Simbol–X : mission overview

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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 spacecraft in a formation flying configuration, Simbol–X uses for the first time a 20–30 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 us to elucidate outstanding questions in high energy astrophysics such as those related to black-holes accretion physics and census, and to particle acceleration mechanisms, which are the prime science objectives of the mission. After having undergone a thorough assessment study performed by CNES in the context of a selection of a formation flight scientific mission, Simbol-X has been selected for a phase A study to be jointly conducted by CNES and ASI. The mission science objectives, the current status of the instrumentation and mission design are presented in this paper.

Keywords: Black Holes, particle acceleration, X–ray telescopes, X–ray detectors, formation flight

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1. SCIENTIFIC AND TECHNOLOGICAL CONTEXT

The discovery of the X–ray sky during the 1960s–80s has opened a fundamental field of astrophysics, recognized by the 2002 Nobel Prize in Physics to R. Giacconi, a pioneer in this field. With the increase power of space observatories, high energy emission has been revealed from objects of all scales in the Universe, from compact sources such as black holes to diffuse hot plasma pervading galaxies and clusters of galaxies, revealing violent processes which are thought to play a major role in the dynamics of these objects. These processes pertain to the two domains of accretion physics and particle acceleration mechanisms.

In accretion physics, the accretion of matter onto Black Holes is a fundamental astrophysics topic. Identifying and understanding this phenomenon has indeed profound implications both on physics, since the Black Hole environment is the only place which allows tests of General Relativity beyond the weak-field limit, and on cosmology since the history of accretion, imprinted in the Cosmic X–Ray Diffuse Background, is thought to have fundamental links with that of the galaxy formation and evolution.

The second domain is also a fundamental astrophysics topic. We are still lacking firm evidences of hadron acceleration in suspected astronomical sites (despite clearly seeing huge electron accelerations), and we are still looking for the origin of the highest energy photons and cosmic rays which have been observed by ground experiments. Observing and understanding the processes at work in various acceleration sites are mandatory steps for resolving these issues.

These two astrophysics fields are best revealed and characterized by their emissions in the X–ray and hard X–ray ranges, the latter probing the most energetic and violent environments and their non thermal population of energetic particles. There is however a very large gap in angular resolution and sensitivity between these two energy domains.

Below ~ 10 keV, astrophysics missions such as XMM–Newton and Chandra are using X–ray mirrors based on grazing incidence reflection properties. This allows to achieve an extremely good angular resolution, down to 0.5 arcsec for Chandra, and a good signal to noise thanks to the focusing of the X–rays onto a small detector surface. This technique has been so far limited to energies below ~ 10 keV because of the maximum focal length that can fit in a single rocket fairing. Hard X–ray and gamma–ray imaging instruments are thus using a different imaging technique, that of coded masks, as those onboard the INTEGRAL or SWIFT missions. This non-focusing technique has intrinsically a much lower signal to noise ratio than that of a focusing instrument, and does not allow to reach angular resolutions better than a few arc minutes. In addition to the difference in angular resolution, there is also roughly two orders of magnitude of difference in point source sensitivity between X–ray and gamma–ray telescopes.

This transition of techniques unfortunately happens roughly at the energy above which the identification of a non-thermal component is unambiguous with respect to thermal emission. Considered from the low energy side, this obviously strongly limits the interpretation of the high quality X–ray measurements, and particularly that related to the acceleration of particles. Considered from the high energy side, this renders impossible the mapping of the gamma–ray emission of extended sources to the scales needed to understand the emission mechanisms by comparing with lower energy data, and this limits the studies to very bright sources only. The hard X–ray range is the energy domain in which fundamental problems of astrophysics 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. This has been shown in particular by the measurements made by the IBIS/ISGRI instrument onboard INTEGRAL which have led to the discovery of a number of highly absorbed sources, mainly pulsars in supergiant systems[1].

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. And indeed, at the beginning of 2004, the CNES space agency has issued a call for proposal of a scientific payload to be flown on a formation flight demonstrator mission to be launched at the beginning of the next decade. The Simbol–X mission has been proposed to CNES in this context.

Simbol–X is a hard X–ray pointed telescope, based on a 20 to 30 m long focal length optics which will extend the focusing technics to energies up to at least ~ 80 keV, offering a gain of over two orders of magnitude in sensitivity and angular resolution compared to the current instruments above 10 keV. In addition to this fundamental breakthrough in the hard X–rays, Simbol–X will have a low energy threshold around ~ 0.5 keV, which will allow to fully cover the transition from thermal to non-thermal emissions, as well as the Iron line region, two important characteristics for the study of the highly variable accreting sources.

Simbol–X has been selected by CNES, together with three other missions, for thorough assessment studies (called "phase 0") which have been performed by a dedicated CNES engineering team in the beginning of 2005. This study, which has covered all the aspects of the mission from payload to ground segment, has demonstrated that the Simbol–X payload and mission implementation fits well within the constraints of the call for proposal issued by CNES. Following this, CNES has selected Simbol–X as the formation flight mission to be further studied in phase A, in a joint program between CNES and ASI.

