Lynx: SIMPLY DESIGNED FOR MAXIMUM SCIENCE RETURN

J. Gaskin, NASA MSFC

AIAA Space Forum 09/17/19

THE PEOPLE BEHIND LYNX

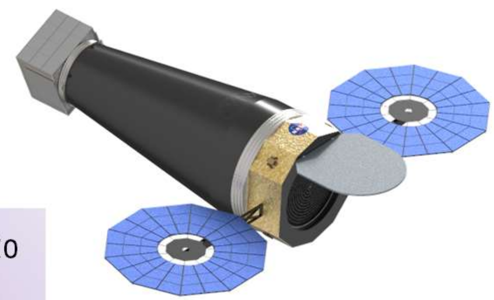
Over 275 total members!

- 22 STDT Members
- 8 Science Working Groups
- Ex-officio International Members
- Instrument Working Group
- Communications Working Group
- Lynx Calibration Working Group
- Optics Working Group

Orgs.	Effort
GSFC	HDXI IDL runs LXM IDL & costing contributed effort MDL (Partial)
JPL (ExEP) + X-ray Optics Community	Optics Trade Study facilitation & Evaluation Contributed effort (>35 Volunteers)
X-Ray Grating Spectrometer Team	XGS Trade Study Team (>10 Volunteers)
CAN Study Partners >50% overall contributed	Creare: LXM cryocooler study Hypres: superconducting ADC study Luxel: blocking filter fab. & test Lockheed Martin: LXM cryo-system Northrop Grumman (w/Ball & Harris): Observatory design & analysis
UAH	MBSE modeling of interfaces, requirements & Observatory error budget
Interim Report Red Team	Chair: C. Kouveliotou (GWU) Contributed effort

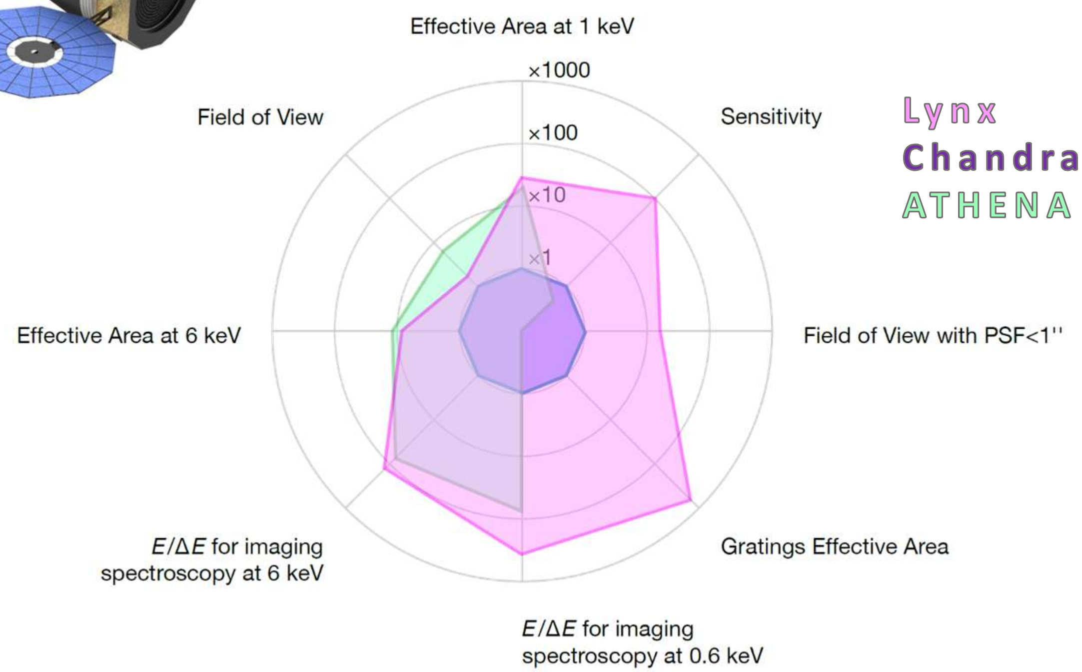
MEET LYNX!

Of the 4 large missions under study for the 2020 Astrophysics Decadal, Lynx is the only observatory that will be capable of directly observing the high-energy events that drive the formation and evolution of our Universe.



Lynx will provide unprecedented X-ray vision into the "Invisible" Universe with leaps in capability over Chandra and ATHENA:

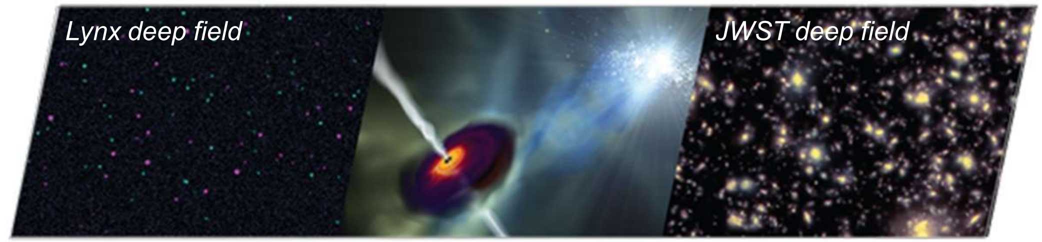
- Large gain in sensitivity over Chandra and over Athena, via high throughput with high angular resolution
- Increased field of view for arcsecond or better imaging
- Significantly higher spectral resolution for point-like and extended sources



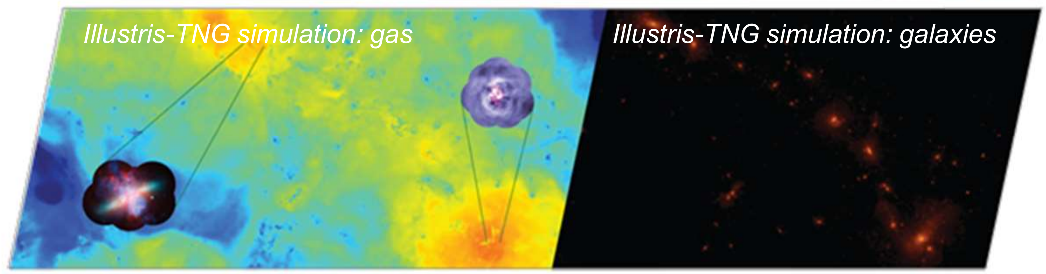
SCIENCE OF LYNX

Through a GO Program, Lynx will contribute to nearly every area of astrophysics and provide synergistic observations with future-generation ground-based and space-based observatories, including gravitational wave detectors.

