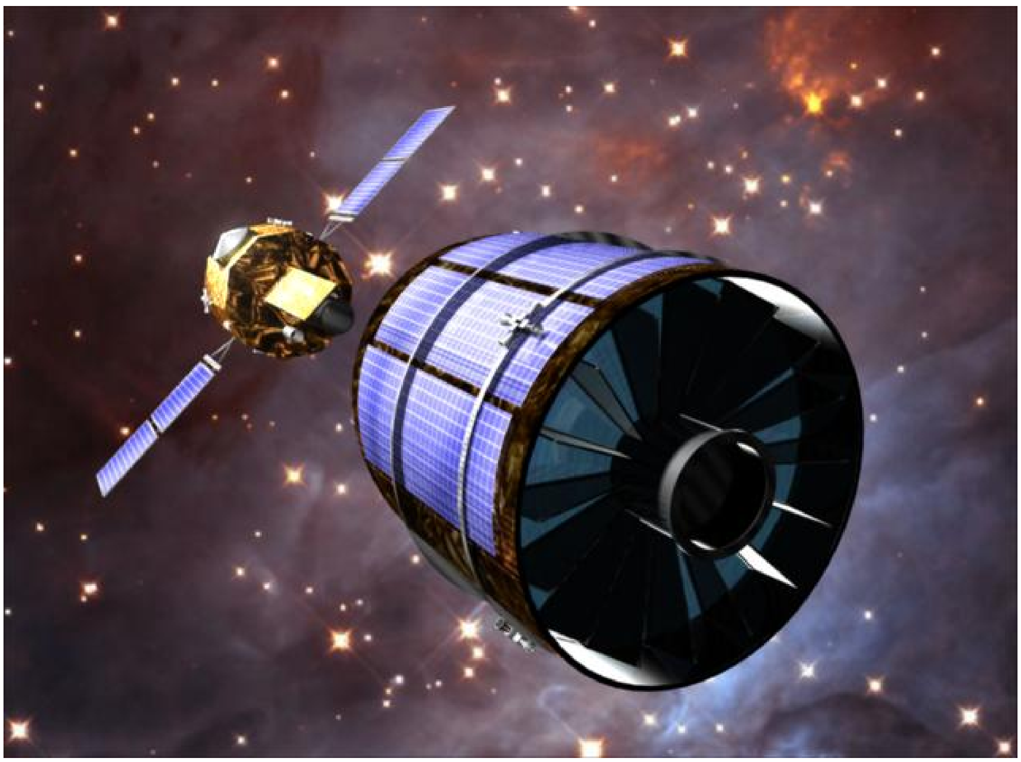
X-Ray Observatory

Study preparation activities
Status Report #2



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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-CV1525] *Cosmic Vision: Space Science for Europe 2015-2025*, BR-247, ESA, 2005.
[RD-StRep] XRO Status report, March 2006, SCI-A/2006/054/NR
[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-HPO1] S.Kraft et al. SPIE Proc., Vol. 5900, 590010-1/12(2005)
[RD-HPO2] K.Wallace et al. Proceedings of ICSO 2006 – Noordwijk – Netherlads (2006)
[RD-MLC1] G.Pareschi, V.Cotroneo, SPIE Proc., Vol. 5168, 53-64 (2003).
[RD-MLC2] D.Lumb et al. submitted to Appl.Opt. (2006).

INTRODUCTION

The X-Ray Observatory (XRO), 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 [RD-CV1525].

A summary of the study evolution has been provided in the previous XRO status report [RS-StRep] issued at the end of March 2006. The work of ESA and JAXA on the revised mission scenario has progressed further over the past 6 months, including internal as well as industrial activities and dedicated technology developments.

The overall Mirror Spacecraft (MSC) configuration (fixed optical bench) has been matured further via preliminary thermo-mechanical analysis, aimed to maximize the area available to the x-ray optics (effective area exceeding 5 m^2 at 1 keV) within the geometric and dynamic loads constraints imposed by the launcher vehicle. An Invitation To Tender for a corresponding industrial study has been issued and activities are expected to start before the end of the year.

The definition of the model payload has increased thanks to the efforts of the PLWG, with conceptual designs for core instruments as well as high priority augmentation units. The release of a new version of the Payload definition Document is planned.

The accommodation of the model payload on the Detector Spacecraft (DSC) is the subject of a dedicated industrial study (parallel competitive) with Alcatel Alenia Space and Astrium. Activities have started in April and are expected to progress over the next few months. The industrial work will allow evaluating the impact of the model payload requirements on the platform, thus allowing to refine the corresponding mass budgets and perform an overall feasibility verification. The definition of the cryogenic chain required by the Narrow Field Instrument is also an important part of the ongoing studies, impacting on the identification of any required technology development activity.

Technology development work is also continuing, especially in the areas of X-ray optics (High Precision millipore Optics - HPO), focal plane detectors (STJ and TES sensors for the Narrow Field Instruments) and cryogenic equipment (double ADR). Formation flying aspects, partly common to other science missions, are being addressed via a dedicated industrial contract and benefit from other ongoing ESA activities.

1 PRELIMINARY STUDY GOALS AND ACTIVITIES

Although the XRO/XEUS mission is not part of the ESA Science programme and subject to the Cosmic Vision 2015-2025 selection process, considerable work has been already performed over the past few years. The present activities are at pre-feasibility level (Phase 0) and aim to prepare adequately for a future assessment study (Phase A level).
The goals of the preliminary XRO study have been already described in the previous report and 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 or planned within the Science Payload and Advanced Concept Office (SCI-AM, Science Missions section):

- Release of a new version of the Payload Definition Document.
- Completion of the industrial study aiming to verify the resources required by the payload and to consolidate its interfaces to the platform (Dec 06 – Mar 07).
- An industrial study aiming to identify a preliminary design of the telescope and to consolidate its interfaces to the corresponding S/C (Nov 06 to June 07).
- An industrial study dedicated to formation flying demonstration (run by SCI-AT).
- Preparation of preliminary Technology Development Plan
- Finalisation of the preliminary risk and cost assessments, including a significant contribution from JAXA.

It should be stressed that these activities were planned on the basis of the existing XRO/XEUS heritage and will be completed over the next few months. Any further activity will depend on the outcome of the Cosmic Vision 2015-2025 process.

2 SCIENCE REQUIREMENTS

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. No changes have occurred since the last status report.

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

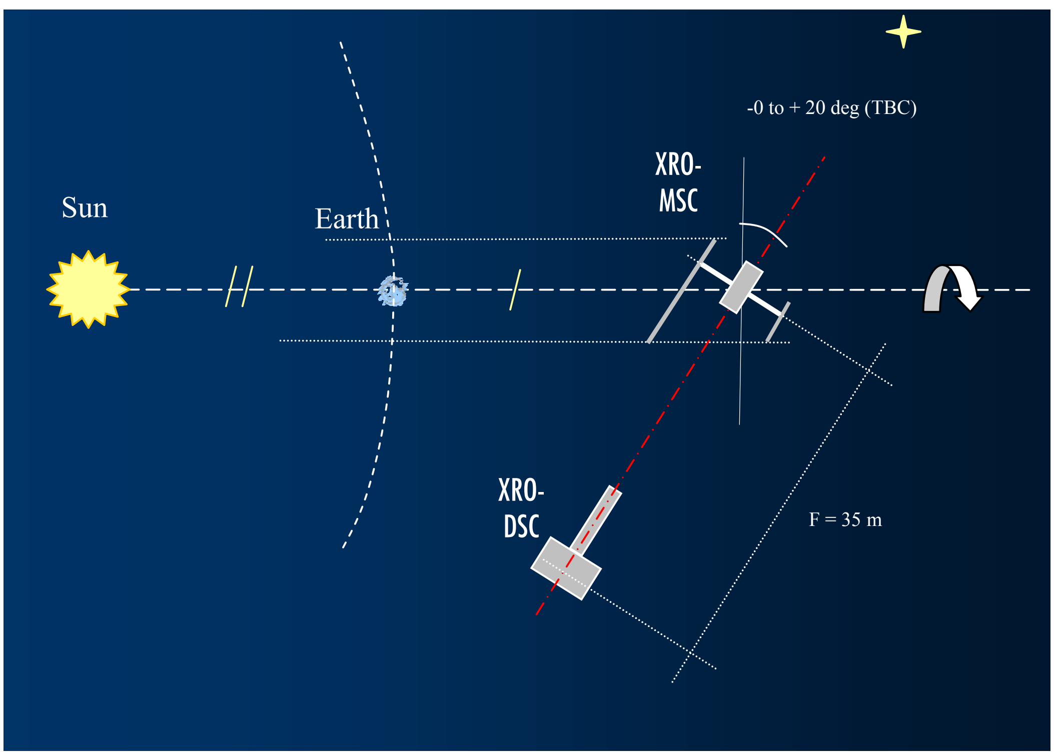
Topic	Effective area (m2)	Energy range (KeV)	Angular res. (arcsec HEW)	Instrument FOV Diameter (arcmin)	Spec. res. (eV, FWHM)	Point source det. sens. (erg cm-2 s-1)	Time res. (s)	Count rate capability	Polarimetry MDP at 3σ conf 100 ks	Observing constraints	Sub-topic requires
Evolution of large Scale 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). $\pm 5^o$ ($\pm 15^o$ 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

