The multimessenger astrophysics of massive black holes

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$$f \sim \frac{c}{2\pi R_s} \sim 10^4 \mathrm{Hz} \frac{M_\odot}{M}$$

Characteristic Strain

Frequency / Hz

Stochastic background

NANOGrav (2019)

IPTA (2030)

Supermassive binaries

Massive binaries

LISA (2034)

Resolvable galactic binaries

Extreme mass ratio inspirals

GW150914

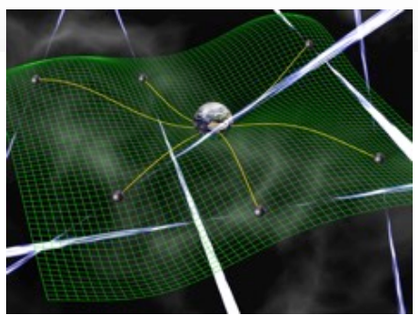
aLIGO (2016)

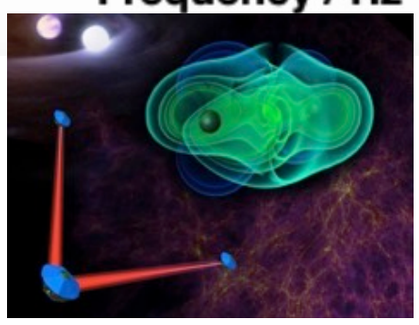
LIGO A+ (2020s)

CE (2030s)

Compact binary inspirals

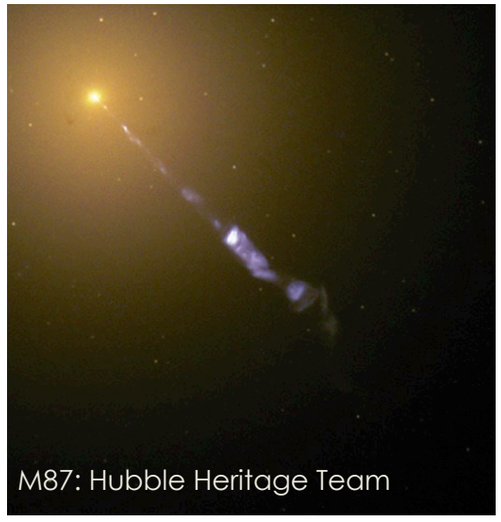
Pulsars

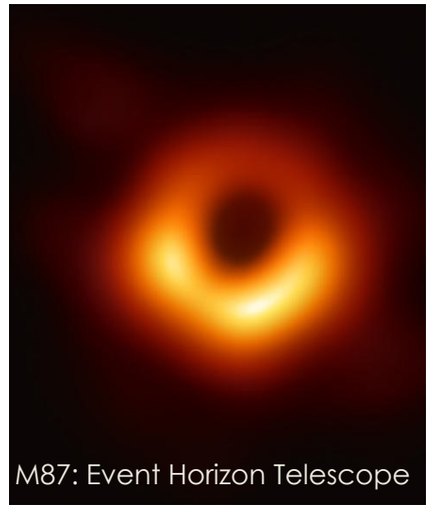




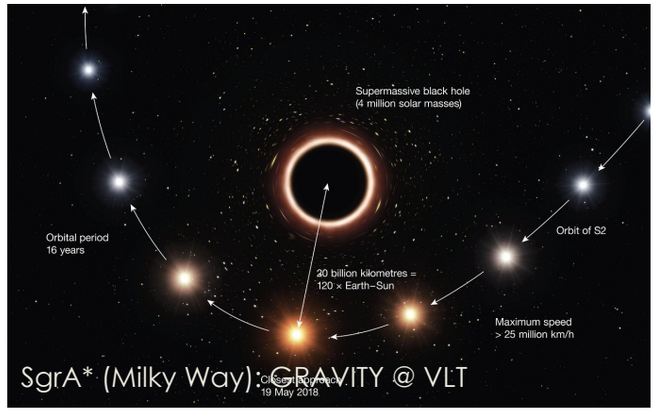
Massive black holes

- Powering AGN and quasars
- Inhabiting the centers of nearby galaxies, including the Milky Way
- Mass > 10^4 M_{sun} up to (?) ~10^{10} M_{sun}





What's their origin?
How to MBHs grow in mass?
How do MBHs pair and merge?