The Dawn of Black Holes



The Invisible Drivers of Galaxy *and* Structure Formation

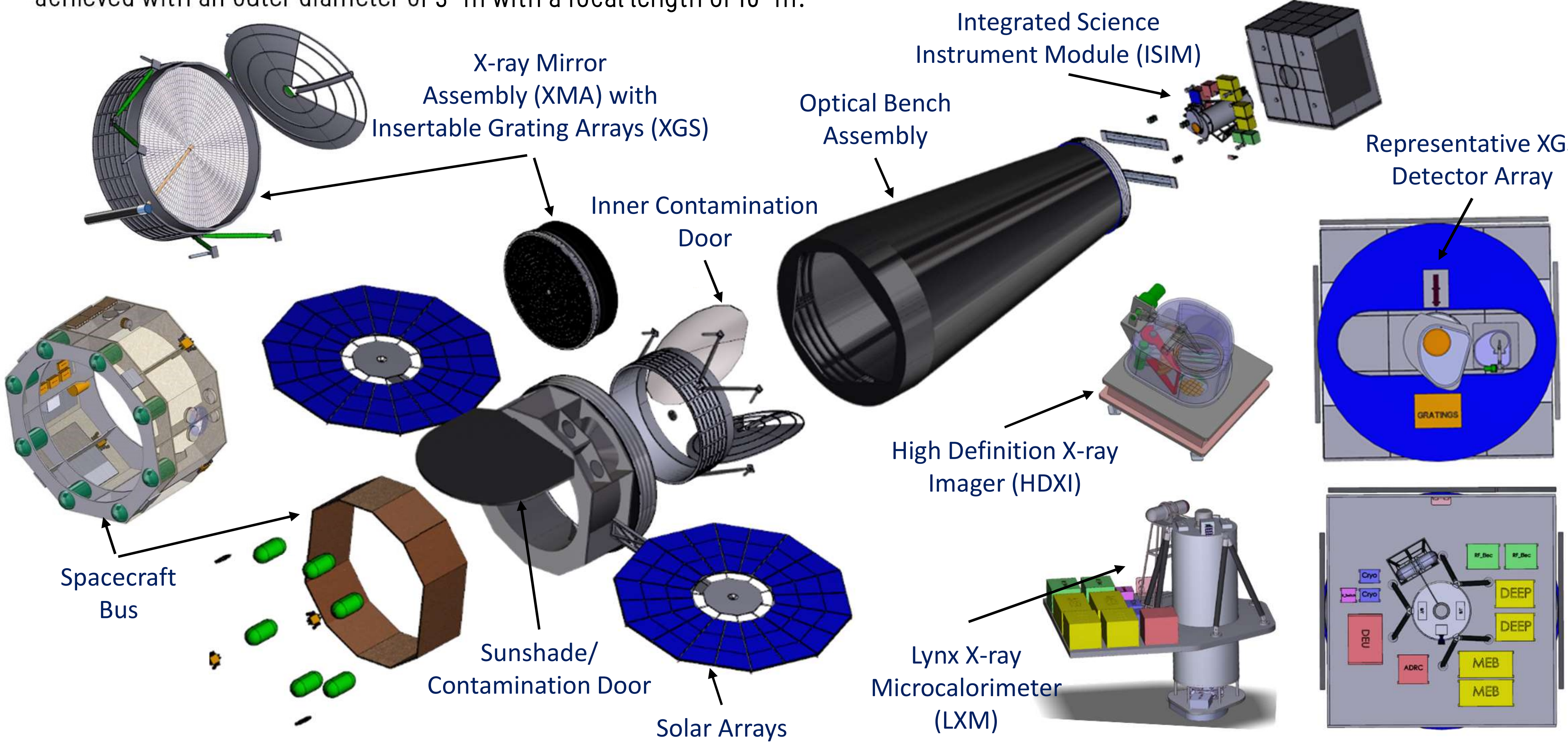


The Energetic Side of Stellar Evolution and Stellar Ecosyste*ms*

Endpoints of stellar evolution | *Stellar birth, coronal physics, feedback* | *Impact of stellar activity on habitability of planets*

LYNX OBSERVATORY CONFIGURATION

2 m^2 of effective area at E = 1 keV is required to execute the three science pillars in under 50% of the 5-yr mission timeline. This is achieved with an outer diameter of 3-m with a focal length of 10-m.



