XEUS Telescope
Performance Specification
and
Interface Requirements

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1. INTRODUCTION

The XEUS mission is conceived as an X-ray space observatory that aims to detect and perform spectroscopy of faint astrophysical sources located at high redshift [RD-1]. The XEUS space segment consists of a mirror spacecraft [RD-3] and a detector spacecraft [RD-2] flying in formation. The mission profile considers a single launch of the mirror spacecraft (MSC) together with the detector spacecraft (DSC) with Ariane V (AV). The spacecrafts will be placed together into an L2 halo orbit. A large X-ray telescope is accommodated on the Mirror Spacecraft. This telescope integrates a large number of mirror modules built using a high density pore optics (HPO) technology [RD-4]. The present document specifies the XEUS telescope performance and interface requirements.
2. TELESCOPE OPTICAL DESIGN and MANUFACTURING REQUIREMENTS

2.1 Telescope Optical design:

R-211-1 The XEUS telescope shall make use of the pore optics technology to approximate a Wolter I design configuration (see Fig. 1a).

The Wolter design employs pairs of paraboloid and hyperboloid mirrors nested in a co-axial and co-focal configuration. Reduction of the length of individual mirror shells allows two sets of cylindrical mirror stacks placed back to back to approximate the parabola-hyperbola optical design.
Figure 1b: Conical approximation to a Wolter I design

Required conditions for replacement of the paraboloid and hyperboloid surfaces of the Wolter-I system by conical surfaces are described in Fig.1b. The dimensions given represent an average shell of the XEUS mirror system assuming a focal length of 50m.

\[ \alpha = \arctan\left(\frac{R}{F}\right) / 4 \]

\[ D \leq 2F\tan(\varepsilon) \]

\[ L = D / \tan(\alpha) \]

Example: with
\[ F = 50\text{m}, \quad R = 1.5\text{m}, \quad \varepsilon = 2'' \]
\[ \alpha = 0.43^\circ, \]
\[ D \leq 0.97 \text{ mm}, \]
\[ L \leq 58 \text{ mm} \]
2.2 Mirror Manufacturing Technique:

Baseline XEUS pore optics technology [RD-4] use 12 inches silicon wafers as the thin low-density starting material to produce light weight mirror modules. The build-up of such a module starting from a single silicon wafer is summarised starting with Fig. 2a.

Figure 2a: Silicon ribbed plates top view and cross-section with the definition of the describing parameters. The required wedge is given by the difference in C+D on the entry and exit plane sides of the plate. The plate size indicated in this figure is the size used for the development work at the time of writing.

The wedge required for the ribbed plates, is defined in figure 2b. The rib height is wedged uniformly along the length of the ribs, with the total rib height (i.e. C+D in figure 3) being reduced by $\delta$ over the length of the ribs (= length of the plates). The value of $\delta$ is simply derived from the Wolter I design of the XEUS telescope and is a function of the mirror plate position (radial distance from the optical axis, the focal length of the telescope, and the length of plate. The plate size limitations are given from the yield of cutting the plates from the round 300mm diameter wafers, and by the stacking process used to produce the mirror modules, as well as further constraints for assembling the tandems and their mounting into the petal structure. At this time, the limitations in plate size are assumed to be 70-120mm in width, and 200mm in length.
The mirror production begins with ribbed plates that have a very high surface quality on both sides. Processed silicon wafer components are then stacked onto a precision Si mandrel, requiring only a single curvature for the cylindrical surface (see Fig. 2c). Several plates are stacked on top of each other while being curved in the azimuth direction to form a single monolithic unit that is intrinsically very stiff. This mirror stacks is completed by detaching the stack from the mandrel (Figure 2d).

**Figure 2b:** wedged (and ribbed) plates top and side view.

**Figure 2c** Stacking of many silicon ribbed plates onto a mandrel
Two mirror stacks are then mounted in series (precision alignment required), forming the cylindrical approximations to the parabola and hyperbola of a Wolter-I optics. Such mirror modules (paraboloid + hyperboloid) are then integrated on ground into petals, that are subsequently qualified and calibrated. Such units are small enough to allow simple handling, but large enough to simplify the integration and in-orbit. The principle of this hierarchical integration is described in Figure 2e.
Figure 2e: The hierarchy principle for fabrication of the complete mirror assembly, starting from a mirror module made of two mirror stacks. These are combined into a petal containing many modules of mirror pairs and pre- and post-collimators used as X-ray baffles. Finally several petals are integrated onto an optical bench.
In line with the previously described manufacturing process, a XEUS mirror terminology is defined as follows:

A mirror stack is a stack of about 70-100 (TBC) individual mirror plates of 250 micron thickness and 120 x 200 mm maximum size (TBC). The plates are held separated by ribs which form pores of typically 200 x 1000 µm dimension.

