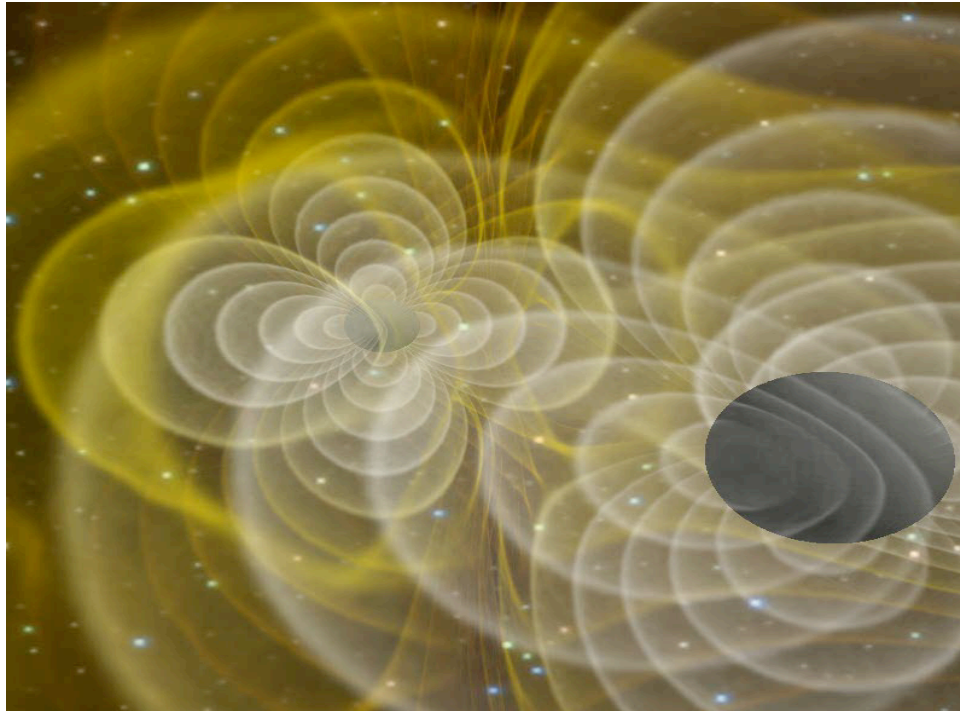
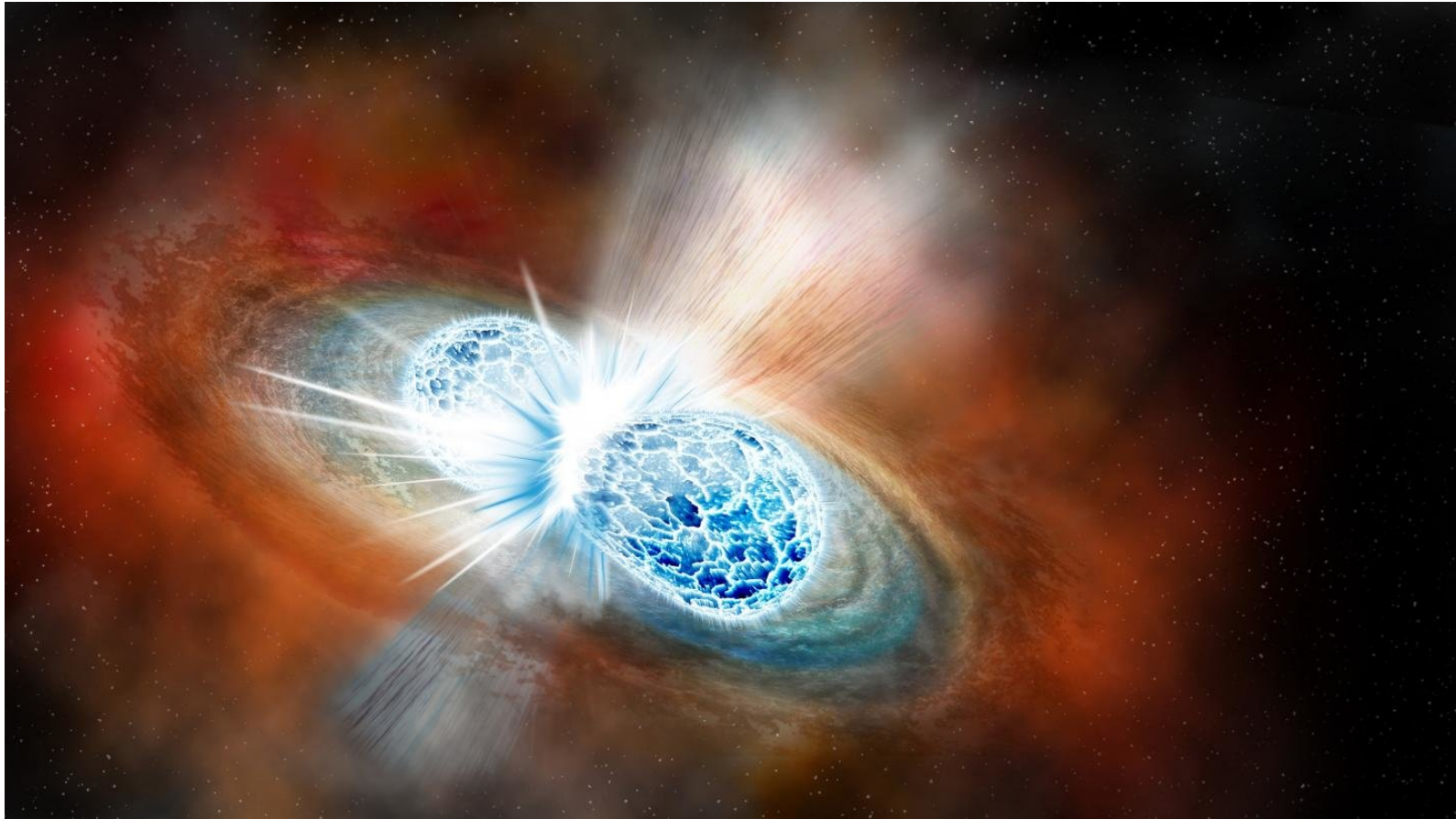


# PHOTONS+SPACETIME=AWESOME



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Vanderbilt University and Fisk University, Chair of NASA LISA Study Team  
[k.holley@vanderbilt.edu](mailto:k.holley@vanderbilt.edu)

So this happened:



Which,  $\sim 150$  Myr later, did this...

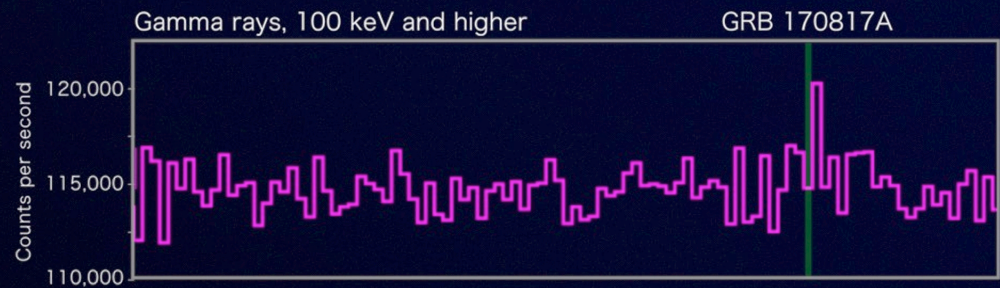
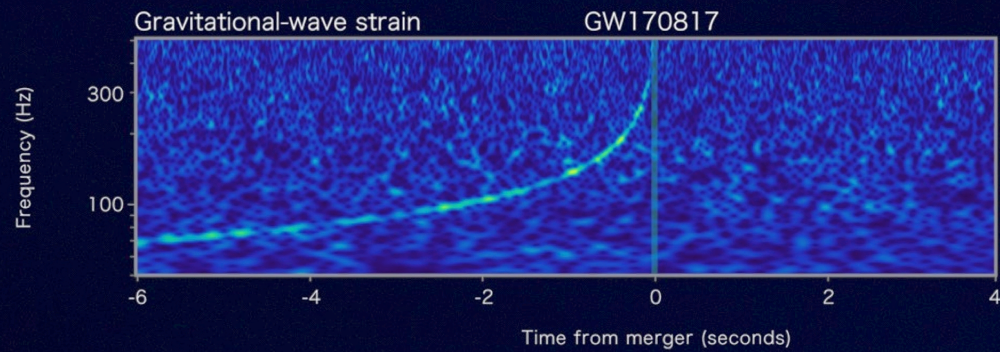
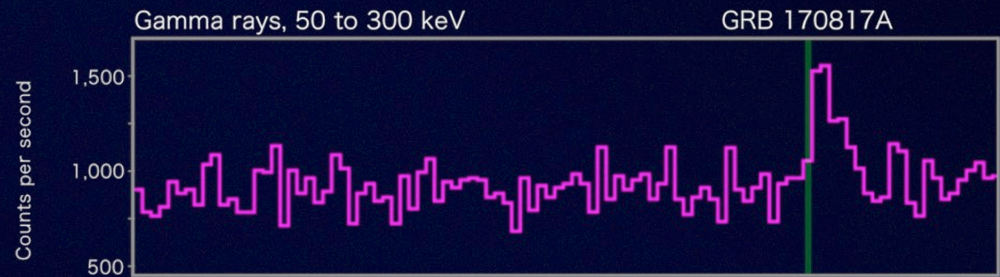
Fermi



