ESA configuration study

of the

International X-ray Observatory

International X-ray Observatory (IXO): terms of reference

A proposal for a joint ESA/JAXA/NASA study of an International X-ray Observatory was accepted at an ESA-NASA bilateral meeting on 2008, July 14, with JAXA concurrence. Input elements to IXO configuration include:

1 - A single large X-ray mirror assembly compatible with both pore optics and slumped glass technology

2 - An extensible optical bench to reach F=20 to 25m + ways to maximise Aeff above 6 keV

3 - Instruments include a wide field imager, a high resolution non-dispersive spectrometer, an X-ray grating spectrometer + instruments with modest resources

4 - The IXO concept must be compatible with both Ariane V and Atlas V 551 launchers.

→ The IXO concept will be the input to the US decadal survey and ESA Cosmic Vision selection process

IXO assessment study overview (preparation for ESA CV selection)

1) Preparation phase: (mid-July 2008 → mid-October 2008)
- Building of an international ESA-JAXA-NASA collaboration scheme
- Definition of the preliminary science requirements
- Preliminary definition of the payload instrumentation

2) IXO CDF mission study: (Phase 0: October 9th → November 11th 2008)
→ Mission concept
→ Consolidated payload definition document + mission requirement document + science requirement document
→ Input to IXO proposal for NASA decadal survey

3) IXO CDF telescope studies: (February/March 2009)
→ Consolidation of critical aspects (MA, deployment bench, cryogenics, straylight, environment)
→ preparation of ITT to industry: **mirror module specification and interface requirements**

4) Two parallel Industry system studies: (Phase A: Q2 2009 → Q2 2010)

5) ESA synthesis of the assessment study (Cosmic Vision selection process): (Q3 2010)
- Mission and payload technical feasibility
- Technology development status
- Risks, programmatic and cost

IXO configuration study

1 – Introduction

2 – IXO mission requirements and spacecraft configuration

– Instrument module

– Service module

– Mirror assembly

3 – Conclusion

IXO payload model

1 single large aperture X-ray telescope:

3 core instruments:

- Wide Field Imager + Hard X-ray Camera
- Cryogenic Imaging Spectrometer (CIS)
- X-ray Grating Spectrometer (XGS)

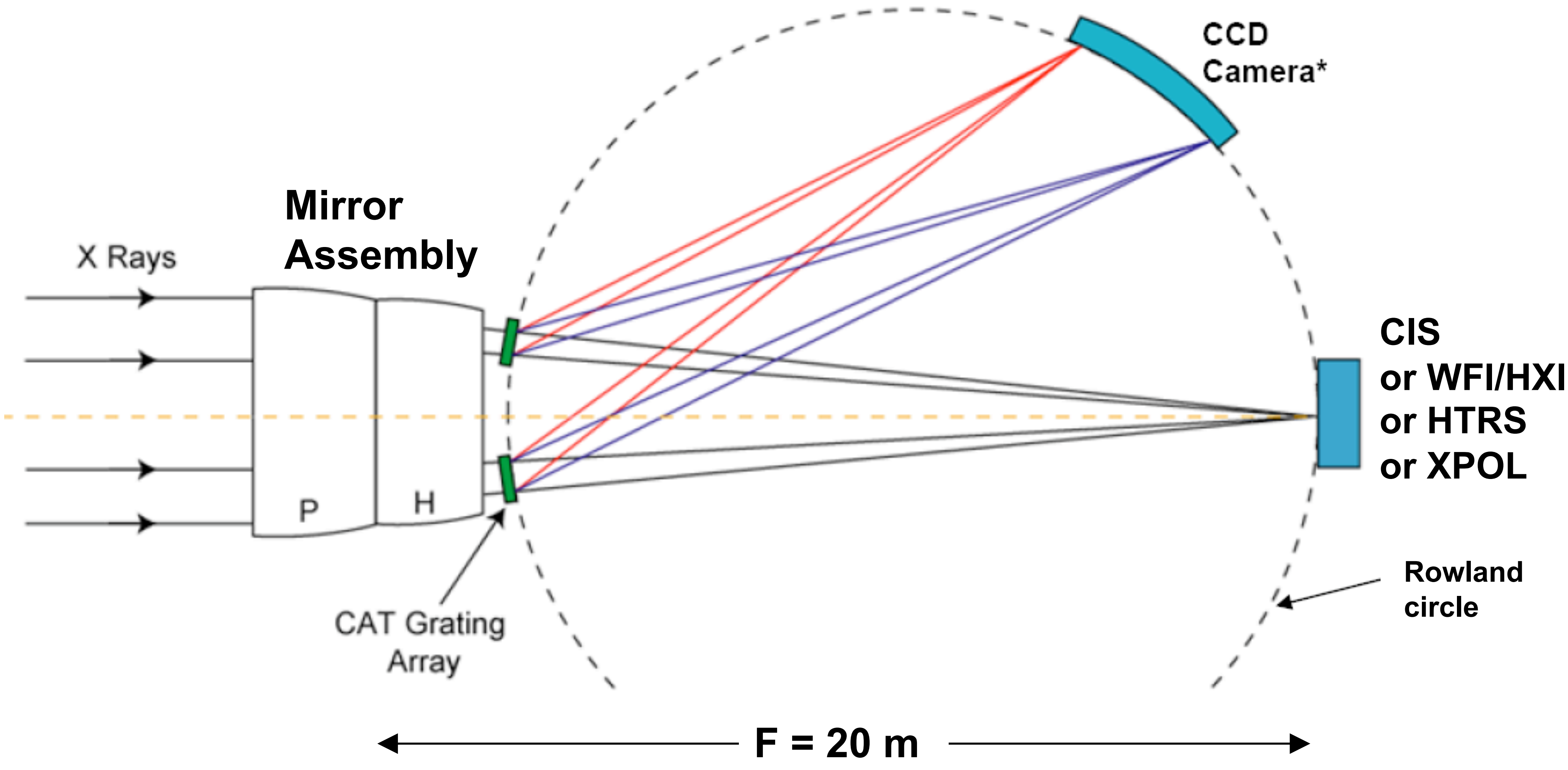
+ 2 additional payload elements:

- High Time Resolution Spectrometer (HTRS)
- X-ray Polarimeter (XPOL)

IXO mission requirements: launcher and orbit

- Launcher: Ariane-5 ECA & Atlas V 551
  - Launcher performance Ariane 5 (excl. adapter) ≈ 6170 Kg
  - Launcher performance Atlas V 551 (excl. adapter) ≈ 6108 Kg
- Target Orbit: direct launch into L2
- 5 years mission (with consumables sized for 10 years operation)
- Launch ≈ 2020

IXO configuration



IXO configuration

X-ray telescope with high energy response

→ long telescope focal length

→ **deployable optical bench**

During science operation,

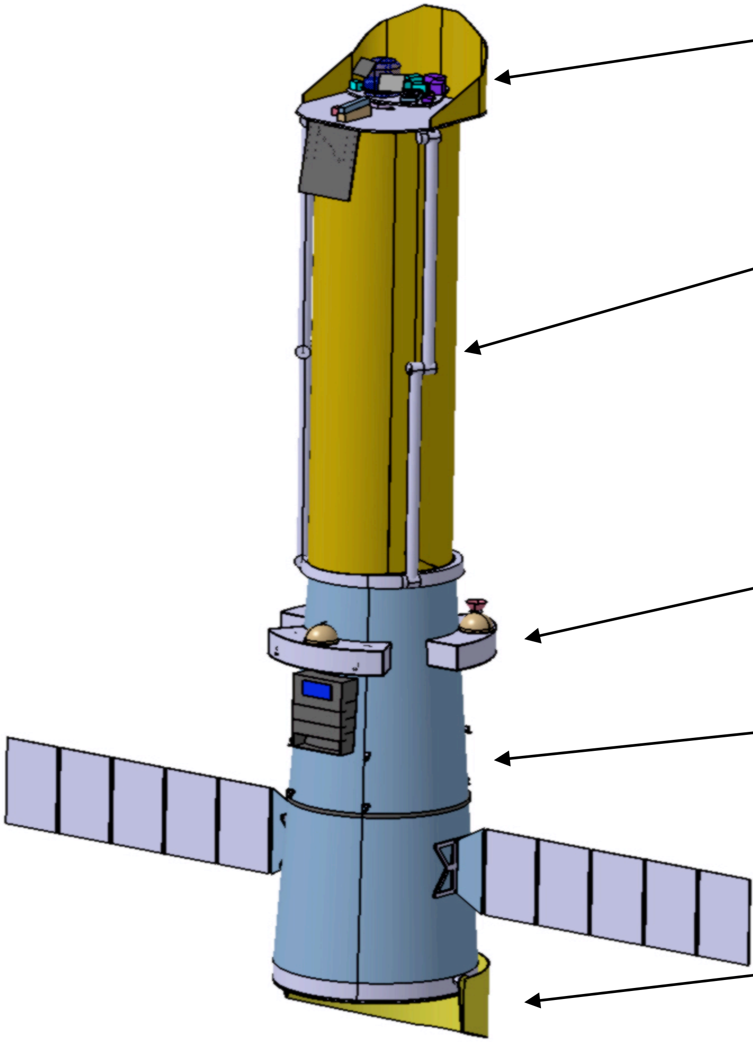
- the grating spectrometer is always operating
- any of the other 4 instruments can be placed at the focus of the X-ray telescope.

