Simbol–X, a formation flight, focusing, broad-band X-ray telescope: calibrations and simulations critical issues

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L. Raimondi

2 Scientifics aims

The very wide discovery space that Simbol−X will uncover is particulary significant for the advancement of two large and crucial areas in high-energy astrophysics and cosmology: black hole physics and census; particle acceleration machanisms.
These two broad topics define the core scientific objectives of Simbol−X. Because of the tight links between galaxy bulges and their central super massive black hole (SMBH), obtaining a complete and unbiased census of SMBH, through direct observations at the energies where the Cosmic X-ray Background (CXB) energy density peaks, is crucial for our understanding of a formation and evolution of galaxies and their nuclei. BH environment is the only known place in the Universe where general relativity can be probed beyond the weak-field limit. About particle acceleration, we are still lacking firm evidences of hadron acceleration in astronomical sites, and we are still searching for the origin of the high-energy photons and cosmic rays.
Hard X-rays observations, possibly combined with $\gamma-$ray and TeV observations, are invaluable tools to identify the processes at work in acceleration sites such as SNR and jets. To achieve its core scientific objectives Simbol−X should [1]:

- resolve at least 50% of the CXB in the energy range where it peaks, thus providing the most complete census of SMBH;
- solve the puzzle on the origin of the hard X−ray emission from the Galactic Center, which harbors the closest SMBH;
- constrain the physics and the geometry of the accretion flow onto both SMBH and solar mass BH;
- map the environment around SMBH characterized by the coexistence of gas components with different dynamical, physical and geometrical properties;
- constrain acceleration processes in the relativistic jets of blazars and gamma ray burst (GRB);
- probe acceleration mechanisms in the strong electromagnetic and gravitational fields of pulsar;

a single spacecraft, the mirror and detectors will be flown on two separate spacecrafts in a formation flying configuration, as sketched on Figure 1

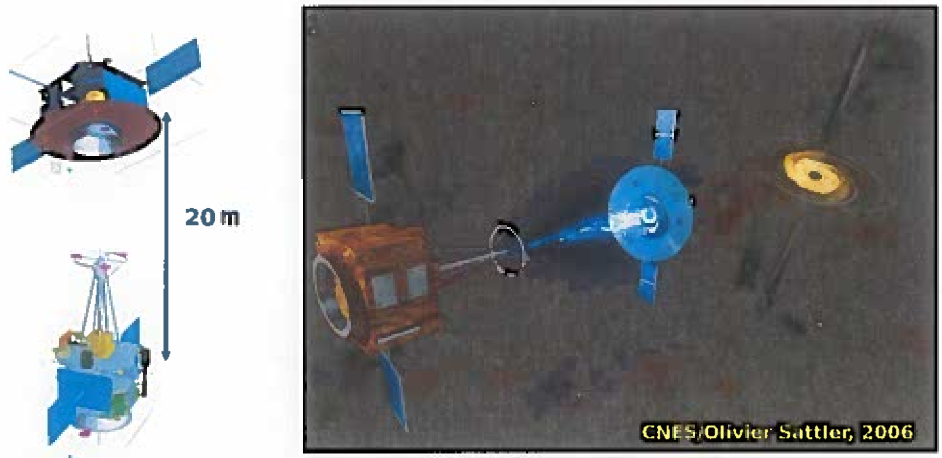

Figure 1: A sketch of the Simbol−X focusing telescope based on two different satellites (one hosting the optics module, the other the focal plane) in a formation flight configuration.

Simbol−X is a pointed telescope, which is nominally required to be able to perform very long uninterrupted observations (10^5 s 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, dictates the requirements on the formation flying stability. The constraint is that the distance between the two spacecrafts (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 center of the focal plane within about ± 20 arcsec. It is also required that the arrival direction of each detected photon can be reconstructed to ± 2 arcsec (radius, 90%), which imposes a knowledge (monitoring) of the relative positions of the two spacecrafts to that level of accuracy.
There are three main components in the Simbol−X payload. The first one is the optics based on grazing incidence mirrors. The Simbol−X optics module will be based on pseudo−cylindrical monolithic Ni electro−formed mirror shells with Wolter I profile, adopting the technology already successfully used for making the gold coated soft X−ray mirrors of the Beppo−SAX [4], XMM−Newton [5] and Jet−X/Swift [6] missions. This approach is well

