TRACKING THE ELUSIVE LYNX INTO THE 2020 ASTROPHYSICS DECADAL SURVEY

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-Presented On behalf of the *Lynx* Team

X-RAY OBSERVATORY

LYNX

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

NASA ASTROPHYSICS PLANNING FOR THE 2020 DECADAL SURVEY

Decadal Survey Missions

Elusive – in the 2010 Decadal

Chandra/AXAF – 1980 Decadal (Ranked 1st)

Proposal submitted in 1976 (“formal beginning”), Launch 1999

IXO – 2010 Decadal (Ranked 4th)

Lost to WFIRST, New Explorer Missions, and LISA

“The technical risk is medium high. Cost threats and uncertainties due to the immaturity of some of the required technologies have added considerably to the cost appraisal.”

Lynx – 2020 Decadal (launch would be ~2036, or 60 years since the start of Chandra)

Why is this time different?
What can we do differently this time?

2020 Decadal Environment

4 large missions are being studied for the 2020 Decadal
- Lynx (Formerly X-Ray Surveyor)
- LUVOIR
- Origins Space Telescope
- HabEx

Probe-class missions ($400M to $1B)
- Astrophysics Probe is defined as mission with total lifecycle cost (NASA's Phase A through E) in range $400M to $1B.

Gravitational wave recent discoveries (L3 contributions)

<u>Relevant X-ray Missions</u>:
ATHENA (ESA) (2028-2038?)
XARM (JAXA) (2021-??)
ASTROSAT (India) (2015-??)
IXPE (SMEX) (2020)
ARCUS (MIDEX) (Phase A)

Continue Explorer class mission cadence or increase cadence?

4 per decade (MIDEX $250M, SMEX $165M)

X-RAY OBSERVATORY
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The Process

Astrophysics Decadal Survey Committee

Selected by the National Academies (NOT NASA!)

New Worlds, New Horizons in Astronomy and Astrophysics recommends a balanced and executable program that will support research surrounding the most profound questions about the cosmos. The discoveries ahead will facilitate the search for habitable planets, shed light on dark energy and dark matter, and aid our understanding of the history of the universe and how the earliest stars and galaxies formed. [http://sites.nationalacademies.org/bpa/bpa_049810]

Deliverables

1. science case
2. notional mission concept
3. design reference mission
4. technology assessment
5. cost assessment
6. top level schedule

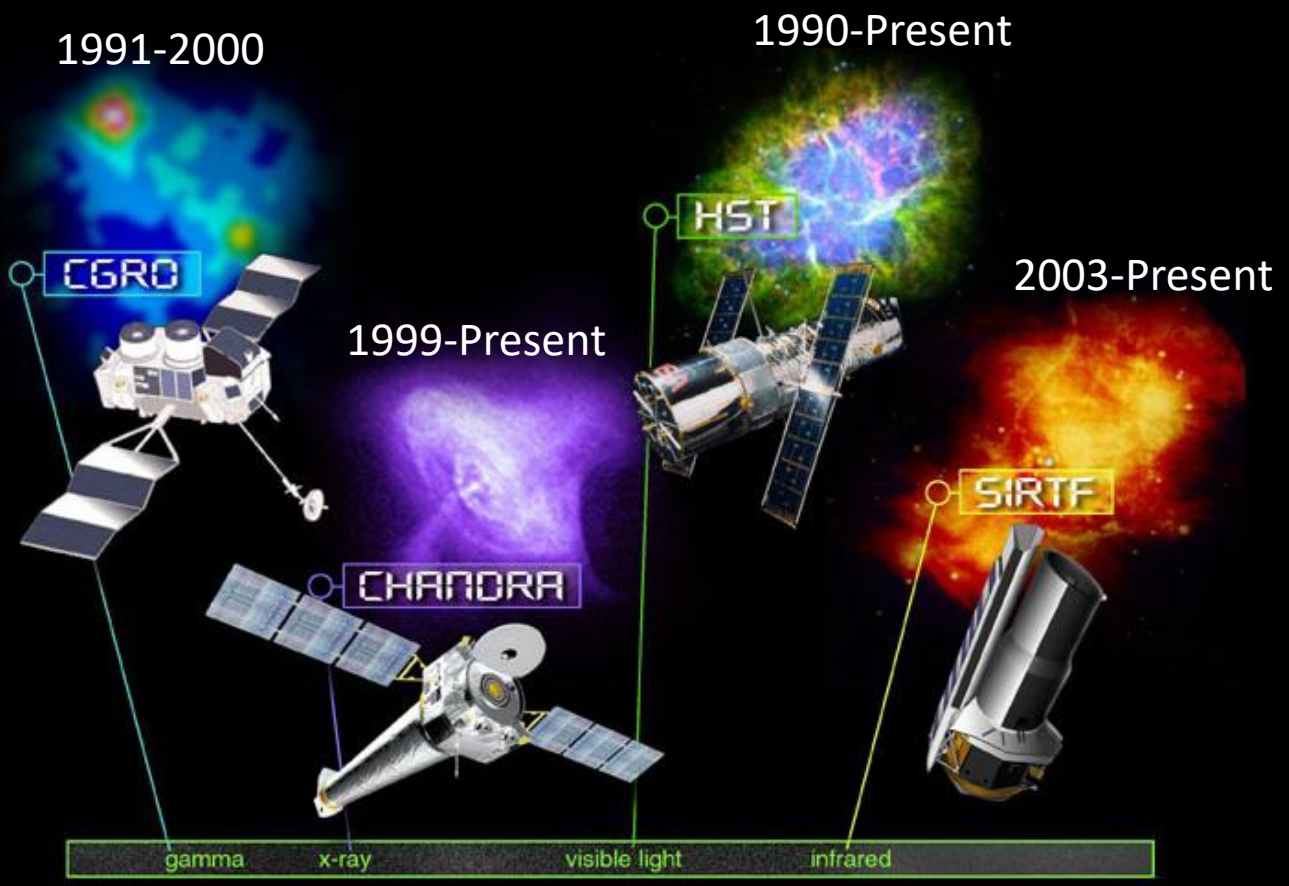
Astronomy Community Chose
4 Missions to Study:

1. **Lynx – X-Ray Mission** (MSFC + SAO)
2. **LUVOIR – Large UV Optical IR** (GSFC)
3. **OST - Origins Space Telescope Far IR** (GSFC)
4. **HabEx – Habitable Exoplanets** (JPL)

NASA's Great Observatories

NASA's Mission:

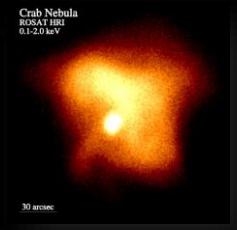
- *Innovate*
- *Explore*
- *Discover*
- *Inspire*



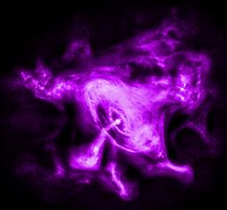
Each observatory was designed to push the state of technology in its intended wavelength region.

X-RAY OBSERVATORY
LYNX

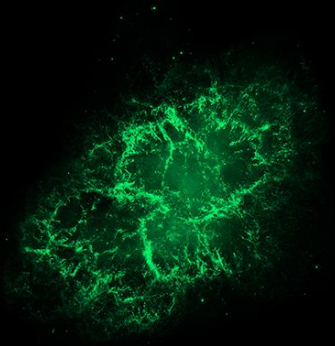
Chandra Vision



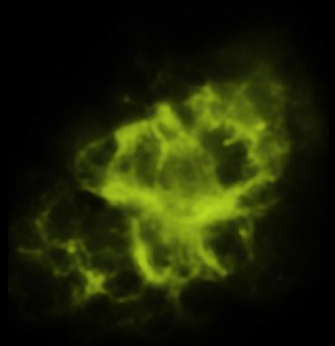
ROSAT
(X-ray)
Resolution: 5 arcsec



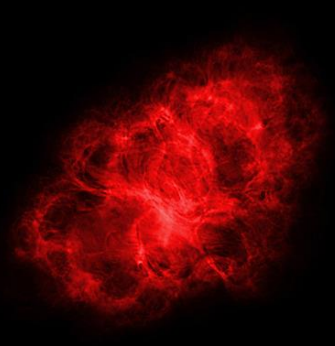
Chandra
(X-ray)
Resolution: 0.5 arcsec



Hubble
(visible)
Resolution: 0.05 arcsec



Spitzer
(IR)

