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Memorie della

The Simbol–X mission

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Abstract. Simbol–X is a hard X–ray mission, operating in the ∼ 0.5–80 keV range, proposed as a collaboration between the French and Italian space agencies with participation of German laboratories for a launch in 2013. Relying on two spacecrafts in a formation flying configuration, Simbol–X uses for the first time a 20 m focal length X–ray mirror to focus X–rays with energy above 10 keV, resulting in over two orders of magnitude improvement in angular resolution and sensitivity in the hard X–ray range with respect to non-focusing techniques. The Simbol–X revolutionary instrumental capabilities will allow to elucidate outstanding questions in high energy astrophysics such as those related to black-holes accretion physics and census, and to particle acceleration mechanisms. Simbol–X has been selected for a phase A study which is jointly conducted by CNES and ASI. We give in this paper a general overview of the mission, as consolidated close to the end of the phase A.

Key words. Black Holes – Particle Acceleration – Hard X–rays – Formation Flight

1. Introduction

The discovery of the X–ray sky during the 1960's–80's has opened a fundamental field of astrophysics, recognized by the 2002 Nobel Prize in Physics to R. Giacconi, a pioneer in this field. The steady increase in capability of space observatories, from the beginning of X–ray astronomy in the 1960's up to the large space facilities available today, led to the de-

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tection of high-energy radiation from objects of all scales in the Universe, from compact sources such as black holes and neutron stars, to diffuse hot plasma pervading galaxies and clusters of galaxies. Thanks to these advancements we now know that the basic physical processes behind the emission of energetic radiation in most cosmic sources pertain to two main categories: accretion physics and particle acceleration mechanisms.

The use of early technology based on collimated detectors on board the UHURU, Ariel-V, and HEAO1 satellites led to the discovery of less than one thousand X–ray sources in the whole sky, most of which at redshift z less than ~ 0.5. The advent of grazing incidence soft X–ray ($E < 3$ keV) mirrors at the end of the 1970's increased by orders of magnitude the discovery space for compact accreting sources, for galaxies with an active nucleus and for high temperature thermal plasma sources. The imaging detectors on board the Einstein satellite produced the first large scale observations of AGNs up to $z = 2$–3 and systematic mapping of galaxies, clusters of galaxies and supernova remnants. Today, the superior image quality of Chandra and the high throughput of XMM–Newton (both operating up to ~ 10 keV) have expanded the discovery space even further.

Above 10 keV the situation contrasts strikingly with this picture. The most sensitive observations performed so far have been carried out using collimated instruments like the BeppoSAX PDS or the coded mask instruments aboard INTEGRAL and Swift. More than two orders of magnitude separate the sensitivity and angular resolution in hard X–rays compared to the one that is achieved by X–ray telescopes below 10 keV. This situation is recalling the pre-Einstein era during the 1970's. In practice this limits the study of the hard X–ray sky to very bright sources only, and this is also prevents the interpretation of data in crowed regions, as well as the mapping of extended sources to the scales needed for correlation with other wavelength.

The hard X–ray domain is however of fundamental importance, as this is where accretion and acceleration phenomena have their essential signature, either via non thermal emissions characterizing populations of particles accelerated to extreme energies, or via thermal emissions revealing the presence of very hot comptonising plasmas as those believed to exist close to compact objects. In addition, whereas low energy X–rays are stopped by a relatively small amount of matter, hard X–rays are extremely penetrating and can reveal sources that are otherwise left hidden.

A clear requirement for future high energy astrophysics missions is thus now to bridge this gap of sensitivity, by offering an instrumentation in the hard X–ray range with a sensitivity and angular resolution similar to that of the current X–ray telescopes. In order to do this, a hard X–ray focusing optics is needed. Such an optics can readily be implemented by a simple extension of the current X–ray mirror technology to long focal lengths. At the same time, there is now the emerging technical possibility to design missions using multiple spacecraft flying in a constrained formation, which has led, in 2004, the CNES space agency to issue a call for proposal of a scientific payload to be flown on a formation flight demonstrator mission.

