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NHXM: a New soft and Hard X-ray imaging and polarimetric Mission

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Abstract. The hard-x-ray band above 10 keV remains ripe for exploration at the high sensitivities and fine angular scales afforded by newly-developed hard-x-ray optics. Also ripe for exploration is the field of x-ray polarimetry, a fundamental tool, so far virtually unused, to understand the physics and morphology of X-ray sources, where non-thermal and/or spherical emission is common. The New Hard X-ray Mission (NHXM) 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: Black hole census, cosmic evolution and accretion physics, Acceleration mechanism and non-thermal emission, Physics of matter under extreme conditions.

Key words. Missions, X-ray imaging, X-ray polarimetry, black-holes, compact objects, accretion physics, acceleration mechanism, non-thermal emission, cosmology.

1. Introduction

Virtually every class of astrophysical object, from ultra-compact BHs and NSs, through normal stars, and star formation regions to diffuse hot plasma pervading galaxies and clusters of galaxies has been found to emit X-rays. Even planets and comets are known to be X-ray sources.

Thanks to these advances we know the three primary physical processes behind the emission of energetic radiation: accretion physics, astrophysical shocks, particle acceleration mechanisms. Thermal and non-thermal components can be cleanly separated above 10 keV, but unfortunately more than four orders of magnitude separate the sensitivity in hard Xrays achieved by BeppoSAX, Suzaku, INTEGRAL and Swift from that achieved by Xray telescopes below 10 keV. In addition, X-rays are usually emitted in highly aspherical geometries so that high degrees of polarization are expected (in contrast to the optical band, dominated by stellar processes). Unfortunately, although X-ray polarimetry was born in the 70s, advancements have so far been marginal.

A fine hard X-ray imaging and polarimetry observatory will allow, for the first time, to uncover the bulk of accretion power in the Universe, the physics of accretion and of cosmic accelerators.

To this end we have designed a new mission, NHXM. We will now briefly outline the scientific goals and provide a brief description of the mission.

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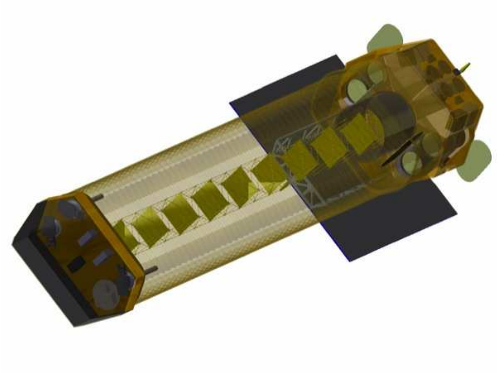

Fig. 1. An artistic view of the NHXM observatory. The four mirror modules are on the satellite platform and the focal plane cameras on the detector platform at the end of the deployable truss.

2. Scientific objectives

Black hole census, cosmic evolution and accretion physics. Accretion onto compact objects efficiently converts gravitational energy into radiation. This is the dominant process producing X-rays in the Universe. The cosmic history of accretion is encoded in the CXB, which peaks at 30 keV and is mostly produced at z=1-2. The origin of this hard emission, the sources responsible for its production, and the complex interplay between the AGN power and their host galaxies remain poorly understood. Resolving 70% of the CXB at its peak will uncover elusive AGNs heavily obscured by gas and dust. Follow-up studies of these objects will provide invaluable insight into the interplay between the SMBH 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 circumnuclear matter. Accretion can occur at very different rates. At very low accretion rates the complex physics involved will be investigated through the broad-band spectroscopy of the SMBH at the Galactic Centre, taking advantage of its flaring variability. Since this region is extremely crowded, excellent imaging capability is mandatory.

Acceleration mechanism and non-thermal emission. Winds and jets from AGNs propagate for extremely long distances (Mpc scales) and can be responsible for significant energy injection into the interstellar matter in galaxies and intra-cluster gas. However, despite a wealth of observations on this feedback process, the physics behind the formation of jets and their emission mechanisms remain quite poorly understood. Similarly, cosmic rays are believed to be accelerated in shocks, both in supernova remnants and in the intracluster medium. However, the details of shock development and cosmic ray production remain a mystery. Sensitive broadband imaging, spectroscopy and polarimetry can provide breakthroughs in all these problems.

Physics of matter under extreme conditions. General relativistic effects on emission line pro-files, 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 in understanding 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. Polarimetry extended to the 10-35 keV band will allow the detailed study of the broad cyclotron resonance, in accreting high-magnetic field X-ray pulsars where high polarizations are expected. Polarization measurements will test models for the transfer of radiation in these extreme conditions, and determine the field geometry.

3. The mission profile

NHXM is designed specifically to address the above topics via: broad 0.5-80(120) keV band for imaging and spectroscopy, 15 HEW angular resolution at 30 keV, sensitivity limits providing > 3 orders of magnitude better than those available in present day instruments, broadband (2-35 keV) imaging polarimetry.

