The *Lynx* X-Ray Surveyor Mission

Abe Falcone (Penn State University)

Presented on behalf of the Lynx Team

<u>Community STDT</u>
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
- Peers deeply into ***origin and evolution of structure*** in the Universe

Lynx Concept Team

<u>Community Science & Technology Definition Team</u>
F. Özel, Arizona (Co-Chair)
A. Vikhlinin, SAO (Co-Chair)

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E. Quataert, Berkeley
C. Reynolds, UMD
D. Stern, JPL

+ Instruments Working Groups: Mark Bautz (Chair)
HDXI Co-Chairs: Abe Falcone, Ralph Kraft
uCal Co-Chairs: Simon Bandler, Enactali Figueroa-Feliciano
Grating Co-Chairs: Randy McEntaffer, Ralf Heilmann

+ Optics Working Group:
Co-Chairs: Mark Schattenberg, Lester Cohen

+ 8 Science Working Groups

There are >250 people across academia, industry, government, and non-US space agencies involved in 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

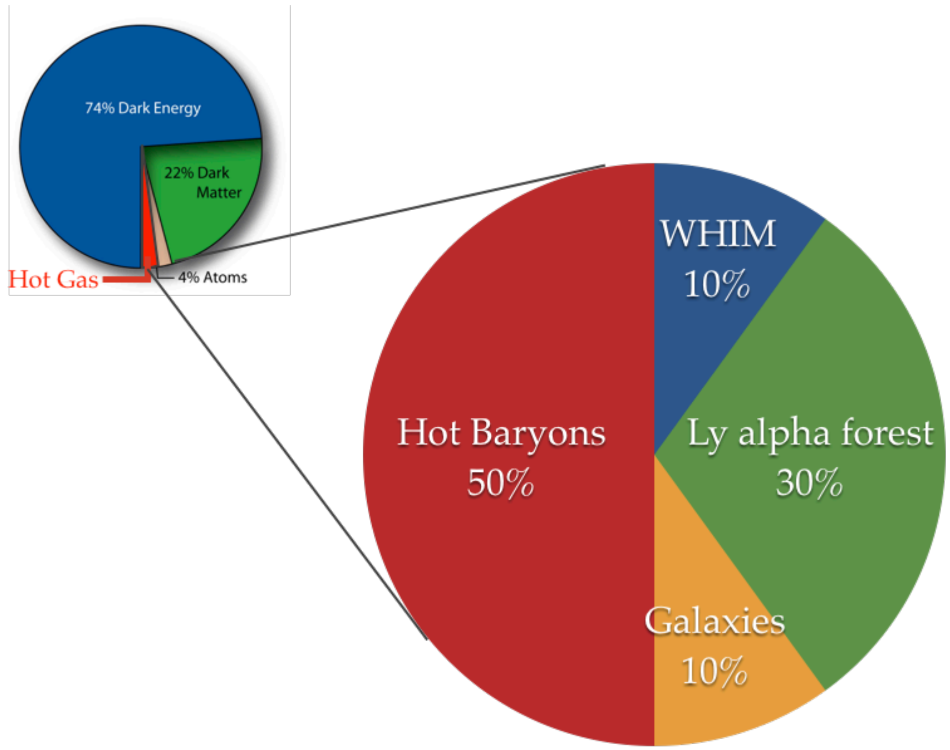
3. A **technology assessment** including: current status, roadmap for maturation & resources

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.

We should be looking at the hot gas

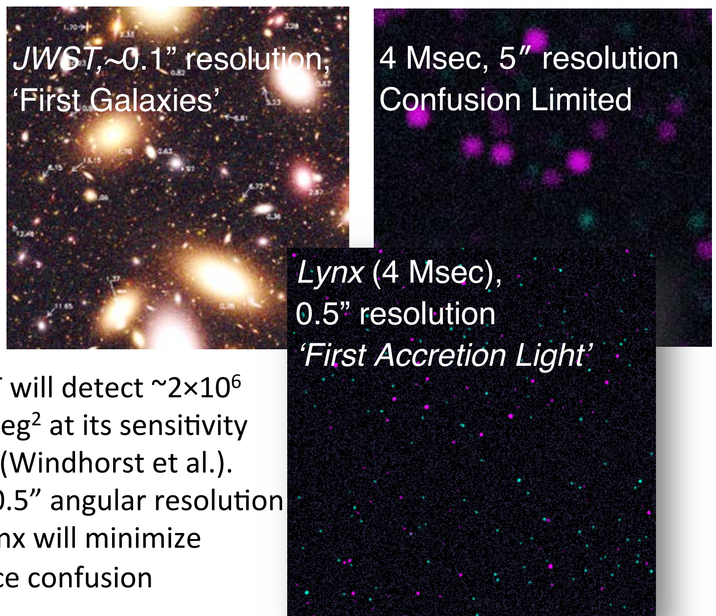
(with required angular & spectral resolution)



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.

