X-RAY OBSERVATORY

LYNX

Lynx Mirror Assembly: Seeing Through the Details

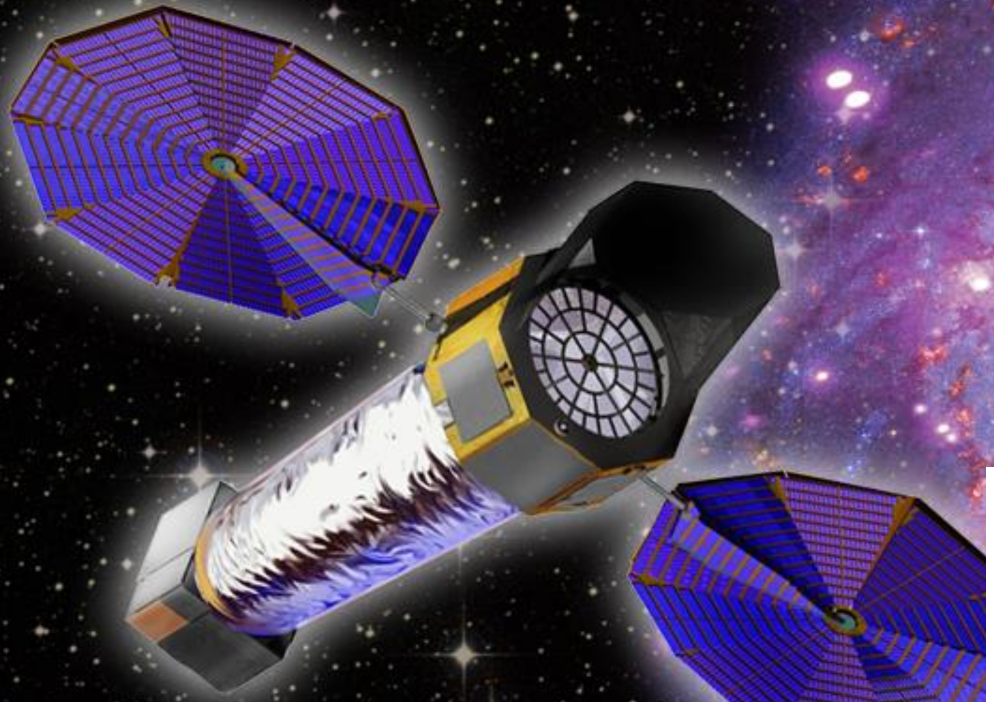
Jessica A. Gaskin (Lynx Study Scientist, NASA MSFC)

NASA MSFC

PCOS/Aerospace

TRL Assessment

May 2017



STDT	Total Gaps	TRL 2 Gaps	TRL 3 Gaps	TRL 4+ Gaps
HabEx	13	0	7	6
LUVOIR	10	1	3	6
Lynx	5	~~1~~	4	1
OST	11	3	4	4

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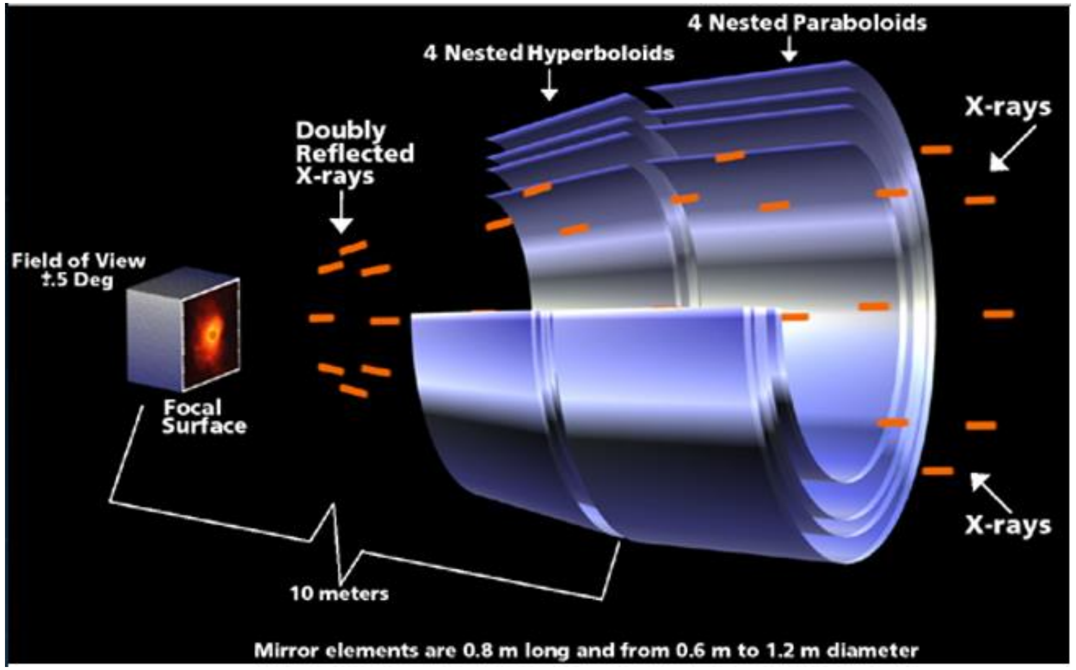
Challenges

- Large effective area is achieved by nesting a few hundred to many thousands of co-aligned, co-axial mirror pairs.
- Must fabricate thinner mirrors to allow for greater nesting of mirror pairs and larger effective area while reducing mass
- These thin mirrors must be better that 0.5” HPD requirement.
- Must mount and coat these thin optics without deforming the thin optic, or must be able to correct deformations.

Science Driven Requirements

Lynx Optical Assembly	
Angular resolution (on-axis)	0.5 arcsec HPD (or better)
Effective area @ 1 keV	2 m^2 (**met with 3-m OD**)
Off-axis PSF (grasp), A*(FOV for HPD < 1 arcsec)	600 m^2 $arcmin^2$

Chandra did it! Why can’t Lynx?

