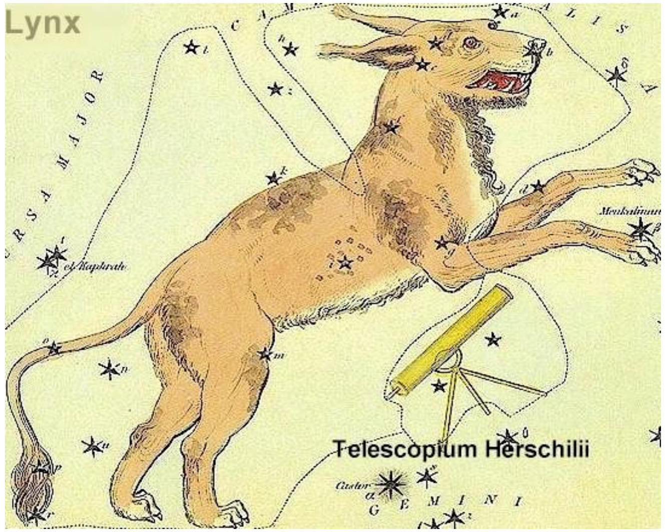
# Lynx Mission Concept Status

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

Presented on behalf of the Lynx Team




Community STDT
F. Özel, Arizona (Co-Chair)
A. Vikhlinin, SAO (Co-Chair)

S. Allen, Stanford
M. Bautz, MIT
W. N. Brandt, Penn State
J. Bregman, Michigan
M. Donahue, MSU
J. Gaskin, MSFC (Study Sci.)
Z. Haiman, Columbia
R. Hickox, Dartmouth
T. Jeltema, UCSC
J. Kollmeier, OCIW

A. Kravtsov, U. Chicago
L. Lopez, Ohio State
R. Osten, STScI
F. Paerels, Columbia
D. Pooley, Trinity
A. Ptak, GSFC
E. Quataert, Berkeley
C. Reynolds, UMD
D. Stern, JPL

- A symbol of great insight with the ability to see through solid objects to **reveal the true nature of things**.
- Much of the baryonic matter and the settings of the most active energy release in the Universe are visible primarily or exclusively in the X-rays

**There are ~250 people across academia, industry, government, and non-US space agencies involved with the Lynx Concept Study**

# Lynx and the 2020 Astrophysics Decadal Survey

**Lynx will revolutionize our view of the Universe by providing unique insight into the high-energy drivers that govern its formation and evolution.**

- × 50 higher throughput while maintaining *Chandra's* angular resolution.
- × 16 larger solid angle for sub-arcsec imaging
- × 800 higher survey speed at the *Chandra* Deep Field limit
- Significant improvement in Resolving Power for grating spectroscopy
- High-resolution, spatially resolved spectroscopy on fine scales

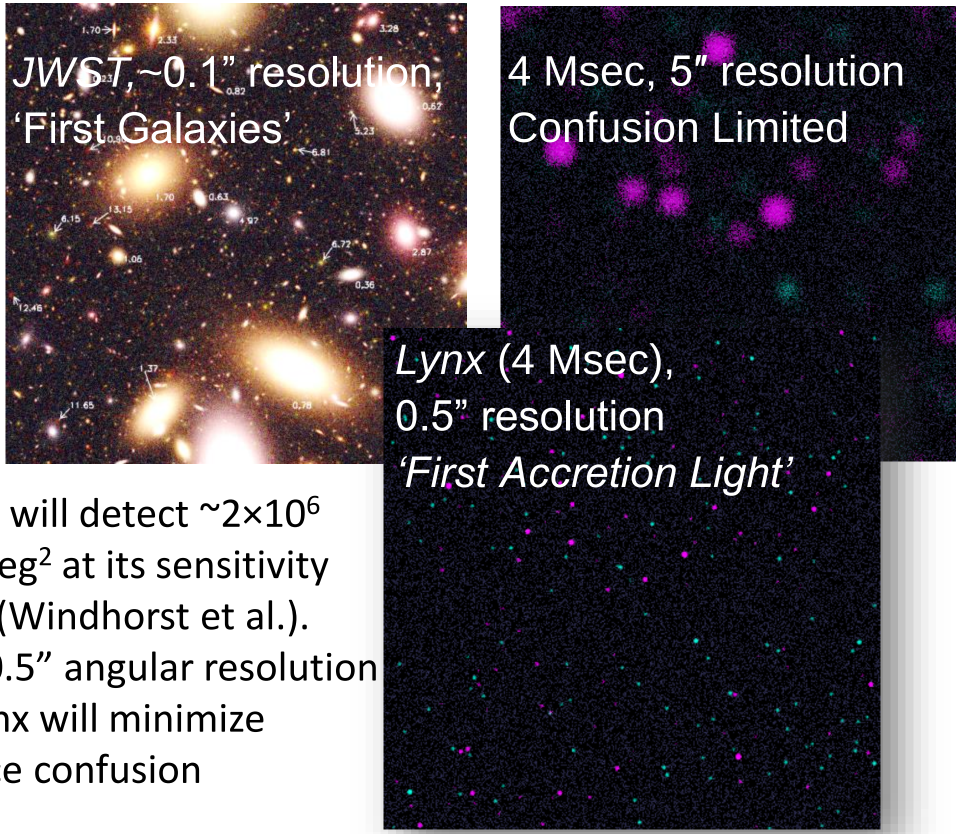
**Astro2020 Decadal Study Input:**

1. A **science case** for the mission
2. A **design reference mission and observatory**, including a report on any tradeoff analyses
3. A **technology assessment** including: current status, roadmap for maturation & resources
4. A **cost assessment** and listing of the top technical risks to delivering the science capabilities
5. A **top level schedule** including a notional launch date and top schedule risks.

# The Dawn of Black Holes

*Lynx* will observe the birth of the first seed black holes at redshift up to 10 and provide a census of the massive black hole population in the local and distant universe, follow their growth and assembly across cosmic time, and measure the impact of their energy input on all scales.

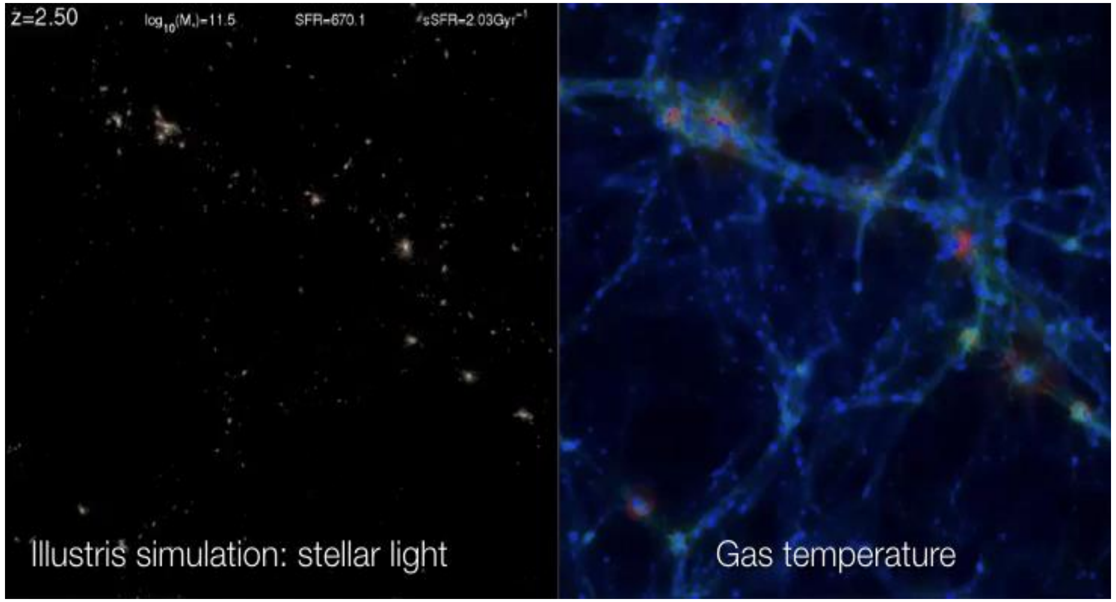
Simulated 2x2 arcmin deep fields




JWST will detect ~2×10$^{6}$ gal/deg$^{2}$ at its sensitivity limit (Windhorst et al.). The 0.5" angular resolution of Lynx will minimize source confusion

# The Invisible Drivers Behind Galaxy Formation and Evolution

The assembly, growth, and the state of visible matter in the cosmic structures is largely driven by violent processes that heats the gas in the CGM and IGM. The exquisite spectral and angular resolution of *Lynx* will make it a unique instrument for mapping the hot gas around galaxies and in the Cosmic Web.