LYNX MISSION DESIGN

Mission Risk Class A

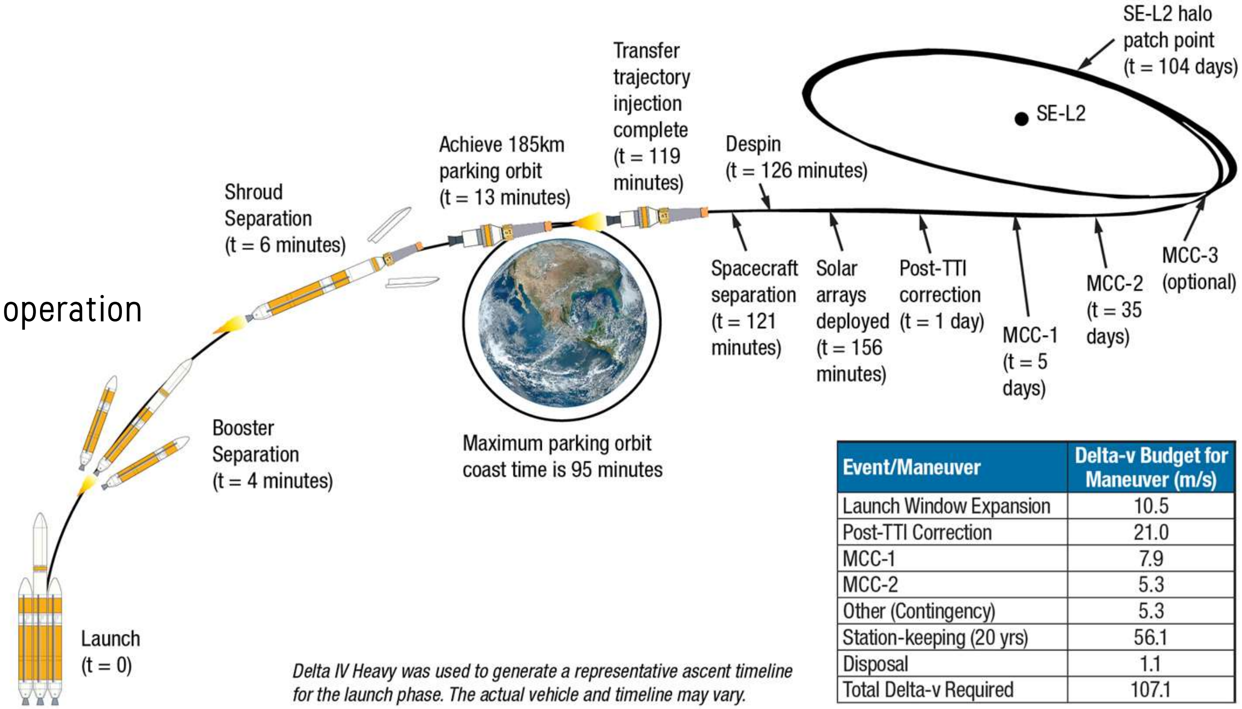
Launch Vehicle:
- Heavy class, 5-m fairing
- SLS co-manifested payload study underway

Mission Life:
- 5 years, extendable to 20 years
- >20 years with power management and modified operation
- Designed for No-to-Minimal In-Space Servicing

Orbit:
- Halo around SE-L2

Communication:
- Up to 3 x per day via DSN
- Maximum of 240 Gbits/day
- Downlink Rate 22.2 Mb

Mission Operations:
- Chandra-like
- Primarily General Observer Program



Event/Maneuver	Delta-v Budget for Maneuver (m/s)
Launch Window Expansion	10.5
Post-TTI Correction	21.0
MCC-1	7.9
MCC-2	5.3
Other (Contingency)	5.3
Station-keeping (20 yrs)	56.1
Disposal	1.1
Total Delta-v Required	107.1

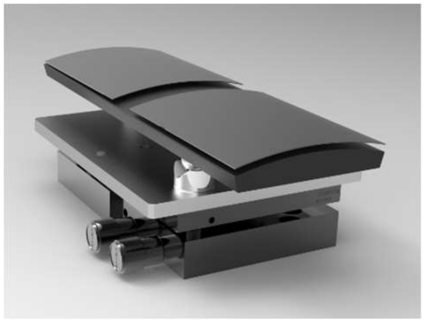
Delta IV Heavy was used to generate a representative ascent timeline for the launch phase. The actual vehicle and timeline may vary.

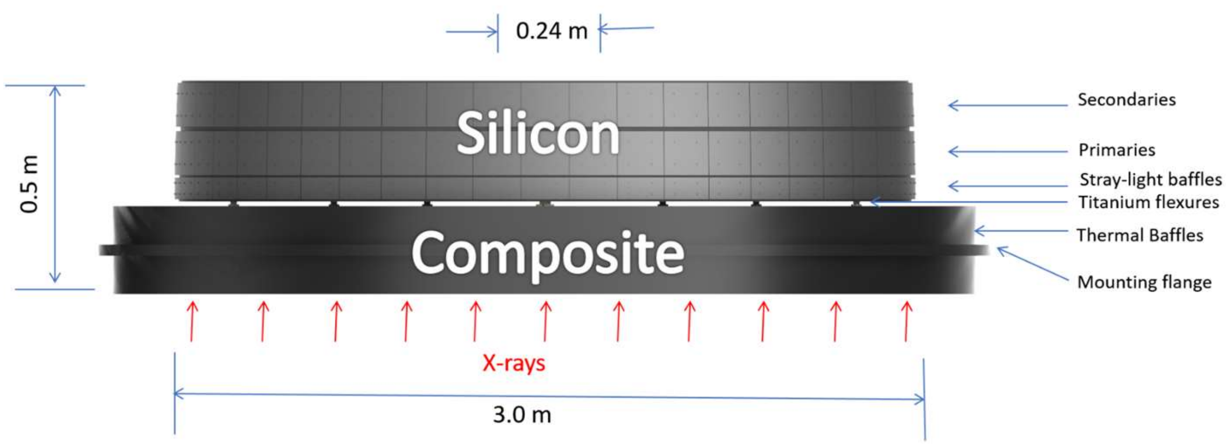
Ascent timeline provided by NASA LSP for a Delta-IV Heavy.

