Lynx and LISA

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GWSIG
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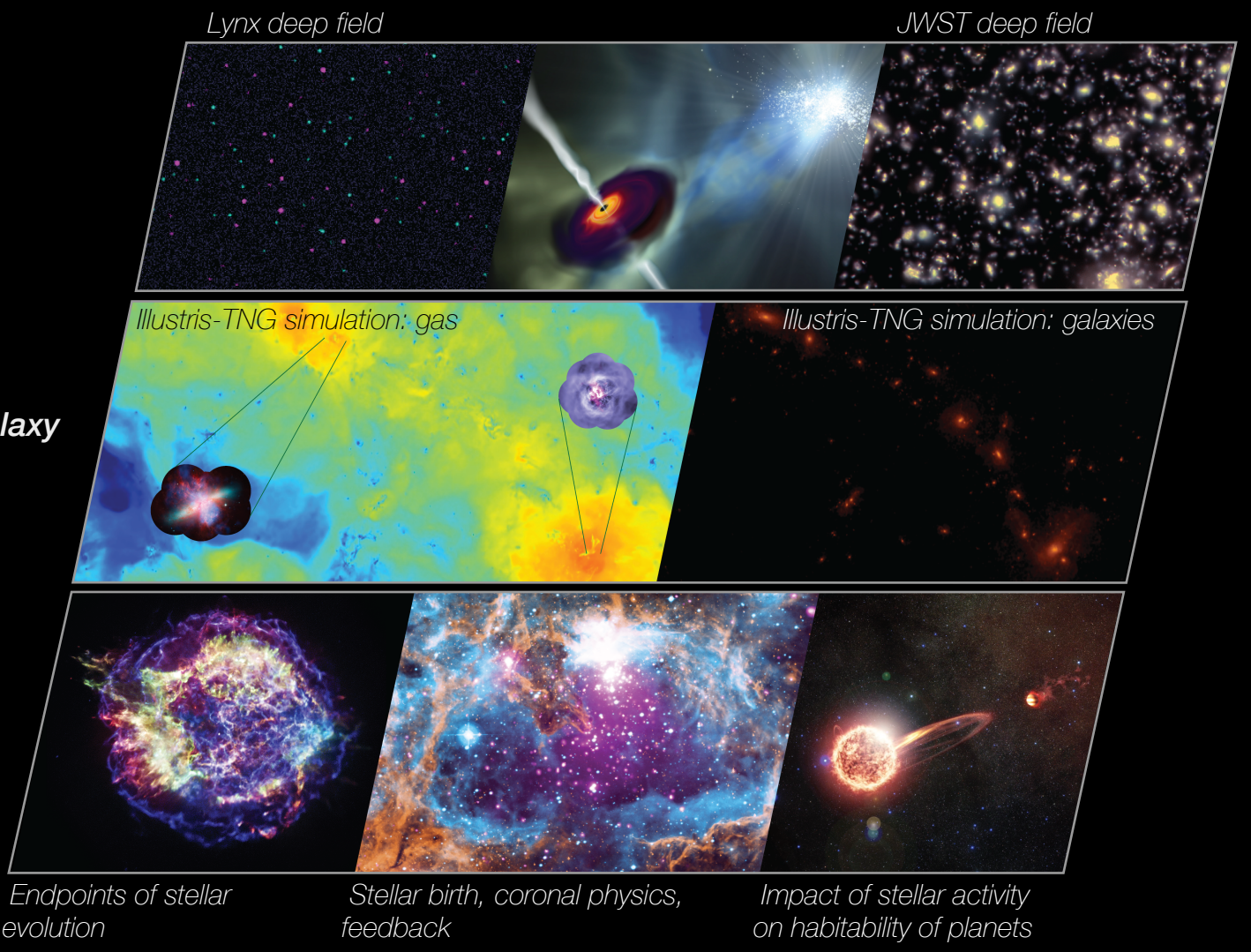
X-RAY OBSERVATORY