LIGO-Virgo



INTEGRAL



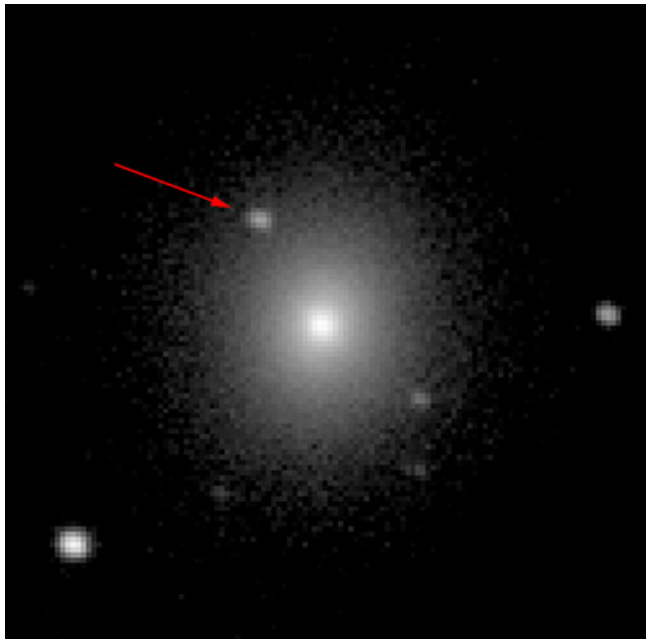
and changed **EVERYTHING!**

Over 1/3 of astronomy community joined in to follow the event

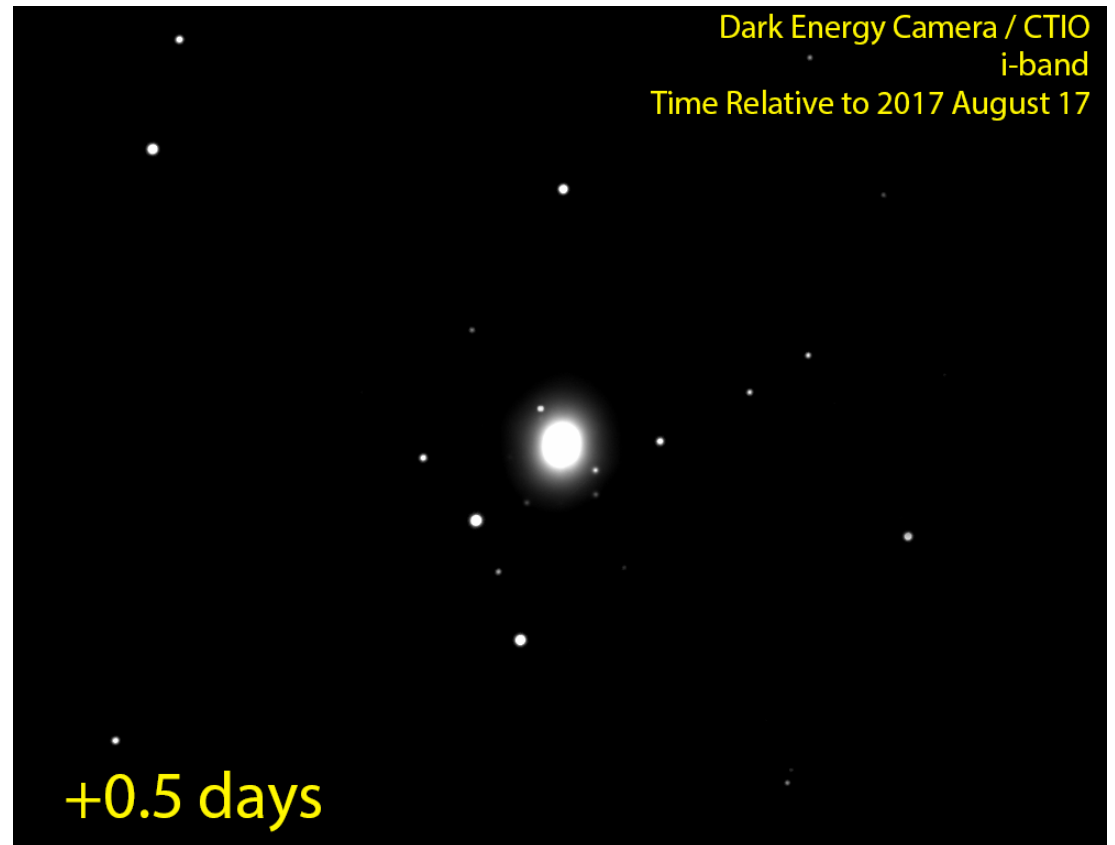
Swopes 1m



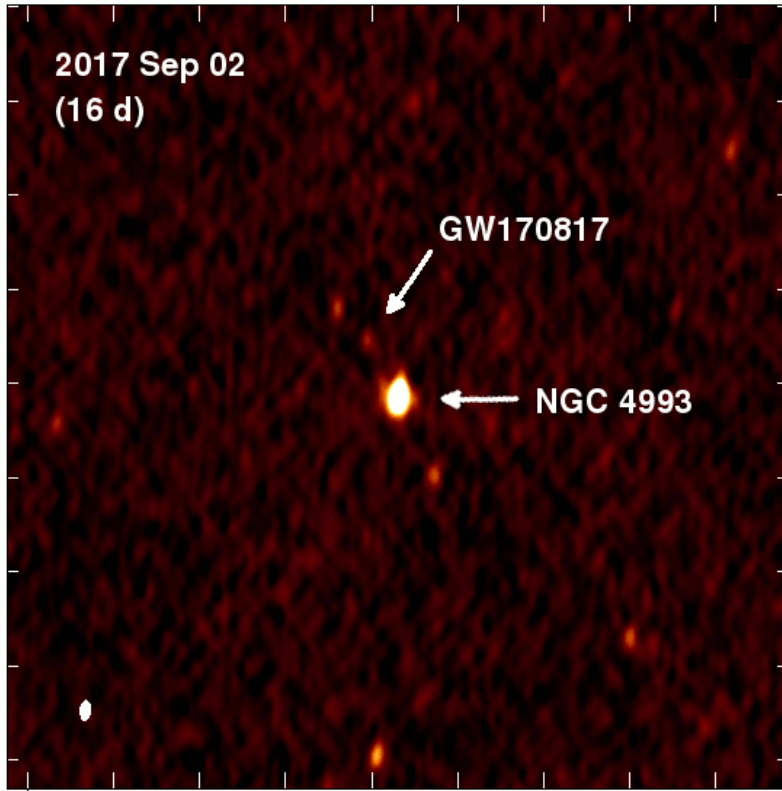
Blanco 4m



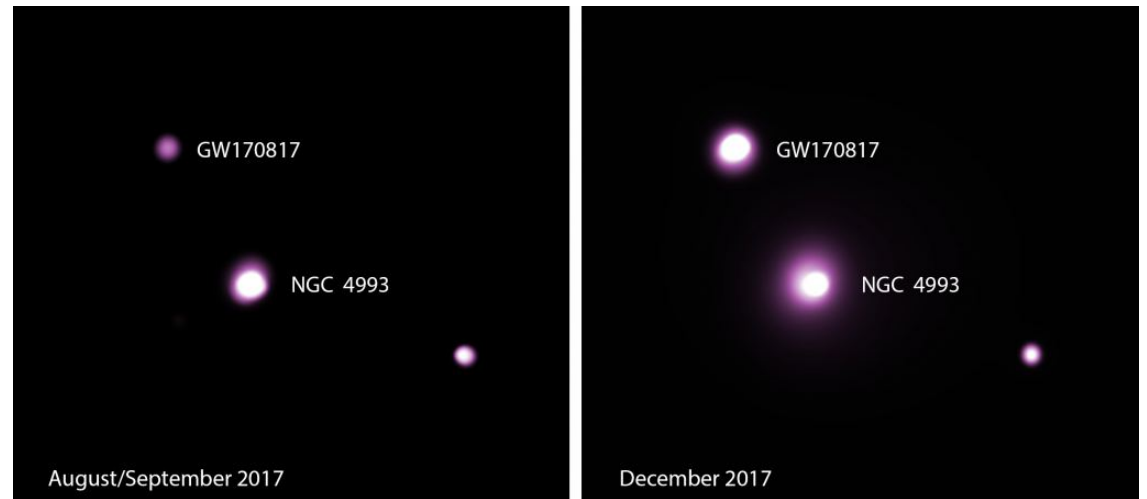
Dark Energy Camera / CTIO  
i-band  
Time Relative to 2017 August 17



...and at different wavelengths...