The Simbol–X mission has been selected in this context, as a mission to be conducted as a bilateral collaboration between CNES and ASI. The mission is currently ending a phase A study. We report here on the mission characterisitics and implementation at this stage. An earlier description of the mission can be found in Ferrando *et al.* (2006).

2. Scientific requirements

2.1. Scientific objectives

Offering "soft X–ray" like angular resolution and sensitivity in the hard X–ray range, up to ~ 100 keV, Simbol–X will provide a dramatic improvement for investigating key issues in high energy astrophysics. This will allow to perform detailed studies on a very wide range of sources, such as Galactic and extra-galactic compact sources, supernovae remnants, cluster of galaxies, or young stellar objects.

The very wide discovery space that Simbol–X will uncover is particularly signifi-

Table 1. Simbol–X top level scientific requirements

Parameter	Value
Energy band	0.5 – ≥ 80 keV
Field of view (at 30 keV)	≥ 12 arcmin (diameter)
On axis sensitivity	$\leq 10^{-14}$ c.g.s. 10–40 keV band, 3σ, 1 Ms
On axis effective area	≥ 100 cm^2 at 0.5 keV ≥ 1000 cm^2 at 2 keV ≥ 600 cm^2 at 8 keV ≥ 300 cm^2 at 30 keV ≥ 100 cm^2 at 70 keV ≥ 50 cm^2 at 80 keV
Detectors background	$< 2\ 10^{-4}$ counts $cm^{-2}s^{-1}keV^{-1}$HED $< 3\ 10^{-4}$ counts $cm^{-2}s^{-1}keV^{-1}$LED
Line sensitivity at 68 keV	$< 3\ 10^{-7}$ ph $cm^{-2}s^{-1}$, $3\ \sigma$, 1 Ms ($2\ 10^{-7}$ goal)
Angular resolution	≤ 20 arcsec (HPD) at E < 30 keV ≤ 40 arcsec (HPD) at 60 keV (goal)
Spectral resolution	E/ΔE = 40–50 at 6–10 keV E/ΔE = 50 at 68 keV
Absolute timing accuracy	100 μs (50 μs goal)
Time resolution	50 μs
Absolute pointing reconstruction	≤ 3 arcsec (radius, 90 %) (2 arcsec goal)
Mission duration	2 years of effective science time, with provision for at least 2 calendar years extension
Total number of pointings	> 1000 (nominal mission), with provision for 500 during the 2 years extension

cant for the two large and crucial areas in high energy astrophysics and cosmology, namely Black Holes physics and census, and Particle acceleration mechanisms. They constitute the core scientific objectives of Simbol–X which drive the requirements on the mission. They have been explicited in Phase A by the Simbol–X Joint Scientific Mission Group , and are described in details by Fiore *et al.* (2007). They are in short :

– to resolve at least 50 % of the Cosmic X–ray Background (CXB) in the energy range where it peaks, thus determining the fraction and evolution of obscured sources and providing a more complete census of Super Massive Black Holes (SMBH);
– to solve the puzzle on the origin of the hard X–ray emission from the Galactic centre that harbours the closest SMBH;
– to constrain the physics of the accretion flow onto both SMBH and solar mass Black Holes
– to constrain acceleration processes in relativistic Jets of blazars and Gamma Ray Bursts;
– to probe acceleration mechanisms in the strong electromagnetic and gravitational fields of pulsars;
– to measure the maximum energy of electron acceleration in supernova remnants shocks, and search for hadron acceleration in these sites;
– map the controversial non-thermal emission in clusters of galaxies, and if con-

firmed, determine its origin and its impact on clusters evolution.

In addition to these top priority objectives Simbol-X will be capable of performing breakthrough studies on several other areas like:

- the equation of state and the magnetic field of neutron stars;
- nucleosynthesis in young SNR;
- the formation of stars and planets;
- non-thermal emission of active stars;
- shocks in the intracluster medium pervading groups and clusters of galaxies;
- extended thermal plasmas in Galactic and extragalactic sources

2.2. Scientific requirements

The requirements necessary to achieve the core science objectives of the mission are given in Table 1. We shortly discuss the more salient ones below.

The 10–40 keV sensitivity is driven by the CXB science goal. This is the also the main driver for the angular resolution requirement in several aspects. It is needed to reach the required sensitivity, by keeping the internal and cosmic backgrounds as small as possible, and to limit the source confusion below 10 % at this sensitivity.

