The Lynx Optics Working Group: objectives and current status

Mark Schattenburg
MIT Kavli Institute for Astrophysics

Lester Cohen
Harvard-Smithsonian Center for Astrophysics

SPIE Conference on Optics for EUV,
X-Ray, and Gamma-Ray Astronomy VIII

San Diego, Aug. 8, 2017

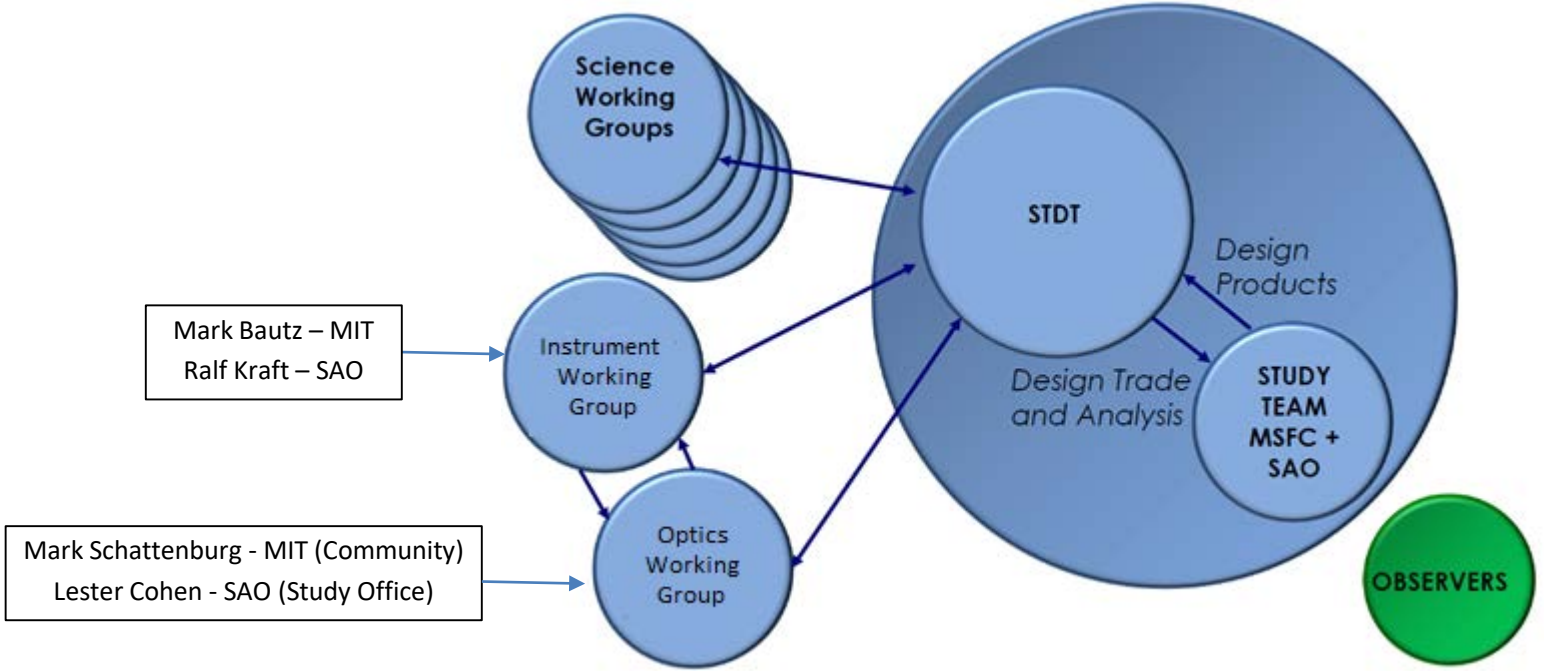
SPACE NANOTECHNOLOGY LABORATORY

NASA

Massachusetts Institute of Technology

What is the Optics Working Group?

