THE ELECTROMAGNETIC COUNTERPARTS TO GRAVITATIONAL WAVE SOURCES FROM GROUND TO SPACE-BASED FACILITIES

WILL THE ENERGETIC UNIVERSE MEET THE GRAVITATIONAL WAVE UNIVERSE?

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Exploring the Hot and Energetic Universe:
The first scientific conference dedicated to the Athena X-ray observatory
Madrid, 8-10 September 2015
ESA/ESAC

- The previous century witnessed a great revolution in astrophysics, driven by improvements in observing capabilities across the electromagnetic (EM) spectrum. Serendipitous discovery of new classes of sources

- X-ray sky has revealed a violent ever changing Universe full of **accreting neutron stars and accreting black holes of all flavors**

- Guided by X-ray observations (precious heritage) + predictive power of General Relativity + complex input physics ruling energetic phenomena **portrait sources of gravitational waves:** prime targets are **coalescing neutron stars and black holes of all flavors**

- Gravitational Wave Universe holds a great potential for discovery of the unknown

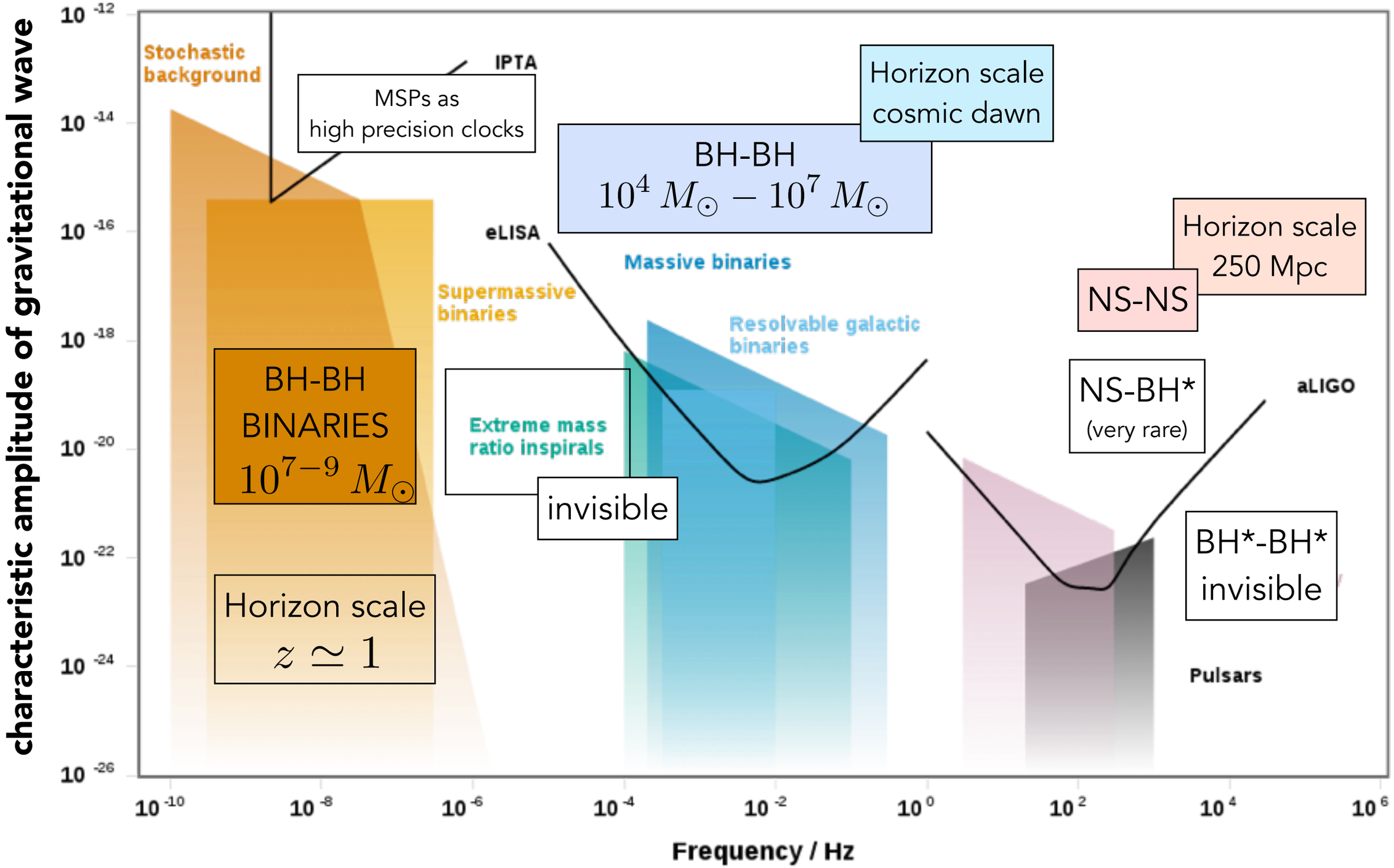
- GW sky provides access to a Universe that can not be observed in any other way: “invisible” as our carriers are gravitational waves

- Flow of information from *ATHENA* and from the GW Universe is complementary and where there is overlap, information is genetically diverse