In this paper, after giving the top level science objectives of the mission and the corresponding requirements, we report on a possible mission implementation, as resulted from the CNES phase 0 study, and on the current status of the payload definition and design at the beginning of phase A. More detailed informations on the payload definition can be found in accompanying papers in this conference, by Pareschi *et al.*[2] and Cusumano *et al.*[3] with main focus on the optics, and Dirks *et al.*[4] and Tenzer *et al.*[5] with main focus on the focal plane. Earlier descriptions of the mission have been given in Ferrando *et al.*[6, 7].

2. SCIENTIFIC OBJECTIVES AND REQUIREMENTS

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 and will allow us 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 significant for the two large and crucial areas in high energy astrophysics and cosmology :

Black Holes physics and census, and

Particle acceleration mechanisms,

which define the core scientific objectives of Simbol–X and are briefly described in the following.

2.1 Black Hole physics and census

If it is generally admitted that the accretion of matter onto compact objects, in particular Black Holes, occurs via a very dynamic accretion disk, the way that this disk evolves, the mechanisms that form the often observed relativistic jets, as well as the origin of the high energy radiation remain unclear. Finding the origin of the observed emission, e.g. synchrotron in a jet, Compton from a hot corona, reflection from a disk, and identifying the geometry of the system necessitates accurate measurements of the hard–X ray continuum simultaneous to that of the Iron line shape. Moreover, the Iron line shape strongly depends on General Relativity effects occurring in the strong field close to the Black Hole, which can thus be evidenced.

Simbol–X is targeted to provide such measurements for Black Holes of all masses in up to now uncharted regimes, dynamical conditions, or locations. Regarding regimes, these include the determination of the quiescent state hard X–ray spectra for Galactic Binary systems, which are expected to strongly depend on the type of accreting object, neutron star or Black Hole, as well as on the accretion flow physics. Regarding dynamical conditions, Simbol–X will provide very detailed spectra for a very large sample of AGNs on their dynamic time scale, a few ks, allowing to truly disentangle the emission processes and geometry. Regarding locations, Simbol–X will allow the first mapping of the hard X–ray emission in nearby Galaxies, like Andromeda and M33, providing absolute luminosities for binary systems and allowing population studies for other galaxies than ours.

Last, but not least, on Black Hole physics, a major goal of Simbol–X is to provide a definitive measurement of the high energy emission of the super-massive black hole at the centre of our Galaxy, SgrA*, which is still unknown despite deep INTEGRAL observations[8]. The understanding of this astonishingly quiet object and its relations with its surroundings, as well as the origin of the puzzling high energy diffuse emission in the centre of the Milky Way, is crucial for understanding the much farther away galactic cores.

On Black Hole census side, the major goal of Simbol–X is to resolve the long standing question of the nature of the Cosmic X–ray Background (CXB). The CXB is believed to be the most direct probe of accretion activity onto super-massive black holes, and determining its origin gives major constraints for the formation and evolution of structures in the Universe. If the major fraction of the CXB has been resolved into discrete sources below ~ 7 keV, only half of it has been accounted for in the 7–10 keV band, and essentially nothing is directly known above 10 keV, and in particular in the 20–40 keV band in which the CXB spectrum is peaking. Observational and theoretical evidences based on soft X–Rays deep fields have led to the conclusion that a significant fraction of the CXB is due to obscured Compton thick sources. However, such a conclusion remains unconstrained by the available observations, and a major breakthrough is needed to validate the CXB synthesis models and to assess the values of their parameters, such as the space density and evolution of these obscured sources. With a sensitivity better than 1 μCrab in the 20–40 keV band, Simbol–X will resolve more than 50 % of the CXB in this fundamental energy range, providing an unbiased census of the super-massive black holes in the Universe, allowing to determine the light-up and evolution of accretion onto super-massive Black Holes.

2.2 Particle acceleration mechanisms

This second broad topic is in direct relation with the still unsolved problem of the origin of the cosmic-rays, both for the physical mechanisms of acceleration by themselves, as well as for the astrophysical sites where they are taking place.

In the first place, Simbol–X will observe acceleration by shocks in supernova remnants and jets. In supernova remnants, the non thermal emission arises from electrons of tens of TeV energies, and the cut-off of the spectrum is directly linked to the maximum energy of the electrons. Beyond giving access to cut-offs over a few keV, allowing the determination of the highest electron energies, measuring the synchrotron spectrum in a very broad range into the hard X–rays will permit a solid determination of the cut-off frequency without relying on the assumption of a pure power-law spectrum between radio and X–rays, which is questioned by non linear acceleration theory. In addition, Simbol–X will also map the supernova remnants, and correlate these data with radio and the TeV gamma–rays data (as e.g. Aharonian *et al.*[9]). Putting these together will unambiguously allow to disentangle the different emission components, looking for the expected but not yet firmly identified signature of hadronic acceleration.

Relativistic electrons (E ~ 1–100 GeV) and large-scale magnetic field are present in the intergalactic medium of clusters of galaxies, as revealed by radio observations of diffuse synchrotron emission. These relativistic electrons can interact with the CMB photons to give inverse Compton non-thermal hard X–ray radiation. Present detections of hard X–ray emission in clusters with non-imaging instruments suffer from low signal to noise and their interpretation is ambiguous. Simbol–X will map this emission, determine its origin and disentangle the thermal and non-thermal components. Correlated with radio observations, the observation of the non-thermal X-ray emission, if confirmed, will allow to map both the magnetic field and the relativistic electron properties, key information to understand the origin and acceleration of relativistic particles in clusters and its impact on cluster evolution.