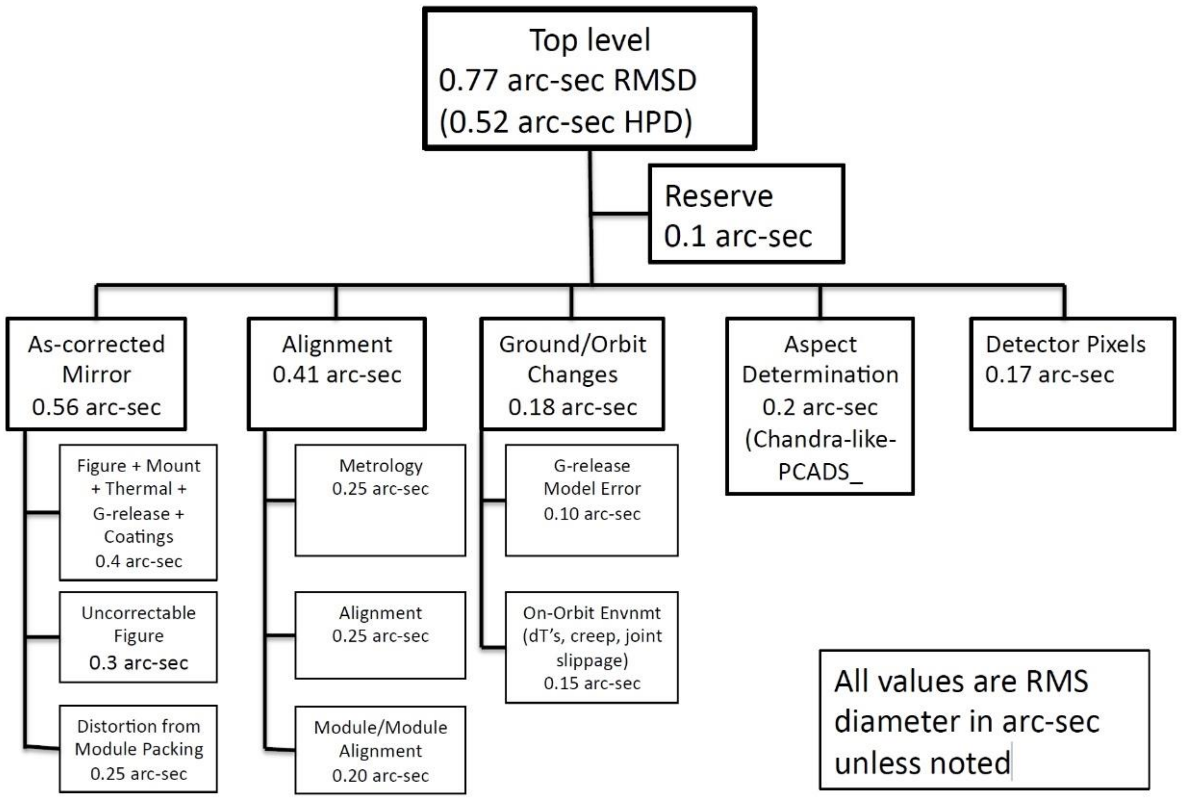


Challenges

- Systems engineering
  - Error budgets
  - Defining local and global structures and allocating requirements to each
- Understanding and mitigating coating stresses
- Structures and mounting
  - Epoxy creep
  - Alternative pinning techniques
  - Different challenges for sub-assemblies and aggregation
- Thermal control of the assembled telescope
- Community mirror metrology (and calibration) assets
  - Gravity distortion (for example) during mirror metrology is much worse than *Chandra*

M. Pivovaroff (SPIE 2016)

Example Working Error Budget

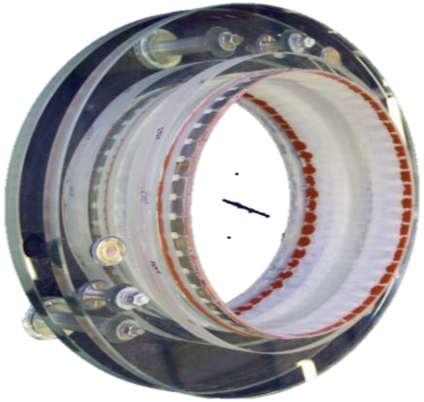


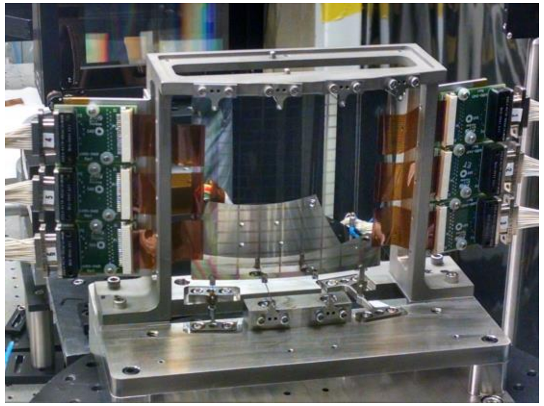
L. Cohen (OWG Talk 2016)

Overcoming Challenges

3 Viable Lynx Mirror Architectures Studied

- Full Shell (K. Kilaru/USRA/MSFC, G. Pareschi/OAB)
- Adjustable Optics (P. Reid/SAO)
- Meta-Shell Si Optics (W. Zhang/GSFC)

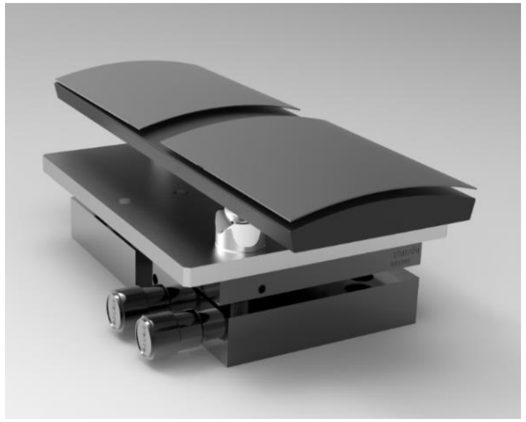




One of these will be selected for the Design Reference Mission Concept. Additional feasible concepts will be included in the Final Report to the Decadal.

Must Develop Technology Maturation Plan:

- Define State-of-the-art
- Maturation (and development) Milestones
- Schedule & Cost



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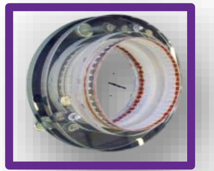
Lynx Mirror Assembly

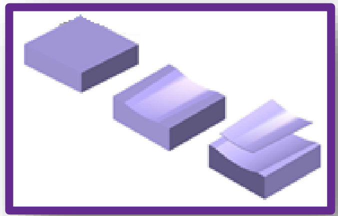
FABRICATION

Thermal Forming (GSFC, SAO)

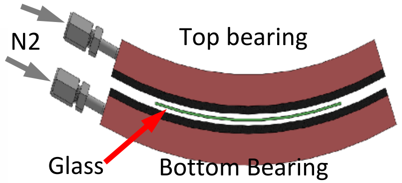
Full Shell (Brera, MSFC, SAO)



Si Optics (GSFC)



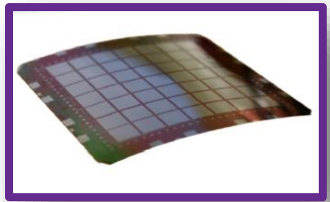
Air Bearing Slumping (MIT)



Testing/Simulation/Modeling

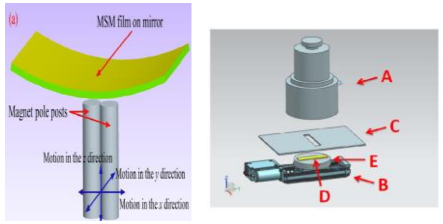
CORRECTION

Piezo stress (SAO/PSU)

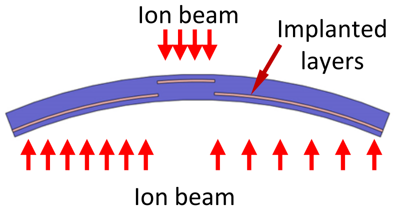


Deposition (MSFC, XRO)

