via direct replication of multilayers (e.g. Pt/C/Ni) from TiN-coated superpolished mandrels (see ([3, 4]). The effective area for three mirror modules is shown in Fig. 2, both for the baseline and for the goal configuration.

2.2 The spectral imaging cameras and the polarimetric camera

The spectro-imaging detectors at the focus of three MMs have to match the high-energy X-ray multilayer optics performance over the broad 0.3 - 80(120) keV energy range, providing a very low background environment. A hybrid detector systems will be used with two detection layers, plus an effective anticoincidence system. Two very compact modules, hosting the Low Energy Detector (LED) and the High Energy Detector (HED), will also provide an active and passive shielding.

The LED will be placed on the top of the focal plane assembly and will essentially cover the energy range 0.3-10 keV. The baseline configuration foresees a back illuminated, NIMO, CCD-230/23 with 30 μm pixels (2048$\times$2048 format) and 120 μm (goal 150 μm) depletion layer device. Another possibility is to use a Macropixel detector based on an active pixel sensors concept,

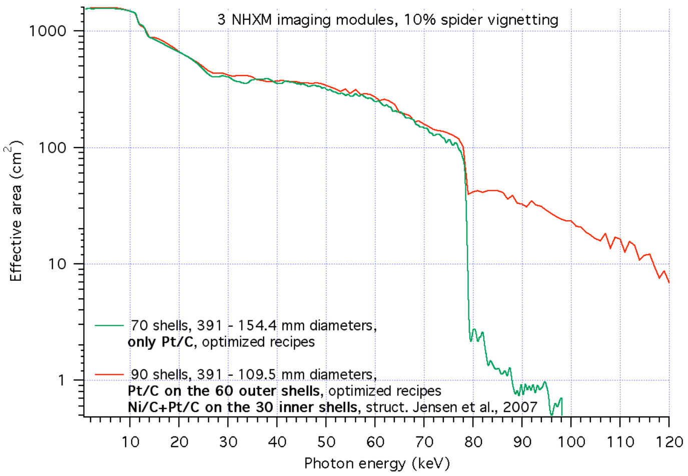

Figure 2: Effective area of 3 MUs; baseline (green), goal (red).

DEPFET (DEpleted P- channel Field Effect Transistor), that has already been extensively studied and characterized in the context of Simbol-X and IXO.

The HED will be mounted below the LED and it will perform spectral imaging of hard X-ray photons in the 7-80(120) keV energy band. The HED baseline is formed by four pixellated, 1mm thick and 2x2 cm size each, Schottky barrier CdTe crystals. Each pixel is connected to its own read-out ASIC electronics by a proper bonding. A first CdTe+ASIC hybrid module has already been realized using the same ASIC developped for the polarimeter XPOL (e.g. [5]).

Passive and active shielding surrounds the detector units except for the solid angle corresponding to the optics focused beam.This anti-coincidence system will be realized using well-known inorganic scintillators like NaI or CsI crystals, already successfully used in a number of focal plane detectors aboard X- and gamma-ray telescopes.

The polarimetric imaging camera is based on a Gas Pixel Detector (GPD), a position-sensitive counter with proportional multiplication and a finely subdivision of the charge collecting electrode: the ionization tracks produced in the gas by the photoelectrons are imaged, allowing the reconstruction of the direction of the first part of the track before it is randomized by scattering. The GPD is based on a gas cell with a thin entrance window, a drift gap, a charge amplification stage and a multi-anode readout plane which is the pixellated top metal layer of a CMOS ASIC analog chip. Two detectors, inside a single camera, will be located at the focus of a MM, by a sliding (or a rotary) device: a low energy polarimeter (LEP) and a medium energy polarimeter (MEP) [6]. The LEP permits sensitive imaging spectropolarimetry in the 2–10 keV energy band. The base-line mixture is He-DME at 1 atm with 1 cm absorption gap. The gas cell is a stack of MACOR frames. The MEP is similar to the LEP but for the gas cell which is filled with a Ar-DME mixture, at pressure of 3 atm and a thickness of 3 cm for an operating range of 6-35 keV. The LEP and the MEP will be housed in a box which also functions as a passive shield with a front baffle to exclude sky background. A filter wheel inside the box carries polarized and unpolarized calibration sources.

2.3 The Wide Field X-ray Monitor

The WFXRM design is based on the combinations of two Wide Field Camera Units (WFCU) whose design is based on the heritage of the SuperAGILE X-ray monitor that operates successfully since 23 April 2007 onboard the AGILE mission, demostrating the feasibility of a large-area, light, compact and low-power X-ray imager with an arcmin resolution and steradian- wide field of view. Each WFCU is composed by a 35x35 cm 2D Asymmetric Coded Mask coupled to a 20x20 cm Silicon Drift Detectors (SDD). The SDD has a one-dimentional read-out with a drift time of 5μs that provides an asymmetric 2-D position resolution. Together with the thin Tungsten asymmetric coded mask located 15 cm away from the detector layer, this provides an angular resolution of 3’ (in the readout direction) $\times 1.5^\circ$. The 2-D angular resolution of the WFXRM is achieved combining two WFCU, each rotated 90° with respect to the other and it is further enhanced by the coarse angular resolution of each WFCU on the second direction [7]. In the baseline configuration the WFXRM will be composed by 4 units, located inside the central platform cylinder and coaligned with the NHXM pointing direction. The addition of four more units, allowing for a full sky coverage, will be evaluated during the next phases.

The WFXRM will operate in an autonomous mode with an onboard data processing software, providing fast burst triggering (GRB in <1 s) and source location (PSLA <1 arcmin). It will also perform a X-ray sky survey in the 2-50 keV band.

3. Conclusions

The proposed NHXM mission is based on a novel concept that brings together for the first time simultaneous high-sensitivity, hard-X-ray imaging, broad-band spectroscopy and polarimetry. With this capability, NHXM will perform groundbreaking science in key scientific areas, including: i) Black hole census, cosmic evolution and accretion physics; ii) Acceleration mechanism and non-thermal emission; iii) Physics of matter under extreme conditions.

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