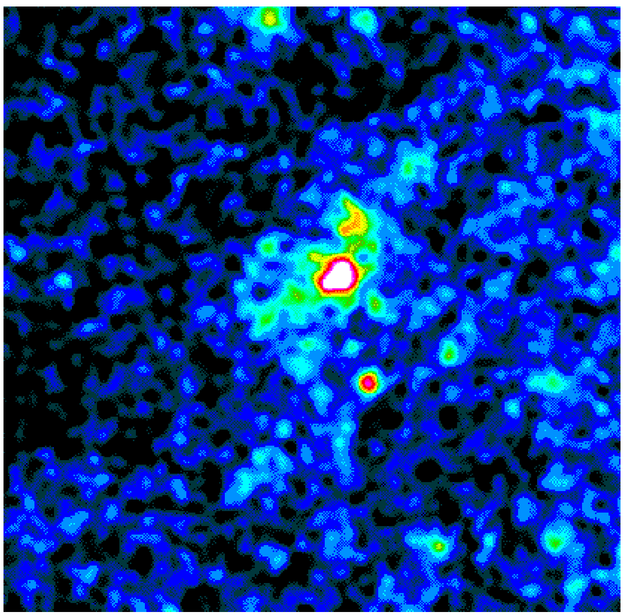
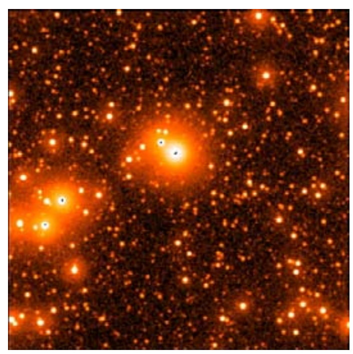
X-Ray Observatory

Study preparation activities
Status Report





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LIST OF ACRONYMS:

AD:	Applicable Document
AO:	Announcement of Opportunity
CaC:	Cost at Completion
CCN:	Change Contract Notice
CDF:	Concurrent Design Facility
CP:	Chemical Propulsion
CSG:	Centre Spatial Guinea
DSC:	Detector Spacecraft
FDIR:	Failure Detection Isolation & Recovery
FF:	Formation Flying
FOV:	Field Of View
FPA:	Focal Plane Array
HEO:	Highly Elliptical Orbit
HPO:	High precision Pore Optics
HXC:	Hard X-ray Camera
HTRS:	High Time Resolution Spectrometer
ITT:	Invitation To Tender
L2:	Second Lagrange point (Sun-Earth system)
LV:	Launcher Vehicle
MOC:	Mission Operations Centre
MSC:	Mirror Spacecraft
NFI:	Narrow Field Instrument
PI:	Principal Investigator
P/L:	Payload
PDD:	Payload Definition Document
PSE:	Payload Support Elements
RA:	Risk Assessment
S/C:	Spacecraft
SLM:	System Level Margin
SOC:	Science Operations Centre
TDA:	technology Development Activity
XPOL:	X-ray Polarimeter
XRO:	X-Ray Observatory
WFI:	Wide Field Imager

LIST OF REFERENCE DOCUMENTS:

[RD-CDF] XEUS – CDF study report CDF-31(A), October 2004.
[RD-SciRD] Science Requirements Document – v4.0 – 31 March 2006
[RD-Sci] A.N.Parmar et al. SPIE Proc., Vol. 5488, 388-393 (2004).
[RD-MRD] Mission Requirements Document – draft – March 2005
[RD-PL] D.Lumb, SPIE Proc., Vol. 5488, 539-548 (2004).
[RD-PDD] Payload Definition Document – v3.1 – March 2006
[RD-HPO] S.Kraft et al. SPIE Proc., Vol. 5900, 590010-1/12(2005)
[RD-MLC] G.Pareschi, V.Cotroneo, SPIE Proc., Vol. 5168, 53-64 (2003).
[RD-Opt] M.Bavdaz et al. SPIE Proc., Vol. 5488, 829-836 (2004).

INTRODUCTION

The X-Ray Observatory, also known as XEUS (X-Ray Evolving-Universe Spectroscopy), is one of the potential future missions identified in the framework of the ESA Call for Themes issued in April 2004. Preliminary studies on a post XMM-Newton mission assumed a LEO scenario, with two S/C's in formation flying, 6 m^2 (at 1 keV) effective area mirror and a focal length of 50 m. The mirror optics was originally based on the same technology used for XMM (replicated nickel mirrors), while the mission scenario was assuming a multiple launch approach and the use the ISS as servicing post for the observatory.

In September 2003, ESA investigated non-ISS related scenarios, focusing on the adoption of an innovative optics technology (Silicon High precision Pore Optics – Si HPO) and on an even larger observatory (effective area of order 10 m^2 at 1 keV) at L2. This new configuration triggered the interest of the US scientific community, resulting in a joint ESA/JAXA/NASA effort. A number of activities have been performed on this mission profile, including dedicated CDF studies, both at ESA and NASA [RD-CDF]. The profile was again assuming a formation flying approach, with a deployable mirror supported during launch by a dedicated canister. Baselined LV was Ariane 5 or Delta-IV Heavy. Although the study activities were conducted in collaboration with NASA, differences remained in the overall configuration, especially on the Mirror Spacecraft (MSC) side, due to different model payload assumptions (including the addition of reflection gratings behind some parts of the mirror) .

Following the decision of NASA to suspend collaboration on a joint study, ESA and JAXA have jointly started in the third quarter of 2005 a revision of the mission configuration, aimed to remain compatible with the available level of resource and reduce development risks and time.

The revised XRO mission scenario described in this document is based on an A5 launch to L2, a composite S/C composed by Detector (DSC) and Mirror (MSC) unit inserted as a single stack into final orbit and then flown as a formation during science operations, with a focal length of order 35 m. The DSC is designed to support the payload units (including the provision of the required cryogenic chain) and track the focus point of the mirror as to maintain it at the instrument focal plane. The MSC design is based on a fixed optical bench, using the volume offered by the LV fairing, a solution that offers a more mass effective structure, simpler baffling and a more favourable thermal environment for the telescope optics, with an effective area exceeding 5 m^2 at 1 keV.

The reference payload [RD-PDD] is based on a set of core instruments and a set of high priority augmentation units (to be included if resource allows). The core instruments are represented by a single cryogenic Narrow Field Imager (NFI, providing high energy resolution spectroscopy capability between 0.2 and 6 keV over a FOV of 0.75 arcmin diameter) and a Wide Field Imager (WFI, providing imaging and spectroscopy between 0.5 and 15 keV over a FOV of 7 arcmin diameter). The high priority augmentation units include a Hard X-ray Camera (HXC), a High Time Resolution Spectrometer (HTRS) and an X-ray Polarimeter (XPOL).

This document provides a summary of the preliminary results of this revision process, including an overview of the envisaged study approach.

1 PRELIMINARY STUDY GOALS AND ACTIVITIES

The goals of the preliminary XRO study are briefly recalled below:

- Consolidation of the science requirements.
- Definition of the mission requirements driving the spacecraft definition.
- Identification and down-selection of optimal mission profiles.
- Further maturing and definition of the reference payload.
- Preliminary definition of the flight segment design through preliminary industrial work and confirmation of overall feasibility and potential technology development needs.
- Preliminary definition of the ground segment requirements, of the mission and of the science operations requirements.
- Identification and analysis of most critical areas, design and cost drivers, including aspects involving international cooperation.

In order to achieve these goals, the following activities are in progress within the Science Payload and Advanced Concept Office (SCI-AM, Science Missions section):

- Preparation of all reference and applicable documents required for the study.
- Internal conceptual design of the revised mission configuration, so as to provide a solid starting point for any future activities.
- An industrial study aiming to verify the resources required by the payload and to consolidate its interfaces to the platform (Apr to Dec 06).
- An industrial study aiming to identify a preliminary design of the telescope and to consolidate its interfaces to the corresponding S/C (Sep 06 to May 07).
- Numerous iterations with the scientific community on the telescope design and on the reference payload, to trigger further definition and consolidation of critical areas [RD-PDD, RD-SciRD].
- Preliminary risk and cost assessments.