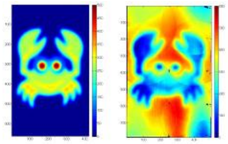
Magnetic & deposition stress (NU)



Ion implant stress (MIT)



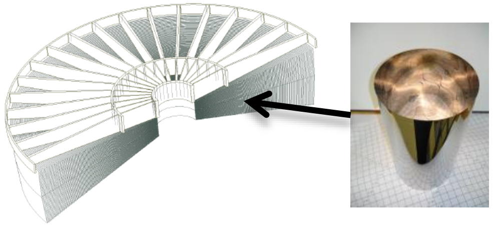
Ion beam figuring (OAB)



Testing/Simulation/Modeling

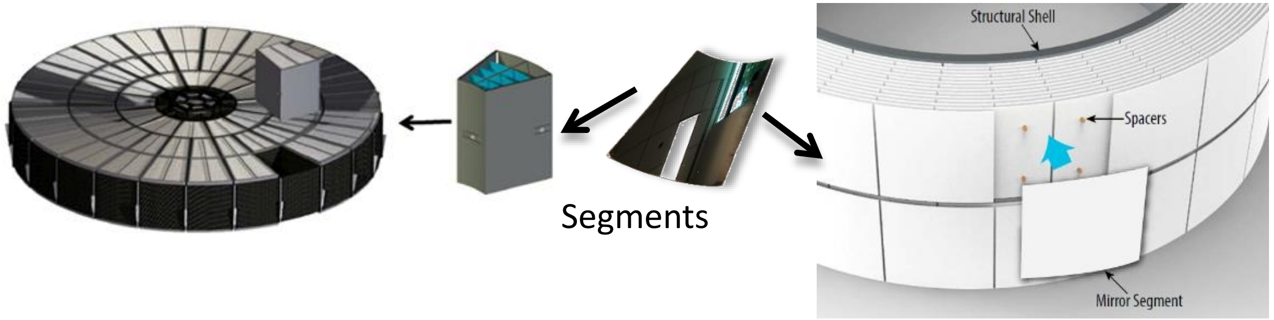
INTEGRATION

Full shells Assembly



Segmented Wedge Assembly

Meta-Shell Assembly



Testing/Simulation/Modeling

Schattenburg talk to NASA PCOS SIG, 04/2016 - Modified

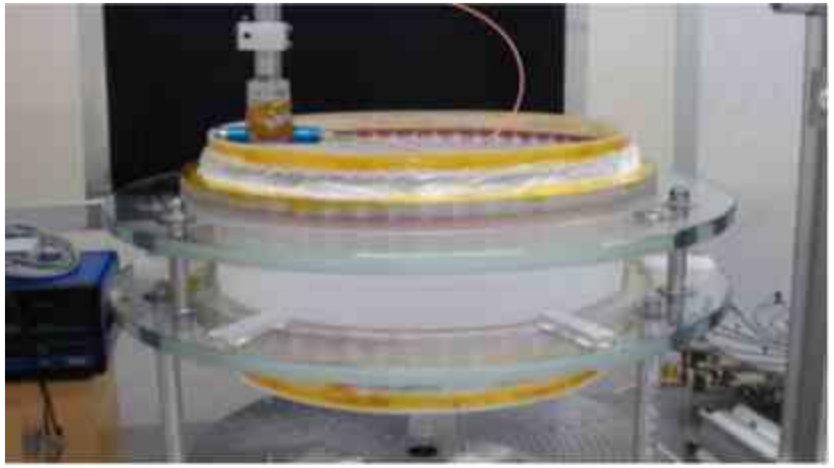
Full Shell Status (G. Pareschi & Team - OAB)

Same approach used for Chandra, but mirrors (shells) need to be thinner

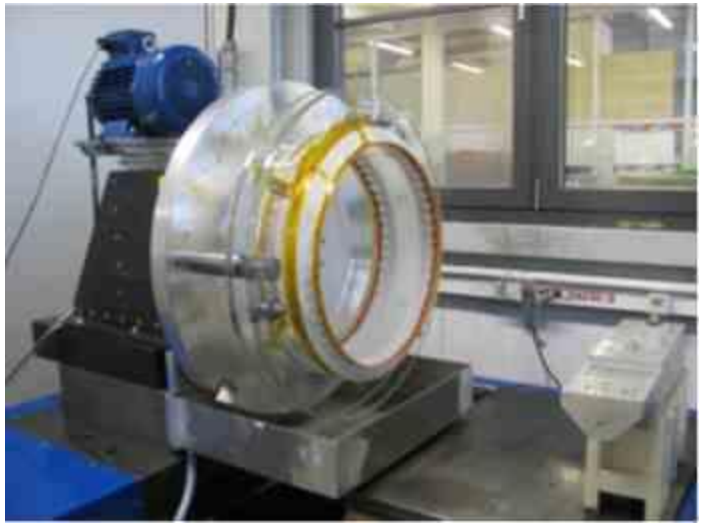
- Limited (<200) number of shells (produced/assembled)
- Azimuthal symmetry of the shells (measure/correct)
- Coating effects are mitigated by the symmetry
- Primary and secondary surface can be joined or detached

Some issues to be investigated

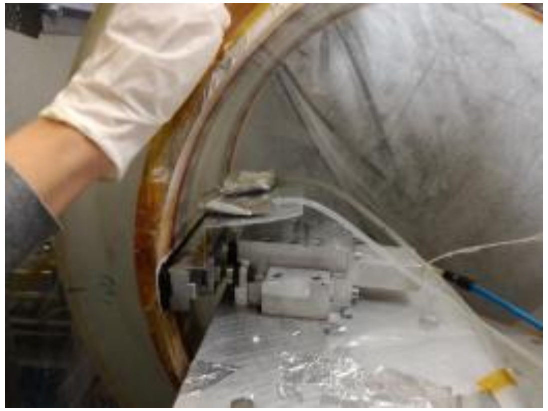
- Large shells need to be thicker: thickness drives the mass of the assembly
- Large shells are not easy to sustain during manufacturing
- The surface correction and coating process may be more difficult

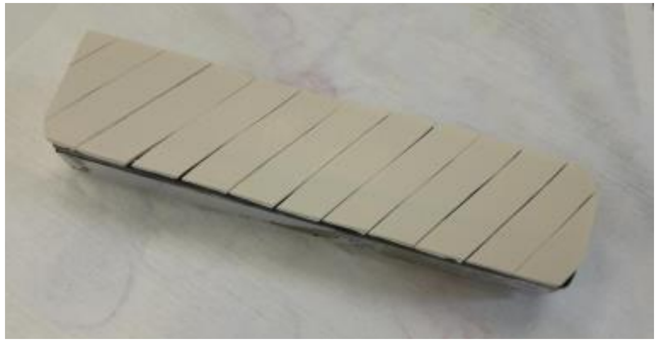


Integration into the Shell Supporting System



Fine grinding to correct the out of roundness and longitudinal profiles





After the grinding, the use of spinning bonnet tool has been successfully implemented on the precision lathe to obtain the profile