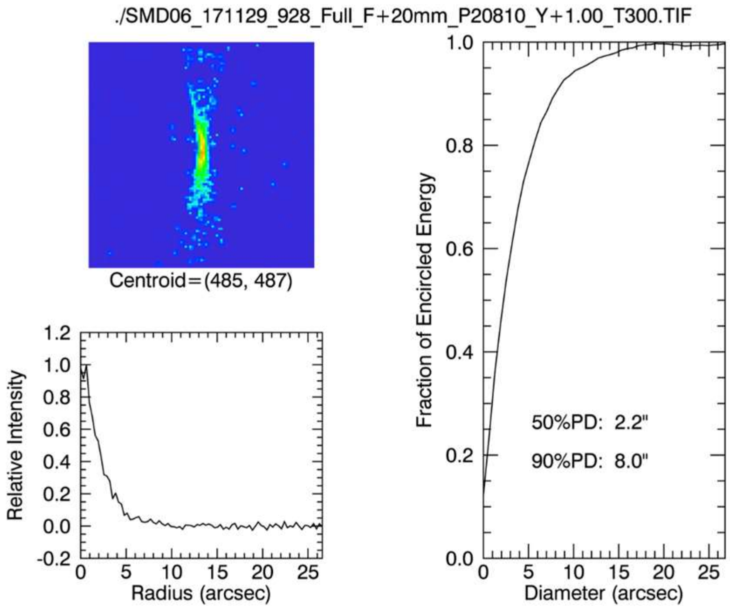
LYNX MIRROR ASSEMBLY – SILICON METASHELL OPTICS

XMA Parameter	Requirement
Energy Range	0.3–10 keV
Angular Resolution	0.5 arcsec HPD on-axis; < 1 arcsec HPD across the FOV
Grasp **(Effective Area * FOV for <1 arcsecond PSF)**	~600 m^2 $arcminutes^2$
Field of View	10 arcmins radius
Effective Area @ 1 keV	2 m^2

Direct polished mono-crystalline silicon



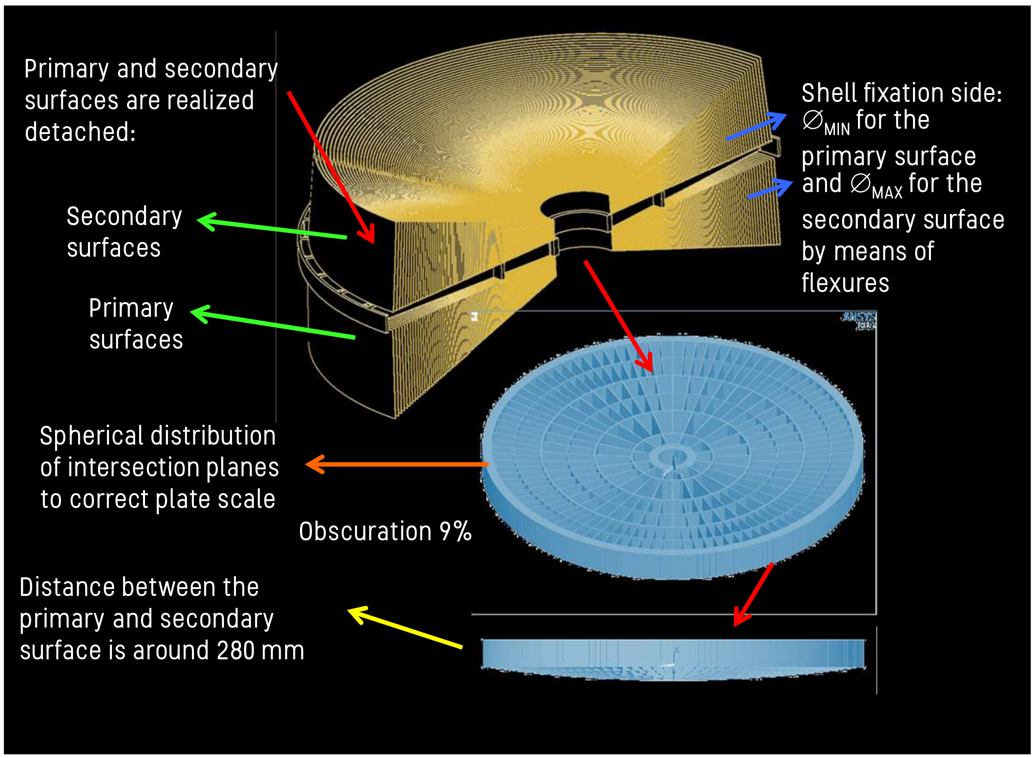




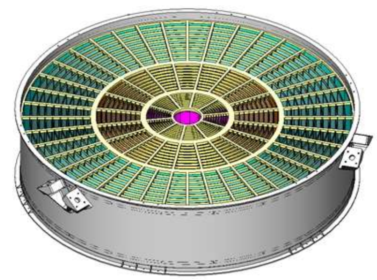
FEASIBLE ALTERNATES – FULL SHELL & ADJUSTABLE OPTICS

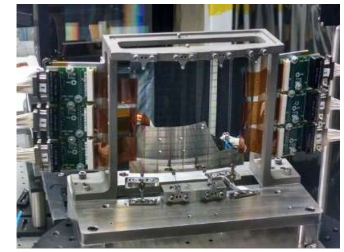
- G.Pareschi, M.Civitani, S.Basso & INAF Team (INAF-OAB)
- K. Kiranmayee , J. Davis, R. Elsner D. Swartz & MSFC Team (MSFC/USRA)