Although the preliminary study activities follow a top-down approach, from the science requirements, down to the mission specification and the system definition, a Design-To-Cost method is imposed to minimise costs.

2 SCIENCE REQUIREMENTS

The large throughput and good angular resolution of XRO will allow the *detailed* spectral investigation of sources which are too faint for study with the current generation (*Chandra, Suzaku* and XMM-*Newton*) of X-ray observatories [RD-Sci]. One of the main science goals of XRO is to investigate the high-redshift Universe. A large fraction of the total baryonic matter in the Universe is now known to reside in the X-ray emitting component of clusters and groups and the study of their properties will be another important topic for XRO. The accretion power onto massive black holes is the dominant component of the total X-ray emission in the Universe, so conversely the ability to trace this evolution will be an important diagnostic of the evolution of black holes and the coeval growth of galaxies with cosmic time. Probing the high-energy emitting regions around collapsed objects provides the best laboratory for testing the physics of matter in extreme gravity environments. In addition to these specific themes, the unprecedented high collecting area will make an enormous impact on studies of nearby objects which have been a mainstay of traditional X-ray astronomy, and therefore we also discuss the detailed spectroscopic, timing and polarimetric investigations of brighter objects that will be addressed by XRO. For each of the 3 topics identified in CV2015-2025 call for themes a number of sub-topics have been determined, each of which provides the driver for one, or more, of the science requirements to be met by XRO:

1. Evolution of Large Scale Structure and Nucleosynthesis:
   a. Formation, dynamical and chemical evolution of groups and clusters. This is the driver for spectral grasp, the product of the FOV, area, and spectral resolution for the high spectral resolution instruments.
   b. Baryonic composition of the Intergalactic Medium. This drives the ultimate spectral response required from the high spectral resolution instruments.
   c. Enrichment dynamics, inflows, outflows and mergers. This drives the stability of the absolute spectral calibration of the high spectral resolution instruments.

2. Coeval Growth of Galaxies and Supermassive Black Holes:
   a. Birth and growth of supermassive black holes which drives the overall FOV size and the limiting sensitivity
   b. Supermassive black hole induced galaxy evolution which drives the angular resolution requirements.

3. Matter under Extreme Conditions:
   a. Gravity in the strong field limit with drives the ultimate timing resolution required.
   b. Equations of State studies which drive the product of collecting area and spectral response for the high spectral resolution instruments, as well as the polarization performance.
   c. Acceleration phenomena which drive the high energy (>10 keV) spectral grasp.

The latest version of the Science Requirements Document was approved by the XEUS Science Definition Team in March 2006 [RD-SciRD]. A summary of the main parameters and related values is provided in table 2.1

Figure 2.1: Simulated XRO Deep Field 10^{44} erg s^{-1} AGN Spectrum with a rest frame 500 eV equivalent width relativistically distorted Fe line (Laor profile).

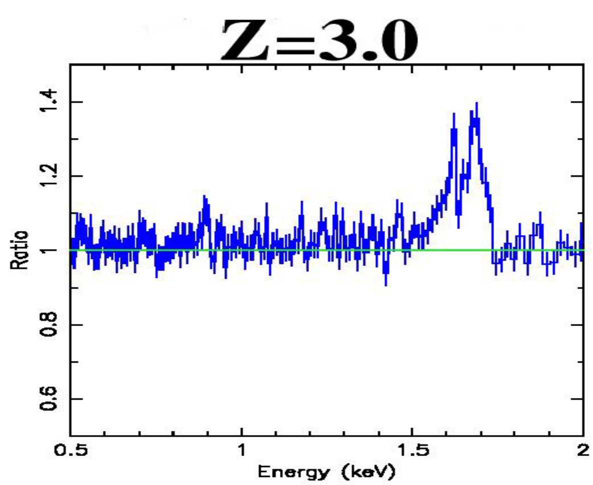


Table 2.1 – Summary of the Science Requirements [RD-SciRD]

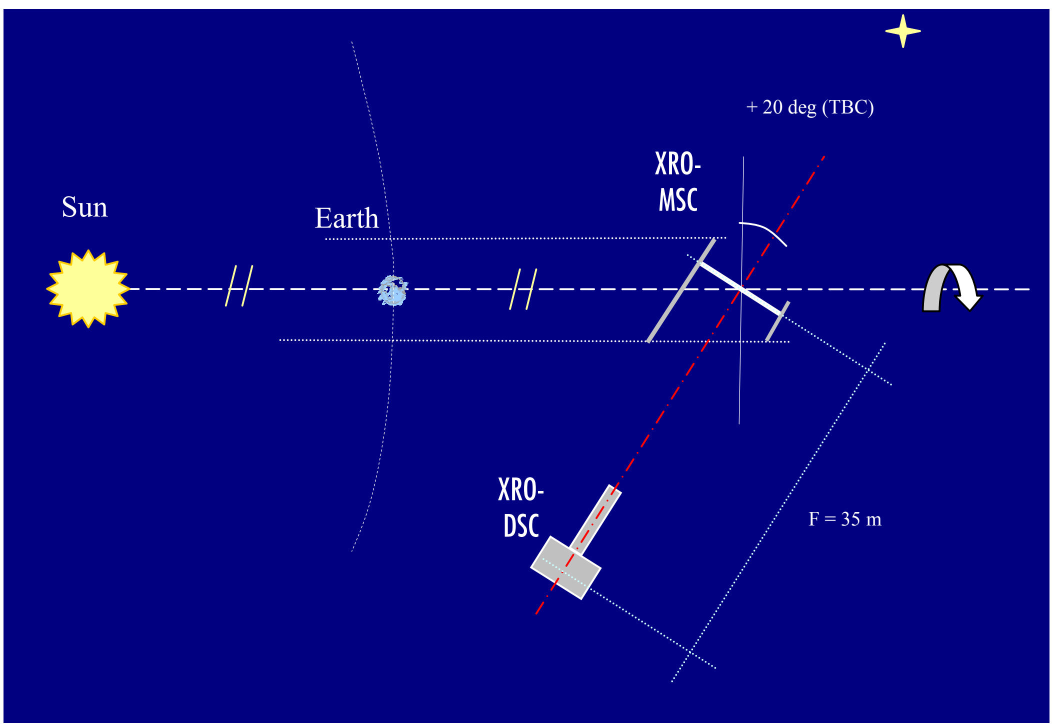
Topic	Effective area (m2)	Energy range (KeV)	Angular res. (arcsec HEW)	Instrument FOV Diameter (arcmin)	Spec. res. (eV, FWHM)	Point source det. sens. (erg cm-2 s-1	Time res. (s)	Count rate capability	Polarimetry MDP at 3σ conf 100 ks	Observing constraints	Sub-topic requires
Evolution of large Scale Structure and Nucleosynthesis											
Formation, dynamical and chemical evol. of groups and clusters	1.0 @ 0.2 keV 1.5 @ 0.2 keV (goal) 5 @ 1 keV	0.2-6 NFOV 0.2–10 LFOV 0.2-40 (goal)	5 2 (goal)	7 (LFOV) 0.75 (NFOV) 1.7 Ø (high priority goal)	2 eV @ <2 keV	N/A	N/A	N/A	N/A	N/A	NFOV LFOV
Baryonic composition of the IGM (WHIM)	1.0 @ 0.2 keV 5 @ 1 keV	0.2 – 6	5	0.75	2 eV @ 500 eV 1 eV @ 500 eV (goal)	N/A	N/A	N/A	N/A	N/A	NFOV
Enrichment dynamics	5 @ 1 keV	0.2 – 6	5 2 (goal)	5 (LFOV) 0.75 (NFOV)	1 eV @ 1 keV (goal) 2 eV @ 2 keV (goal) 6 eV @ 6 keV 3 eV @ 6 keV (goal)	N/A	N/A	N/A	N/A	N/A	NFOV LFOV
Coeval Growth of Galaxies and Super-massive Black holes											
Birth and growth of super-massive black holes	1.0 @ 0.2 keV 5 @ 1 keV 1 @ 10 keV, 0.1 @ 15 & 40 keV (goals)	0.1 – 10 0.1-40 (goal)	5 2 (goal) 10 @ 40 keV	5 (LFOV) 7 (goal)	150 eV @ 6 keV 1 keV @ 40 keV (goal)	$4\ 10^{-18}$ (0.2-10.0 keV; 4σ)	N/A	N/A	N/A	>500 ksec visibility once per 6-month observing season	LFOV HXC
Super-massive black hole induced galaxy evolution	5 @ 1 keV	0.1 – 10 0.1-40 (goal)	5 2 (goal)	0.75 (NVOV) 5 (LFOV)	6 eV @ 6 keV 3 eV @ 6 keV (goal)	N/A	N/A	N/A	10% MDP 0.1 mCrab	N/A	NFOV LFOV
Matter Under Extreme Conditions											
Gravity in the strong field limit	2 @ 7 keV 1 @ 10 keV (goal)	0.5 – 15 0.5-40 (goal)	N/A	N/A	150 eV @ 6 keV	N/A	10	$8\ 10^3$ s <1% pileup LFOV. <10% pileup NFOV	2% MDP 10 mCrab. 3σ conf.	10^3 s (10^5 s goal) continuous observ. >2 weeks/season	LFOV HXC
Equations of State	5 @ 1 keV 2 @ 7 keV 1 @ 10 keV (goal) 0.1 @ 15 keV (goal)	0.2 – 6 1 – 15 HTRS 1 – 40 (goal)	N/A	N/A	5 eV @ 2 keV 200 eV @ 6 keV	N/A	10^{-5} (high pri. goal)	$2\ 10^6\ s^{-1}$ (with <10% deadtime) HTRS	2% MDP 10 mCrab (10 ksec). 3σ conf.	10^3 s ($5\ 10^4$ s goal) continuous observ. ToO <1 day (goal). $\pm5^o$ ($\pm15^o$ goal) range of Sun angles	HTRS NFOV
Acceleration phenomena	0.1 @ 15 keV (goal) 0.1 @ 40 keV (goal)	1 – 15 1 – 40 (goal)	10 @ 40 keV (goal)	5 x 5	1 keV @ 40 keV (goal)	N/A	N/A	N/A	2% MDP 2 mCrab. 3σ conf.	N/A	HXC