Acceleration by shocks is also believed to take place in the relativistic jets of blazars, for which Simbol–X will fully characterize the variable synchrotron emission. Coupled with the inverse Compton component, measured by gamma–ray experiments like GLAST and HESS, but also for some of them directly by Simbol–X thanks to its broad range, this will definitely constrain the different emission models, as e.g. Self-Synchro-Compton versus Compton on external photons. Still on the jet side, Simbol–X will have the sensitivity to map the hard X–ray emission in extended jets, such as those of Cen A and Pictor A, separating the jet emission from the bright emission of the accreting object. This will allow in particular the characterization of the emission in the hot spots, looking also there for the emission mechanisms at work and for the maximum energy of the accelerated electrons.

Simbol–X will finally provide time resolved spectroscopy with unprecedented signal to noise ratio of the hard X–ray emission of pulsars and their environment, probing the acceleration mechanisms known to be at work in these extreme conditions of electromagnetic fields. Moreover, thanks to its good angular resolution, Simbol–X will allow to resolve several plerions, disentangling the pulsar emission from the contribution from the Nebula.

2.3 Other breakthrough areas

In addition to the priority objectives discussed above, Simbol–X will be capable of making breakthrough studies on several other areas. They include :

• the determination of the nature of Ultra Luminous X–ray sources, suspected to be intermediate mass Black Holes, via the hard X–ray spectral shape measurement and its comparison with bona fide Black Hole systems. In addition, with Simbol–X it will be possible to look for Quasi Periodic Oscillations, known to be best revealed in hard X–rays, which if present can provide a measurement of the Black Hole mass,

• the determination of the magnetic field of neutron stars, via the measurement of cyclotron lines features and their dynamics in a much larger sample than in the ~ 15 HMXB pulsars for which they have been observed so far,

• the understanding of the role of X–ray activity in star formation, in regions which are by nature transparent to hard X–rays only,

• and last but not least, the test of explosive nucleosynthesis models in young supernova remnants.

In this latter topic, the key measurement in the hard X–ray range is that of the ^{44}Ti isotope, which is visible through the 68 and 78 keV lines emitted in its decay chain. The ^{44}Ti yield depends on the supernova type, and for gravitational ones on the mass-cut and the physics of the explosion. Measuring unambiguously its abundance, through its decay lines, gives unique constraints on the nucleosynthesis models. With Simbol–X we will map the ^{44}Ti emission in Cas A, with the aim of characterizing the explosion by looking for possible asymmetries and measuring the ejecta speed. We will also measure the ^{44}Ti mass produced in SN 1987A, the only supernova for which the progenitor is known, giving there an invaluable constraint to nucleosynthesis theory.

2.4 Scientific requirements

Table 1 gives the requirements of the mission to achieve the scientific objectives discussed above. We shortly comment some of them below.

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 around pulsars. 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 thus need 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 iron lines, also variable in accreting systems.

The angular resolution, with a goal of 15'' (Half-Power Diameter) is necessary in several aspects. It is needed to reach the

Parameter	**Requirement**
Energy band	~ 0.5 to > 80 keV
Spectral resolution	E/ΔE = 40 @ 6 keV E/ΔE = 50 @ 68 keV
Field of view (50 % vignetting)	> 9' – goal 13' (diameter)
Angular resolution	< 20'' – goal 15''
Absolute pointing reconstruction	~ 2'' (radius, 90 %)
On axis effective area	> 600 cm^2 @ 8 keV > 450 cm^2 @ 20 – 40 keV > 100 cm^2 @ 70 keV
On axis continuum sensitivity	< 1 μCrab (3 σ, 1 Ms) in 20 – 40 keV band
On axis line sensitivity @ 68 keV	< 10^{-7} ph/cm^2/s (3 σ, 1 Ms)
Absolute timing accuracy	< 100 μs – goal 50 μs
Mission duration	> 2 years of scientific programs (~ 3 yrs of mission)

Table 1 : Top Level Scientific requirements for the Simbol–X mission.

required sensitivity for point sources, by keeping the internal and cosmic backgrounds in the source region as small as possible. It is also needed to limit the source confusion below 10 % at the required sensitivity in deep observations, to resolve features like radio-galaxy hot spots, and to avoid confusion in complex and crowded regions like the Galactic Centre.

A large (for such a telescope) field of view, with a goal of 13'', is an obvious advantage for mapping extended sources, such as supernova remnants, avoiding often the need for mosaicing, as well for ensuring the collection of a statistically meaningful sample of hard X–ray selected sources in deep observations needed for resolving the CXB, without an excessive investment of observing time.