Direct Polished Fused Silica or Similar

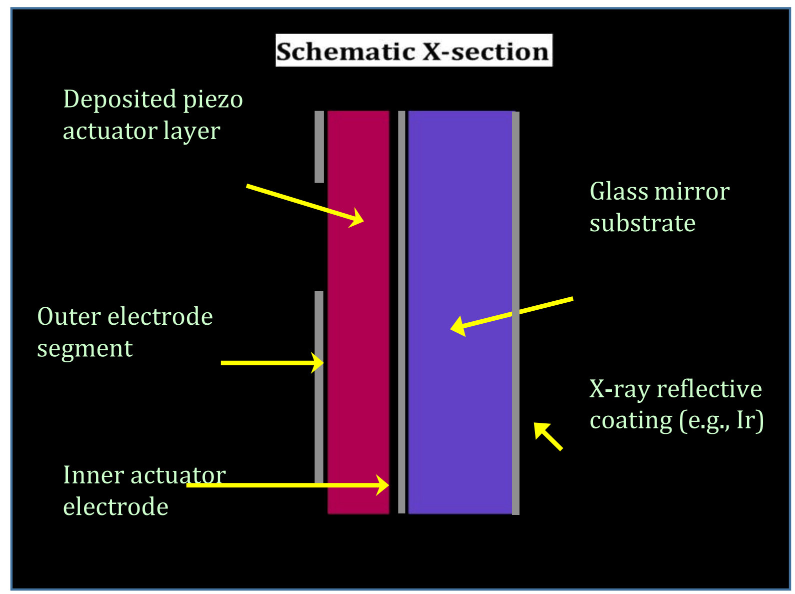


- P. Reid
- SAO Adjustable Optics Team
- PSU Adjustable Optics Team





Slumped glass with sputter deposited piezoelectric material



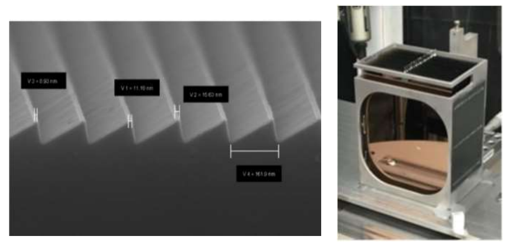
LYNX X-RAY GRATING SPECTROMETER

The XGS will provide high-throughput, high-resolution spectra at soft energies (0.2-2 keV).

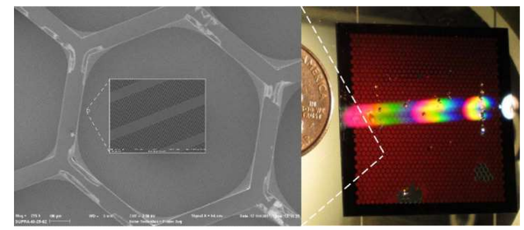
Lynx Instrument Working Group XGS Leads:

R. McEntaffer (PSU), Ralf Heilmann (MIT)

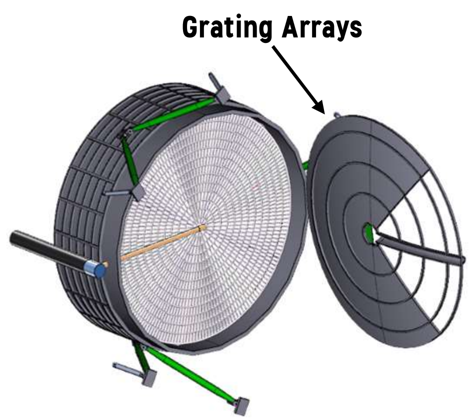
XGS System	**Requirement**
Energy Range	0.2-2.0 keV
Effective area	4,000 cm^2 @ 0.6 keV [Chandra is ~20 cm^2 @ 0.5 keV for HETG]
Spectral Resolving Power, R	5,000 @ 0.6 keV (R=10,000 Desired)
Line-spread function width	1 arcsecond
XGS Readout	**Requirement**
Readout Pixel size	16 μm x 16 μm
Readout noise (rms)	$\leq$ 4 e^-
Readout Energy Resolution	~80 eV @ 277 eV (95% encl. energy)
Number of Readout Detectors	9 (OPG), 18 (CAT)



Off-Plane Grating Array, Penn State



Critical Angle Transmission Grating Array, MIT

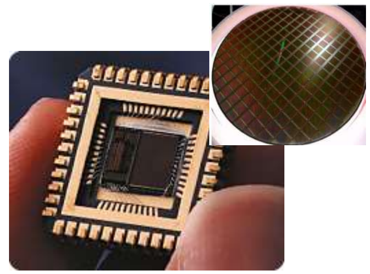


HIGH DEFINITION X-RAY IMAGER

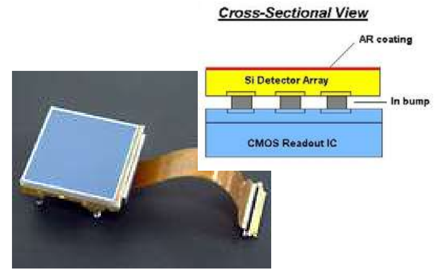
High Definition X-ray Imager (HDXI)

- Lynx Instrument Working Group HDXI Leads:
  M. Bautz (MIT), R. Kraft (SAO), A. Falcone (PSU)

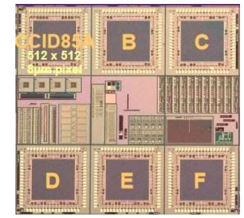
HDXI Parameter	Requirement
Energy Range	0.3-10 keV
Field of view	23 arcminutes x 23 arcminutes
Pixel size	16 µm x 16 µm (0.33 arcsecs)
Energy Resolution	60 eV (FWHM) @ 1 keV
Read Noise	$\leq$ 4 e^-
Full-field count rate capability	8000 ct s^{-1}
Frame Rate Full-field Window (20x20 pixels)	 > 100 frames s^{-1} >10,000 windows s^{-1}