***Facility Class Observatory: Exploration Science with a Rich Community-Driven General Observer Program!***

# Lynx Optical Assembly

High-resolution X-ray Optical Assembly: 3 Viable Architectures – Trade Study

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

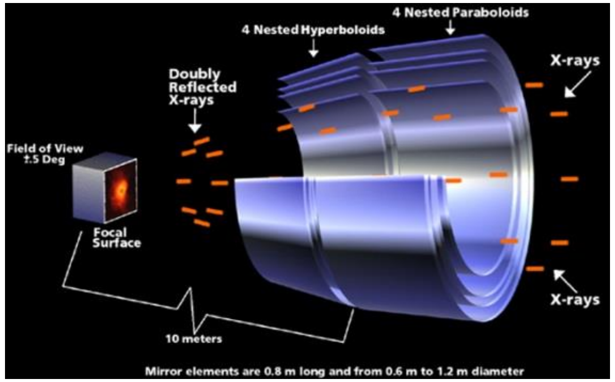
OWG will make a formal recommendation to STDT: 6/1/18
STDT Finalizes their decision: 7/1/18

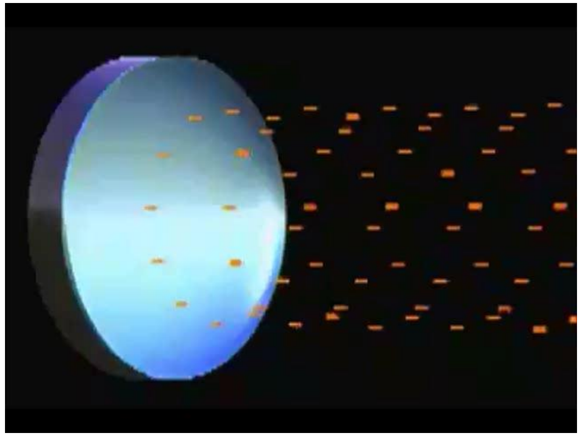
*Up-select will be based on Science, Technical and Programmatic criteria (TBF)*

- *Does the configuration Satisfy Science Requirements?*
- *Is there a feasible path for development?*
- *Are there existing X-ray measurements and/or analyses?*
- *Can it interface with the spacecraft and survive launch?*

***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),<br>A*(FOV for HPD < 1 arcsec) | ≥ 2 $m^2$ * 300 $arcmin^2$ |
| Wide FOV sub-arcsec Imaging | 10 arcmin radius |



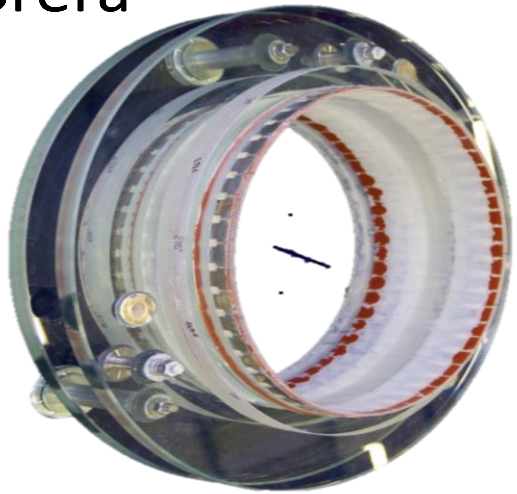
CXC/D. Berry

# Full shell Optical Design

(G. Pareschi et al. OAB, K. Kilaru et al. USRA/MSFC)

R. Elsner (NASA MSFC)

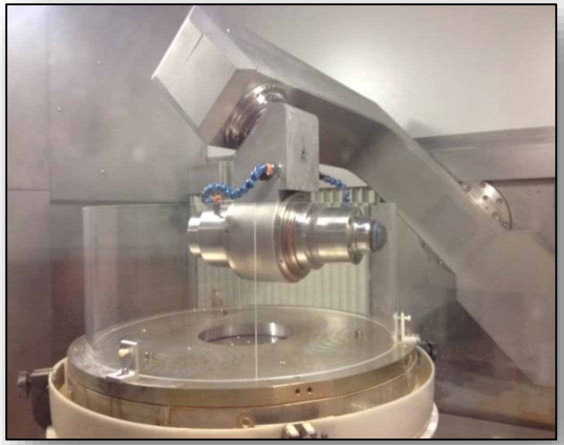
## Brera



The mirror shell should have low density, low CTE, high modulus of elasticity and high yield strength. It should also be a material that is not too difficult to figure and polish.

- Fused Silica
- Readily available
- Fine-grinding to 1.5 µm OOR (P-V) + polish to 5-6 nm RMS microroughness
- Ion beam figuring corrections

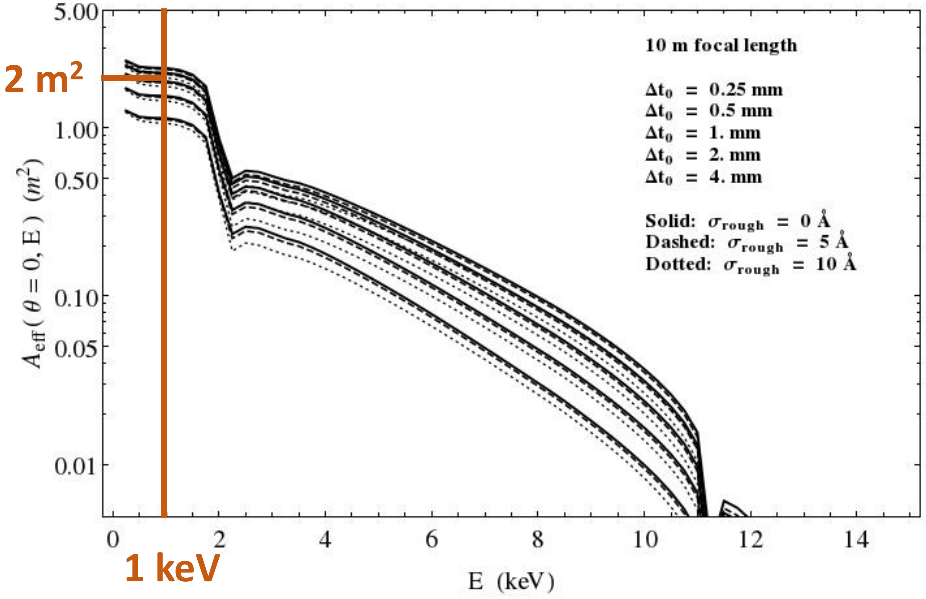
## MSFC



- Be, BeAl
- Procure diamond-turned, heat treated, NiP alloy coated shells (<100 µm RMS)
- NiP is a hard material and can be figured, polished/superpolished
- Diamond-turn and Zeeko polish
- Differential deposition corrections

