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The X-ray polarimeters on-board the NHXM mission

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The New Hard X-ray imaging and polarimetric Mission (NHXM) makes a synergic use of broad band spectroscopy (0.3-80 keV, 120 keV goal) and polarimetry (2-35 keV) as complementary diagnostics of the same astrophysical systems. Here we describe the polarimeters on-board NHXM. Two Gas Pixel Detectors, filled with different mixtures which are based on Helium and Argon, are placed alternatively in the focus of one out of the four telescopes. The instruments are sensitive in the 2-10 keV (LEP, Low Energy Detector) and 6-35 keV (MEP, Medium Energy Detector) energy bands. The performance is comparable, with a Minimum Detectable Polarization at 99% confidence level of 9.7% (LEP) and 13% (MEP) for a 1 mCrab source and an observation lasting 100 ks. Spectroscopy with moderate resolution (20% at 6 keV) and timing (8 μs) will be performed contemporaneously to polarimetry. Unique capabilities among next mission of X-ray polarimetry is the possibility to image the source with an angular resolution which basically is that of the optics, about 15-20 arcseconds, and to extend the energy band above 10 keV.

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1. Introduction

The polarization of the radiation emitted by astrophysical sources has been extensively studied in many bands of the electromagnetic spectrum with very important results. This is not surprising, as two more parameters (the degree and the angle of polarization) are added, helping in discriminating between different models which can be otherwise equivalent on the basis of spectroscopic, timing or imaging observations only. In particular, polarization studies provide unique information on the level of anisotropy of the system, which may be due either to asphericity in the matter (or in the radiation field) distribution or to e.g. the presence of a strong, ordered magnetic field. The polarization degree measures the amount of asphericity, while the polarization angle pinpoints the main axis of the system. In the X-ray band, polarimetry has suffered severe limitations due to the lack of sensitivity of the previously flown X-ray polarimeters, based on the classical techniques of Bragg diffraction at nearly 45° and the Thomson scattering at nearly 90°. Hence, despite the study of the polarization of X-ray emission has been recognized as a fundamental tool in investigating the geometry and the physics of astrophysical sources, the only positive detection of X-ray polarization so far has been the integrated emission of the Crab Nebula [1, 2, 3].

The interest in X-ray polarimetry is also proved by the approval of the Gravity and Extreme Magnetism SMEX (GEMS) by NASA, an explorer mission to be launched by 2014 [4] which will perform sensitive polarimetry between 2 and 10 keV thanks to newly developed photoelectric polarimeters exploiting the Time Projection Chamber concept [5, 6]. With respect to other designs, e.g. the Gas Pixel Detector [7, 8, 9, 10], this kind of detectors pay the higher detection efficiency (possibly up to 100%) with the lack of any imaging capability and with an intrinsic azimuthal asymmetry. These make mandatory to use painstaking techniques, including rotating the instrument around the observing direction, to suppress the background and average out the systematic effects and prevent the angular resolved polarimetry of extended sources, except for a few cases, or of crowded fields.

2. Polarimetry with NHXM

The New Hard X-ray imaging and polarimetric Mission (NHXM) is a mission which was presented in response to the "Call for a Medium-size mission opportunity for a launch in 2022" recently issued by ESA [11]. NHXM is dedicated to study cosmic sources in the hard X-rays through broadband imaging, spectroscopy and polarimetry with a angular resolution comparable to that achieved below 10 keV (goal performances are 10" below 10 keV, 15" below 30 keV and 40" at 60 keV). Three out the four identical telescopes of NHXM are devoted to imaging and spectroscopy between 0.3 and 80 keV (120 keV goal), while a polarimetric camera is in the focus of the forth unit. The latter is composed of two Gas Pixel Detectors which are quite similar but for the gas cell which are different to provide optimal sensitivity in a wider energy band [12]. The Low Energy Detector (LEP) is provided with a gas cell 1 cm thick filled with Helium and DME at 1 atm to cover the energy band 2-10 keV, while the gas cell of the Medium Energy Detector (MEP) is 3 cm thick and it is filled with a mixture Argon-DME at 3 atm to operate between 6 and 35 keV. A sliding or rotating device places in the focus of the optics alternatively the LEP or the MEP. A filter wheel carries polarized and unpolarized sources to check the performances of the instruments throughout