→ **instrument exchange mechanism**

The instruments shall be protected from particle background and stray-light

→ **cylindrical baffles and/or (deployable) shroud**

IXO configuration



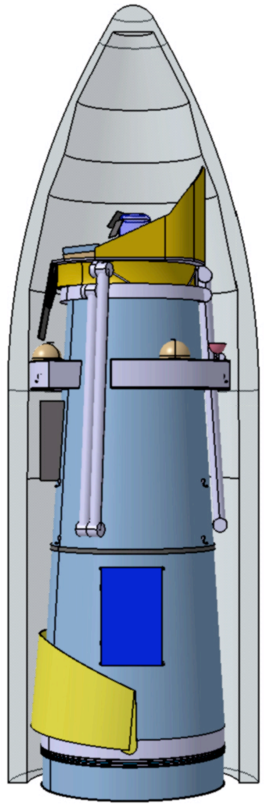
Instrument module

Optical bench deployment mechanism (+ deployable shroud)

Service module

Fixed conical optical bench

Mirror assembly (+ deployable sun shield)



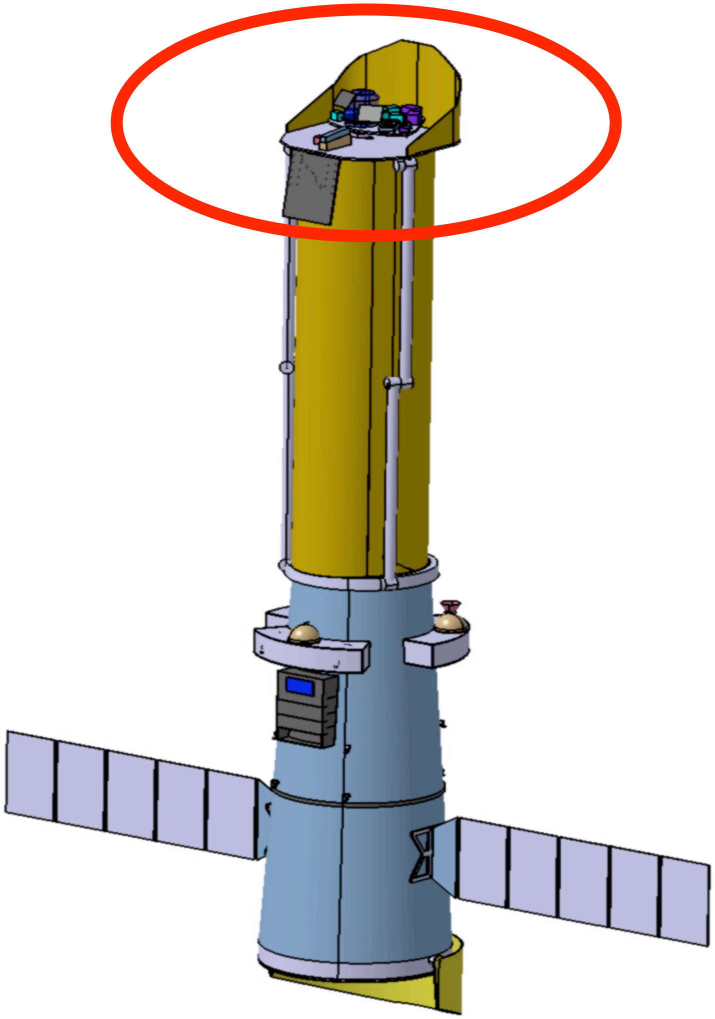
IXO configuration study

1 – Introduction

2 – IXO spacecraft configuration

- **Instrument module**
- Service module
- Mirror assembly

3 – Conclusion



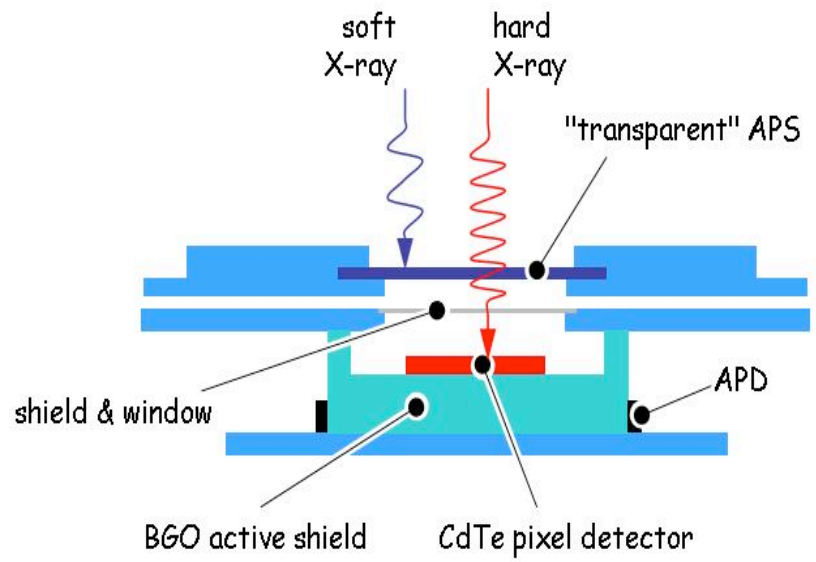
IXO instrument module: resources summary

Instrument	Power	Mass	Data rate	Comment
WFI	280 W	90 kg	<1Mbps	
HXI	43 W	31 kg	<1Mbps	
XPOL	44 W	15 kg	<1Mbps	
HTRS	113 W	31 kg	MM	
CIS	521 W 576 W recycling	243 kg	<1.7Mbps	Incl cryogenics & 100K radiator
XGS	68 W	52 kg	158 kbps 1.8Mbps peak	Incl gratings & baffle

IXO instrument module: WFI+HXI

WFI specifications:

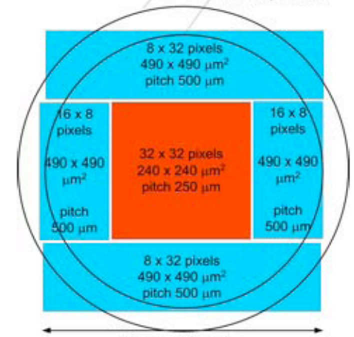
- Imaging spectrometer 0.1-15keV
- Single Si chip array of 1024x1024 active pixels
- Pixel Pitch=100µm
- Area = $102 \times 102 mm^2$ = 17.5’x17.5’



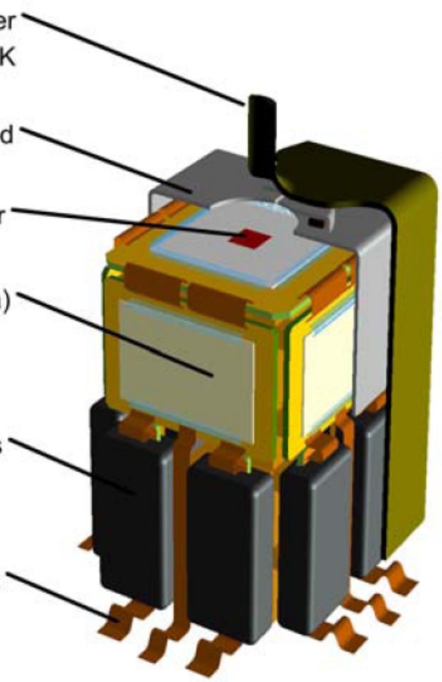
HXI specifications:

- Imaging spectrometer extension to 40keV
- FOV = 12’ circular
- Based on Si + CdTe double-sided strip detectors
- Mounted behind WFI (detector 30mm out of focus TBD)
- BGO anti-coincidence