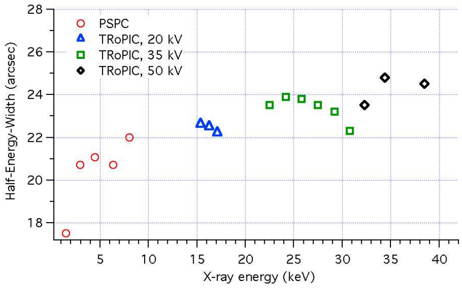

Fig. 2. HEW as a function of energy for an engineering model of NHXM measured at the Panter X-ray calibration facility.

In addition, NHXM has the ability to locate and actively monitor sources in different states of activity, permitting their detailed study.

The NHXM payload subsystems are based on development studies carried out in recent years, in some cases prototypes have already been built. The payload includes:

4 MM with good imaging capability in the band 0.3-80(120) keV; 3 MM are coupled with 3 SIC (two detection layers plus anticoincidence); 1 MM is coupled with the PIC: two 2-35 keV polarimetric detectors; 1 WFXRM sensitive in the 2-50 keV band to find active and transient sources.

The mirror modules: the four identical NHXM Mirror Modules will be based on nested confocal electroformed Nickel-Cobalt alloy shells with Wolter I profile. Nanostructured multilayer X-ray reflecting coatings will permit a larger FOV and an operating range from 0.3 keV up to 80 keV and beyond. These will be sputtered onto the internal surface of the gold-coated thin shells after replication from the mandrels. Each MM is equipped with 70 (90 in the goal configuration) shells with a focal length of 10 m and interface diameters in the range 390 to 150 mm. Several engineering models with integrated shells coated with W/Si and Pt/C multilayer films (200 bilayers) have been developed and tested at the Panter-MPE X-ray calibration facility (Fig. 2) demonstrating the feasibility with a microroughness of < 4 Å (Pareschi et al. 2009; Tagliaferri et al 2010).

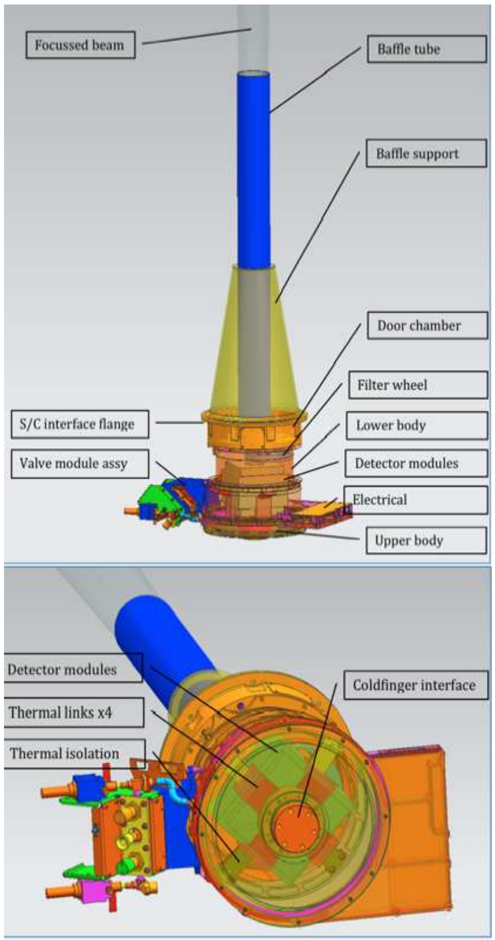

Fig. 3. The spectral-imaging focal plane camera.

The three identical spectral imaging cameras: X-rays focused by the mirrors enter the camera via an extended graded baffle tube, which protrudes 900 mm from the focal plane. The Low Energy Detector (LED) and High Energy Detector (HED) detectors are hosted inside two very compact modules, allowing for independent development. They will also provide an active and passive shielding to minimise the shielding mass by being in close proximity to the detectors (see Fig. 3). The baselined LED is an e2V CCD device thinned to 150 μm, to ensure adequate transmission for energies above 10 keV, with a 120 μm depletion layer (goal 150 μm, i.e. fully de-

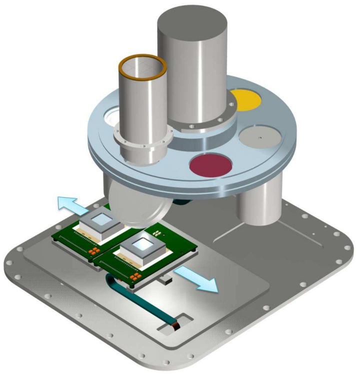

Fig. 4. The polarimetric focal plane camera.

pleted). An alternative solution would be to use a Macropixel detector based on an active pixel sensors concept (DEPFETs) already extensively studied and characterized in the context of Simbol-X and IXO (Lechner et al. 2008). The HED will be mounted below the LED and will perform spectral imaging of hard X-ray photons in the 7-120 keV energy band and it is based on a 1-2 mm thick pixellated CdTe detectors read out by a bump-bonded ASIC chip. The CdTe sensor is a Schottky type diode with Al contacts on the junction side. This type of configuration collects electrons at the pixels, and holes at the uniform ohmic contact on the opposite side. A first CdTe+ASIC hybrid module has already been realized, proving its feasibility (Bellazzini et al. 2010).