$$h = \frac{\delta L}{L}$$

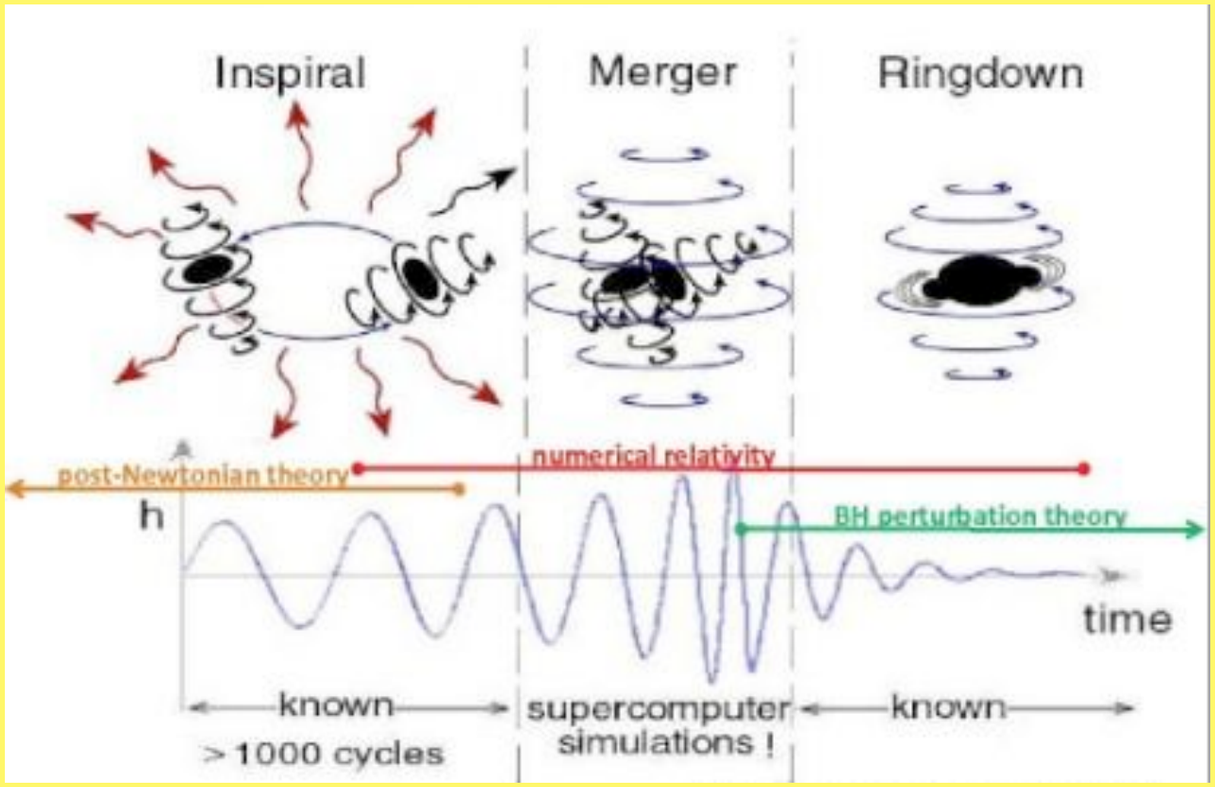
THE GRAVITATIONAL WAVE SOURCE LANDSCAPE

- over a huge frequency interval -



KIP THORNE CARTOON

COMPACT -COALESCING BINARIES - STANDARD SIRENS



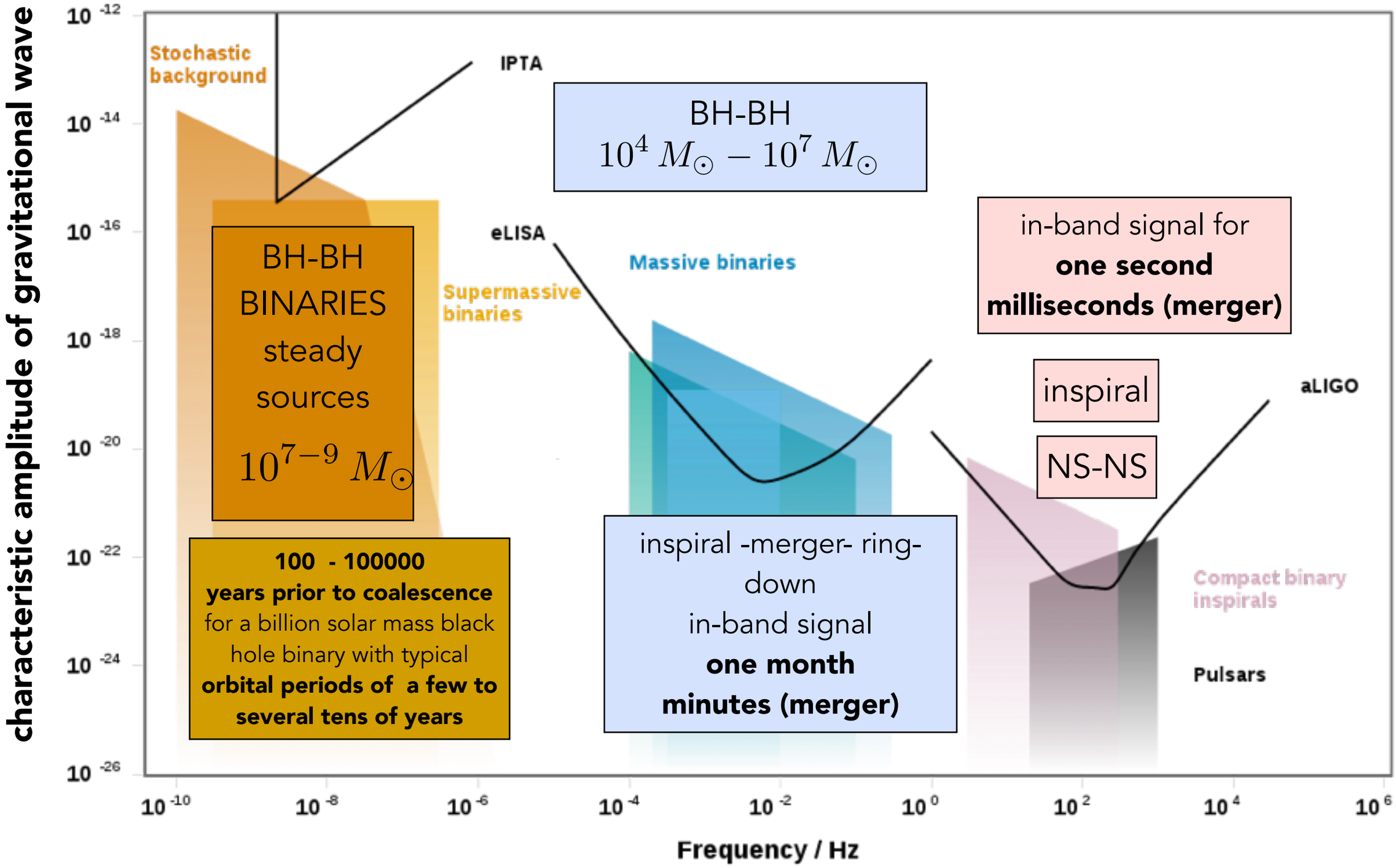
DIRECT MEASURE OF THE LUMINOSITY DISTANCE

An independent measure of the redshift, e.g. from the detection of the EM counterpart
returns the cosmological parameters now measured through "gravity" ...
-study of the host galaxy & environment-

$$h = \frac{\delta L}{L}$$

THE GRAVITATIONAL WAVE LANDSCAPE

COINCIDENT DETECTION



THE GRAVITATIONAL UNIVERSE

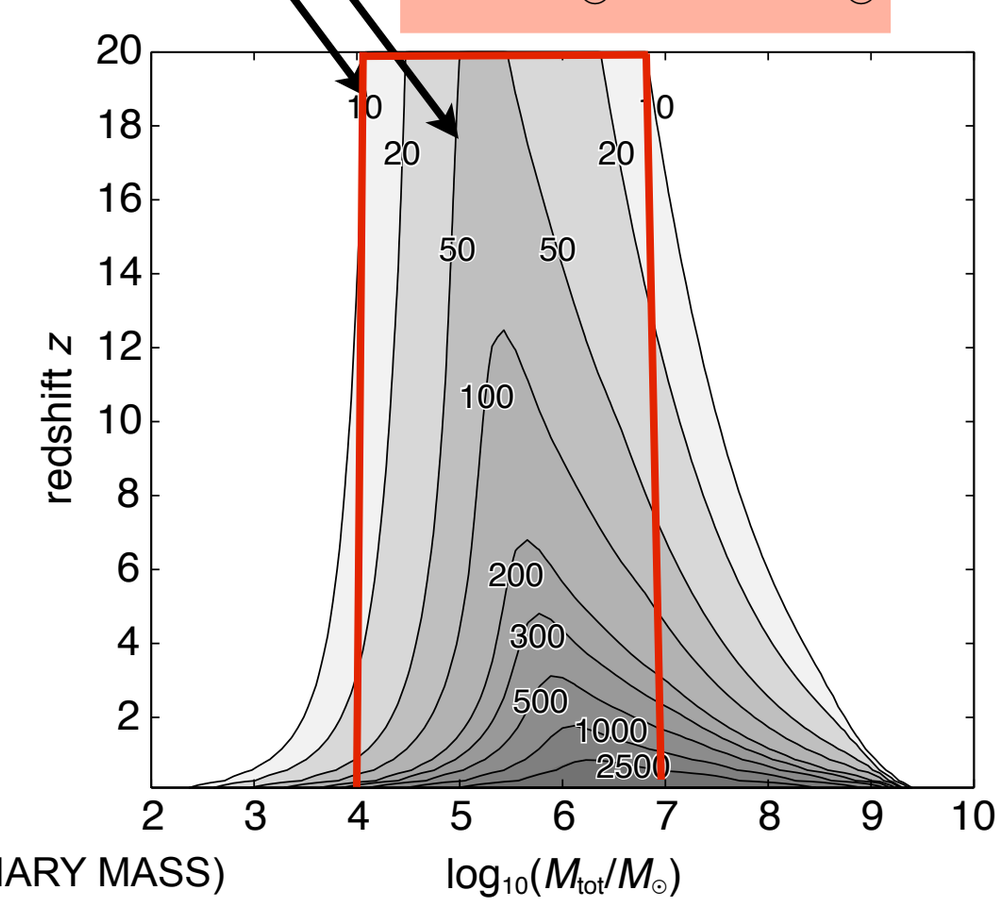
"coalescing binary black holes"
in galaxy mergers
across the Universe

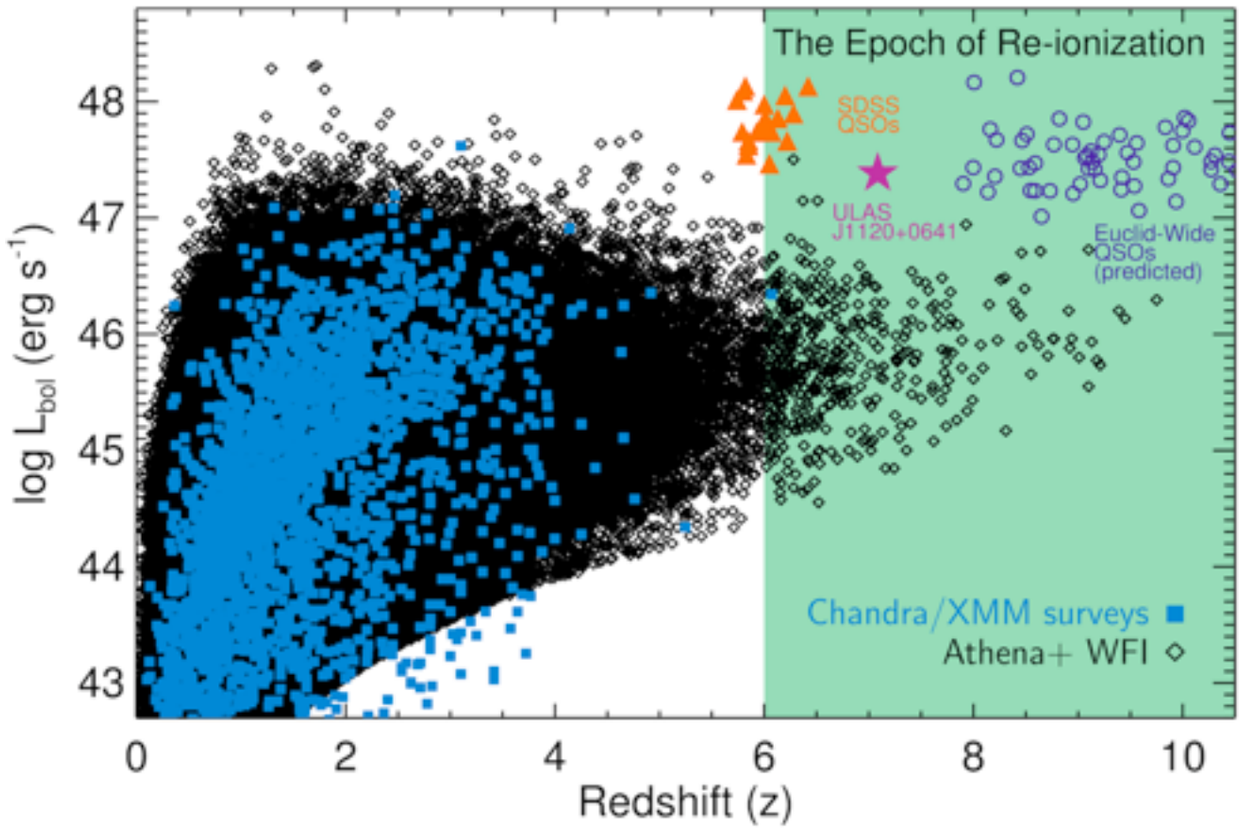
$$L_{\rm GW}^{\rm coal} \simeq \frac{c^5}{G} = 3.6 \times 10^{59}\,{\rm erg\,s^{-1}}$$