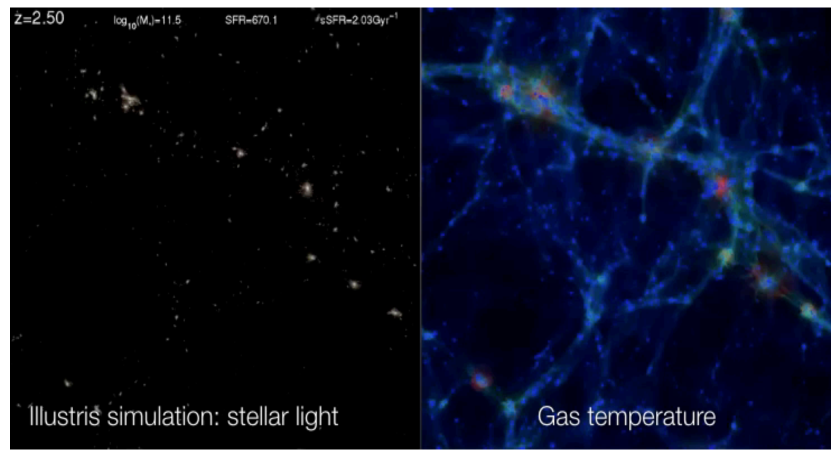
Simulated 2x2 arcmin deep fields



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)

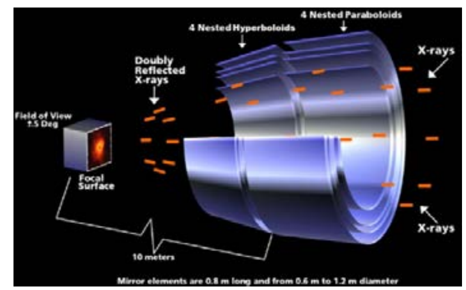
OWG will make a formal recommendation to STDT: 6/1/18
STDT Finalizes their decision: 7/1/18

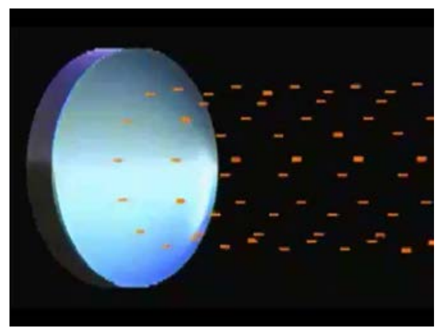
Up-select will be based on Science, Technical and Programmatic criteria (TBF)