See Talks: 10399-30, 10399-31, 10399-32 , Wed 11:30 AM, Room 9

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| $\Delta t_0$ (mm) | 0.25 | 0.50 | 1.00 | 2.00 | 4.00 |
| | | | $f$ = 10 m | | |
| $N_{shells}$ | 259 | 235 | 199 | 155 | 108 |
| $\Delta t_{max}$ (mm) | 0.6875 | 1.375 | 2.75 | 5.5 | 11.0 |
| $r_{i,max}$ (cm) | 136.4 | 136.4 | 136.2 | 136.0 | 135.4 |
| $r_{i,min}$ (cm) | 25.1 | 25. | 25.1 | 25.0 | 25.2 |
| $r_{f,max}$ (cm) | 137.4 | 137.4 | 137.2 | 137.0 | 136.4 |
| $r_{f,min}$ (cm) | 25.1 | 25.1 | 25.2 | 25.1 | 25.3 |
| $\ell_{min}$ (cm) | 9.498 | 9.486 | 9.515 | 9.473 | 9.563 |
| $A_{eff}(1\ \mathrm{keV})^{1,2}$ (m$^2$) | 2.270 | 2.126 | 1.890 | 1.551 | 1.142 |
| $A_{eff}(6\ \mathrm{keV})^{1,2}$ (m$^2$) | 0.213 | 0.190 | 0.157 | 0.117 | 0.078 |
| $A_{eff}(10\ \mathrm{keV})^{1,2}$ (m$^2$) | 0.037 | 0.031 | 0.024 | 0.016 | 0.010 |
| $M_{CE,tot}$ (Mg) | 0.125 | 0.234 | 0.417 | 0.686 | 1.016 |
| $M_{Ni,tot}$ (Mg) | 1.747 | 3.277 | 5.839 | 9.617 | 14.24 |
| $V(1\ \mathrm{keV})^{2,3}$ (%) | 9.762 | 9.674 | 9.545 | 9.403 | 9.264 |
| $\sigma_{D,module}(1\ \mathrm{keV})^{2,4}$ (arcsec) | 0.921 | 0.921 | 0.92 | 0.919 | 0.918 |
| $\alpha_{i,max}$ (arcmin) | 116.5 | 116.5 | 116.4 | 116.1 | 115.7 |
| $\alpha_{i,min}$ (arcmin) | 21.5 | 21.5 | 21.6 | 21.5 | 21.7 |
| $\Delta r_{i,max}$ (mm) | 10.817 | 10.807 | 10.788 | 10.749 | 10.673 |
| $\Delta r_{i,min}$ (mm) | 0.864 | 0.861 | 0.862 | 0.850 | 0.852 |
| $\Delta r_{f,max}$ (mm) | 10.899 | 10.894 | 10.884 | 10.865 | 10.826 |
| $\Delta r_{f,min}$ (mm) | 0.869 | 0.867 | 0.871 | 0.863 | 0.875 |

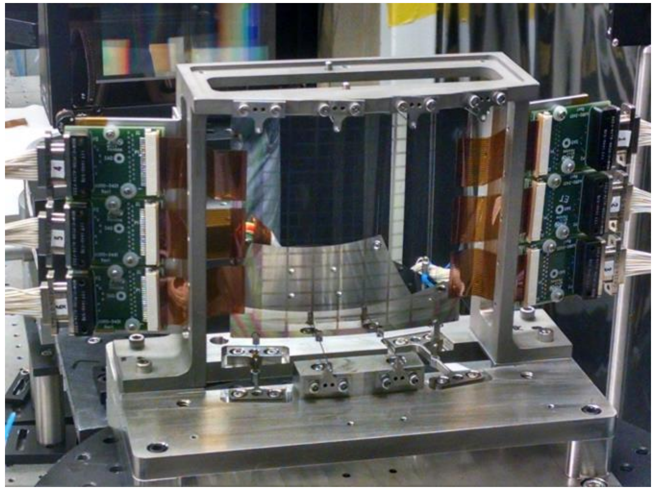


# Adjustable Optics Status

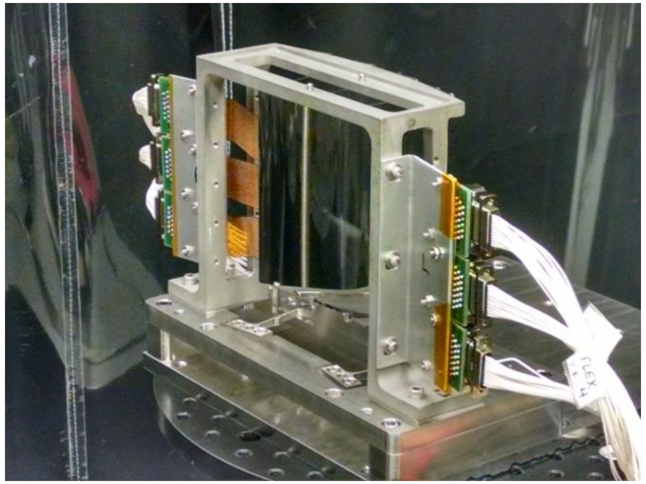
(Reid et al. SAO)

- 112 piezo-actuator cylindrical test mirror
  - Demonstrated ~ 7 arcsec HPD (single bounce, 1 keV) slumping performance (Cotroneo, 10399-33)
  - Demonstrated anisotropic conductive film electrical connectivity with minimal distortion (DeRoo, 10399-58)
  - Demonstrated 100 percent PZT yield (Walker, 10399-56)
  - Problem with 2nd to final step mounting (DeRoo)
- Piezo stress and stress compensation (Walker)
  - Identified major cause of large non-uniform stress (Rapid Thermal Annealer) and testing correction for future test optic

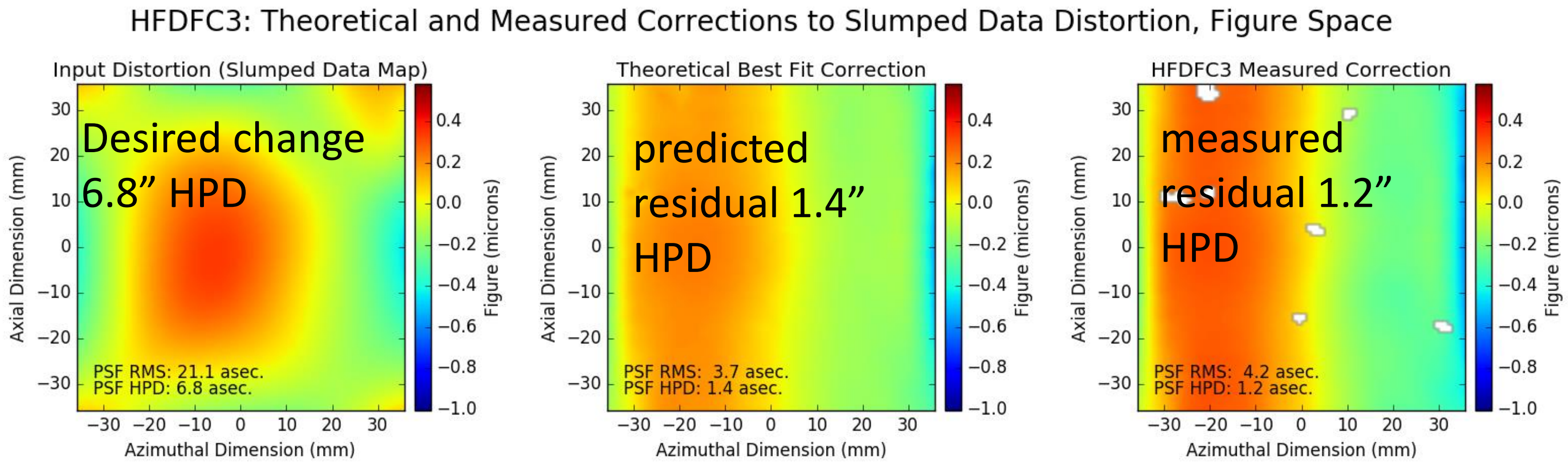
**Back, convex, piezo side**



**Front, concave, X-ray reflecting side**



Major advance: successfully produced deterministic figure change via computer control of all 112 adjusters.