Radio – VLA

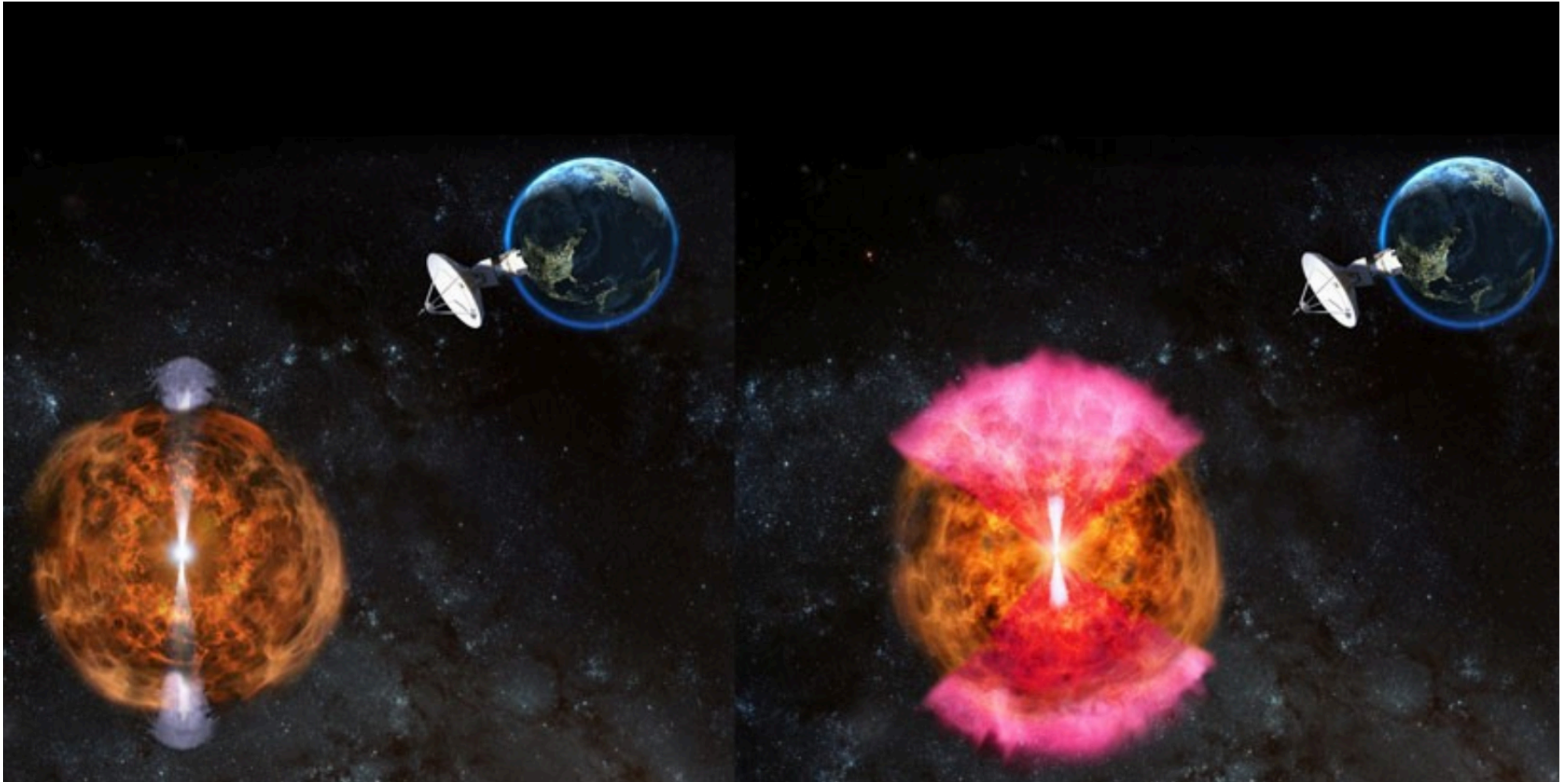


Xray – Chandra

*Credit: NASA/CXC/McGill University/J. Ruan et al.*

and still observe it today.

Whoa...a whole new way to think about short GRB ejecta!

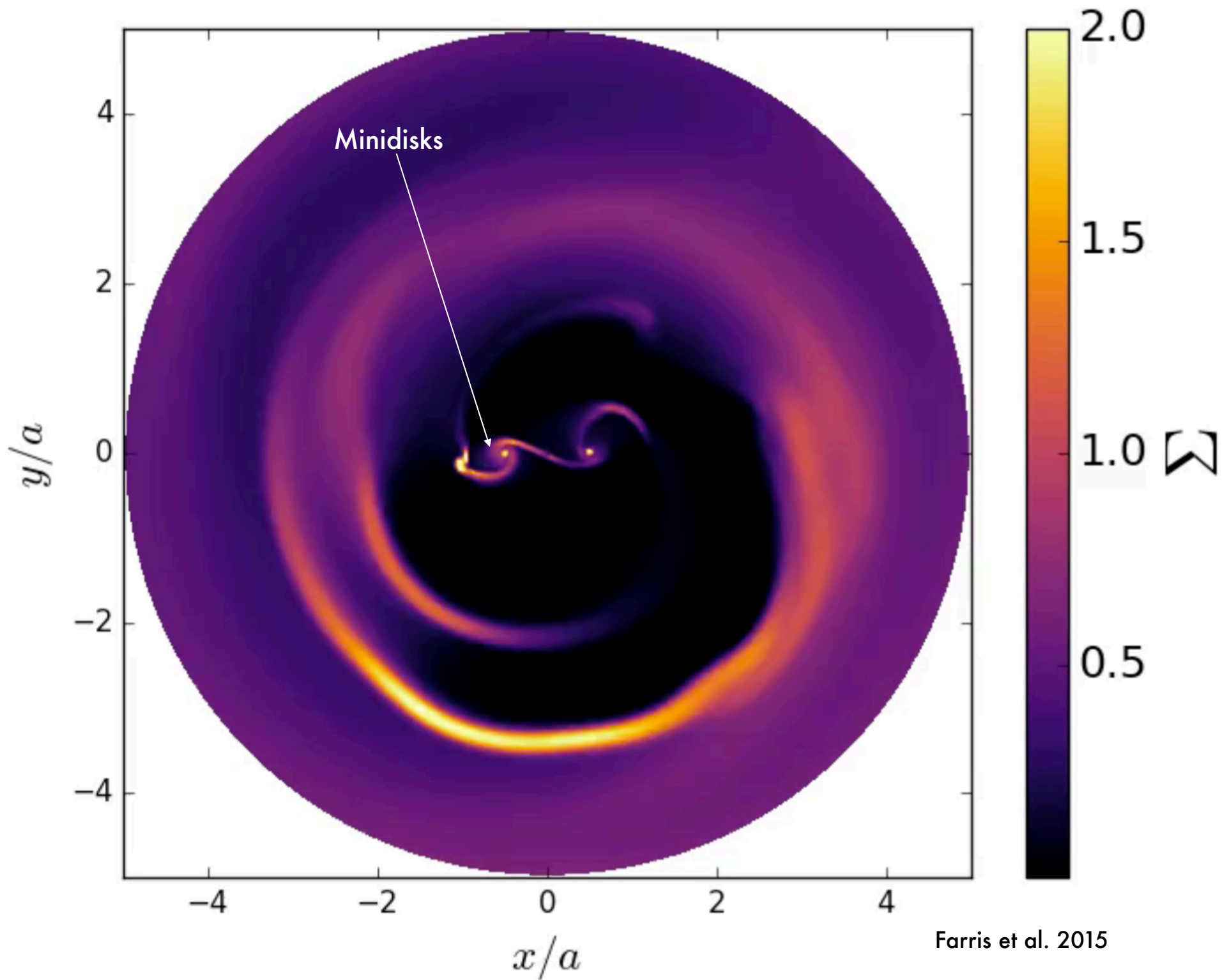


Since prompt electromagnetic counterparts are **so** valuable...the hunt is on for counterparts to black holes