- *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

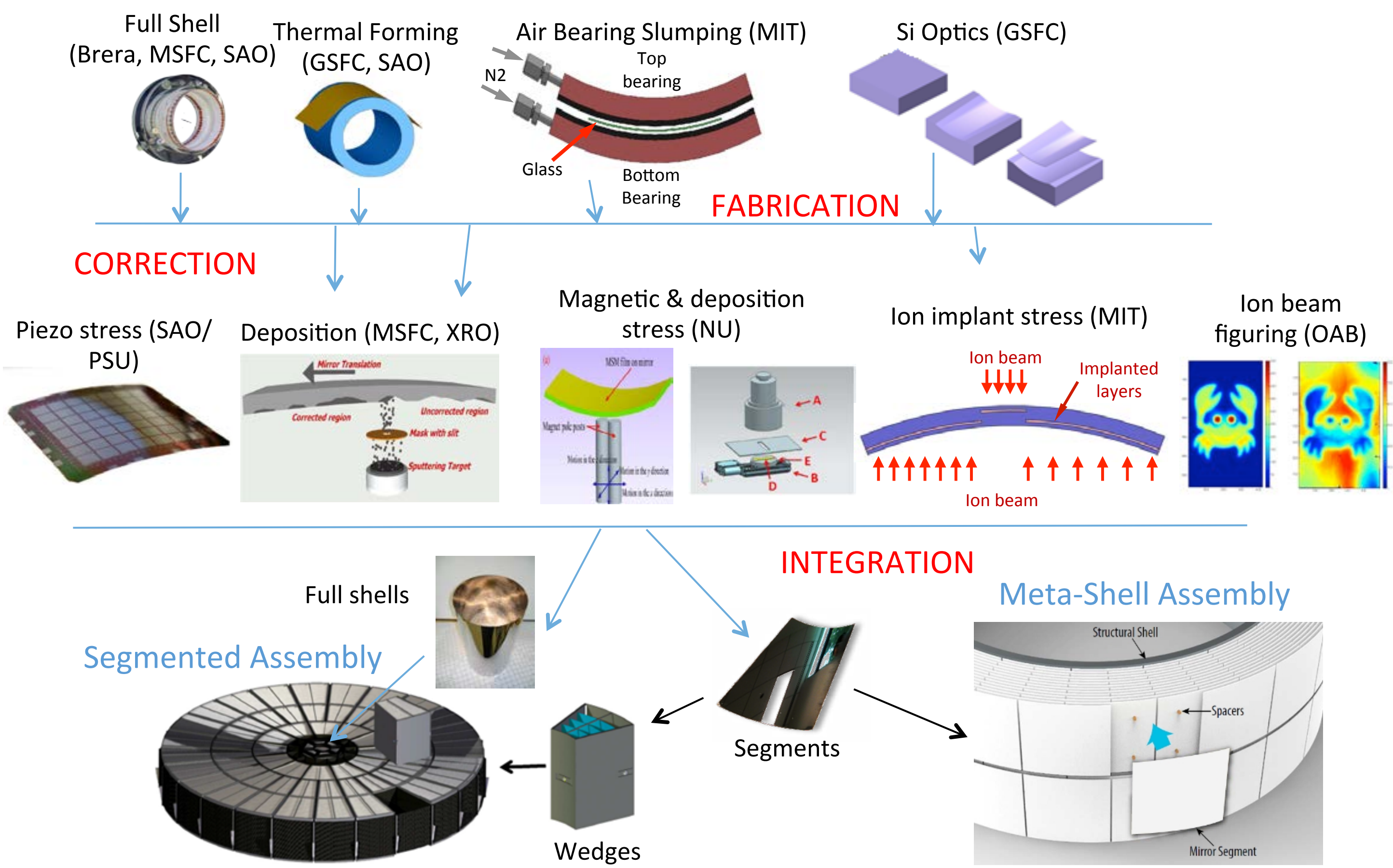
Lynx Optical Assembly	
Angular resolution (on-axis)	0.5 arcsec HPD (or better)
Effective area @ 1 keV	2 m^2 (met with 3-m OD)
Off-axis PSF (grasp), A*(FOV for HPD < 1 arcsec)	≥ 2 m^2 * 300 $arcmin^2$
Wide FOV sub-arcsec Imaging	10 arcmin radius





CXC/D. Berry

Lynx Optical Assembly



Lynx Science Instruments

Instrument Working Group Lead: M. Bautz (MIT)

•High Definition X-ray Imager (HDXI)

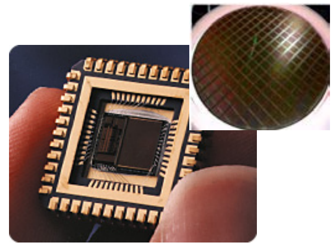
- HDXI Leads: R. Kraft (SAO), A. Falcone (PSU)
- Instrument Design Study (On-going @ MSFC ACO)

•X-Ray Grating Spectrometer (XGS)

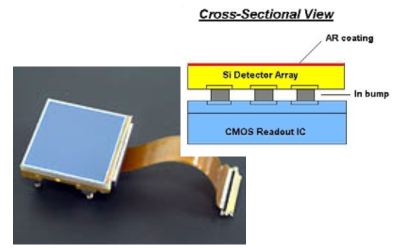
- XGS Leads: R. McEntaffer (PSU), Ralf Heilmann (MIT)
- Instrument Design Study (On-going @ MSFC ACO)

•Lynx X-ray Microcalorimeter (LXM)

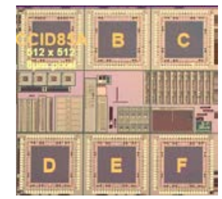
- LXM Leads: S. Bandler (GSFC), E. Figueroa-Feliciano (Northwestern)
- Instrument Design Lab (Completed 1st IDL @ GSFC)