The broad range, from ~ 0.5 to at least 80 keV is mandatory for constraining and separating the different continuum and absorption emission parameters, both for accretion physics and in acceleration physics. A good sensitivity at low energy, which is not the main focus of Simbol–X, is particularly needed because of the strong variability of accreting sources, which have to be observed simultaneously in the soft and hard X–ray range. Similarly, the good spectral resolution required at 6 keV, is needed for the measurement the shape of broad Fe lines, also variable in accreting systems.

A large (for such a telescope) field of view is mandatory for collecting a statistically meaningful sample of hard X–ray sources in deep observations for resolving the CXB. This is also an obvious advantage for mapping extended sources, such as supernova remnants, avoiding often the need for mosaicing.

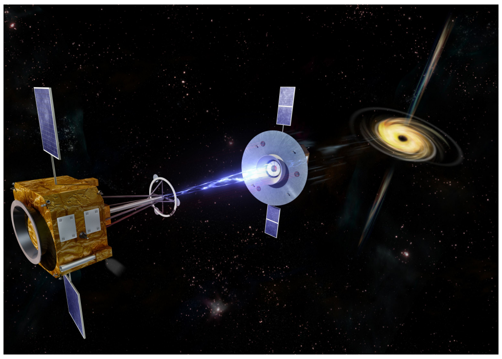

Fig. 1. Artist view of the Simbol–X configuration in flight, during observation, with mirror and detector spacecrafts in a constrained formation. The sky baffle around the optics module, and the collimator on top of the focal plane assembly are clearty visible. The focused radiation from the high energy source is highlighted in blue.

Finally, the absolute pointing reconstruction is required for the idenfication of sources for follow-up at other wavelengths, as well as for a clear identification of the sources in crowded regions, as the Galactic center, especially in relation with the study of SgrA* flares.

3. Mission concept

The scientific payload of Simbol–X is made of a single instrument, an X–ray telescope covering the full energy range. This telescope consists of a classical Wolter I optics focusing X–rays onto a focal plane detector system. The gain in the maximum energy that can be focused is achieved by having a long focal length, ~ 20 m. Since this cannot fit in a single spacecraft, due to the limited size of fairings, the mirror and detectors are flown on two separate spacecrafts in a formation flying configuration, as sketched on Figure 1.

Simbol–X is a pointed telescope, which is required to be able to perform very long uninterrupted observations (100 ks or more) on the same target. The necessity to have a stable image quality, as well as to keep the full field of view inside the detector area, dictate the requirements on the tightness of the formation flight control, which is in the cm range in all directions. In order to reach the attitude reconstruction requirement, the knowledge (monitoring) of the relative positions of the two spacecrafts is required at the about ± 0.5 mm level.

In this novel concept there is no tube between the optics and the detectors. A key issue is then to prevent the detectors from seeing X–rays coming from outside of the field of view, which would generate a very large unwanted background. This is done by combining a sky baffle on the mirror spacecraft and a collimator on the detector spacecraft, on top of the detector payload (see Ferrando *et al.* (2005) and Malaguti *et al.* (2005) for more details). They can be seen in Fig. 1. In Simbol–X they provide a full closure of the unwanted sky.

3.1. Optics

A full description of the optics module is given by Pareschi (2007). We simply recall the general features here.

The Simbol–X optics is a unique Wolter I nested shells mirror. These shells will be made following the Nickel electroforming replication method (Citterio *et al.* 1988), building on the experience of the Brera Observatory and its associated industrial partners. The long focal length coupled to the requirement to have a large filling factor lead to a total number of shells of about 100. Compared to the XMM–Newton mirror case, the shell thicknesses are reduced by a factor of ∼ 2, while still having the required angular performances.

The shells coating will however be different from that of previous instruments. While conventional monolayer coatings do provide the extension to high energy thanks to the long focal length, they give a limited field of view. The large field of view required in this mission can be achieved only with multi-layers coating, which is now the baseline for the Simbol–X mirror.