IXO instrument module: CIS



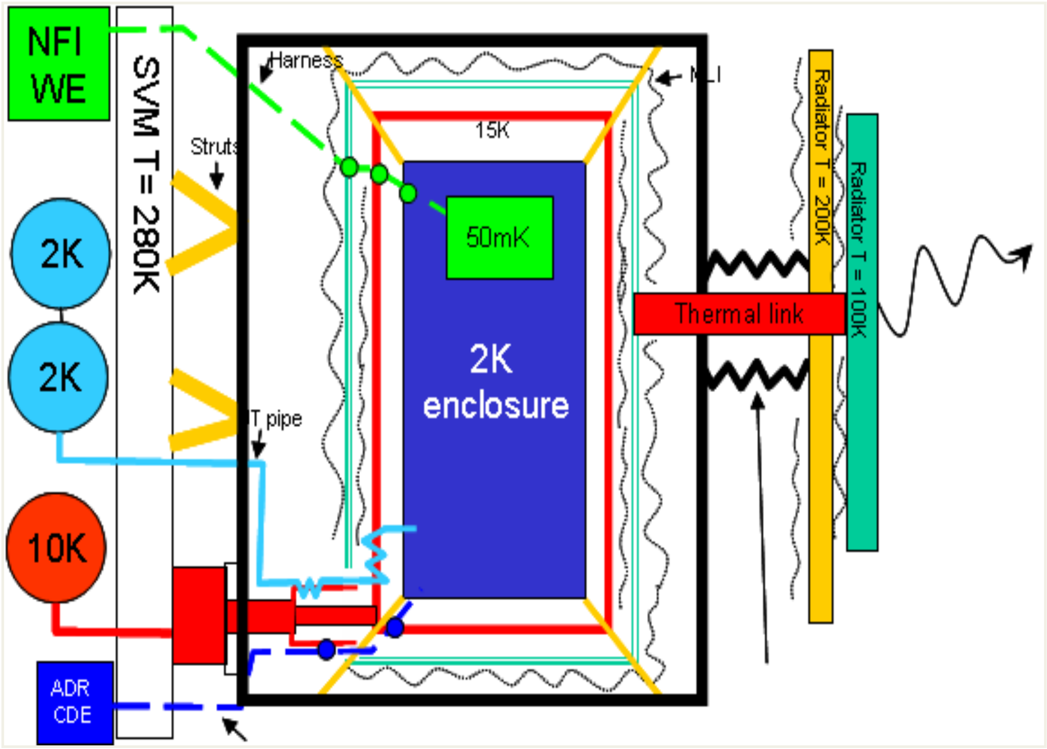
- Cryogenic imaging spectrometer based on TES
- Energy range = 0.1-10keV
- Inner array: 40x40 pixels (300x300 μm^2), ΔE<2.5eV
- Outer array: 52x52 pixels (600x600 μm^2) , ΔE<10eV
- T_{det} = 100mK ±1µK (50mK cooler I/F)
- FoV = 5.4 x 5 .4 arcmin
- CDF baseline: most demanding combination of European (NFI) and US (XMS) concepts
- Assumed US detector and Europe cooler



IXO instrument module: CIS

- 280K cryostat + 100K radiator
- 2 stage 10-15K Stirling cooler (2x)
- 2-2.5K JT cooler (4x)
- (300mK sorption cooler
  + 50mK ADR)

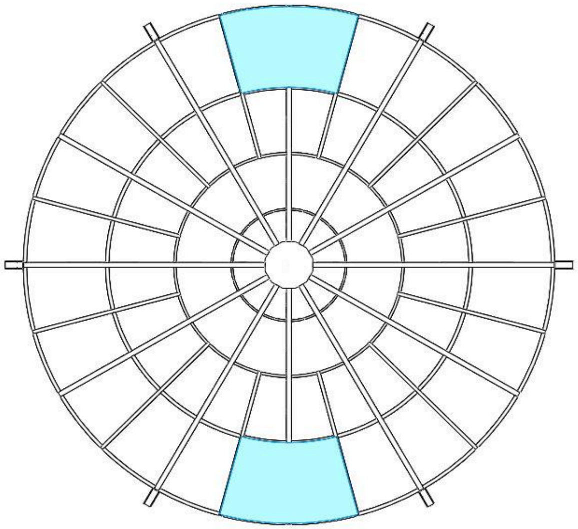
- Redundant pre-cooler concept
- Cryostat @ RT -> simplifies I/F and testing



IXO instrument module: XGS

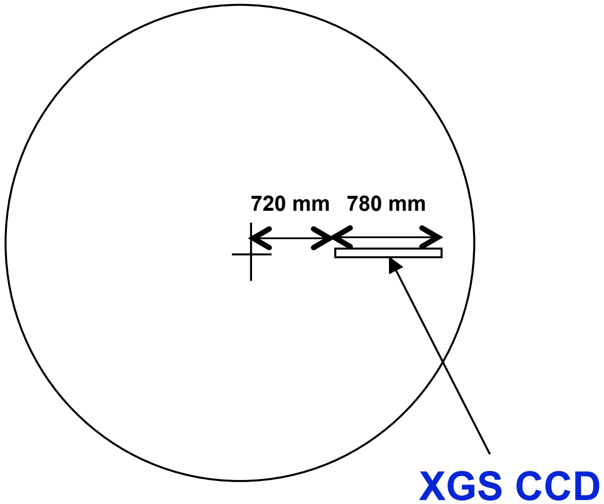
XGS grating box assumptions (based on a CAT design):

- Selected 1.1 m < R < 1.9 m and two sectors of 22.5° each.
- Box dimensions ~70 x 80cm structure support Al ~2cm deep (silicon grating only 3 microns thick)
- 2.4 kg incl 20% margin each box
- No attempt to address mounting to mirror, unit calibration, temperature constraints etc . . .



XGS camera assumptions:

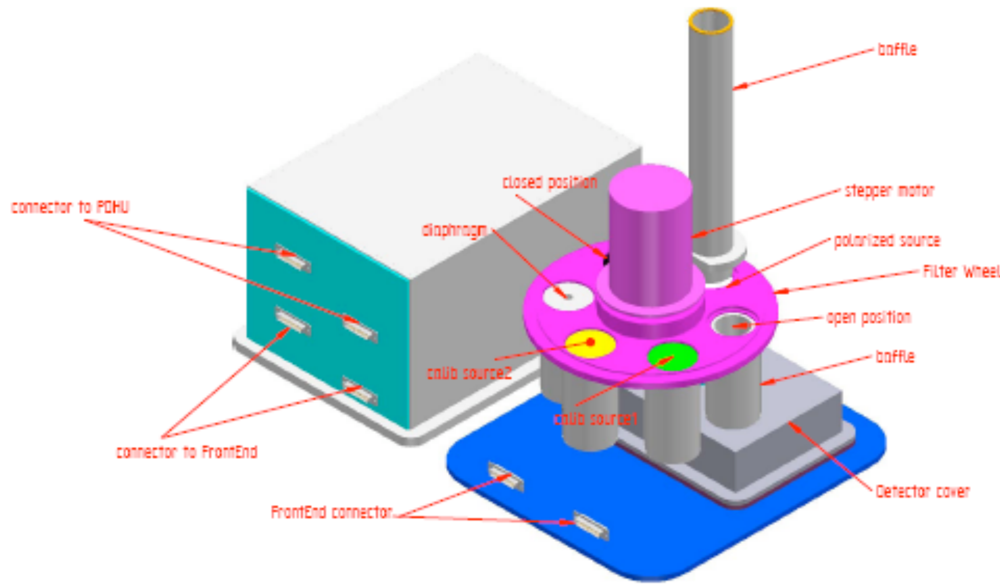
- Mass ~ 20.4kg incl margins.
- Power ~ 65 W incl margin + 3W CCD thermal control
- No translation stage needed at 3 σ error level
- Refocussing mechanism needed