3 MISSION REQUIREMENTS

The main mission requirements are summarised below. The complete set of requirements to be applied to future system level studies is in preparation [RD-MRD].

- Baselined launch vehicle is an Ariane 5 - ECA (from CSG).
- Direct transfer into halo orbit, with duration of ~ 3 month.
- Halo orbit around L2 (typical amplitude ~ 700000 km, typical period ~ 6 month).
- Autonomous formation flying capability as required by the telescope optical design requirements and as to allow un-interrupted science observations (up to 800 ksec).
- Core payload including one Narrow Field Instrument and the Wide Field Imager. High priority augmentation units (second Narrow Field Instrument, HXC, HTRS, and XPOL) to be accommodated as system resource allows.
- Provision of cryogenic chain required to support the science payload [RD-SciRD].
- Use of functional elements from other ESA missions and introduction of design-to-cost measures as to reduce cost in order to meet the potential CaC allocation.

Figure 3.1: XRO in formation flying at L2 and related Sun Aspect Angle during observations (preliminary value, To Be confirmed following the consolidation of the MSC design).



4 DEFINITION OF THE REFERENCE PAYLOAD

The actual scientific payload for the X-Ray Observatory mission will be selected on a competitive basis, following an Announcement of Opportunity that will be open to the international scientific community. In order to proceed with the assessment study at system level in an effective manner, it was decided to establish a Payload Working Group with membership from the science community, whose task was to provide detailed input on the design and resource requirements of representative (and state-of-the-art) instruments for the so-called reference payload [RD-PL]. The reference payload comprises instruments that satisfy the measurement requirements as defined in [RD-SciRD].

A summary of the XRO reference payload [RD-PDD] is provided in the table below (under the assumption of F=35m). Two categories are identified: a) core units; b) high priority units.

Presently two different Narrow Field Instrument designs are available:

1) NFI1 is based on a focal plane of super conducting tunnel junctions (STJ), operated at a temperature of < 300 mK via a 3He Sorption Cooler (or as an alternative an Adiabatic Demagnetisation Refrigerator (ADR) if a temperature below 250 mK is required).
2) NFI2 is based on a focal plane array of micro-calorimeters, operated at about 50 mK via an ADR;

In consideration of the expected launcher performance and of the resource demands of both Detector Spacecraft and Mirror Spacecraft, it has been assumed to limit the model payload to the Wide Field Camera and a single Narrow Field Imager. Given the early definition stage of the mission, it is not possible to make a definitive choice on the actual NFI design and therefore both designs will be analysed in the context of the XRO/XEUS payload accommodation study. In other words, both configurations (WFI + NFI1 and WFI + NFI2) will be investigated, including different cryogenic chain designs, based on ADR and spacecraft units.

On the basis of the estimates produced in [RD-PDD], it is expected that the nominal XRO payload (WFI+NFI) will have a total mass of order 350 kg (including cryogenic chain) and a power of order 800-900 W.

The science data rate for the nominal payload (NFI+WFI) is presently estimated to be of order 1.0 Mbps. A significant data rate increase is anticipated when considering the presently envisaged needs of some of the high priority payload units (HXC, HTRS and XPOL).

Table 4.1 – Summary of the reference payload, assuming F=35m [RD-PDD].

Characteristic	**Wide Field Imager**	**Narrow Field Imager (Option 1)**	**Narrow Field Imager (Option 2)**
Detector type	Semiconductor (DEPFET arrays)	Superconductors STJ	Superconductors TES
Mass (kg) (*)	71	76	43
Power (W) excluding Dc/Dc converts and including margin	202	91	115
Operating temp.	210 K	300 mK	50 mK
Cooling	Radiator/Peltier	Closed cycle cooler & sorption cooler / ADR	Closed cycle cooler & sorption cooler / ADR
Detector Size (mm^2)	80 x 80	7.5 x 7.5	7.68 x 7.68
Energy Range (keV)	0.05 – 15	0.2-6	0.2-6
Energy resolution (FWHM)	70 eV @ 1 keV	2eV@500 6eV@ 2keV	6 eV @ 6 keV
Pixel size (µm)	78	150	240
Number of pixels in one dimension	1024	50	32
Field of View (arcmin)	7	0.74	0.75
Baffle length (cm – assuming a MSC skirt of 36.5 cm)	575	71	71
Characteristic	**Hard X-Ray Camera**	**High Time Resolution Spectrometer**	**XPOL**
Detector type	Compound semicond. array	Silicon Drift Diodes (SDD)	Gas microwell detector
Mass (kg) (*)	45	16	24
Power (W) excluding Dc/Dc converts and including margin	33	84	58
Operating temp.	220 K	250 K	290 K
Cooling	Radiator	Radiator	None
Detector Size total (mm)	51	12	15
Energy Range (keV)	15 - 40	0.5 - 10	1-10
Energy resolution	1 keV @ 40 keV	50-250 eV @ 0.5-10 keV	900 eV @ 6 keV
Pixel size (µm)	480	2000	50
Number of pixels in one dimension	96	5	320
Field of View (arcmin)	5	1.2	1.5
Baffle length (cm – assuming a MSC skirt of 36.5 cm)	430	112	140

(*) Mass values excluding main baffle and including maturity margins.

4.1 The Payload Definition Document

The reference payload described in the Payload Definition Document (PDD) plays a key role in determining the required platform resources and performance level. A new version of the PDD (v3.0) has been released in consultation with the PLWG. Considerable effort has been put in establishing realistic reference designs and corresponding resource estimates, without pre-empting any future instrument Announcement of Opportunity (AO).

A realistic estimate of the instrument requirements is thus critical to the system level activities. In order to consolidate such requirements, a preliminary industrial study is presently running to assess the actual Detector Spacecraft (DSC) resources required by the payload and the related configuration impact, in line with the boundary conditions applying to the mission. Specific emphasis is put on the cryogenic chain required to support the instrument operations (NFI) and on X-Ray straylight rejection.