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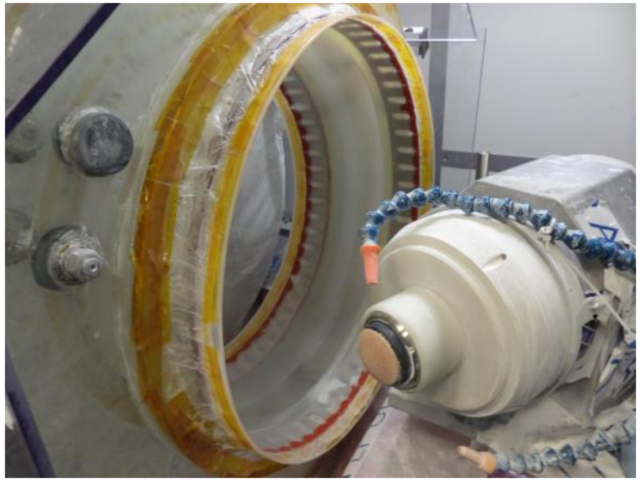
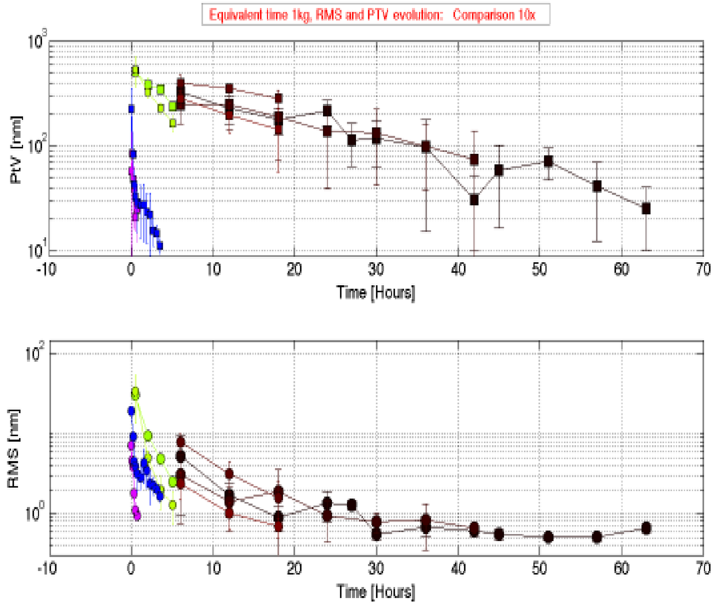
Full Shell Status

The superpolishing made more effective using 3M Trizact abrasive tapes

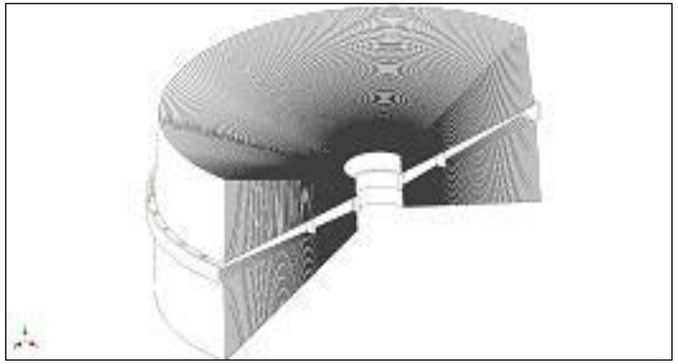


Reduced Superpolishing Time

Superpolishing time much improved: mean PTV and RMS (MFT 10x) In blue are reported the data of the last tests on shells#4 compared to the typical time needed for simple pitch tool (in black).



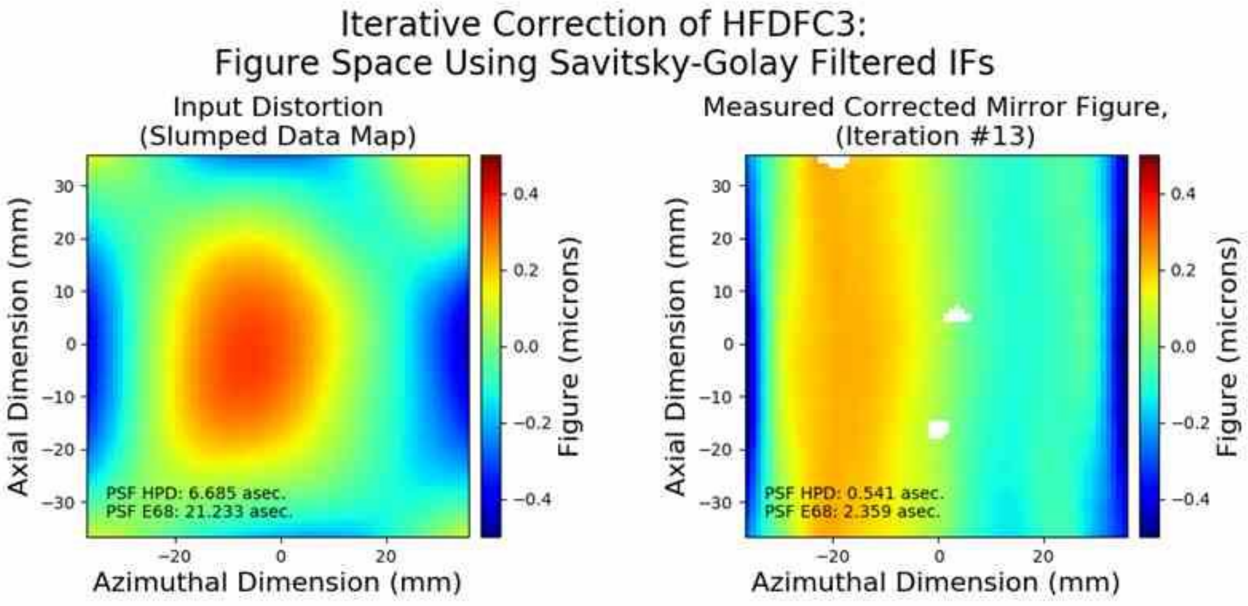
Trade-off study on mounting configuration successfully completed



- Continue to optimize the configuration
- The entire polishing process (including the ion-figuring correction) is being tested on dummy shells
- Waiting for (expected!) funds from ASI for the development of a representative breadboard based on 2 shells to be X-ray tested based on the mounting configuration

