Flight Programs and X-ray Optics Development at MSFC

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ABSTRACT

The X-ray astronomy group at the Marshall Space Flight Center is developing electroformed nickel/cobalt x-ray optics for suborbital and orbital experiments. Suborbital instruments include the Focusing X-ray Solar Imager (FOXSI) and Micro-X sounding rocket experiments and the HERO balloon payload. Our current orbital program is the fabrication of a series of mirror modules for the Astronomical Roentgen Telescope (ART) to be launched on board the Russian-German Spectrum Roentgen Gamma Mission (SRG.) The details and status of these various programs are presented. A second component of our work is the development of fabrication techniques and optical metrology to improve the angular resolution of thin-shell optics to the arcsecond-level. The status of these x-ray optics technology developments is also presented.

Flight Programs

Micro-X

Description:

Micro-X is a sounding rocket based payload consisting of x-ray optics (provided by MSFC) and a calorimeter detector led by MIT.

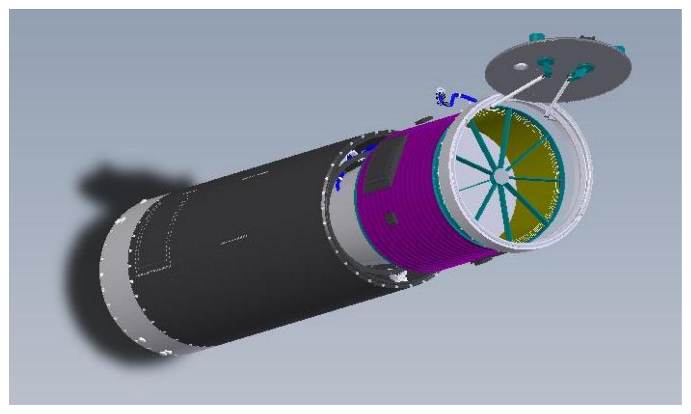
Micro-X will fly in early 2015 and make high-spectral-resolution images of supernova remnants .Puppis A and Cas A.

Design of the 0.5-m-diameter Micro-X optics has just begun.

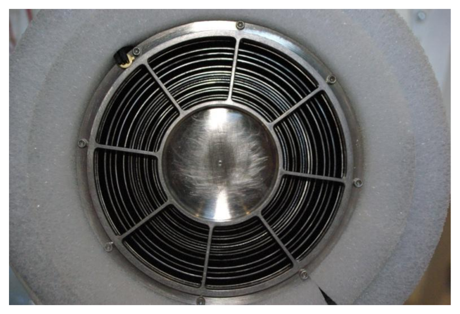
Customer:

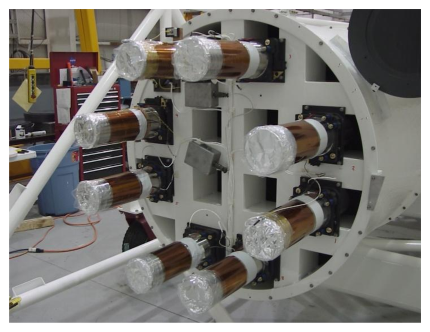
Massachusetts Institute of Technology / Tali Figueroa

Funded by the Science Mission Directorate, through the low-cost access to space program.



High Energy Replicated Optics (HERO)

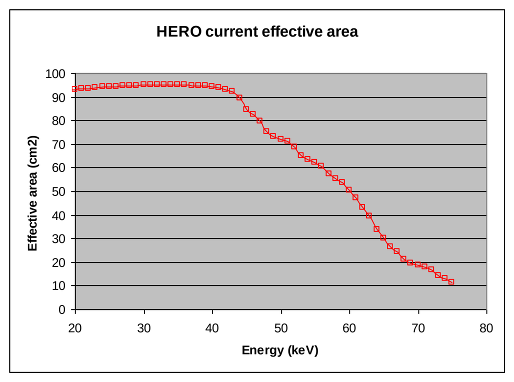




HERO, for High Energy Replicated Optics, is a balloon program designed to demonstrate MSFC optics and perform science.

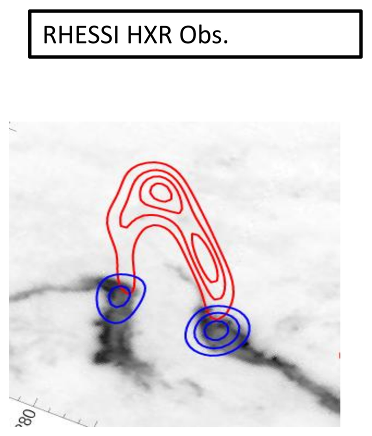
Utilizes in-house-fabricated hard-x-ray mirrors plus supporting x-ray detectors, gondola and pointing system.