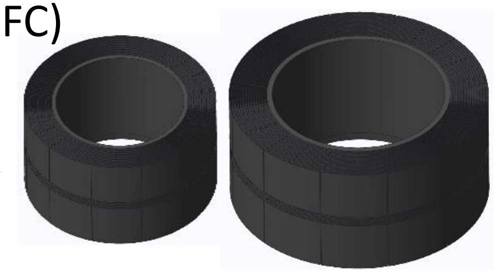

Prediction values (HPD, RMS) are computed at 1 keV for 0.375 deg graze for single reflection. (DeRoo)

See Talks: 10399-56, 10399-58, Thurs 1:40 PM, 10399-33, Wed 2:00 PM, Room 9

# Meta-Shell Status

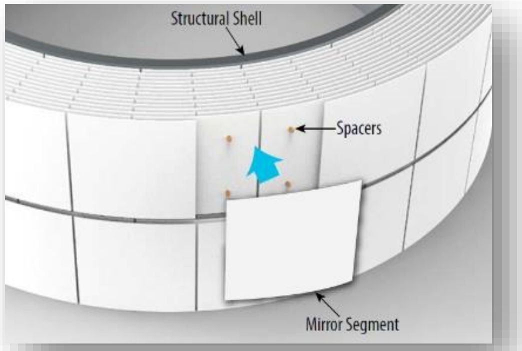
(Zhang et al. NASA/GSFC)

**Segments**

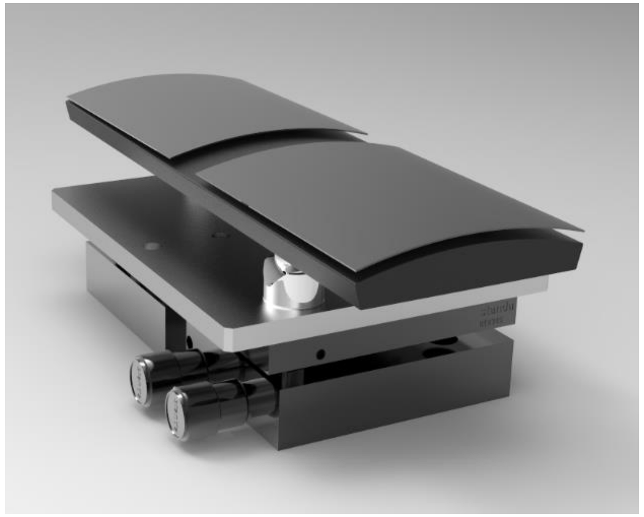


**Meta-shells**

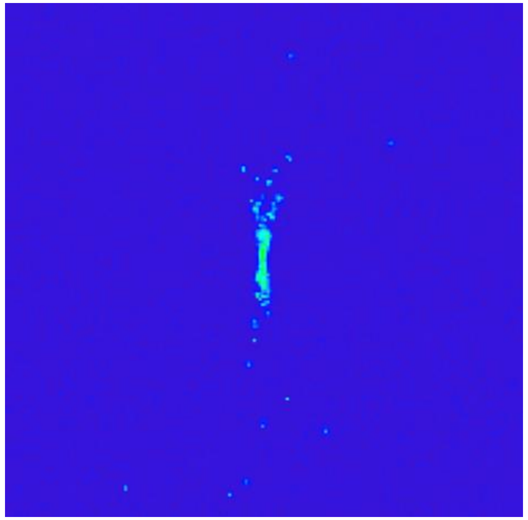
**Assembly**




| Component | Contribution to HPD (") | |
|---|---|---|
| | Lynx Rqrmnt | Expected |
| Mirror segments | 0.2 | 2.0 |
| Alignment | 0.1 | 1.5 |
| Bonding | 0.1 | 0.5 |
| Thermal | 0.2 | 0.2 |
| Gravity release | 0.1 | 0.1 |
| **Total** | **0.3** | **2.5** |



**Single-Pair X-ray Test Module**



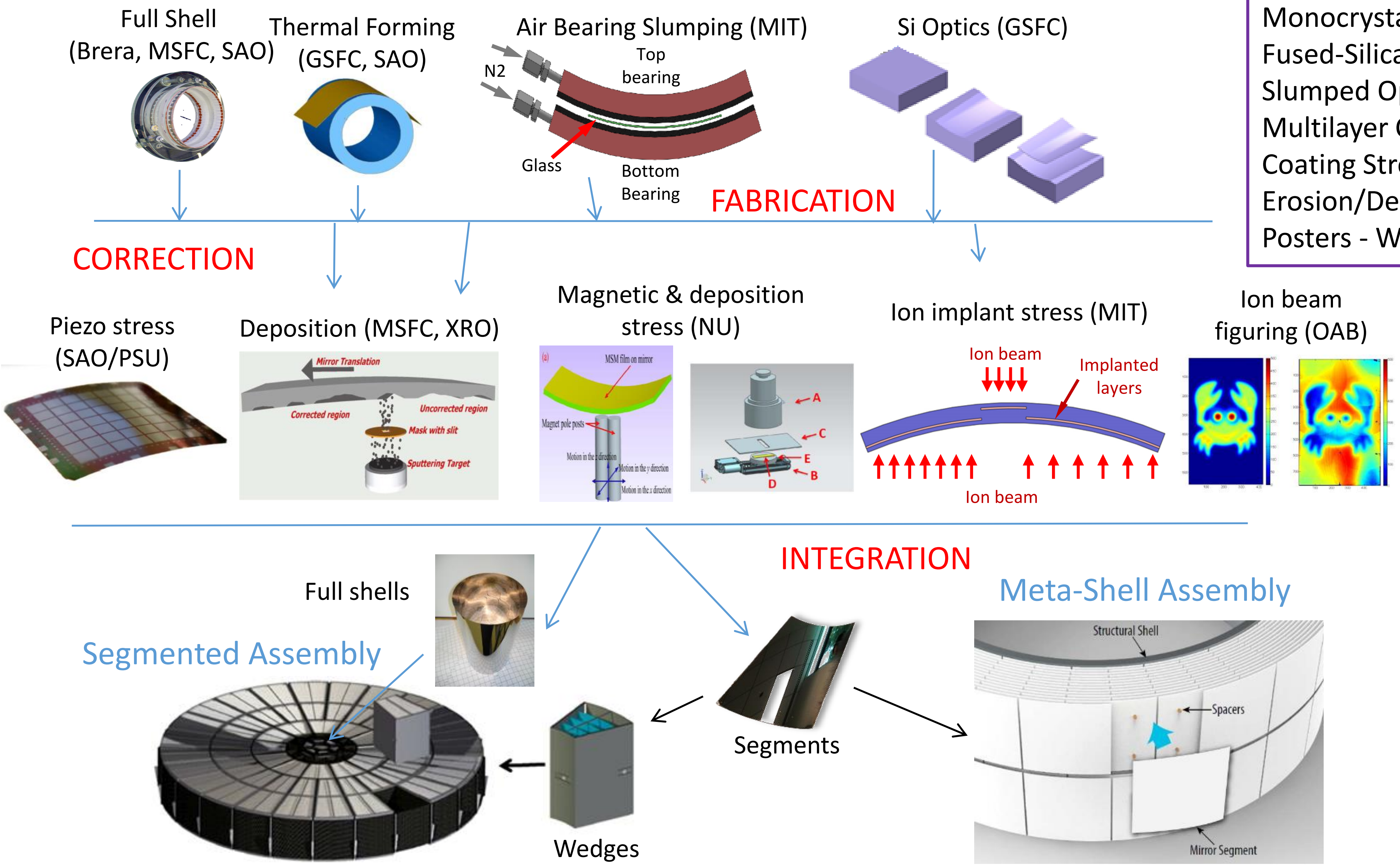
**Full Illumination 4.5 keV X-rays 3.8" HPD**

See Talks: 10399-27, 10399-28, 10399-29, Wed 10:30 AM, Room 9

# Lynx Optical Assembly

See Sessions:

Monocrystalline-Si Optics, Wed 10:30 AM
Fused-Silica Optics: Wed 11:30 AM
Slumped Optics, Wed 2:00 PM
Multilayer Coatings, Wed 4:10 PM
Coating Stress, Thurs 9:20 AM
Erosion/Deposition Figuring, Thurs 10:50 AM
Posters - Wednesday