Monolithic CMOS, Sarnoff/SAO & MPE

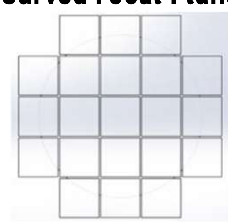


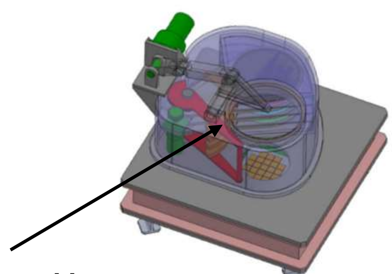
Hybrid CMOS, Teledyne & PSU



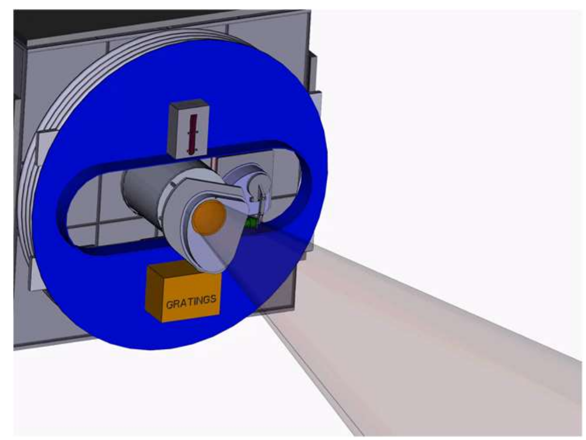
Digital CCD with CMOS readout, MIT-Lincoln Laboratory

Curved Focal Plane





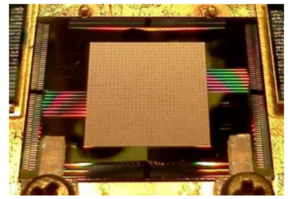
Filter Assembly

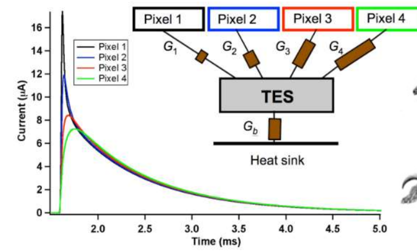


LYNX X-RAY MICROCALORIMETER

Lynx X-ray Microcalorimeter (LXM)

- Lynx Instrument Working Group LXM Leads: S. Bandler (GSFC), E. Figueroa-Feliciano (Northwestern)



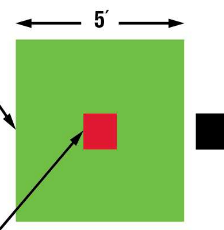


Main Array	**Requirement**
Energy Range	0.2-7 keV for 3 eV
Field of view	5 arcmins x 5 arcmins
Pixel size	1 arcsec x 1 arcsec
Energy Resolution	3 eV (FWHM)
Enhanced Main Array	**Requirement**
Energy Range	0.2-7 keV for 3 eV
Field of View	1 arcmin x 1 arcmin
Pixel Size	0.5 arcsecs x 0.5 arcsecs
Energy Resolution	3 eV
Ultra High-Res. Array	**Requirement**
Energy Range	0.2-0.75 keV
Field of View	1 arcmin x 1 arcmin
Pixel size	1 arcsec x 1 arcsec
Energy Resolution	0.3 eV (FWHM)

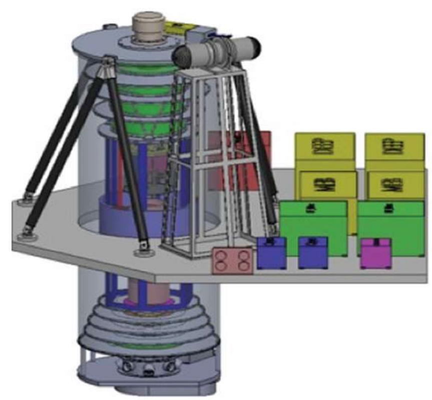
Lynx X-ray Microcalorimeter, GSFC

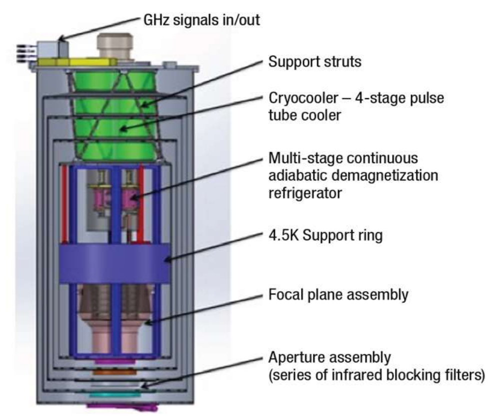
Main array
- 1″ pixels, 5′ FOV, 50 μm pixels
- 0.2–7 keV energy range
- ~3 eV energy resolution
- 86.4 kpix total pixels
- 10 HEMTs

Enhancement main array
- 0.5″ pixels, 1′ FOV, 25 μm pixels
- 0.2–7 keV energy range
- 1.5 eV energy resolution
- 12.8 kpix total pixels
- 6 HEMTs



Ultra-hi-res array
- 1″ pixels, 1′ FOV, 50 μm pixels
- 0.2–0.75 keV energy range
- 0.3–0.4 eV energy resolution
- 3.6 kpix total pixels
- 6 HEMTs





Enabling Technologies TRL Assessment Summary

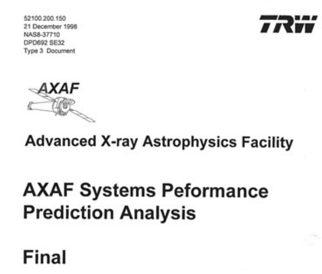
At Decadal Studies Management Team request, the ExEP, PCOS, and COR Program Offices and the Aerospace Corp assessed the TRL of tech gaps submitted by the teams as of Dec. 2016. Assessment was presented June 2017.