IXO instrument module: XPOL

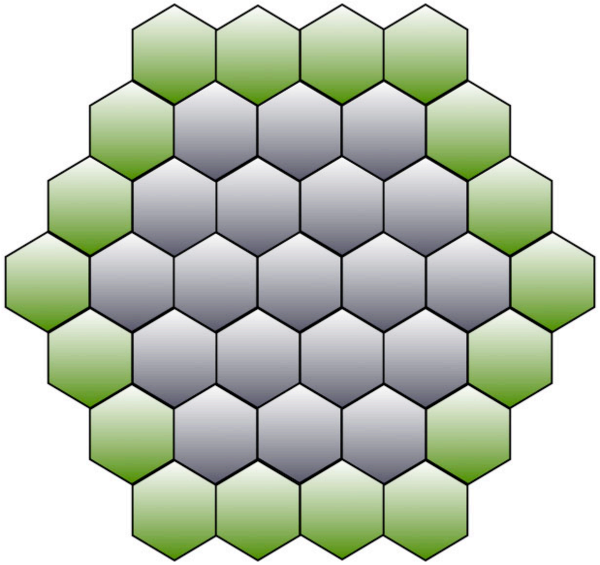
X-ray polarimeter based on scintillating gas cell

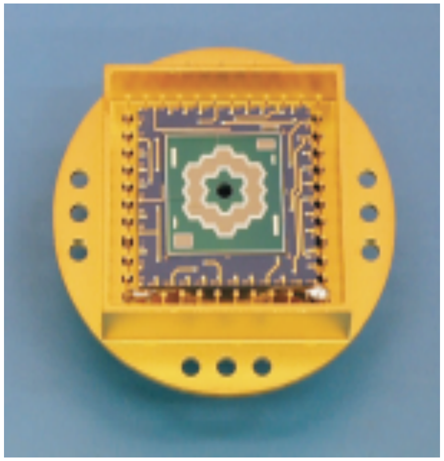
- Track detection gives polarization angle
- 300 x 352 pixels (50x43.3µm^2)
  FOV = 2.6'x2.6'
- E=2-10keV, E/ΔE=6
- T_{det}=283K ±2K
- Room temp electronics
- 1 detector head + FEE & 1 back-end box all on MIP



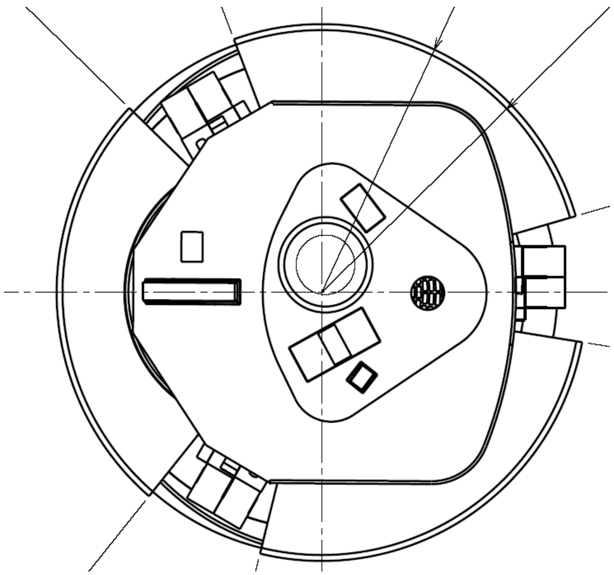
IXO instrument module: HTRS

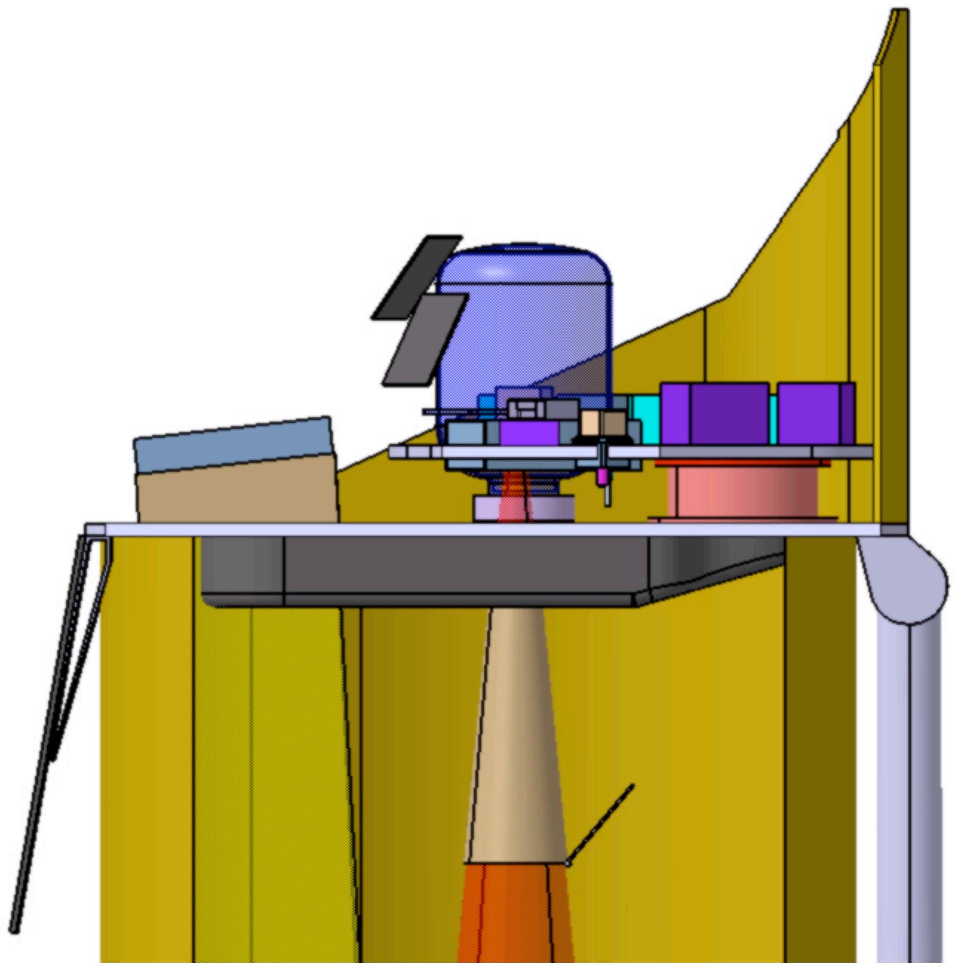
- High time resolution spectrometer: ~1Mcps, 10us resolution
- 0.5-20keV
- based on 37 Silicon drift detector diodes – placed in defocused beam (182mm)
- T_{det} = 253K ±1K
- 1 detector head + FEE & 1 electronic box on MIP
- The instrument is non-imaging
- Multiple pixels are used for distributing the photons and achieving higher count-rate capability





IXO instrument module: configuration



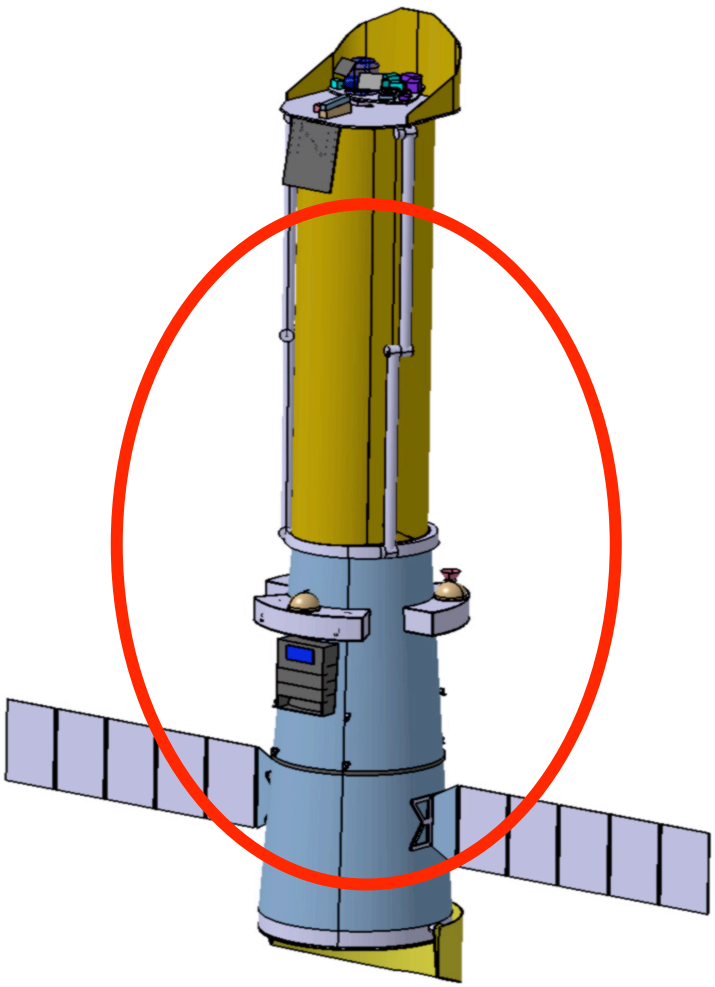


IXO configuration study

1 – Introduction

2 – IXO spacecraft configuration
- Instrument module
- **Service module**
- Mirror assembly