LYNX



The Dawn of Black Holes

The Invisible Drivers of Galaxy and Structure Formation

The Energetic Side of Stellar Evolution and Stellar Ecosystems

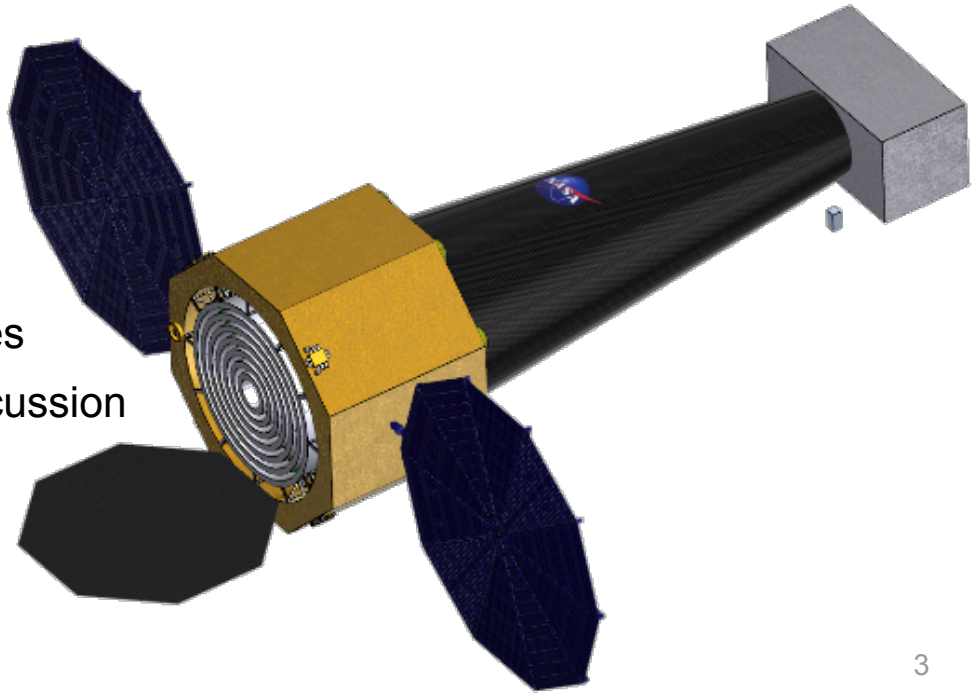
Endpoints of stellar evolution

Stellar birth, coronal physics, feedback

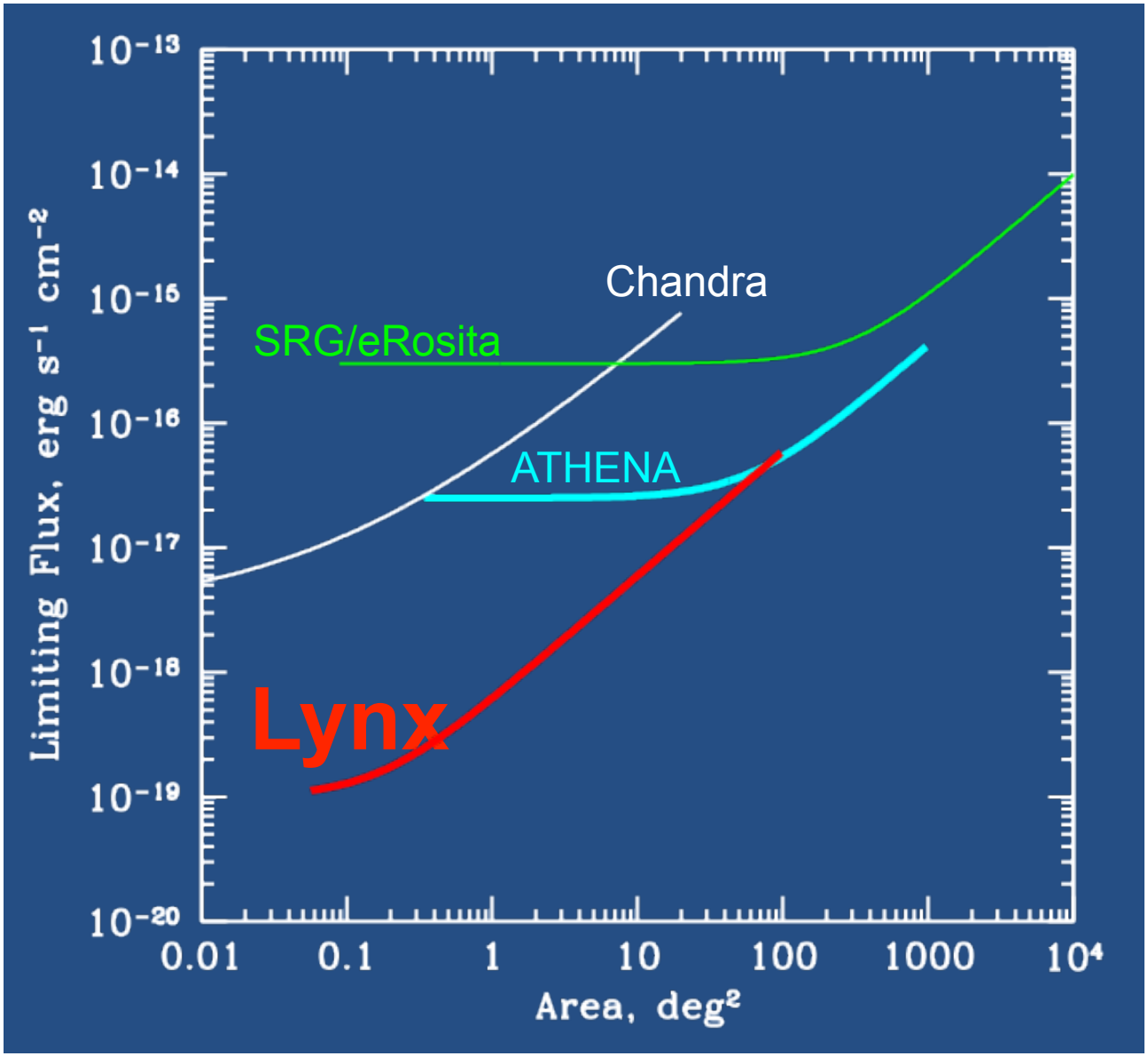
Impact of stellar activity on habitability of planets

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 m^2 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