A concise version of the main mission requirements is provided below. The complete set of requirements to be applied to future system level studies will be prepared after the call for missions and the related mission selection process, eventually leading to a proper Mission Requirements Document [RD-MRD].

- Baselined launch vehicle is an Ariane 5 - ECA.
- Direct transfer into halo orbit, with transfer duration of ~ 3 month.
- Halo orbit around L2 (typical amplitude ~ 700000 km, typical period ~ 6 month).
- Nominal mission lifetime of 5yr, extendable to a total lifetime of 10 yr.
- 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].
- Mission Operation Centre (MOC) in charge of complete formation (DSC+MSC) and separate Science Operations Centre (SOC).
- Use of functional elements from other ESA and JAXA 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 REFERENCE PAYLOAD & RELATED S/C ACCOMMODATION

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 and also reflect the cooperation scenario of the mission. The reference payload described in the previous status report [RD-PL] is being used to progress further with the assessment study, with specific reference to the instruments accommodation and the definition of the corresponding platform resource needs (power, mass, thermal, etc.).
A summary of the XRO reference payload [RD-PDD] is provided in the table below (under the assumption of F=35m, with core and high priority core units). In the context of the Instrument accommodation study (section 4.2), two different Narrow Field Instrument designs (STJ and TES based respectively) continue to be investigated, with particular attention to the corresponding cryogenic chain design and related S/C interfaces.

4.1 Evolution of the Payload Definition Document

It is planned to release an updated version of the Payload Definition Document (PDD) in consultation with the PLWG following the completion of the industrial activities on the instruments accommodation.

The ongoing industrial activities have triggered further definition work at instruments level, with the aim to better quantify the interface and the resource requirements. In particular the needs of the Narrow Field Instruments have been subject of specific analysis, due to the strong impact on the definition of the corresponding cryogenic chain onboard the DSC.
Additional information has become available also on the high priority units HXC, XPOL and HTRS. Examples of such model designs are shown in the figures 4.1.1 (WFI), 4.1.2/3 (NFI1/2).

Figure 4.1.1 – Reference design of the WFI Focal Plane Assembly.

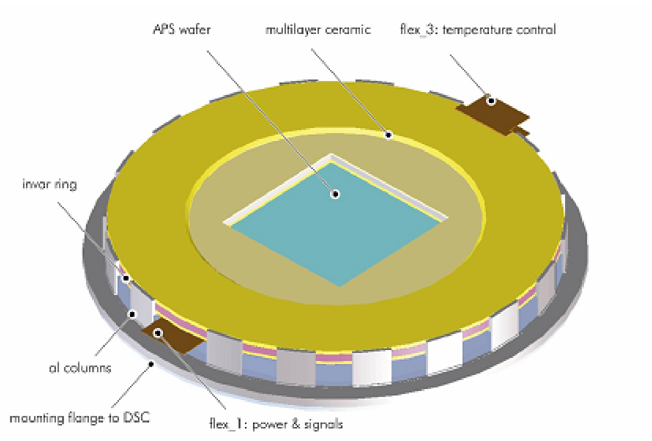


Table 4.1 – Summary of the reference payload, assuming F=35m [RD-PDD].

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	8.5 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 (dia)	0.74 x 0.74	0.75 x 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 pixel detector
Mass (kg) (*)	45	16	11
Power (W) excluding Dc/Dc converts and including margin	33	84	41
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	2-10
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

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

Figure 4.1.2 – Preliminary 3D drawing of the NFI1 (STJ) Focal Plane Assembly (lateral illumination).

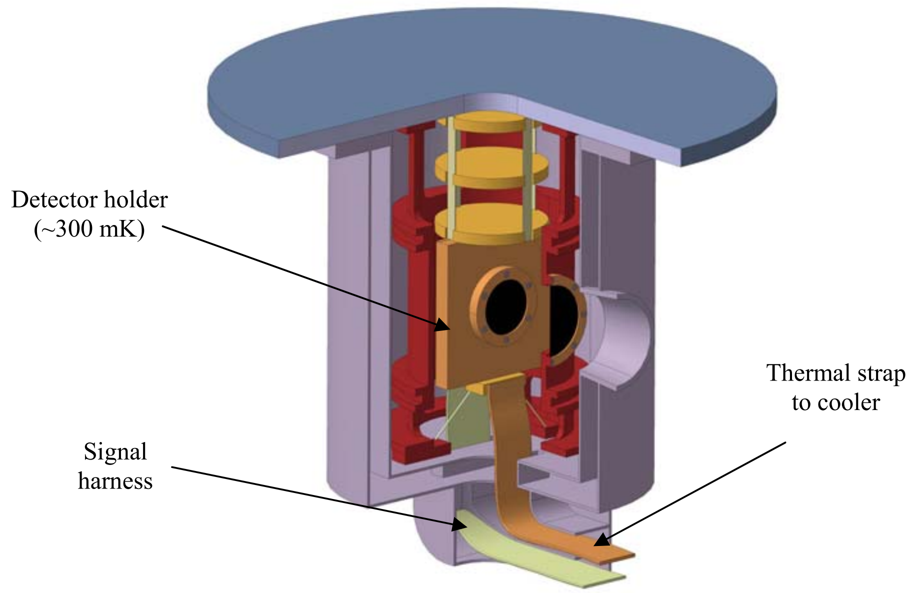
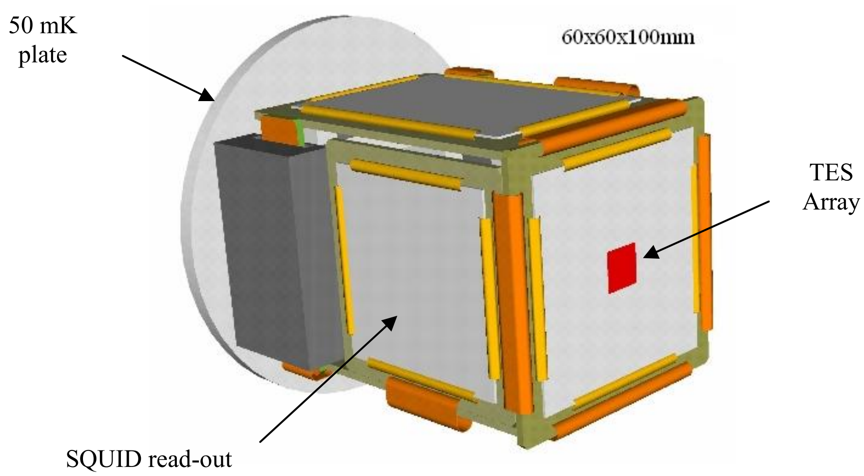


Figure 4.1.3 – Preliminary 3D drawing of the NFI2 (TES) Focal Plane Assembly.