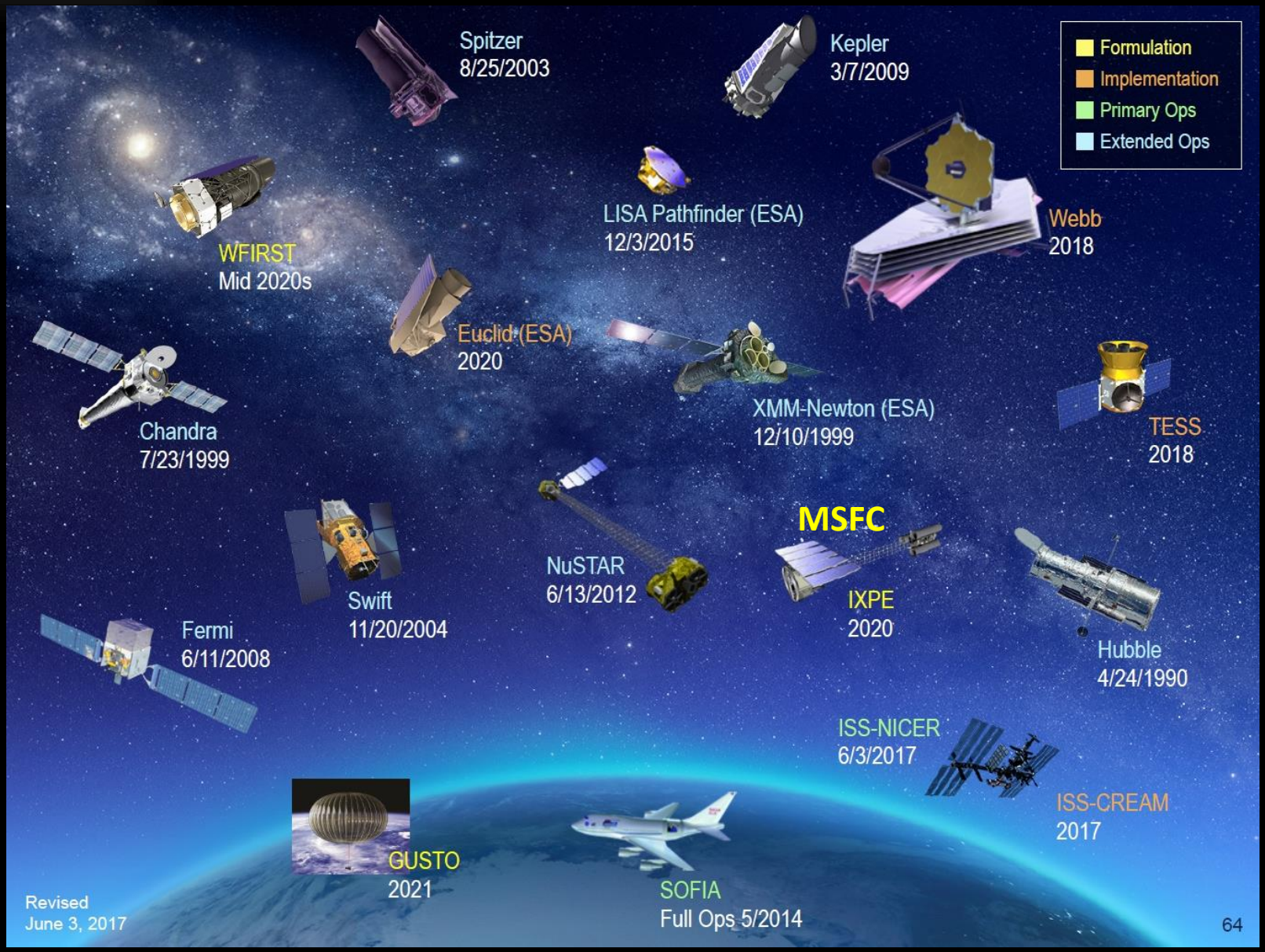


VLA
(radio)

XMM-OM
(UV)

X-RAY OBSERVATORY LYNX

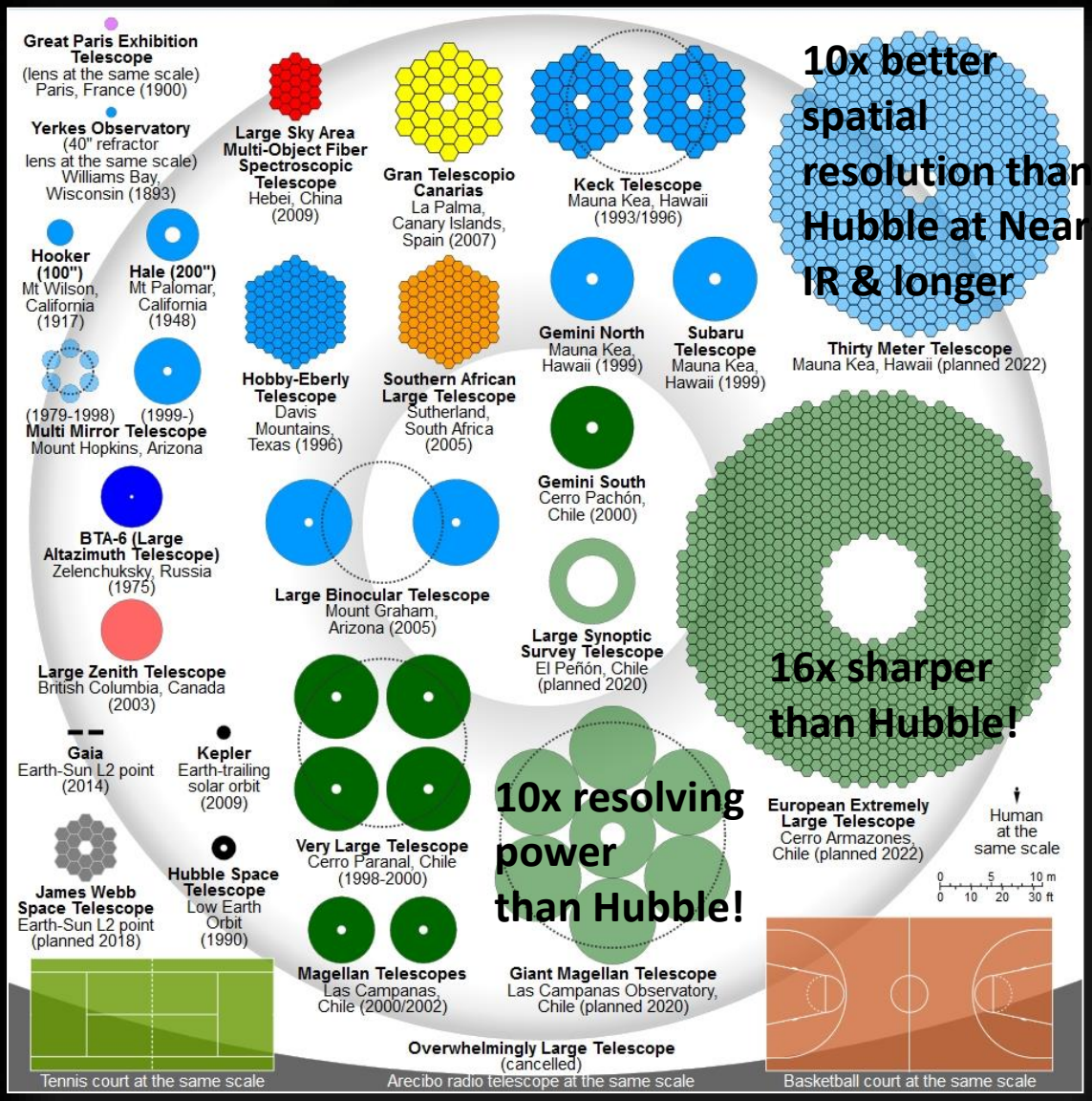
Astrophysics Landscape



Hertz, 2017

X-RAY OBSERVATORY
LYNX

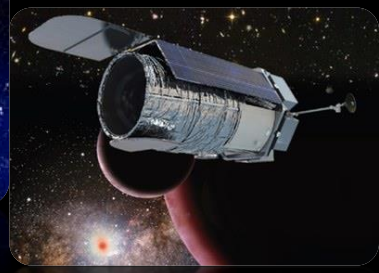
Ground & Space



ATHENA

- Mapping hot gas structures & determining their physical properties
- Searching for SMBH

WFIRST



- Dark Energy
- Exoplanets
- Large Area NIR Surveys

What's Next ???