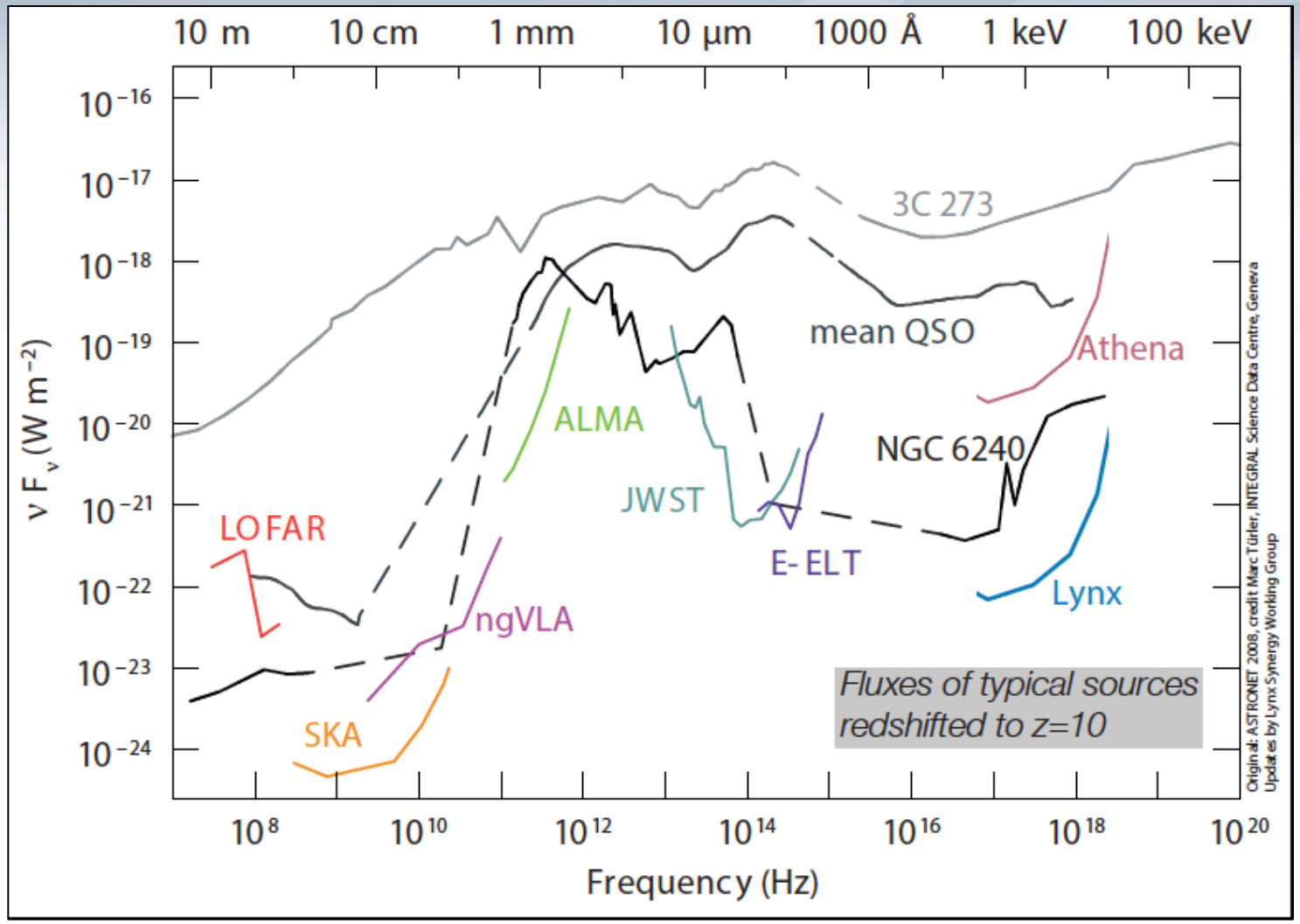


Angular resolution
Chandra: ~ 0.5” – low area, poor off-axis performance

Athena: ~5”; ~ 1.4-2 m^2

Lynx: < 0.5”; ~ 2-3 m^2

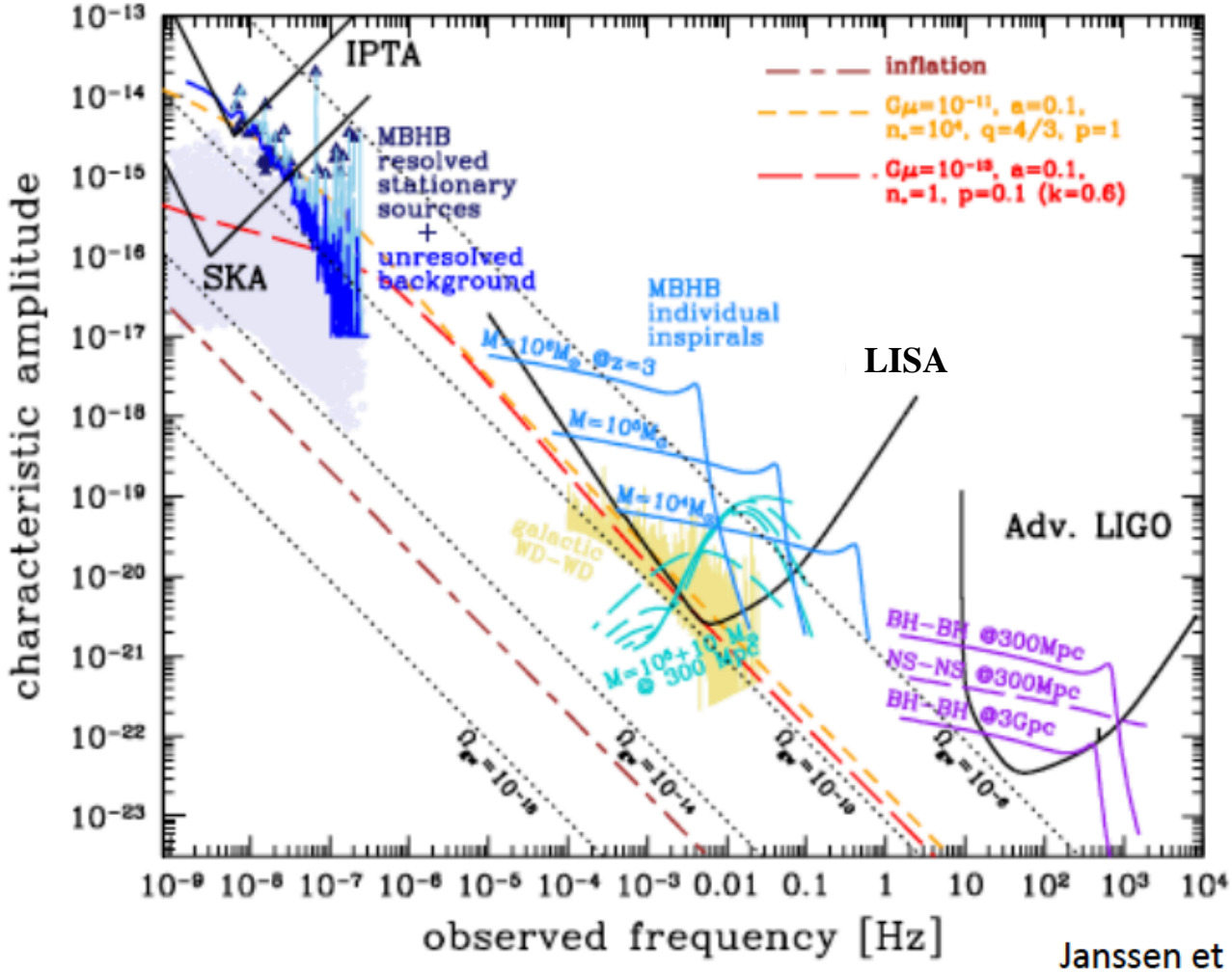
Lynx in the context of contemporaneous EM observatories