Table 2: Main parameters of the Simbol–X mirror module assuming a focal length of 20 m

Focal length	20 m
Mirror configuration	Wolter I
Coating	Pt/C multilayer
Outer and inner diameter	65–26 cm
Mirror heigh (parabola + hyperbola)	60 cm
Shell material	Ni
Wall thickness (max–min)	0.4–0.2 mm
Expected angular resolution (HPD)	15–20 arcsec
Field of view @30 keV (FWHM)	12 arcmin

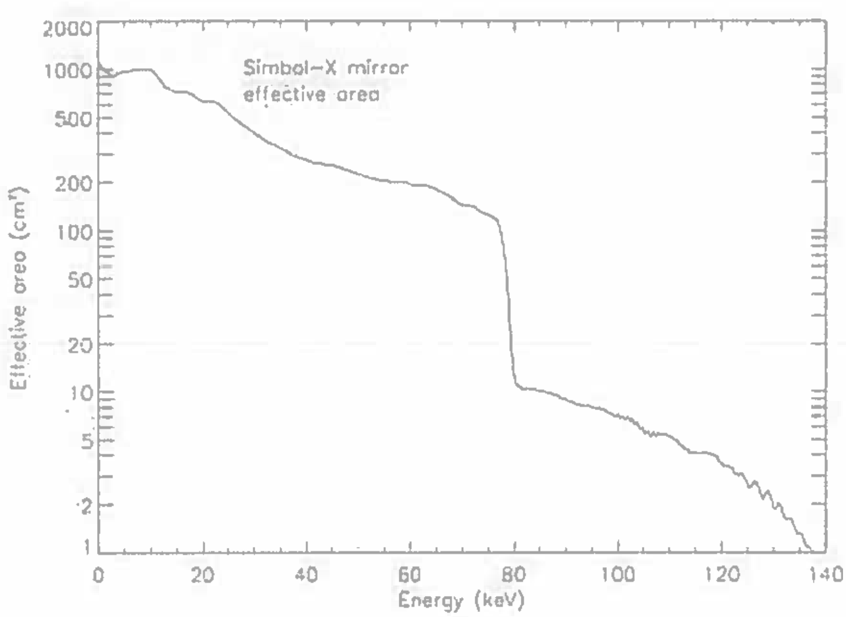

Figure 2: Theoretical on–axis effective area for the Simbol–X optics configuration based on a 20 m focal length whose parameters are reported in Table 2 [4].

vanced and it will be consolidated during the Phase A study. The detectors Quantum efficiency trend is shown in figure 3

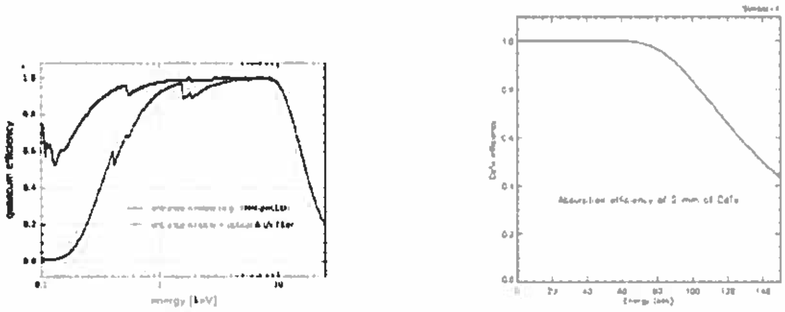

Figure 3: Quantum efficiency. SDD (left side) and CZT (right side) [4].

A third fundamental component of the payload is given by an efficient active and passive detector background shielding, effective not only to prevent the particle background, but also to shield against the diffuse X−ray sky background component falling in from outside the field of view of the X−ray telescope. In addition to the intrinsic characteristics of these three components, the telescope performances are also relying on one other important system, which are the formation flight attitude reconstruction system.