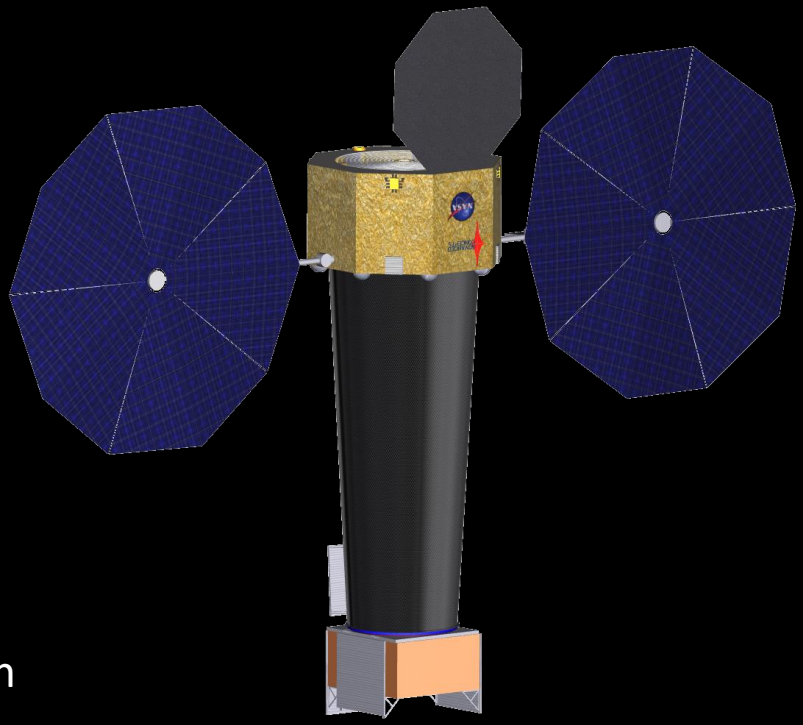
https://xkcd.com/1294/

By Cmglee - https://commons.wikimedia.org/w/index.php?curid=33613161

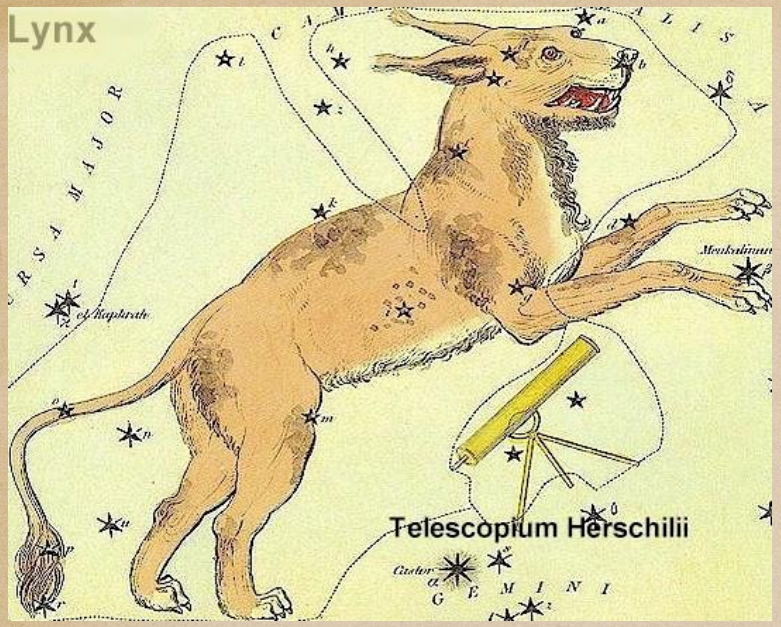
Meet *Lynx*!

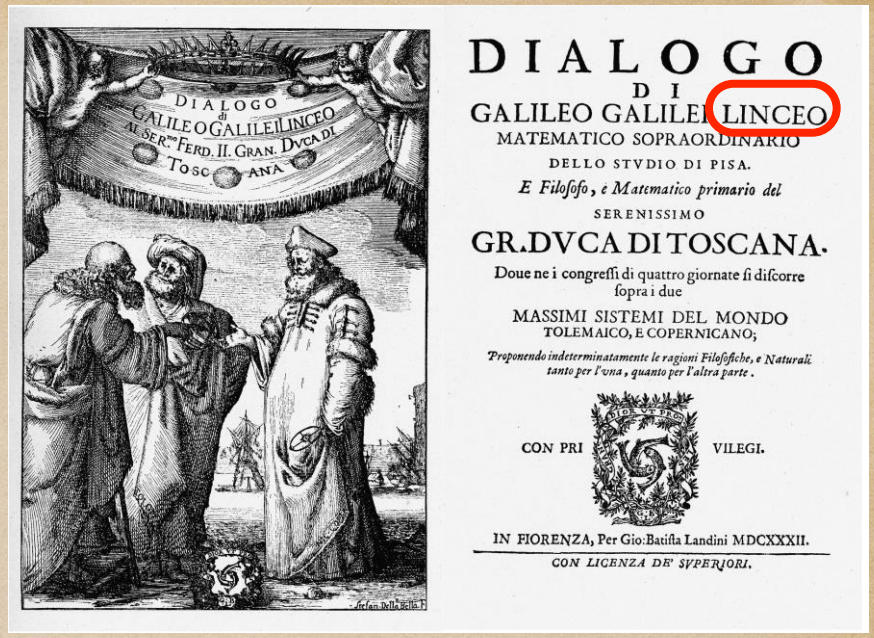
***Lynx* is a large X-ray Observatory that will revolutionize our view of the Universe by providing unique insight into the high-energy drivers that govern its formation and evolution.**

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



Lynx - Acronym Free!





- A symbol of great insight
- Ability to see through rocks and trees to **reveal the true nature of things**.

The historic Accademia dei Lincei (Academy of the 'Lynx-eyed') based their name on this ability to perform incisive and penetrating investigations of the natural world.

Galileo was a proud member, and **the Academy of the Lynx coined the term telescope** for his marvelous device for peering into the cosmos.

- 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

Meet The Team!


Steve Allen, Stanford


Megan Donahue, MSU


Laura Lopez, Ohio State


Jessica Gaskin, MSFC (Study Scientist)


Alexey Vikhlinin, SAO (Co-Chair)


Feryal Özel, Arizona (Co-Chair)


Piero Madau, UCSC


Ryan Hickox, Dartmouth


Mark Bautz, MIT


Daniel Stern, JPL


Eliot Quataert, Berkeley


Zoltan Haiman, Columbia


Niel Brandt, Penn State


Tesla Jeltema, UCSC


Rachel Osten, STScI


Dave Pooley, Trinity


Chris Reynolds, UMD


Andrey Kravtsov, Chicago


Joel Bregman, Michigan


Juna Kollmeier, OCIW


Frits Paerels, Columbia


Andy Ptak, GSFC

- **8 Science Working Groups**
- **Optics Working Group**
- **Calibration Working Group**
- **Communications Working Group**
- **Instrument Working Group**
- **7 ex-officio International members**

Over 275 total members!

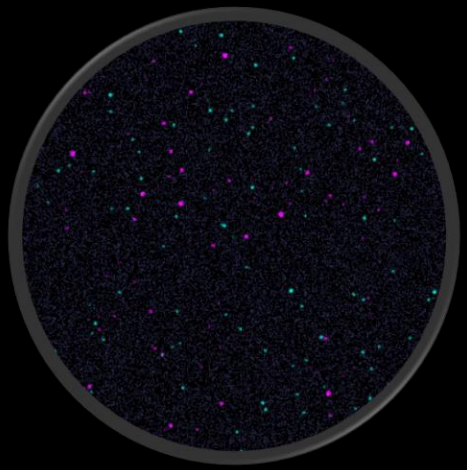
Science Pillars

The Dawn of Black Holes

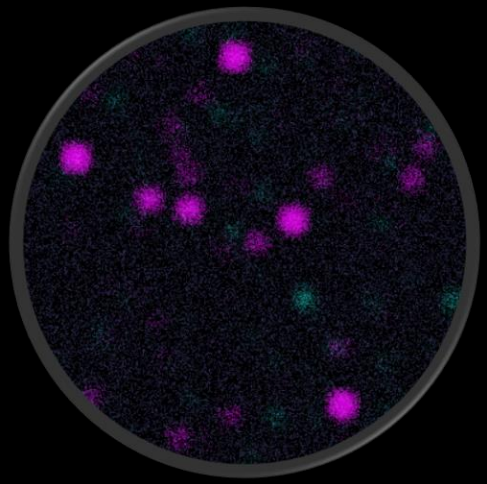
Lynx will observe the birth of the first black holes, when the universe was ~ half a billion years old (z ≈ 10) and provide a census of the supermassive black hole population in the local and distant universe, follow their growth and assembly across cosmic time, and measure the interplay with their surroundings on all scales.