# Lynx Science Instruments

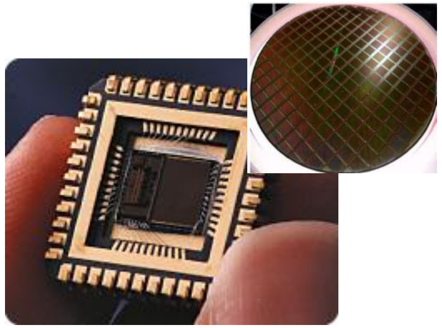
- High Definition X-ray Imager (HDXI)
  - HDXI IWG Leads: M. Bautz (MIT), R. Kraft (SAO), A. Falcone (PSU)
  - Instrument Design Study (On-going @ MSFC ACO)

  *[See Papers: 10397-1, 10397-2, 10397-3, 10397-5]*

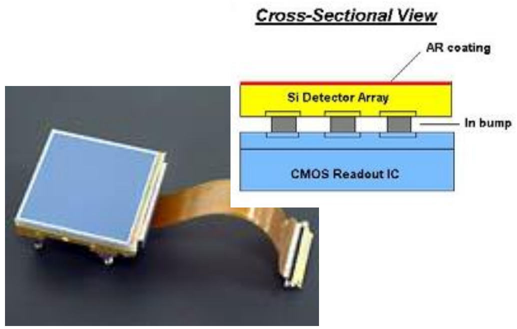
- X-Ray Grating Spectrometer (XGS)
  - XGS IWG Leads: R. McEntaffer (PSU), Ralf Heilmann (MIT)
  - Instrument Design Study (On-going @ MSFC ACO)

  *[See Talks: 10399-38, 10399-39, 10399-40, Wed 4:10 PM]*

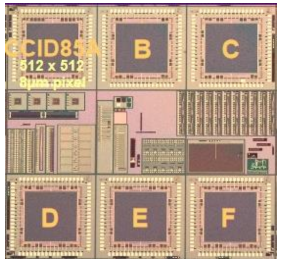
- Lynx X-ray Microcalorimeter (LXM)
  - LXM IWG Leads: S. Bandler (GSFC), E. Figueroa-Feliciano (Northwestern)
  - Instrument Design Lab (Completed $1^{st}$ IDL @ GSFC)



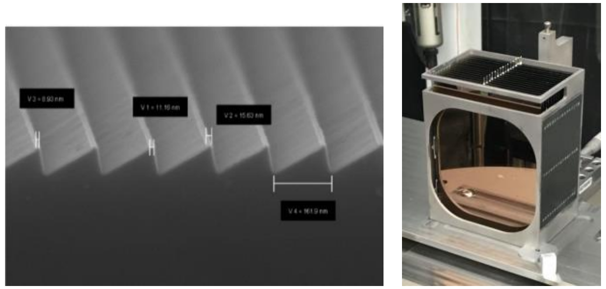
**Monolithic CMOS**



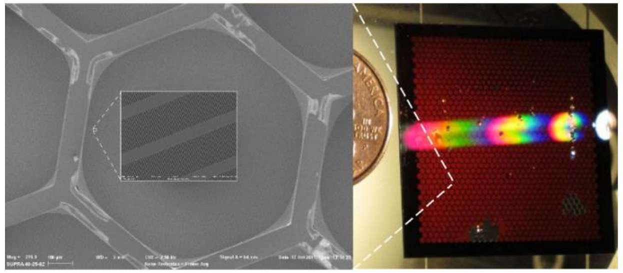

**Hybrid CMOS**



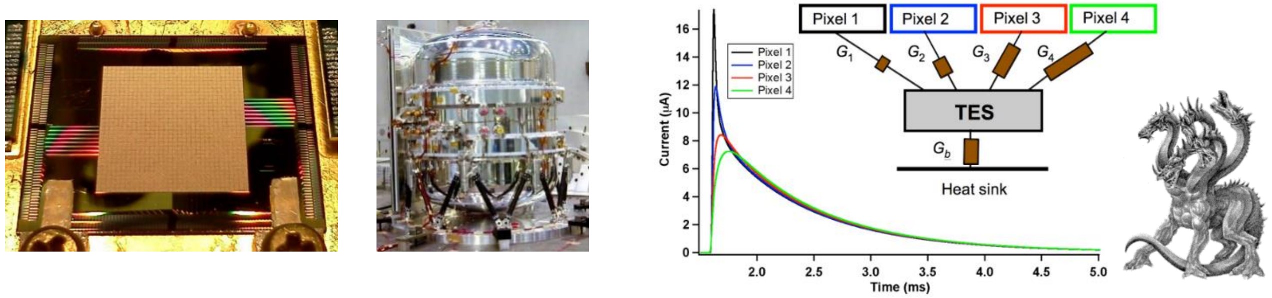

**Digital CCD with CMOS readout**



**Off-Plane Grating Array**



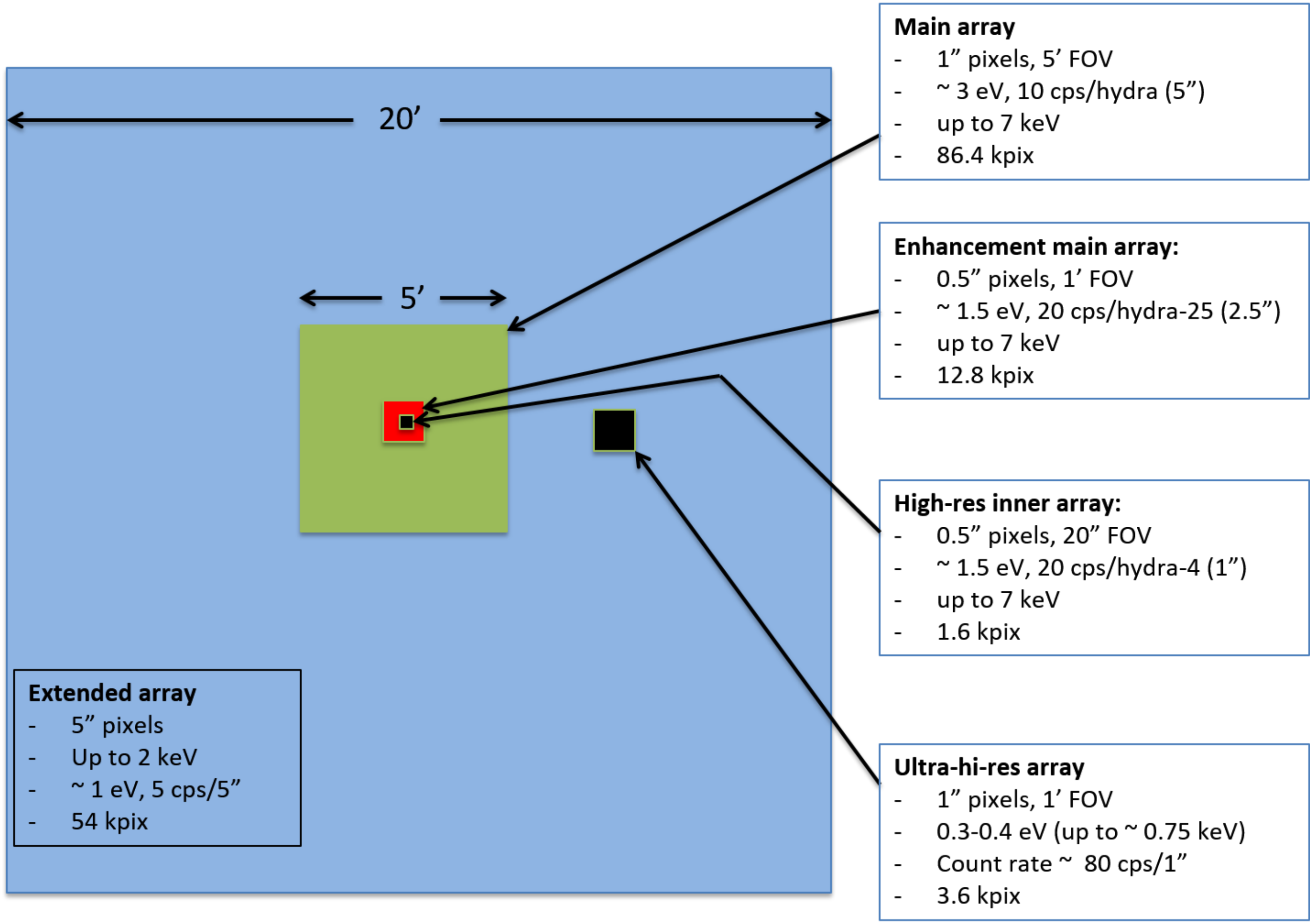
**Critical Angle Transmission Grating Array**




