



Development of high throughput soft X-ray telescope with four-fold reflection optics

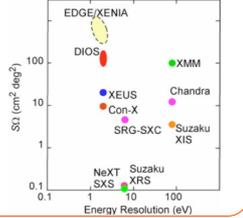
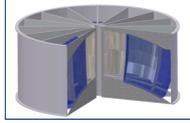
Cosmic Chemical Evolution Workshop, June 2-4, 2010 @ St. Michaels, USA

Tawara, Y., Sugita, S., Sakurai, I., Kurebayashi, Y. (EcoTopia Science Institute, Nagoya University)

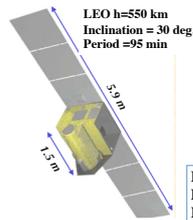


Science target : Exploring the new region of the cosmic web, WHIM and cluster at virial radius

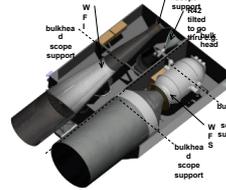
FXT(4-stage x-ray telescope) :
Optics with large GRASP optimized for low surface brightness diffuse source



DIOS (Diffuse Intergalactic Oxygen Surveyor) **XENIA** (A Probe of Cosmic Chemical Evolution)



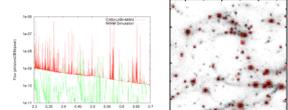
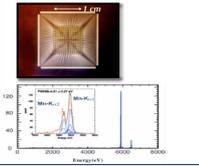
Focal length 70 cm
Diameter 60 cm
Mirror height 4 x 4 cm



Focal length 120 cm
Diameter 95 cm
Mirror height 7 x 4 cm

XSA (TES X-ray spectrometer array) : (5 eV @1.5keV)

→ Detect OVII, OVIII K α emission lines from the fields strongly contaminated by Galactic foreground emission



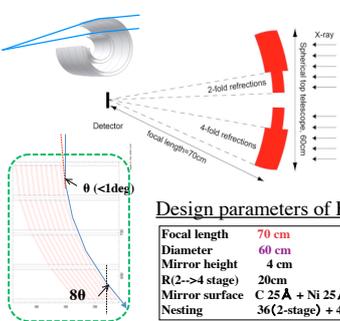
FXT baseline design parameters

Effective area	> 100 cm ²
Field of view	50° diameter
GRASP (S Ω)	> 100 cm ² deg ² @ 0.6keV
Angular resolution	4' (16 x16 pix)
Energy resolution	5 eV (FWHM) @0.3-1.5 keV
Energy band	0.3-1.5 keV
Mission life	5 yr

XRT for CRIS (Cryogenic Imaging Spectrometer)

Effective area	> 1000 cm ²
Field of view	50° diameter
GRASP (S Ω)	> 400 cm ² deg ² @ 0.6keV
Angular resolution	4'
Energy resolution	3 eV (FWHM) @0.3-1.5 keV
Energy band	0.3-1.5 keV
Mission life	3 yr

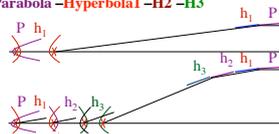
Four-fold reflection optics



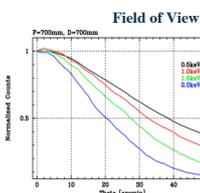
Design parameters of FXT-DIOS

Focal length	70 cm
Diameter	60 cm
Mirror height	4 cm
R(D->4 stage)	20cm
Mirror surface	C 25 Å + Ni 25 Å + Pt 300 Å
Nesting	36(2-stage) + 41 (4-stage)

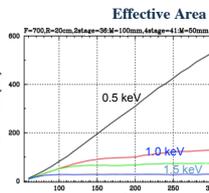
Extended Wolter-I optics:
Parabola-Hyperbola-H2-H3



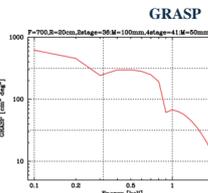
Effective area : S(4-stage) = 1.5 x S(2-stage)
Angular Resolution : Required performance : 3-4 arcmin HPD corresponding to TES pixel size
Error budget : positioning < 8 μ m (short mirror) slope error < 0.2 arcmin (rms, each stage) (corresponding to 4 fold reflection)