Number of modules	8
Number of shells	14
Inner, outer diameters	50, 94 mm
Shell thickness	0.25 mm
Focal length	6 m
Angular resolution	~ 13-15 arcsec HPD shells 23 arcsec modules
Field of view	9 arcmin at 40 kev

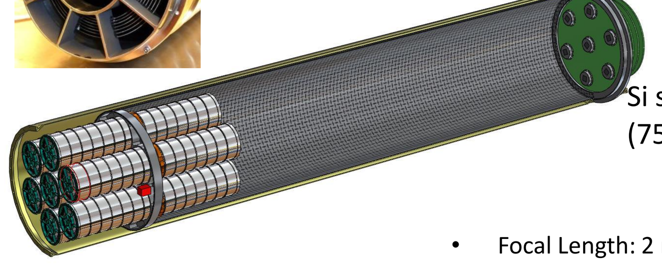


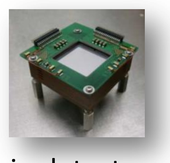
FOXSI : Focusing Optics X-ray Solar Imager

Need to be able to measure weak coronal output against bright footprints, with good angular resolution



Replicated optics telescope module
(7 shells & 7 modules)

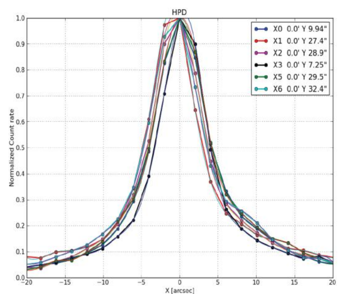


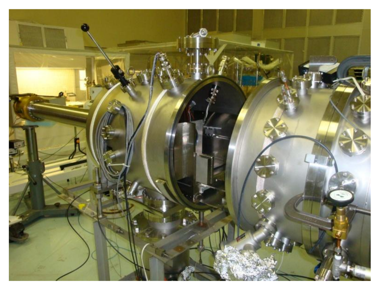


Si strip detectors
(75μm)

Payload Description:

FOXSI is a sounding rocket based payload led by the University of California, Berkeley and consisting of x-ray optics provided by MSFC and focal plane detectors provided by Japan.





- Focal Length: 2 m
- Number of modules: 7
- Number of shells: 7 (10)
- Optics Type: Wolter I
- Outer shells radius: 51.51 mm
- Inner shell radius: 37.99 mm (32.48 mm)
- Shell length: 60 cm.
- Energy range: 4 – 15 keV
- Measured angular resolution 22-26 arcsec HPD
- Model fits the measured effective area

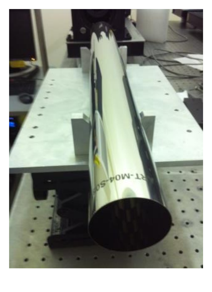
Astronomical Roentgen Telescope ART

MSFC has designed and is fabricating four ART x-ray optics modules under an International Reimbursable Agreement between NASA and with IKI. The modules have to be delivered to the IKI in June 2013

Deliverables: 1 engineering unit (6 shells + mass simulators) and 4 flight units (28 shells/unit)

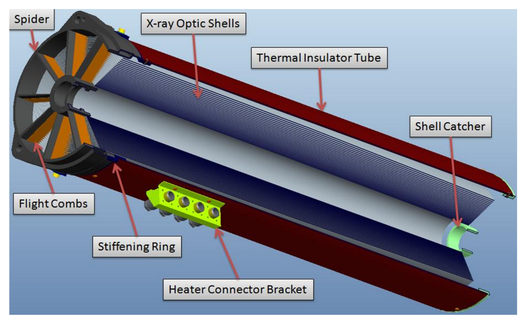
ART flight module specifications

Parameter	Value
Number of Shells per Module	28
Shell Coating	> 10 nm of iridium (> 90% bulk density)
Shell Total Length, inner and outer diameters	580 mm, 50 mm, 150 mm
Encircled Half Energy Width	Less than 1 mm diameter, center of field of view Less than 2.5 mm diameter, 15 arcmin off axis
Mirror Module Effective Area	≥ 65 cm^2 at 8 keV (on axis)
Module Focal Length	2700±1 mm
Allowable Total Mass per Module	17 kg including thermal control system
Minimal resonance frequency	40 Hz
Operating Temperature Range	17° C to 23° C