$$E_{\rm GW} \simeq 0.08 M c^2$$

CURVES OF CONSTANT SIGNAL-TO-NOISE RATIO

$10^4\,M_\odot - 10^7\,M_\odot$





THE ENERGETIC UNIVERSE

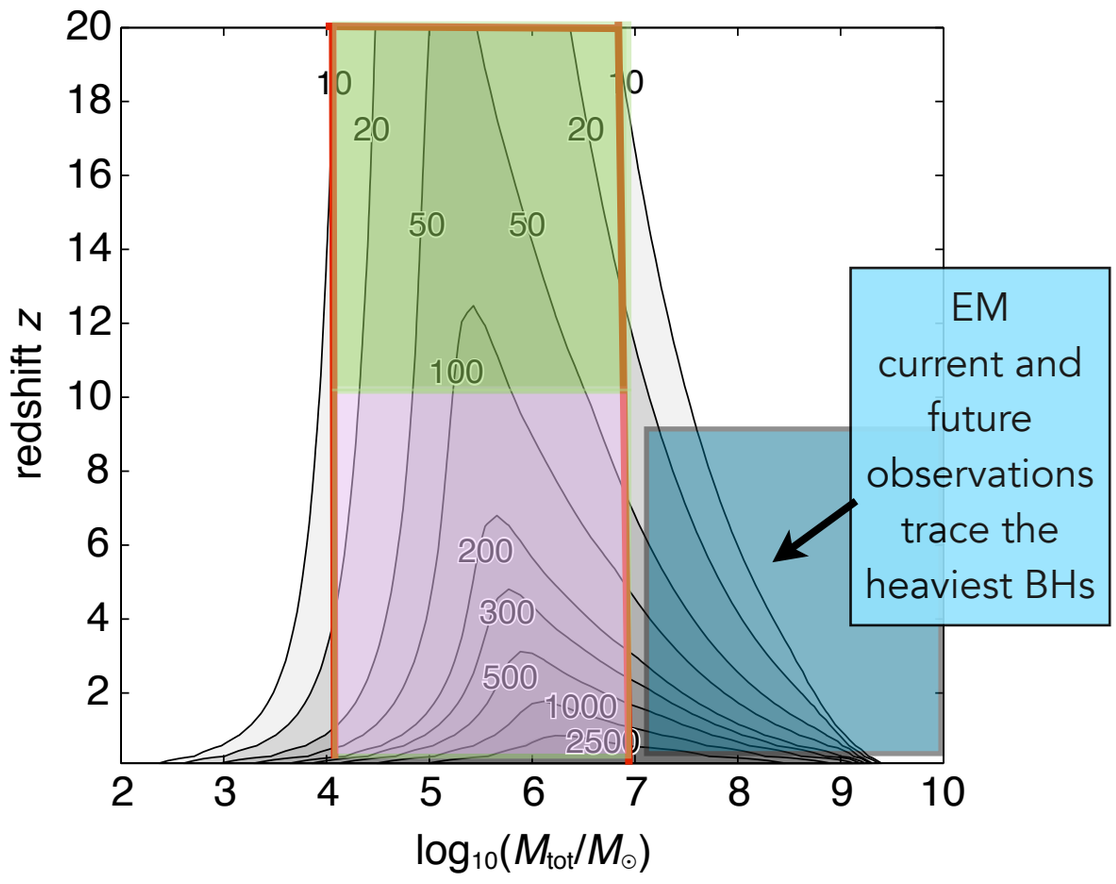
enlarge the sample
"**accreting (obscured) black holes**"
in galaxies
over a wide range of luminosities
@ high z
... tracing the supermassive BHs

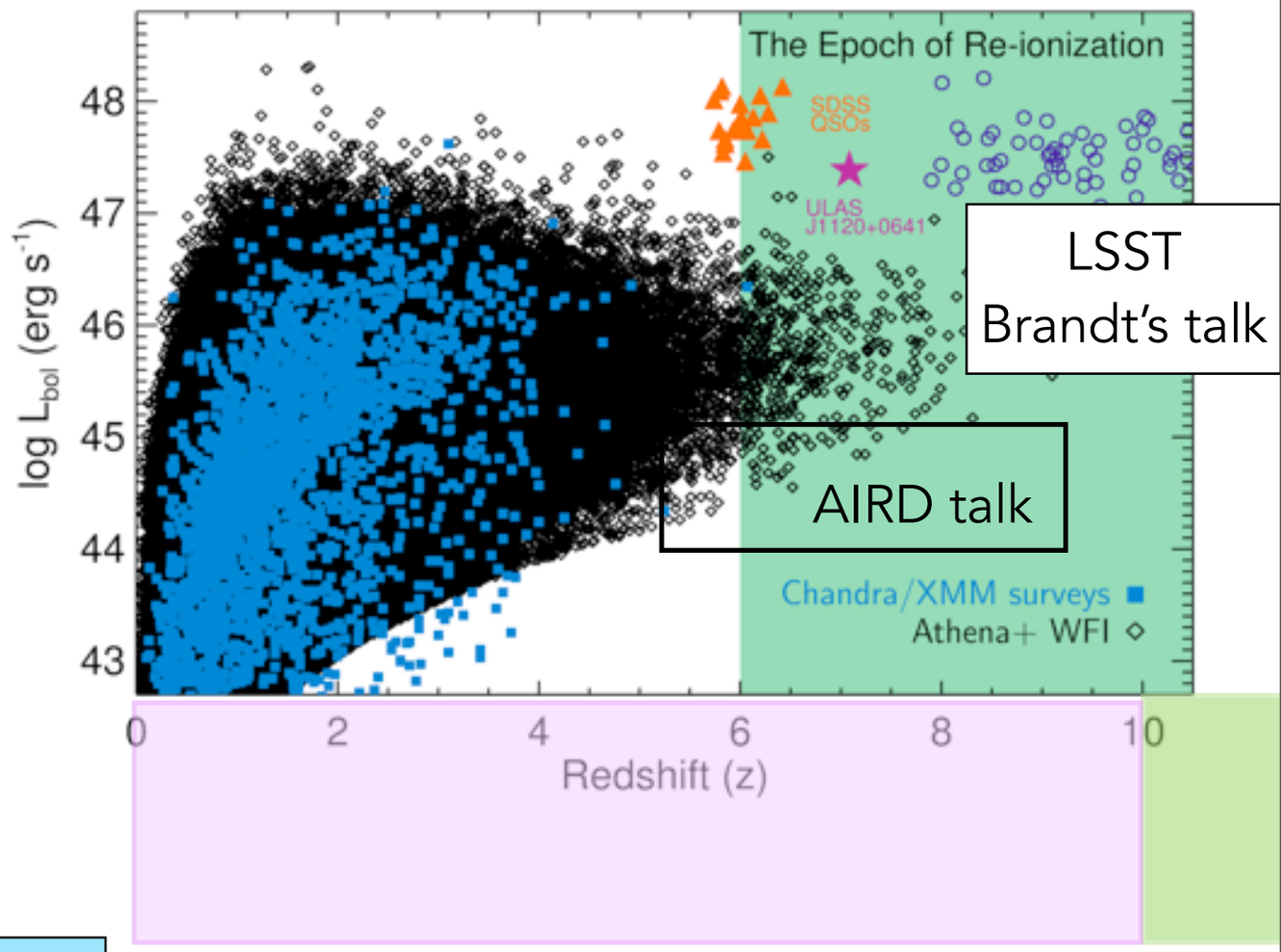
COMPLEMENTARITY

THE GRAVITATIONAL UNIVERSE

"coalescing binary black holes"
mission's goal
high redshift SEEDS
"infant black holes"

"coalescing binary black holes"
mass & spin measurements
up to 0.1%-1% precision
reconstruction of the history