4.2 Payload accommodation study – preliminary results

Instruments accommodation is considered as a critical issue to be studied in advance of any system level study. Identification of optimal cryogenic chain for NFI, analysis of critical requirements impacting on overall DSC configuration and determination of S/C resource required to support the model payload are the objectives of this activity.
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 depends upon the focal length, the mirror skirt size and the size of the detector, with WFI (and HXC) posing the most challenging requirements given the large instrument FOV (and energy range). Additional optics baffling will be implemented directly on the mirror elements.

Two parallel industrial contracts (Alcatel Alenia Space and Astrium) are investigating the payload accommodation, in which the emphasis is on estimating the overall instrument resource requirements, defining interfaces and conceptually designing the cryogenic system and the payload module.

The payload have two distinct drivers on the spacecraft design; the long WFI baffle driving the launch configuration and the NFI cryogenic system driving the thermal and mechanical design of the spacecraft.
The baffle length is driven by the MSC skirt size, which currently is assumed to be very small due to the need to maximize the mirror area and avoid any deployable unit / mechanisms on the MSC. The optimum division between the skirt on MSC and baffle on DSC will not be investigated in detail before a potential system study, thus a worse case approach has been used resulting in baffle lengths approaching 8 m for WFI. The baffle design will be detailed as part of the study, making sure the straylight levels are within the specifications. Additionally, the contractors are investigating possible particle deflection solutions to see if this can be more efficiently performed at DSC level instead of MSC level, as substantial mass savings could be possible.
The cryogenic cooling system required by NFI will not only dictate the thermal design, but it will also drive the overall volume of DSC. In the contracts no pre-selection of cooling systems has been performed, thus a wide range of cooling systems are under investigation; from cryostats to mechanical coolers (higher temperature stage), and from ADRs to sorption coolers (lower temperature stage). Example of different cold stage coolers under consideration for the XRO cryogenic chain are shown in 4.2.1 and 4.2.2
Cleanliness requirements imposed by the MSC optics and by the individual instruments are also being analysed in view of establishing cost effective solutions for the spacecraft design and the related AIV/T activities.

Figure 4.2.1 – Right: 4K Sorption Cooler under development at the University of Twente. Left: Herschel sorption cooler potentially re-usable onboard XRO (courtesy of *CEA-CBT*).

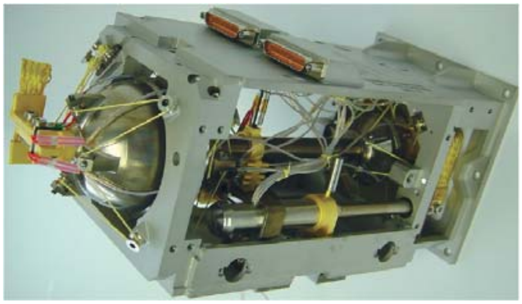
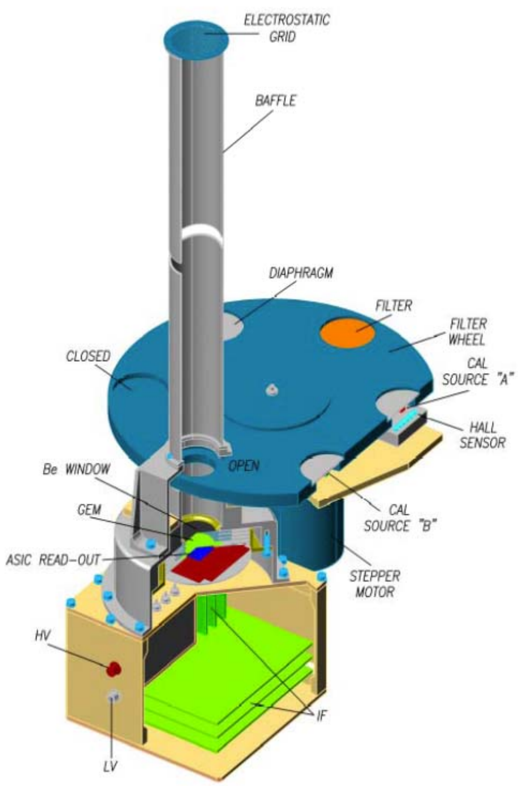
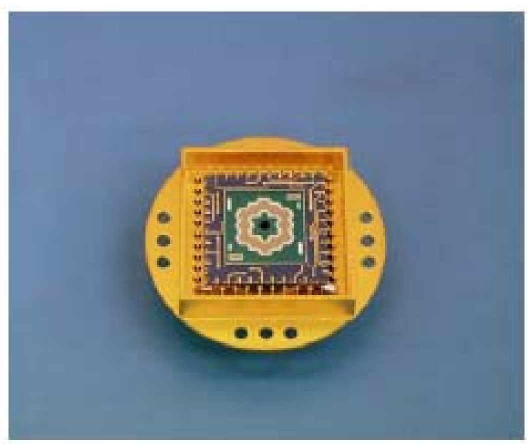


Figure 4.2.2 – Left: Schematic view of the X-Ray Polarimeter. Right: photograph of the semiconductor detector proposed for XTRS.





The contractors are investigating possible instrument locations within the DSC. Accommodating all the instruments including the ancillary instruments is challenging due to the limited volume on the spacecraft, the large baffles and sunshields that blocks the view to the mirror, the large cryogenic system reducing available volume and the need for accommodating formation flying equipment. Investigation of recommended locations for the instruments is therefore a main task in the study. Until now, some preliminary accommodation of payload and design of payload module have been performed, in Figure 4.2.3 two alternative configurations for different cryogenic chains can be seen. The figure illustrates the impact in configuration the choice of cryogenic chain has.

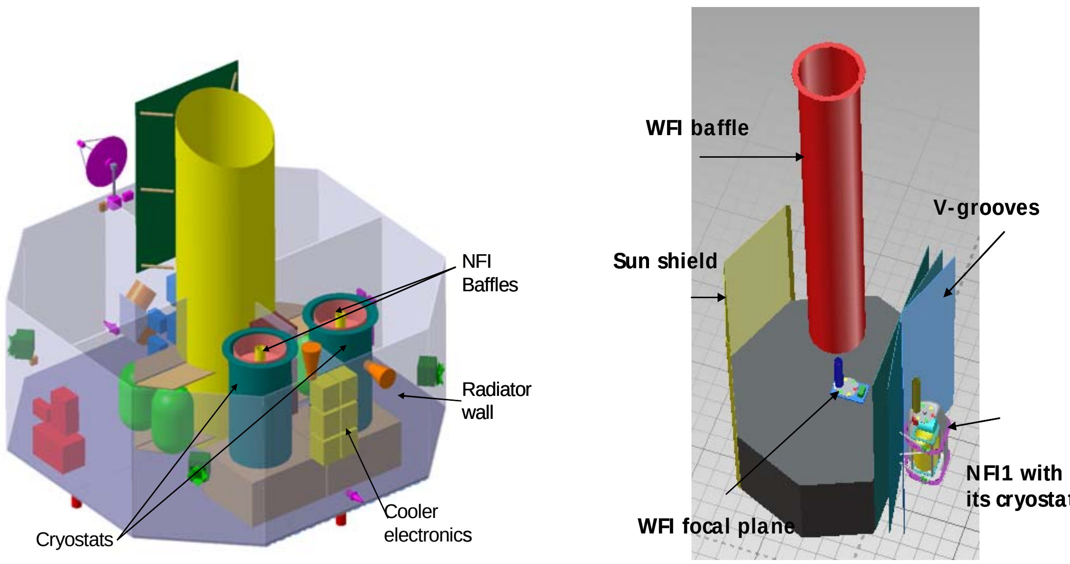


Figure 4.2.3 Instrument accommodation for two different cryogenic systems

The parallel instrument accommodation studies are expected to be completed by Q1/07. The results obtained will allow to refine the model payload and to issue a consolidated Payload definition Document. More importantly, the work done on instruments accommodation will allow achieving a higher level of definition during the following system level activities.