An informal group of folks interested in helping
to define and develop x-ray telescope optics for Lynx



OWG Membership

40+ members representing a broad cross section of the community

Ryan Allured	Smithsonian Astrophysical Observatory	Diab Jerius	SAO/ Chandra X-Ray Center
Carolyn Atkins	STFC UK Astronomy Technology Centre	Kiranmayee Kilaru	USRA/NASA Marshall Space Flight Center
Stefano Basso	INAF - Osservatorio Astronomico di Brera	Ralph Kraft	Smithsonian Astrophysical Observatory
Wayne Baumgartner	NASA Marshall Space Flight Center	Herman Marshall	MIT Kavli Institute
Jay Bookbinder	NASA/ARC	Ryan McClelland	NASA GSFC / SGT Inc.
David Broadway	NASA MSFC	Takashi Okajima	NASA's Goddard Space Flight Center
Brandon Chalifoux	MIT	Howard Padmore	LBNL
Kai-Wing Chan	NASA/GSFC & UMBC	Giovanni Pareschi	INAF - Brera Astronomical Observatory
Daniele Cocco	SLAC national accelerator laboratory	Lisa Poyneer	Lawrence Livermore National Laboratory
Lester Cohen	Harvard-Smithsonian Center for Astrophysics	Paul B. Reid	Harvard-Smithsonian Center for Astrophysics
Vincenzo Cotroneo	Harvard-Smithsonian Center for Astrophysics	Timo Saha	NASA/GSFC
Casey DeRoo	Harvard-Smithsonian Center for Astrophysics	Bianca Salmaso	INAF - Osservatorio Astronomico Brera
Manel Errando	Department of Physics - Washington U.	Mark Schattenburg	MIT Kavli Institute
Daniel Evans	NASA Headquarters	Eric Schwartz	Smithsonian Astrophysical Observatory
Abe Falcone	Pennsylvania State University	Dan Schwartz	Smithsonian Astrophysical Observatory
Charly Feldman	University of Leicester	Peter Solly	NASA GSFC Code 662 [SGT]
Mark Freeman	Smithsonial Astrophysical Observatory	Douglas Swartz	NASA/MSFC/USRA
Jessica Gaskin	NASA MSFC	Harvey Tananbaum	SAO
Terry Gaetz	CXC/SAO	Susan Trolier-McKinstry	Pennsylvania State University
Karen E. Gelmis	NASA MSFC	James Tutt	The Pennsylvania State University
Danielle Gurgew	The University of Alabama in Huntsville	Mel Ulmer	Northwestern University
Ralf Heilmann	MIT	Alexey Vikhlinin	Smithsonian Astrophysical Observatory
Mourad Idir	BNL/NSLSII	David L Windt	Reflective X-ray Optics LLC
Anders Clemen Jakobsen	DTU Space	William W. Zhang	NASA Goddard Space Flight Center

OWG Major Milestones

- NASA approves OWG charter, Aug 2016
- Kickoff telecon, Nov 2016
- Lynx Industry day, MSFC, May 22-23, 2017
- Technology roadmap effort kickoff, Aug. 8, 2017 (**today!**)
- Telescope reference design “Up Selection” final review, April/May 2018

Interest Groups and Leads

- Optics made from full-shell substrates — Lester Cohen, SAO
  - Manufacture, including mounting
- Optics made from segments — Dan Schwartz, SAO; Will Zhang, GSFC
  - Manufacture, including mounting
- Post-manufacture figure correction — Brandon Chalifoux, MIT; Mel Ulmer, NorthWest
  - Set-and-forget, either before or after launch
  - Active control during mission
- Mirror metrology — Ryan Allured, MIT Lincoln Lab **(we need a co-chair!)**
  - During fabrication, installation, alignment and flight
- Systems — Ryan McClelland, GSFC; Paul Reid, SAO
  - Error budget
  - Thermal, power and mass considerations
  - Stress and creep
- Mirror coatings — David Broadway, MSFC; David Windt, XRO, Inc.
  - Multilayer coatings to enhance performance
  - Stress control

Lynx Optics Design Teams

- The OWG and the Study Office have selected three promising telescope optics technical approaches for consideration:
  - Full shell mirrors
  - Segmented mirrors – static shape
  - Segmented mirrors – adjustable shape
- All three approaches will be carried by the Lynx STDT into the Decadal Review with down selection proposed during Mission Phase A
- Three optics design teams (ODT) have been identified whose role is to develop and champion particular technical approaches
  - Full Shell (Leads: Kiran Kilaru, MSFC; Giovanni Pareschi, Brera)
  - Segmented Static (Lead: Will Zhang, GSFC)
  - Segmented Adjustable (Lead: Paul Reid, Harvard-SAO)
- In mid-2018 the OWG will “up select” a single mirror reference design for in-depth study and costing to target final submittal to the Decadal Review