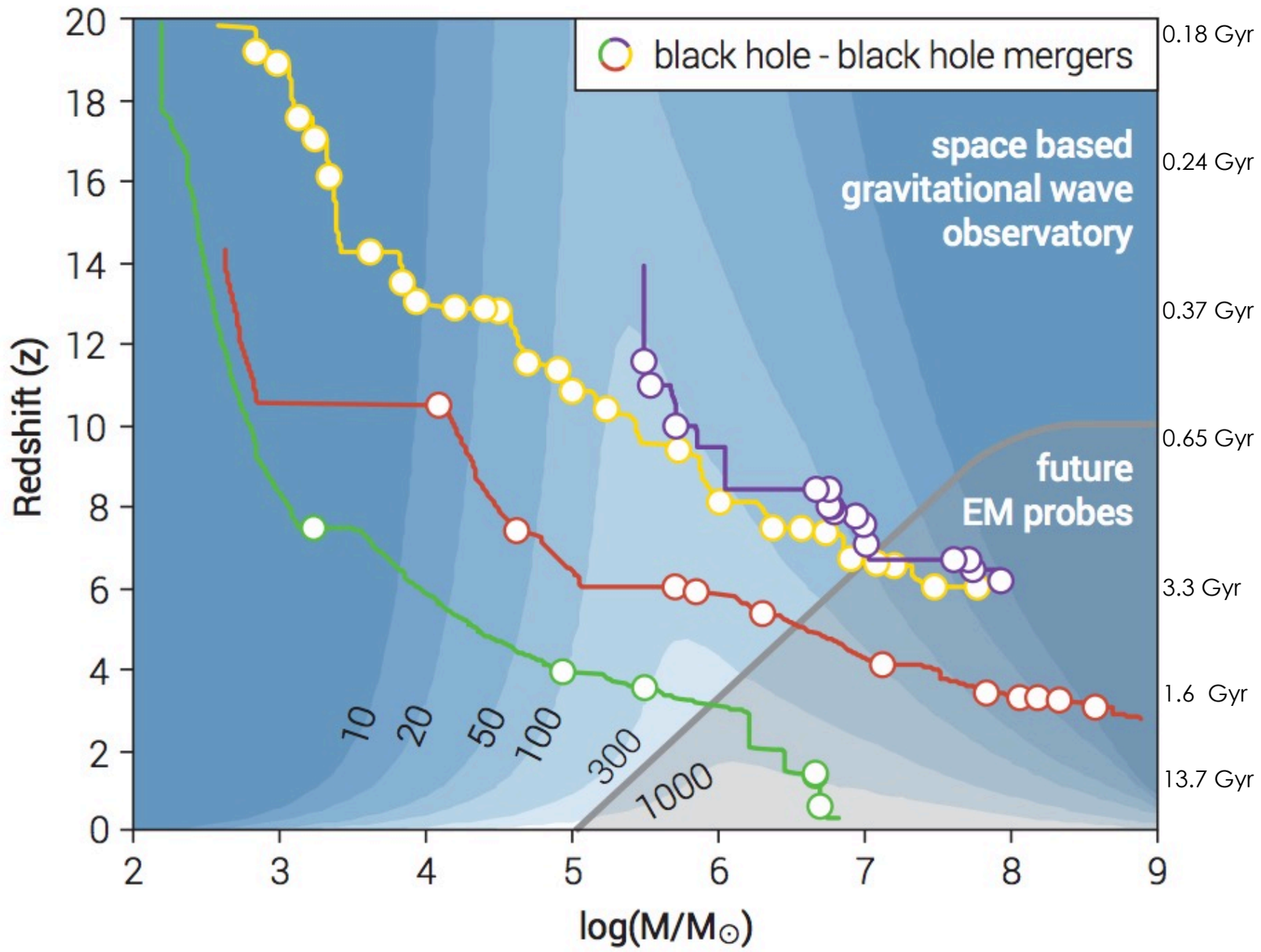


Multimessenger science with massive black holes

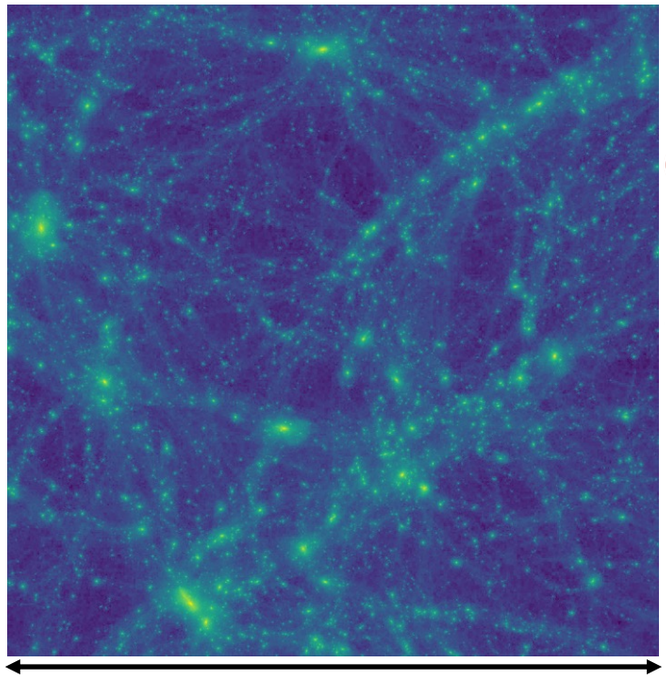
Massive black holes (MBH) grow along with galaxies through