FWHM Resolution 7-8 arcsec

Spiders with baffles for 5 (4 + 1 spare) flight and 1 qualification units

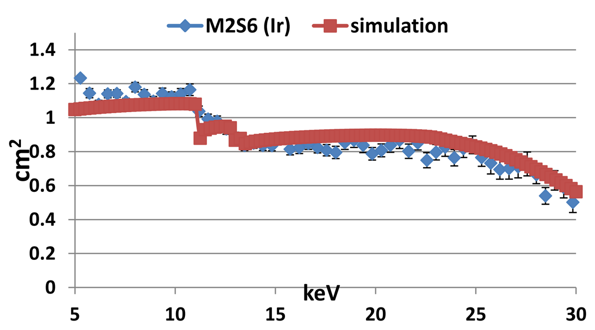


ART mirror module design

Test was performed at the MSFC's Stray Flight facility

Shell M02-S06 has been tested, the angular resolution is found to be 30 arc seconds HPD, which would correspond to the module performance of ~35 arc seconds

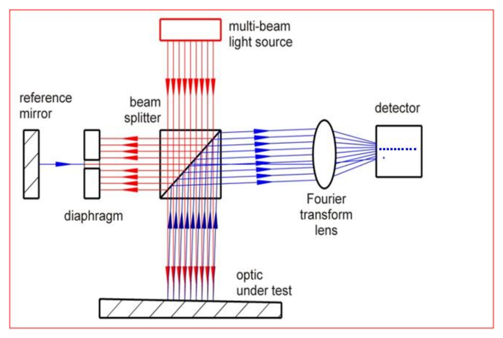
The effective area of the shell exceeds requirements



Effective area of the M02-S06 shell mirror measured (blue) and model (red)

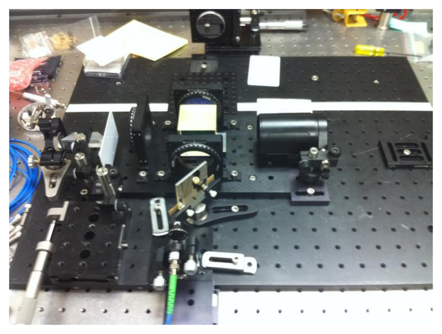
Technology development

Multi-beam long trace-profiler

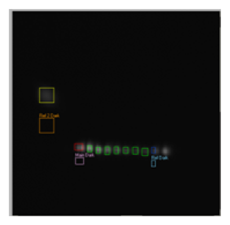


Schematic of the MBLTP

- Make use of advanced technology - Higher resolution and faster 2D detectors, Stable optical sources
- Increase the speed & accuracies of measurements - **Multiple beams**



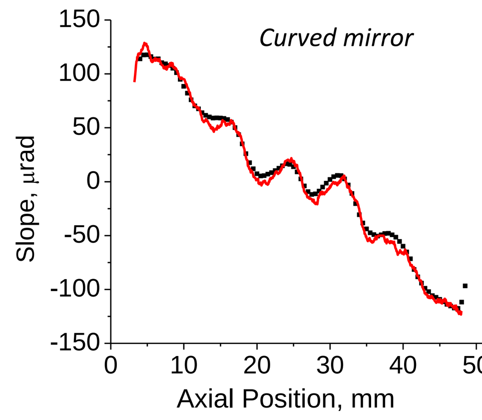
MBLTP breadboard, the detector is not shown (on right)

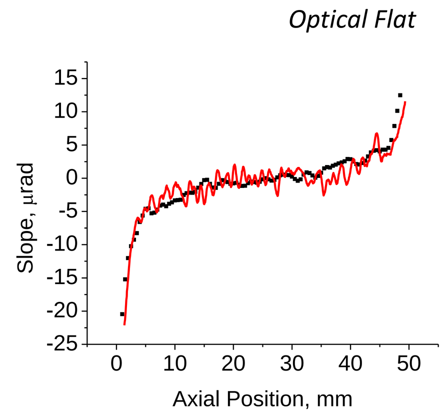


Screenshot of the detector window. Reference beam is on top left.

- Detector -36 mm x 24 mm area, 7.4 x 7.4 μm pixel size, 1.3 fps for partial frame of 4872x800
- Custom designed FT lens – air-spaced doublet lens, 500 mm focal length, 50 mm diameter.
- The system resolution due to the detector-lens pair is estimated to be ~ 0.23 microrad.Berkeley National Labs has provided software code, we have adapted it for new detector and to track ten beams

❖Test have been performed with manual translation stage and thermal enclosure
❖Translation by 1 mm
❖The slope profiles from the individual beams are stitched