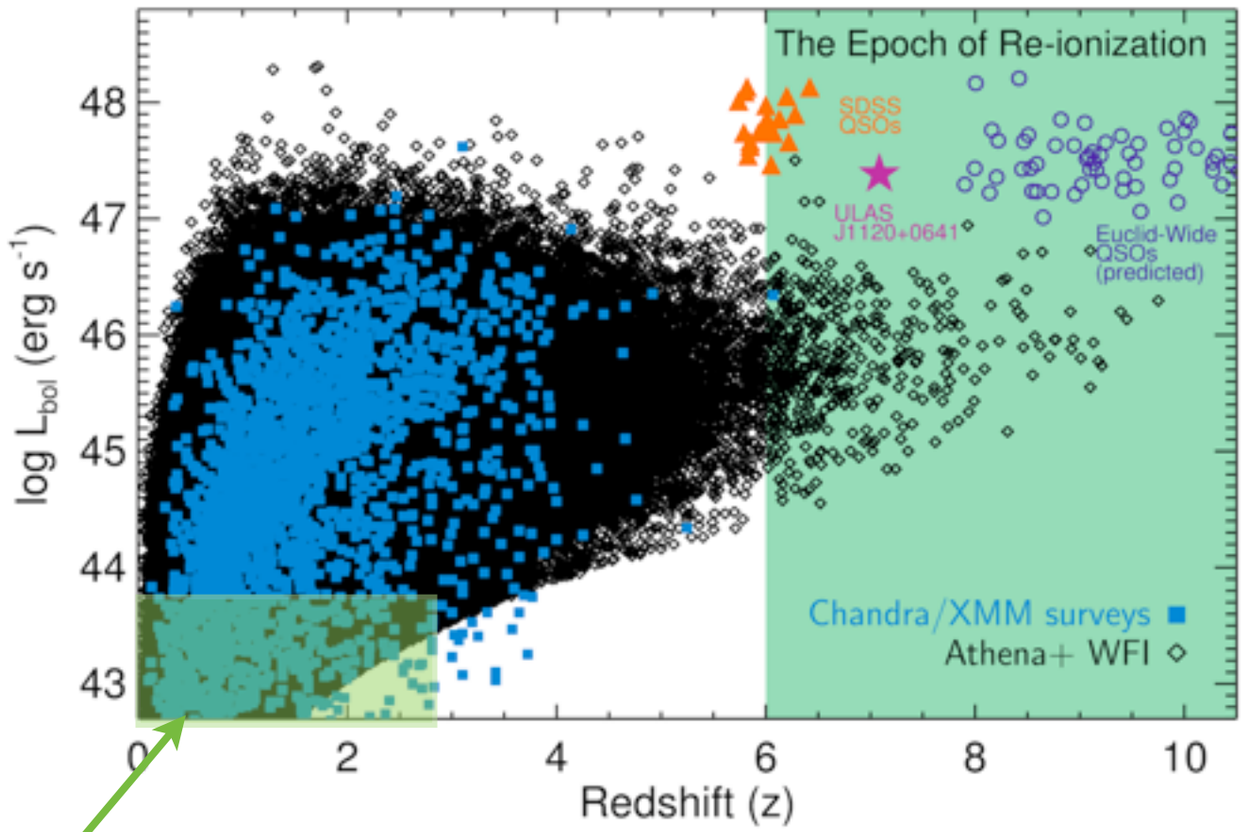


$$L_E \simeq 1.8 \times 10^{43} \left(\frac{10^5 \, M_\odot}{M} \right) \, \mathrm{erg\,s^{-1}}$$

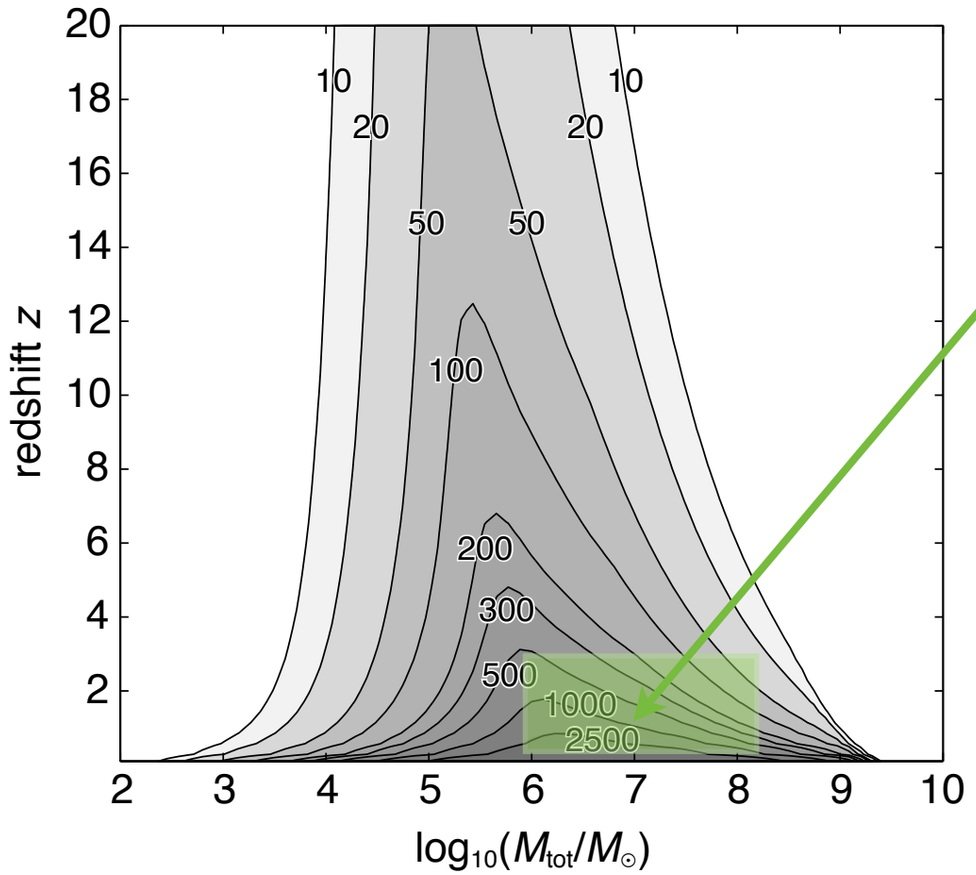
We will reveal a population of BHs EM invisible @ very high z
and under-luminous @ low z

OVERLAP but over
differently selected “samples”

THE ENERGETIC UNIVERSE



THE GRAVITATIONAL UNIVERSE



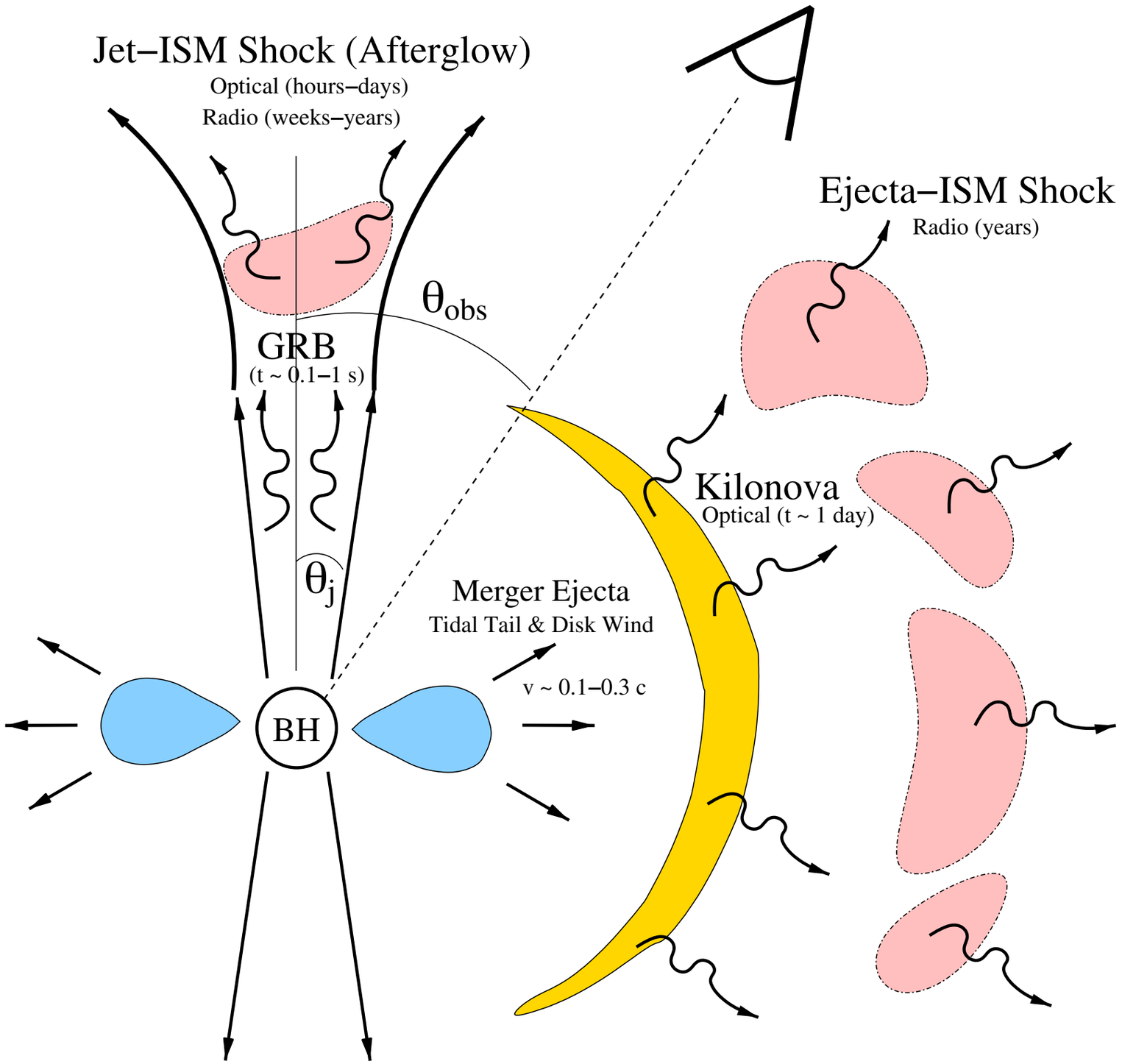
SYNERGY

- Which are the perspectives of observing
  EM precursors -- EM coincident detections -- EM afterglows of GW events?

- **.. ancestors & relics**

- Role of *ATHENA*?