Black hole evolution, Lynx, and GW observatories

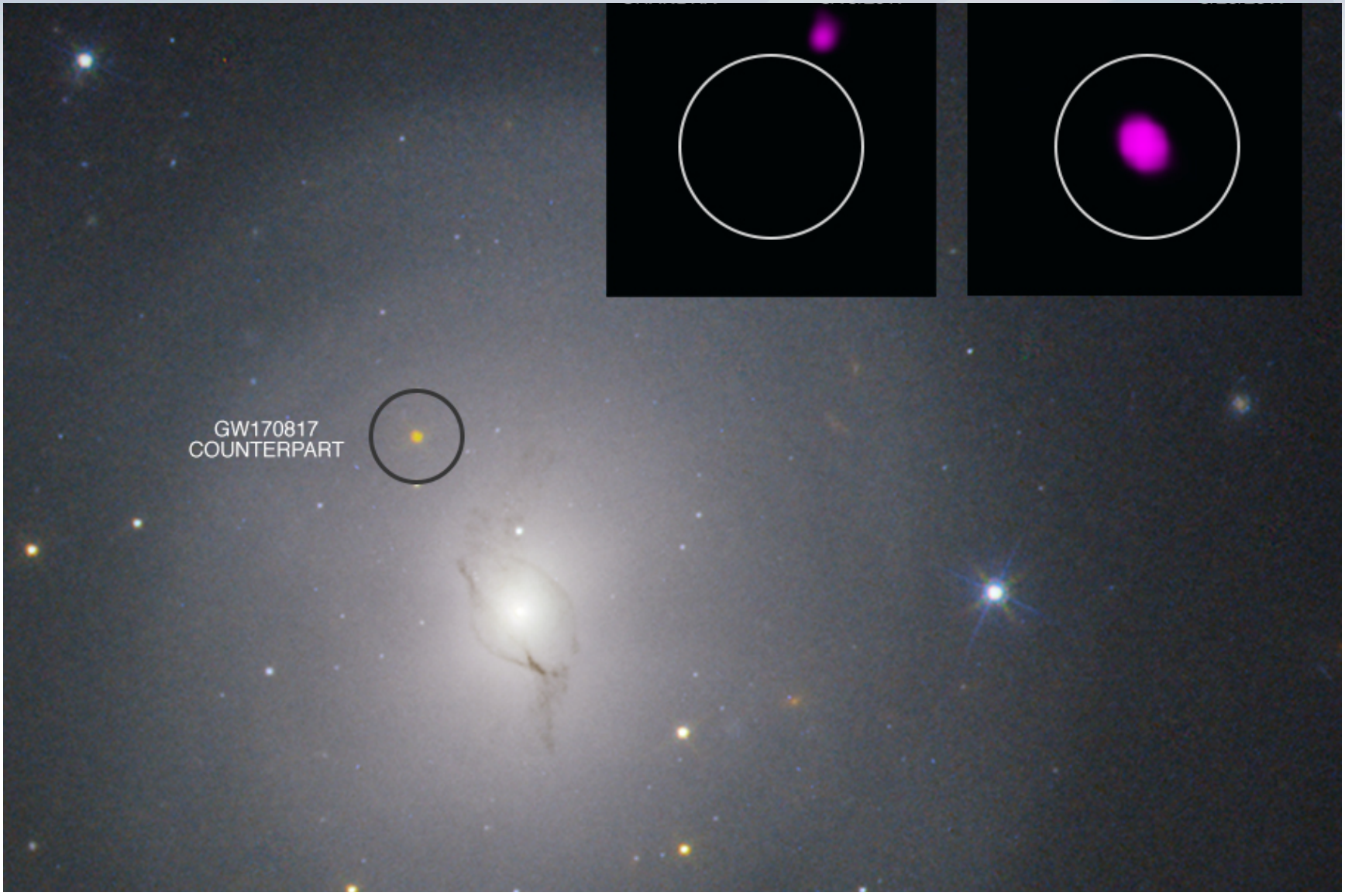
- Key Lynx theme is the origin and evolution of black holes
- The picture of black hole evolution is incomplete unless LISA/LIGO sources are understood
- LIGO will reveal nearby stellar-mass binary systems as they merge (BH/BH, BH/NS, NS/NS)
- LISA will reveal distant mergers ($z \leq 20$) and provide 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