3. MISSION CONCEPT AND DISTRIBUTED PAYLOAD

Simbol–X is basically built using 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, which will be in the 20–30 m range (see optics section below). Since this cannot fit in a single spacecraft, due to the limited size of fairings, the mirror and detectors will be flown on two separate spacecraft 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 formation flying stability. The constraint is that the distance between the two spacecraft (along the telescope axis) must be kept at the focal length value within about ± 10 cm, whereas the intersection of the telescope axis must be at the centre of the focal plane within about ± 1 cm. In order to reach the attitude reconstruction requirement, the knowledge (monitoring) of the relative positions of the two spacecraft must be known within about ± 0.5 mm.

We describe below the two payload components which are the optics and the focal plane assembly, as well as the baffling issue, which is crucial for ensuring that the required sensitivity will be reached.

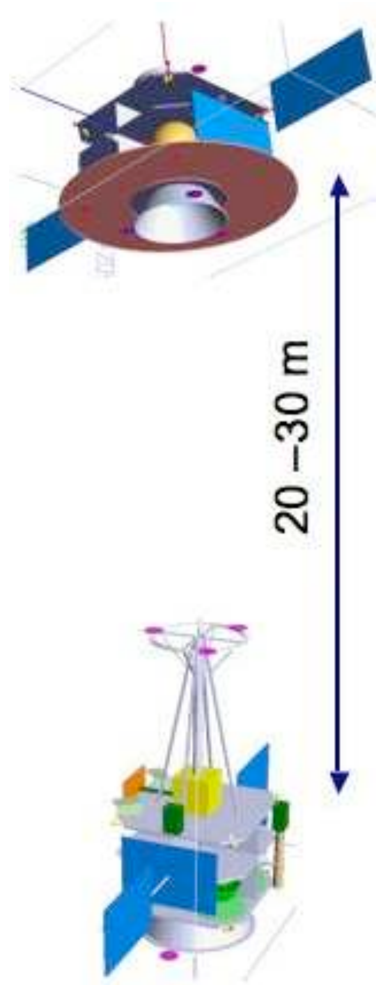


Figure 1 : Sketch (not to scale) of the Simbol–X configuration in flight, with mirror (top) and detector (bottom) spacecraft kept on a constrained formation. The focal plane unit has a ~ 1.5 m collimator on top, while the mirror spacecraft carries a ~ 3 m diameter circular sky baffle (see Section 3.3).

3.1 Optics and sensitivity

The Simbol–X optics is a unique Wolter I nested shells mirror. These shells will be made following the Nickel electroforming replication method[10], for which the Brera Observatory and its associated industrial partners have acquired a large experience through the building of the BeppoSAX, SWIFT, and XMM–Newton mirrors. 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 thickness to diameter ratio for the shells will be reduced so that the mass of the mirror stay within the mission constraints. At the current level of overall design of the mission, the mass mirror allocation is about 300 kg (without margins). With such a mass, and for this number of shells, the angular resolution will be no worse than 30 arcsec (FWHM) as experimentally proven[11]. Further improvements on the optics design are being worked out in phase A in order to reach the required value of 20 arcsec.

Because the optics properties entirely rely on the total reflection phenomenon, which is characterized by a very large reflectivity at grazing angles until a critical angle beyond which the reflectivity falls rapidly down to almost zero, conventional single layers coatings limit the field of view to relatively small values. For example, the single layer Pt coating considered in first discussions of the mission[6] give a 6 arcmin field-of-view, insufficient with respect to the mission requirements discussed above. This problem is solved by using a multi-layer coating, which by exploiting Bragg diffusion allow to reach larger reflection angles. We are thus now considering a multi-layer coating for the Simbol–X mirror. The description and optimization of the multi-layer reflectors can be found in Cotroneo & Pareschi[12]. Besides increasing the field of view, as discussed above, the multi-layer coating also offers the advantage to increase very significantly the energy range up to 80 keV and above. This will allow to effectively cover the region of the ^{44}Sc lines (68 keV and 78 keV) as required. In order to optimize the optics given the requirements and constraints, a parametric search has been initiated at the start of phase A, varying focal length, filling factors, and largest diameter. More details can be found in Pareschi *et al.*[2] in this volume.

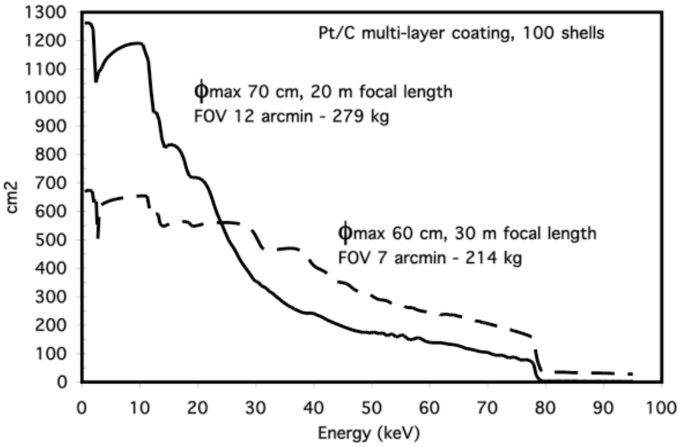


Figure 2 : Mirror effective areas for two study cases. Both are assuming a multi-layer coating. Characteristics are given in the figure.