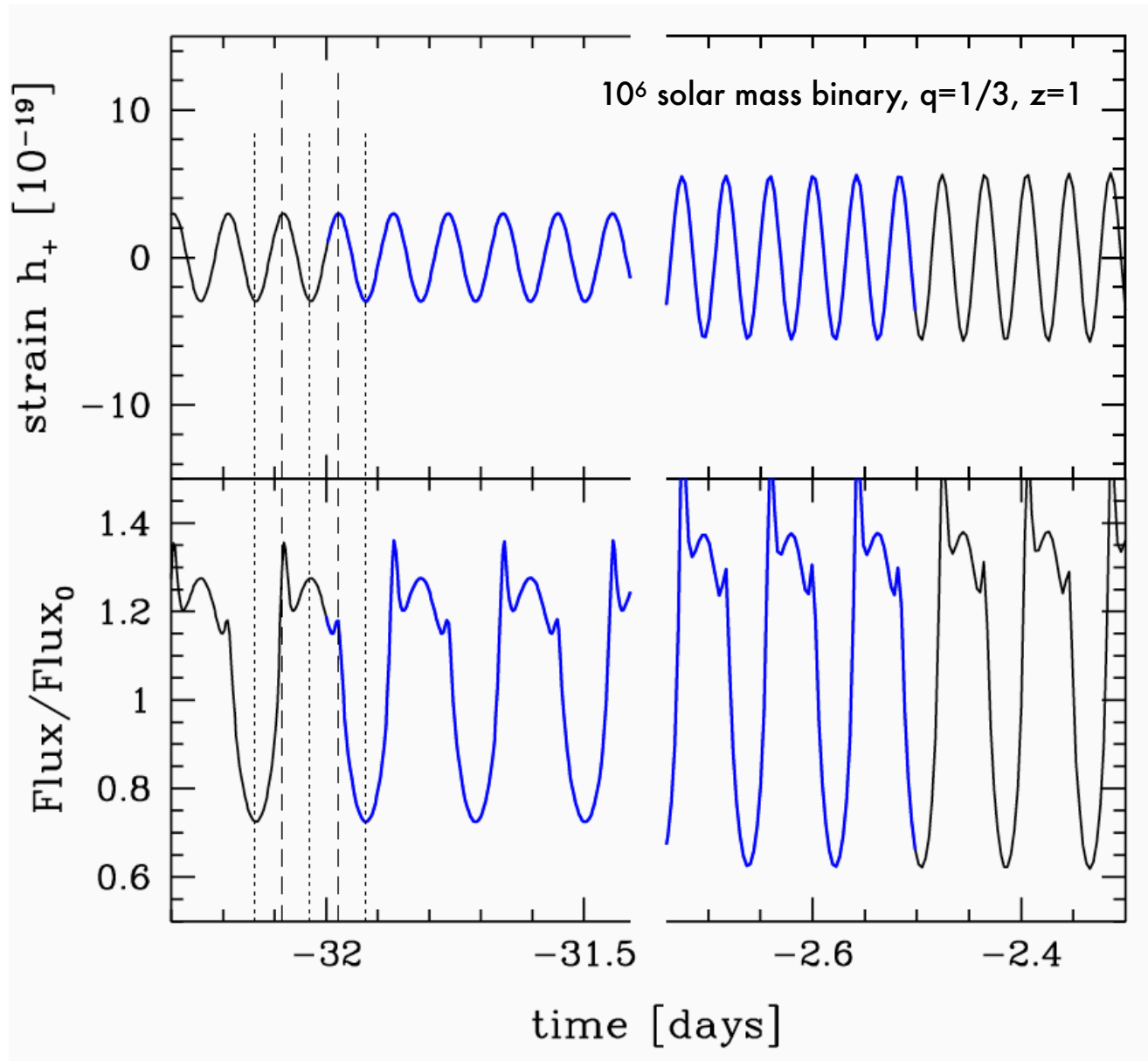


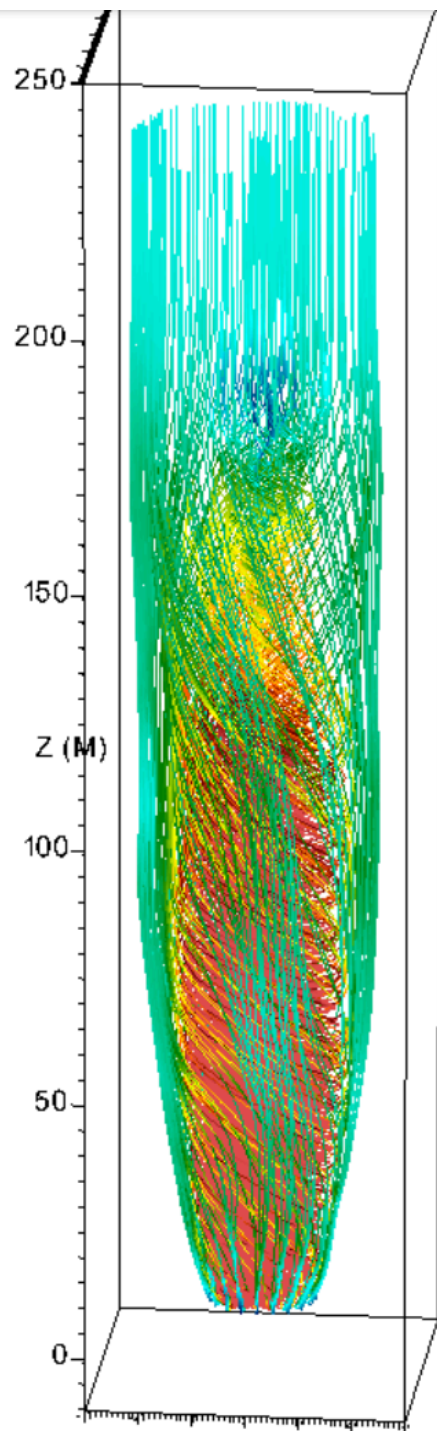
just kidding





# Doppler modulation of minidisks may yield an Xray chirp as a precursor

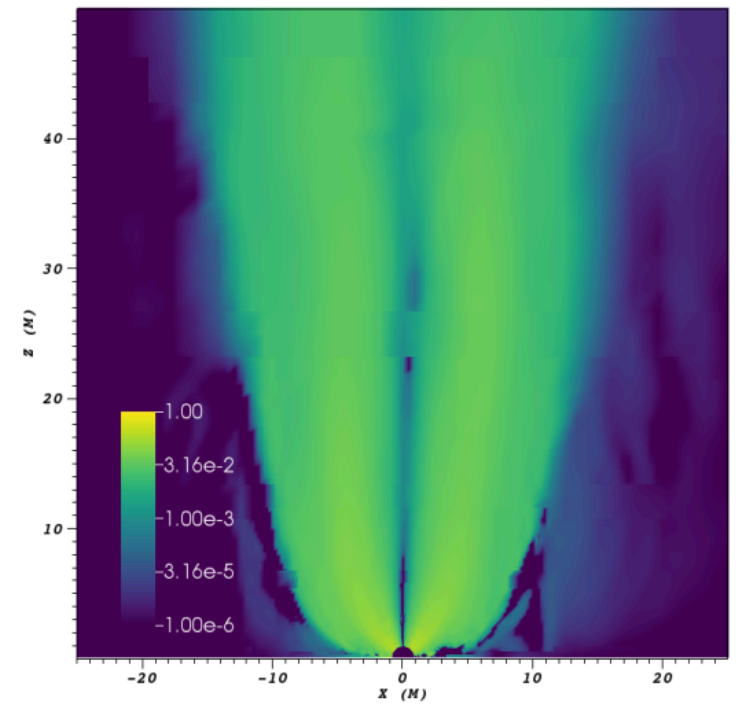
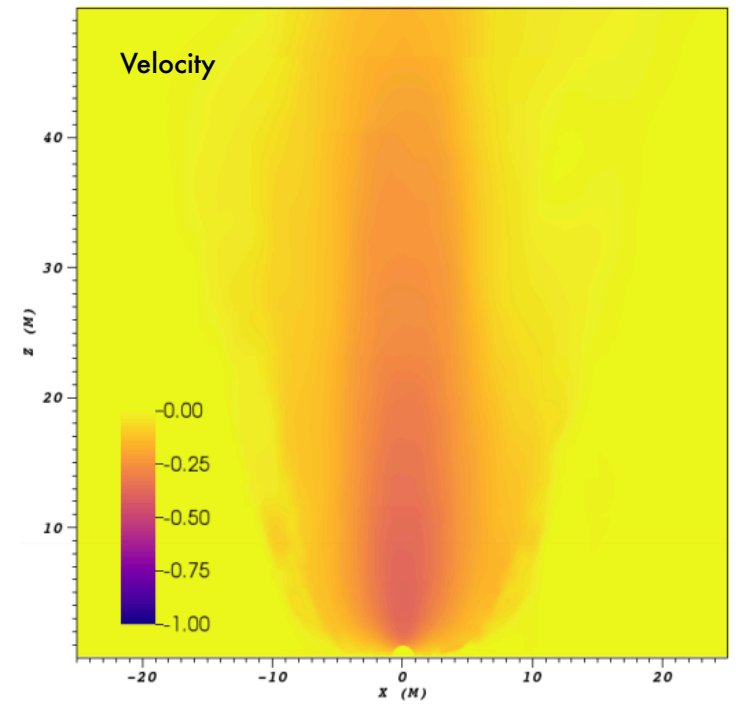




Magnetic field lines at the pole

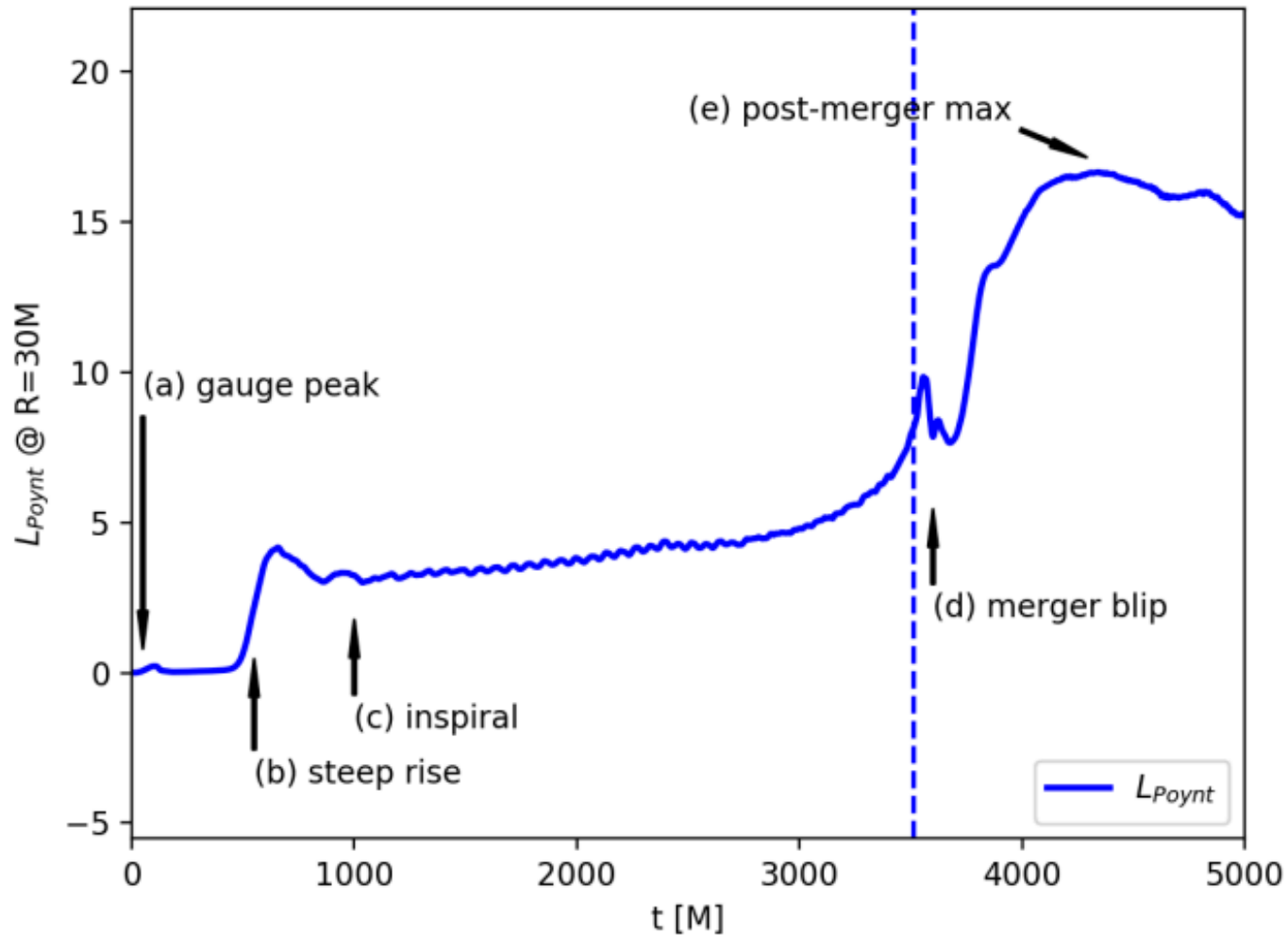
Magnetic fields  
carry Poynting  
flux along the  
newly-formed jet