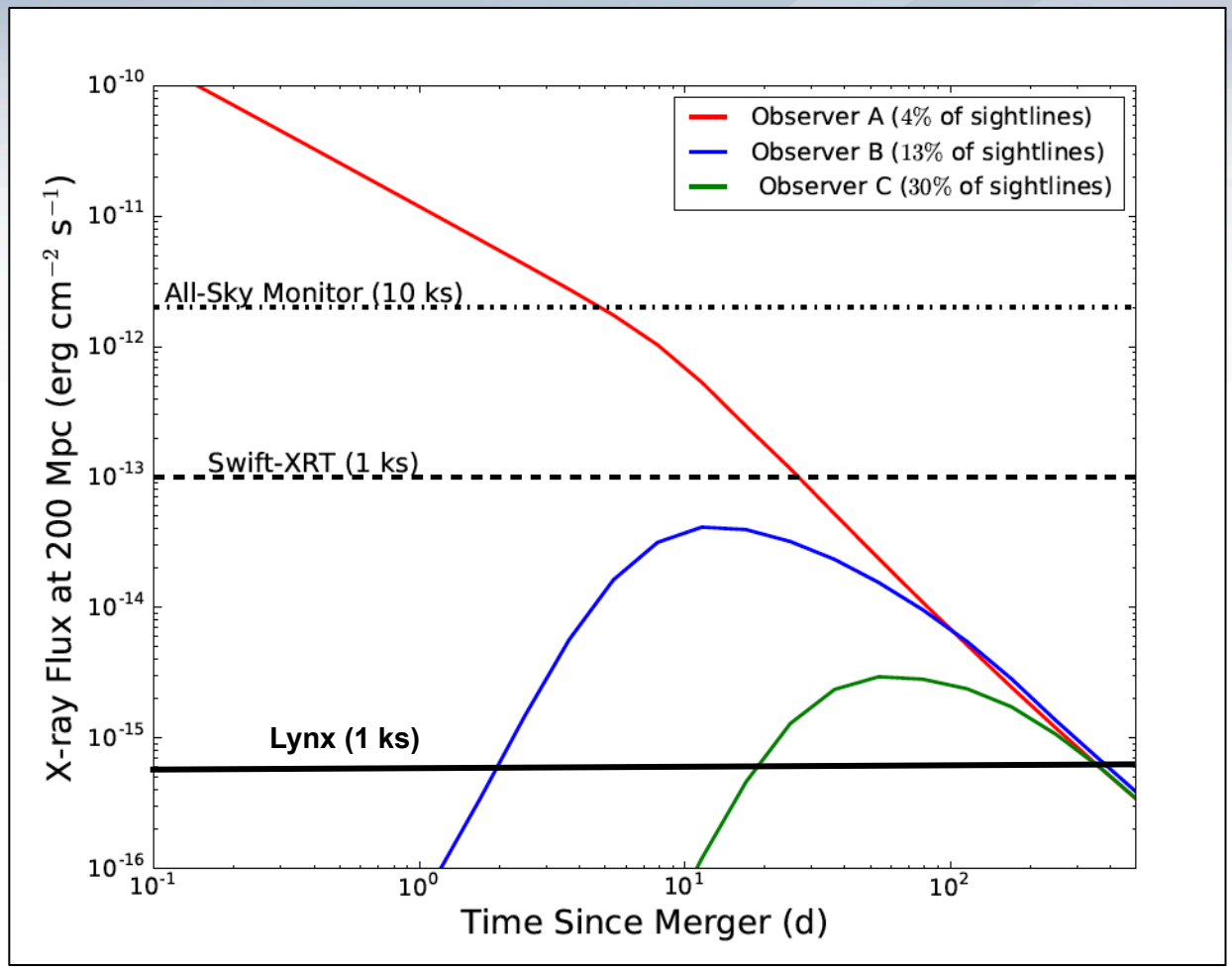


Janssen et al. 2014

Chandra detection of EM counterpart to GW170817



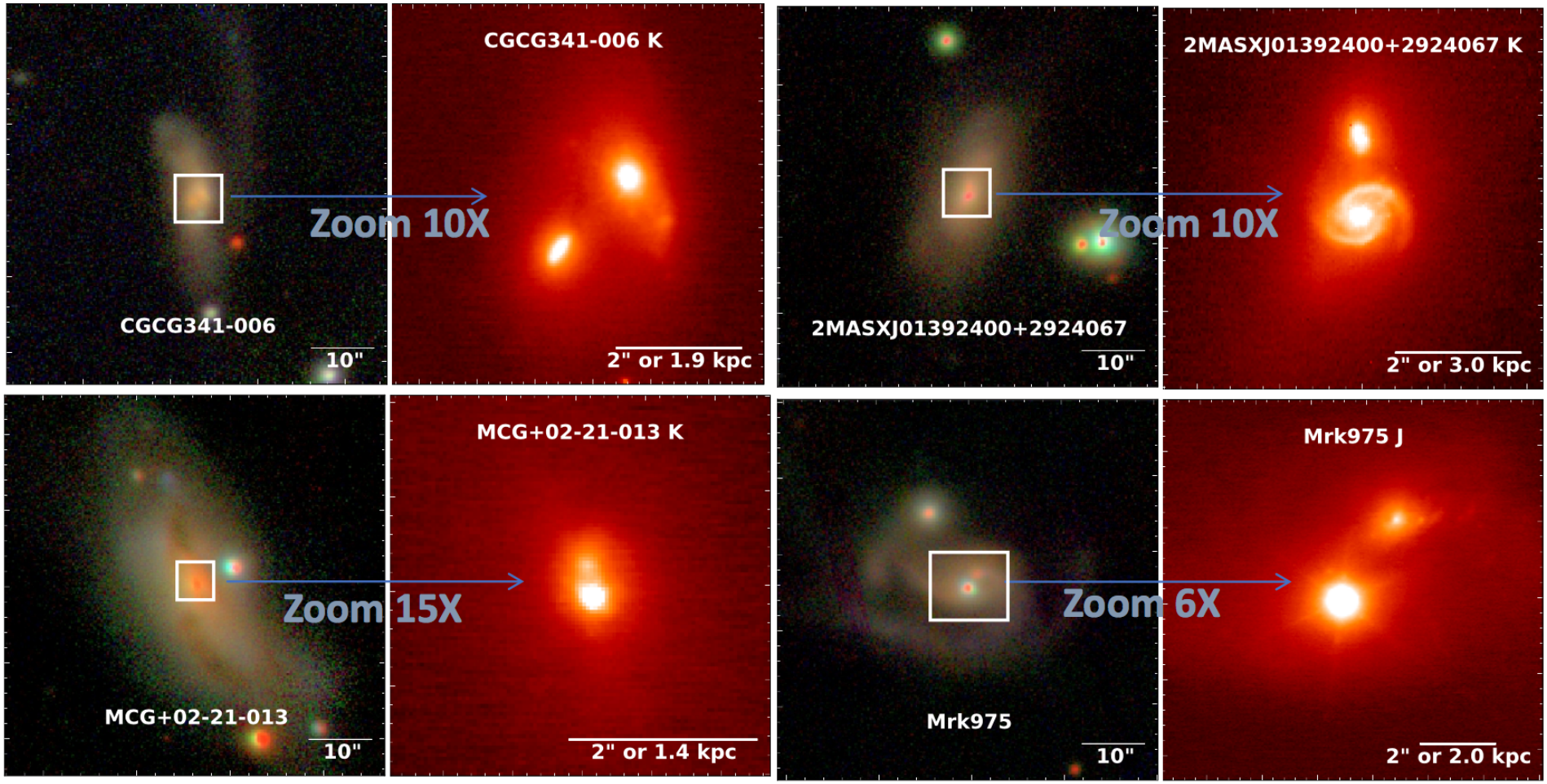
Observing merger counterparts



Lynx makes visible many more counterparts than current observatories because it makes far off-beam detections possible