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 development of the baseline optics design, based on X-Ray High precision Pore Optics (X-HPO) has progressed considerably [RD-Opt, RD-HPO1] since the last status report.
The first HPO tandem assemblies have been integrated and tested at the Bessy synchrotron radiation facility, followed by preliminary X-ray illumination tests at Panther [RD-HPO2], see figure 5.1.1. In parallel the development of the Form-Fit-Function unit of the XRO petal (CeSic structure) has moved into manufacturing phase (see figure 5.1.2). Integration of the FFF unit with the first tandem assemblies is expected by the end of the year.

Figure 5.1.1: First HPO tandem assembly (partly populated and with Al instead of CeSic brackets – courtesy of Cosine Research).

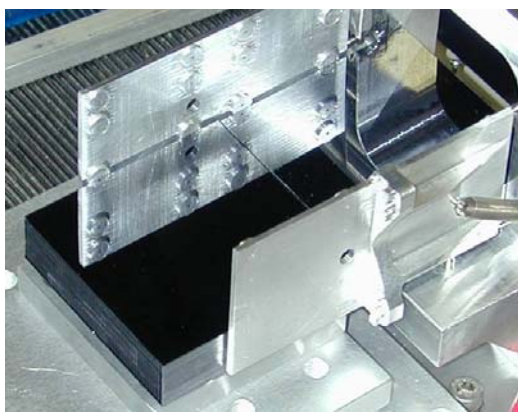


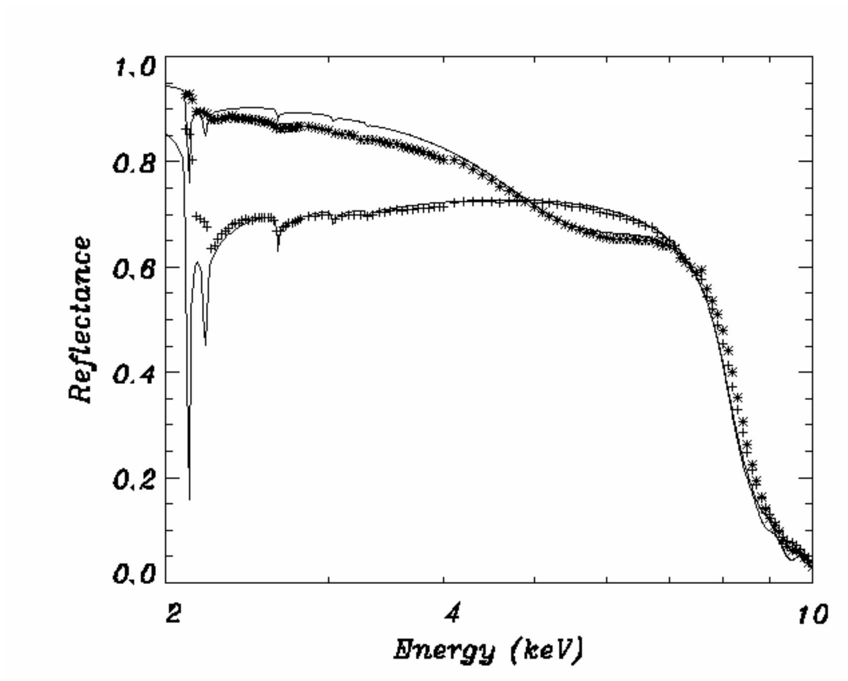
Figure 5.1.2: Form-Fit-Function unit of the future XRO petal structure (courtesy of Kayser-Threde).

5.2 Effective area as a function of photon energy

Work on the definition of the mirror effective area as a function of the photon energy continues on different fronts, including HPO optics performance, petal design, MSC geometric constraints as well as optics coating. All ongoing analysis work 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 possibility of including additional deposition of multi-layers [RD-MLC] has been explored in more detail, with dedicated measurements on Si substrates representative of the XRO optics coated with Pt-C bi-layers. The tests have been performed at PTB/BESSY. Figure 5.2.1 shows the reflectance as a function of energy at grazing angle 0.57 deg for a Pt coated Si plate and an equivalent sample with a 10 nm C overcoat.

Figure 5.2.1: Energy scan at grazing angle of 0.57deg. The + points correspond to the reflectance of the Pt coated sample (no C overcoat), while the * points refer to the 10 nm C overcoat.



The results illustrated above show a significant enhancement of reflectance at energies below 4 keV, enhancement that can play an important role in the maximisation of the telecope effective area.

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 be constantly verified in parallel with the evolution of the system configuration and of the optics technology.

5.3 Telescope configuration

The Mirror S/C configuration described in [RD-StRep] has been analysed in further detail with two main objectives: a) to confirm its structural feasibility of the launch stack (DSC on top of MSC) at the level of a preliminary FEA; b) to improve the definition of the MSC configuration and identify critical areas to be analysed by industry.
The preliminary FEA has demonstrated the structural soundness of the proposed design concept, based on the use of the 1194H launcher adapter. Such adapter, thanks to its specific load capability, allows maximising the area available to the fixed optical bench, with an inner cylinder diameter of about 1200 mm. The exercise is to be considered as preliminary, although a representative mass distribution of the HPO optics has been already taken into account.
A design concept (primary structure of MSC) compatible with the fairing boundary conditions and with the launch load requirements has been identified, based on a realistic manufacturing scenario (CFRP), not calling for technology demonstration. The feasibility of the design depends critically on the height of the COG stack (MSC+DSC) and will need constant monitoring and further validation. The analysis also showed that the preliminary mass apportionment between DSC and MSC is realistic and compatible with the corresponding x-ray optics allocation (assuming a focal length of 35m and aiming to meet the 5 m^2 requirement on the effective area at 1 keV).
Initial work has been performed on protective measures required to minimise the optics contamination during the different mission phases. The preliminary MSC design considers individual petal covers (1 cover/petal), installed on top of the radial beams of the optical bench. Such covers would have to be installed on both sides (entrance/exit) of the petals. Alternative concepts (e.g. single protective cover) are yet to be explored. It should be noted that such an issue will also have to take into account stray light issues and the eventual presence of additional baffling elements, as required by the optical design.
An industrial XRO telescope accommodation study will be placed by the Agency by the end of 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 and protected by dedicated covers (left: partially open – right: completely open).

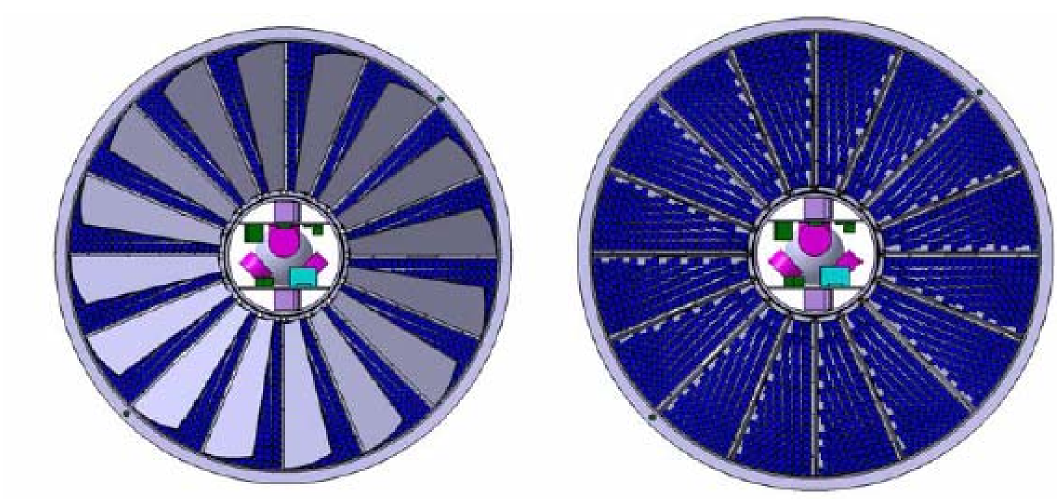


Figure 5.3.2: Exploded view of the preliminary telescope configuration (MSC), including primary structure, optics, covers and S/C subsystems. The cylindrical Sun baffle is not shown.