**Lynx X-ray Microcalorimeter**

**IWG = Instrument Working Group**

# Lynx Science Instruments: Requirements




## High Definition X-ray Imager (*Notional*)

| | |
|---|---|
| Energy Range | 0.2 – 10 keV<br>QE > 90% (0.3-6 keV), QE > 10% (0.2-9 keV) |
| FOV | 22′ x 22′ (4k x 4k pixels) |
| Pixel Size | < 16 x 16 μm (≤ 0.33″) |
| Read Noise | ≤ 4 $e^-$ |
| Energy Resolution | 37 eV @ 0.3 keV, 120 eV @ 6 keV (FWHM) |
| Frame Rate | > 100 frames/s (full frame)<br>> 10000 frames/s (windowed region) |
| Radiation Tolerance | 10 yrs at L2 |

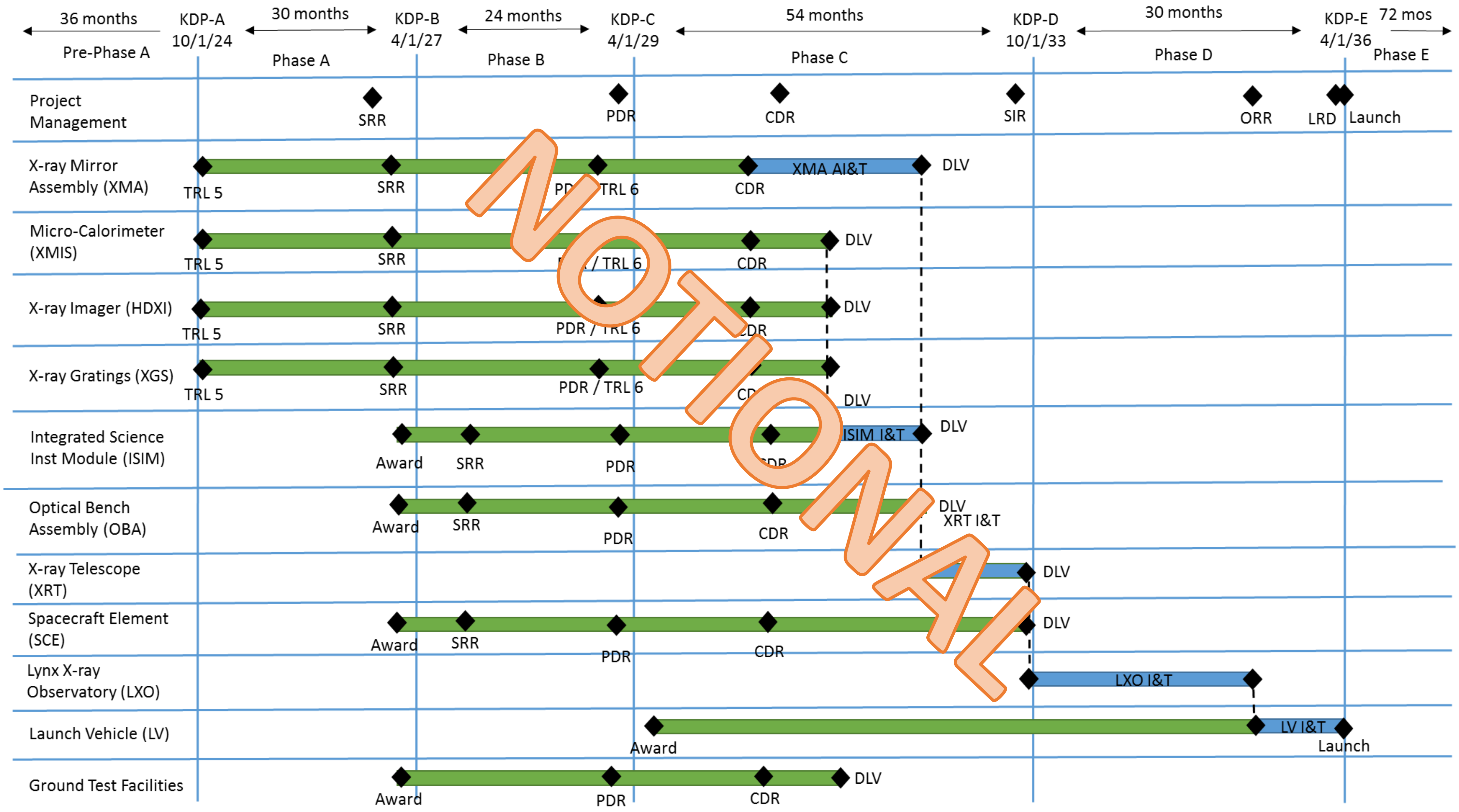
## X-ray Grating Spectrometer (*Notional*)

| | |
|---|---|
| Effective Area | ~4000 $cm^2$ @ 0.3 keV (63% azimuthal coverage) |
| Resolving Power, R | > 5,000 |
| Energy Resolution | < 5 eV (FWHM) |
| Count Rate Capability | < 1 count/s/pixel |
| Array size | 300 x 300 pixel array |

## Lynx X-ray Microcalorimeter (*Notional*)

| | |
|---|---|
| Pixel Size | 1″ (50 μm pixels for 10-m focal length) |
| FOV | At least 5′ x 5′ |
| Energy Resolution | < 5 eV (FWHM) |
| Count Rate Capability | < 1 count/s/pixel |
| Array size | 300 x 300 pixel array |

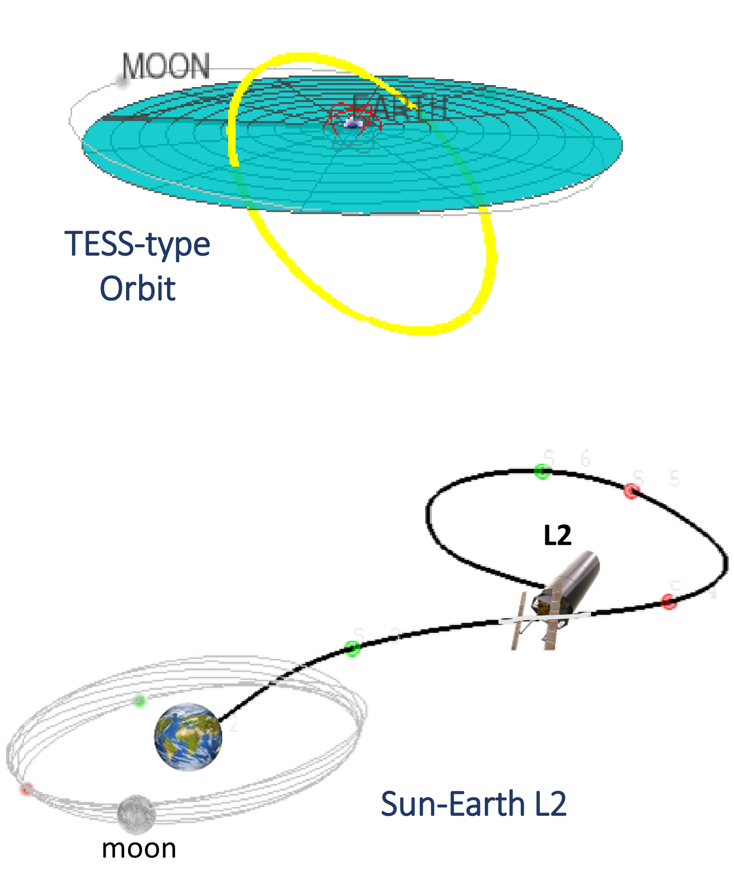
# Lynx X-ray Observatory – Notional Mission Lifecycle Schedule



