Lynx and LISA

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The Dawn of Black Holes

The Invisible Drivers of Galaxy and Structure Formation

The Energetic Side of Stellar Evolution and Stellar Ecosystems

Endpoints of stellar evolution
Stellar birth, coronal physics, feedback
Impact of stellar activity on habitability of planets
Lynx Current Baseline Architecture

• Large X-ray telescope (0.2 – 12 keV)
  – Largest ever combination of aperture size and angular resolution in X-ray band
  – Effective area 2 – 3 m² at 1 keV
  – High angular resolution – 0.5 arcsec or better over modest (~10 arcmin) field of view

• Three focal plane instruments
  – Megapixel X-ray calorimeter
  – Wide field imager (~40 arcmin FoV)
  – High resolution grating spectrometer

• Mission
  – High orbit
  – 5-year design lifetime
  – Simple architecture – few deployables
  – Rapid response capability under discussion
Survey capabilities for a 15 Msec program

Angular resolution
Chandra: ~ 0.5” – low area, poor off-axis performance

Athena: ~5”; ~ 1.4-2 m²

Lynx: < 0.5”; ~ 2-3 m²
Lynx in the context of contemporaneous EM observatories
Black hole evolution, Lynx, and GW observatories

• Key Lynx theme is the origin and evolution of black holes
• The picture of black hole evolution is incomplete unless LISA/LIGO sources are understood
• LIGO will reveal nearby stellar-mass binary systems as they merge (BH/BH, BH/NS, NS/NS)
• LISA will reveal distant mergers ($z \leq 20$) and provide a census of premerger binary SMBHs
• Lynx has unique power to find EM counterparts of all types of mergers and provide astrophysical context for GW events
• LISA is the only space major observatory planned for the 2030’s: emphasis on synergy will be important for the Lynx science case
• This is a **MUST** for Lynx – fits all criteria:
  – Fits into our major science
  – Broad importance for science
  – Unique to X-rays
  – Unique to Lynx (not in Athena domain)
  – Breakthrough progress
  – Feasible
GW facility capabilities

Janssen et al. 2014
Chandra detection of EM counterpart to GW170817
Observing merger counterparts

Lynx makes visible many more counterparts than current observatories because it makes far off-beam detections possible.
Dual Nuclei In Highly Absorbed AGN

Keck adaptive optics

Koss + submitted, using Swift BAT selected luminous absorbed AGN
Track of binary in the LISA band

Example:
\[ M_{\text{tot}} = 10^6 M_\odot, \quad q = 1/3, \quad z = 1 \]

Enter LISA band:
\[ 125 R_g \]

Localized (10 deg^2):
\[ 38 R_g \]

Tidal radius < 10 R_g:
\[ 387 \text{ cycles} \]

\[ V(\text{orb}) \sim O(0.1c) \]
\[ T(\text{orb}) \sim O(\text{hr}) \]

(Haiman 2017)
LISA binaries will be surrounded by gas

1. Most galaxies contain SMBHs
   - SMBH mass correlates with galaxy size

2. Galaxies experience several mergers
   - typically a few major mergers per Hubble time

3. Most galaxies contain gas
   - $M < 10^7 \, M_\odot$ SMBHs are in gas-rich disk galaxies
   - $M > 10^7 \, M_\odot$ SMBHs are in “dry” ellipticals, but still with gas

4. Both SMBHs and gas are driven to new nucleus (~kpc)
   - SMBHs sink by dynamical friction on stars and on DM
   - gas torqued by merger and flows to nucleus

$\Rightarrow$ common outcome: pair of SMBHs in gas disk
X-ray chirp inevitable

- Optical – X-ray emission from quasars from 10-1000 \( R_g \)
- Smaller than tidal truncation radius for wide binary
- Minidisk \( \sim \) quasar disk
- Doppler effect modulates brightness at \( O(v/c) \)

\[
\frac{\Delta F}{F} = (3-\alpha) \left( \frac{v_{||}}{c} \right)
\]

\[\alpha = \frac{d\ln F}{d\ln \nu}\]

Farris et al. (2015)

Tidal force from companion truncates minidisk
Gravitational lensing size scales of quasars

X-rays: Chartas, Rhea, Kochanek et al. (2015)

Fig. 1 X-ray half-light radii of quasars as determined from our microlensing analysis versus their black hole masses.
EM vs. X-ray chirp

$10^6 \, M_\odot$ binary, $q=1/3, \, z=1$

$\rightarrow \quad D/c = 3 \times 10^{18} \, s$

$\rightarrow \quad t_{\text{orb}} = (1+z)2\pi R/10 c_s/c \sim 4000 \, \text{sec}$

(orbial time at merger)

$\Rightarrow \quad \Delta c/c \sim t_{\text{orb}} / [D/c] \sim 10^{-15}$

$(10-100 \times \text{better from S/N}=10^{2-3}) \sim 10^{-17}$

Improve bounds from GW phasing alone ($\lambda_g \geq 10^{16} \, \text{km}$)

Berti+(2005), Will (2006)
Summary

• If Lynx is highly ranked by the decadal, it will fly contemporaneously with LISA.
• A key Lynx theme is the origin and evolution of black holes, including how they grow via mergers.
• Lynx will be able to detect and localize black hole merger counterparts to high redshift (z ≥ 10).
• The enhanced X-ray emission expected from many close binary black holes will enable Lynx to localize and monitor them as they merge.
HIGH ENERGY ASTROPHYSICS
IN THE 2020’S AND BEYOND

18-21 MARCH 2018
ROSEMONT, ILLINOIS

Photo: National Science Foundation/LIGO/Sonoma State University/A. Simonnet
Backup Slides
Lynx in context

Comparison of nominal sizes of primary mirrors of notable optical telescopes. Dotted lines show mirrors with equivalent light-gathering ability.

https://en.wikipedia.org/wiki/Large_Synoptic_Survey_Telescope
LISA reach

(Accepted LISA proposal, science justification)