- aLIGO NS-NS COALESCENCES



- **Merger model for SHORT GRBs**: (i) energy requirement and rates, (ii) clean environment to avoid significant baryon loading, (iii) lack of associations with supernovae, (iv) redshift distribution (z~0.1-1.5) indicating typical progenitor delay times of less than e few Gyrs, (v) occurrence in both late and early type galaxies with rate influence by both stellar mass and star formation activity, (vi) off-sets (10% bursts have off-sets >20 kpc) indicative of natal kicks or dynamical origin in globular clusters, (vii) evidence of collimation, (viii) under-luminous afterglow
- NS-NS mergers (20 per year) are expected to generate an EM signal - formation of an hyper-accreting highly magnetized disc of debris. The GW signal is expected to anticipate the EM signal. GW detection should work as a “trigger”
- **The localization region for Advanced LIGO/Virgo is100 deg^2- a challenge for EM follow-up**

GW signal acts as trigger
SEARCH of low redshift (z<0.1) sGRBs off set

see Berger 2014 for a review & discussion

- eLISA COALESCENCES

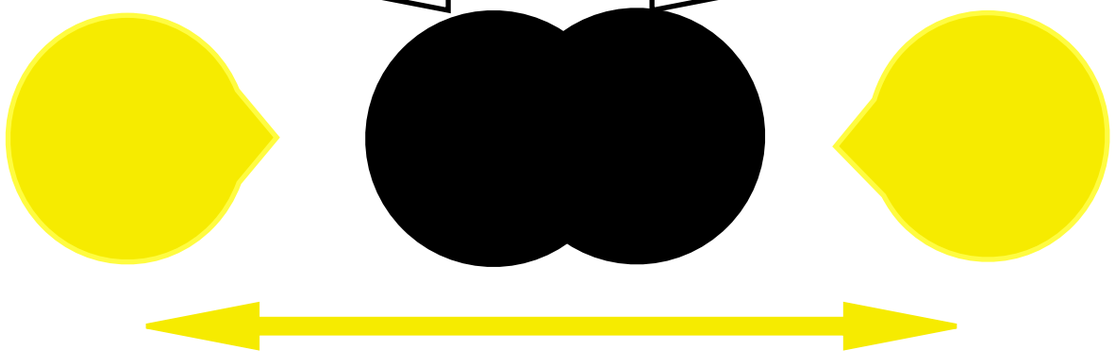
- Will black holes attend coalescence in vacuum?
  (coalescence occurs on μ-pc scales)

... focus hypothetically on A RING OF GAS

NEAR ZONE: EM minute BURST ?

$$\delta t_{\rm spacetime} \sim c/R_g$$

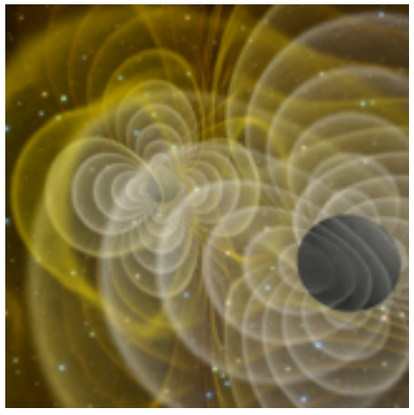
$M_{\rm gas}$



$$R \lesssim 10\, R_G$$

$$\delta t_{\rm gas} \sim T_{\rm orbital} \sim (c/R_G)(R/R_g)^{3/2} \sim \delta t_{\rm spacetime}(R/R_g)^{3/2}$$

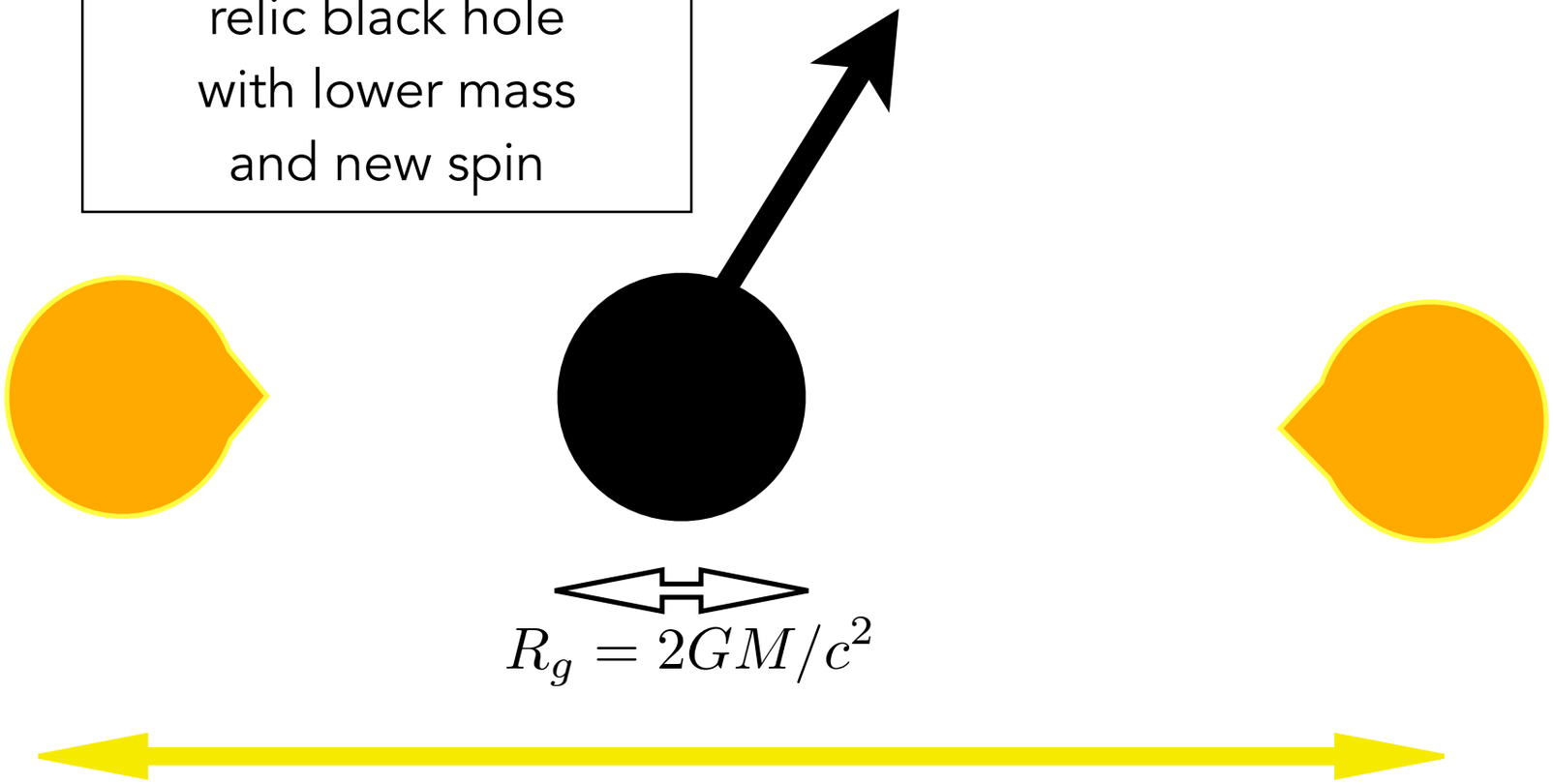
- In the highly fluctuating dynamical spacetime gas is shock-heated and cools radiatively
- stretching of magnetic field lines - collimated jet
- prompt emission @ the level of the Eddington luminosity
- duration depends on the amount of gas mass
- spectra: depending on opacity, the flare can be in X-rays



Krolik 2010
Palenzuela et a. 2012
Van Meter et al. 2012

THE FAR ZONE: LONG (month) AFTERGLOW ?

relic black hole
with lower mass
and new spin



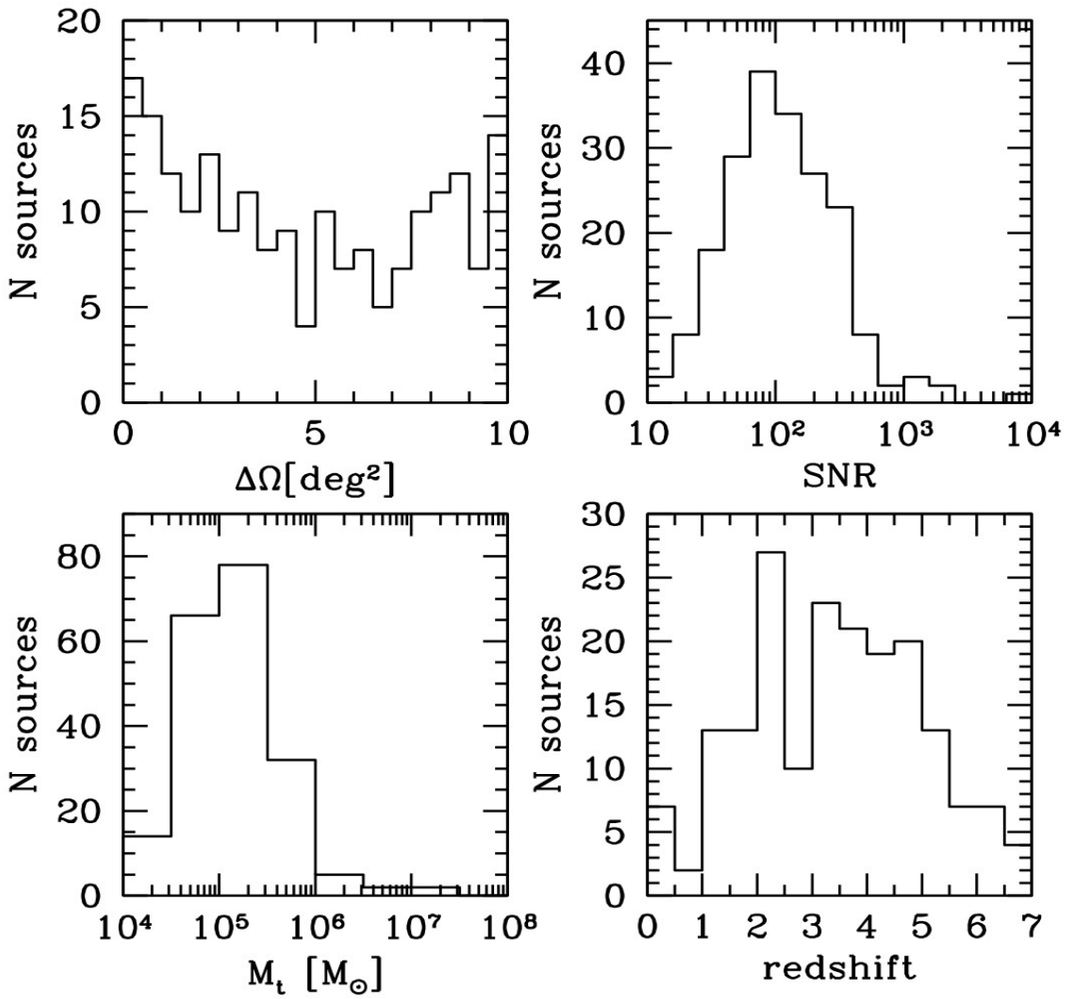
$$R_g = 2GM/c^2$$

$$R \sim 100\, R_G$$

$$\delta t_{\rm gas-dissip} \gg \delta t_{\rm spacetime}$$

- Sudden Mass loss by GW (1%-10%)
- Sudden change of angular momentum- oblique orbits precess. Lense Thirring torques related to the new spin of the new black hole