JWST,~0.06" resolution,
'First Galaxies'

Lynx (4 Msec),
0.5" resolution (minimal source confusion)
'First Accretion Light'



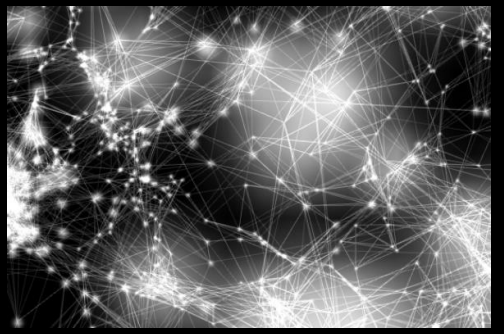
4 Msec, 5″ resolution
Confusion Limited



- The detection of quasars at z > 6 unveils the presence of supermassive black holes of a few billion solar masses
- The rapid formation process of these early SMBHs is still a mystery. Such discovery implies that seed black holes must have formed early on, and grown via either rapid accretion or BH/galaxy mergers.

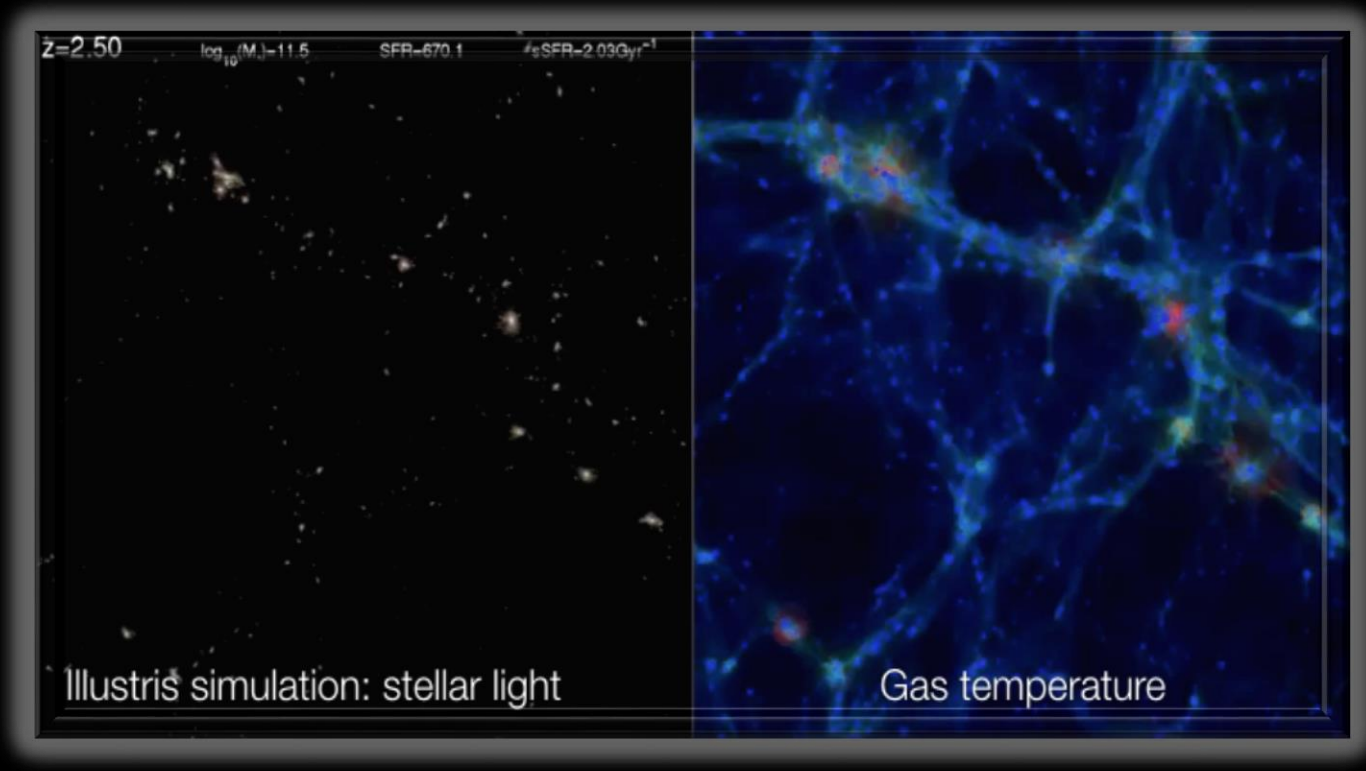
Latif & Ferrara 2016)

Science Pillars



The Invisible Drivers Behind Galaxy Formation and Evolution

The assembly, growth, and state of visible matter in 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.



Observatory-Class Science

Lynx will significantly contribute to our understanding of Stellar Lifecycles and will uniquely constrain their local environments and provide insight into our own solar system

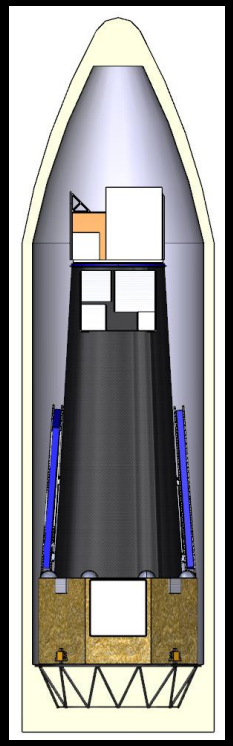
How do stars form?
How do circumstellar disks evolve, form planetary systems?
How diverse are planetary systems?
Do habitable worlds exist on other stars?
How do rotation and magnetic fields affect stars?

- Uniquely Observe and Characterize feedback from star formation using observations of the Milky Way and Local Group galaxies
- Use X-ray surveys of pre-main sequence stars to map instantaneous star formation in different environments
- Use Lynx data on SNR and stellar remnants to understand the SN explosion mechanism