# Mission Design + Trades

- Structures [*Launch vehicle Trade*]
- Thermal
- Propulsion
- Avionics [*Comm Trade*]
- GNC [*Rapid response capability Trade*]
- Power
- Mechanisms [*Moveable optics vs. instrument table Trade*]
- Environments [*Orbit Trade*]

BEST OPTIONS

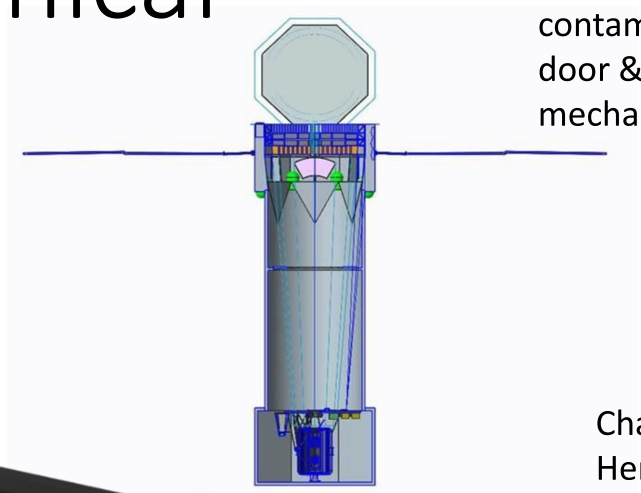



## *Orbit Trade (SE-L2 vs. TESS)*

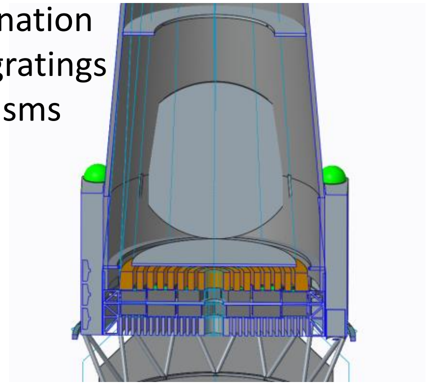
- Launch Vehicle (Both)
- Delta-V (SE-L2)
- Thermal Environment (SE-L2)
- Eclipsing (SE-L2, just)
- Communications (TESS)
- Meteroid Environment (Both)
- Radiation Environment (average/worst case – TBD)
- Serviceability (SE-L2)
- Disposal (TESS)
- Station Keeping (TESS)
- Disturbance Environment (Both)

- ***NASA MSFC Advanced Concept Office: J. Mulqueen, A. Schnell, R. Hopkins, R. Suggs, J. Garcia, S. Sutherlin, T. Boswell, A. Dominguez, P. Capizzo, J. Rowe, L. Fabisinski***

