Status of Lynx Mission Concept Study

Alexey Vikhlinin (Harvard-Smithsonian Center for Astrophysics) on behalf of the Science & Technology Definition Team
Lynx Science & Technology Definition Team

Steve Allen
Stanford

Megan Donahue
MSU

Jessica Gaskin
MSFC, study scientist

Laura Lopez
Ohio State

Alexey Vikhlinin (Chair)
SAO

Feryal Ozel (Chair)
Arizona

Mark Bautz
MIT

Ryan Hickox
Dartmouth

Piero Madau
UCSC

Andrey Kravtsov
Chicago

Eliot Quataert
UCB

Zoltan Haiman
Columbia

Neil Brandt
Penn State

Tesla Jeltema
UCSC

Rachel Osten
STScI

Dave Pooley
Trinity

Chris Reynolds
UMD

Joel Bregman
Michigan

Juna Kollmeier
Carnegie

Fritz Paerels
Columbia

Andy Ptak
GSFC

Daniel Stern
JPL

+8 ex-officio members from NASA and foreign agencies, 7 Science Working Groups, Optics Working Group, Instruments Working Group
Key decisions and work topics for the Lynx science team

✓ What kind of observatory Lynx should be?
✓ How big?
✓ Detailed requirements for the optics
✓ Science instrument suite, and requirements
  • Complete mission design
  • Progress in technology, develop technology roadmap
  • Write up the science case
Major Science Pillars

• The Invisible Drivers of Galaxy Formation and Evolution

• The Dawn of Black Holes
The Invisible Drivers of Galaxy Formation and Evolution

• This topic concentrates on a critical and well-defined aspect of the broader subject of galaxy formation. It is related to numerical cosmology, extragalactic astronomy, AGNs, ISM physics, star formation, etc.

• **Breakthrough progress:** Lynx will be uniquely capable of observing the state of baryons in galactic haloes with \( M > \text{Milky Way} \); measure the energetics and statistics of all relevant feedback modes; new unique insights on the physics of feedback to inform numerical models.

• **Unique Lynx contribution:** In galaxies with \( M > \sim \text{Milky Way} \), the relevant baryonic component is heated and ionized to X-ray energies. Needed observations rely on high-resolution spectroscopy and the ability to detect low surface brightness continuum emission (both unique to Lynx), and on a capability to map large areas in the sky in OVII, OVIII etc.
Incisive Diagnostics of CGM/IGM

Oppenheimer et al '16: EAGLE simulation: Oxygen census and Ionization Fractions

$L^*$ galaxies: >50% of O is in CGM
~80% of that is observed in X-ray transitions (OVII at 0.57 keV, OVIII at 0.65 keV)
Mock Lynx observation of gas halo in a galaxy from Illustris Simulation. Credit: R. Kraft, A. Bogdan, S. Nulsen, J. ZuHone

Cosmic Web simulation clipped at the Lynx sensitivity threshold

Phase diagram for the baryons in the Local Universe (theoretical prediction from Davé et al. 2010). Heated gas ($T>10^5$ K) in virialized halos and Cosmic Web accounts for >40% of all baryons by mass.

Diffuse gas in Cosmic Web

X-ray

halos of virialized objects

voids

galaxies

Hot gas in galactic halos and Cosmic Web filaments will be observable in emission with direct imaging both in continuum and brightest emission lines, and in absorption in X-ray gratings spectra of background AGNs.
The Dawn of Black Holes

Simulated 2x2 arcmin deep fields observed with JWST, Lynx, and ATHENA

- This topic is an essential component of the broad subject of the Early Universe as it goes through the reionization epoch and the first generations of galaxies emerge. Of interest to all astronomers working on the early universe, galaxy formation, black holes.

- **Breakthrough progress:** The origin of SMBHs is a mystery and will likely remain the mystery until 2030s. Lynx is uniquely positioned to detect the SMBH at their seed stage or soon after.

- **Unique Lynx contribution:** Low-mass black holes, generically, are best observed at X-rays. Reaching into the seed regime requires sensitivities $\sim 1e-19$ erg/s/cm$^2$, which only Lynx can achieve.
transformations in galaxy evolution, since around that time both the luminous QSOs and the star formation rate. Galaxy mergers and accretion laments during cosmic high noon were likely to be the driving force behind the processes of star formation, is turned star-forming discs into larger discs or quenched spheroidal systems hosting supermassive black holes of billions of solar. In this framework, massive black hole binaries inevitably form in large numbers, over a variety of 34

Signs of galaxy mergers with dual black holes at wide separations (on the order of kpc) come from observations of dual AGNs in optical and X-ray surveys, while observations of binary black holes with sub-pc scale separations 35

10 20 50 1000 300 100 2 3 4 5 6 7 8 9 2 4 6 8 10 12 14 16 18 20 142 301
Redshift (z) log(M/M\odot)
0 9
space based gravitational wave observatory
future EM probes
black hole - black hole mergers
The Dawn of Black Holes
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The Dawn of Black Holes

LISA sensitivity to supermassive black hole mergers

Redshift (z) vs. log(M/M_{\odot})

- black hole - black hole mergers
- space based gravitational wave observatory
- Lynx
- future EM probes

black hole - black hole mergers

Lynx

space based gravitational wave observatory

future EM probes
• 0.5″ angular resolution on-axis

• Effective area of 2 m² at ~1 keV. Implies a 3m diameter for the mirror system — can be accommodated by current launch vehicle fairings. **Soft-band throughput is ~ 50x Chandra**, 

• Sub-arcsec imaging out to 10 arcmin radius. **Speed for sensitive surveys is 800x Chandra**

• “Invisible Drivers” science requires high resolution spectroscopy with gratings (R~5,000-10,000) and microcalorimeter (0.5–1″ pixels, up to 1–2 eV energy resolution).
**Recent assessment of technology gaps for Lynx by NASA PCOS office**

### Lynx

<table>
<thead>
<tr>
<th>Total Gaps</th>
<th>TRL 2 Gaps</th>
<th>TRL 3 Gaps</th>
<th>TRL 4+ Gaps</th>
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<th>ID</th>
<th>Technology Gap</th>
<th>TRL</th>
<th>Note</th>
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<tbody>
<tr>
<td>1</td>
<td>High-resolution lightweight X-ray optics</td>
<td>2</td>
<td>Should the required system-level angular resolution be achievable with mirror-level resolution of 2 arcsec, and/or if the factor currently limiting mirror-level performance to 2 arcsec and a credible technological extension are identified, this TRL would be at 3.</td>
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<tr>
<td>2</td>
<td>Non-deforming X-ray reflecting coatings</td>
<td>3</td>
<td>Thin glass substrate coated with Pt showed identical thickness coatings on two sides resulted in minimal net distortion</td>
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<tr>
<td>3</td>
<td>Megapixel X-ray imaging detectors</td>
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<tr>
<td>4</td>
<td>Large-format, high spectral resolution X-ray detectors</td>
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<tr>
<td>5</td>
<td>X-ray grating arrays</td>
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