Baker et al. 2017

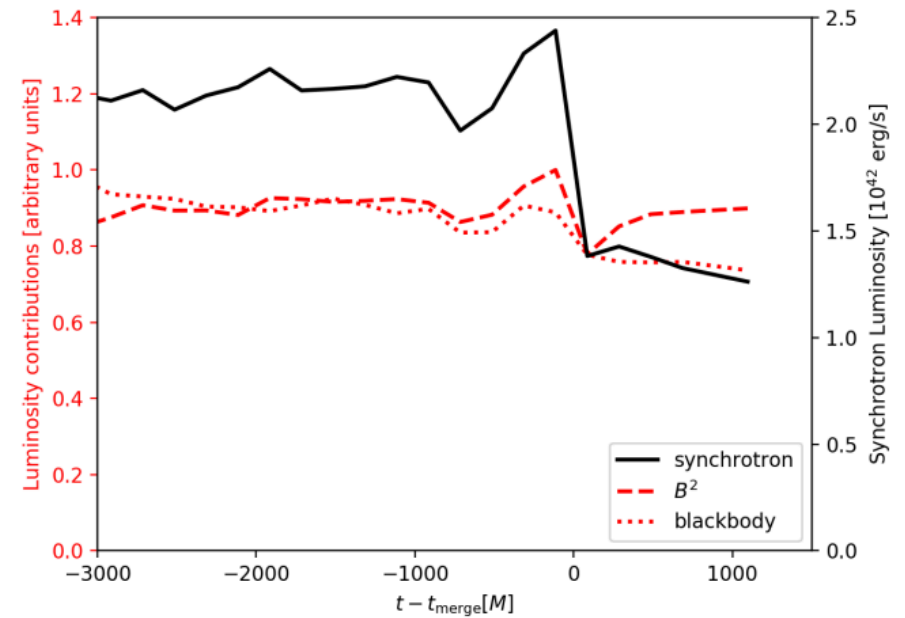
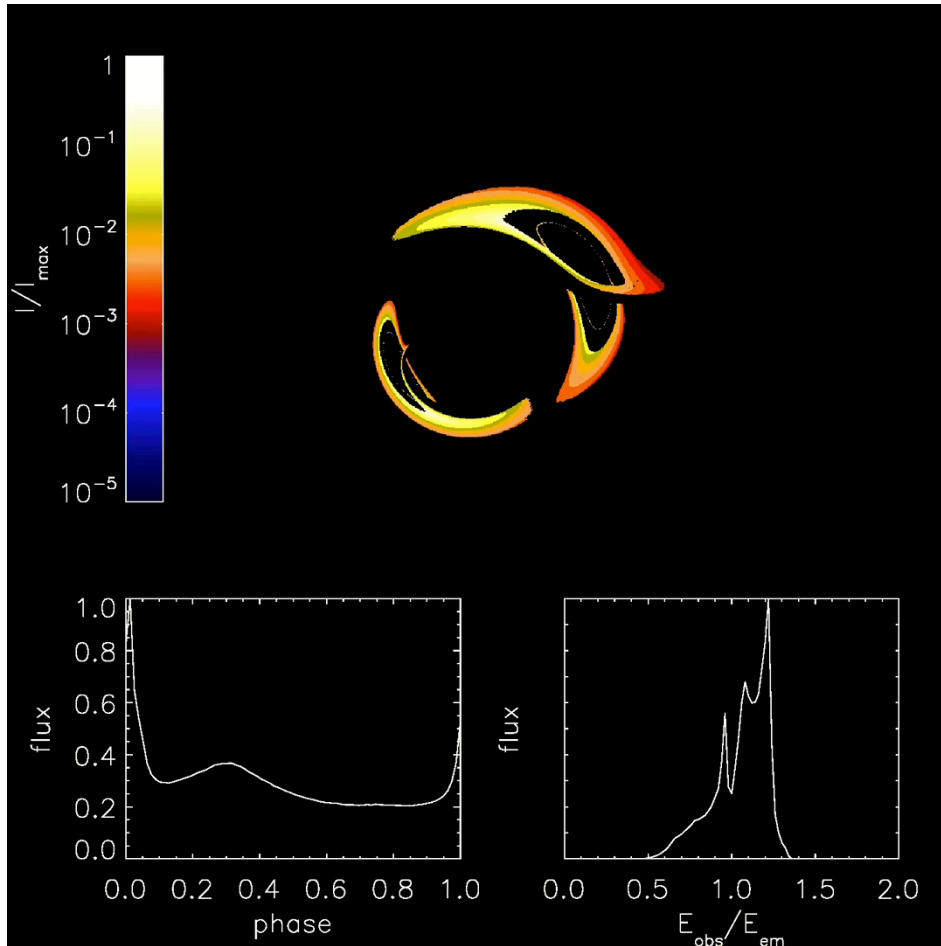


Poynting vector

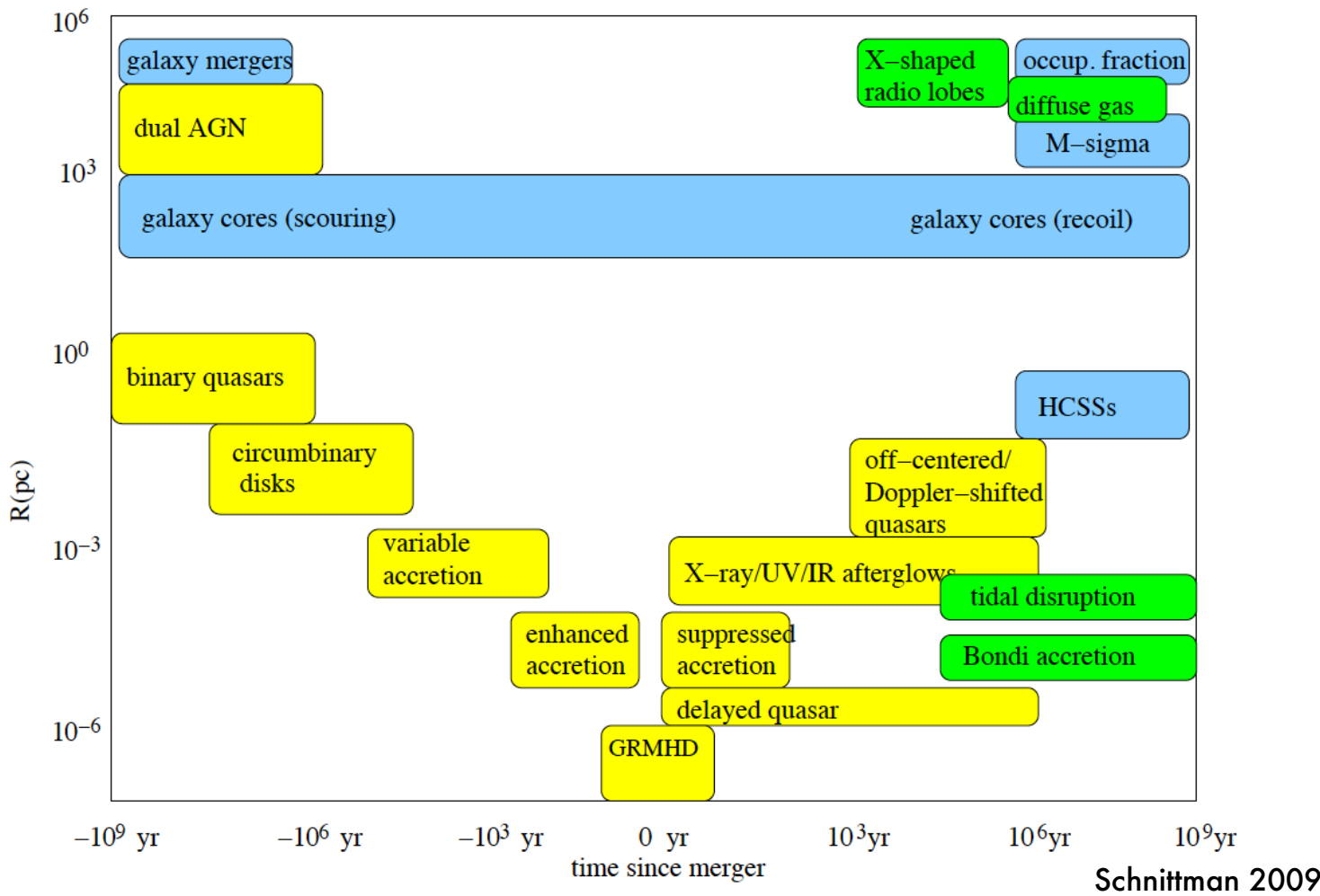
Which could translate into a prompt increase in photon emission post merger



# Lensing coronal synchrotron emission close to the BBH may yield a sharp **drop** in luminosity post merger



While the theoretical and technological dust settles,  
 let's think beyond electromagnetic counterparts



Astronomers! For objects with orbital periods of seconds — hours...  
Imagine what you could do with:

Masses — 1%

Distances — 10% or better

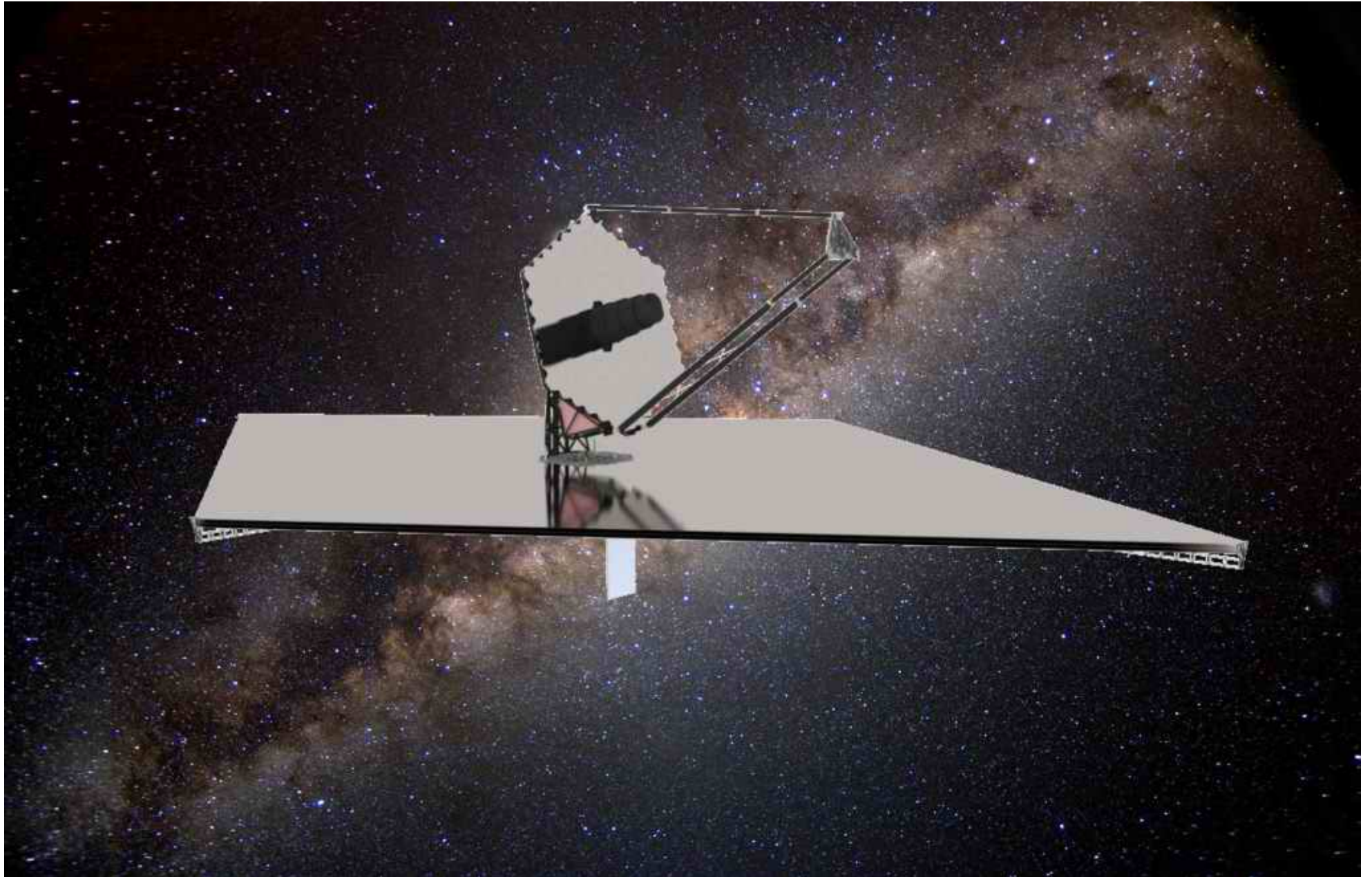
Spins — 1-10%

Spin directions — 10 degrees

Sky localization — 10 deg<sup>2</sup> (Sometimes down to ~ arcmin)

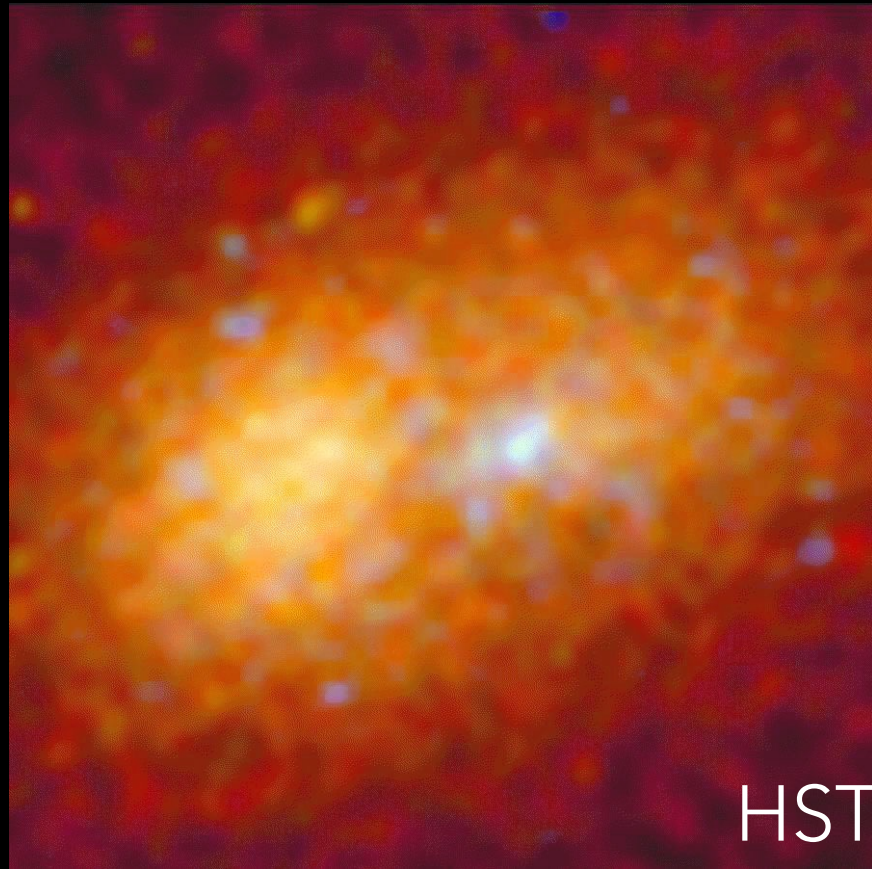
Eccentricity — 1%

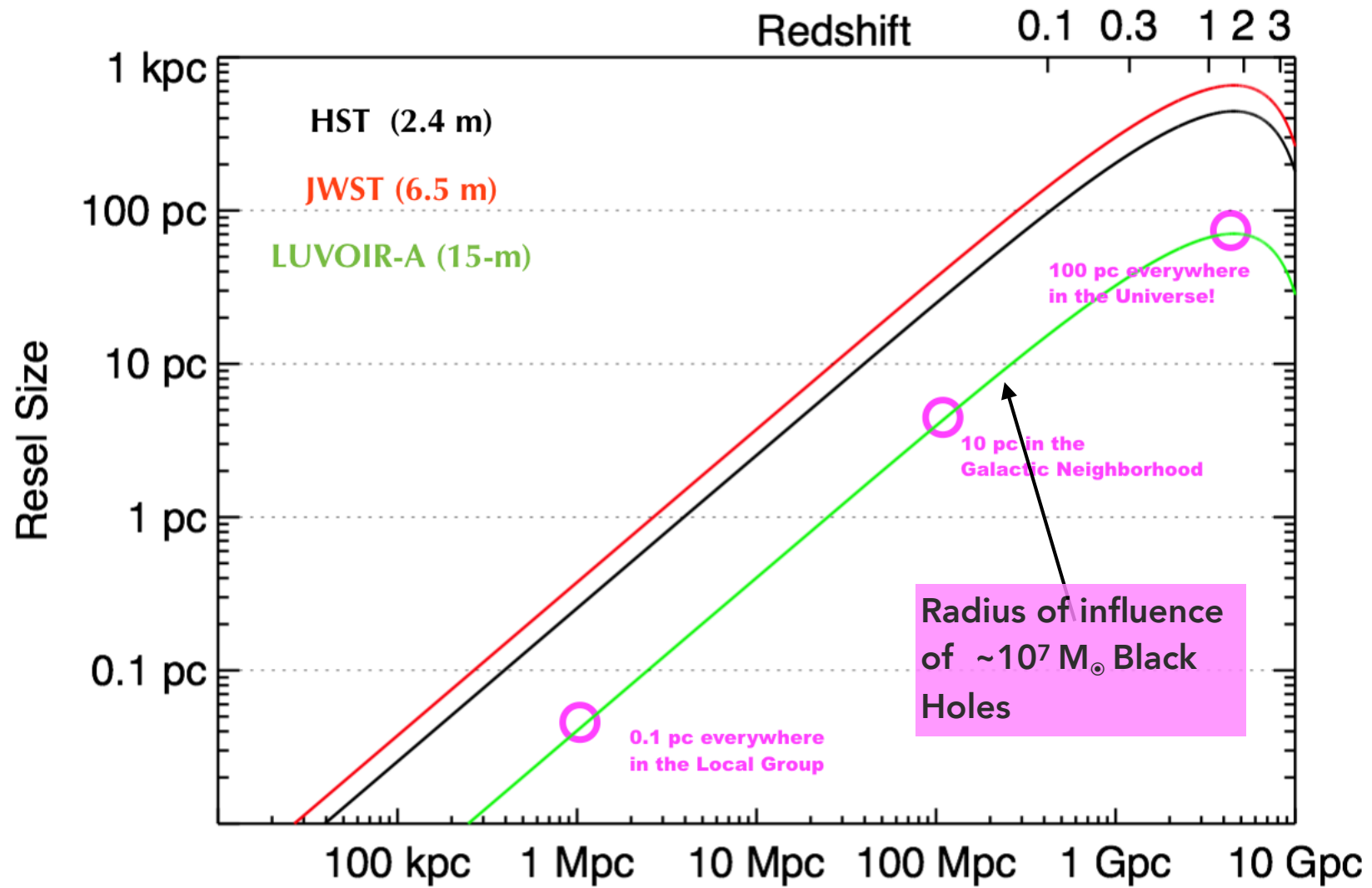
# Large UV Optical IR mission LUVOIR – 15m