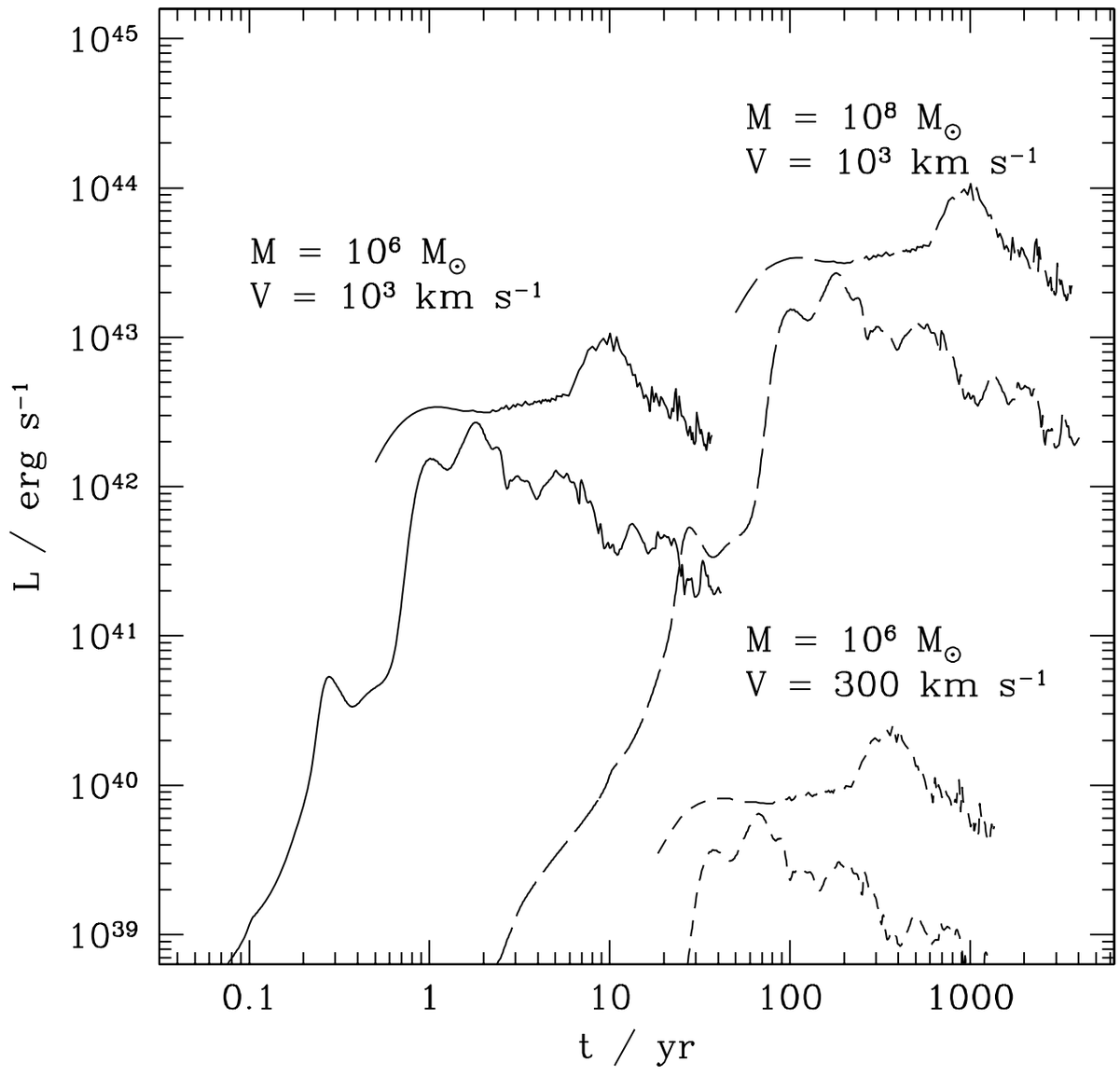
- 10 deg^2

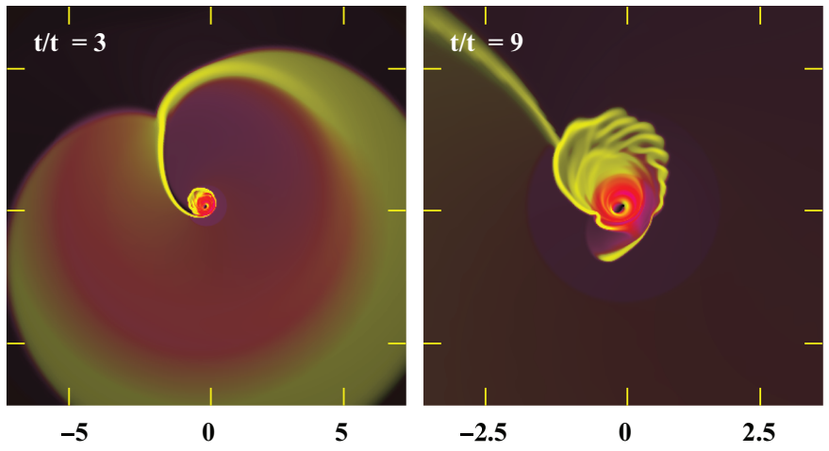


Sesana, Petiteau, MC unpublished material

- Starting from a meta-catalogue of simulated sources
- eLISA plans to perform analysis in real time
- **SKA** field of view (FOV) of 10 deg^2 and μJy sensitivity for 1 hour of integration time, high chance of detecting the transient out to z=5 5-10 radio transients can be discovered
- **LSST** with FOV similar to SKA r=27.7: a handful of sources below z=0.3
- **eROSITA** with 10^{-15} flux and FOV of 0.83 deg^2 one source at z=1
- **Fermi** like (20% sky coverage) best chances
- difficult task is in finding a unique signature of an off-on sources after the GW trigger but ..knowing the "time zero" of coalescence will help.
- difficult task is to identify the source in a "sea" of transients. By 2030 we will know much more on the **transient sky**

Black hole merger: the first light after 0.1-100 years
"relic glow"





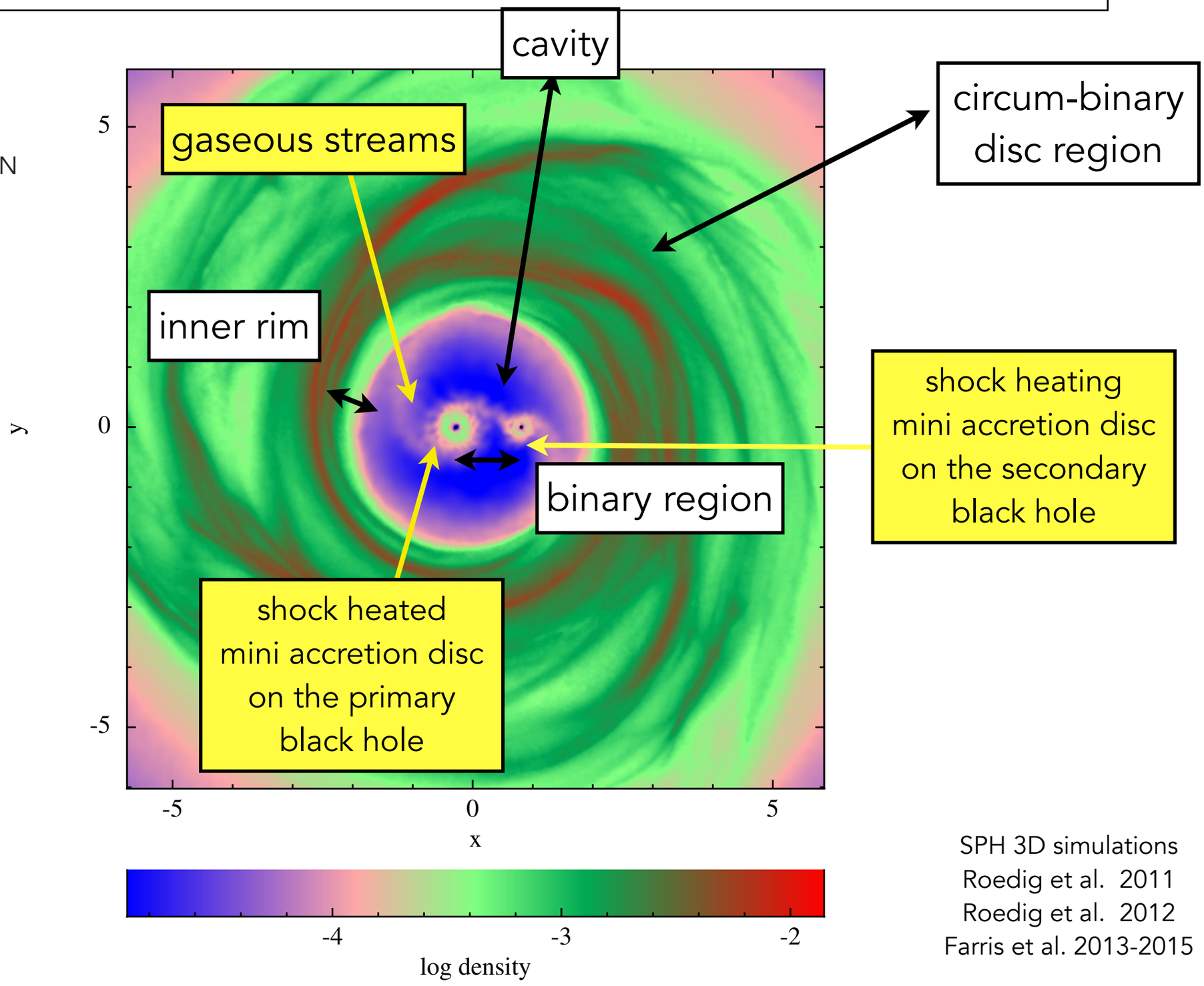
Dragging and impact of the recoiling black hole with its accretion disc off centre X-ray source