Field of View



Effective Area



GRASP

Fabrication process of replica foil mirror

Fabrication Method : Same as Suzaku, Astro-H

Cutting of Al substrate & conical Shape heat forming



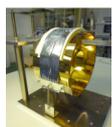
Glass mandrel and : need selection of better mandrel



Epoxy spraying system
Epoxy thickness control : d = 20 +/- 3 μ m



Epoxy curing process (50 °C, 12h) and separation : need additional force to fix conical substrate to cylindrical glass mandrel



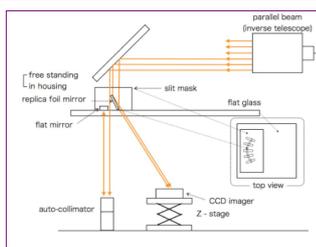
New feature of fabrication process for FXT

Large difference between conical shape of mirror substrate and cylindrical glass mandrel

Radius	Top	Bottom	T-B(mm)	θ (deg)	(T-B:Suzaku)
Stage 1	89.97	89.33	0.64	0.9	(0.26 mm)
Stage 2	89.33	87.42	1.91	2.7	(0.76 mm)
Stage 3	87.42	84.26	3.16	4.5	
Stage 4	84.26	79.78	4.48	6.3	

New method to press substrate to the mandrel : Silicon rubber + cloth + PI film + spring (both side) (No evidence of distortion in the process of "50 °C, 12h" for substrate without epoxy)

Optical measurement system



Optical parallel beam measurement of each stage mirror shape in free standing or in housing condition. Partial image ; circularity and slope error.

One reflection focal length of each stage(DIOS)
Stage 1 : 2810.6
Stage 2 : 918.3
Stage 3 : 533.9
Stage 4 : 362.2

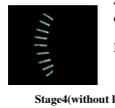
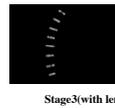
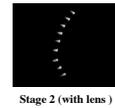
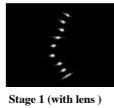
HPD = 2 x sqrt(4) x 2.35 x (rms slope error)

1 reflection image of heat formed aluminum foil of 4-th stage with nominal diameter of 180mm, inclination of 6.3 deg to optical axis.



Expected HPD (4-reflection equivalent) = 4 arcmin

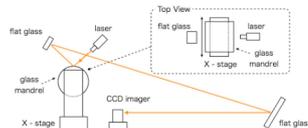
Optical off-focal plane image of Replica foil mirrors used for X-ray test at MSFC.



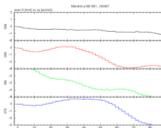
4th stage circularity error →
Expected HPD (4-refl. equival.) = 8'

Optical measurement of axial slope error of replica mandrel

Laser measurement system

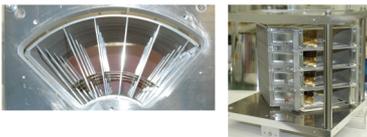


axial slope distribution (arcmin)



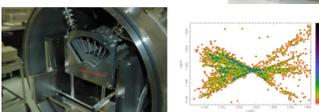
slope error < 0.42 arcmin rms required for 4 stage HPD < 4'

FXT Demonstration model for DIOS and X-ray measurement '09



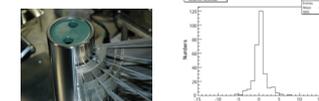
Focal length 700 mm
element mirrors : one set
diameter : 180 ϕ (primary top)
reflecting surface : Au
X-ray energy : Al-K 1.5 keV

To verify A_{eff}, $\Delta\theta$, f, FOV etc



The effective area : 0.21 cm²
expected effective area : 0.218 cm² (@ 1.5 keV)
The focal length : Consistent with designed value of 700 mm Diverging beam effect --> + 5 mm / not sensitive due to poor HPD
The angular resolution : HPD (0 - 360 deg) = 11.6 arcmin (Expected HPD = 4 arc min)

→ Mirror shape error ?



Alignment-bar positioning reproducibility < 3 μ m
measured groove position error = 1.6 μ m rms

Future Prospect

Within this year
Improvement of angular resolution of each stage element mirror
Production and X-ray measurement of 10 nested demonstration model

Toward mission proposal
Production of large scale model
Development of large replica mandrel (D > 50 cm) : metal substrate + round thin glass plate pursuing 1/8 segmented mirror
Ni, C coating for maximized effective area