Role of the OWG

- Assist writing study plans for the Study Office and Optics Development Teams (ODT), review work products
- Assist in Study Office studies (on volunteer basis)
- Participate and review technology roadmap exercise
- Participate and review error budget process
- Review ODT progress and studies
- Recommend a reference design
- Help prepare documentation for Decadal submission

Role of Study Office

- Assist the ODT to perform required studies, if requested (e.g., mechanical/thermal modeling, ray tracing, etc.)
- Solicit OWG for reviews of ODT progress
- Solicit OWG for reviews of Study Office plans and work products
- Develop (with OWG) criteria and methodology for mirror “up selection” process
- Accept and review OWG recommendation for up selection and present to the STDT
- Assist up-selected ODT to prepare detailed studies for the Decadal submission

Formal Lynx Optics Requirements

- HPD < 0.5” on-axis at E = 1 keV
- Mirror effective area A > 2 m^2 on-axis at E = 1 keV
- Off-axis PSF requirement at E = 1 keV expressed in terms of grasp:

  A * (FOV for HPD <1”) ≥ 2 m^2 * 300 $arcmin^2$

  (e.g., 20’ diameter field = 314 $arcmin^2$)
- Outermost mirror shell diameter < 3 m

Note:

- No firm requirements yet for E = 6 keV
- No requirement yet for innermost mirror diameter
- No specific coating requirement

Design Teams Must Provide (1)

- Convincing evidence that 0.5” mirrors/assemblies are doable and can be scaled from lab to industry during Phase B > Phase C-D.
- An error budget, which at the top-most level provides 0.4” (TBD) Half Power Diameter as its goal. (Mirror level, not mission level!)
- We expect that each Optics Design Team (ODT) will have similar error budget forms and allocations for each term but they will differ due to the specific technology used. Each team should include any/all error budget terms or current allocations that are 0.05” or above.
- A roadmap for all areas of study that will move an X-ray mirror assembly (similar to the Chandra High Resolution Mirror assembly (HRMA)) to the required level of performance.

Design Teams Must Provide (2)

- Mirror manufacture plan (from soup to nuts !)
- Metrology for all phases (manufacturing, assembly, alignment, etc)
- Coatings (reflectivity, micro-roughness, stress, stability, adhesion, etc)
- Mounting
- Stress (all environmental phases, residual stress, bonding, figure correction techniques, etc.)
- Alignment & assembly
- Correctability
- Telescope resolution, mass and power budgets
- Technology roadmap including TRL target dates
- Calibration plan

Lynx Technology Roadmap Effort

Lynx Telescope Technology Roadmap

* Strawman information based on <Pause and Learn TRL Presentation June 2017.pptx>

Lynx Mission Phases					Pre-Phase A				Phase A			Phase B		Phase C				Phase D			
					Oct-21			Oct-24			Mar-27		Mar-29				Sep-33			Mar-36	
Lynx Mission Milestones										SRR			PDR		CDR				PER		Launch
Lynx Telescope Systems	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
1.0 **X-ray Optics Assembly**																				
* High resolution lightweight x-ray optics	Gate 0																			
* Non-deforming reflecting coatings	Gate 0																			
1.1 Segmented Passive	Gate 0																			
1.2 Segmented Adjustable	Gate 0																			
1.3 Full Shell	Gate 0																			

Please come to the Lynx Roadmap kickoff meeting!
Location: Marriott Marquis Hotel, Marina D (8-10 pm tonight)