3 – Conclusion



IXO service module

Power subsytem:

- Max- power requirement: 4.5 kW
- 26.4 m2 deployable solar array (Ga As cells)
- Li-ion battery (MA temperature control before Sun acquisition – 650 W during 2 h)

Telecommunication:

- 90 Gb/day (8.7 Mbps during 3 hours)
- X bands around 8 GHz (10 MHz band)
- Standard equipment: 10W RF power
  (2 X/X transponder, 2 TWTA, 2 LGA, 1 40cm HGA, 1 RFDU)
- New Norcia 35 m antenna G/S (baseline)

IXO service module

Data handling decentralized architecture:

- On Board Computer (OBC) located in the S/C Bus
- Instrument Control Unit (ICU) located on the instrument platform for interfacing the IXO payloads/instruments
- 2 x 250 Gbit memory using SDRAM technology located in the instrument platform

Propulsion:

- A Monopropellant system using Hydrazine (N_2H_4) is selected:
- 24 20N thrusters
- 3 Titanium diaphragm tanks (Planck mission heritage)

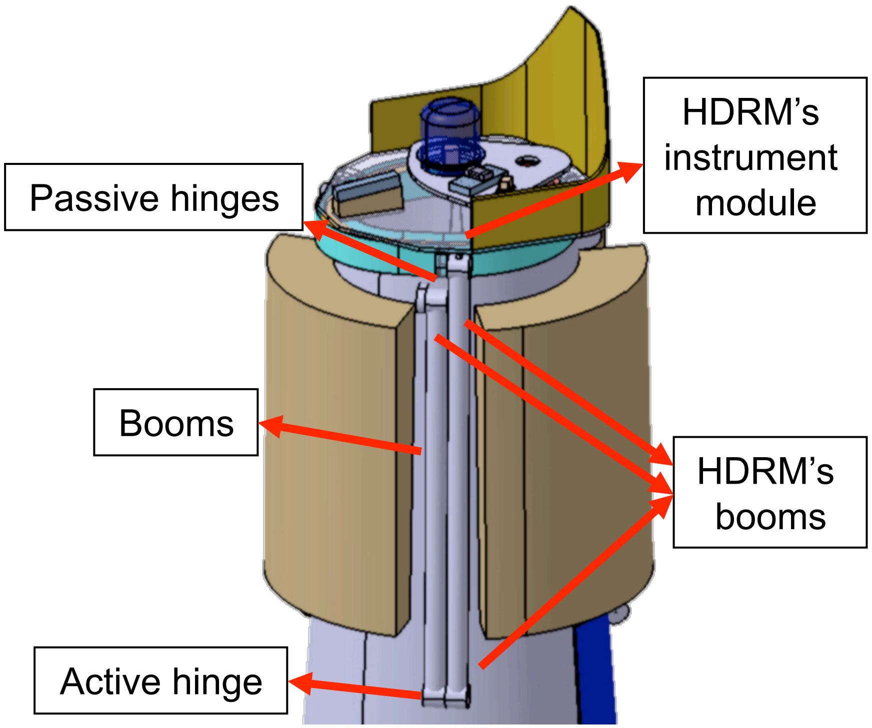
IXO service module: mechanisms

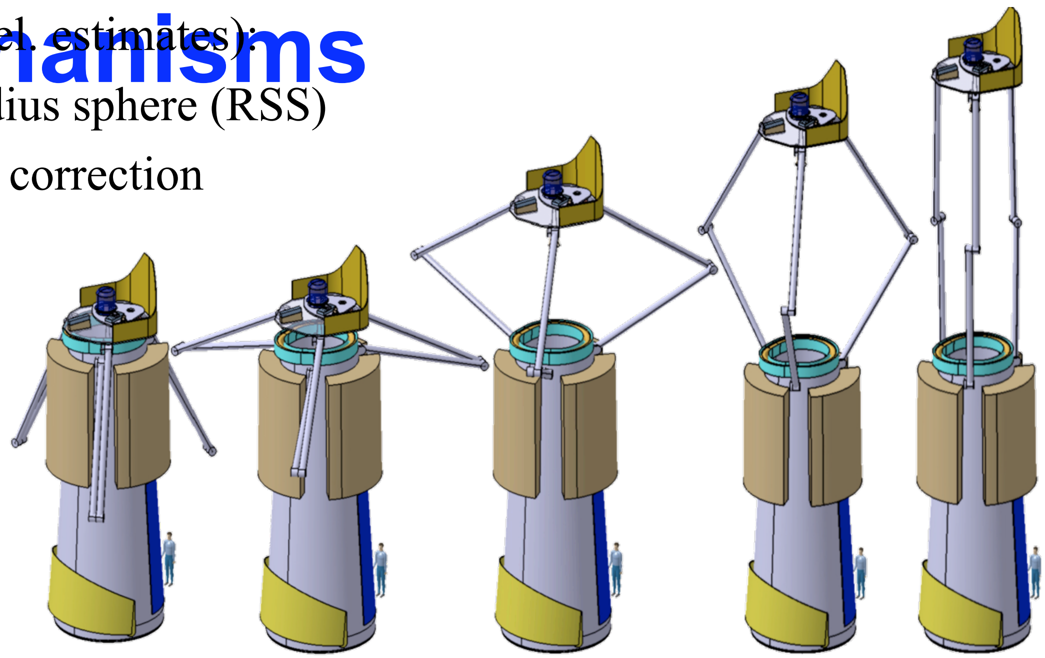
- Optical bench deployment mechanism (articulated boom concept)
- Instrument exchange and refocusing mechanism
- Mirror assembly deployable sun shield
- Outer mirror assembly ejectable cover
- High gain antenna pointing mechanism
- Solar array deployment mechanism
- Instrument baffle cover and contamination venting doors

IXO service module: deployment mechanisms

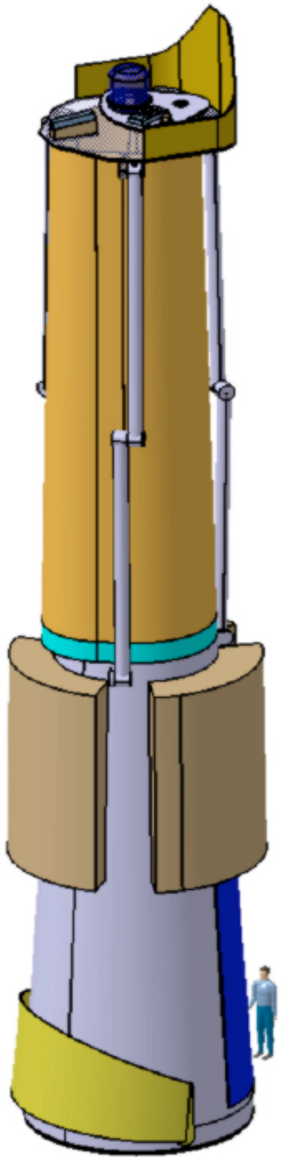
- Performance in deployed configuration (prel. estimates):
  - Deployment accuracy: 1.2 mm radius sphere (RSS)

→ displacement calibration + pointing correction





Shroud Scale Model



The GSFC Blanket shop created a 1/25th scale prototype that stows to about 7% of nominal extension length. (3.5/49)

49 cm
65 cm max

14.5 cm ID
18 cm OD

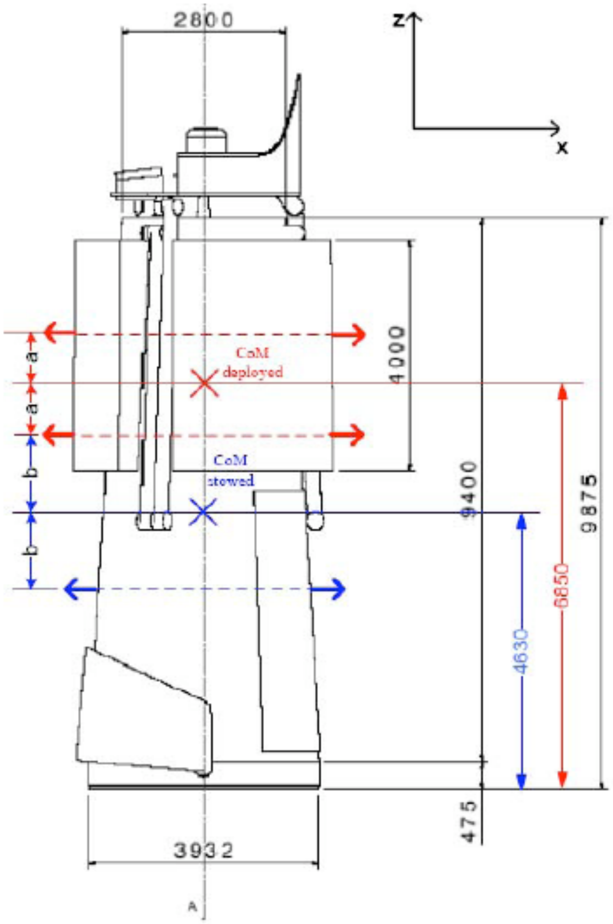
Preliminary IXO pointing and optical bench stability requirements