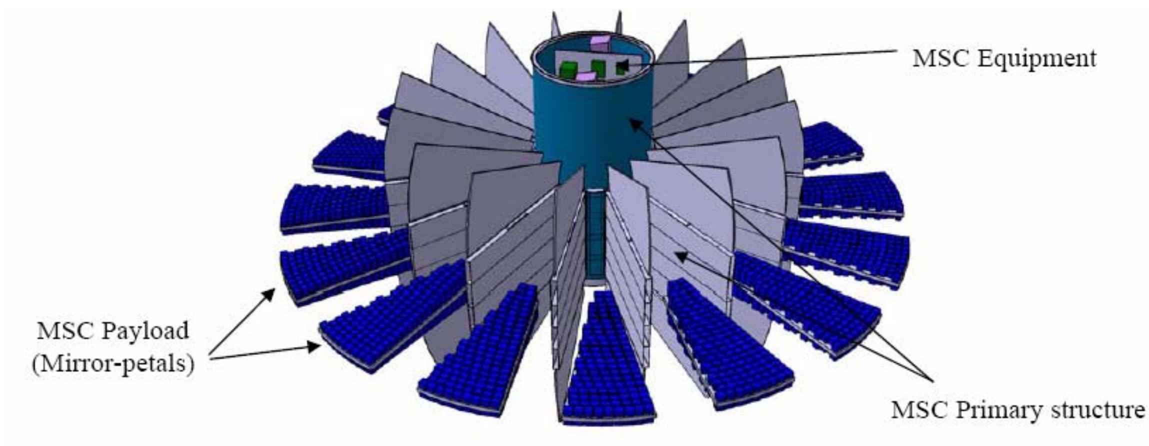
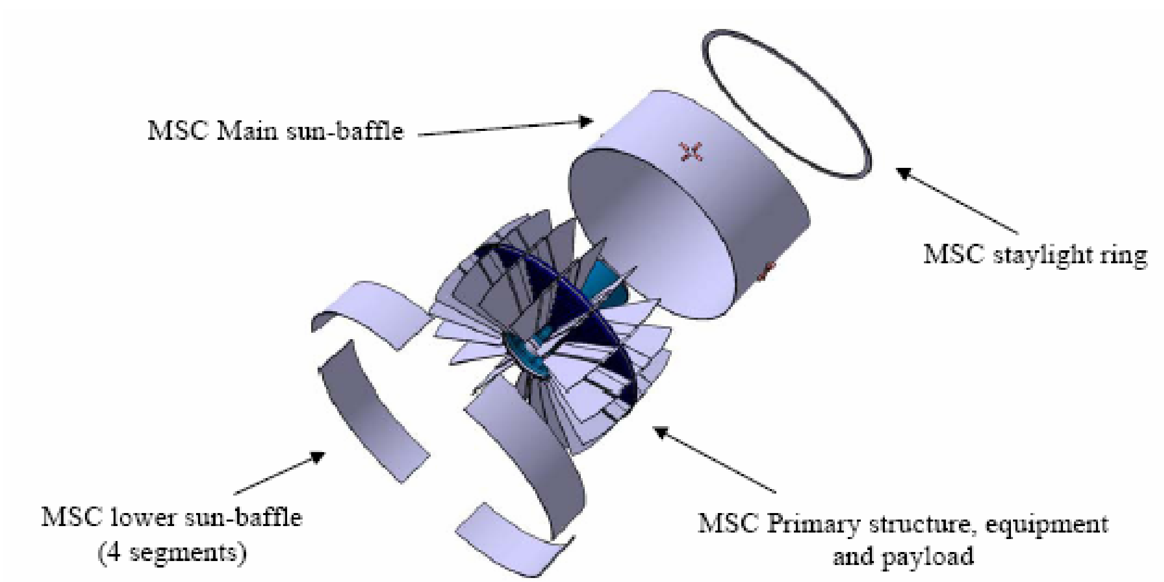


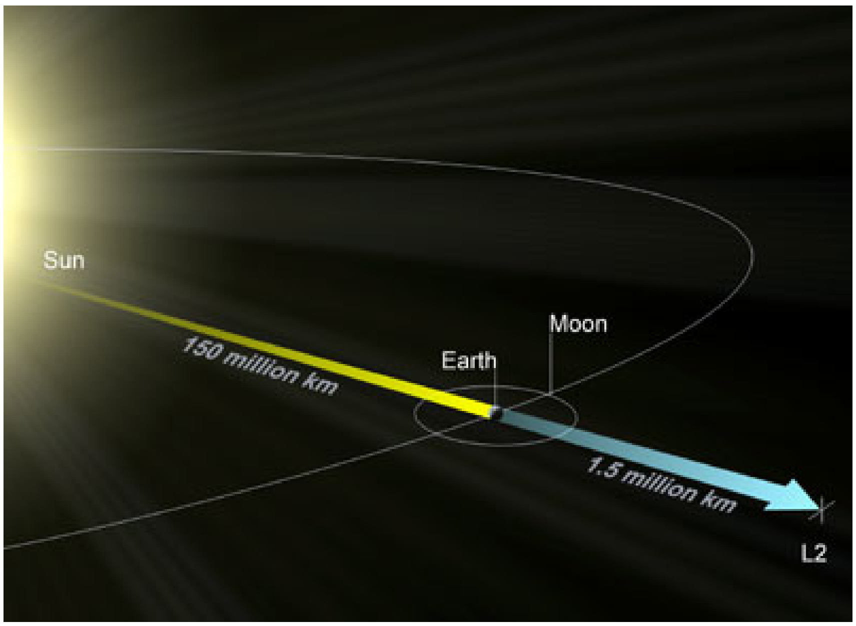
Figure 5.3.3: Exploded view of the preliminary telescope configuration (MSC), including the cylindrical Sun baffle.



6 MISSION PROFILES

The XRO mission profile continues to be based on a dedicated Ariane 5 ECA 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.

Figure 6.1: Halo orbit around the second Libration point of the Sun-Earth system (L2).



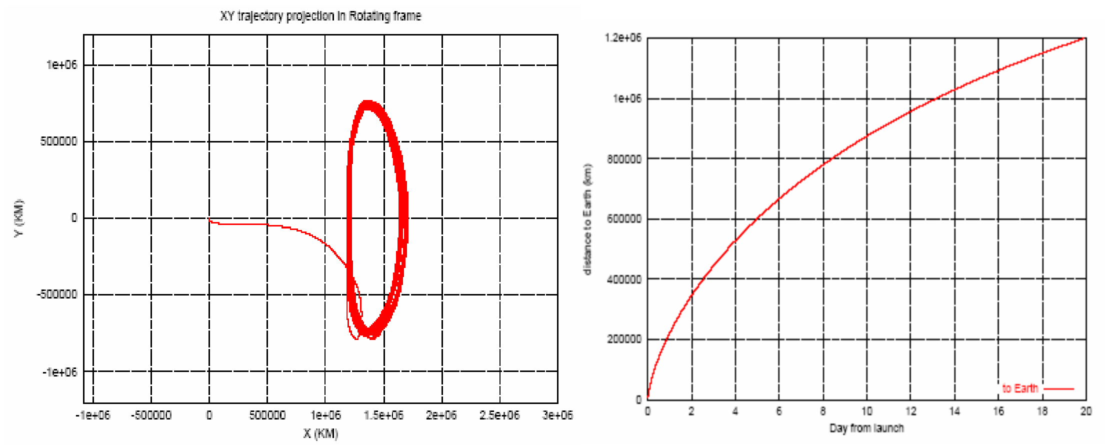
Such a mission profile is well known to ESA based on the work already performed for Herschel, Planck and Gaia. On this basis, XRO can benefit from considerable existing knowledge. Additional effort has been put by ESOC on consolidating specific aspects of the mission profile, including:

- preliminary analysis of launch window in the case of freely reachable orbits;
- Determination of the corresponding delta-V budgets;
- Preliminary analysis of smaller amplitude orbits (reduced Sun-S/C-Earth angle);
- First assessment of the orbit determination accuracy by ranging measurements.