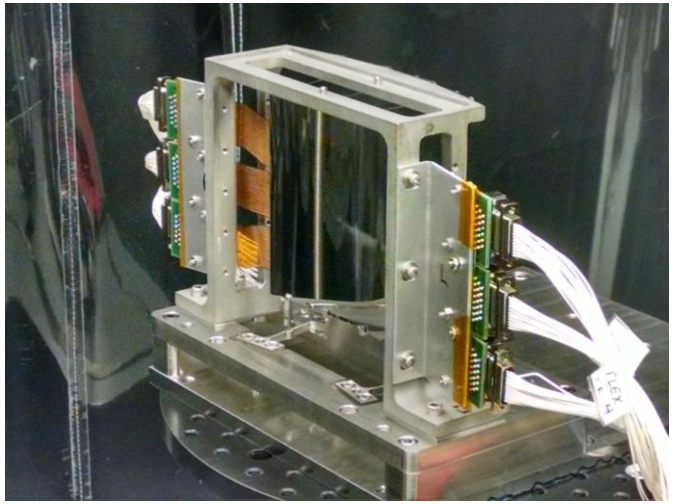
Adjustable Optics Status (P. Reid & Team - SAO)

Correcting slumping errors
Control mirror figure to ~ 0.5 arcsec HPD



•Mounted adjustable mirror 0.4 mm thick, 112 piezo cells

•ACF bonded electrical connections



Relative Correction

Left – slumped mirror figure = figure to be corrected (~ 7 arcsec HPD @ 1keV, 1 surface); **Right** – *measured* (using metrology) difference between imparted figure correction and desired figure correction (~ 0.5 arcsec HPD)

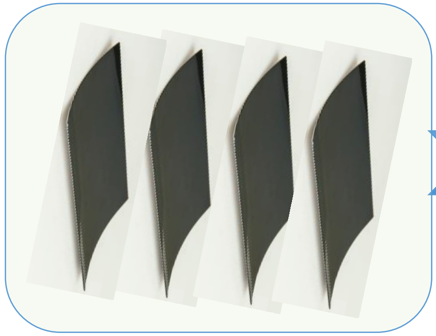
Critical proof-of-concept aspect met for adjustable X-ray mirrors. Still lots to do before 0.5" HPD optics can be realized.

Adjustable Optics Status

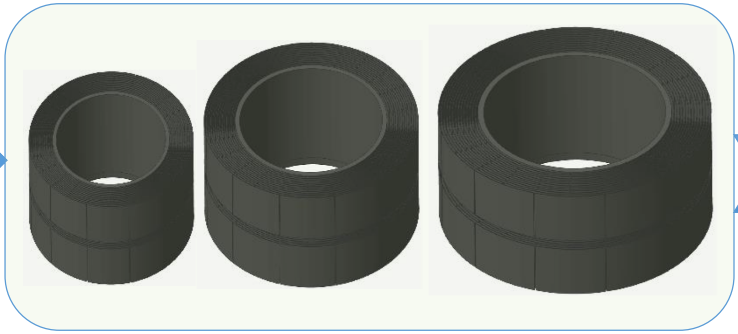
- Slumping to high precision Wolter-I mandrel
- Implement side mirror mount
  - Modeled and designed, parts being ordered
- Incorporation of next level of back surface electronics integration
  - Insulating layer with conductive *vias* and narrower gap between piezo cells
    - 0.2mm vs 1.0mm
    - Mirrors in fabrication now, ~ 288 piezo cells (5mm x 5mm)
- Repeat optical mounted mirror test describe on previous slide with higher fidelity mirror
- Single mirror X-ray test
- Extend single mirror mount to mirror pair
- Incorporate row-column addressing via ZnO thin film transistors printed directly on mirror
- Mount, correct, align, and test mirror pair at MSFC SLF with target 1 arcsec HPD 1 keV performance.

Silicon Meta-Shell Status (W. Zhang & Team - GSFC)

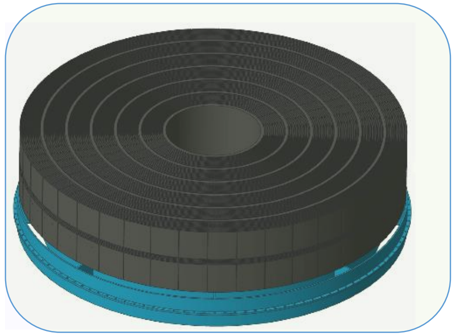
Three-Level Hierarchy



1. 40,000 Mirrors



2. 12 Meta-shells



3. 1 Assembly

Four Technical Elements

1. Precision-polishing of Mono-crystalline silicon.

2. Coating to maximize reflectivity w/o distortion.

3. Alignment using four precision-machined spacers.

4. Permanent bonding w/o frozen-in distortion.

Two Foundational Principles

1. Mono-crystalline silicon can be processed deterministically because it has no internal stress.

2. An X-ray (curved) mirror's location and orientation are kinematically determined by four points.

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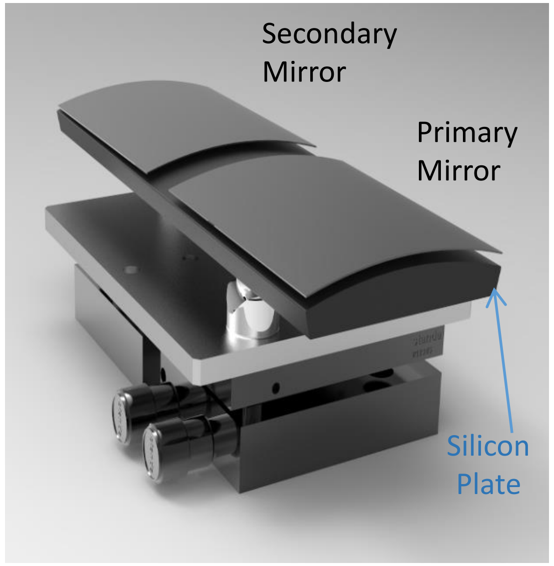
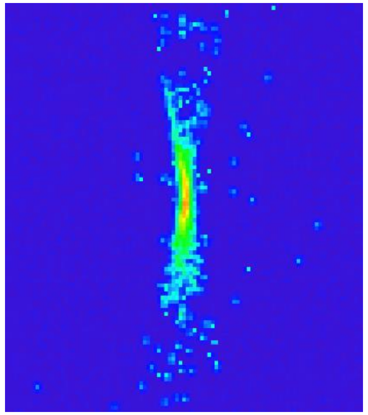
Silicon Meta-Shell Optics Status

- **The meta-shell optics have been shown by STOP (structural, thermal, and optical performance) analysis to meet**
  - Mass, effective area, FOV, and stray-light requirements,
  - Structural requirements to survive launch, and
  - Thermal and gravity release requirements to preserve PSF on-orbit.
- **The four technical elements have been validated by building and X-ray-testing mirror modules,**