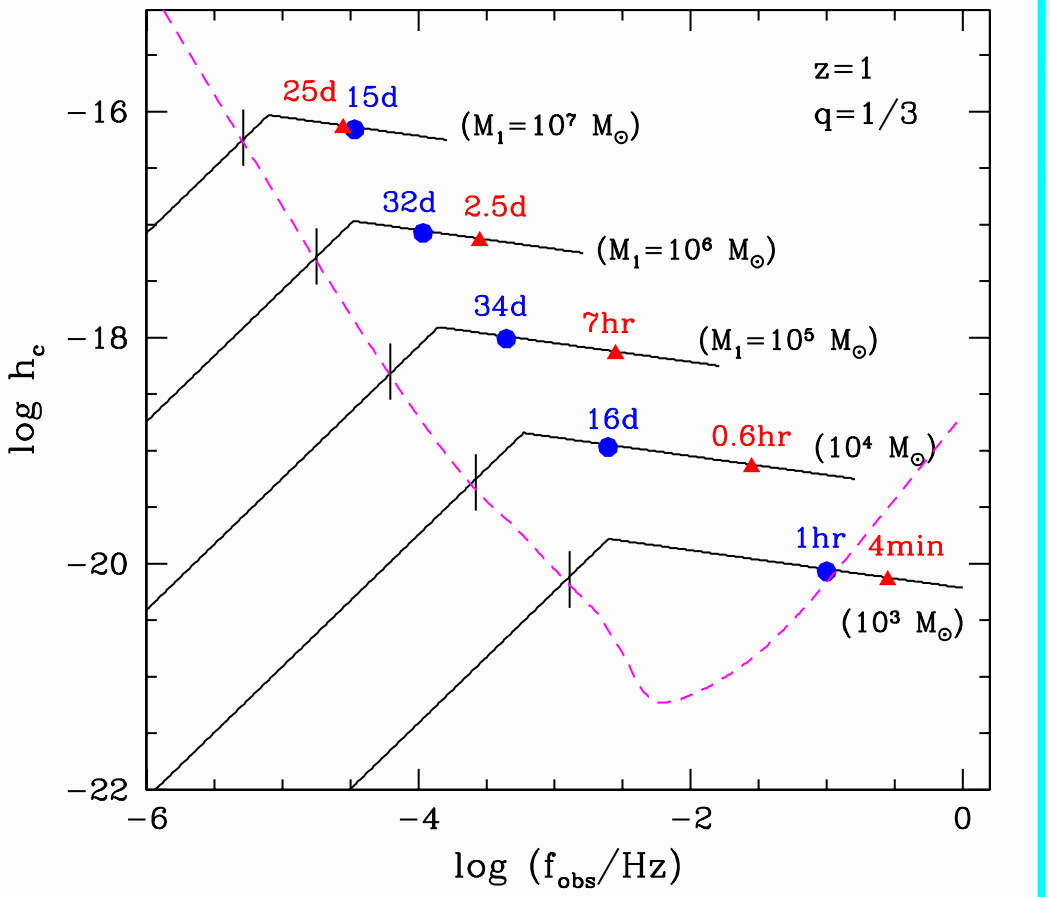
Dual Nuclei In Highly Absorbed AGN

Keck adaptive optics



Koss + submitted, using Swift BAT selected luminous absorbed AGN

Track of binary in the LISA band



(Haiman 2017)

Example:

$M_{tot}=10^6 M_\odot$, q=1/3, z=1

Enter LISA band: 125 R_g

Localized (10 deg^2): 38 R_g

Tidal radius < 10 R_g: 387 cycles

V(orb) ~ O(0.1c)
T(orb) ~ O(hr)

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

→ common outcome: pair of SMBHs in gas disk

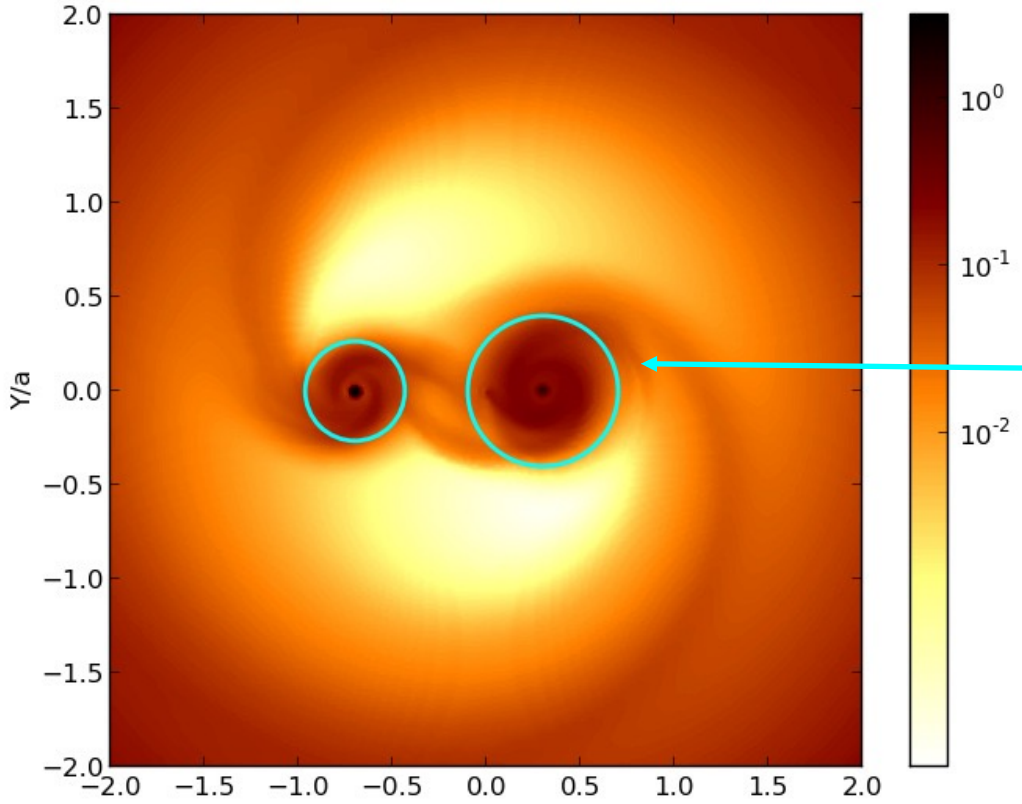
X-ray chirp inevitable

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

$\Delta F_\nu/F_\nu=(3-\alpha)(v_{||}/c)$

$\alpha=d\ln F_\nu/d\ln \nu$

Farris et al. (2015)