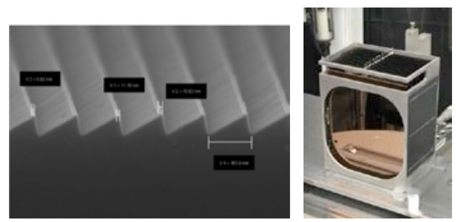
Monolithic CMOS



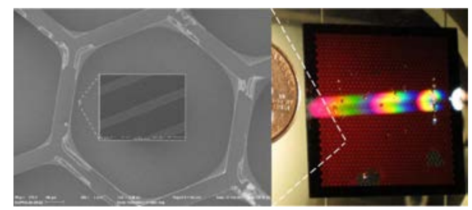
Hybrid CMOS



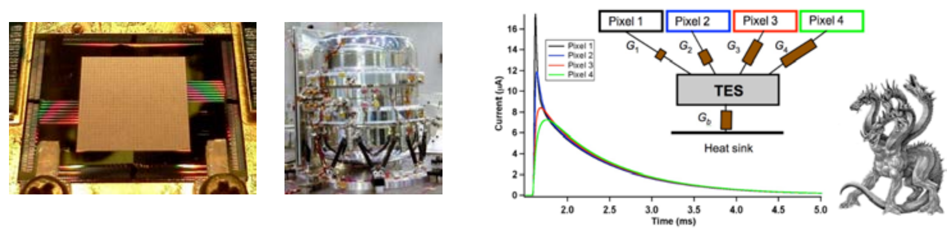
Digital CCD with CMOS readout



Off-Plane Grating Array

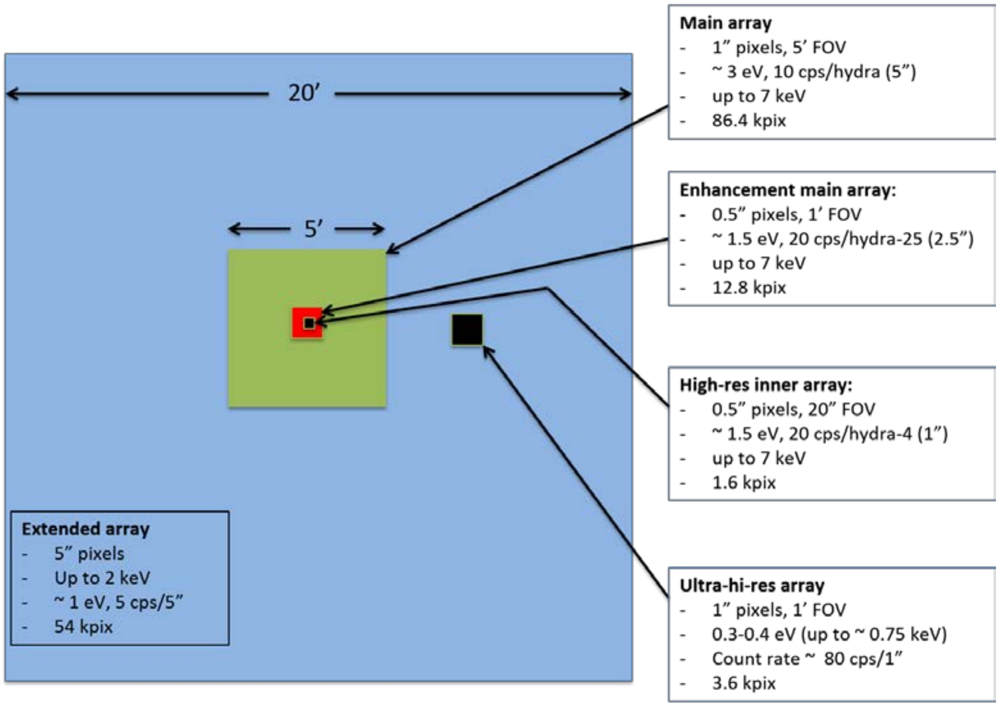


Critical Angle Transmission Grating Array



Lynx X-ray Microcalorimeter

Lynx Science Instruments: Requirements



Notional Calorimeter Pixel layouts

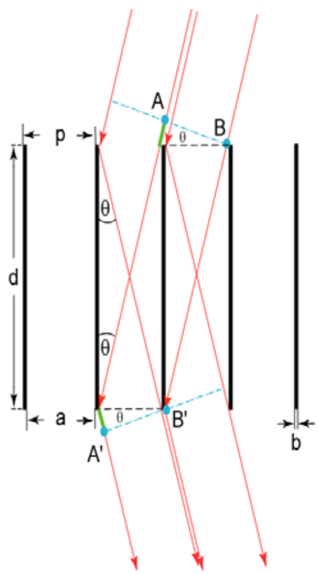
High Definition X-ray Imager (*Notional*)	
Energy Range	0.2 – 10 keV
QE (including filter)	>0.85 at 0.5-7 keV, >TBD from 0.15-0.5 keV
FOV	22′ x 22′ (4k x 4k pixels)
Pixel Size	< 16 x 16 µm (≤ 0.33″)
Read Noise	≤ 4 e^-
Energy Resolution	≤ 70 eV@0.277 keV, ≤ 150 eV@5.9 keV (FWHM)
Frame Rate	> 100 frames/s (full frame) > 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