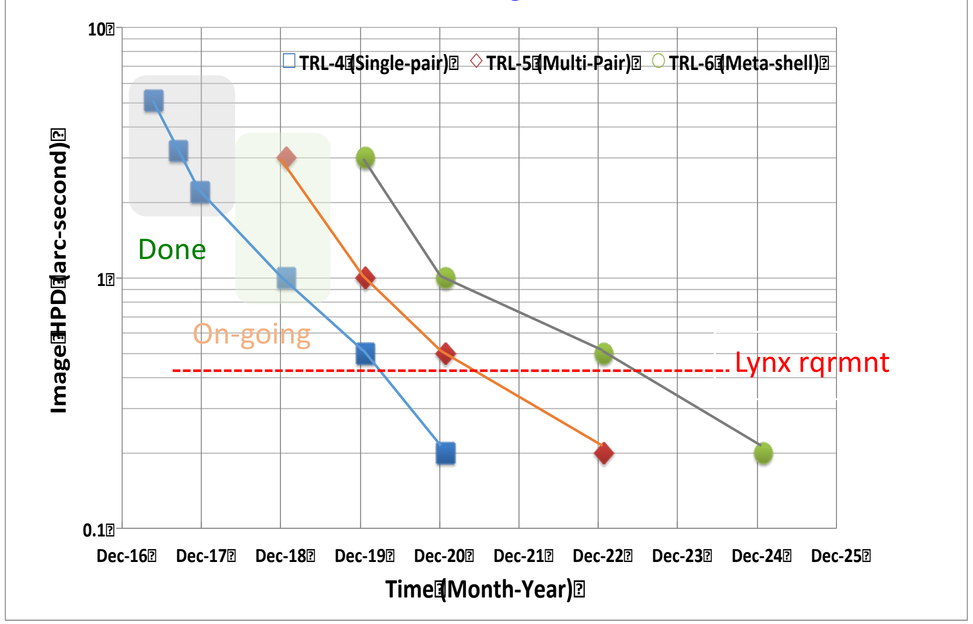
  achieving 2.2” HPD as of Dec 2017.
- **Further refinement for all four elements is needed to meet PSF requirements.**





2.2” HPD image,
Full illumination with
Ti-K X-rays (4.5 keV)

Status and Expectations



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Lynx Mirror Architecture Trade

- Charter from STDT chairs calls for a recommendation for "one Primary Mirror Optical Assembly architecture to focus the design for the final report and identify any feasible alternates."
- The Lynx Mirror Architecture Trade (LMAT) Working Group represents scientific and technical leadership across academia, NASA, and industry
- Full signed charter: [Lynx Optics Trade Study]

Lynx Mirror Assembly Trade – Charter
2/2/2018

A. Background

Lynx is one of four large mission concepts studies funded by the NASA Astrophysics Division for development by a Science and Technology Definition Team (STDT).[1] Recently, the Lynx Red Team recommended that a down-select plan be created for the mirror and gratings technologies in time to make choices for the final report. The Lynx Science and Technology Definition Team (STDT) recognizes that a credible and feasible path to maturing the Lynx mirror assembly is crucial to a compelling and executable Lynx mission concept. Therefore, following deliberations within the Lynx Optics Working Group (OWG) and Study Office and corroborated by the Lynx Red Team recommendations, the STDT commissions a trade study to recommend a reference mirror design that demonstrates a technological path to realizing the science envisioned by the STDT. This document charters the plan for the trade study deliverables, trade process and membership. The goal for completion of the trade study is July 13 2018 in support of Milestone M6 (draft final report) as required in the Management Plan for the Decadal Large Mission Studies[2].

B. Deliverables

The Lynx Mirror Assembly Trade (LMAT) Working Group is chartered by the Lynx STDT to deliver to the Lynx STDT Chairs by the goal of July 13 2018 a recommendation for one Primary Optical Assembly architecture to focus the design for the final report and identify any feasible alternates. The LMAT Working Group participation is defined in Section C.

The recommended option, upon review by STDT and acceptance by the STDT Chairs, will serve as the reference design for the Lynx mission concept for Milestone M6. All other feasible architectures identified in the trade process will be included in the Lynx Technical Roadmap.

* * *

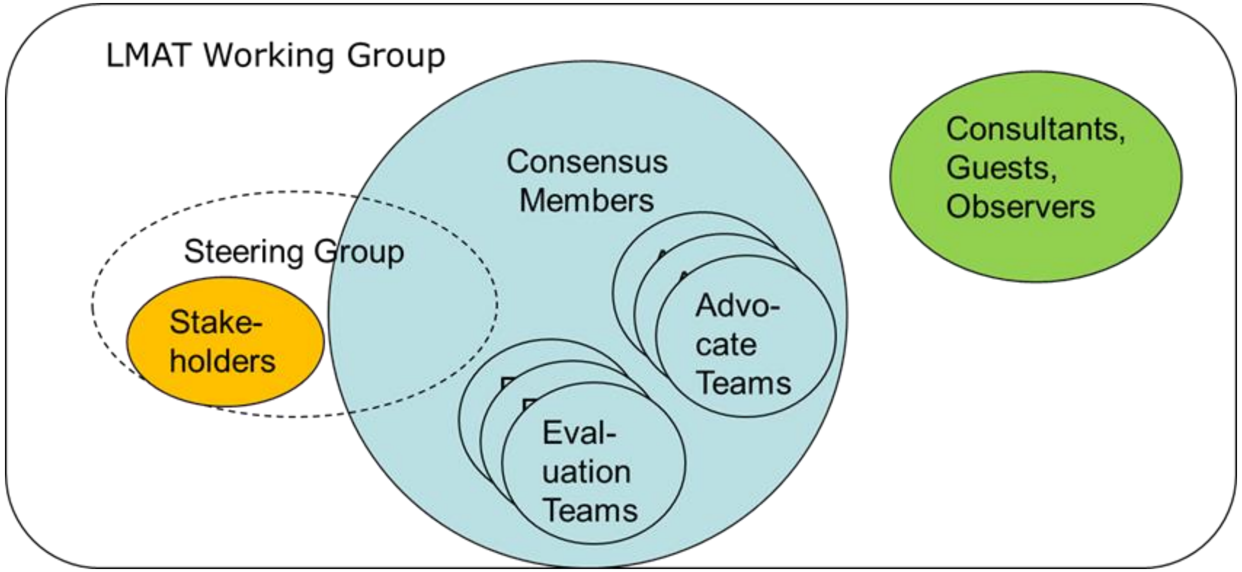
Feryal Ozel
STDT Chair, Lynx
Professor of Astronomy
University of Arizona

Digitally signed by Alexey Vikhlinin
Date: 2018.02.05 15:42:32 -05'00'

Alexey Vikhlinin
STDT Chair, Lynx
Deputy Associate Director, High Energy Astrophysics Division
Harvard-Smithsonian Center for Astrophysics

Lynx Mirror Assembly Trade Study

- Using JPL-facilitated Kepner-Tregoe process (***JPL contributed effort)***
- Each optics technology will be evaluated against the decision criteria by programmatic, technical and science teams
- Trade criteria is chosen by the full LMAT team and requires consensus from the 'Consensus Members'



LMAT Process:

- Kickoff Telecon with Steering Group
- Kickoff Telecon with the LMAT Working Group
- Establish consensus criteria for a successful trade outcome
- Description of options for evaluation
- Evaluation of Science, Technical, and Programmatic criteria
- Reach consensus by LMAT Consensus Members on evaluation criteria, risks, and opportunities
- Reach consensus via Consensus Member recommendation
- LMAT delivery recommendation to the STDT by 7/13/18