Rossi et al. 2010

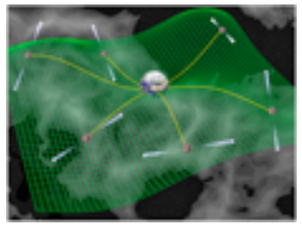
- Is there any gas around binary black holes prior to coalescence?

Ancestors...1000... years prior to merger ....
Tidal coupling phase - The circum-binary scenario

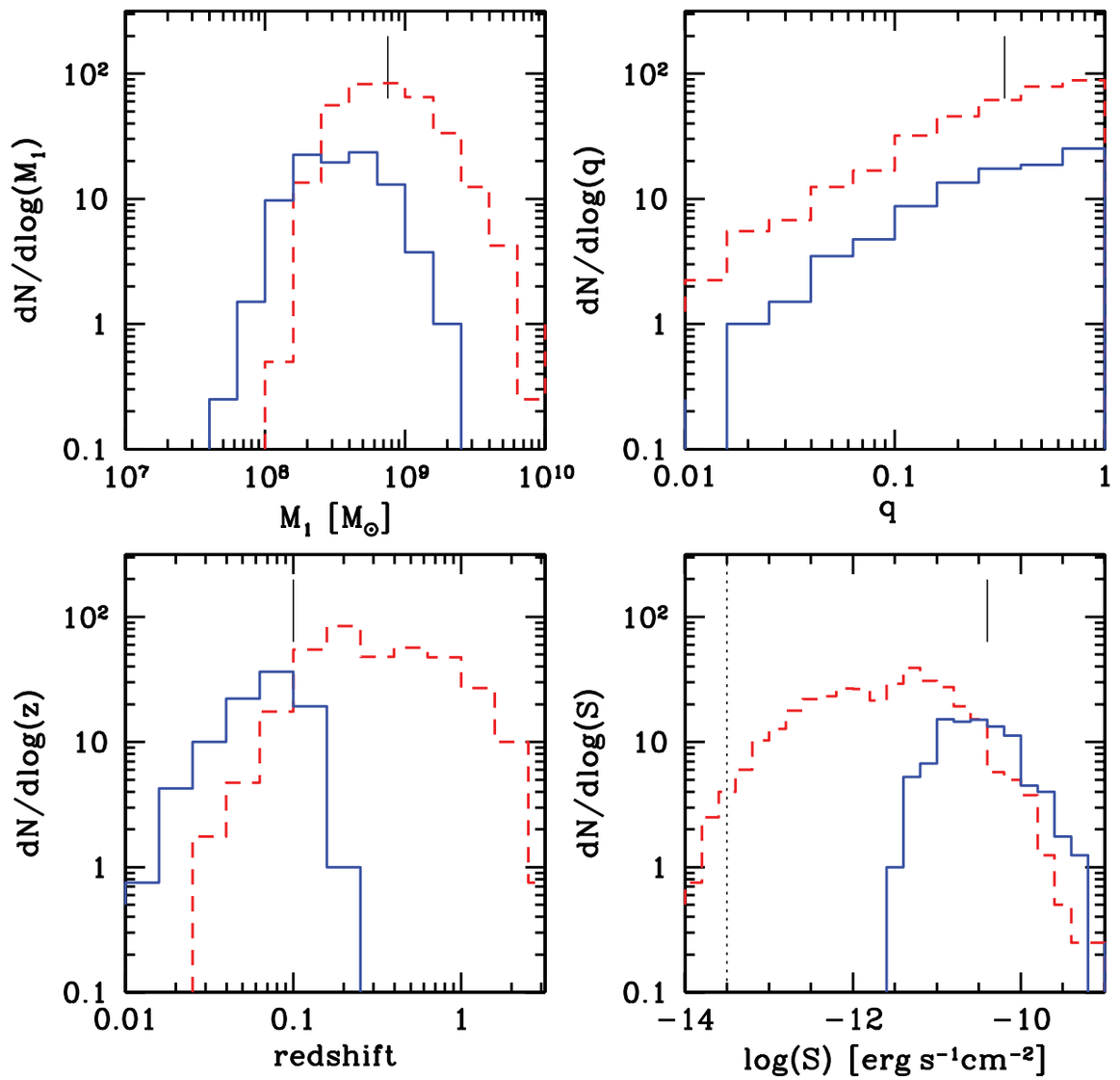
- PERIODIC VARIABILITY
- ENHANCED ACCRETION



SPH 3D simulations
Roedig et al. 2011
Roedig et al. 2012
Farris et al. 2013-2015



- Accretion (X-rays) is contemporary to the GW signal for the PTA sources
- Relativistic iron line