Examples of calculated effective area curves are shown in Figure 2. Two different geometric configurations are considered. The first one corresponds to a 60 cm outer diameter and a 30 m focal length; the field of view reached in this configuration is of 7 arcmin falling short the 9 arcmin minimum requirement. The second one assumes for the outer diameter the maximum value possible to build with existing facilities, as well as a shorter focal length of 20 m. This option has the advantage of increasing very significantly the field of view up to 12 arcmin, as well as the effective area below ~ 25 keV, but the drawback of having much less effective area above 30 keV, which falls essentially to zero at the Pt K edge at 78.4 keV. It has also a much larger mass than the first option. These two curves illustrate the range of performances that can be expected for the final design. As said above, this will be optimized during the phase A study

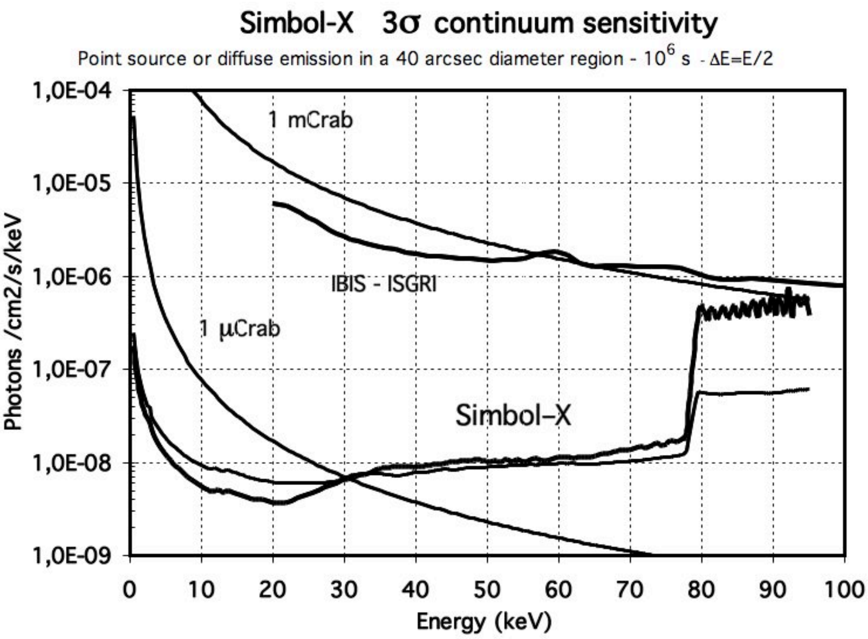


Figure 3 : continuum sensitivity of Simbol–X, for the two study cases of the optics corresponding to Figure 2. The sensitivity is calculated with the same internal background assumptions as in Ferrando *et al.*[6], ~ 7 10^{-5} cts/cm^2/keV. The sensitivity is calculated for 1 Ms of observation, for a better comparison with INTEGRAL, and $\Delta E = E/2$. The thicker Simbol–X curve corresponds to the full line curve in Figure 2 (20 m focal length, 12 arcmin of FOV), the thinner curve to the dashed curve of Figure 2 (30 m focal length, 7 arcmin FOV).

with respect to the science requirements and the mission constraints.

These two curves were used to estimate the sensitivy to Simbol–X for the detection of point sources, shown in Figure 3. This sensitivity was calculated for a 40 arcsec extraction region which contains 90 % of the source photons. It is worthwhile to note that the two curves have in fact a very similar sensitivity up to the Pt K edge, despite their different effective area. The reason is that, compared to the 30 m focal length case, the smallest effective area of the 20 m focal length case is compensated by the fact that the background in the extraction zone is also smaller because of the smaller plate scale. On this figure has also been plotted the IBIS/ISGRI sensitivity to point sources, for the same observation parameters. One can readily see that more than two orders of magnitude are gained by Simbol–X up to at least ~ 80 keV whatever the final design.

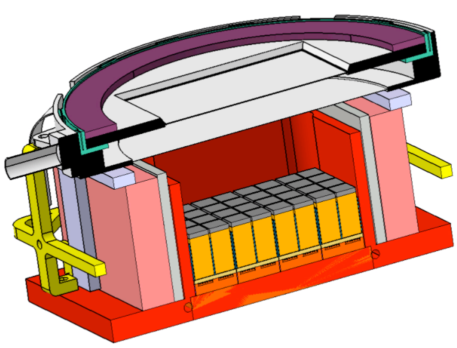
Besides this main optimization process, we are also working on two other aspects of the optics design. One is related to the thermal control. Because the optics module has both sides open to space, this is much more demanding than for classical telescopes "with tubes". In order to minimize these thermal loads, it is anticipated to cover each side of the mirror by a thin aluminized foil, with support of sub-micron size in order to minimize the absorption at low energy (see also discussion in Ferrando *et al.*[7]). The other one is related to the amount of possible stray-light contamination, which is studied through ray-tracing calculations and which appears not be not a real issue (see Cusumano *et al.*[3]).

3.3 Focal plane assembly

Simbol–X is equipped with a single spectro-imaging focal plane assembly. A full description of the current system is given by Dirks *et al.*[4] in this conference and is not repeated here. For the sake of completeness we simply mention the main characteristics of this system as it is at the start of the phase A study.