A mirror module is a combination of a front and a rear mirror stack emulating a double cylinder approximation to a Wolter I design.

A mirror petal is a group of TBD mirror modules equipped with a front and a rear collimator used as X-ray baffles. The size of a mirror petal is typically 1.3 (TBC) meter in the radial direction.

The mirror optical bench is the mechanical structure that supports the mirror petals with the needed alignment accuracy.

The XEUS telescope consists of the mirror optical bench equipped with all mirror petals and of all the necessary equipment needed to fulfil the XEUS telescope performance, functional, interface, configuration, interface, environment and operational requirements. Hence, the XEUS telescope also included thermal hardware for thermal control, magnetic deflectors [RD-6] to prevent low energy electrons or protons from hitting the X-ray detectors, protection covers to protect the optics against contamination on-ground and during the early in-orbit phases, optical and thermal baffles for stray-light prevention and thermal environment control … etc.
3. PERFORMANCE and FUNCTIONAL REQUIREMENTS

3.1 Opto-mechanical design specification and performance requirements

- R-311-1 The optical design of the XEUS telescope consists of nested co-axial and co-focal segmented mirror shells that are double-cone approximations to a Wolter-I design.

- R-311-2 The mechanical design of the XEUS telescope shall consist of an assembly of mirror modules consisting of 2 stacks. Each stack shall include a maximum of 80 individual cylindrical mirror plates of 250 micron thickness and 120 x 200 mm max size (TBC).

- R-311-3 The telescope design shall be fully compatible with the mirror manufacturing techniques described in Sect.2.2.

Design specification and in-orbit performance requirements are as follows:

- R-311-4 Telescope focal length: 35 m
- R-311-5 Telescope Field of View: 7.5 arcmin diameter
- R-311-6 Optical design: double-cylindrical approximation to a Wolter I
- R-311-7 Mirror coating: Iridium
- R-311-8 On-axis effective area at 1 keV: > 5 m² and as large as possible within all other requirement constraints.
- R-311-9 On-axis image quality (HEW) at 1 keV: < 2 arcsec (excluding mirror plates manufacturing errors)

3.2 Top-level functional requirements.

- R-321-1 The XEUS telescope shall focus X-ray with the throughput and image quality specified above.

- R-321-2 The XEUS telescope shall be equipped with X-ray baffles preventing X-ray photons that have not been reflected twice by the front and rear mirrors of the double-cone telescope from hitting the telescope field of view.
- R-321-3 The XEUS telescope shall be equipped with a magnetic deflector that provides a B.L product greater than 1700 Gauss-centimetre where B is the magnetic field in the telescope exit aperture oriented in a tangential (circumferential) direction that applies over a length l parallel to the telescope optical axis.

- R-321-4 The XEUS telescope shall be equipped with an optical baffle and a non-deployable skirt that prevent optical and X-ray photons around the pointing direction from hitting directly (i.e. without any reflection) and without attenuation the focal plane detector. The 1/e attenuation energy shall be 17 keV.

- R-321-5 The XEUS telescope shall be equipped with protective contamination covers that protect the optics against particle and molecular contamination on-ground, during launch and during the early in-orbit phase.

- R-321-6 The thermal control subsystem of the XEUS telescope shall limit the temperature of the mirror modules to the following values:
  - Operational: >150 K with room temperature (293 K) operation as a goal.

- R-321-7 The telescope performance and functional requirement shall be met when operating in the space environment at the Lagrangian L2 point in a telescope pointing direction at an angle of 90 +0/-20 degrees from the Solar disk center.

- R-321-8 The in-orbit lifetime of the telescope shall be greater than 10 years.

- R-321-9 The overall mass of the telescope shall be lower than 2700 kg including maturity margins and before system level margin including the mirror modules equipped with mirror plates, the petal structure, the X-ray baffles, the optical bench, the contamination covers and associated mechanisms, the outer Sun/thermal baffle and the skirt.