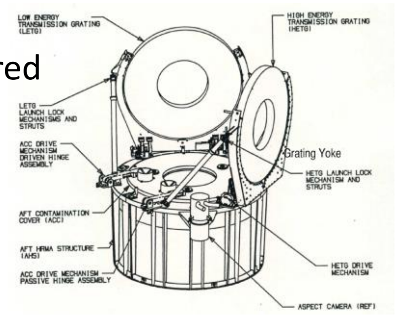
# Mechanical Design

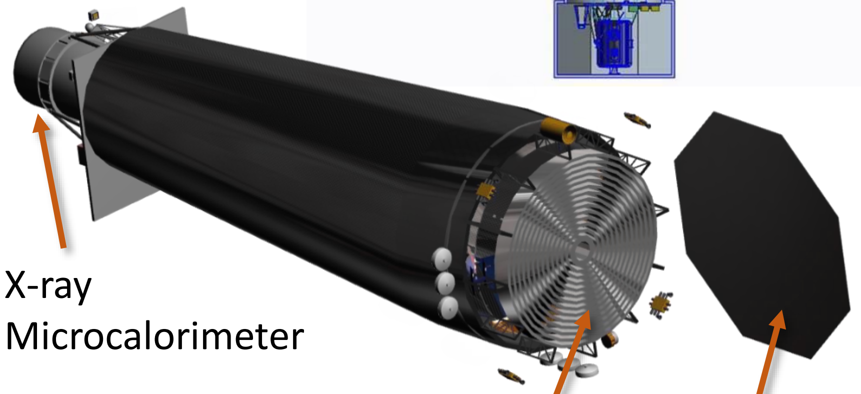


Internal contamination door & gratings mechanisms



Chandra Heritage Considered

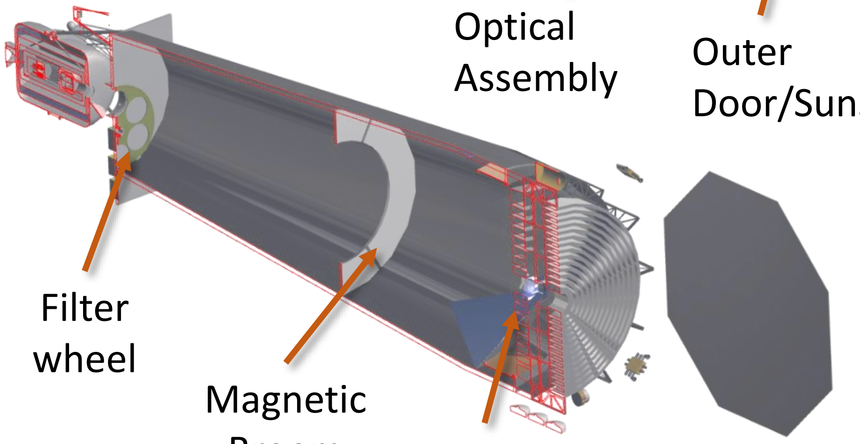


X-ray Microcalorimeter

Optical Assembly

Outer Door/Sunshade

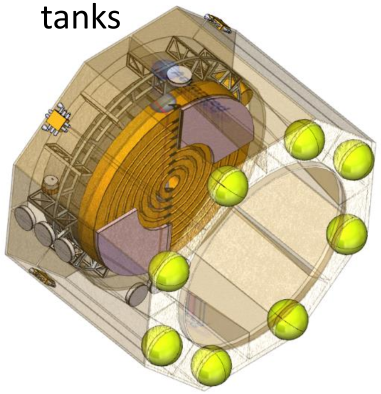


Filter wheel

Magnetic Broom

Grating Array

Mono-prop tanks

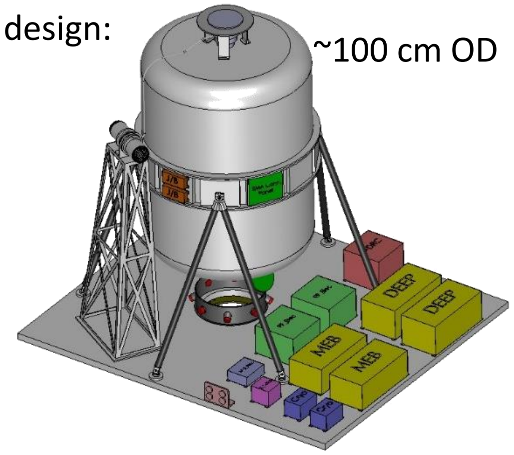


## Integrated Science Instrument Module

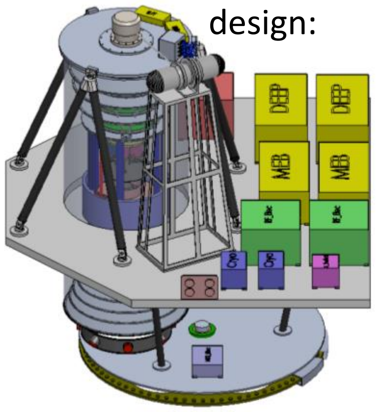
### X-ray Microcalorimeter Designs

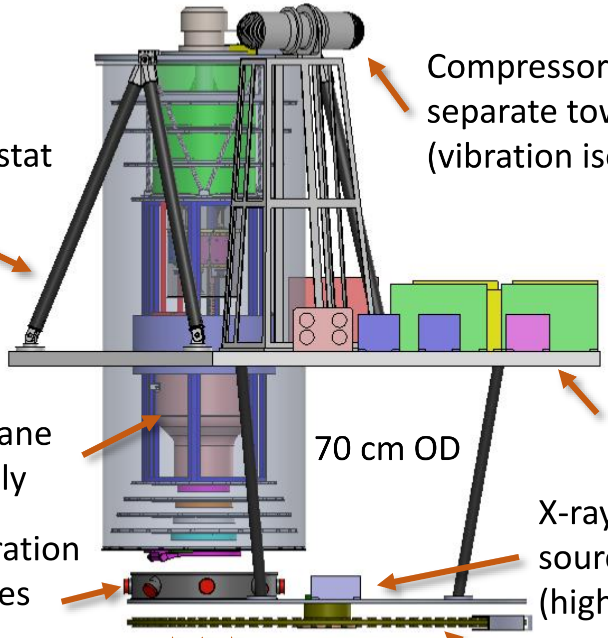
Internal strut design:

~100 cm OD



Thrust tube design:





Compressor on separate tower (vibration isolation)

Bipod cryostat supports

Deck: to be attached to movable table and focusing mechanisms

Focal Plane Assembly

70 cm OD

X-ray calibration source electronics (high voltage)

Calibration sources

X-rays in from telescope

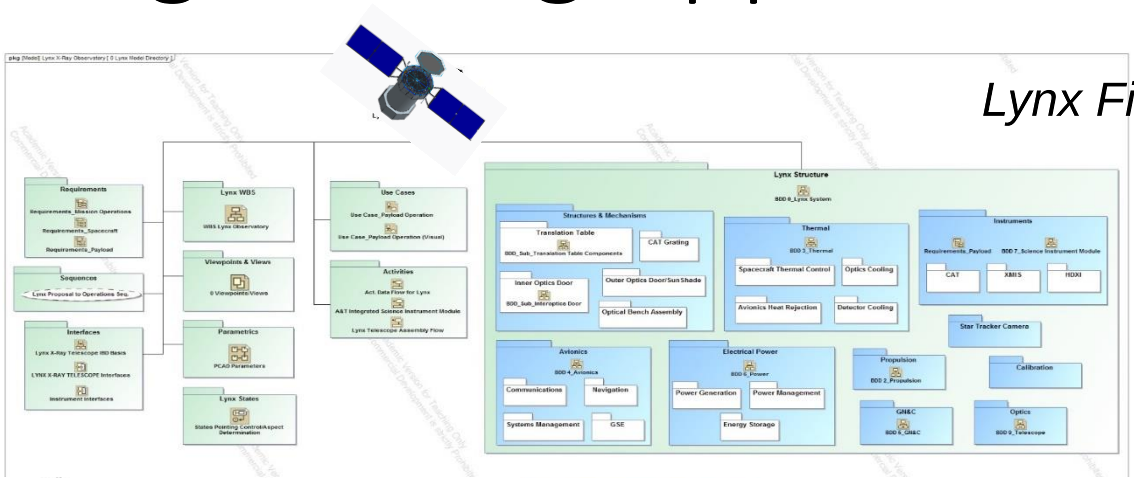
Filter wheel

**S. Bandler, NASA GSFC**

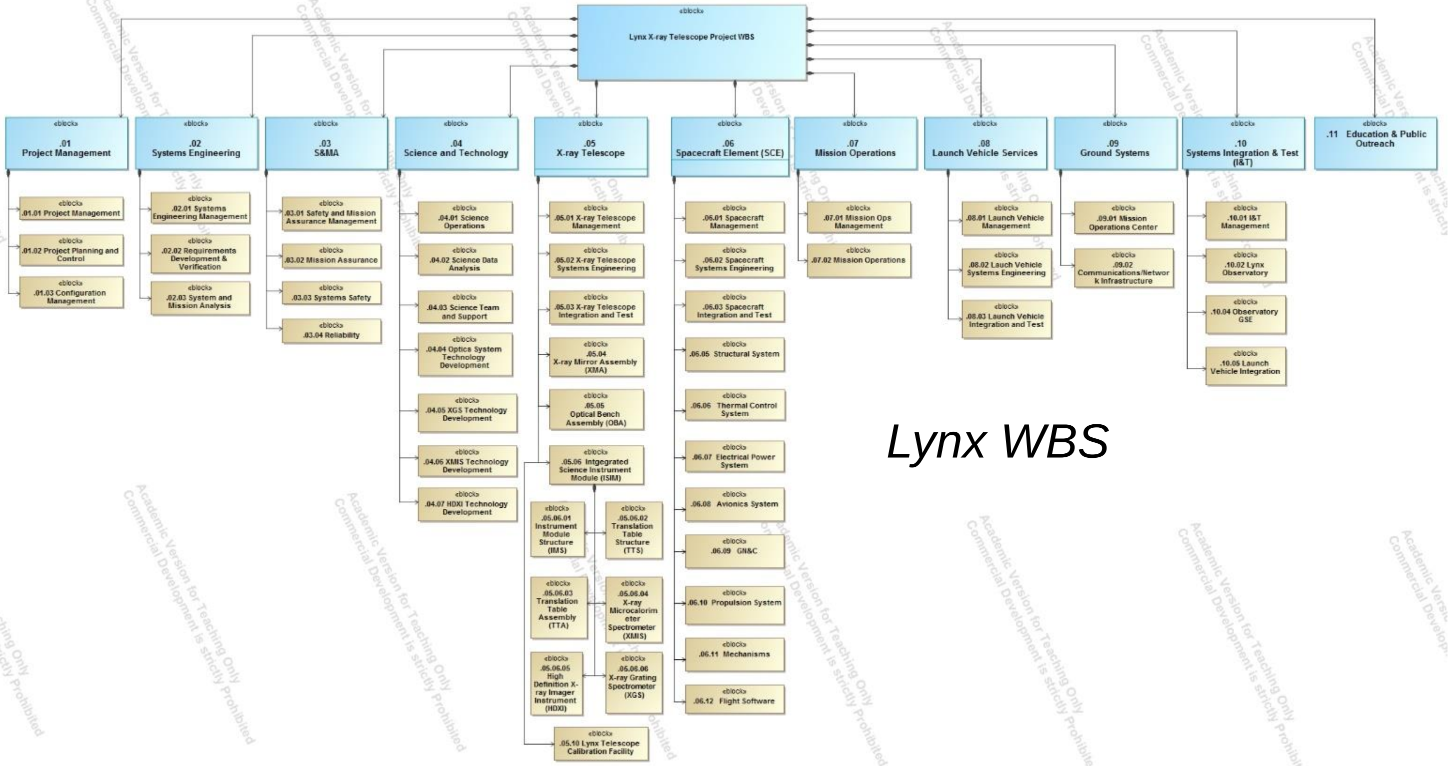
# Model Based Systems Engineering Approach

***Focused on Concept of Operations***

- WBS + dictionary
- Stakeholder Viewpoints
- System Block Diagrams
- System Interface Diagrams (internal and external)
- Use Diagrams
  - Manufacturing
  - AI&T (major sub-systems)
  - Ground Operations
  - Launch Integration
  - Launch Operations (launch, deployment, T&CO)
  - Mission Timeline
  - Science Operations
  - Off-nominal Operations
- Functional Block Diagrams
- System Requirements (Level 1 and 2)




*Lynx File Structure*




*Lynx WBS*

# Thank You!

For the latest Lynx news and events, and to sign up to the News Distribution visit us at:

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

Jessica.Gaskin@NASA.Gov