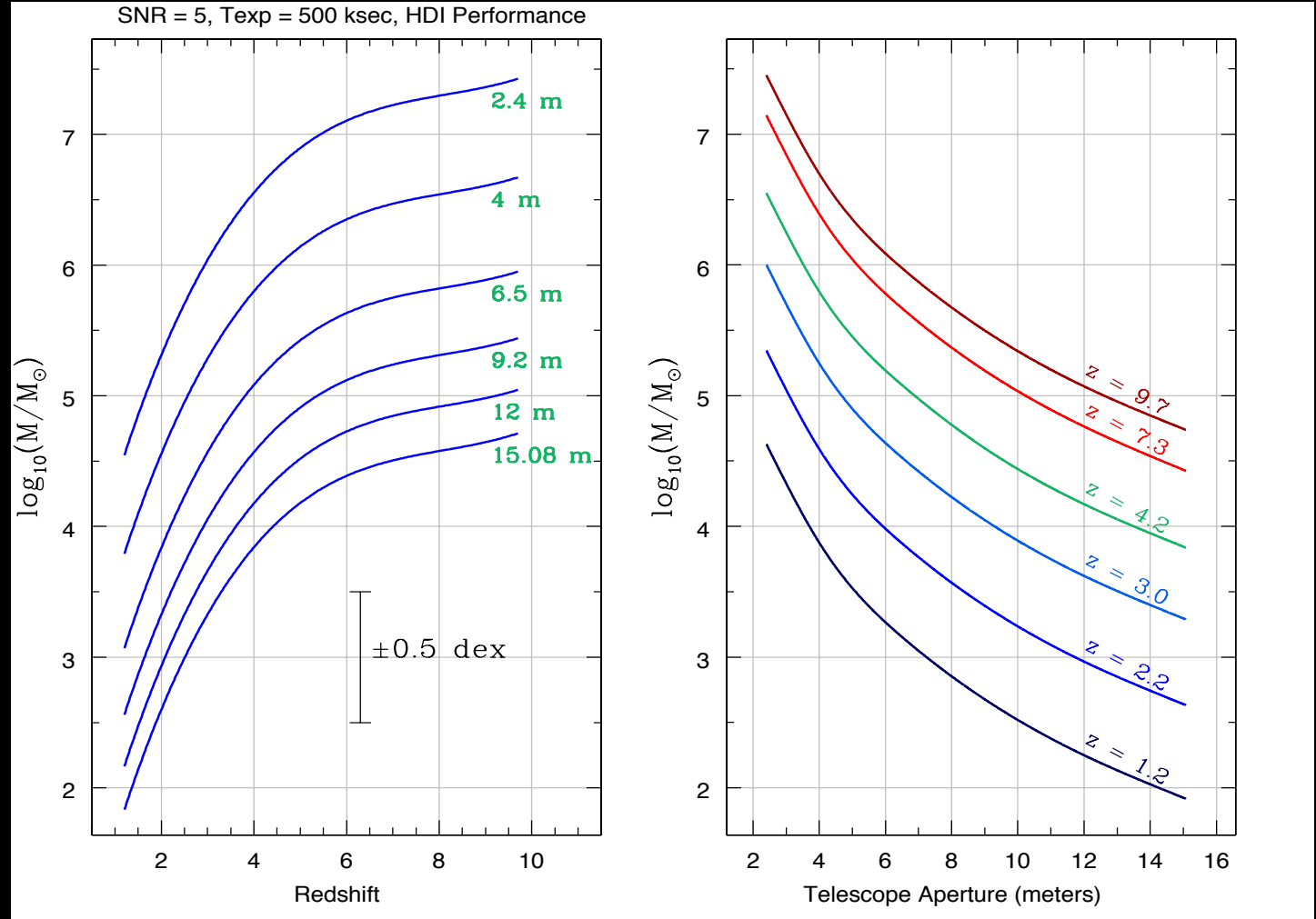


LET'S COMBINE THE EXQUISITE RESOLUTION OF  
LUVOIR WITH LISA DATA



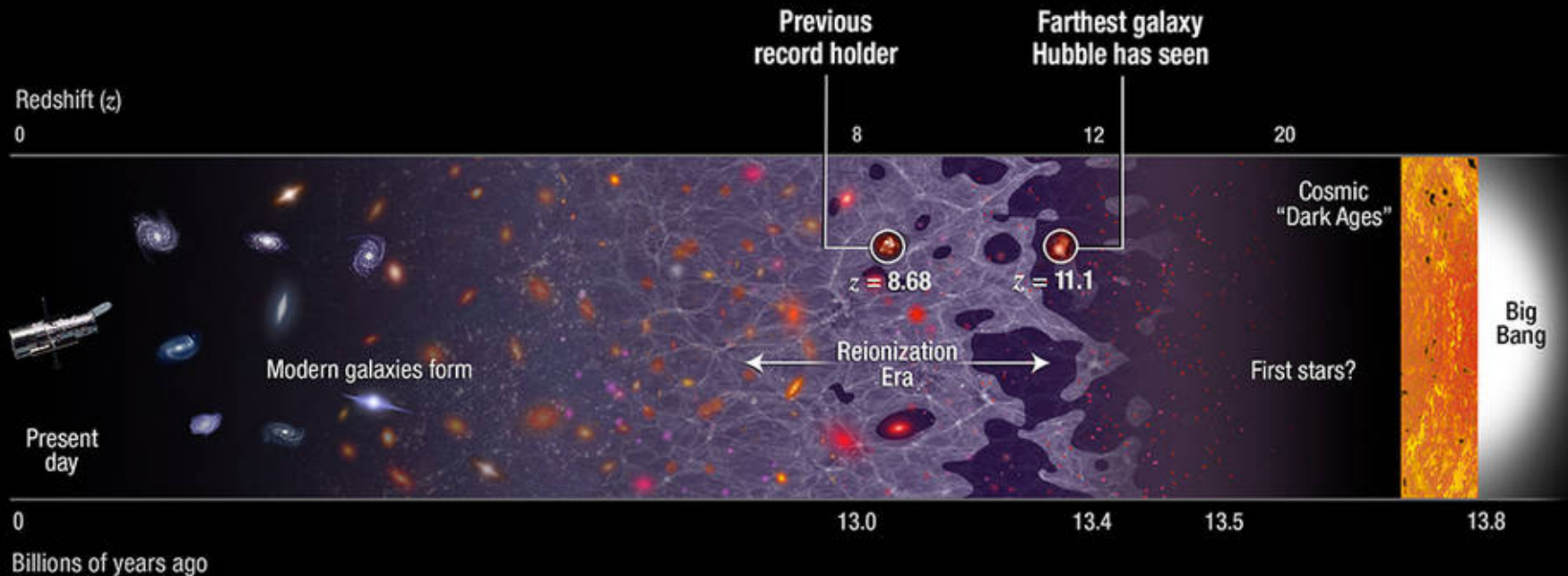


# LUVOIR CAN PEER INTO LISA HOST GALAXIES, EVEN FOR IMBH/SEED BH HOSTS



# LISA+LUVOIR can help understand co-evolution of galaxies and SMBHs across cosmic time

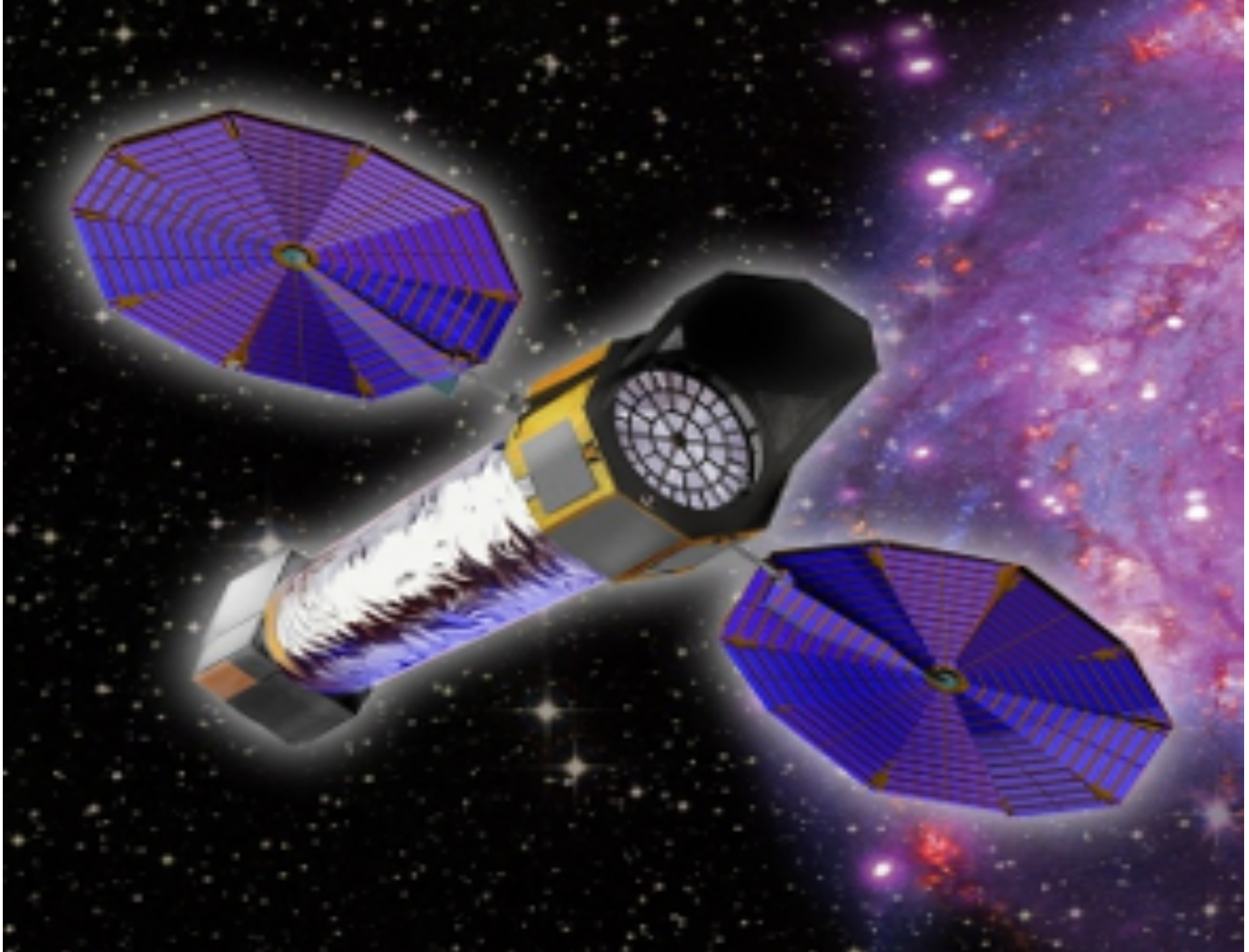
## Hubble spectroscopically confirms farthest galaxy to date