- R-321-10 The volume of the telescope (including skirt and outer baffle equipped with solar panels) shall be included within a cylinder of 4.57 m diameter and 6.0 m length (TBC) limited by the fairing of the Ariane V launcher.
4. CONFIGURATION REQUIREMENTS

A detailed description of the mirror spacecraft configuration is given in the Mirror Spacecraft Definition Document [RD-3]. The optical bench is currently assumed to consist of an inner ring, a still to be defined number of radial spokes that provide support for the mirror petals and an outer ring that will carry the outer sun baffle.

R-411-1 The inner part of the optical bench shall interface with the spacecraft service module, that consists of a central cylinder of a 1.2 m diameter. This central cylinder can be attached to the Ariane 5 launcher through an 1194H adapter and contains all the subsystem of the MSC bus.

R-411-2 The outer sun baffle itself shall carry solar panels.

R-411-3 The sun baffle shall prevent Sun light from hitting the mirror modules, the optical bench and the inner spacecraft service module for any telescope pointing direction within the accessible sky area.

R-411-4 The accessible sky area consists of a 360 degree strip limited by a pointing direction perpendicular to the Sun direction and by a pointing direction 20 deg outwards the Sun direction.
Figure 3a: XEUS mirror and detector spacecrafts in launch configuration

Fig.3b: XEUS mirror spacecraft with the outer telescope (including the petals, optical bench and outer sun/thermal baffle) and the inner service module.
Fig 3c: XEUS outer baffle preventing direct Sunlight to illuminate either the service module or the telescope petals.

Figure 3d: XEUS Mirror (left) and detector (right) spacecrafts in the formation-flying operation configuration. The telescope focal surface on the detector spacecraft is equipped with a 8 m length cylindrical baffle (TBC) that limit the detector view factor to the telescope structure. An outer telescope baffle also prevent light to hit directly (i.e. without any reflection) the focal plane detector.
5. INTERFACE REQUIREMENTS

5.1 Interface requirements with the service module of the mirror spacecraft

5.1.1 Mechanical Interface

R-511-1 The telescope optical bench shall interface with the service module structure that has the following specifications:
- Height: 2.5 m
- Diameter: 1.21 m
- Interface to launcher: 1194 H
- Wet mass: 750 kg (including maturity and system level margin)
- CoM: 1.25 m above the separation plane
- Structure: TBD

R-511-2 Four optical corner cubes for formation flying shall be accommodated in a thermally stable environment with a large baseline.

R-511-3 Four cluster of four monopropellant thrusters will be located external to the sun baffle and provision for piping shall be provided between the tanks in the central spacecraft service module and these thrusters.

5.1.2 Electrical Interface

R-512-1 The sun baffle shall accommodate a body mounted solar array of 8 m$^2$ with related harness to the central cylinder. The solar array mass density is 3 kg/m$^2$.

R-512-2 The XEUS telescope electric power consumption shall be lower than 100 W.

5.1.3 Thermal Interface

R-513-1 Thermal dissipation from the central cylinder will be about 400 W during science operation. The locations of the radiators on the mirror spacecraft service module are TBD, but parts of the dissipated power can, if beneficial, be used for thermal control of the telescope.
5.2 Interface requirements with the detector spacecraft

R-521-1 The XEUS telescope baffling system shall prevent any pixel in the telescope field of view to receive X-ray photons from the sky (i.e. without a double parabola + hyperbola reflection). For the purpose of the telescope X-ray baffling (skirt) definition, an x-ray baffle length of 8 m shall be assume on the detector spacecraft around the telescope field of view at the telescope focal point.

R-521-2 In launch configuration the DSC shall be located on top of the MSC with an 1194 interface. The DSC has a maximum wet mass of 2000 kg and its center of mass is located 1 m above the interface to the MSC.

6. ENVIRONMENT REQUIREMENTS

R-611-1 The performance of the XEUS telescope shall be verifiable on ground.

R-611-2 The telescope performance, functional, configuration and interface requirements shall be met in-orbit after passing through the Ariane V launch environment nad after 10 years of operation.

R-611-3 Standard design margin shall be applied.

7. REFERENCE DOCUMENTS