Tidal force from companion truncates minidisk

Gravitational lensing size scales of quasars

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

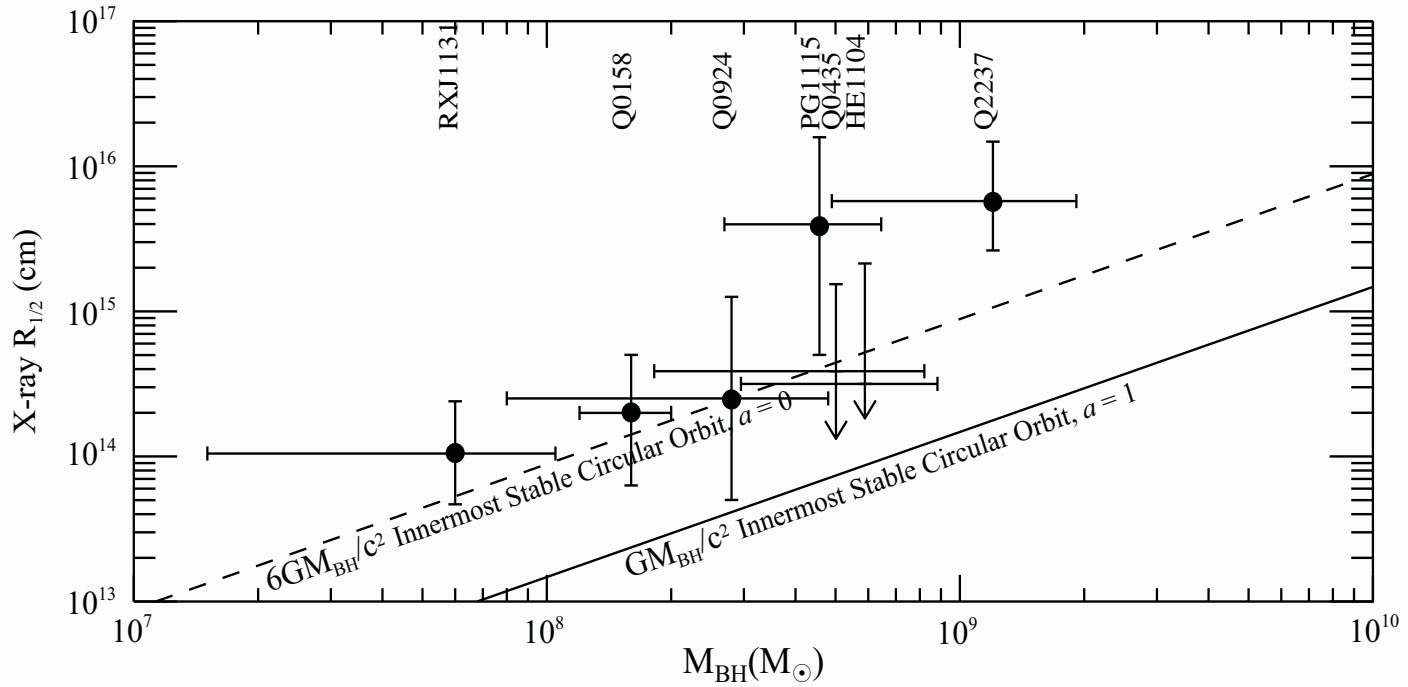


Fig. 1 X-ray half-light radii of quasars as determined from our microlensing analysis versus their black hole masses.

EM vs. X-ray chirp

Test $A_{gw} \propto f^{2/3} e^{-i2\varphi}$ *vs* $A_{\gamma} \propto f^{1/3} e^{-i\varphi}$

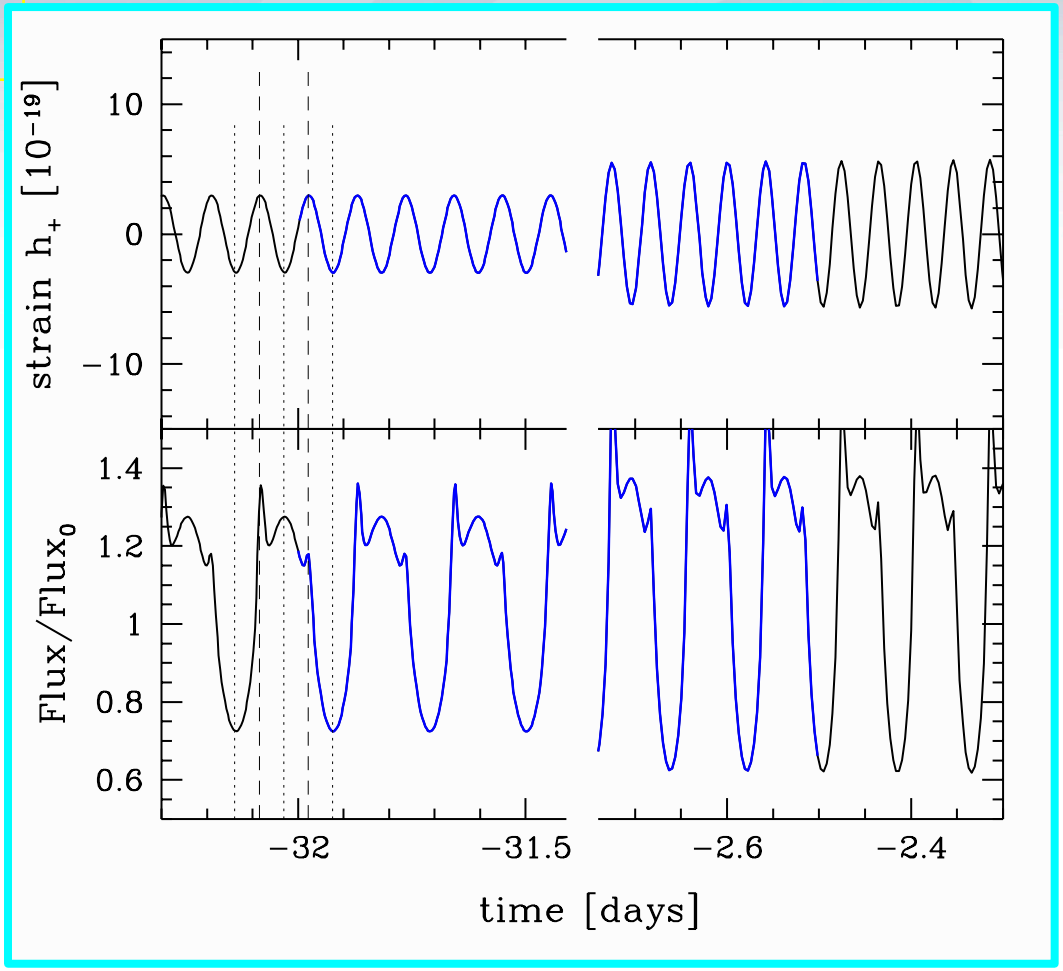
$10^6\ M_\odot$ binary, q=1/3, z=1

→ $D/c = 3\times10^{18}$ s

→ $t_{orb} = (1+z)2\pi 10 R_S/c \sim$ 4000 sec (orbital time at merger)

=> $\Delta\, c/c \sim t_{orb} / [D/c] \sim 10^{-15}$ (10-100 × better from S/N=$10^{2\text{-}3}$) ~ 10^{-17}

Improve bounds from GW phasing alone ($\lambda_g \gtrsim 10^{16}$ 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 ($z \geq 10$).
- 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