Future releases of the PDD are planned at a later stage so as to reflect the results of the industrial studies and the instrument evolution. Examples of such model designs are shown in the figures 5.1.1 (WFI), 5.1.2 (NFI1/2).

Figure 5.1.1 – Reference design of the WFI Focal Plane Assembly.

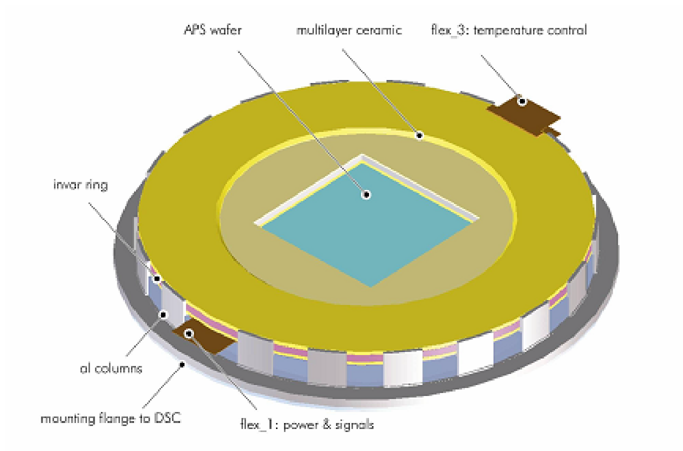
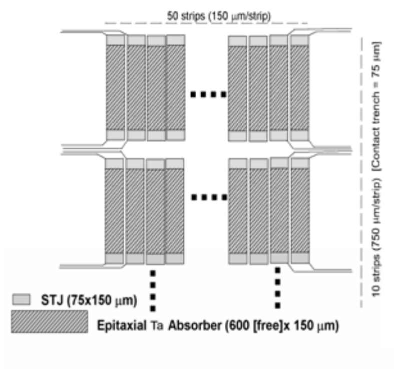
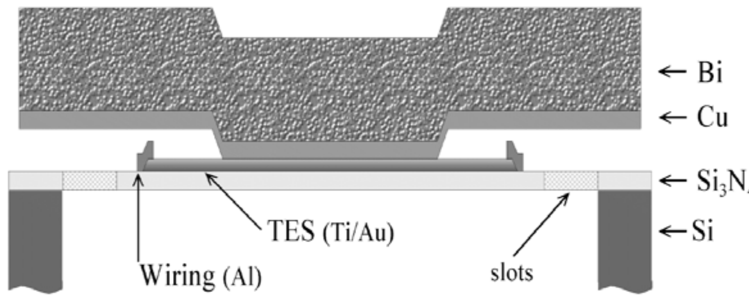


Figure 5.1.2 – Schematic diagram of the NFI Focal Plane detector (NFI1 – STJ / NF2 - TES).





4.2 Payload accommodation aspects

The X-Ray Observatory will be a three-axis stabilised telescope, relying on formation flying of MSC and DSC at a distance of 35 m (focal length). The instruments shall be installed in the DSC, and the illumination of the individual focal plane will be enabled by a shift of position (both along the optical axis and on the perpendicular plane) performed by the spacecraft. The main characteristics of the envisaged accommodation are:

- The overall philosophy to have platform provided (as opposed to instrument provided) cryogenic coolers, so as to maintain clear responsibility and interfaces on such mission critical items.
- The installation of the instruments inside the DSC body to guarantee: a) exploitation of the DSC body size to implement the baffling requirements; b) additional radiation shielding.
- A baffle system forward of the instruments is required to reject stray X-ray and optical stray light. Overall baffling will be distributed between MSC (in the form of a skirt around the mirror) and baffles mounted in front of the instruments on the DSC. The baffle length is dependent upon the focal length, the mirror skirt size and the size of the detector, with WFI posing the most challenging requirements given the large instrument FOV. Additional optics baffling will be implemented directly on the mirror elements.

Figure 4.2.1 – Adiabatic Demagnetisation Refrigerator under development for XRO (courtesy of *MSSL*). Engineering model (left side) and assembly drawing (right side).

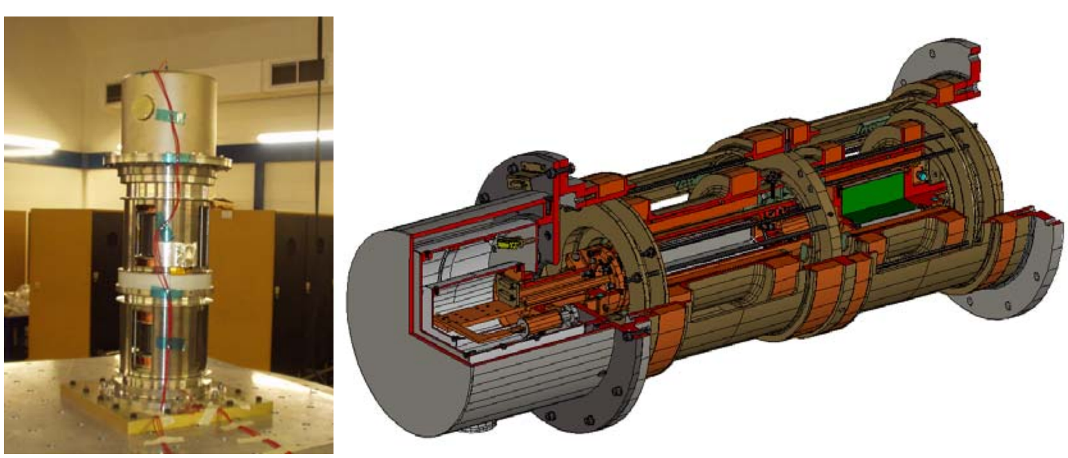
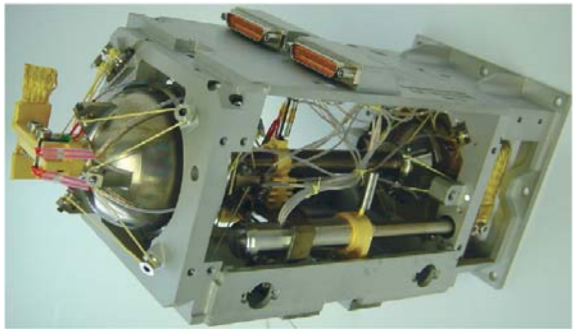


Figure 4.2.2 – Herschel sorption cooler potentially re-usable onboard XRO (courtesy of *CEA-CBT*).



5 THE MIRROR

The X-Ray Observatory relies on innovative technologies to deliver the required effective area within the available system resources. The preliminary mirror accommodation and MSC configuration activities aim to take full advantage of such a technology, while retaining compatibility with the mission requirements, in terms of overall volume and mass.

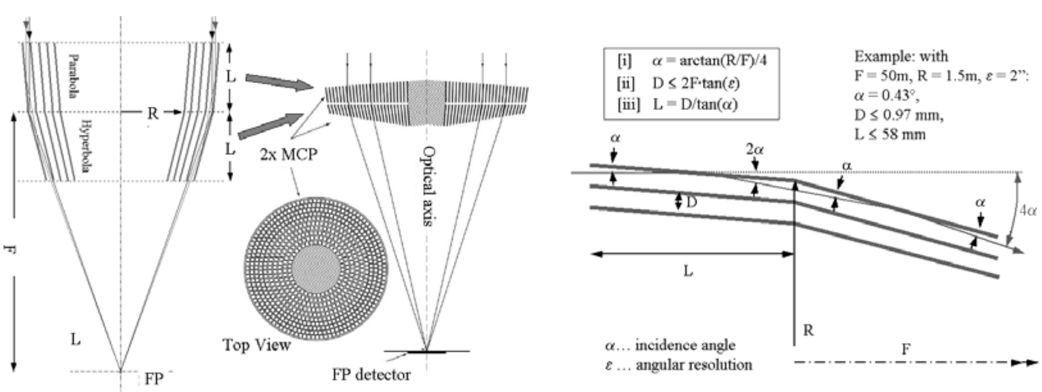
5.1 HPO development activities

The baseline optics design is based on X-Ray High precision Pore Optics (X-HPO), a technology currently under development with ESA funding [RD-Opt, RD-HPO], in view of achieving large effective areas with low mass, reduce telescope length, high stiffness, and a monolithic structure, favoured to handle the thermal environment and simplify the alignment process. In addition, due to the higher packing density and the associated shorter mirrors required, the conical approximation to the Wolter-I geometry becomes possible. Figure 5.1.1 outlines the required structure, and that the conical approximation is facilitated by the choice of a large focal length (35m) for XRO.