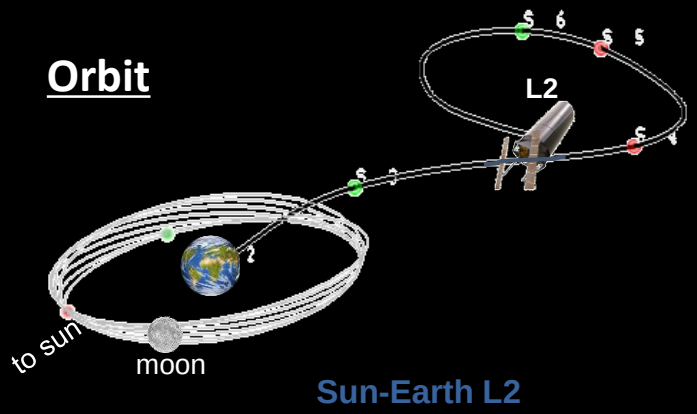
Lynx Mission

Launch Vehicle

Heavy-class launch vehicle is needed



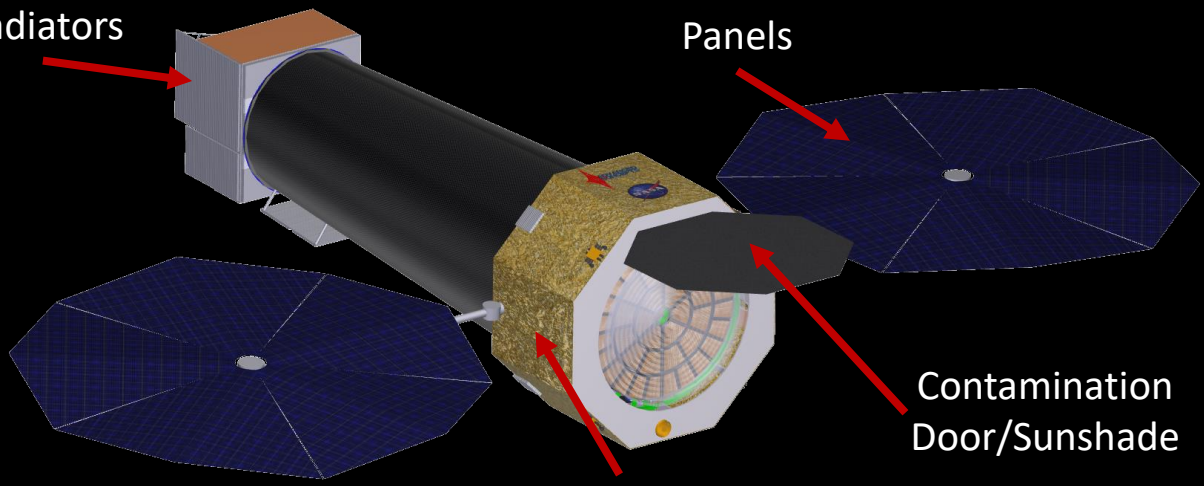
Orbit

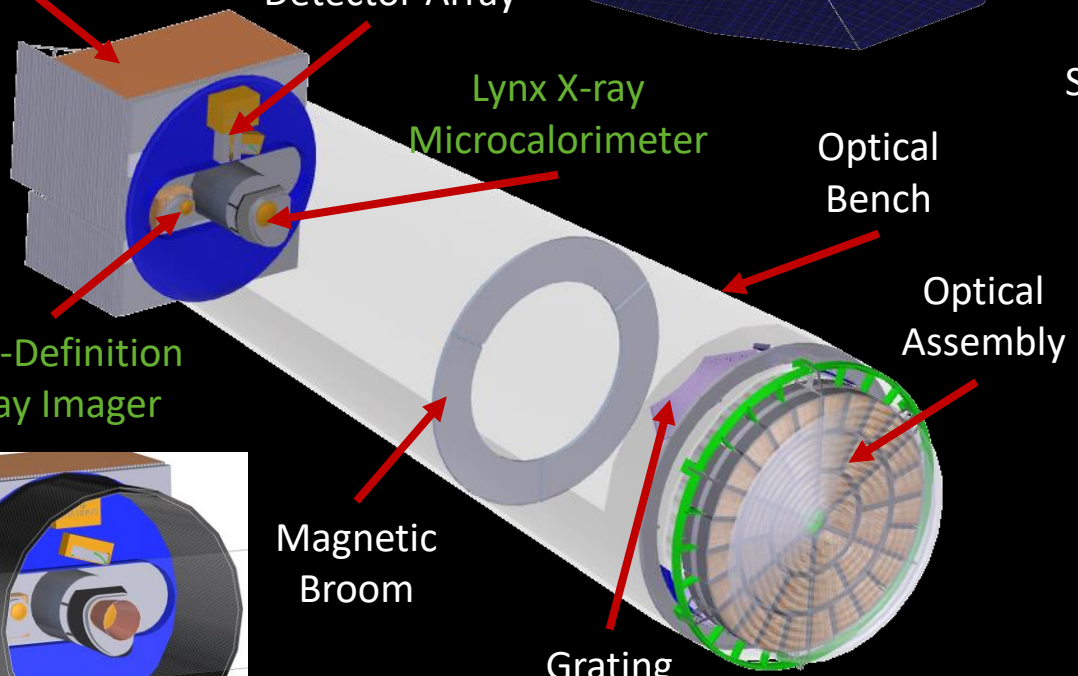


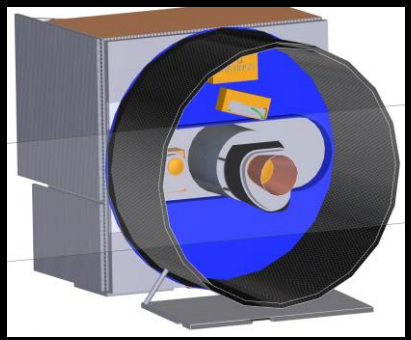
Mission Lifetime : Baseline mission is 10 years, extendable for an additional 10 years

Mission Operations: Chandra-like. Lynx will have a primary science program combined with a general observer program

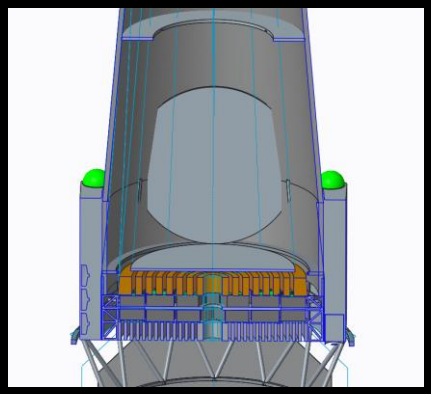
Lynx Observatory



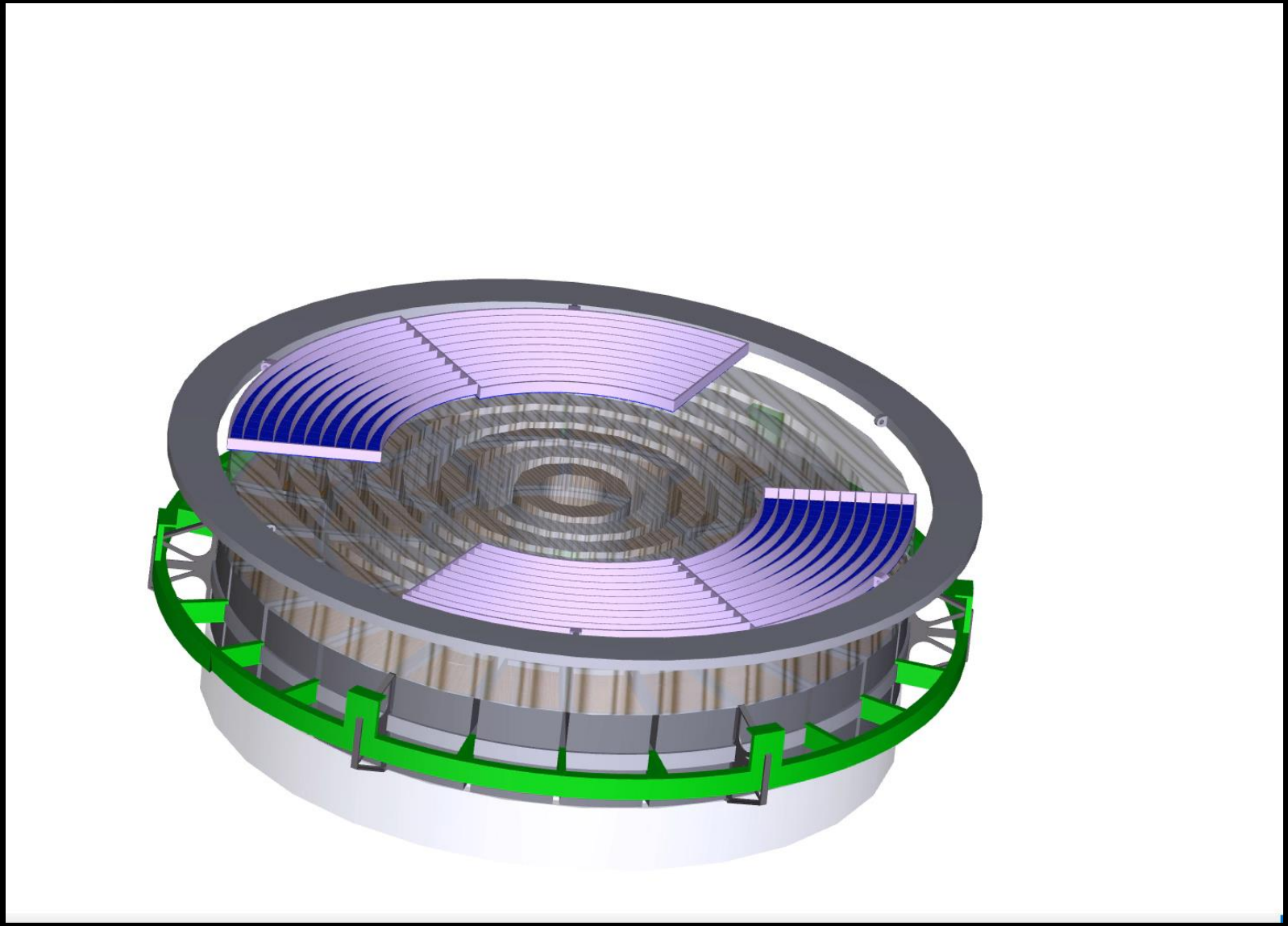




Internal contamination door & gratings mechanisms

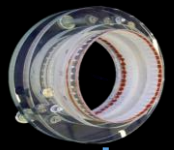


Lynx Animated



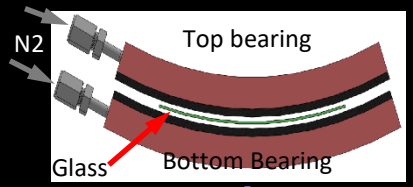
Taxonomy of X-ray Telescope Fabrication

Full Shell (Brera, MSFC, SAO)

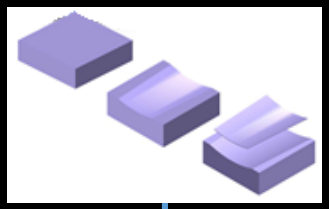


Thermal Forming (GSFC, SAO)

Air Bearing Slumping (MIT)



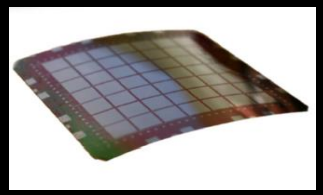
Si Optics (GSFC)



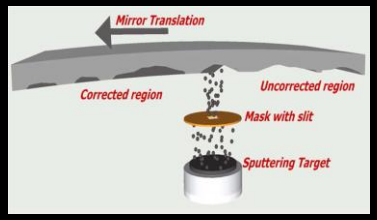
FABRICATION

CORRECTION

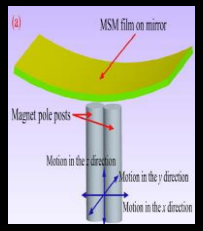
Piezo stress (SAO/PSU)