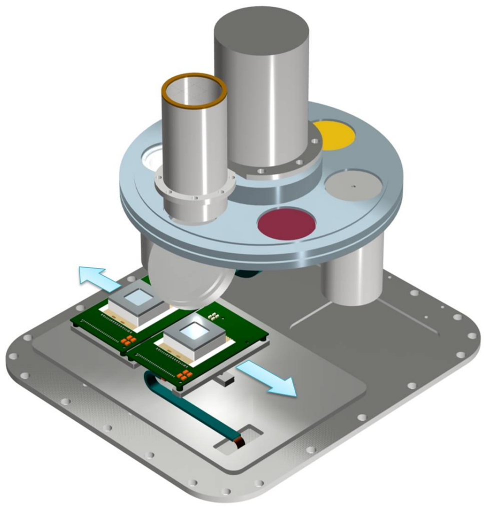

Figure 1: Focal plane assembly of the polarimetric camera.

	LEP	MEP
Energy range:	2-10 keV	6-35 keV
MDP (in 100 ks, 1 mCrab):	9.7%	13%
Angular resolution:	15”	20”
Mixture:	He-DME 1 atm	Ar-DME 3 atm
Cell gas thickness:	1 cm	3 cm
Background:	0.1 μCrab	0.4 μCrab
FoV:	5×5 arcmin	
Energy resolution:	<20% at 6 keV	
Timing resolution:	8 μs	

Table 1: Characteristics of the polarimeters on-board NHXM.

the whole mission (see Figure 1). The payload of NHXM include also a wide-field X-ray monitor sensitive between 2 and 50 keV and the possibility to repoint the satellite on a time scale less than 1 hour on trigger.

The characteristics of polarimeters on-board NHXM are reported in the Table 1.

3. Scientific objectives

NHXM will be an ideal observatory to study non-thermal processes, acceleration mechanism and the behavior of matter in extreme conditions. NHXM will make available contemporaneously and in a wide energy band both imaging polarimetry and imaging spectroscopy, which are complementary yet independent diagnostic of the same phenomena.

In Figure 2a we report the sensitivity of the LEP and of the MEP. Some of the field where NHXM will provide breakthrough results are:

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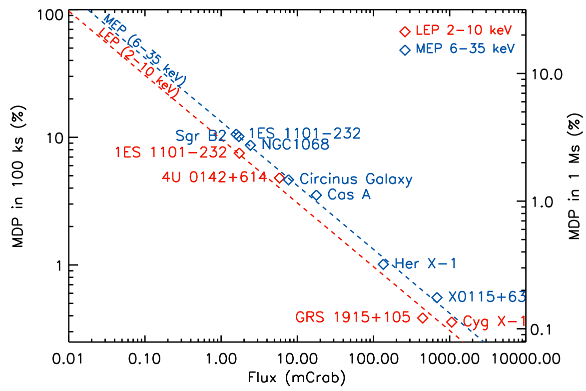
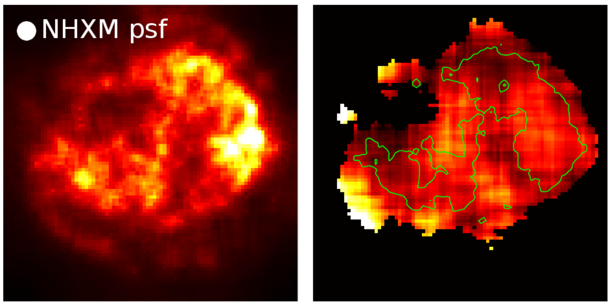


(a)



(b)

Figure 2: (**a**) Minimum detectable polarization (at the 99% confidence level) for the LEP and the MEP. The dashed lines refer to sources with a Crab-like spectrum. Sources with harder or softer spectra locate below and above the lines. The sensitivity for bright sources will allow for phase or energy resolved polarimetry at 1-2% level. (**b**) Cas A as imaged by XMM between 8.10 and 15 keV (left) and hardness ratio (right) [13]. Superimposed is the NHXM MEP point spread function. The field of view is sufficient to image all the source with a single pointing.