Lynx Mirror Assembly Trade Team

Facilitator

Gary Blackwood	NASA ExEP/ JPL	

Consensus Members

Members at Large

Mark Schattenburg	MIT	

Advocates

Kiran Kilaru		USRA / MSFC	Full Shell
Giovanni Pareschi	INAF / OAB		Full Shell
William Zhang		NASA GSFC	Silicon Meta-shell
Peter Solly		NASA GSFC	Silicon Meta-shell
Paul Reid		Harvard SAO	Adjustable Segmented
Eric Schwartz		Harvard SAO	Adjustable Segmented

Science Evaluation Team (SET)

Daniel Stern	NASA JPL
Frits Paerels	Columbia University
Ryan Hickox	Dartmouth

Technical Evaluation Team (TET)

Gabe Karpati		NASA GSFC	TET Lead
Ryan McClelland		NASA GSFC	structural/thermal
Lester Cohen		Harvard SAO	structural
Gary Mathews	retired	Kodak	systems engineering
Mark Freeman		Harvard SAO	thermal / SE
David Broadway		NASA MSFC	coatings
Dave Windt		Company	coatings
Marta Civitani		OAB	optical design, test
Paul Glenn		Company	metrology
Ted Mooney		Harris	polishing
Chip Barnes		Ball	systems engineering

Programmatic Evaluation Team (PET)

Jaya Bajpayee	NASA ARC	PET Lead
John Nousek	Penn State	
Karen Gelmis	NASA MSFC	
Steve Jordan	Ball	
Charlie Atkinson	NGAS	

Subject Matter Experts, Observers and Guests (not inclusive):

Denise Podolski	NASA STMD
Rita Sambruna/Dan Evans	NASA HQ
Terri Brandt/Bernard Kelly	NASA PCOS
Vadim Burwitz	MPE
Susan Trolier-McKinstry	Penn State
Casey DeRoo	U. Iowa
Kurt Ponsor	Mindrum
TBD	Optics Working Group
TBD	Optics Working Group

Steering Group

Feryal Ozel	University of Arizona	
Alexey Vikhlinin	Harvard SAO	
Jessica Gaskin	NASA MSFC	
Robert Petre	NASA GSFC	
Doug Swartz	NASA MSFC	
Jon Arenberg (Bill Purcell/Lynn Allen)	NGAS (Ball/Harris)	
Jaya Bajpayee	NASA ARC	consensus member
Gabe Karpati	NASA GSFC	consensus member
Mark Schattenburg	MIT	consensus member

LMAT F2F – Reach Consensus on Trade Criteria


Tracking the Elusive Lynx

Rare and maddeningly elusive, the "ghost cat" tries to give scientists the slip high in the mountains of Montana

Seldom-seen rulers of their wintry domain, lynx may face new threats. (Ted Wood)

By Abigail Tucker

SMITHSONIAN MAGAZINE | SUBSCRIBE

Face-to-Face Trade Criteria Meeting

- Date: March 21 (1pm-5pm – or later as needed) – 22 (8am-2pm)
- Location: Hilton Chicago O'Hare Airport, 10000 W O'Hare Ave, Chicago, IL 60666
- Dublin/London Room

AGENDA

- Day 1: Develop consensus on trade criteria
- Day 2:
  - Reach consensus on trade criteria;
  - Introduction of mirror architecture option that will be evaluated in the trade
  - Slides should address:
    - Description of flight architecture
    - Current state of the technology (recent manufacturing, test and/or analysis results)
    - Plans between now and early 2020 (prior to Decadal)
    - Anything else the advocate considers important for LMAT to know

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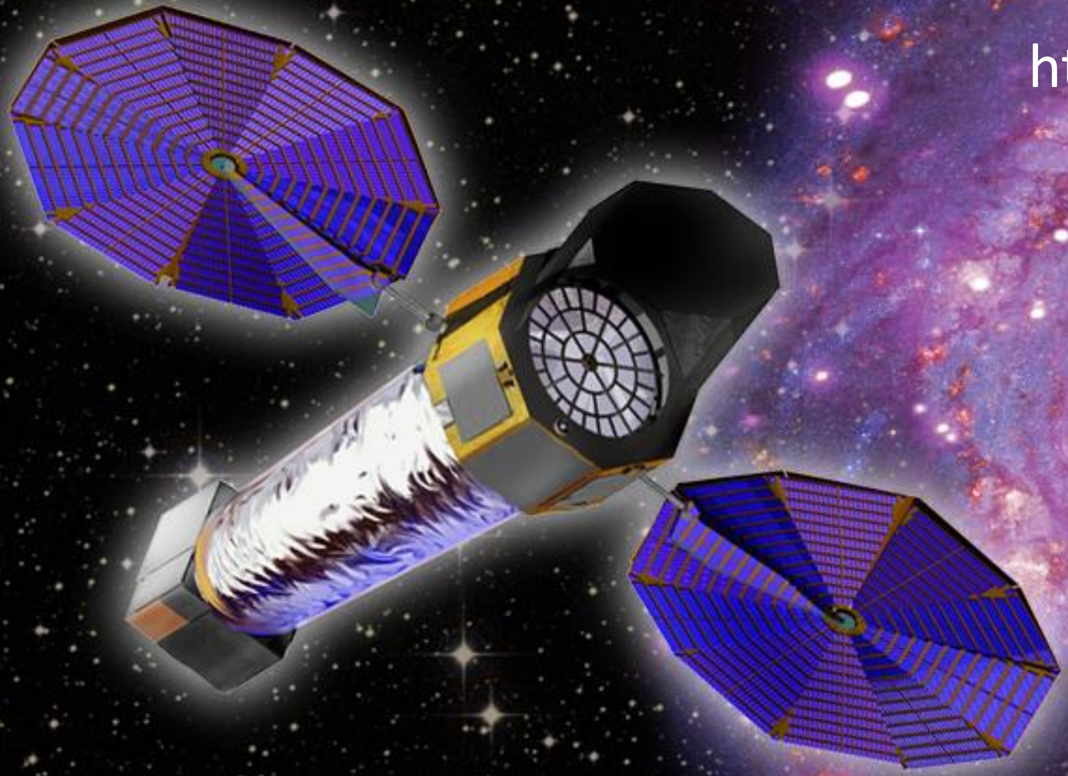
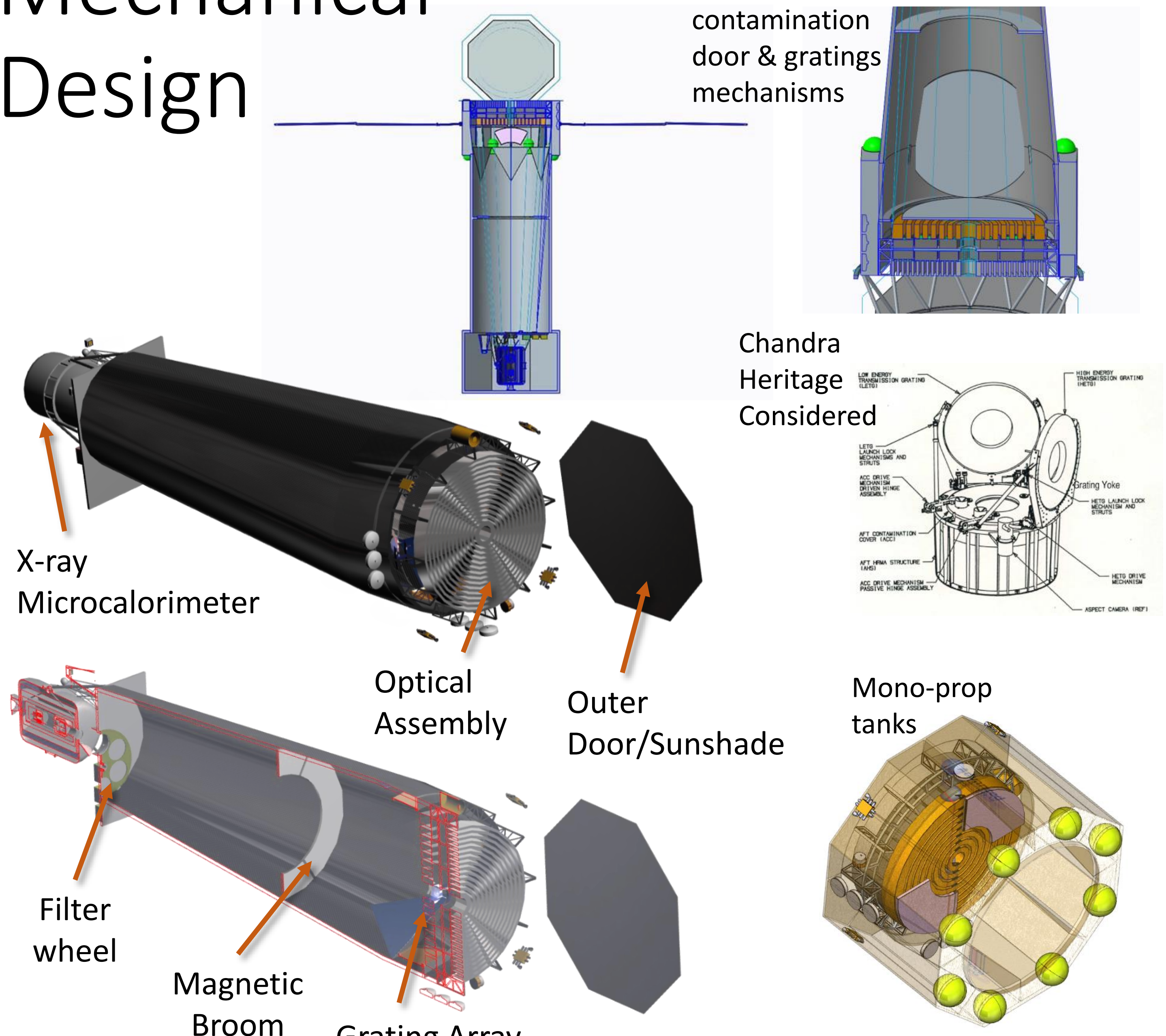
Thank You!