The X-HPO units are fabricated starting from high quality selected 12” (300mm) Si wafers, double sided polished with a flatness better than 180nm (measured over 25x25mm^2). Processed silicon wafer components are then stacked onto a precision Si mandrel, requiring only a single curvature (for the conic surface). Several plates are stacked on top of each other while being curved in the azimuthal direction to form a single monolithic unit that is intrinsically very stiff, as well as possessing very good temperature stability without differential expansion problems (see figure 5.1.2).

Two such HPO units, each consisting of 70 ribbed silicon plates, are first co-aligned and then joined together by two CeSiC brackets to form an X-ray Optical Unit (XOU). The XOU provides a three-point interface to the petal structure (figure 5.1.3). Precision alignment of the two HPO units is required, forming the conical approximations of the parabola and hyperbola of a Wolter-I optics. The XOU units are small enough (typical size without baffling is 10 cm x 10 cm x 20 cm) to allow simple handling, but large enough to simplify the petal integration. The XOU’s are hard locked into the petals on ground and are not changed / adjusted in flight.

Figure 5.1.1: Normal Wolter and pore structured optics. Conditions for replacement of the Wolter-I parabolic and hyperbolic surfaces by simple conical surfaces (in this case F=50 m).



The petals also incorporate the baffling systems required, both for X-ray and IR/visible/UV. These baffling systems define the bore sight and field of view of the XRO telescope, and provide in addition thermal and contamination control for the sensitive optics. The petals are mounted on the MSC optical bench and the design of the corresponding interfaces (based on a 3 point, isostatic approach) is ongoing. A petal technology demonstrator is presently under development (ESA contract awarded to Kayser-Threde, Cosine Research, SRON, MPE), with the aim to fabricate a first radially shaped segment, with an external radius of 2100 mm, a depth of ~0.8 m and an angular aperture of about 21 deg.

Figure 5.1.2: Si wafer stacking and curving procedure leading to the fabrication of a single HPO unit.

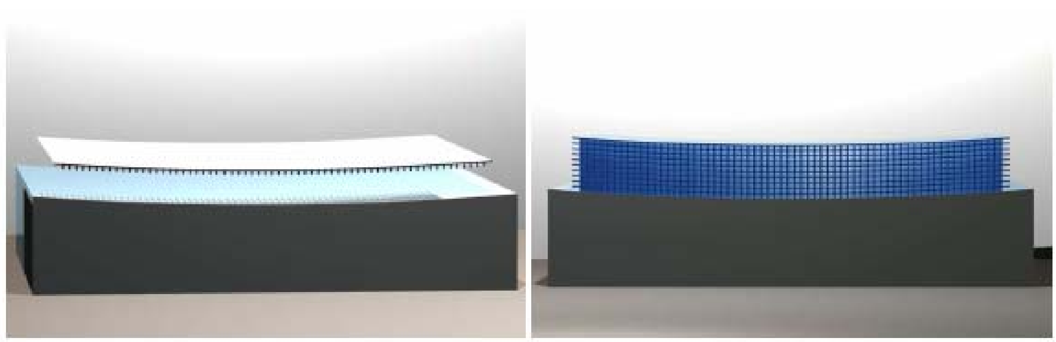
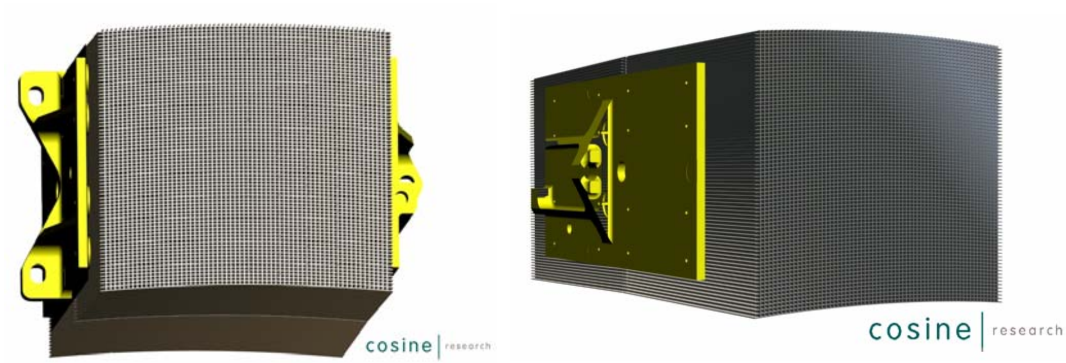


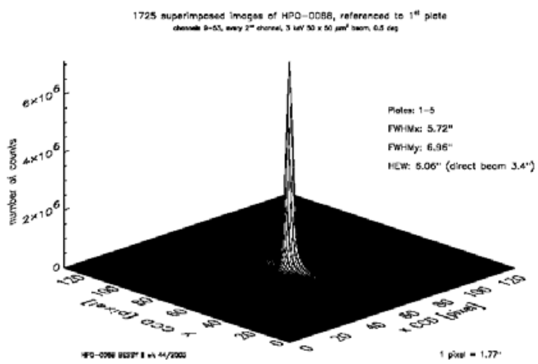
Figure 5.1.3: X-ray Optical Unit (HPO tandem assembly): Several of such XOU’s are currently being assembled to demonstrate high resolution X-ray lenses made of silicon pore optics (courtesy of *Cosine Research*).

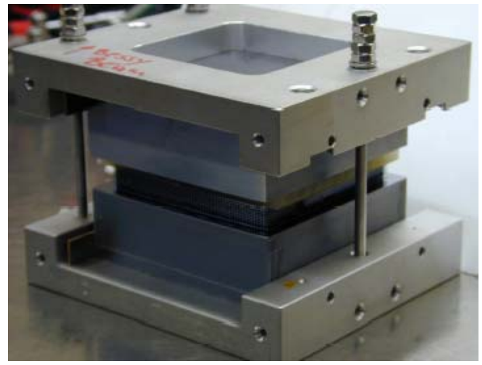


The HPO development has an angular resolution requirement of 5 arcsec and a goal of 2 arcsec (HEW). Preliminary tests have been conducted on different HPO development models and the first results are now available (figure 5.1.4). The current HPO status has demonstrated the potential of the Si based optics technology, by:

- Developing the principle of the mirror plate production and stacking technology
- Identifying the critical areas and improvement options

Figure 5.1.4: HPO development models – preliminary test results obtained with a 3 keV beam monochromatic (4 crystal) pencil beam of 0.05x0.05 mm^2, and a CCD camera at 2738 mm from sample, providing a resolution of 1 pixel = 23.5 um = 1.7 arcsec. Single reflections were measured at 0.5 deg incidence angle, and 1725 single beam measurements, uniformly distributed over the sample plate stack, were overlapped. Considering the intrinsic beam size, the results are within the requirements for XRO of < 5 arcsec resolution HEW. The figure on the right shows the test plate stack.