ID	Technology Gap	TRL	
1	High-Resolution 'Lightweight' Optics	~~2~~ 3	**Multiple Technologies 3-4 by mid-2020**
2	Non-deforming X-ray Reflecting Coatings	3	
3	Megapixel X-ray Imaging Detectors (HDXI)	3	**Multiple Technologies**
4	X-ray Grating Arrays (XGS)	4	**Multiple Technologies**
5	Large-Format, High Spectral Resolution X-ray Detectors (LXM)	3	**Subsystem Heritage**

THE LYNX SYSTEM – ERROR BUDGETS

- The quantities listed are key to achieving mission science goals and are considered key technical performance metrics (TPMs).
  - Image quality (system)
  - Effective area
  - Spectral resolution
  - Observing efficiency (related to effective area)

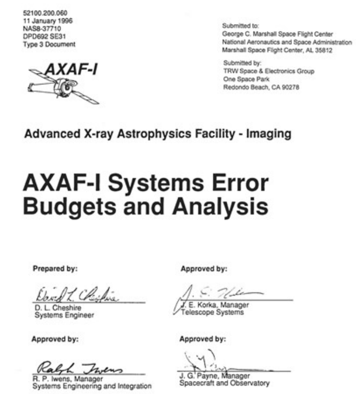
- All key TPMs will have a budget to manage the flow down of requirements and make an assessment of expected performance (prediction) and the path to achieving the expected performance.
  - Gives confidence in the requirements vs. capabilities assessment
  - Gives confidence in the development path for the key payload elements


AXAF

Advanced X-ray Astrophysics Facility

AXAF Systems Peformance Prediction Analysis

Final


AXAF-I

Advanced X-ray Astrophysics Facility - Imaging

AXAF-I Systems Error Budgets and Analysis

Prepared by:

D. L. Cheshire, Systems Engineer

Approved by:

E. Korka, Manager, Telescope Systems

Approved by:

R. P. Iwens, Manager, Systems Engineering and Integration

Approved by:

J. G. Payne, Manager, Spacecraft and Observatory

IMAGE QUALITY– ERROR BUDGET

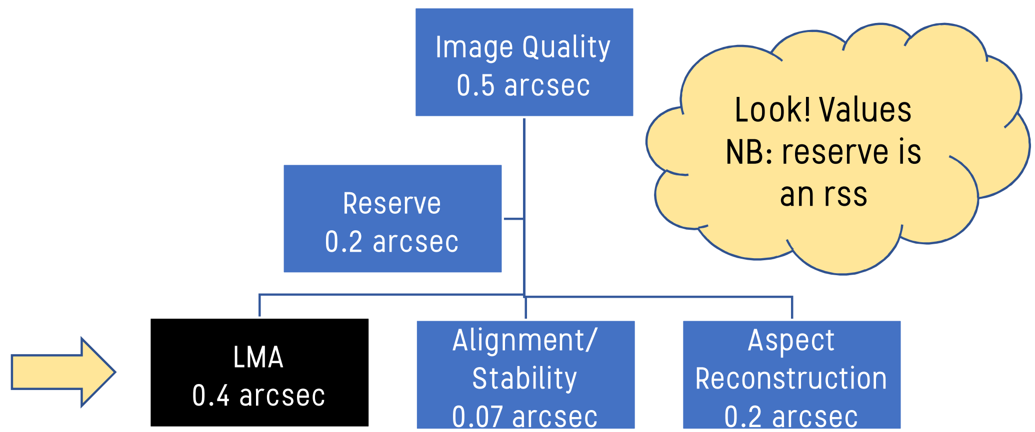
- Shows how Lynx collects data and makes an image on the celestial sphere
- Lynx looks like Chandra (structurally)
- Lynx Mirror Assembly is 1/3 the f/# so alignment/stability is tighter

NORTHROP GRUMMAN

HARRIS

Ball

Source of Error		Allocation or Requirement (arcsec HPD)	State of the Art (arcsec HPD)	Determination & Verification	Bridging the Gap between State-Of-Art and Requirements
Optical Prescription	Diffraction	0.10	0.10		
	Geometric PSF (on-axis)	0.00	0.00		
Mirror Segment Fabrication	Mirror Substrate	0.20	0.50		
	Coating	0.10	0.20		
Meta-Shell Construction	Alignment	0.10	1.60		
	Bonding	0.20	0.40		
Integration of Meta-shells to XMA	Alignment	0.10	0.10		
	Attachment	0.10	0.22		
Ground to Orbit Effects	Launch shift	0.10	0.10		
	Gravity Release	0.10	0.14		
	On-orbit thermal	0.10	0.16		
On-Orbit Performance (RSS)		**0.40**	**1.77**		