accretion and MBH-MBH mergers

Over time they sweep the LISA band

Detection possible in GW + EM



Massive black hole mergers

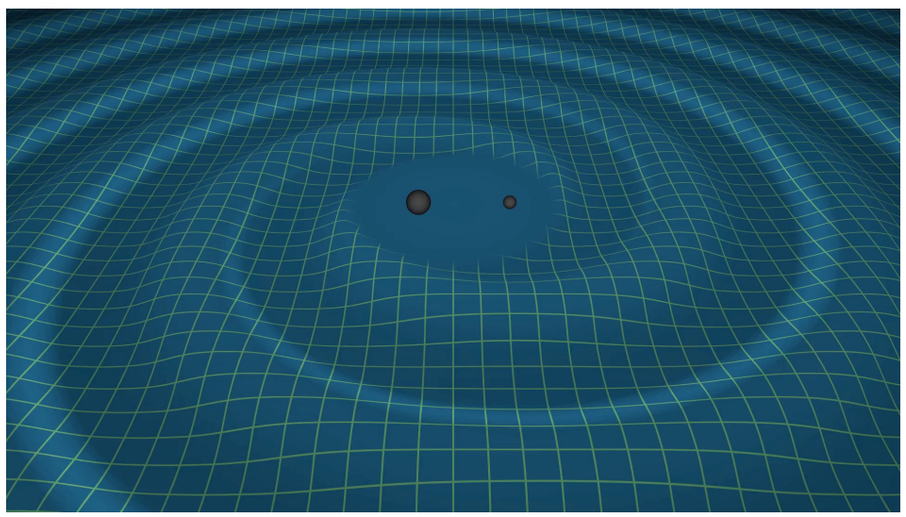


~100 Mpc (cosmology)