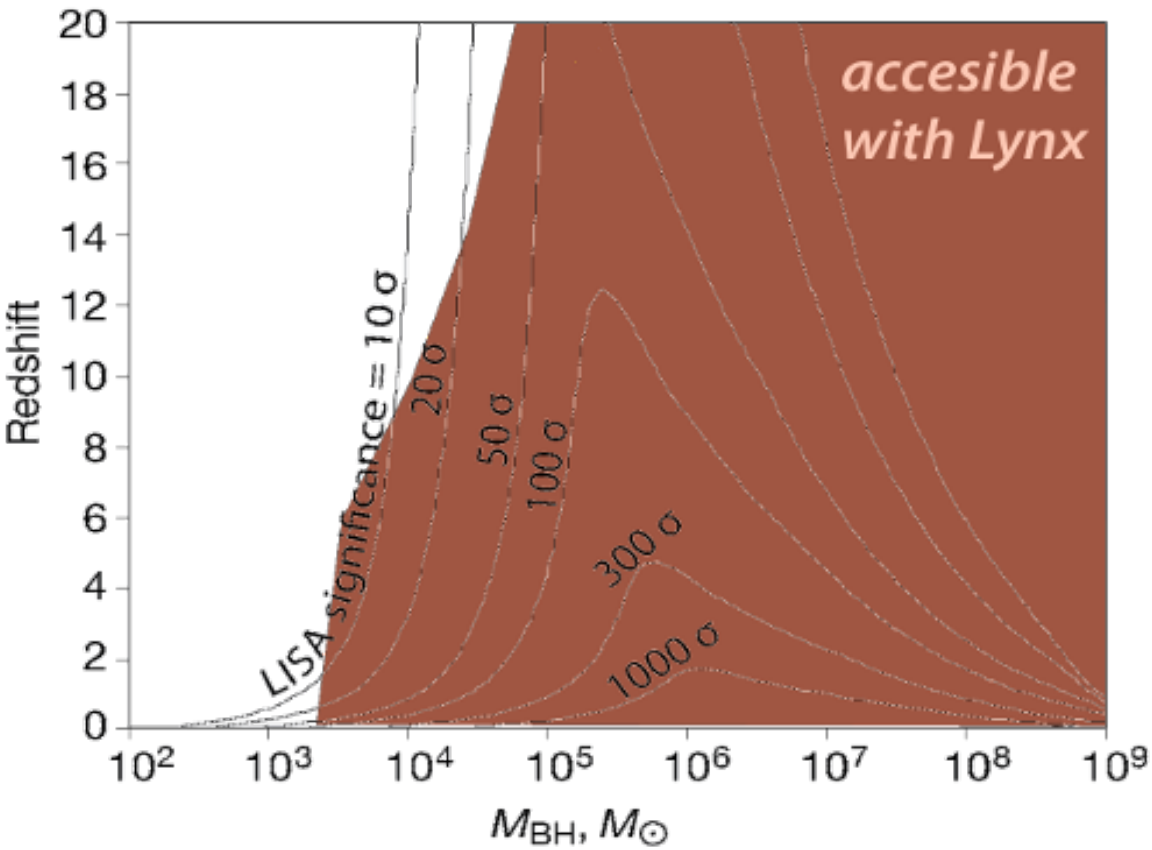
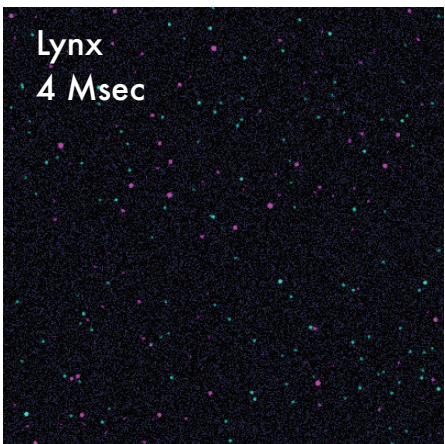
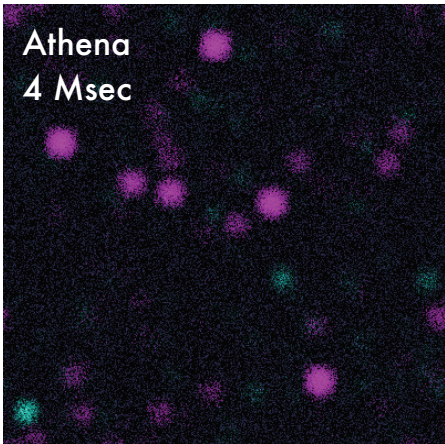
**LUVOIR can  
help maximize  
LISA science,  
even without  
electromagnetic  
counterparts!**

- accurate black hole mass measurements up to  $z \sim 8$  for  $10^5 - 10^7 M_{\odot}$
- connecting SMBH birth/growth during the dark ages
- the type of galaxy for SMBH hosts
- BH occupation fraction up to  $z \sim 8$  and for  $M_{\text{gal}} = \text{small}$
- find evidence of binary black holes (enlist time-domain?)
- look for recoiling AGN (can get 3-d space velocity) – maps to SMBH spin and mass ratio before SMBH merger
- measure galaxy merger rate to constrain SMBH merger dynamics (esp. @ low mass end)
- hypervelocity stars from 3-body scattering out to Coma?
- pulsar planets, nearby highly eccentric and/or hot Jupiter planets (regardless of inclination)
- nuclear structure to connect EMRIs to tidal disruption events, and to constrain core scouring
- observations of compact binaries to better understand common envelope phase
- BAO in the dark ages, but need map from BBH to galaxies...

# Lynx – high resolution X-ray mission

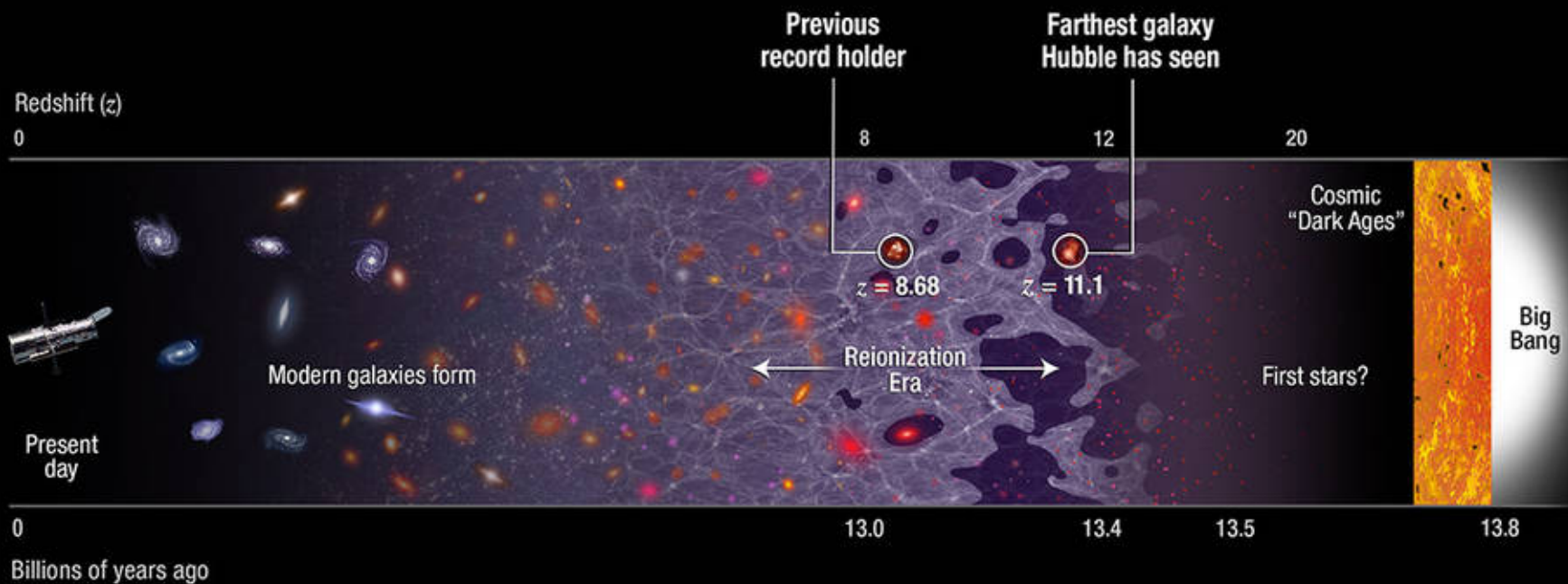


# The combo of high resolution and deep sensitivity make it a game-changer

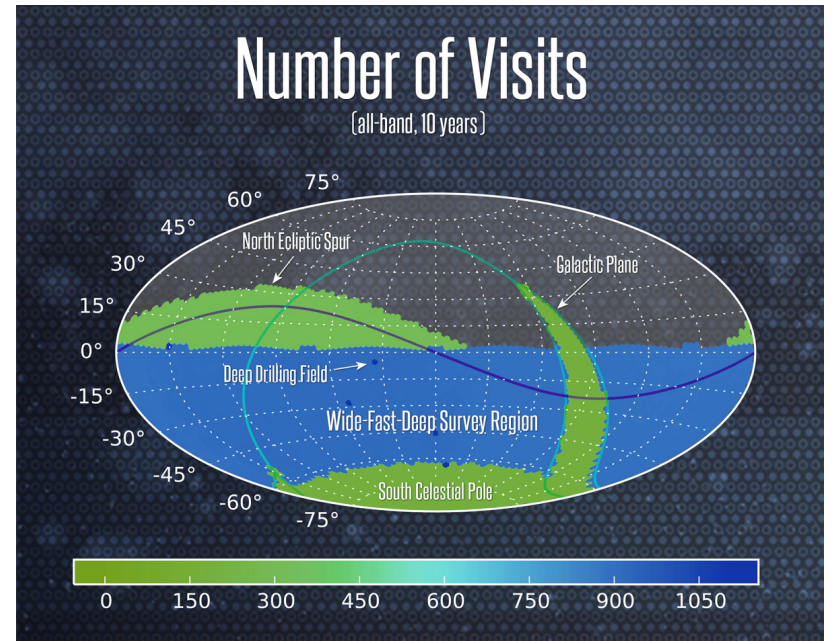


# Lynx can help understand co-evolution of galaxies and SMBHs across cosmic time

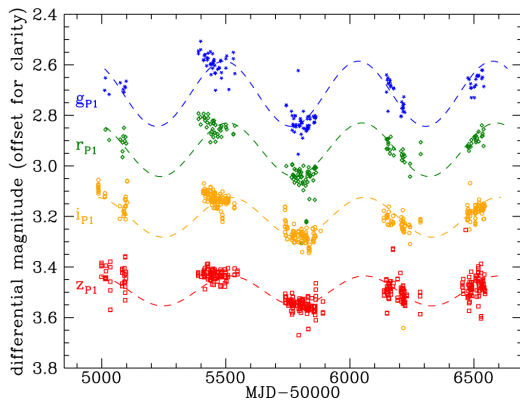
## Hubble spectroscopically confirms farthest galaxy to date







## Pan-Starrs PSO J334.2028+01.4075



Periodicity caused by  
 $542 \pm 15$  day orbit of a  
 $10^{10}$  solar mass binary at  
 $0.05 < q < 0.25$  @  $z=2.06$   
 – separation of  $\sim 10 R_s$ !!

Liu et al. 2015

**Stay tuned: By  
 2028, LSST  
 should find  $\sim 10^4$   
 BBH candidates**