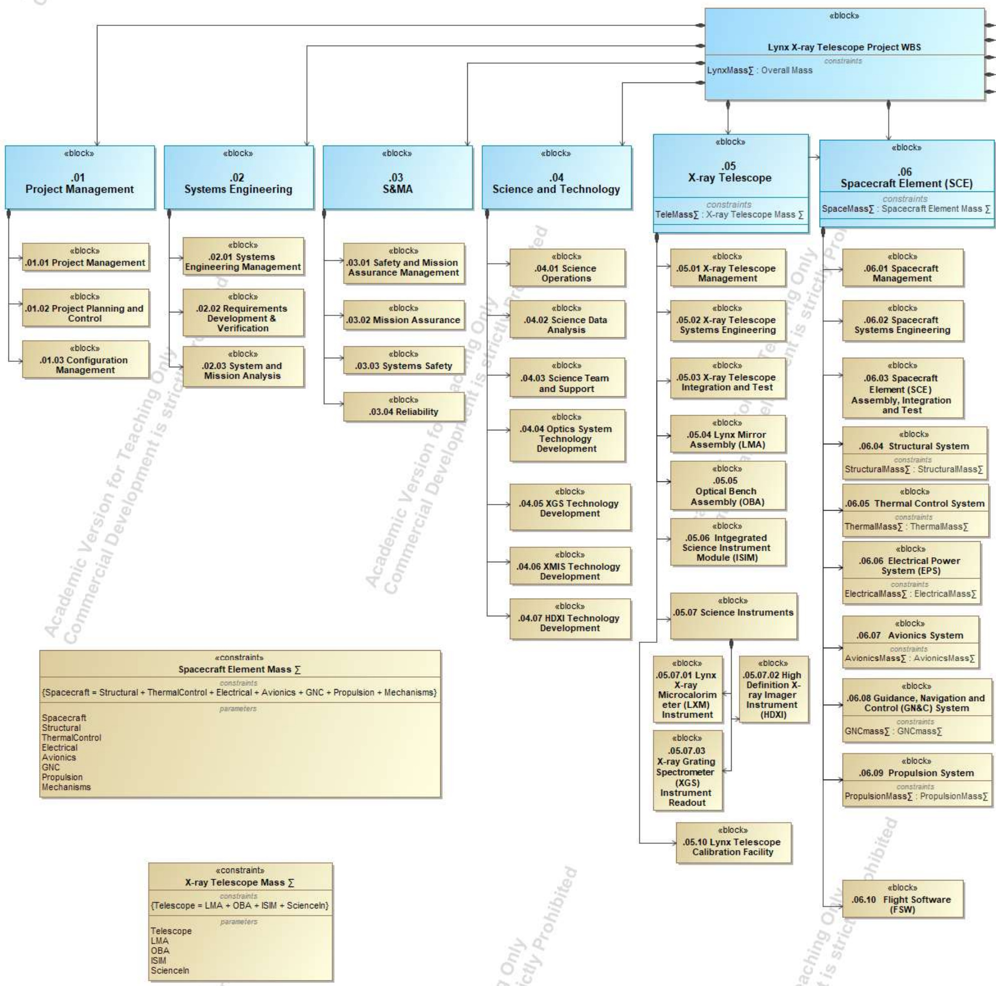


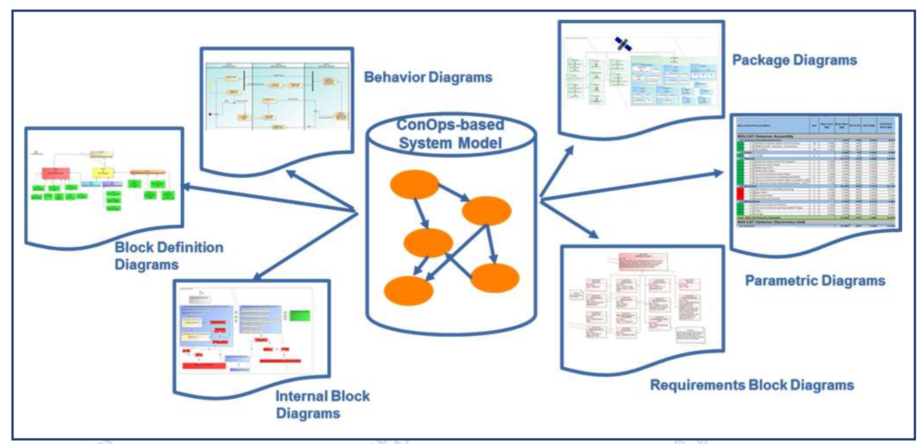
LMA
- Mirror quality
- Element to element alignment
- Meta shell alignment
- Design residual
- 1g-0g effects
- Mount induced distortion

Alignment/Stability
- LMA to ISIM alignment and stability (not corrected by aspect solution)
- ISIM to focal plane alignment and stability not corrected by aspect solution)
- Thermal distortion

Aspect Reconstruction
- Centroid errors guide stars
- Centroid errors fiducial lights
- Fiducial transfer optics drift

MODEL BASED SYSTEMS ENGINEERING





JATIS Special Section on Lynx & Website

SPIE. DIGITAL LIBRARY | CONFERENCE PROCEEDINGS | PAPERS | PRESENTATIONS | JOURNALS | EBOOKS | Search Digital Library

Scope

The Lynx X-Ray Observatory will radically change the way we see the universe by answering some of the most persistent questions of our time: How and when did the first supermassive black holes form, and how do they co-evolve with their host galaxies? What processes drive the formation and evolution of the largest structures in the universe? What high-energy processes play critical roles in the birth and death of stars, and how do they influence planet habitability?

The ability to answer these questions is made possible through the Lynx payload design. Currently in concept phase, Lynx is designed to have leaps in capability over NASA's existing flagship Chandra and the European Space Agency's (ESA) planned Athena mission. More specifically, Lynx will have a 50-fold increase in sensitivity via the coupling of superb angular resolution with high throughput, 16× larger field of view with arcsecond or better imaging, and 10 to 20 times higher spectral resolution for both point-like and extended sources. The primary purpose of this special section is to present details of the Lynx observatory and expected on-orbit performance. Related topics of interest include, but are not limited to:

- instrument and x-ray optics descriptions (system and subsystems)
- structural, thermal, and optical performance
- in-flight performance predictions and modeling
- data analysis algorithms
- instrument-related software systems
- spacecraft systems critical to in-flight performance
- systems engineering practices
- applied lessons learned from previous missions
- planning for the 2030s.

This special section focuses on technical aspects of the Lynx mission and instrumentation. Purely science discussions are to be published elsewhere. All submissions will be peer reviewed. Peer review will commence immediately upon manuscript submission, with a goal of making a first decision within 6 weeks of manuscript submission. Special sections are opened online once a minimum of four papers have been accepted. Each paper is published as soon as the copyedited and typeset proofs are approved by the author. Submissions should follow the **guidelines of JATIS**. Manuscripts should be submitted online at **http://JATIS.msubmit.net**. A cover letter indicating that the submission is intended for this special section should be included.

Important JATIS Information:

- Papers due October 1, 2018
- Published in Spring 2019
- http://JATIS.msubmit.net

Lynx Websites:

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

https://www.lynxobservatory.com/#home-section

”one builds large missions not because they can do what a small mission can do better. The large missions can do what a small mission can’t do at all.”

– Dr. Megan Donahue, Professor Michigan State University
President American Astronomical Society
Lynx STDT Member