4 Scientific calibrations criticalities

X−ray telescope calibration measurements are canonically devoted to:

- Validation of the telescope scientific performances
- Scientific characterization of the telescope
- Validation of the telescope mode simulation model(s)
- Production and maintainance of the calibration database (CalDB) files

It is also important to the end-to-end calibration tests. Its key aim is the verification and scientific calibration of the global properties of the whole Simbol−X telescope system. Its importance/roles can be summarized in the following points:

- We need a calibration source that must cover a 0.5–80 keV energy band, an unprecedent broad–band;
- That calibration source could be mono–chromatic or with a continuous spectrum;
- We need a reference–detector that can work in that wide energy band;

- long focal length:
  Simbol–X focal length is three times longer that all precedent telescopes. That causes calibration problems as detailed above;
- Hybrid (3 detectors) focal plane;
  Simbol–X covers a broad energy–band with only two detectors;
- broad energy range (three decades);
- formation flying (2 spacecrafts).

In Europe is available in Munich the 130 m long PANTER Test facility operated by MPE, that has been used to calibrate several X–ray telescopes (like Rosat, XMM, SAX, Swift, Suzaku). The utilization of the PANTER facility with 20 m focal lengths poses chalenging practical problems, due to the difficulties of positioning and handling the optics inside the vacuum tube (as the focal length would not fit into the 12.5 m–long handling chamber normally used for mounting the optics). Considering that the diameter of the Simbol–X telescope is not much less than the internal diameter of the long (123 m) vacuum tube and that the pencil beam setup needs a complex tip_tilt jig supporting the telescope, it could be necessary to modify the facility. Apart this practical problem, there are two other difficulties to consider:

- the incoming X-ray beam divergence is (for a 20 m focal length) comparable to the incidence angle on the mirror surfaces, even with a $\sim$ 100m long vacuum tube. This translates in a severe effective area loss for double reflection optics, in addition to the canonical effects related to the finite distance of the source. The latter are normally present also with shorter focal lengths ($\leq$ 10 m), but they can usally be corrected because the effective area being sampled is a significant fraction of the total ($>$ 50%);
- the photon incidence angle variation from parabola to hyperbola, thus causing different reflectivity responses.

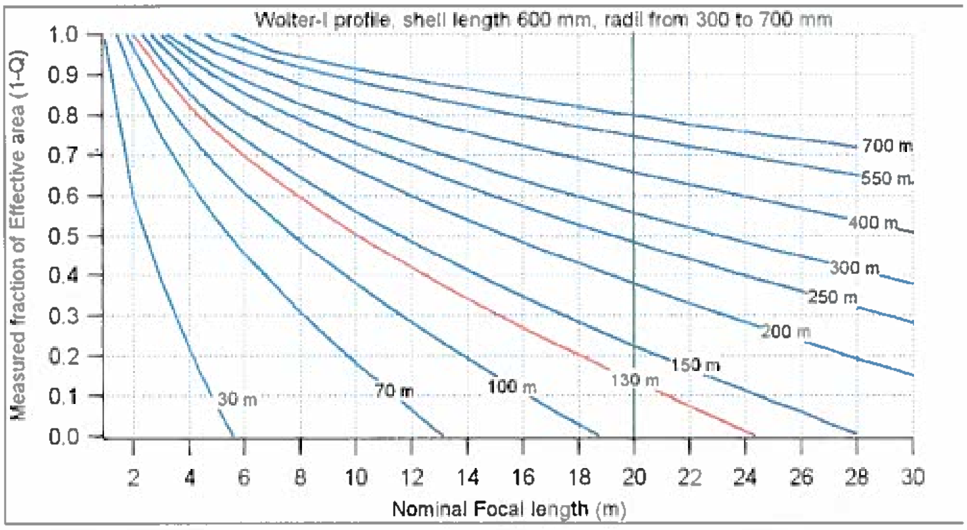

Figure 4: The 1-Q fraction of the measured effective area in double reflection for Wolter–I mirrors.