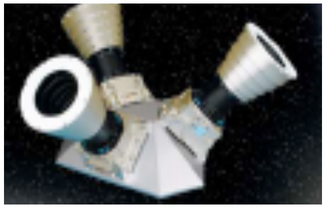
Preliminary image quality error budget (HEW on-axis at 1 keV):

- Mirror module manufacturing errors:	4.30 arcsec
- Optical design (conical approx.~ 3 arcsec)	
- Mirror figuring errors:	
- Mirror mid-frequencies errors & surface roughness:	
- Mirror plate alignment/confocality:	
-Mirror assembly system errors:	1.20 arcsec
- Assembly and integration	
- 1 g release	
- Thermal environment	
- Other (e.g. moisture release)	
- S/C pointing and optical bench distorsions:	2.00 arcsec
- Events relative lateral measurement accuracy	
- Absolute longitudinal displacement errors	
- Margin: (including PSF sampling/detector pixel size)	1.00 arcsec
Total (assuming RSS summation):	5.00 arcsec

IXO service module: attitude and orbit control system

- **Guidance, Navigation and Control Equipments:**
  - Actuators
    - 5 Honeywell reaction wheels: HR16 (120 Nms)
    - 24 monopropellant thruster: 22 N
  - Attitude sensors
    - Sodern autonomous star tracker: Hydra
    - TNO fine sun sensor (calibrated bias error: 0.01°)
    - TNO sun acquisition sensor (accuracy < 1°)
    - SAE MEMS rate sensor (rate bias drift < 5°/hr)
  - Alignment monitoring camera
    - Sodern coarse lateral sensor (derived from Hydra) FoV: 1° – accuracy < 1”





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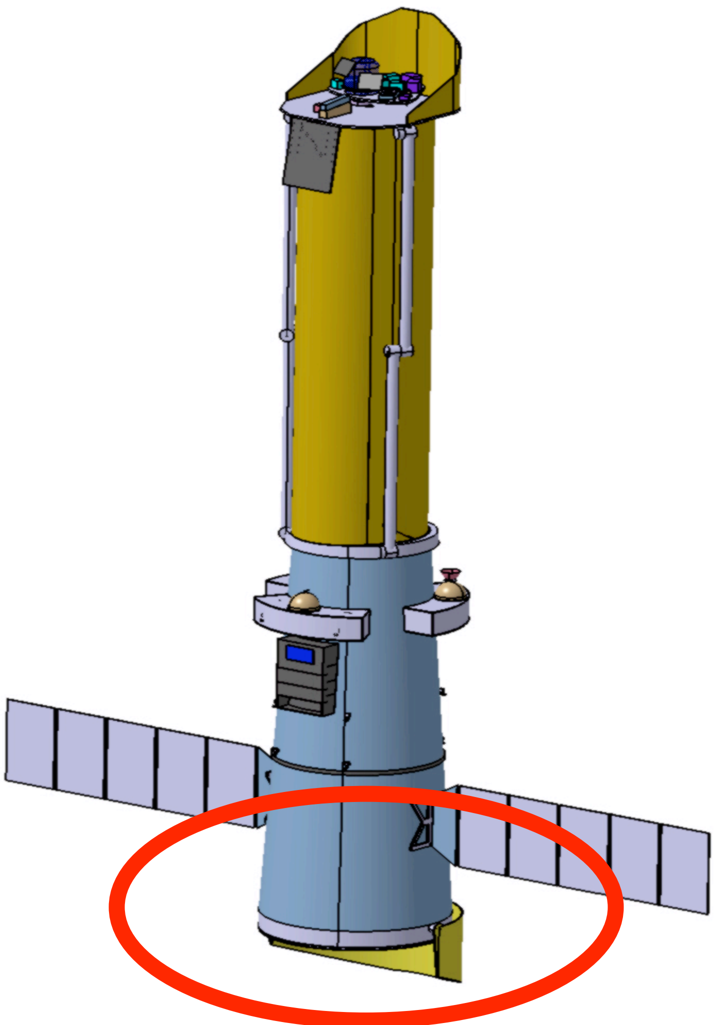
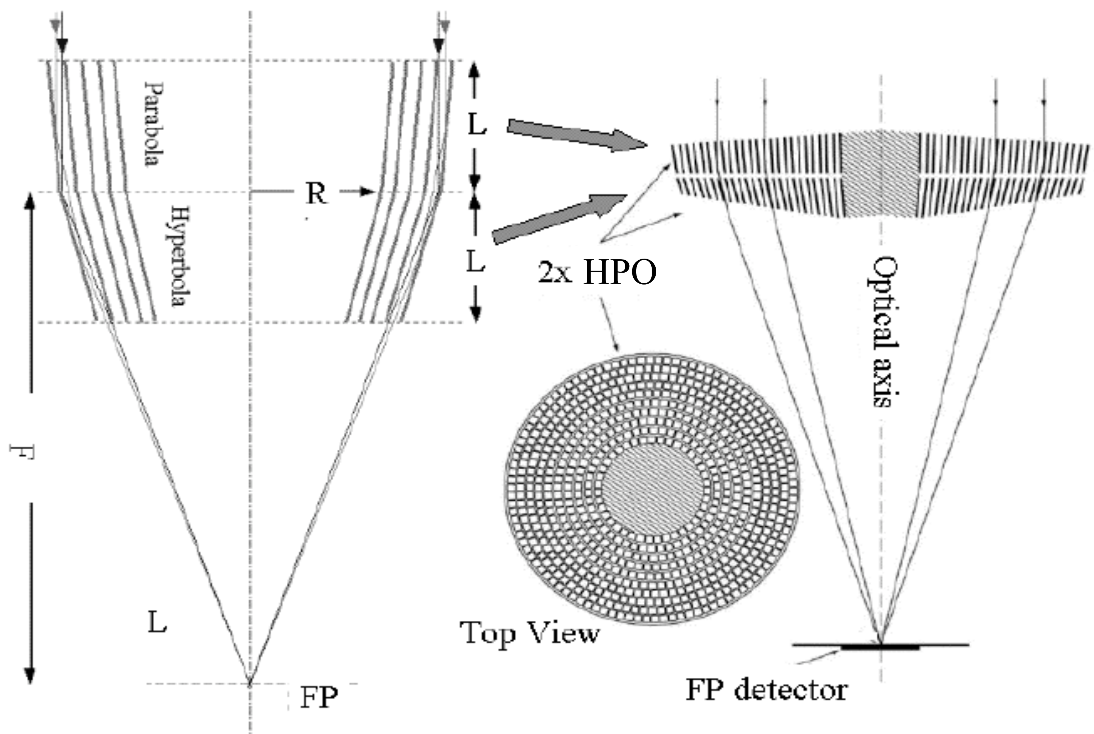
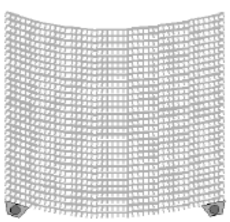


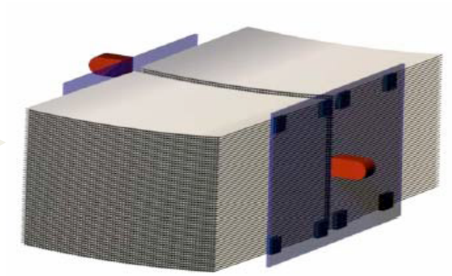
IXO mirror assembly: specification requirements