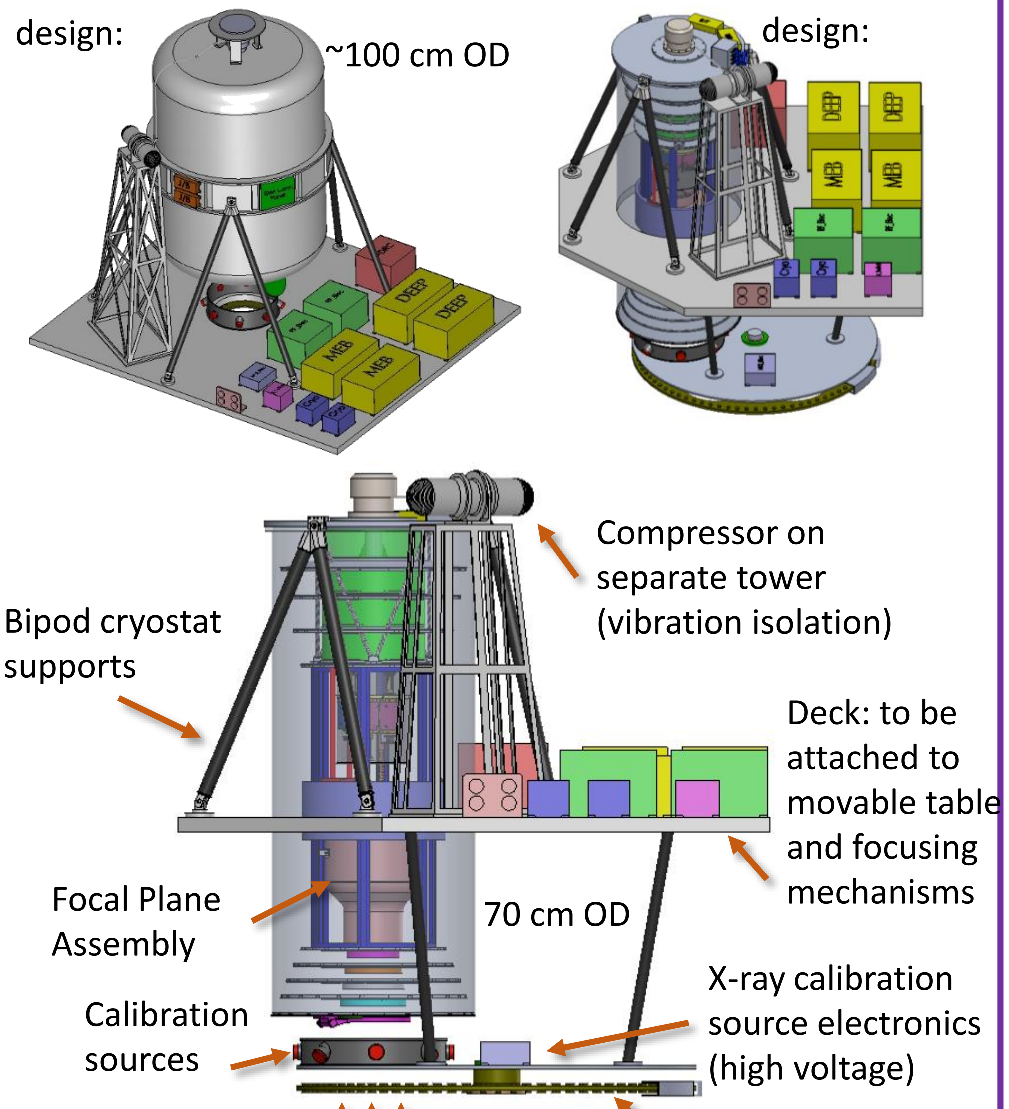
https://wwwastro.msfc.nasa.gov/lynx/



Mechanical Design



Integrated Science Instrument Module



S. Bandler, NASA GSFC