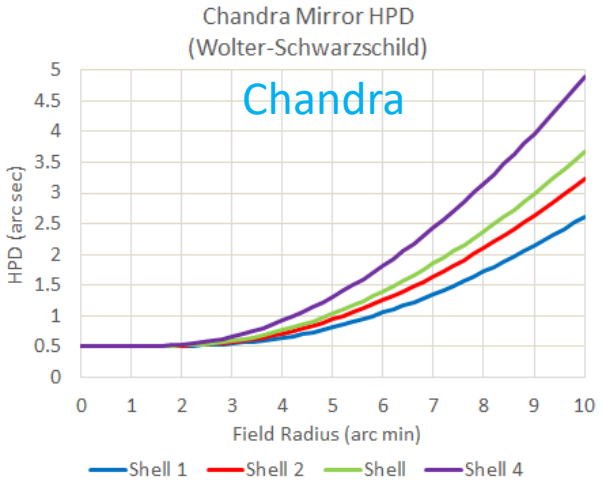
Next Critical Deliverable for the ODT

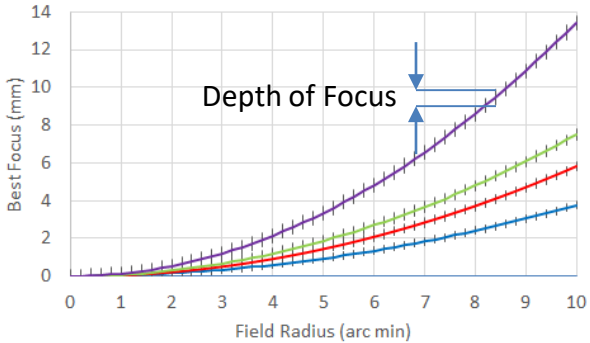
Proof of Principle Ray Trace Study

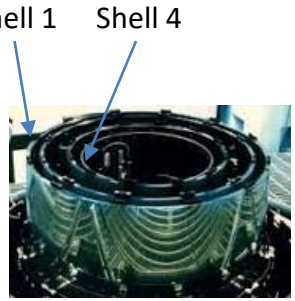
Optics Design Teams should provide a ray trace study including:

1. On-axis effective area as a function of energy, extending to at least 12 keV
2. PSF HPD @ 1 keV as a function of off-axis angle
3. PSF HPD @ 6 keV as a function of off-axis angle
4. Please provide 2 and 3 for both flat an optimal focal surfaces, however use the same optimal focal surface for 2 and 3
5. Vignetting/shading/attenuation as a function of off-axis angle for E = 1 keV and E = 6 keV
6. All off-axis calculations should be extended to at least 10 arcmin radius, and preferably 15