Requirements: X-Ray Gratings

CATG (MIT)



Grating equation:

$m\,\lambda = p\,(\sin(\theta) + \sin(\beta_m))$,

m = diffraction order

Blazing: $\beta_m \sim \theta$

High reflectivity:

$\theta < \theta_c$ = critical angle of total external reflection

Strawman:

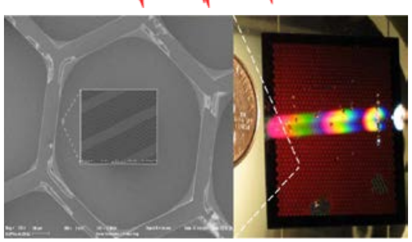
Silicon grating, $\theta = 1.5^{\circ}$

p = 200 nm

b = 40 nm

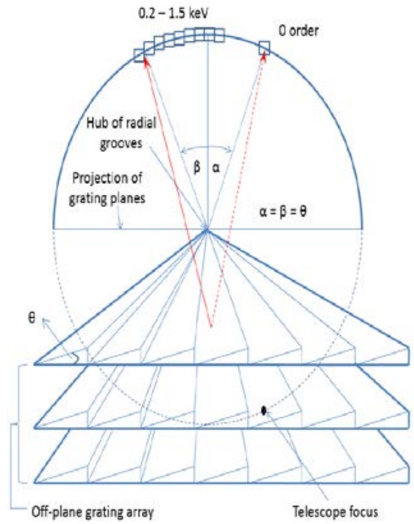
d = 6 μm

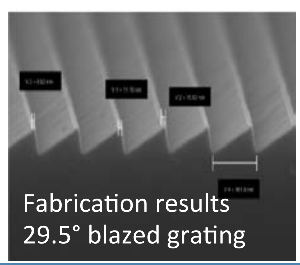
aspect ratio d/b = 150



200 nm-period silicon grating membrane with integrated L1 & L2 supports, > 30x8 mm^2

OPG (Penn State)





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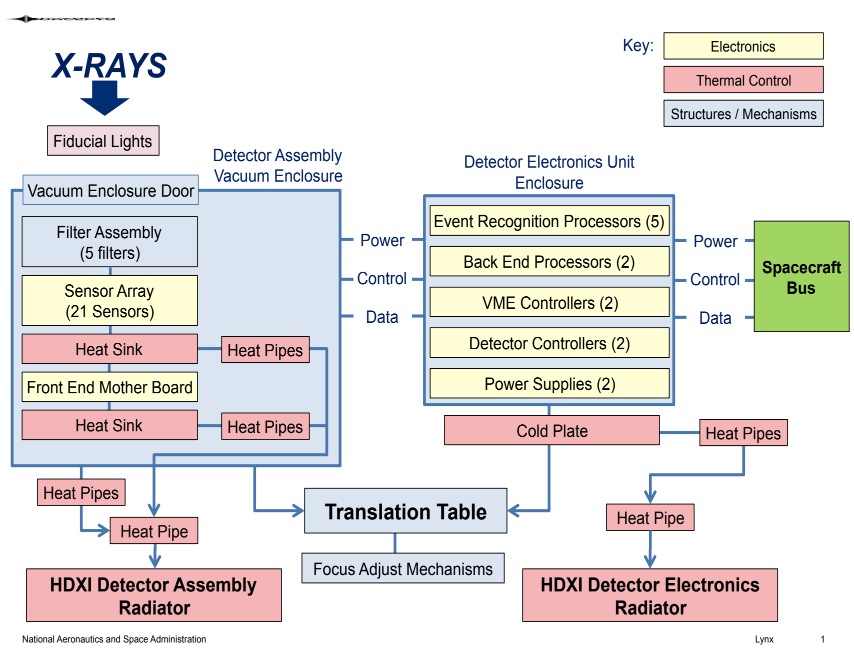
High Definition X-ray Imager (HDXI)



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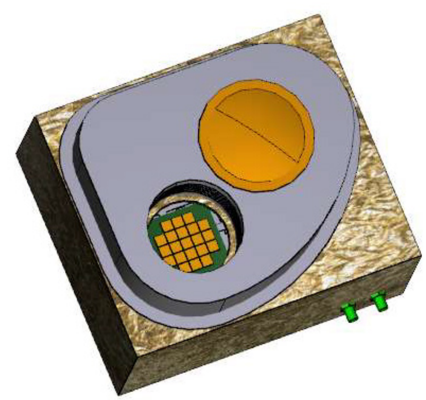
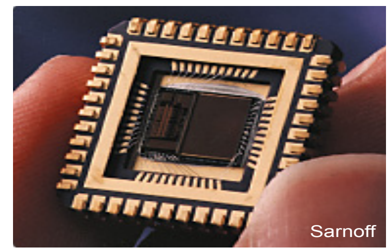
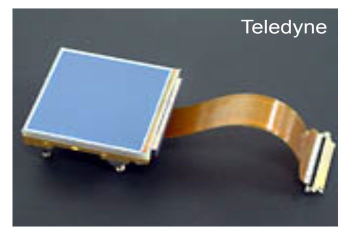