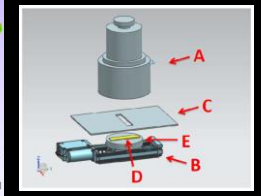


Deposition (MSFC, XRO)

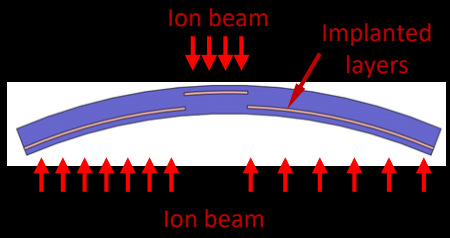


Magnetic & deposition stress (NU)

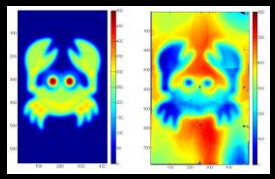




Ion implant stress (MIT)



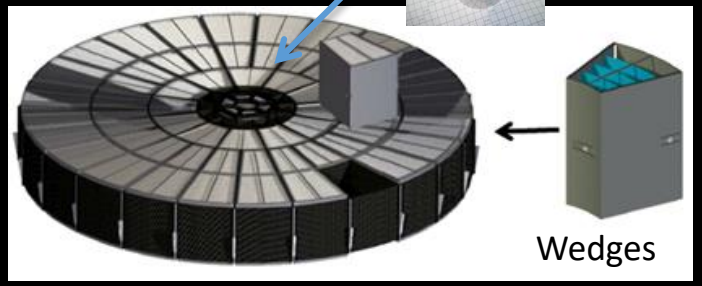
Ion beam figuring (OAB)

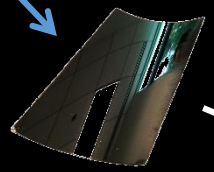


INTEGRATION

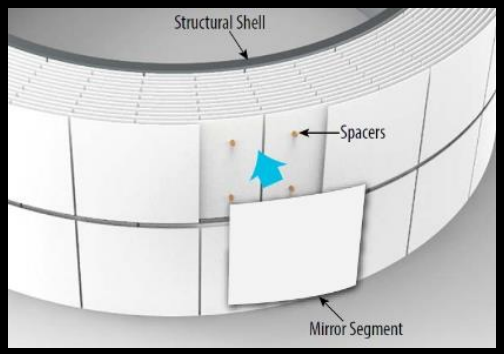
Full shells

Segmented Assembly





Meta-Shell Assembly



Lynx Optical Assembly

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

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

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 $arcmin^2$
Wide FOV sub-arcsec Imaging	10 arcmin radius

Decisional Criteria

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

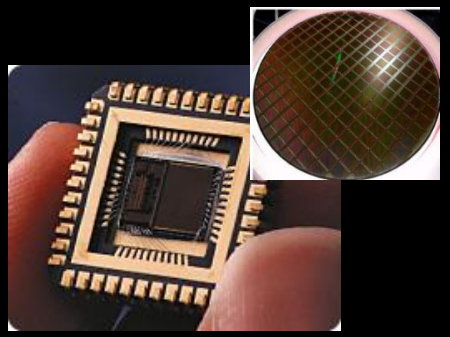
Examples (not a complete list):
- *Does the configuration Satisfy Science Requirements?*
- *Is there a feasible path for development?*
- *Is there a feasible error budget?*
- *Are there existing X-ray measurements and/or analyses?*
- *Can it interface with the spacecraft and survive launch?*

Optics Working Group:
Innovative technologies for mirror elements are pursued at MSFC, SAO, GSFC, MIT, etc. The *Lynx* Optics Working has been charged with developing a working optical design, identify industry participation, and to assist the STDT with trades and development relevant to the technology roadmap.

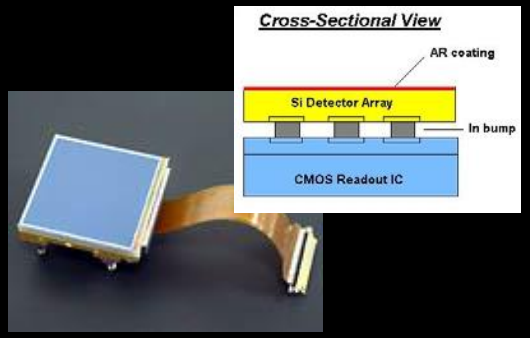
OWG will make a formal recommendation to STDT in Summer 2018

Lynx Instrument Suite

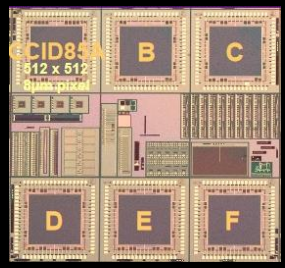
High Definition X-ray Imager (HDXI)



Monolithic CMOS



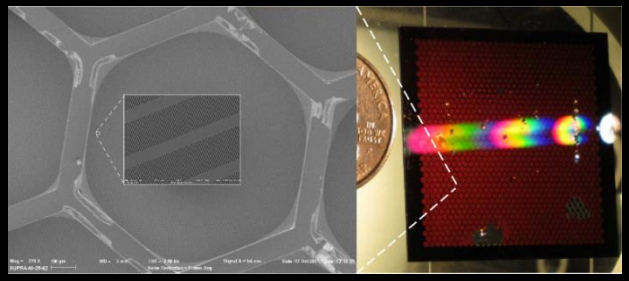
Hybrid CMOS



Digital CCD with CMOS readout

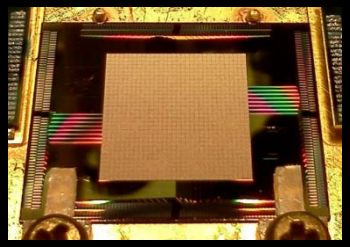
X-Ray Grating Spectrometer (XGS)

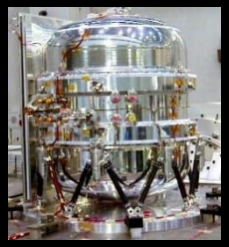
Off-Plane Grating Array

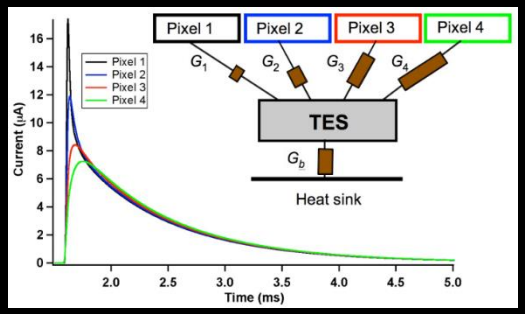


Critical Angle Transmission Grating Array

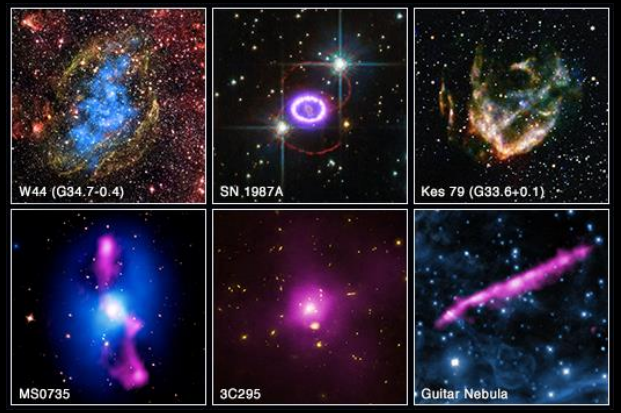
Lynx X-ray Microcalorimeter (LXM)



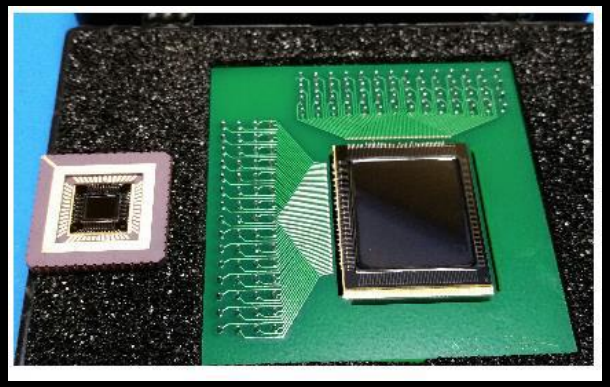




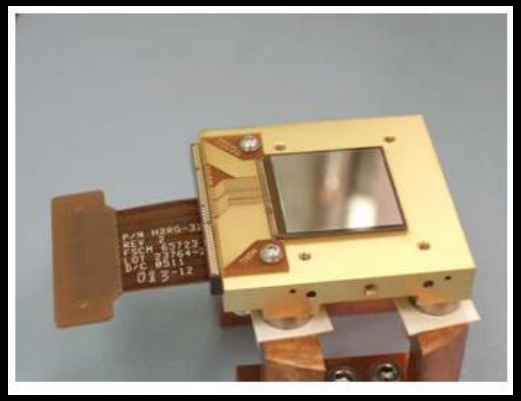
High Definition X-ray Imager (HDXI)



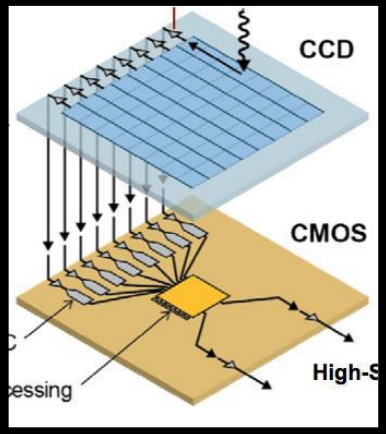
Every X-ray observatory launched in the past 20 years has flown CCDs. Lynx will use Active Pixel Sensors.