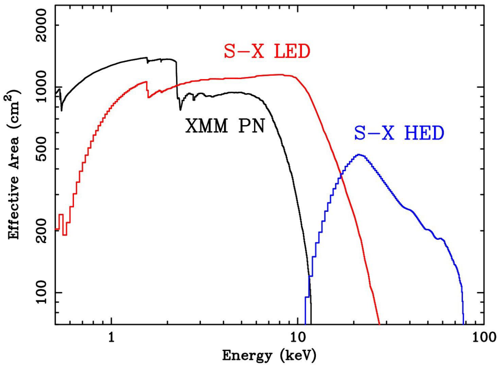

Fig. 2. Effective area of Simbol–X, per detector. This is compared to that of the EPIC/PN camera onboard XMM–Newton.

3.2. Detector payload

A full description of the detector payload is given by Laurent *et al.* (2007). For the sake of completion, we simply recall here the main characteristics of the system.

At the focal surface of the mirror is placed the focal plane assembly (FPA). As it is not possible to cover the full Simbol–X energy range with the required spectral resolution by a single detector, the FPA is made of two spectro-imaging detectors, on top of each other, the Low Energy Detector (LED) and the high Energy Detector (HED). Both of them cover $\sim 8 \times 8$ cm^2, and have the same pixel size of 625 μm, oversampling the mirror HPD by a factor of ∼ 3.

The LED, first encountered by the beam focused by the optics, is a silicon drift detector which covers the energy range from ∼ 0.5 to ∼ 20 keV. It is operated in sequential readout, with extremely fast frame times (128 μs for full frame), thanks to its APS design. The HED is made of a mosaic of 4-side juxtaposable pixelated CdTe crystals, 2 mm thick, with 256 pixels each. They are self-triggered detectors, and sub-micro seconds timing accuracies can be achieved. The HED will cover the high energy range, with ∼ 100 % efficiency at 80 keV.

These two detectors are surrounded by an active anti-coincidence shield, which will allow to reach the required low level of background. If this is classical in gamma–ray ex-

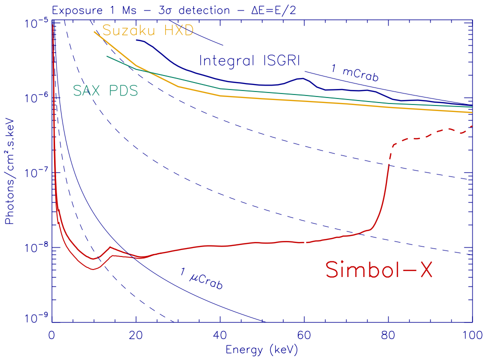

Fig. 3. Continuum sensitivity of Simbol–X, for source detection at 3 σ. See text for details.

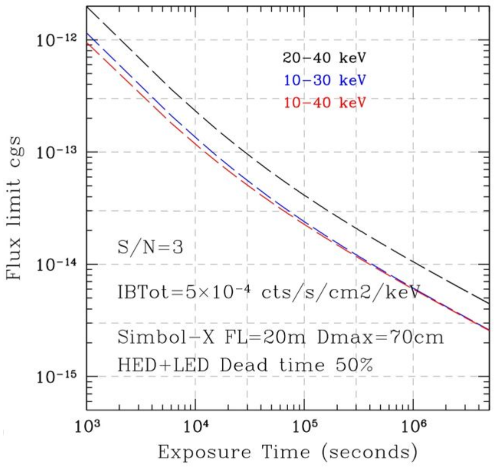

Fig. 4. Band sensitivity of Simbol–X. See text for details.

periments, this will be the first time that this is achieved in the soft X–ray range. This has however a cost in terms of dead time for the LED, which is estimated to be $\leq$ 50 % in full frame, and $\leq$ 15 % in window mode, for conditions of solar minimum.

The Figure 2 shows the effective area of the full telescope system, taking into account the mirror response, the quantum efficiency of the detectors, and the transmissions of the different filters and thermal blankets accross the beam.

3.3. Expected performances

The performances of the full telescope system, in terms of sensitivity, have been evaluated with the reference configuration as shortly described above, and reflected into the response files made available for the workshop. They are shown in Figures 3 and 4.