Pencil–beam set–up for Simbol–X optics characterization

The standard technical solution to overcome the divergence problems caused by the X–ray source finite distance is by means of pencil beam illuminating only one sector of the mirror. This technique has already been adopted for previous X–ray missions, e.g. ASCA [10], but it has never been implemented to characterize optical system with an angular response below 1 arcmin. The pencil–beam illumination allows the characterization of selected mirror sectors with a thin X–ray beam emerging from a open slit in an opaque screen. In these conditions, the beam divergence is strongly reduced and the optics angular offset can be properly set, in order to make the finite distance effects negligible for the considered mirror sector. The characterization (PSF and EA) of the complete mirror shell is then achieved by spinning the optics around its axis, and adding together offline the performed measurements.
The main drawback of the pencil–beam approach is the associated illuminated area strong reduction, which naturally implies an increase of the integration time required to reach significant photon statistics. This effect can

Integration time

The estimation for the error in the Effective Area A_e(E) measurement within the energy band ΔE can be done on the basis of the poisson's statistics. If we indicate with N_R the number of collected photons in the focal plane at photon energies between E and E+ΔE, and with N_D the number of incidence photons emerging from the entrance slit in the same energy band (assuming that the detector quantum efficiency is the same for either direct or focused beam), it is easy to prove that the relative error in the determination of A_e, ϵ_A, is simply given by:

$$\epsilon_A(E) = \frac{\sigma_A}{A_e} = \sqrt{\frac{1}{N_R} + \frac{1}{N_D}} \tag{1}$$

Moreover, one should note that all measurements have to be repeated for different biases (10, 30, 50 keV) of the X−ray source, in order to cover the Simbol−X energy band. Hence, the total integration time can be, on average, quoted as:

$$\Delta t = 3(N\Delta t_R + \Delta t_D) \tag{2}$$

where N is the number of windows masks to be adopted for the pencil−beam setup, in order to fulfill the measurement tolerance.
For the computation of the HEW statistical error, we consider the Encircled Energy function as the integral of the effective area around the focus.
The key concept is a pencil−beam setup which allows to reach high accuracy in EA and HEW determination within an acceptable integration time.
For instance, to obtain HEW measurements at three different energies with an error of 5%, an integration time of 8 to 28 hours is required, depending on the number of used windows and the intensity of the source, within a flux limit $< B_{max} >$ to avoid pile−up. The first integration time would be needed with 11 windows and $< B > / < B_{max} >$=50%.
With the same fluxes, number of windows, and error limits, the integration time for EA would be 15 to 48 hours with a in focus measurement, or less, if the calibration is performed out of focus [3].

6 In-flight calibrations

Simbol−X in-flight calibrations will consist of mainly two parts:

Applications

In my thesis work I have simulated the X−ray diffuse emission expected from the Galactic Center (GC) with the simulator. In particular, three theoretical models of this diffuse emission have been considered: a thermal emission model, synchrotron emission model, an integrated emission of faint and unresolved Galactic point−like sources. I simulated the diffuse emission from GC using these three models. The aim was to study how and if Simbol−X would be able to distinguish between the three physical processes for the origin of this diffuse emission. I found that Simbol−X will characterize the different physical processes and will a large number of spectral information about the nature of resolved and unresolved compact sources near the GC. The GC simulations with SDD and CZT are shown in figure 6 (thermal emission model) and figure 7 (integrated emission of faint and unresolved Galactic poin−like sources model).

8 Future developments

Scientific simulator updates

In the future, it would be desirable to modify the simulator to obtain a facility that can better study the several kind of objects either, point−like or extended−like, and can allow to setup the telescope parameters easily. The simulator features that we wish to potentiate:

- extended sources morphologies. The only form reproducible with the simulator is, at present, a circular form with a King brightness distribution;
- the maximum number of point−like sources that can be simulated simultaneously is, at present, fixed at 100. It would be desiderable to increase this number to, at least, 10000;
- the Fortran language is not much versatile. One possibility could be to rewrite a new simulator, starting from the old, in a much flexible language like C++ or IDL.

Calibration science−driven statistical requirement

The accuracy level of the calibration, in terms of e.g. effective area and PSF model characterization, is driven by the required upper limit on the systematic error associated with a given observation. Previous high energy focussing telescope missions (e.g. XMM−Newton, Chandra, Swift/XRT) have assumed the canonical value of 10% as the reference figure of merit for the accuracy of the various parameters. A science−driven rationale for the required accuracy is given, in the specific case of Simbol−X, starting from effective area and PSF:

- Effective area. The impact of an uncorrected systematic feature on the measurement of the spectral parameters depends on many factors. First of all, a systematic error affects scientific results only when it is not negligible with respect to the statistical error. Then its impact will be function of its spectral position and of the shape and intensity of the input spectrum.

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