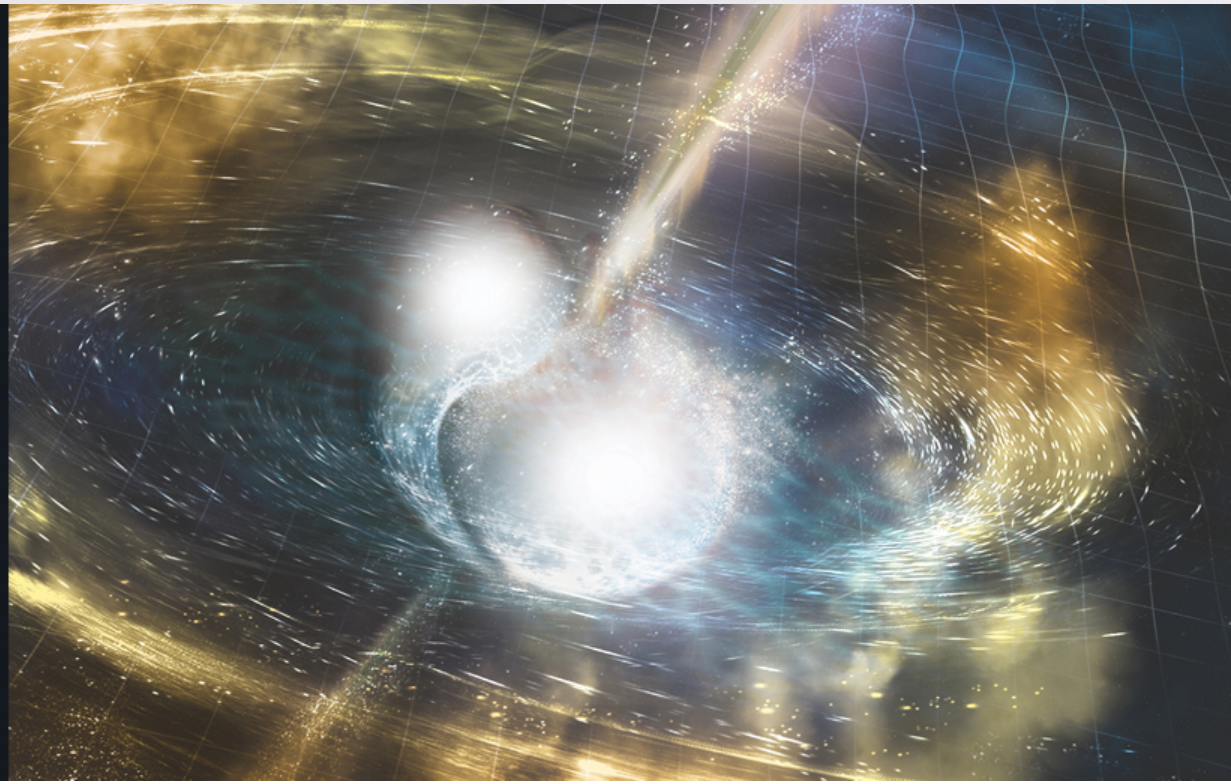
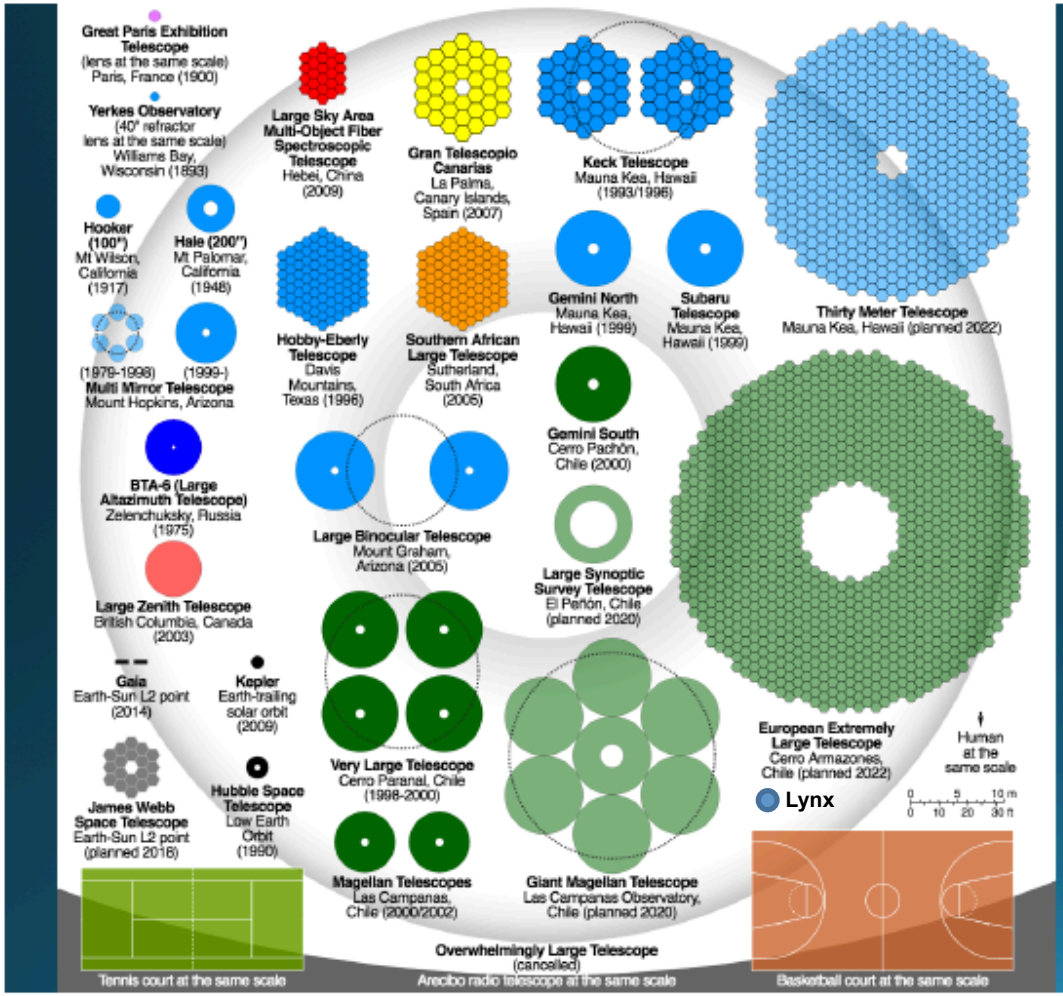


Photo: National Science Foundation/LIGO/Sonoma State University/A. Simonnet

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

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LISA reach

(Accepted LISA proposal, science justification)