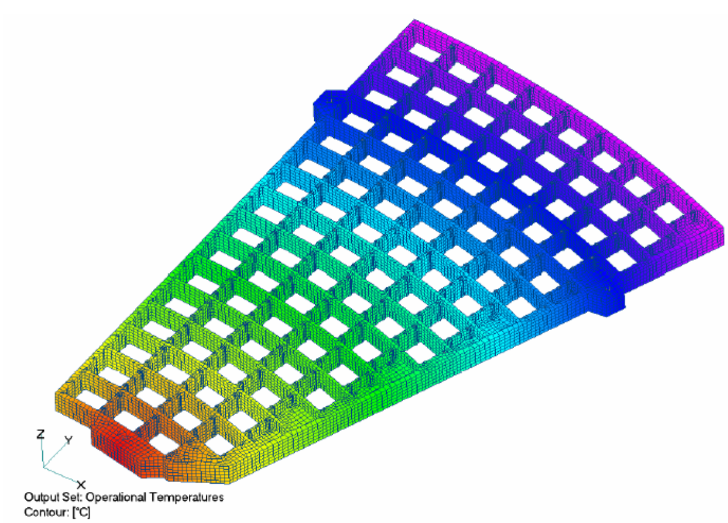


The HPO development activity is also addressing:

- Further improvement of the Si optics module fabrication
- The structure of the petals (producing a bread-board structure by Nov 2006)
- The interface of modules to petals
- Providing the interface details for the MSC mirror bench
- Testing will be expanded to full beam and cryogenic temperatures starting in Q3/2006

Figure 5.1.5 shows the latest design of the petal structure, in line with the recent evolution of the overall MSC configuration (radial shape).

Figure 5.1.5: X-HPO petal structure – FEA model (courtesy of Kayser-Threde).



5.2 Effective area as a function of photon energy

A crucial part of the telescope design is the definition of the mirror effective area as a function of the photon energy. This task is particularly important as it impacts not only on science but also very significantly on the overall system in terms of total S/C mass, formation flying requirements, baffling design and configuration. Although iterations are to be expected as the project evolves, a preliminary analysis has been conducted.

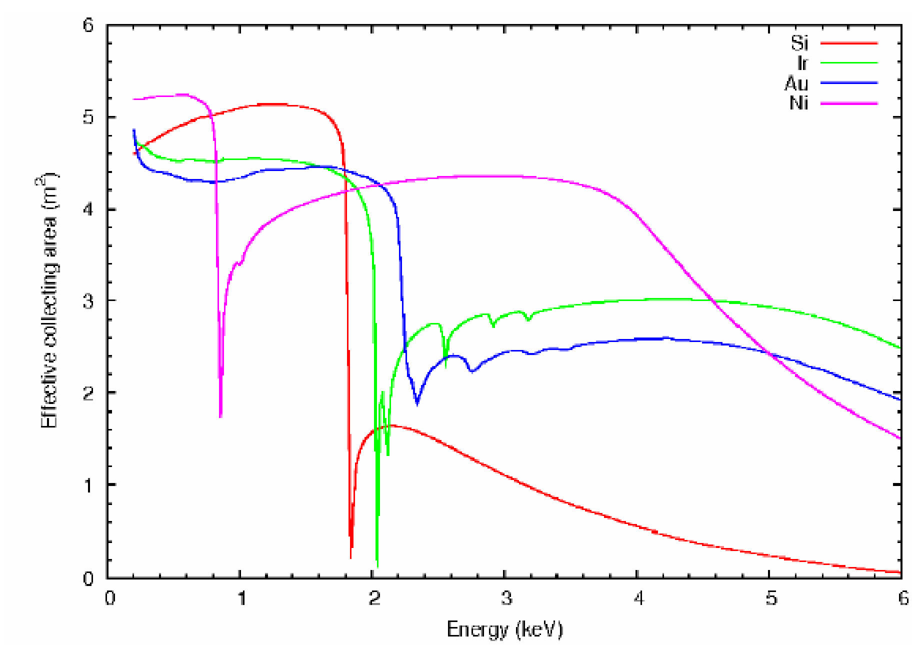
The definition exercise depends on a considerable number of parameters, such as: mirror size and available geometric area, HPO performance, choice of specific optics coating, focal length. A considerable number of iterations are required in order to establish the optimal compromise in terms of science performance and available system resource.

The analysis performed to date by ESA in collaboration with the Telescope Working Group is based on the assumption of a nominal focal length of 35 m and a geometric area available to the mirror limited by the launcher fairing and by the inner S/C body. The ongoing analysis includes the expected petal and XOU area efficiencies, assuming both the performance of the present optics demonstrator as well as future possible optimisation.

Different assumptions have been made on the adoption of possible single layer coatings on the X-HPO units, such as bare Silicon, uniform Iridium, Gold and Nickel coatings (see Figure 5.2.1). The additional deposition of multi-layers (e.g. Carbon over-coating) could allow further performance optimisation, although specific technology development is required [RD-MLC].

Achieving the requirement of an effective area of 5 m^2 at 1 keV [RD-SciRD] is a high priority for the XRO study that will require specific attention and will be verified in parallel with the evolution of the system configuration and of the optics technology.

Figure 5.2.1: Preliminary estimates of effective area versus photon energy for a specific mirror / petal configuration and different X-HPO coatings (without multi-layer coatings).



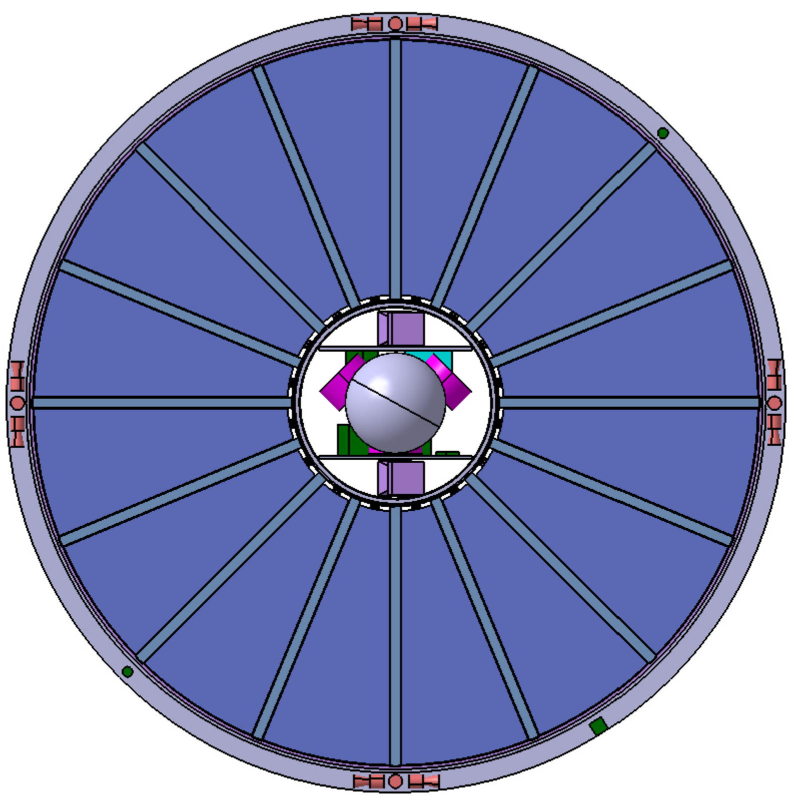
5.3 Telescope configuration

The presently envisaged mission configuration is based on a fixed optical bench, with circular symmetry around the optical axis. The radial mirror elements (present assumption is 16 petals, see figure 5.3) are supported by structural beams, departing from the centre of a cylindrical MSC body. The optics elements are protected from direct Sun illumination by a baffle (see section 6) which also plays an important role with respect to diffuse x-ray straylight rejection and telescope thermal control. The overall telescope configuration aims to take maximum advantage of the available launcher fairing volume, to meet the requirement of an effective area of 5 m^2 at 1 keV. A distributed (MSC and DSC) approach is adopted for the rejection of the diffuse X-ray background, including a fixed skirt and the Sun baffle on the MSC side and specific baffles for each focal plane instrument on the DSC side.

Work is ongoing to define adequate protective measures to minimise the optics contamination during the different mission phases. Specific activities will be initiated to verify the need for baffling at petal level, while a preliminary thermal analysis of the telescope bench and related optics elements is being carried out by ESA, on the basis of the latest MSC configuration and latest X-HPO data.

An industrial XRO telescope accommodation study will be placed by the Agency by Q2/Q3 2006. The study will last for 9 month and allow defining the telescope design, including mirror optical bench, thermal control, baffling and interfaces requirements.

Figure 5.3.1: On-axis view of the preliminary telescope configuration (MSC). Radial petals support the optic units, while a central S/C bus contains all required subsystems. The mirror petals are surrounded by a cylindrical Sun baffle.