Monolithic CMOS (Sarnoff/SAO, and MPE)



Hybrid CMOS (TBE/PSU)



Digital CCDs w/ CMOS readout (LL/MIT)

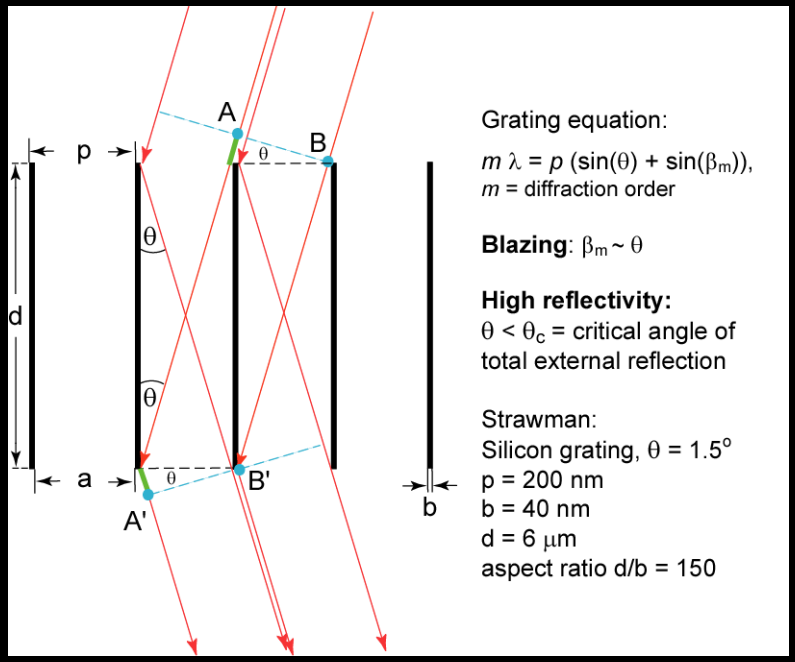
Key improvements over CCDs

- Orders of magnitude higher frame rates
- Significantly improved radiation hardness
- Fully addressable
- Lower power
- Near room temperature operation
- Large format (up to 4Kx4K) abuttble devices
- Near Fano-limited resolution over entire bandpass

X-Ray Grating Spectrometer (XGS)

Lynx XGS will provide high spectral resolution (R > 5000) and high effective area (~4000 cm^2) at low energies (0.3-1.0 keV)

CATG (MIT)



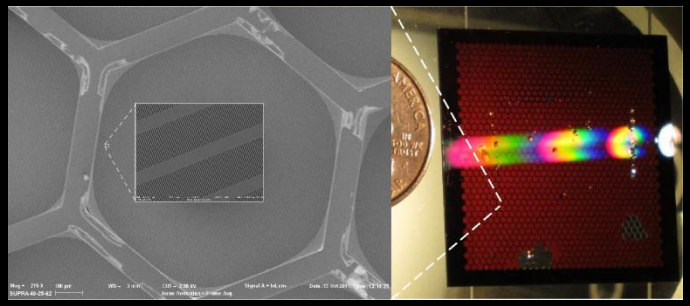
Grating equation:

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

Blazing: $\beta_m \sim \theta$

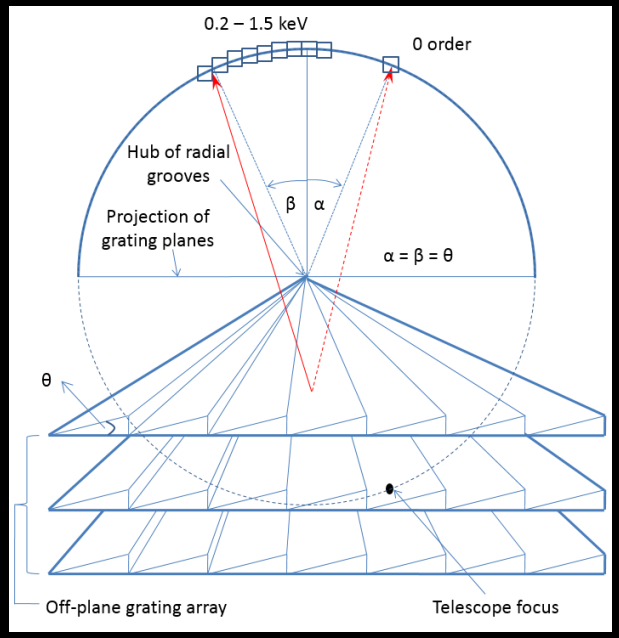
High reflectivity:
$\theta < \theta_c$ = critical angle of total external reflection

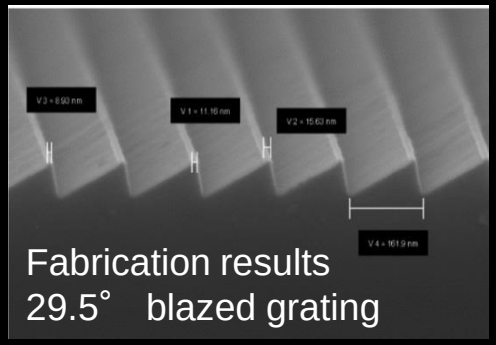
Strawman:
Silicon grating, $\theta = 1.5^\circ$
p = 200 nm
b = 40 nm
d = 6 μm
aspect ratio d/b = 150



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

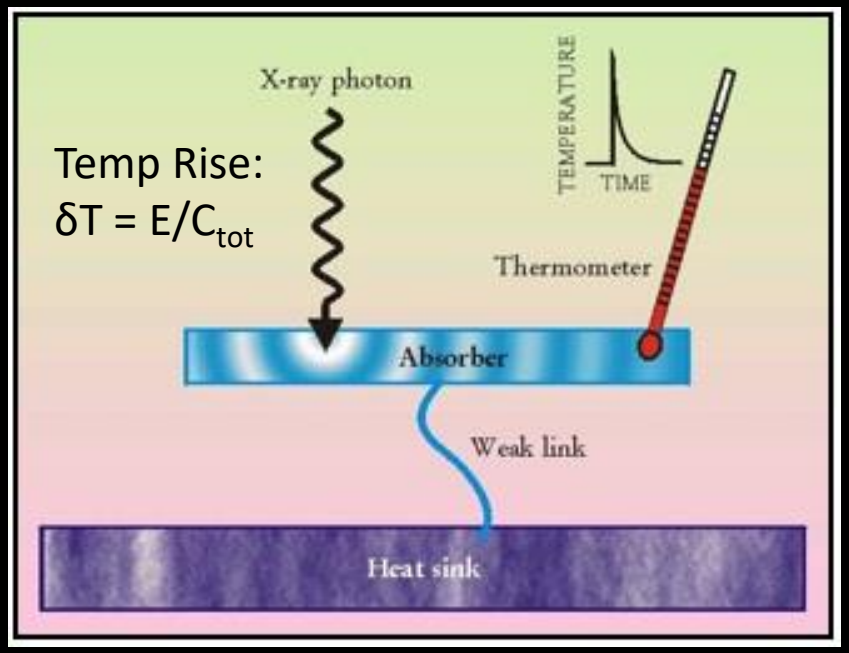
OPG (Penn State)