The analysis of the launch window shows the availability of suitable launch opportunities around the full year, meeting the applicable constraints, including absence of eclipses during transfer and nominal operations.
A direct transfer remains the preferred solution with respect to alternative scenarios (e.g. intermediate HEO orbit by LV, followed by a S/C provided delta-V manouvre to halo orbit injection or Lunar Gravity Assist manouvres).
Additional work will now focus on the identification of an optimal strategy with respect to the transfer flight (single composite Vs. separated spacecrafts), including S/C design and testing

considerations as well as the complexity of operations control. The present baseline is to fly as a single composite (DSC+MSC) and to separate only after completion of all major orbit manouvres. In the case of free-transfer mission, operational conditions (S/C-Earth distance > $1.2 \cdot 10^6$ km) can be reached in 20 days (see figure 6.2).

Figure 6.2: Halo orbit around *L*2: ecliptic projection (left side), S/C Earth distance evolution over first 20 days (right side).



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). On the basis of JWST the assumed LV performance is now considered as realistic.
- Present baseline assumes the use of a medium size fairing in conjunction with an 1194H adapter. It is assumed that in the launch stack MSC supports DSC, thus avoiding the use of any alternative approach (e.g. SPELTRA / SYLDA) that would significantly affect the total S/C launch mass.
- 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 defined by ESA and illustrated in the previous status report is or will be verified and analysed by industry in the context of the ongoing DSC instrument accommodation study and of the forthcoming telescope accommodation study (MSC).
The reference configuration is based on the need for Formation Flying (FF), imposed by the telescope focal length (~ 35m).
The preliminary mission analysis and LEOP scenario work are base-lining that the two S/C units would be launched in a stack (DSC supported by MSC) and fly to L2 as a single composite (thus reducing operations complexity during transfer and injection).

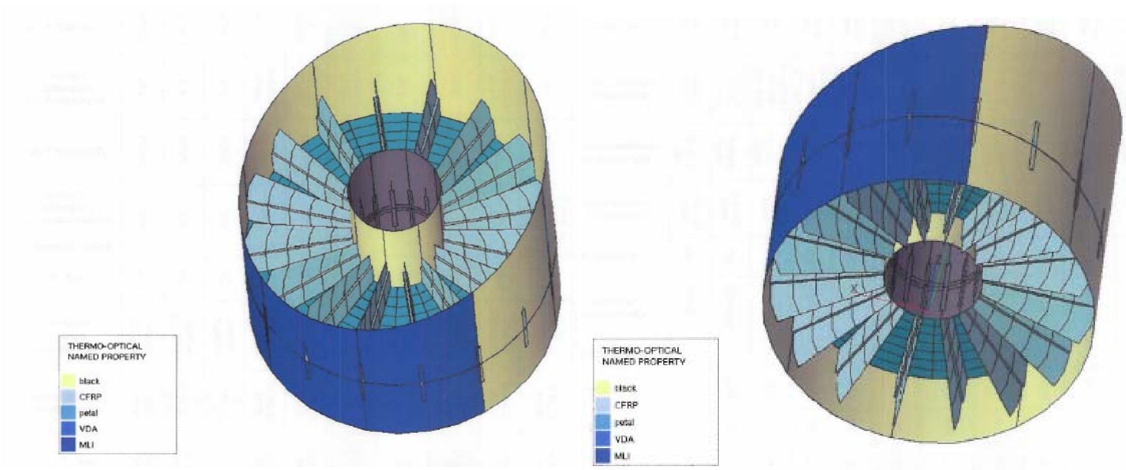
The reference MSC configuration proposed by ESA has been subject to a preliminary structural analysis that has identified design solutions compatible with the 1194H adapter and with the telescope effective area requirements. Such design solutions are within reach from a manufacturing and technology point of view, thus not posing any major design problems. Issues that call for additional attention are: a) protection of the optics from contamination during all mission phases (see section 6.3); b) optimisation of the X-ray optics thermal environment; c) detailed analysis of optics alignment requirements (possibly avoiding the need for dedicated re-alignment mechanisms); d) verification of the MSC re-pointing strategy based on reaction wheels. The latest reference configuration for the MSC is illustrated in Figures 6.2.2, 6.2.3 and 6.2.4.

Over the past few months a preliminary thermal analysis of MSC has been performed, with emphasis on the thermal environment experienced by the x-ray optics elements (see figure 6.2.1). The analysis aims to identify the applicable temperature range and gradients for the different petal locations within the Sun baffle of the MSC. The analysis needs proper finalisation, but the main results can be summarised as follows:

- Modified MSC configuration has considerably simplified the thermal design, allowing increasing the operating temperature to values above 150K (depending on petal location).
- Radiative heat exchange dominates the thermal environment.
- Given the existing view factors to space, active heaters can be used only to smooth the temperature gradients at specific locations rather than increase the nominal operating temperatures.
- Reasonably uniform temperature can be assumed within each optics petal, while larger variations between adjacent petals exist depending on orientation respect to Sun.

The configuration of the DSC is being defined by Astrium and Alcatel Alenia Space in the context of the instruments accommodation study (see figure 4.2.3 of this report). The main drivers remain the instrument accommodation requirements, the cryogenic chain selected for NFI1/2 and the need for instrument baffling at different focal plane positions in addition to the accommodation of the formation flying metrology.

Figure 6.2.1: Thermo-optical properties used in the preliminary thermal analysis of the MSC.



The studies have highlighted a number of important issues:

- The critical role played by the cryogenic chain in the definition of the S/C configuration and of the corresponding resource demands. A considerable amount of effort has been invested in performing extensive trade-offs on alternative cryogenic solutions.
- The large mass impact of any redundancy requirement imposed on the cryogenic chain required by NFI1/2.
- The very demanding baffling requirements, which combined with the large FOV of the WFI and HXC instruments lead to very significant design challenges with a large mass impact. These results indicate that the presently assumed instrument FOV must be considered as a maximum upper limit and that alternative solutions to the baffling problem must be explored.

The S/C mass budgets (for both DSC and MSC) are continuously updated on the basis of the ongoing MSC and DSC configurations work, with the objective 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 is enforcing in all industrial activities a design-to-cost approach in all industrial activities, so as to allow XRO remaining compatible with the programmatic constraints of the ESA science budget.

Figure 6.2.2 – Composite spacecraft: reference configuration in the A5 fairing.