6 MISSION PROFILES

The XRO mission design is based on a dedicated Ariane 5 launch, a direct *transfer/injection phase* to L2 and an *operational phase*.

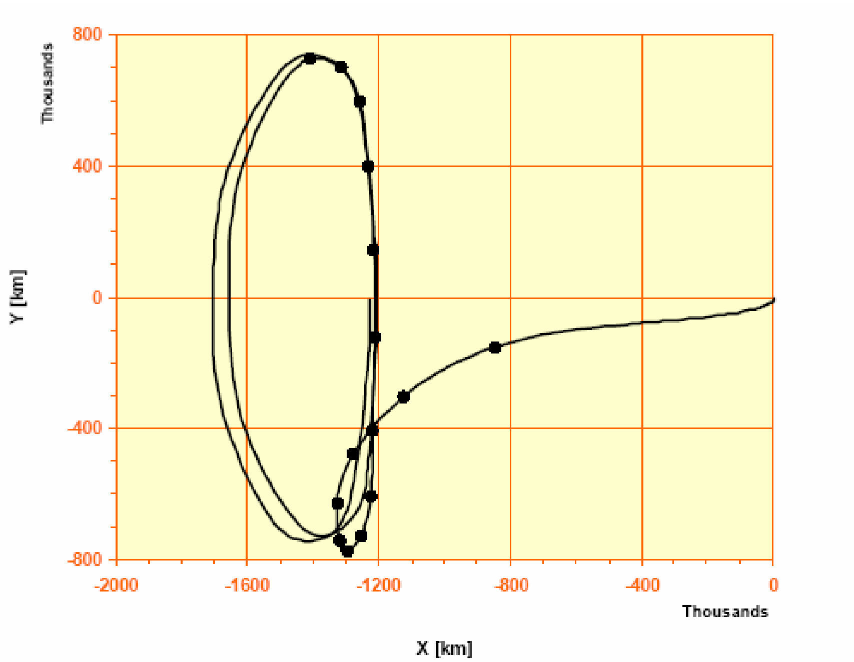
A Halo orbit around the second Libration point of the Sun-Earth system (L2) is selected as providing optimal conditions with respect to perturbations, stable thermal environment, lack of eclipses, and sky visibility.

Typical Halo orbits around L2 have amplitude of order 700,000 km and periods of about 6 month. A preliminary analysis [RD-CDF] has indicated that these Halo orbits require very limited maintenance (~ 1 m/s per year). Furthermore, for such Halo orbits injection can be performed along an Earth escape direction, thus avoiding a dedicated insertion manouvre. Hence, the Delta-V requirement for the XRO is rather small and dominated by the correction for the launcher dispersion correction (~ 25 m/s). Additionally, some minor manouvres are required during the transfer such as a first trimming manouvre about 8 days after launch (~ 2 m/s) and a mid-course correction manouvre about 50 days after launch (~ 1 m/s).

A direct launch is preferred to any alternative scenario (e.g. intermediate HEO orbit by LV, followed by a S/C provided delta-V manouvre to halo orbit injection) on the basis of the expected Ariane 5 – ECA performance (~ 6.6 t) and of the additional complexity, cost and risks associated to different solutions.

Alternative strategies will be identified in the following part of the study, including any specific aspects related to launch opportunities during the year.

Figure 6.1: Halo orbit around L_2 in synodic space: ecliptic projection, Earth at coordinate (0, 0) and Sun along positive *x*-axis [RD-CDF].



6.1 Launcher

The launch vehicle (LV) considered in this preliminary study phase is the Ariane 5 (ECA), launched from Kourou (CSG). A few issues should be highlighted:

- LV performance is estimated at 6.6 t for a direct injection into L2 orbit, with a near-parabolic and a low inclination orbit (as for JWST launch).
- Present baseline assumes the use of a medium size fairing in conjunction with an 1194H adapter.
- Different configurations for the launch stack are to be investigated during the future system level studies.

6.2 Preliminary spacecraft configuration

The overall S/C configuration will be defined following dedicated industrial activities. Nevertheless, in order to focus the design effort and adequately prepare the industrial work, a preliminary reference configuration has been defined in ESA. Such a configuration is based on the need for Formation Flying (FF), imposed by the telescope focal length (~ 35m). XRO is based on a Detector S/C (DSC) supporting all focal plane instruments, providing the main TM downlink capability to ground control and responsible for maintaining formation with the Mirror S/C (MSC, supporting the telescope mirror). The two S/C units would be launched in a stack (present baseline assumes DSC supported by MSC) and fly to L2 as a single composite (thus reducing operations complexity during transfer and injection).

The recent activities have focused on the configuration of the MSC, with the target of maximising the mirror effective area within the constraints of a fixed optical bench, fitting in the A5 fairing. The following requirements are the main drivers for the MSC configuration:

- Maximisation of the mirror area within launcher fairing.
- Provision of adequate structural integrity and stiffness (driven by launch loads).
- Provision of a thermal environment compatible with the operational and alignment requirements of the optics.
- Protection of optics from contamination.
- Rejection of diffuse x-ray straylight.
- Compatibility with formation flying requirements.
- Minimisation of deployment mechanisms and complex AIV/T activities.
- Minimisation of development activities as well as overall risk and cost.

The latest reference configuration for the MSC is illustrated in Figures 6.6.1, 6.6.2 and 6.6.3. The adoption of a cylindrical Sun baffle allows increased operating temperature of the mirror optics, contributes to the rejection of diffuse straylight, reduces the contamination effects and supports the solar arrays required to power the spacecraft. The size and geometry of the Sun baffle are designed to match the required Sun Aspect Angle during observations. The actual off-pointing angles (towards and away from the Sun) will be consolidated by dedicated thermal and straylight analysis and subject to a specific consolidation process during the project evolution. Straylight rejection is implemented through the combined effect of the cylindrical Sun baffle and the fixed anular area surrounding the mirror (perpendicular to the telescope optical axis).

The thermal control of the mirror optics will be addressed through a preliminary model to verify the envisaged operating temperature and related gradients, which critically affect the mirror performance. The design will take advantage of the inner S/C cylinder, of the Sun radiation impinging on the Sun baffle and of specific measures to control the view factors to space and the thermo-optical properties of the S/C surfaces.

All the platform subsystems would be located in the central cylindrical body, sized to match the dimensions of the 1194H adapter, which also plays an important structural function, supporting the DSC in the launch stack as well as the mirror elements and the Sun baffle, via 16 (TBC) radial beams. The MSC re-pointing manouvres would be performed using reaction wheels, while thrusters would be used only for wheel desaturation (or possibly for larger amplitude slews) and for orbit maintenance.

Specific contamination measures (e.g. dedicated covers) will be required to protect the optics elements during the launch phase. Possible design solutions will be identified during the industrial activities.

The configuration of the DSC is driven mainly by the instrument accommodation requirements (including the corresponding cryogenic chain), by the need for instrument baffling at different focal plane positions. The platform design drivers include the accommodation of the formation flying metrology, overall thermal control and related interfaces to the cryogenic chain and the payload power and telemetry demands. No specific design activities have been performed on the DSC, given the ongoing industrial study on the reference payload accommodation.

A preliminary S/C mass budget is being consolidated on the basis of the ongoing MSC and DSC configurations work, also including the results of a first structural analysis conducted on the baselined MSC design. The objective is to ensure the capability to support the optics mass corresponding to a full exploitation of the available mirror area, while maintaining adequate design margins as required in this preliminary project phase.

The Agency will put specific emphasis on a design-to-cost approach in all future industrial activities, so as to allow XRO remaining compatible with the programmatic constraints of the ESA science budget.

Figure 6.6.1 – Composite spacecraft: reference configuration in the A5 fairing.