The parameters which are driving the design of the focal plane assembly are : i) the broad energy range, ii) the spectral resolution for the Fe and ^{44}Ti lines energies, iii) the field of view of the optics, iv) the request for oversampling the optics point-spread function, v) the need for a very low background. This has led to use a combination of a low and high energy detector on top of each other, surrounded by a combination of active and passive shielding, as shown in Figure 4. The pixel size for each of these detectors will be ~ 500 × 500 μm^2.

The low energy detector, first encountered by the beam focused by the optics, is a silicon drift detector with DEPFET (DEPleted Field Effect Transistor) readout, also called "Macro Pixel Detector" or "Active Pixel Sensor". It will cover the energy range from ~ 0.5 to ~ 20 keV. Prototypes of macro pixel detectors have already been developed, built and tested by the MPI semiconductor laboratory[13]. The baseline design is to cover the field of view with a single wafer, which will be logically divided into four quadrants of 64 × 64 pixels each. In nominal "full frame mode", all four quadrants are read out in parallel at a frame time which is anticipated to be at most 256 μs. A faster read out is possible by reading only a part of the full area, i.e. by defining "window" modes. Timing accuracies better than ~ 50 μs can thus be achieved. Laboratory results and calculations have proven that the required spectral resolution will be achieved at moderate temperatures, in the –20 to –40°C range.



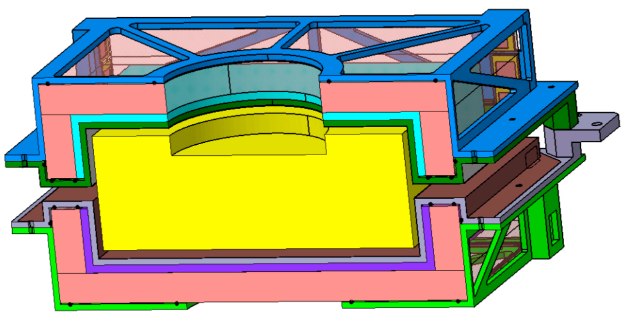


Figure 4 : sketch of the detector assembly. Left : internal detectors system, cut-view, with Macro-Pixel Detector on top, the array of Cd(Zn)Te modules at the bottom, and the active and passive shielding walls on the sides. Right : the internal detector system (central volume) is surrounded by additional active and passive shieldings, in two halves.

The high energy detector, located a few cm below the low energy one, will be constructed from 4-side juxtaposable pixelated CdTe or CdZnTe crystals, with a surface of ~ 10 × 10 mm^2 covered with 256 pixels. The crystal thickness, needed for stopping the highest energies will be ~ 2 mm. Each crystal is connected to its own read-out electronics, the IDeF-X (Imaging Detector Front-end for X-rays) ASIC developed by CEA/Saclay[14]. Each unit forms a complete individual X–ray camera which allows operating in the 5–100 keV range partly overlapping the low-energy range of the silicon detector. In the current design eight individual X-ray cameras are merged to form a 2-by-4 module having its own flex for in- and output signals. The detection plane will be covered with eight of such modules, as seen on Figure 4 (left). As these detectors are self-triggered, sub-micro seconds timing accuracies can be achieved. Finally, laboratory results have also shown here that the required spectral resolution can be reached at moderate temperatures, similar to those needed by the low energy detector.

An important point of the design is the need to reach an overall background level of less than 10^{-4} cts/cm^2/s/keV. In order to do this, the imaging detectors are entirely surrounded (except for the opening to the sky) by an active anticoincidence shield coupled to a passive graded shield, which will minimize background photons produced by particles interacting in the material around and inside the detector vessel. The optimization of this shielding from the point of view of the type of detectors and their localization, and the estimation of its efficiency is being investigated by means of Monte-Carlo simulations. First results are given by Tenzer *et al.*[5] in this conference.

Still on the background issue, as there is no telescope tube between the mirror and the focal plane unit in a formation flight configuration, there is a need to protect the detectors from seeing X–rays coming from outside of the mirror, which would otherwise generate an unwanted background. When integrated over even a modest solid angle, the Cosmic diffuse X–ray background has indeed a level much larger than what is required to reach the desired sensitivity. As a matter of fact, in the case of a 2π opening of the detectors on the sky, the sensitivity would be reduced by two orders of magnitude, i.e. the gain in sensitivity brought by the focusing would be entirely lost. This is discussed also in details by Malaguti *et al.*[15]. Although, as indicated in this paper, a small opening angle on the diffuse background is permitted in principle, we are looking into the possibility to entirely baffle the sky, so that only X–rays focused by the mirror reaches the focal plane unit. In order to do that, we combine a “sky baffle” placed on the mirror spacecraft around the mirror, and a collimator placed on top of the focal plane, as illustrated in Figure 1. Both the sky baffle and the collimator will be graded shields to stop the highest X–ray background energies and to avoid unwanted fluorescence lines. The size of overall baffling system, (sky baffle collimator length and diameter) is obviously closely linked to mirror parameters (focal length and outside diameter), but also to the accuracy with which the formation will be kept. The system must play its role without introducing unwanted obscurations (vignetting) for all possible excursions of the two spacecraft positions in displacement and angles. Taking all of this into account, the typical size reached are a collimator of ~ 1.5 m long with a 13 cm inside diameter for a 3 m diameter sky shield.