3 Different HDXI Sensors Approaches

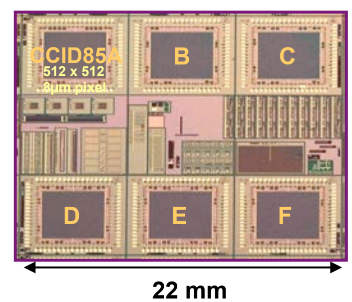
- Monolithic CMOS Active Pixel Sensor
  - Single Si wafer used for both photon detection and read out electronics
  - Sarnoff/SAO and MPE



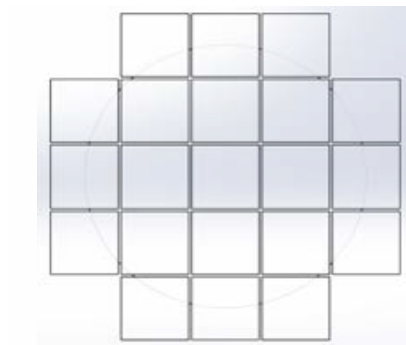
- Hybrid CMOS Active Pixel Sensor
  - Multiple bonded layers, with detection layer optimized for photon detection and readout circuitry layer optimized independently
  - Teledyne/PSU



- Digital CCD with CMOS readout
  - CCD Si sensor with multiple parallel readout ports and digitization on-chip
  - LL/MIT



Notional HDXI Detector Layout Options



Notional schematic layout of detector focal plane : 21 tilted detectors with 1024x1024 pixels (<16 μm pixel pitch) per detector.

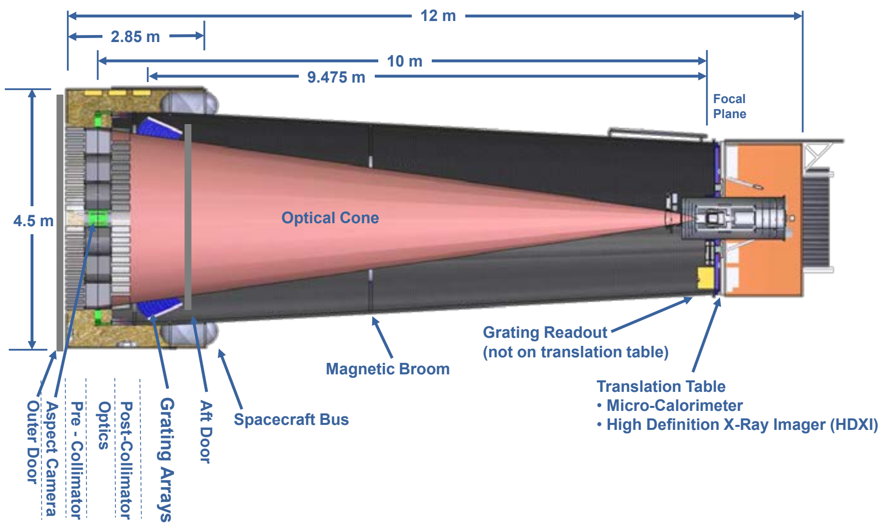
Based on initial ray tracing studies, the multiple tilted detector option appears to be desired (relative to a single 4kx4k) in order to fully realize the angular resolution offered by mirrors with sub-arcsec resolution out to 10 arcmin from center.

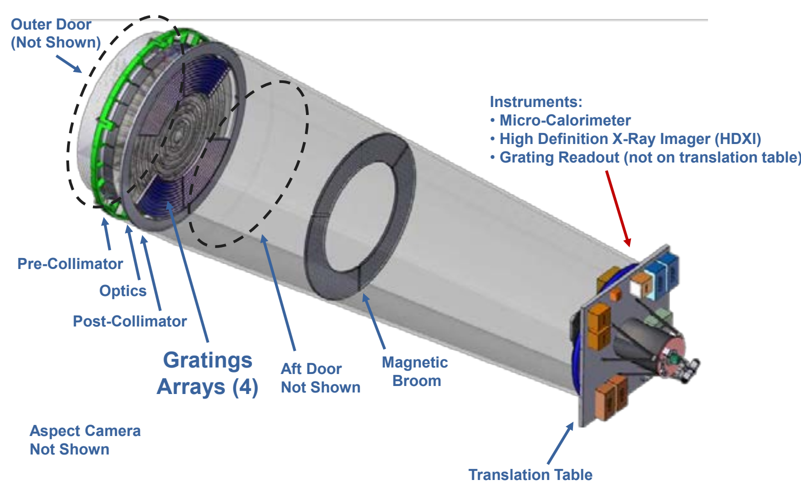
(Curved detectors could also be considered, but they are not necessary for requirements.
Curved detectors could simplify focal plane front-end electronics/wiring by using less detectors.)