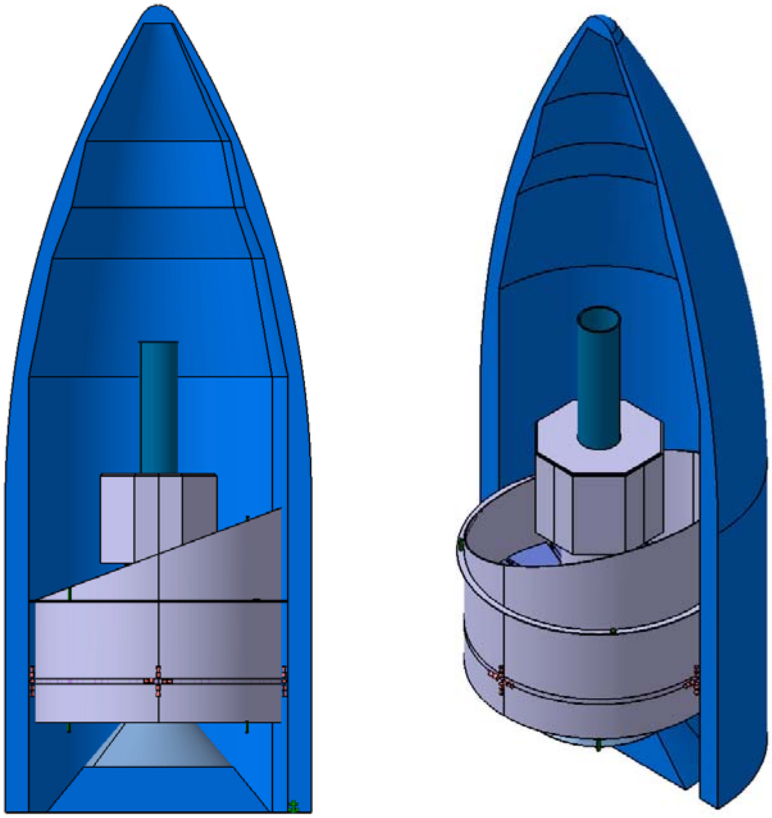


Figure 6.6.2 – Preliminary configuration of the Mirror Spacecraft.

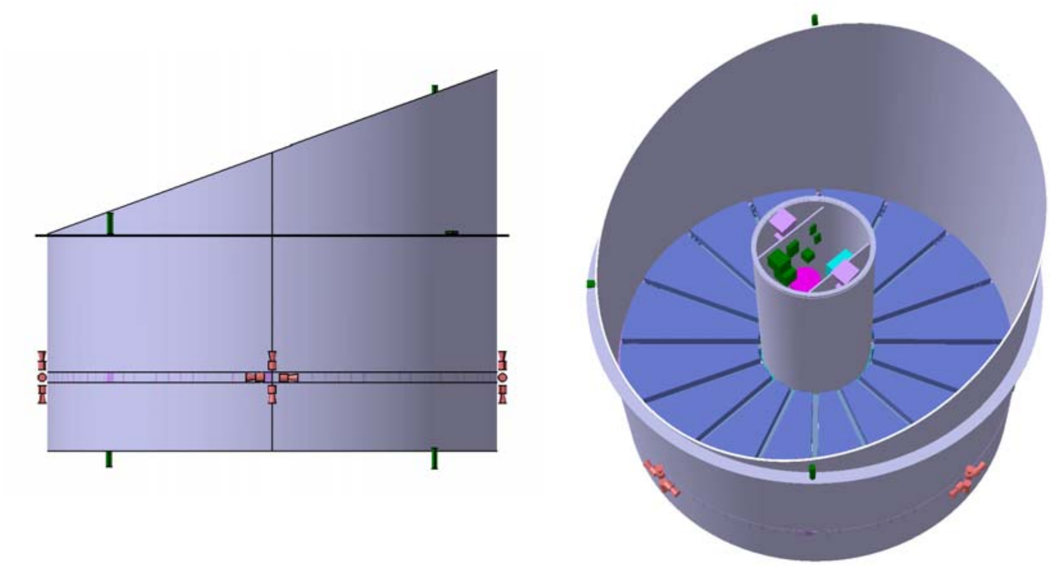


Figure 6.6.3 – DSC and MSC in formation flying.

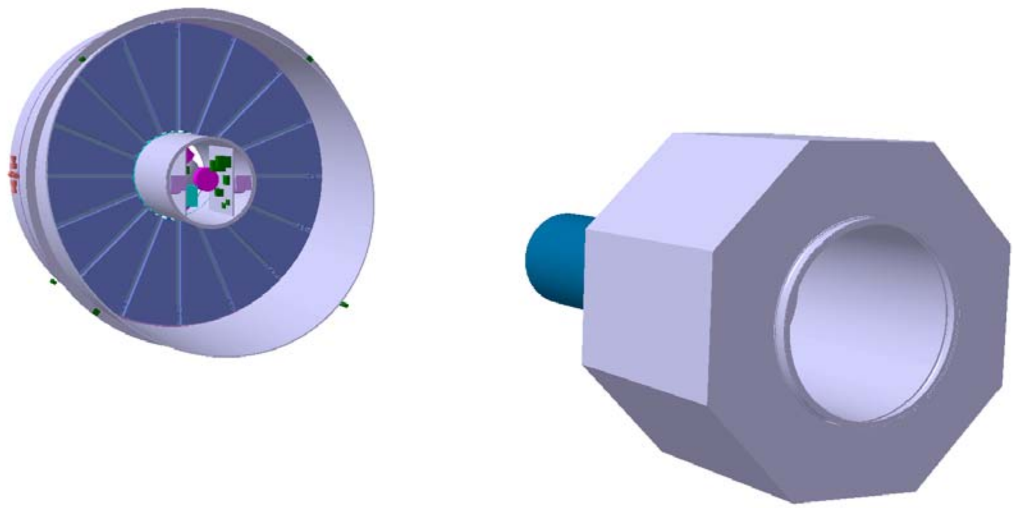


Table 6.6.1 Summary of key S/C parameters

Max DSC mass (wet, including margin)	2000 [kg]
Max MSC mass (wet, including margin)	4400 [kg]
Adapters	200 [kg]
System Level Margin requirement	> 20%

6.3 Ground segment

A summary of the issues and assumptions related to MOC infrastructure and activities are included in this section. Further studies are presently ongoing in collaboration with ESOC.

- The MOC will be based at ESOC (tbc).
- The SOC will be at ESAC (tbc) and will utilise generic planning tools developed for previous astrophysics observatory missions.
- The PI teams will be responsible for the calibration of their instrument data, and the provision of fully calibrated, archival data sets, in line with the Science Management Plan [RD-SciMP]. This activity will be supported by SOC instrument scientists.
- Operations will be pre-planned and tele-commands loaded to the spacecraft into a time tag buffer (e.g. autonomous operations and data storage during non-contact periods).
- The use of one of ESA's Deep Space ground stations in X-band is baselined.

7 INTERNATIONAL COOPERATION

Presently XRO/XEUS is a collaboration between ESA and JAXA however the international scenario could evolve as other partners may be sought.

8 PROGRAMMATIC CONSIDERATIONS

Although several preparatory industrial activities, including technology developments as well as S/C definition activities, were planned before the definition of the Cosmic Vision planning and are regularly continuing, no system level industrial study is foreseen until the outcome of the first part of the Cosmic Vision Programme is clear.

Under the assumption of a mission level assessment study in 2007 and 2008, XRO could be launched at the end of 2017, with nominal operations extending until the end of 2022.

Concerning the development schedule applicable to the mirror elements, the breadboard of the HPO module will be delivered to ESA by the end of 2006, while, should the mission proceed further, then an engineering model could be available by 2009, followed by the development of the required production facilities by 2011 and the delivery of the FM units by 2015.

9 CONCLUSIONS

The XRO mission scenario has been recently revisited in order to reduce overall complexity, risk and cost without compromising in a major way the original science return. The revised science requirements are still very competitive with respect to any other envisaged X-Ray mission and ensure a quantum leap in capability compared to XMM-Newton.

A number of preparatory activities have been started at ESA with the goal of consolidating the mission profile before entering into future system level activities to be conducted by industry. Such activities include industrial studies and are focused on the most critical aspects, such as mirror design and related spacecraft configuration, instruments accommodation and related cryogenic chain.

In parallel the technology development activities of XRO/XEUS continue to proceed, with the first test results becoming available from the mirror module breadboard, the cryogenic chain (ADR system) and focal plane detectors (both STJ and TES based).

This status report provides an overview of the work conducted to date.