Pulsar wind nebulae and acceleration in supernovae remnants: The polarization of the integrated emission of Crab nebula was already measured more than 30 years ago to be about 20%[1]. However a much higher polarization is expected because different regions of the nebula should be differently polarized. NHXM will be able to resolve the pulsar and the structures visible in Chandra images, which is essential to understand how plasma propagates in the nebula and the magnetic field topology. The possibility to perform imaging spectropolarimetry above 10 keV will also allow to study non-thermal emission in supernovae remnants, which should be synchrotron and then highly polarized, without the contamination of thermal photons. Cas A and Tycho's SNR will be accessible with observations of a few days (see Figure 2b).

The past activity of Sgr A*: Even if today Sgr A*, as the galaxy nuclei in the local Universe, is intriguingly faint in X-rays, we have indications that a few hundreds of years ago an intense flare occurred. The X-ray emission from molecular clouds in the Galactic center show the signature of reflection, e.g. a prominent fluorescence iron line at 6.4 keV, a high absorption, a hard spectrum and a variable flux, and, since the required luminosity is by far higher that the Eddington luminosity of a stellar mass compact object, the straighforward conclusion is that the illuminating source was Sgr A* [14, 15, 16, 17, 18]. NHXM will unambiguously prove or disprove this hypothesis because the reflected emission should be highly polarized and the angle of polarization is orthogonal to the impinging direction of the photons [19]. The imaging capability and the low background of NHXM are essential to distinguish in the crowded Galactic center the faint emission from molecular clouds and the hard energy band of MEP will allow to exclude the iron fluorescence line which is expected to be unpolarized. Two 500 ks observations of Sgr B2 and Sgr C between 8 and 35 keV would allow to unambiguously constrain the angular position of the illuminating source with an error lower than a few degrees, depending on the actual degree of polarization.

Cyclotron lines from accreting pulsars: X-ray polarimetry has been recognized as a prime tool to study the accretion and the physics of compact object [20]. The unique contribution of NHXM with respect to other missions (e.g. GEMS) will be the possibility to study the broad cyclotron lines, all reported to be at energies above 10 keV, which should be highly polarized and a sensitive probe to derive the geometry of the emission, i.e. fan beam vs pencil beam models. Polarization measurement would also constrain the angle between the magnetic field and the rotation axis, which is a free parameter in all current models. The presence of a wide field monitor will provide the trigger to observe these variable sources in the most interesting states.

Geometry of Active Galactic Nuclei: Polarimetry in hard X-rays will provide direct information on the emission geometry of AGN. The direct emission of the hot corona, which is assumed to inverse Comptonize seed photons from e.g. the accretion disk, is expected to be polarized if the distribution of seed photons is aspherical. The degree of polarization is largely dependent on the geometry of the corona and therefore polarimetry, especially when exploited together with simultaneous wide band spectroscopy, will be a powerful method to constrain competitive models [21, 22]. The component reflected from the putative torus should be polarized too, and also in this case the NHXM contribution will be unique since the capability to measure the polarization above 10 keV where the reflection dominates. The angle of polarization would reveal the orientation of the torus, which could be compared with the other structures of the source to check for intriguing misalignment. Polarimetry of AGN is well within the possibilities of NHXM with a few days observations, at least for the brightest objects.

Measurements of the spin of galactic black holes: Today the spin of galactic black holes is estimated with two different techniques, the fitting of the thermal continuum and that of relativistic iron lines. Even if these methods allow in principle for very small statistical errors, the systematics are still not well controlled because the results of the two techniques are often in contradiction [23, 24]. The broad band capability of NHXM will allow for an excellent determination of the continuum, which is at the basis of a reliable estimate of the spin with the two techniques, and it will add a third simultaneous independent method, that is the measurement of the rotation of the plane of polarization with energy [25, 26, 27].

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