The polarimetric imaging camera. It will provide polarisation measurements simultaneously with angular, spectral and timing measurements. The instrument is based on a Gas Pixel Detector, a position-sensitive counter with proportional multiplication and a fine subdivision of the charge collecting electrode in such a way that photoelectron tracks can be accurately reconstructed and their emission direction derived (Costa et al. 2001; Bellazzini et al. 2007). Two detectors, inside a single camera (see Fig. 4) and sensitive in the 2-10 and 6-35 keV energy bands, can be alternatively located at the focus of one NHXM telescope, by a sliding (or rotating) device (Soffitta et al. 2010).

The wide field X-ray monitor. The WFXRM is based on the Wide Field Camera Units (WFCU). The combination of two WFCU forms a single Wide Field Camera (WFC), allowing for modular configurations. Our baseline assumes two WFCs located inside the central platform cylinder and co-aligned with the NHXM pointing direction. This design is based on the heritage of the X-ray monitor of the Italian mission AGILE, successfully operating since 2007 (Feroci et al. 2007). A performance improvement is obtained by using large-area and multi-linear Silicon Drift Detectors (SDDs, Vacchi et al. 1991), built on the heritage of the ALICE Inner Tracking System operating since 2008 at the LHC at CERN. The WFXRM is sensitive in the band 2-50 keV with an energy resolution of 250-500 eV FWHM.

4. The mission configuration

NHXM will operate in a circular, low inclination orbit at 600-km mean altitude, that provides a very low background, as proven by the BeppoSAX and Swift missions,. The satellite will be stabilized on three axes with good pointing capability. The NHXM satellite has been designed to accommodate two sets of payload elements (optics and focal planes) on different modules, separated by 10 m. This distance will be maintained with a given alignment and stability. Moreover, the whole system will be compatible with VEGA, the smallest European launcher. A possible launch could be foreseen by 2020 or later, for a mission lifetime of 3 (+2, goal) years. NHXM will be operated as a X-ray observatory. The service platform will carry aboard the following subsystems: i) the central cylinder (main platform structure) hosting the extendible bench canister; ii) the extendible bench connecting the extendable platform, that accommodates the Detector Modules; iii) the four MM, arranged around the external wall of the central cylinder. The platform cylinder and the focal plane assembly (FPA) are arranged in the Detector Platform located at the focal length of 10m by the deployable truss made of carbon fibre reinforced polymer (Fig. 1). After injection into orbit and commissioning, the expandable truss will position the Detector Platform at the operating mirror focal lengths of 10 m. The Detector Platform provides also the thermal control of the FPA, the mechanical structure, the harness connecting the Detector equipment and the metrology devices. The driving performance requirements of this architecture concerns is the focal plane stability over the timescale of an observation, and under large temperature gradients (both axial and circumferential). The focal length must not change by more than $\pm 1 cm$ and the alignment between the optics reference axis and the focal plane reference axis must be stable within ±1.5 arcmin. This condition is mainly guaranteed by the selection of the material and by the thermal control of the Detector Platform and expandable truss. The residual variations of the focal plane position (impacting on HEW) are monitored by a Service Metrology system allowing for a post-facto image reconstruction.

5. Conclusions

The NHXM brings together for the first time simultaneous high-sensitivity, hard-X-ray imaging, broadband spectroscopy and polarimetry. With these capabilities the NHXM will perform groundbreaking science in key scientific areas, including: black hole census, cosmic evolution and accretion physics; acceleration mechanisms and non-thermal emission; physics of matter under extreme conditions.

To address these scientific goals NHXM will have broad band (0.5-80, goal 120, keV) imaging and spectroscopy capability; 15 arcsec HEW angular resolution at 30 keV; sensitivity limits that are > 3 orders of magnitude better than those available in present day instruments; broadband (2-35 keV) imaging polarimetry. Moreover, it will be able to locate and actively monitor sources in different states of activity to becrepointed within 1-2 hrs. The NHXM satellite has been proposed to ESA in response to the Cosmic Vision M3 call. Its configuration and payload subsystems were studied in previous national efforts, leading to a mature configuration compatible with a VEGA launch before 2020.

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