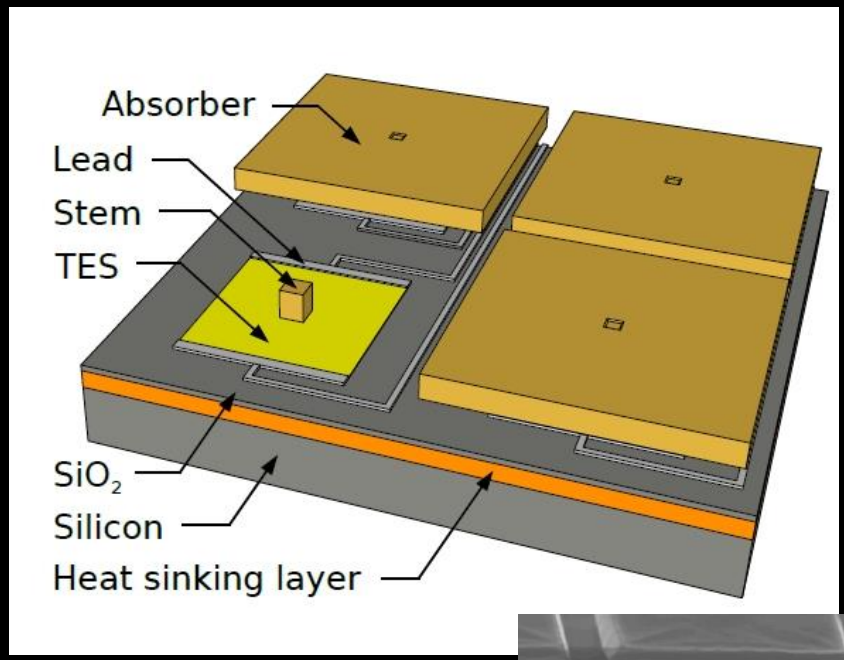




Lynx X-ray Microcalorimeter (LXM)

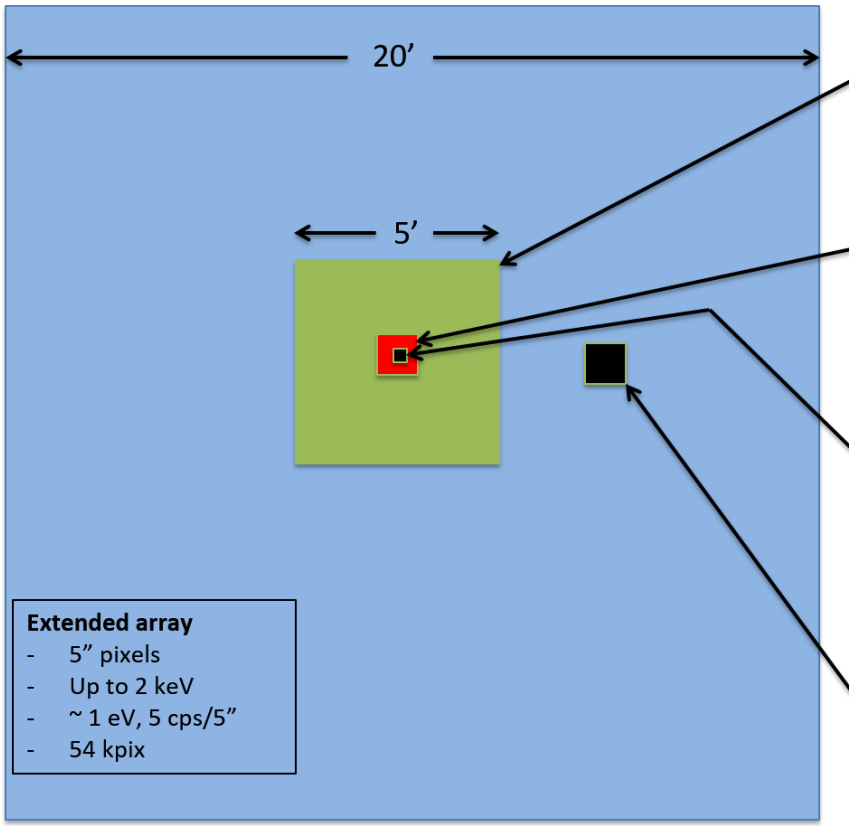
Converts individual incident X-ray photons (0.2-7 keV) into heat pulses and measure their energy via precise thermometry. Must operate at cold temps of ~50 mK.





- Mapping hot gas in nearby galaxies
- Determining the state of the gas in high-z groups and clusters
- Supernova feedback studies
- Observing spatially-resolved plasma outflow velocities (O VII lines)

Lynx X-Ray Microcalorimeter

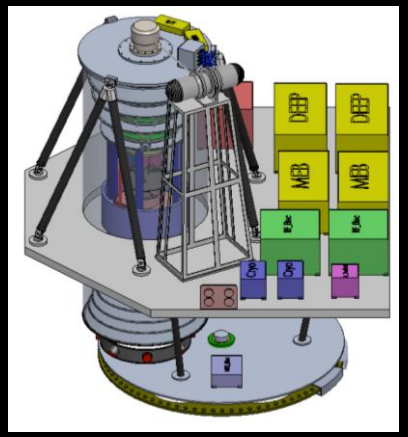


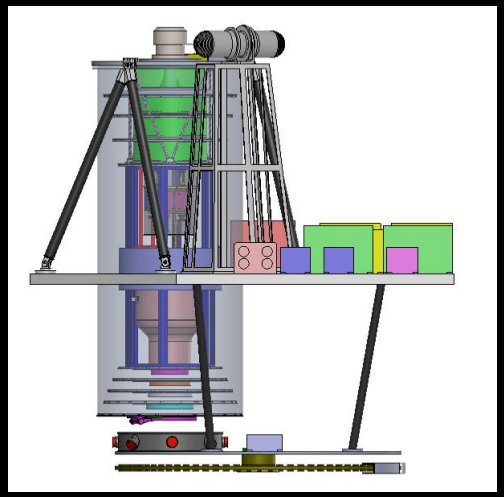
Main array
- 1” pixels, 5’ FOV
- ~ 3 eV, 10 cps/hydra (5”)
- up to 7 keV
- 86.4 kpix

Enhancement main array:
- 0.5” pixels, 1’ FOV
- ~ 1.5 eV, 20 cps/hydra-25 (2.5”)
- up to 7 keV
- 12.8 kpix

High-res inner array:
- 0.5” pixels, 20” FOV
- ~ 1.5 eV, 20 cps/hydra-4 (1”)
- up to 7 keV
- 1.6 kpix

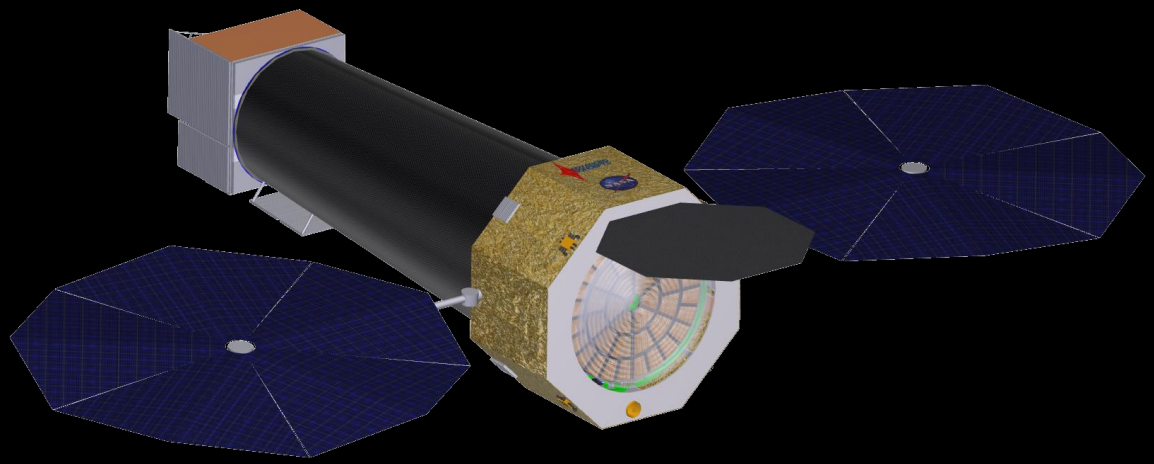
Ultra-hi-res array
- 1” pixels, 1’ FOV
- 0.3-0.4 eV (up to ~ 0.75 keV)
- Count rate ~ 80 cps/1”
- 3.6 kpix





Thank you!

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



- ***Leaps in Capability over Chandra and ATHENA***: 50-100x gain in sensitivity via high throughput with high angular resolution; large field of view for sub-arcsecond imaging; high-resolution spectroscopy for point-like and extended sources
- ***Scientifically compelling:*** frontier science from Dawn of Supermassive Black Holes, to Revealing Invisible Drivers of Galaxy and Structure Formation, to breakthroughs across astrophysics such as: detailed understanding of stellar activity including effects on planet habitability; populations of neutron stars and black holes in Local Group galaxies; highest redshift galaxy clusters; and cosmology
- ***Synergy:*** Great synergy and complementarity with the next-generation facilities —JWST, WFIRST, ATHENA, TMT, EELT, GMT, LISA, ALMA, SKA