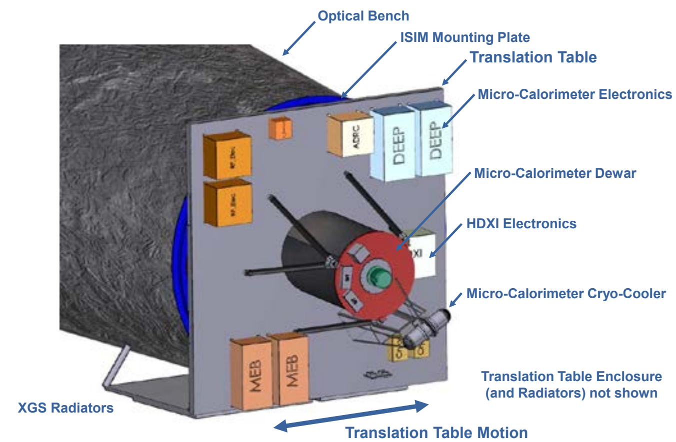
High Definition X-Ray Imager

Technical Challenges

- **Quantum Efficiency:** Hybrids have achieved the depletion depths required for high quantum efficiency across the X-ray band, but the monolithic devices still need to make further developments to achieve these depletion depths
- **Read Noise:** Monolithic architectures have achieved low read noise, but hybrids still need to progress further to achieve < 4 e-
- **Small Pixels/Aspect Ratio:** All devices have achieved small pixel sizes, but further development is needed to do this while retaining other advantages and while limiting impacts of increased charge diffusion due to the increase in the aspect ratio of pixel depth-to-width
- **Rate:** While higher frame rates are already possible with APSs, relative to CCDs, significantly more development is needed to handle the data from these increased frame rates at the focal plane level and to achieve the required read noise while simultaneously achieving fast frame rates for the long-term mission requirements (>100 frame/sec for >16 Mpix cameras)
- **High QE down to 0.15 keV:** STDT science discussions suggest Emphasis on soft (<1 keV) efficiency as a key driver. This will require high quantum efficiency from the sensor and high transmission from the optical blocking filter.

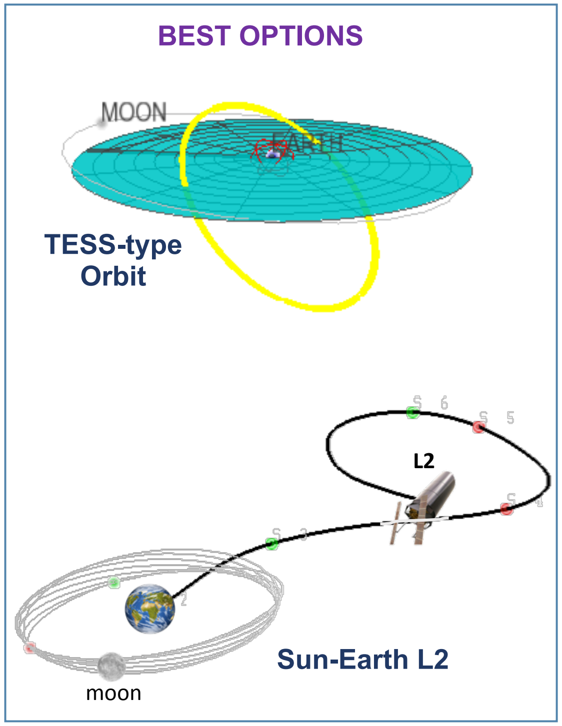

12 m
2.85 m
10 m
9.475 m
Focal Plane
4.5 m
Optical Cone
Grating Readout
(not on translation table)
Magnetic Broom
Translation Table
• Micro-Calorimeter
• High Definition X-Ray Imager (HDXI)
Spacecraft Bus
Outer Door
Aspect Camera
Pre - Collimator
Optics
Post-Collimator
Grating Arrays
Aft Door