4. MISSION STUDY

As mentioned in Section 1, the Simbol–X mission has been studied by a dedicated engineering team of CNES, the PASO. The goal of this study, so called phase 0, was to fully assess the feasibility of the mission, and its cost, as an input in the selection process of the scientific mission to be flown as a formation flying demonstrator. This study has covered all aspects of the mission and its implementation, going well beyond the initial study made in 2003[6]. We give in this section the main output of this study, which represent a possible mission scenario. More details are given in Clédassou & Ferrando[16].

4.1 Orbit, operations, sky visibility

The orbit has been chosen with the two criteria that should guarantee the feasibility of the formation flight, which excludes the low earth orbit at least in the context of this mission, and result in a minimum background. Experience from XMM–Newton has shown that the background level due to the Earth radiation belts particles becomes negligible only above ~ 75,000 km of altitude, which is thus taken for Simbol–X as the minimum altitude for performing science observations (although observations might still have a low background at lower altitudes depending on magnetospheric activity). Given these constraints and the envisioned launcher, the most favorable orbit that came out for Simbol–X is a high elliptical orbit, with a perigee of 44,000 km, an apogee at 253,000 km, and an inclination of ~ 5° at launch assumed to be from Kourou. About 90 % of the time is spent above ~ 75,000 km, i.e. fully useable for scientific observations. During the mission there is no need to maintain exactly the orbit parameters. The important point is to keep the correct

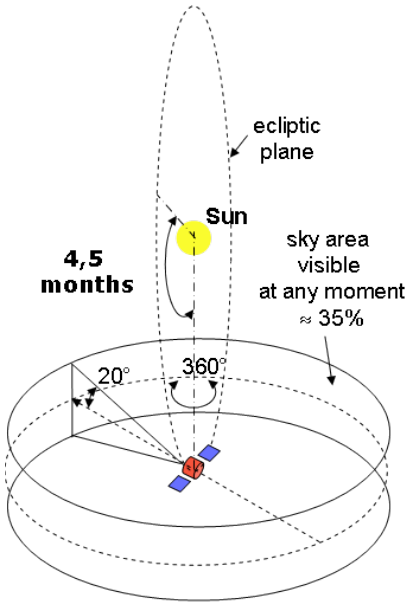


Figure 5 : Simbol–X viewing direction.

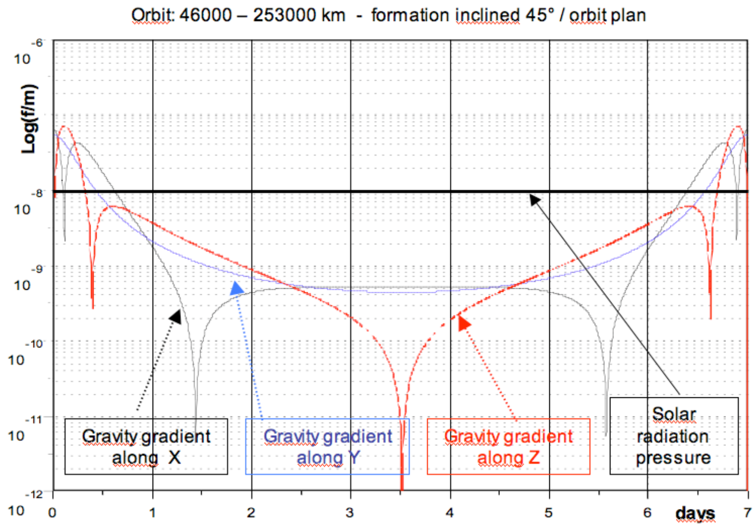


Figure 6 : Comparison of the solar radiation pressure with the gravity gradient along the 7 days of the Simbol–X orbit, for the 3 spatial axes.

orbit period and the phasing with the ground segment to facilitate the operations. In that perspective roughly one manoeuvre per month is expected to maintain the semi-major axis. The result is that orbit parameters evolution are constrained by luni-solar effects and the perigee will for example increase to ~ 70,000 km, and the inclination to ~ 40° after 2 years due to lunar effects combined to semi major axis conservation. This orbit has a period of 7 days, and allows continuous observations during at least 6 days. The day 7 of the orbit, corresponding to the perigee passage, might also be used for observations depending of the actual level of radiation actually encountered close to the (high altitude) perigee.

On the operation side, the orbit can be essentially fully covered by two ground stations, separated by 12 hours. It is however not necessary to have a permanent link with Simbol–X, since the average level of telemetry will be relatively low (about 10 Gbits per week for an average observation plan), and since the system has to be autonomous for its safety in the formation flight configuration. The baseline scheme is thus to have Simbol–X autonomous when performing an observation, with data recorded onboard. Contact with Simbol–X will be made when changing target, which is conducted and followed in real time by the ground, and for regular health check. This amounts to typically one to two hours per day, depending on the observation plan. It is anticipated that for an average observation plan, the science telemetry can in fact be downloaded in a single contact per orbit, at perigee, although download will be possible (at a slower rate) at each contact along the orbit.

Finally, the orientation of the telescope axis with respect to the orbit and the Sun-Earth line is shown on Figure 5. The line of sight shall be 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.