In Figure 3 is given the continuum sensitivity for measuring broad band source spectra with a 3 σ accuracy, in an observation time of 1 Ms, for $\Delta E = E/2$. The Simbol–X sensitivity is calculated by considering the best combination of detectors according to energy, namely only the LED at low energy, the sum of LED and HED signals (and background) in the middle energy range, and only the HED at high energy. The Simbol–X curve takes into account the LED dead time, with the two cases of the window mode (lower curve) and full frame mode (higher curve). The dotted part will strongly depend on the final mirror design and coating, which is not decided at this stage. The Simbol–X sensitivity is compared to that of past and present instruments, all based on collimators or coded masks. The improvement is by more than two orders of magnitude or more up to $\sim$ 80 keV.

In Figure 4 are given sensitivity curves in different bands of interest for the CXB science goal, as a function of observing time. They are obtained with the same assumptions as for the continuum sensitivity curve, and combines the two detectors with a 50 % dead time for the LED. This shows the 10–40 keV band optimizes the flux sensitivity and that a flux limit of 6 10^{-15} cgs is obtained for a 1 Ms exposure time, compliant with the requirements of the mission.

4. Orbit and mission operations

The two spacerafts will be launched together by a Soyuz–Fregat vehicle, from Kourou. This provides the best launch capabilities within the allocated budget. The orbit has been chosen to guarantee the feasibility of the formation flight, which excludes the low earth orbit at least in the context of this mission, and to give a minimum of instrumental background induced by cosmic-rays. With additional considerations of stability, the orbit finally chosen

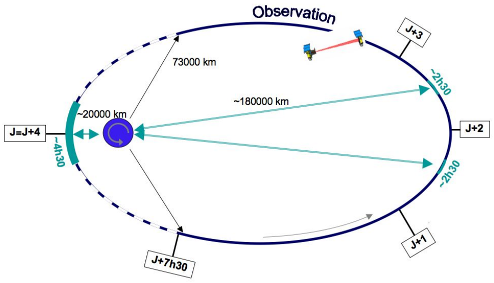

Fig. 5. Simbol–X orbit. The observation period and the nominal contacts with the Malindi ground station are indicated.

is a High Elliptical Orbit, sketched in Figure 5. It has a perigee of ∼ 20,000 km, and an apogee ∼ 180,000 km, and a period of four days. Based on XMM experience, it is considered that this orbit is useful for astrophysical observations for altitudes above ∼ 75,000 km (mininimum of particle background). This gives ∼ 290 ks available for observations, continuously, in one orbit. The orientation of the telescope axis with respect to the orbit and the Sun-Earth line is similar to that of XMM. The line of sight is quasi-orthogonal (± 20°) to the Sun-Earth direction. This quasi-inertial pointing allows to have fixed solar generators and then simplifies mirror spacecraft and detector spacecraft architecture. About 35 % of the entire sky can be accessed at any given time. The entire sky coverage can be accessed in ∼ 4.5 months. The contact with the ground is ensured by a single antenna, in Malindi. The baseline scheme is to have SimbolX autonomous when performing an observation, with data recorded onboard. Contact with SimbolX will be made when changing target, which is conducted and followed in real time by the ground. A slot of two hours is allocated for these operations. During this slot, download of quick-look scientific data will be possible. The full science telemetry will be downloaded in a single contact per orbit, at perigee, which gives the maximum possible data rate.

5. Conclusions

The Simbol–X mission will provide an unprecedented sensitivity and angular resolution in hard X–rays, enabling to solve outstanding questions in high energy astrophysics. The phase A study, which is close to its term at the time of writing, has demonstrated the feasablity of the mission in all of its aspects with the required margins at this level of design, even if some of the requirements, as *e.g.* the attitude reconstruction, are requiring special care. The mission will enter in phase B in beginning of 2008, with a technical and programmatic launch date of 2013. This is ideally placed with respect to the next programs of TeV ground observatories, as well as the launch of JWST, which will allow to perform multi-wave length observations of objects which are prime targets for Simbol–X science goals. This is also ideally placed with respect to the next very large observatories, as XEUS, expected to appear in the end of the next decade. In this context, Simbol–X will be operated as an observatory, with a large opening to the world-wide community.

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