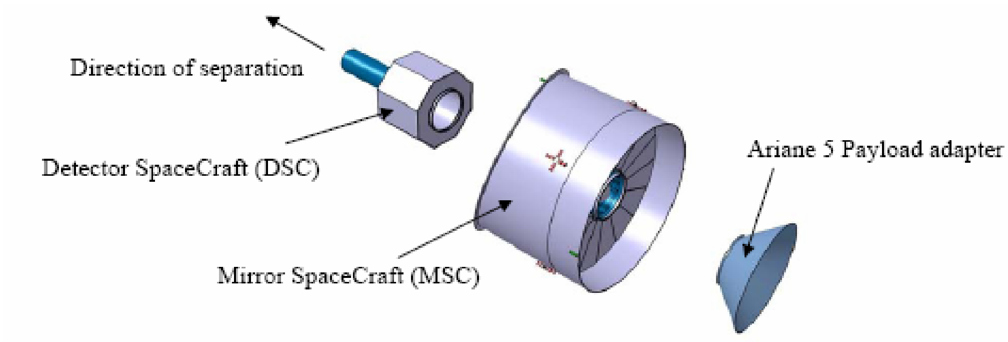
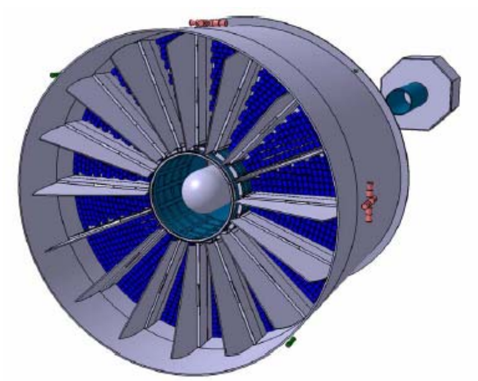


Figure 6.2.3 – DSC and MSC flying in formation



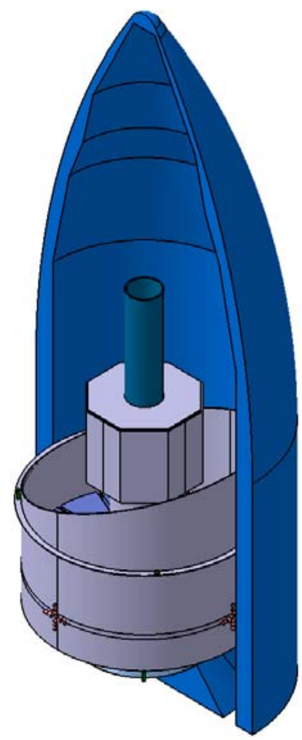


Figure 6.2.4 – Rendering of XRO flying in formation

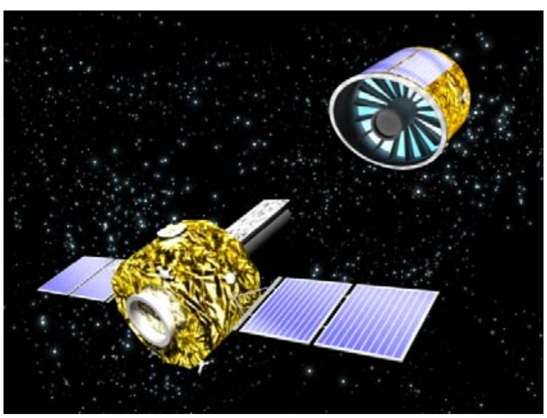


Table 6.2.1 Summary of key S/C parameters

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 Contamination analysis

The XRO science requirements call for large optics effective area at soft X-ray energy (~ 1 keV). The performance of X-ray optics is notoriously sensitive to contamination (both molecular and particulate contamination), thus calling for specific protective measures during all project and mission phases. The ability to detect soft x-ray at energy of order or below 1 keV prevents the possibility to protect the optics by interposing any materials in the optical path (e.g. thin layers of low Z materials). Moreover the large effective area is achieved by means of micro-pore optics, with a very large total surface exposed to contamination effects, depending on operating temperatures and contaminant species.

In order to estimate the contamination effects playing a critical role for XRO, ESA has started the development of dedicated simulation tools, optimised for the analysis of the formation configuration as well as the envisaged MSC and DSC architectures. These tools will allow quantifying the expected level of contamination induced on the x-ray optics by propulsion, thus providing input to ongoing as well as future industrial studies.

6.4 Ground segment & missions operations control

Work on the definition of the ground segment has continued at ESOC, including the possibility to enhance the TM down-link capability of L2 missions by different radiofrequency bands.

Specific emphasis is being put on the need to define in more details the challenges posed by formation flying operations and on the need to contain their cost.

A reference XEUS observation plan has been defined by the Science Advisory Group, with the objective of performing a preliminary analysis of the formation re-orientation and station keeping requirements. The reference observation plan covers a total duration of about 1 yr and also provides a preliminary instrument timeline, useful to better size the demand on spacecraft resource. This observation plan is being used by ESOC for preliminary definition of mission operations control.

7 TECHNOLOGY DEVELOPMENT PLAN

A crucial part of the preliminary XRO study activities is the identification of subsystems and functional units requiring specific technology development before entering definition and implementation phase. This aspect is of particular importance especially in the case of large class missions in view of maintaining development risk within acceptable limits and increasing confidence in the planned cost at completion.

The XRO technology development plan will be finalised after the completion of the corresponding assessment work, including a proper system level study, but significant progress will already be made on the basis of the preparatory activities, namely the DSC instrument accommodation study and the MSC telescope accommodation study. Such progress will allow isolating specific tasks that are on the critical path and call for an early start.

In addition to S/C oriented development activities, the plan will include a section dedicated to payload developments, with the objective of facilitating the work of any future instrument consortia. A first selection of P/L oriented TDA's will be performed after the completion of the ongoing instrument accommodation studies, including the so-called Payload Support Equipment required by more than a single instrument.

7.1 Formation Flying

A specific part of the technology development plan obviously concerns Formation Flying (FF). This innovative and important aspect of XRO mission is common to other scientific projects such as Darwin and it is being addressed through a dedicated contract, aiming to identify the most effective demonstration approach, possibly via ground-based test-beds as opposed to very costly in-flight demonstrators.

In addition to this activity, several studies have been already conducted by ESA on FF, covering a large variety of applications and topics. GNC aspects have been explored in the context of the Darwin studies, while an internal technical analysis on XEUS specific aspects is ongoing at ESTEC. A number of metrology systems will measure attitudes and relative positions of the telescopes, as needed by the control system to deploy and control the formation. A chain of metrology systems allows the measurement accuracy to be refined both in terms of spacecraft pointing and relative positions. A number of coarse sensors, including coarse sun sensors, star trackers and Radio Frequency metrology, are utilized in the initial stages ensuring that the attitudes and positions are good enough to hand over to the subsequent laser metrology systems. Laser metrology systems will bring the relative attitudes and positions to a sufficiently accurate level to start science observations (see figure 7.1). The development of RF and optical sensors has been tackled in separate TRP activities.

Concerning actuators and propulsions required to maintain FF (including both coarse manoeuvres, e.g. slew, and precision formation control), different thrust level are required (e.g. coarse formation manoeuvres require a few mN and a resolution of ~ 0.1 mN, while precision formation flying will make use of μN thrusters with a maximum thrust of ~ 0.1 mN and μN-level resolution). Possible technologies for mN and μN propulsion have been examined and traded-off during a recent ESA internal trade-off, including Cold Gas Microthrusters (CGMT) and Electric Propulsion Systems. Because CGMT thrusters require a considerable amount of fuel due to their low specific impulse, the Electric Propulsion System technology is today considered the baseline for coarse and fine FF manouvres. Several electric propulsion systems exist nowadays and have already been operated in space, such as:

- "RIT-10" developed by EADS Space Transportation, Flight Proven in ARTEMIS
- "T5" developed by QinetiQ, Flight Proven in ARTEMIS

- “Radio-frequency with Magnetic-field ion Thruster” developed by Alenia Spazio, Laben Proel, Engineering Model
- “Mini-HET” developed by ALTA, Engineering Model
- “FEEP-8” developed by ALTA, Engineering Model
- “Indium FEEP Multi-emitter” developed by ARC, Engineering Model
- “RIT-4 micro-Newton ion thruster” developed by GIESSEN University, Prototype
- “Radio-frequency with Magnetic-field ion Thruster” developed by Alenia Spazio, Eng. Model

Generally it is considered to perform testing and validation of all formation flying components, sub-systems and systems as far as possible on their own level (e.g., by traditional representative pseudo-static test beds). The main areas of sub-system validation would be metrology, actuation and control. The final formation flight validation is expected to occur in one or more, potentially modular, FF test facilities, depending on their added value, e.g., given by system-level component interplay or where subsystems are affected by the satellite environment. A “Definition Study for a Formation Flying Ground Testbed” has recently been initiated under ESA contract 19732/06/NL/HB. The prime contractor selected for the study is EADS Astrium. Its major goals are to capture the formation flying requirements of XEUS and Darwin, and to propose test methodologies to provide validation, together with a baseline design proposal. The route currently embarked upon is to follow a phased approach that does not a priori prescribe a demonstration flight or purely ground test bed approach to FF validation.