Outer Door
(Not Shown)
Instruments:
• Micro-Calorimeter
• High Definition X-Ray Imager (HDXI)
• Grating Readout (not on translation table)
Pre-Collimator
Optics
Post-Collimator
Gratings
Arrays (4)
Aft Door
Not Shown
Magnetic
Broom
Aspect Camera
Not Shown
Translation Table


Optical Bench
ISIM Mounting Plate
Translation Table
Micro-Calorimeter Electronics
DEEP
DEEP
Micro-Calorimeter Dewar
HDXI Electronics
Micro-Calorimeter Cryo-Cooler
MEB
MEB
Translation Table Enclosure
(and Radiators) not shown
XGS Radiators
Translation Table Motion

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*]

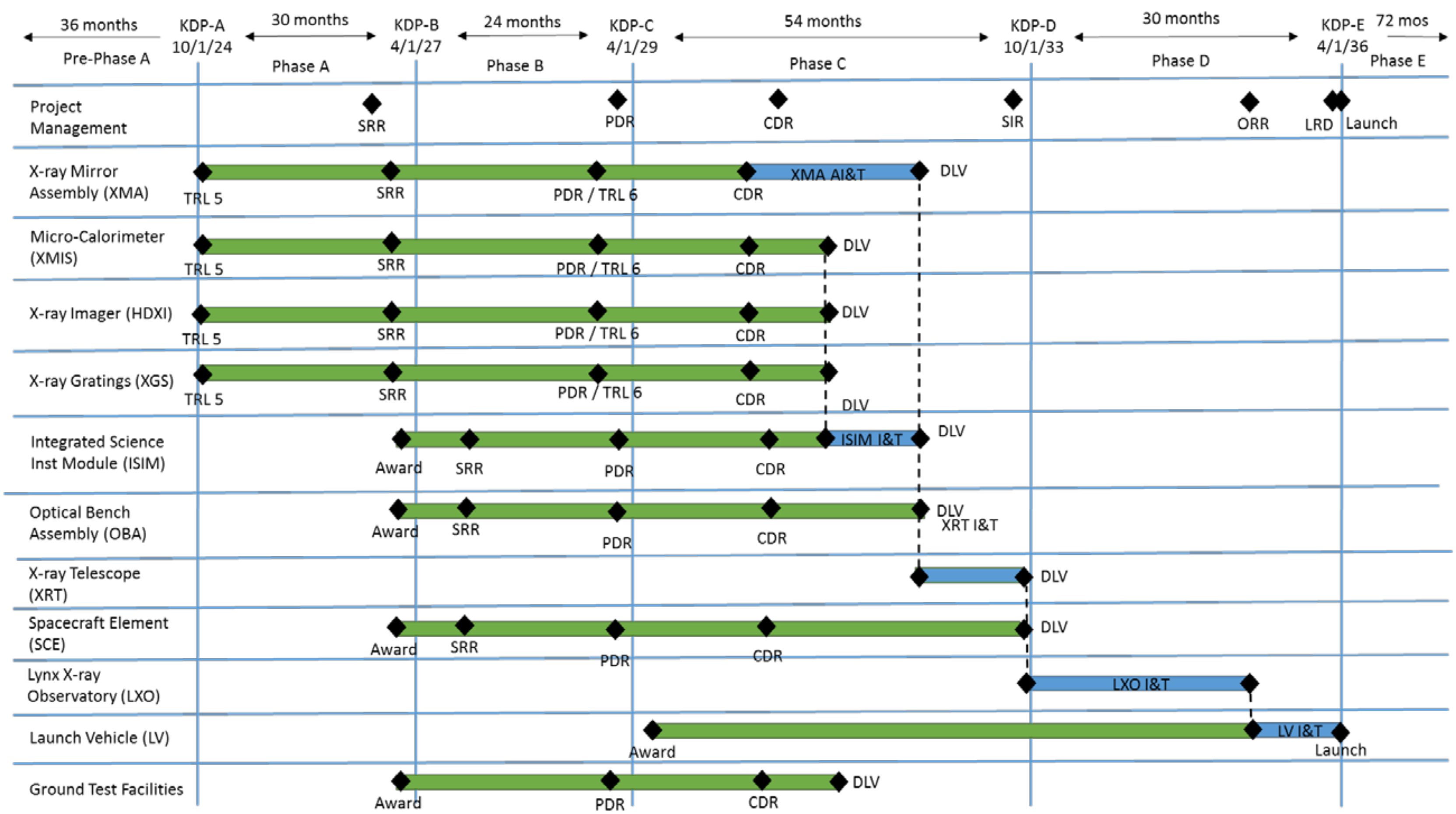


Orbit Trade (SE-L2 vs. TESS)

- 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***

Lynx X-ray Observatory – Notional Mission Lifecycle Schedule



Thank You!

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