Field of View – Chandra vs. Lynx





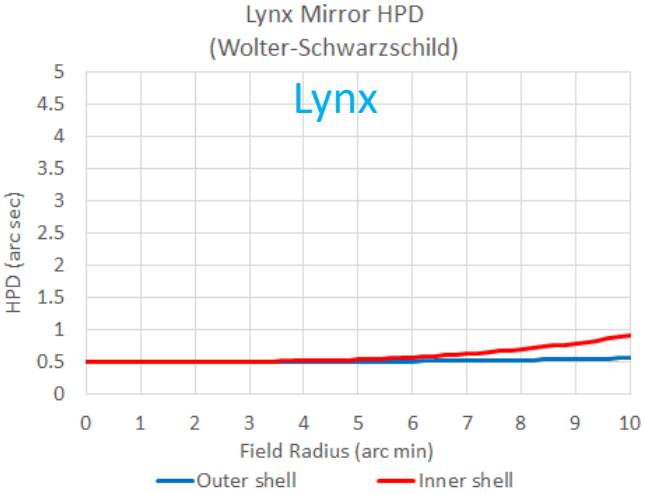


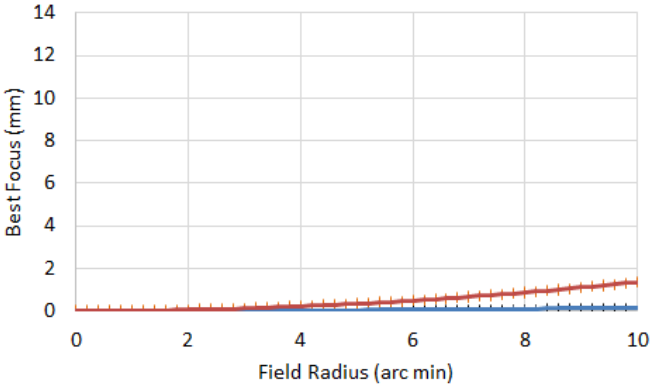
Chandra mirrors

$$\sigma_g = 0.27 \frac{\tan^2\theta}{\tan\alpha} \frac{L}{Z}$$

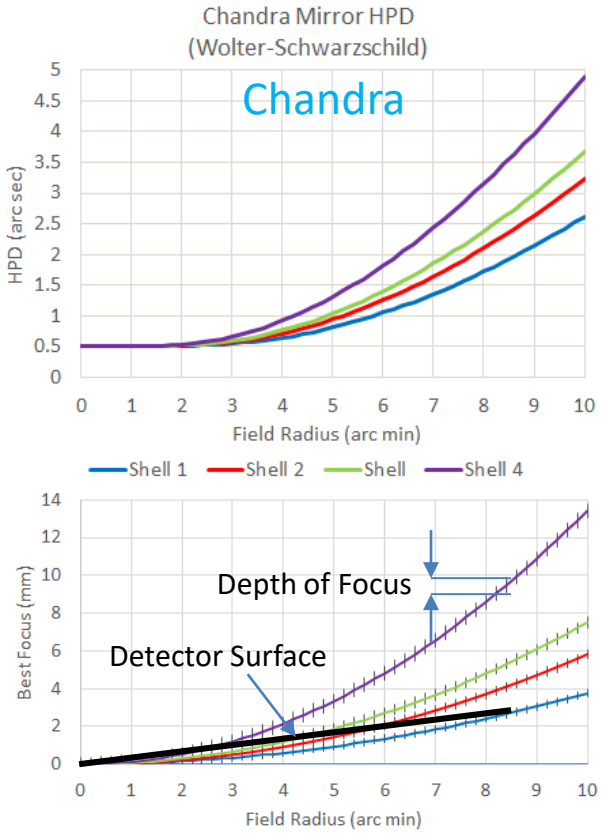
L = mirror length
α = graze angle

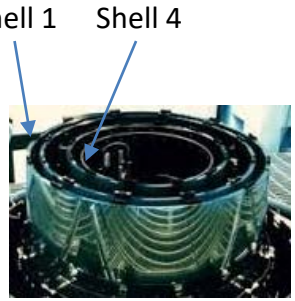
Lynx has tremendously improved FOV compared to Chandra!





Field of View – Chandra vs. Lynx



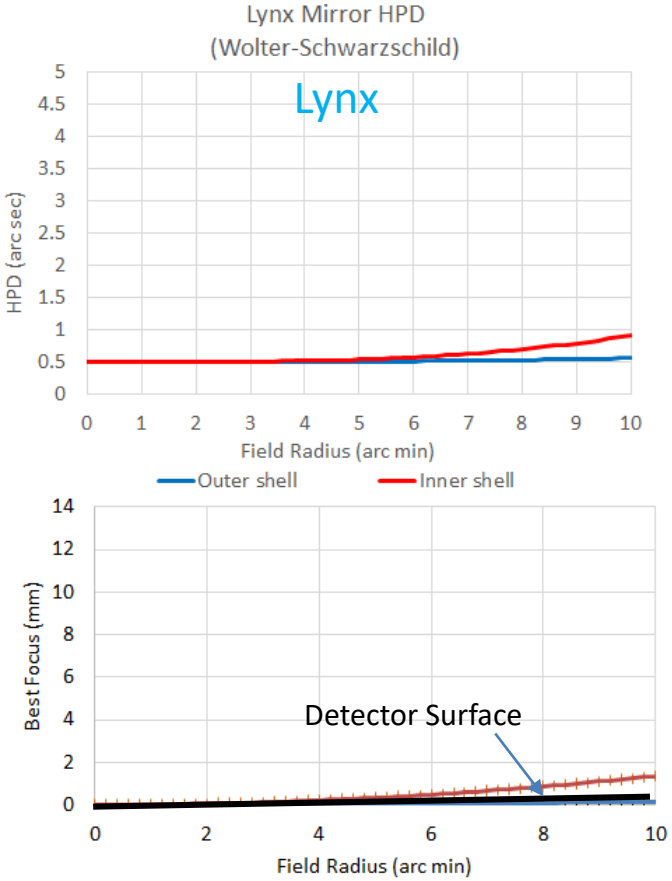


Chandra mirrors

$$\sigma_g = 0.27 \frac{\tan^2\theta}{\tan\alpha} \frac{L}{Z}$$

L = mirror length
α = graze angle

Lynx has tremendously improved FOV compared to Chandra!



Many thanks to OWG members, the Lynx STDT,
Lester Cohen and the Study Office,
and NASA for tremendous support and encouragement!