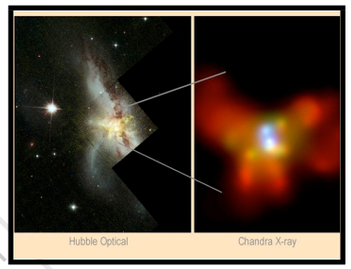
Sesana et al. 2012

blu: before disc freezing
red: after disc freezing

EXPLORING GW ANCESTORS

GALAXY MERGERS

DUAL AGN
kpc apart



KEPLERIAN BINARY

CIRCUMBINARY MINI-DISCS

MERGER

DELAYED AGN

TIDAL DISRUPTION EVENTS

OFF-SET RECOILING AGN

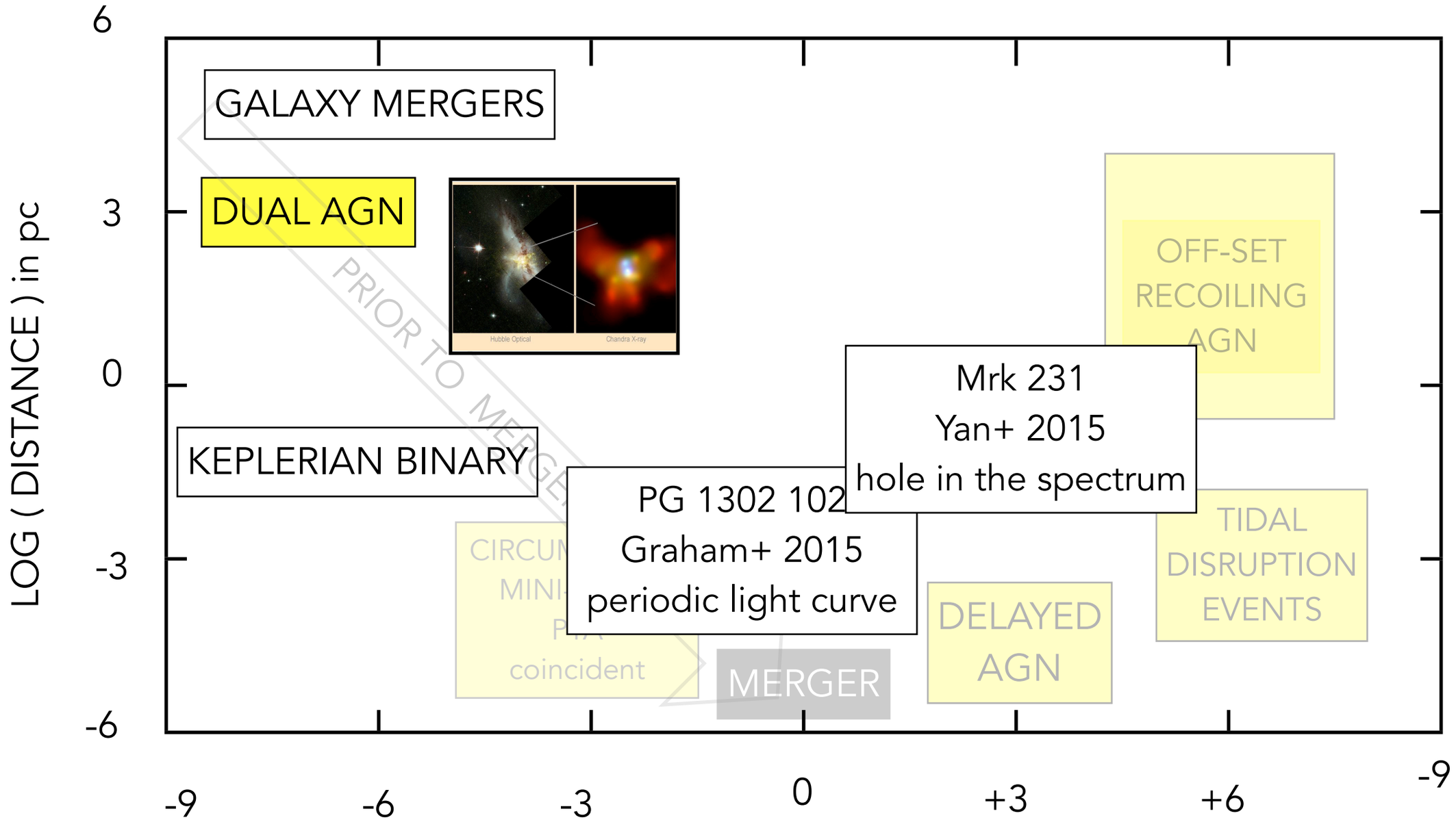
PRIOR TO MERGER

LOG (DISTANCE) in pc

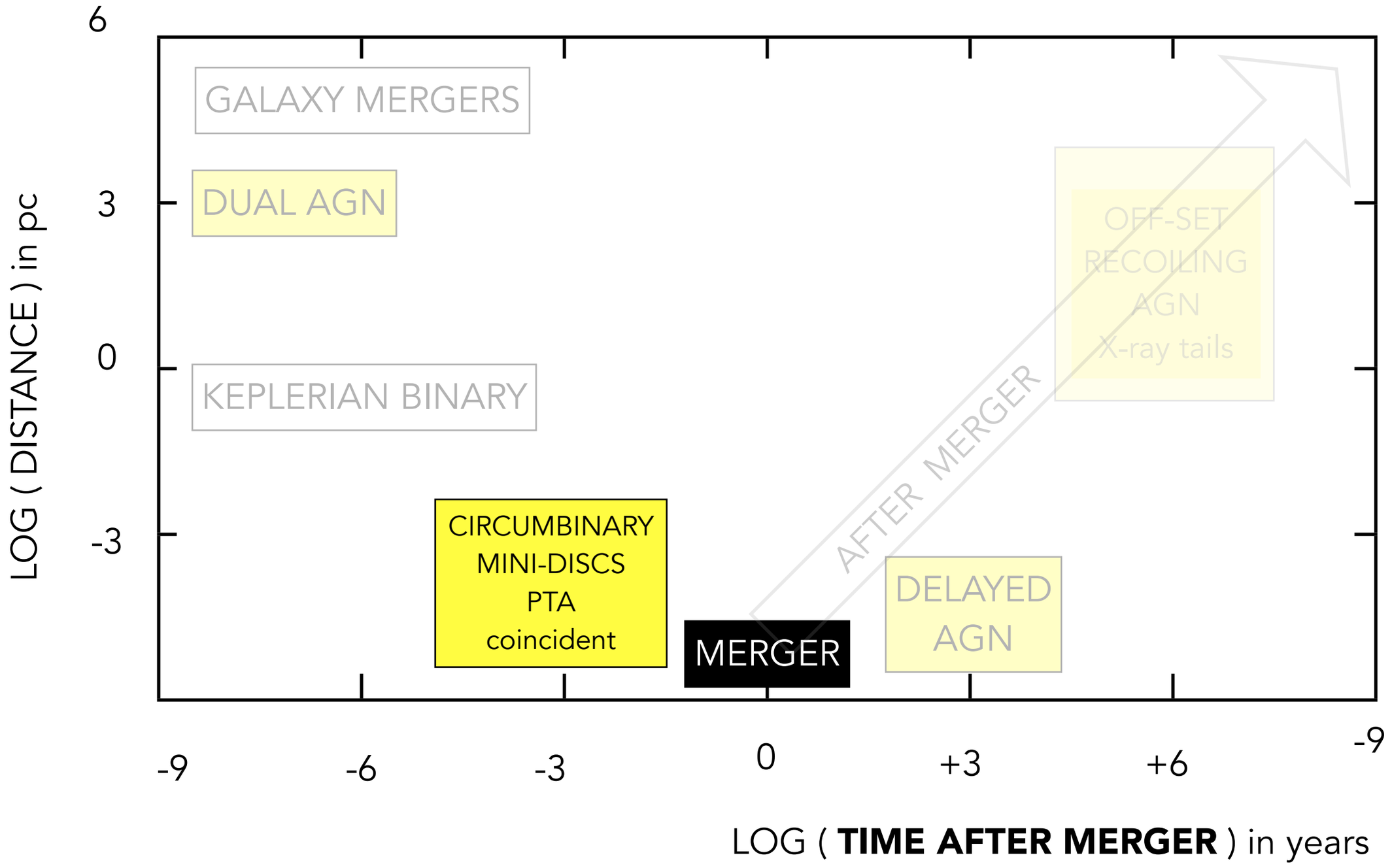
6
3
0
-3
-6

-9 -6 -3 0 +3 +6 -9

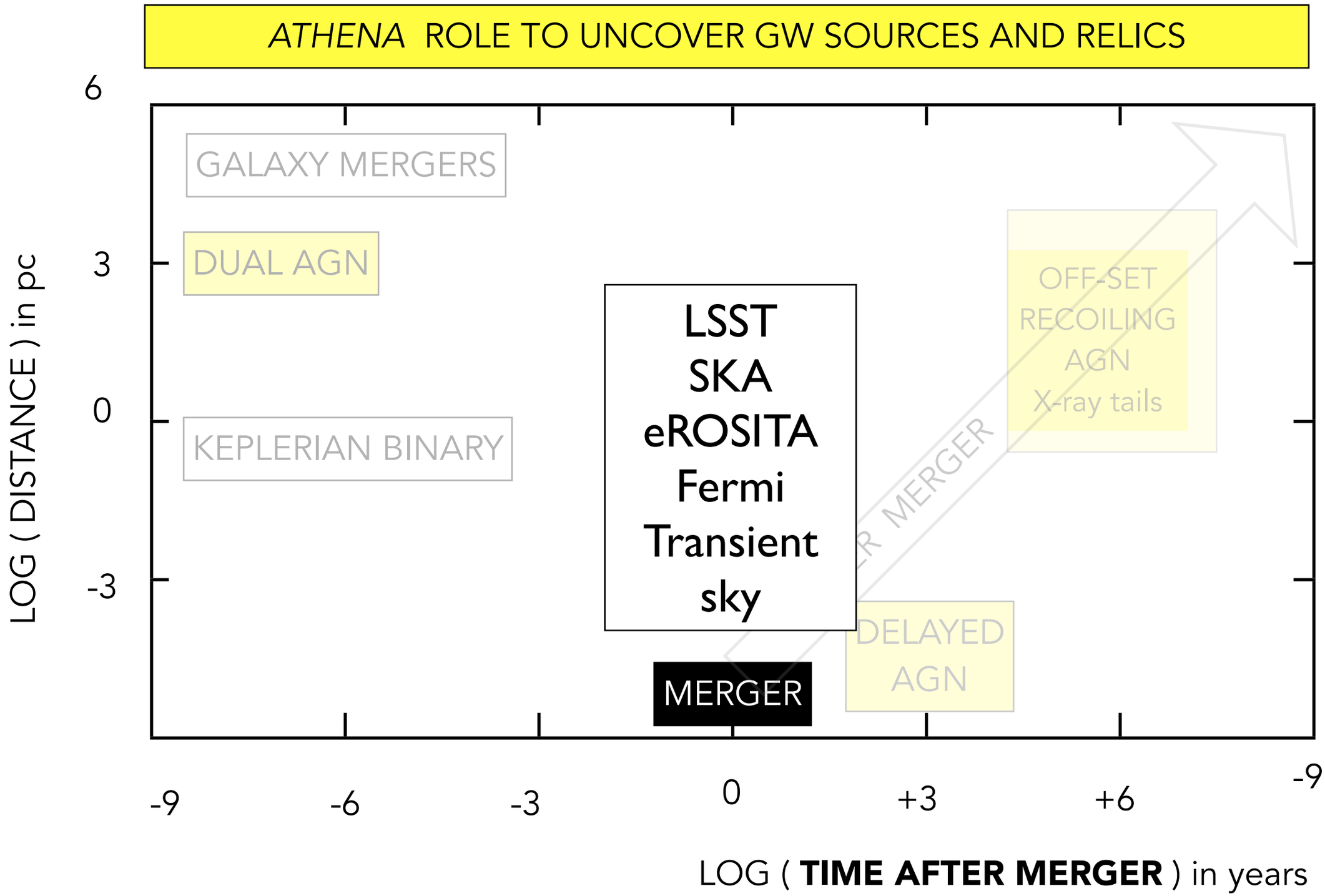
LOG (TIME **PRIOR TO** MERGER) in years


GALAXY MERGERS
DUAL AGN
Hubble Optical
Chandra X-ray
KEPLERIAN BINARY
PG 1302 102
Graham+ 2015
periodic light curve
Mrk 231
Yan+ 2015
hole in the spectrum
OFF-SET
RECOILING
AGN
TIDAL
DISRUPTION
EVENTS
DELAYED
AGN
MERGER
6
3
0
-3
-6
-9
-6
-3
0
+3
+6
-9
LOG (DISTANCE) in pc
LOG (TIME **PRIOR TO** MERGER) in years

"ARCHEOLOGICAL" ROLE OF EM DUAL SOURCES TO UNCOVER GW SOURCES



ATHENA ROLE TO UNCOVER GW SOURCES AND RELICS



BY 2030
impressive increase in the knowledge of the AGN population