4.2 Formation flight

The high altitude of the orbit is very favorable for formation flying because it fully minimizes the gas consumption needed for keeping the formation. Indeed, the gravity gradient between the two spacecraft is smaller than the solar radiation pressure for almost all the orbit except close to perigee as shown in Figure 6. Nevertheless, the gravity gradient being always low, it is envisioned to design the system so that the formation is kept all along the orbit, including at perigee.

The strategy adopted for the Guidance Navigation and Control (GNC) of the formation flight is to have all functions on one spacecraft. The more massive mirror spacecraft will follow its Keplerian orbit, performing the fine pointing to the astronomical source, while the detector spacecraft will perform the GNC functions to keep its position slaved to the telescope axis, in distance and lateral positions. This ensures good performances by decoupling position and fine attitude control. Moreover this concept simplifies in-flight operations and improves system safety. The fine position control for formation flight will be done by cold gas thrusters on the detector spacecraft, hydrazine thrusters being used for orbit transfer and maintenance, and formation slews.

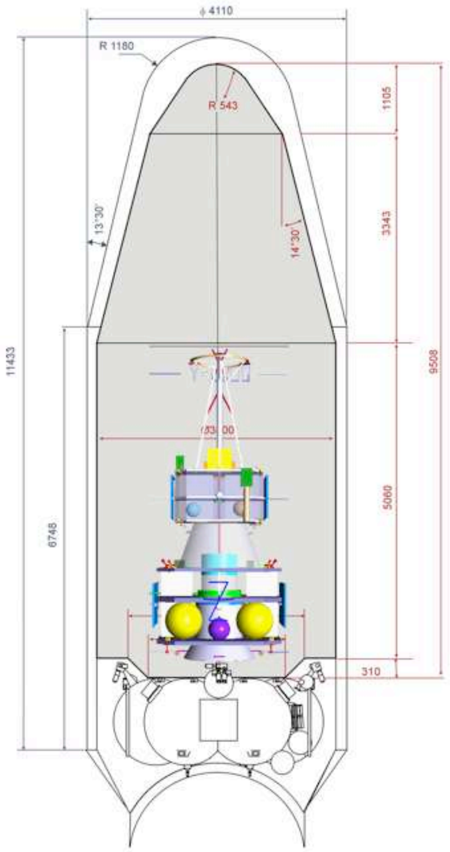


Figure 7 : Composite assembly of the two spacecraft for launch in a Soyuz fairing. The detector spacecraft is mounted on top of the heavier mirror spacecraft.

For the deployment and safing phases, the localization system based on GPS metrology constitutes the baseline. Each spacecraft is equipped with a Rx/Tx terminal (Receiver/Transmitter) plus a set of antennae and the 3D position is reconstructed from the range and line of sight measurements. This system permits moreover to fulfil the observation phases requirements for the relative longitudinal position knowledge. For observation phases, the requirement of relative position knowledge is driving the use of a lateral sensor, including a laser source, which measures the line of sight of the beam reflected by a corner cube with a 1” precision. This sensor is installed on the “detector spacecraft”. Formation guidance is located by choice on the detector spacecraft which directly communicates with the Ground Station, in nominal operations.

4.3 Spacecraft and launch scenario

A relatively hard point of the spacecraft design has been the implementation of the collimator and sky baffle. In addition to its length, the metallic collimator should also not be a source of trouble for the systems in charge of the intersatellite links as well as those needed for the measurements of the relative positioning of the two spacecraft. Depending on its final length, the collimator might be either implemented with the focal plane unit positioned on the spacecraft side facing the mirror, or in a configuration which puts the focal plane unit on the other side of the spacecraft, with the collimator going through the spacecraft structure, rendering the system more compact. The first is the preferred one, for instrumental background reasons. Figure 1 shows drawings of the mirror and detector spacecraft corresponding to this case.

The two spacecraft will be launched together, the envisioned launch vehicle being a Soyuz with a Fregat upper stage. The fairing offers ample space for fitting the two spacecraft. At the start of phase A, it is foreseen to mate the two spacecraft together, as a single composite spacecraft, as shown on Figure 7. Detailed mass estimates have been done, including consumables for an observation program capability of over 1000 targets and three years of operations. The total mass to be launched is around 2.2 tons, including the required margins at this level of study, for a launch capability of ~ 2.3 tons for the desired orbit.

5. CONCLUSIONS

The Simbol–X mission will provide an unprecedented sensitivity and angular resolution in hard X–rays, enabling to solve a number of outstanding questions in the high energy astrophysics. A detailed assessment study was made by CNES in the context of a selection of a scientific mission for a formation flying demonstrator. It has demonstrated the feasibility of the mission within the given programmatic and technical constraints. Together with its scientific value, this has led to the selection of Simbol–X as the formation flight mission to be further studied in phase A.

The phase A activities, jointly conducted by CNES and ASI, will examine more in depth the key aspects of this mission, both on the payload and mission sides. The decision for phase B is expected to be taken in the first half of 2007, for a launch around mid–2013 and a nominal 3 year operational time. As such, Simbol–X will be perfectly timely with respect to the preparation of the very large observatories, as XEUS, foreseen around the end of the next decade.

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