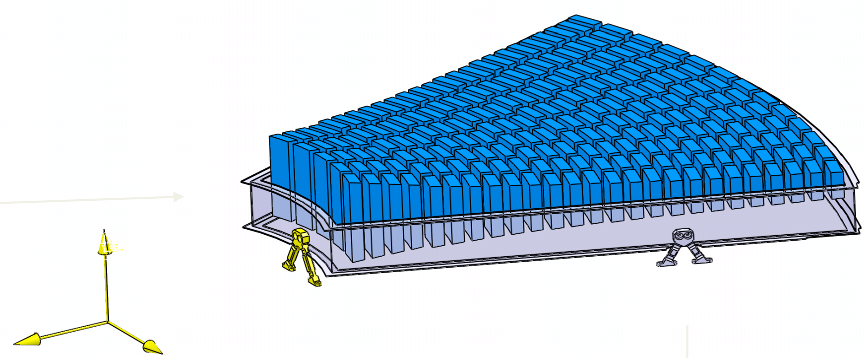


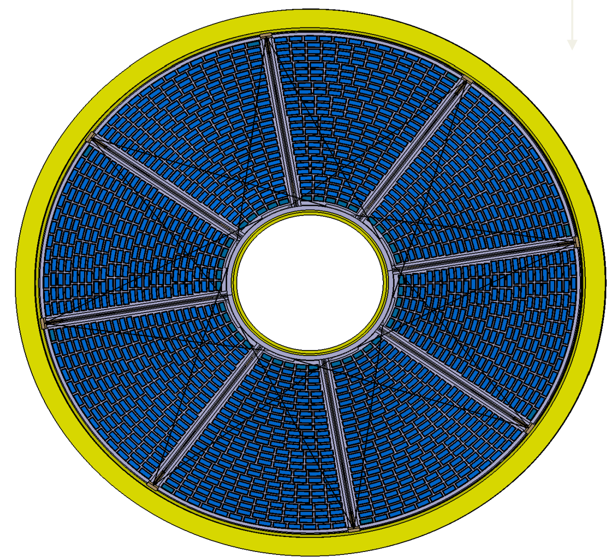
Effective area: 3 m² at 1.25 keV
Image quality: 4.5 arcsec at 1.25 keV
Design: double-conical approx to Wolter I
F = 20 m (accommodation constraints)
FOV = 18 arcmin diameter (WFI)
Technology: pore optics

IXO mirror assembly: manufacturing conc







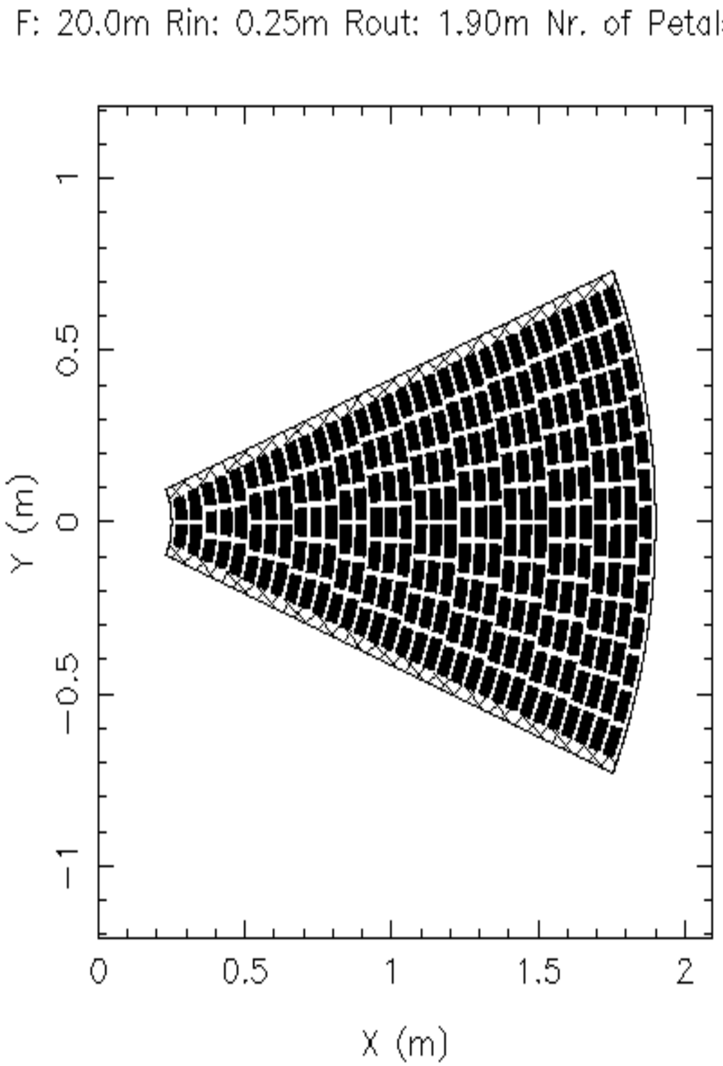


Hierarchical fabrication of mirror assembly

- Mirror stacks
- Mirror module
- Petals
- Optical bench

CDF output: the mass of the IXO mirror assembly shall be lower than 1780 kg

IXO mirror assembly: optical design



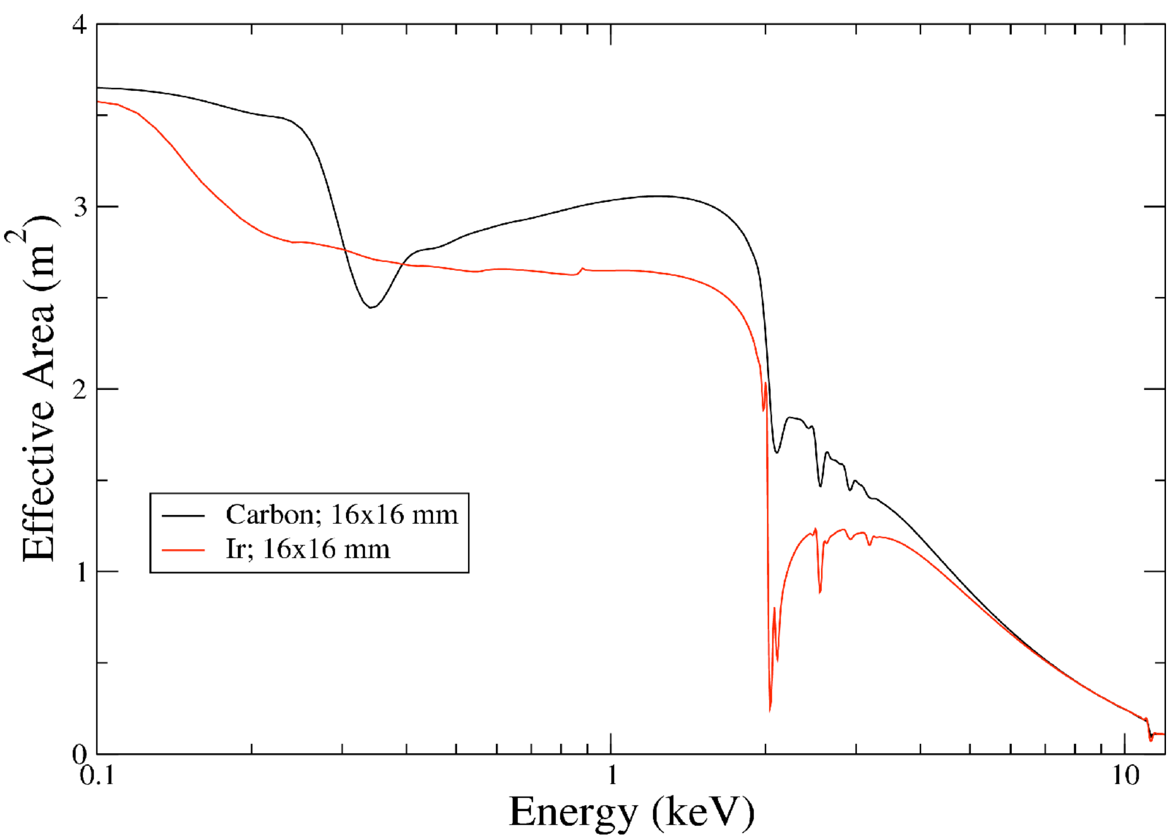
Optical design assumption:

- Inner radius 0.25 m, outer radius 1.90 m
- 32 rows
- 236 mirror modules/petal
- spoke width (7cm)

→ **To achieve the 3m2 Aeff requirements, the azimuthal/ radial spacing of the mirror modules shall be ≤16 mm** (22mm assumed for XEUS)

--> The compatibility of the optical bench structure with the allocated mirror module spacing, mass, spoke width and launch loads has to be demonstrated by FEM analysis.