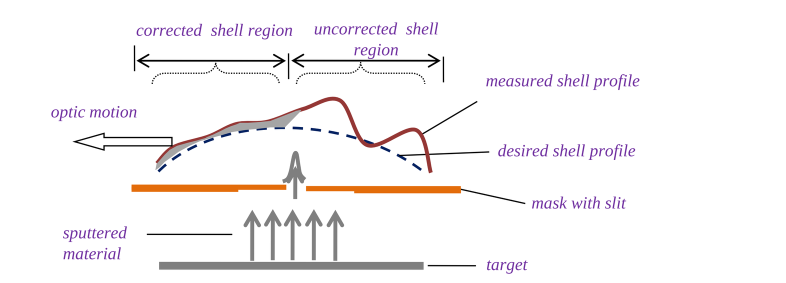


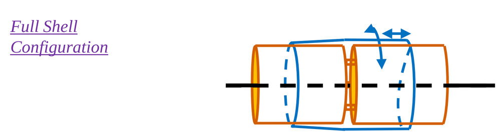
Red – Zygo interferometer, Black - MBLTP

✓ A multi-beam LTP is under development at MSFC in collaboration with Lawrence Berkeley National laboratory and Brookhaven National Laboratory.
✓ The components are fabricated, tested individually and assembled into breadboard.
✓ First tests of the MBLTP has demonstrated the feasibility of the multibeam approach.
✓ This proof of concept study is believed to form a basis of future modular metrology approach where-in an entire length of the test surface can be measured in a single instance using multiple optical beams.

Improving X-ray optics through Differential Deposition

Addressing profile deviations through differential deposition





Proof of concept on few-cm-scale medical imaging optics

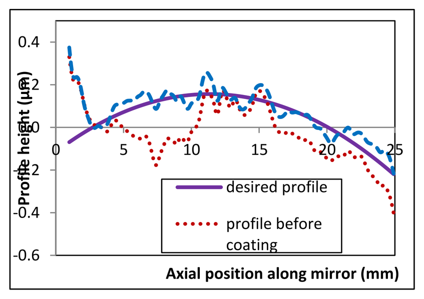
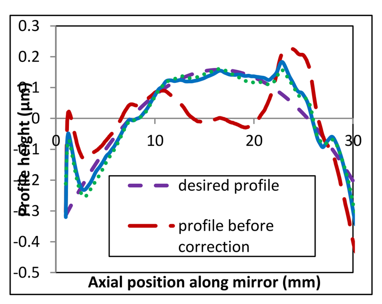
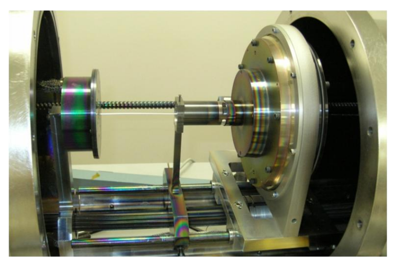
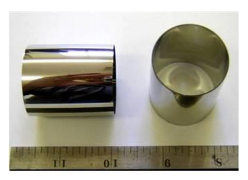


Figure error improvement from 0.11 μm to 0.058 μm rms



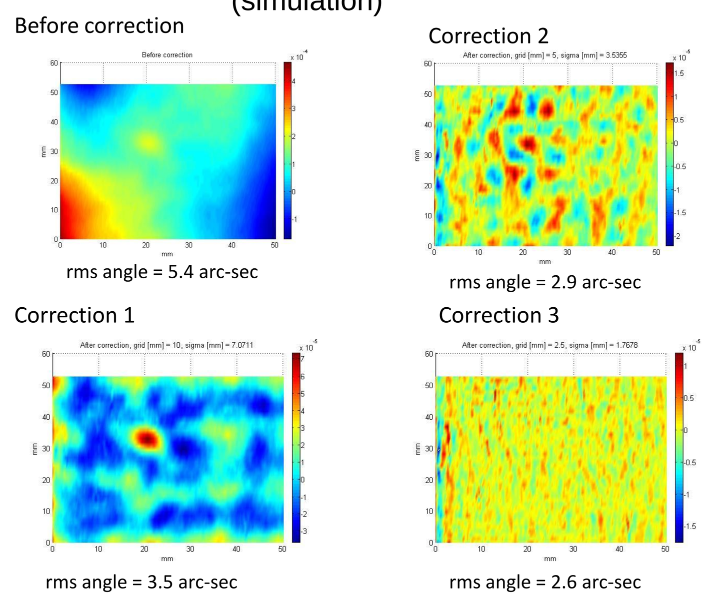
Slope error improvement from 12 arc sec to 7 arc sec rms





Miniature medical optics

Early results for segmented optics (simulation)



Future work will look at addressing:

1. Using finer grids and smaller Gaussian widths.
2. Solving for the entire surface rather than just a small portion.
3. Solving for custom masks to decrease deposition time.