Testing has to be done on ground as far as at all possible as the required investment for space testing is in general far greater than that of even very elaborate and extensive ground testing facilities. Moreover, the flexibility of ground facilities is far superior to space demonstrations and allows the testing of an extensive parameter and scenario space, and the testing of a vast range of hardware and software options and permit the use of state-of-the-art complex test systems. After having captured the FF requirements by the above mentioned definition study, a detailed design activity will follow.

Concerning in-flight demonstration, it should be noted that two parallel design studies of a formation flying demonstration mission (Proba-3) have currently been issued by ESA. At national level, CNES and ASI have initiated a phase A study for Simbol-X, a mission that presents similarities to the overall XRO concept and that could be seen as a precursor to a larger X-ray observatory.

7.2 Payload related development activities

The development of critical payload technologies continues, with dedicated Technology Development Activities in the areas of X-ray optics and cryogenic instruments. The X-ray optics development effort is described in section 5 of this report.

The development of an engineering model of the 50 mK Adiabatic Demagnetisation Refrigerator (presently baselined for the Narrow Field Instrument 2, based on Transition Edge Sensors) is now in the final test phase (see figure 7.2). Dedicated activities on focal plane detectors are also running (including NFI1 and NFI2) or have been completed (WFI).

It is planned to review the results of the ongoing activities and to define future work, taking into account the results of the DSC and MSC accommodation studies.

Figure 7.1 – XRO Formation Flying – top level functional diagram.

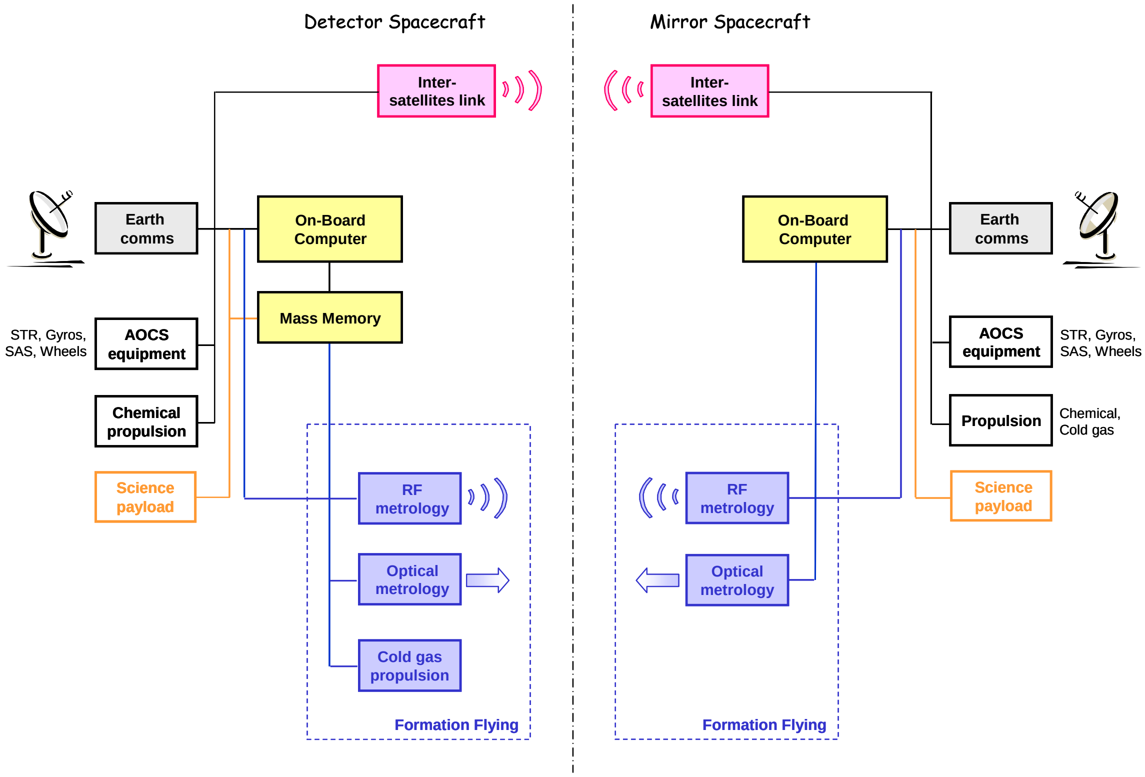
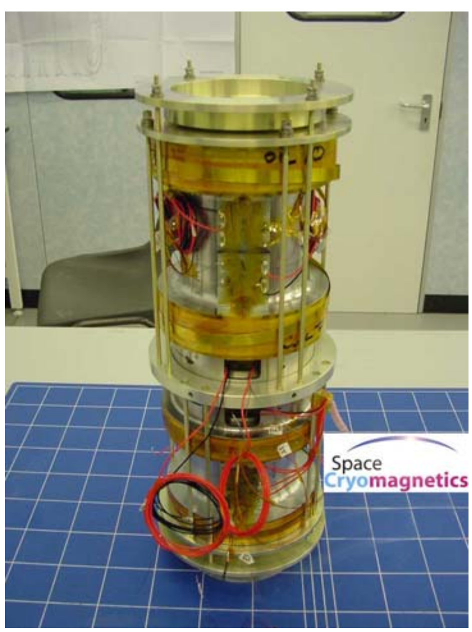


Figure 7.2 – XRO cryogenic chain elements – Engineering Model of 50 mK ADR (courtesy of MSSL and Scientific Magnets).



8 XRO RELATED PRESENTATIONS & PUBLICATIONS

Since the last status report a number of XRO related presentations and papers have been supported by ESA or industry working under ESA contract on XEUS. The list of the main events is provided below:

- SPIE Space Telescopes – May 2006 – Orlando (USA)
- Future X-ra mission workshop – June 2006 – Tokyo (Japan)
- 6th International Conference on Space Optics – June 2006 – Noordwijk (NL)
- COSPAR 35th meeting – August 2006 – Peking (China)
- International Astronautical Conference 2006 – October 2006 – Valencia (E)

9 INTERNATIONAL COOPERATION

Presently XRO/XEUS is a collaborative programme between ESA and JAXA, however the international scenario could evolve as other partners may be sought. The industrial studies ongoing at ESA are taking into consideration potential contributions from JAXA both at instrument and spacecraft level.

10 PROGRAMMATIC CONSIDERATIONS – TOWARDS COSMIC VISION 2015-2025

The preparatory industrial activities, including technology developments and S/C definition activities, which were planned before the definition of the Cosmic Vision process are regularly continuing. However, no system level industrial study is foreseen until the outcome of the first part of the Cosmic Vision Programme is clear.

A complete revision of the XRO technology development plan is expected following the completion of the existing industrial activities and the outcome of the Cosmic Vision selection process.

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.

11 CONCLUSIONS

Preliminary XRO definition work continues, following the revised mission profile described in the previous status report (issued in March 06). All activities focus on a reduction of complexity, risk and cost, capitalising as much as possible on existing technology development activities.

It should be stressed that the present XRO science requirements are very competitive with respect to any other envisaged X-Ray mission and ensure a quantum leap in capability compared to XMM-Newton.

Industrial work on the accommodation of the model payload on the Detector Spacecraft has started (Astrium and Alcatel Alenia Space – parallel competitive study), leading to significant progress on the overall system definition and triggering additional work on the model payload. As a result of this work, ESA will be in the position to issue a consolidated Payload Definition Document and to increase the return from any future system level study. Corresponding industrial work on the telescope accommodation study (MSC) will start before the end of the year.

Internal support activities on critical aspects continue at ESA, with specific emphasis on thermal and contamination analysis (MSC – optics). Technology development activities continue to progress, with the additional test results becoming available from the mirror module breadboard, the 50 mK ADR system in the final test phase and the focal plane detectors (both STJ and TES based).