IXO mirror assembly: performance estimate (TBC)



Without C overcoating:

Aeff (1.25 keV) ~ 2.6 m2

Aeff (6.00 keV) ~ 0.65 m2

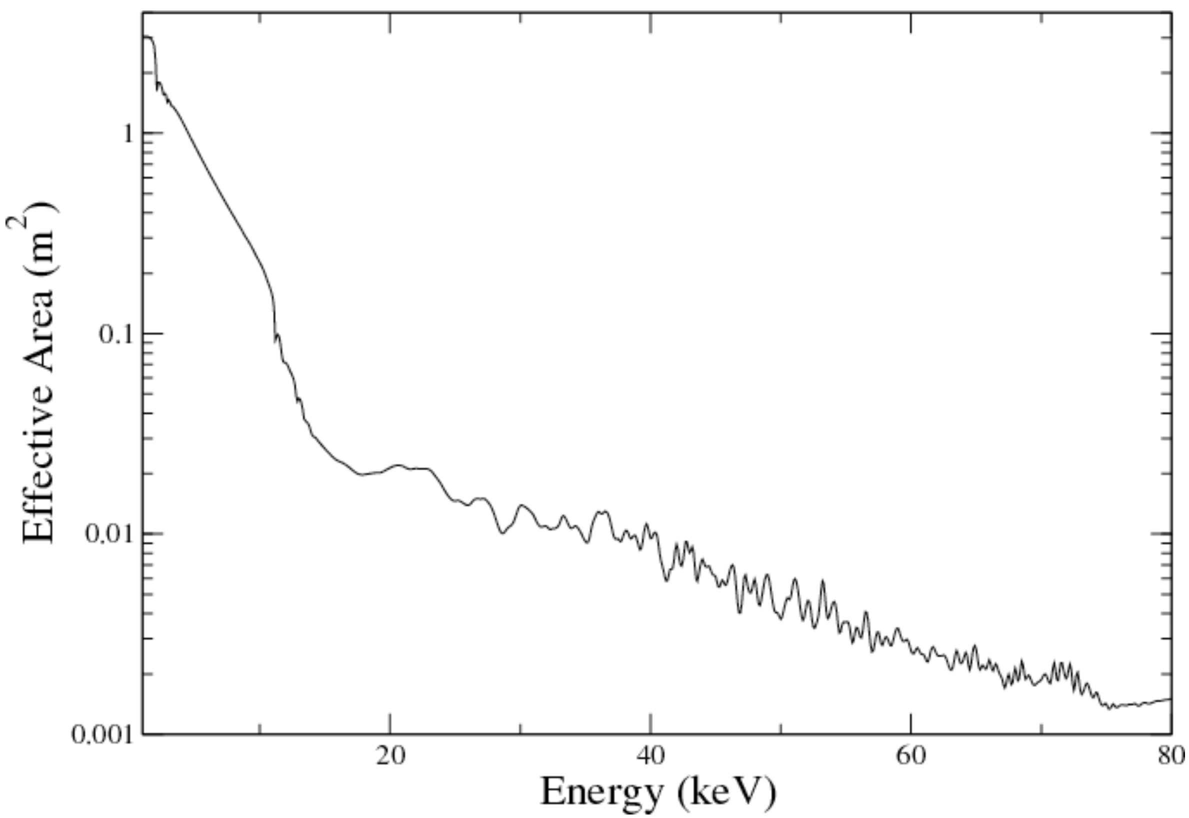
With 90 Angstrom C overcoating:

Aeff (1.25 keV) ~ 3.0 m2

Aeff (6.00 keV) ~ 0.65 m2

To achieve the 3m² Aeff at 1.25 keV requirements, the mirror modules shall be covered with a C overcoating

IXO mirror assembly: performance estimate (TBC)



With JAXA/ISAS multilayer design (courtesy H. Kunieda):

Aeff (30 keV) ~ 150 cm²

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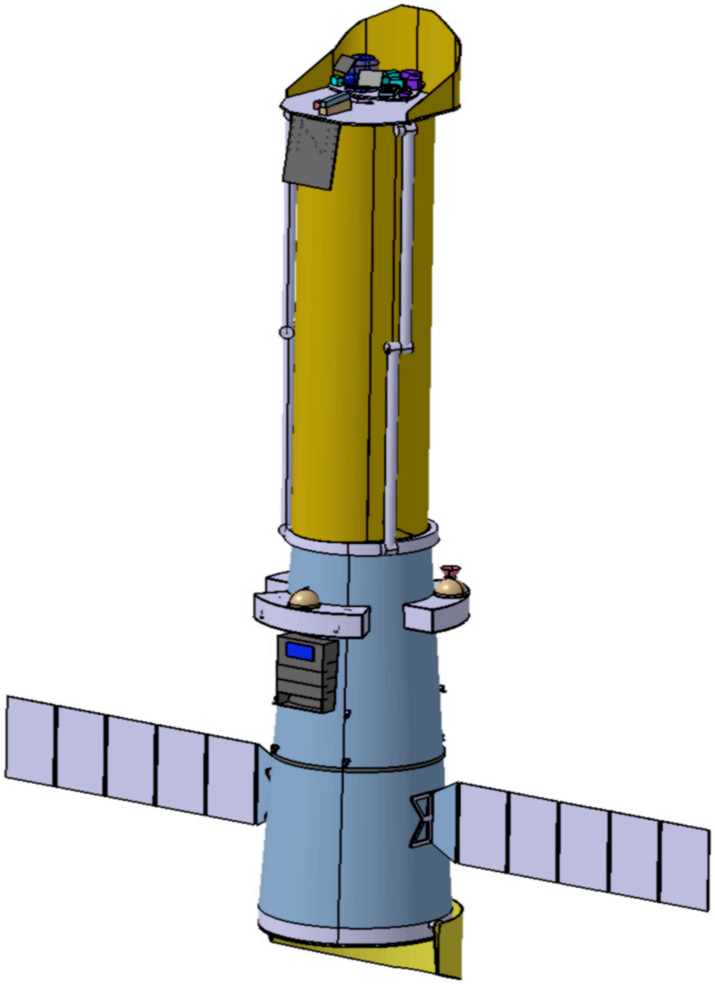

Science Performance Requirements

Mirror Effective Area	3 m^2 @ 1.25 keV 0.65 m^2 @ 6 keV with a goal of 1 m^2 150 cm^2 @ 30 keV with a goal of 350 cm^2	Black hole evolution, large scale structure, cosmic feedback, EOS Strong gravity, EOS Cosmic acceleration, strong gravity
Spectral Resolution	ΔE = 2.5 eV within 2 x 2 arc min (0.3 – 7 keV) . ΔE = 10 eV within 5 x 5 arc min (0.3 - 7 keV) ΔE < 150 eV @ 6 keV within 18 arc min diameter (0.1 - 15 keV) $E/\Delta E$ = 3000 from 0.3–1 keV with an area of 1,000 cm^2 for point sources ΔE = 1 keV within 8 x 8 arc min (10 – 40 keV)	Black Hole evolution, Large scale structure Missing baryons using tens of background AGN
Mirror Angular Resolution	≤5 arc sec HPD (0.1 – 10 keV) 30 arc sec HPD (10 - 40 keV) with a goal of 5 arc sec	Large scale structure, cosmic feedback, black hole evolution, missing baryons Black hole evolution
Count Rate	1 Crab with >90% throughput. ΔE < 200 eV (0.1 – 15 keV)	Strong gravity, EOS
Polarimetry	1% MDP on 1 mCrab in 100 ksec (2 - 6 keV)	AGN geometry, strong gravity
Astrometry	1 arcsec at 3σ confidence	Black hole evolution
Absolute Timing	50 μsec	Neutron star studies

IXO mission concept: conclusion

An IXO mission concept has been established that is:

- compatible with IXO science performance requirements
- technically promising (no show-stopper identified)
- modular and well-suited to an International collaboration

The deployable IXO mission concept presents some risks:

- large number of experiments
- large number of deployable mechanisms
- complex collaboration set-up (high cost risk)

Highest technical risk areas include:

- mirror technology and overall mirror assembly (including grating accommodation),
- cryogenic imaging spectrometer (including cryogenic chain),
- bench deployment mechanism,
- instrument exchange mechanism,
- shroud (deployment and micrometeorites impact/straylight)
- mirror assembly cover/ front sunshield deployment
- instrument alignment vs mirror assembly/ metrology