Gravity

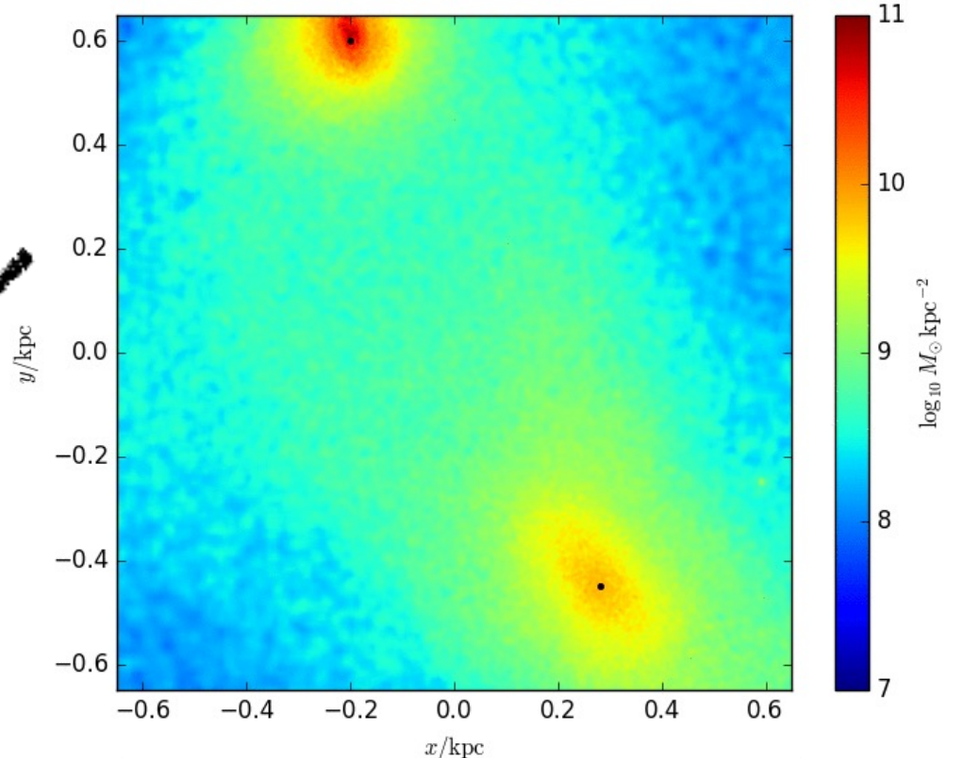
~100 kpc -1 kpc (galaxy mergers)

Dynamical Friction



~1 millipc(BH merger)

Gas torques
Stellar scattering
Triple interactions



~1 kpc-1pc (binary formation)

Courtesy of Hugo Pfister

EM counterparts to MBH mergers

Precursors: use binary signatures to identify MBHs on the way to merger

Afterglows: use merger-induced features to identify where a MBH-MBH merger has taken place

- Starting today: to estimate the potential population and to develop strategies

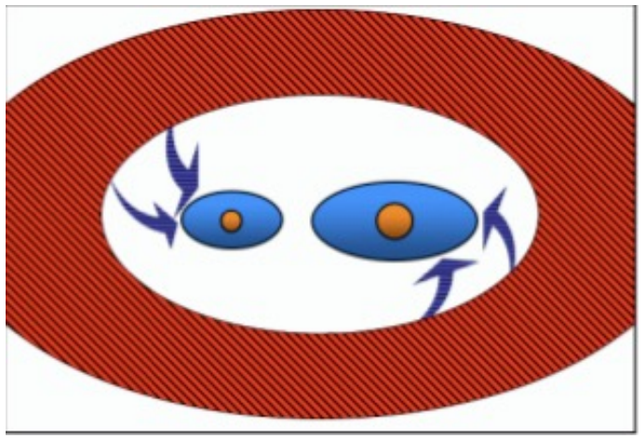
- After LISA's launch and after a PTA detection: to actually measure the redshift and the MBH/galaxy properties

EM counterparts to MBH mergers: *precursors*

Focus on the final stages of the mergers – after the MBHs have formed a binary

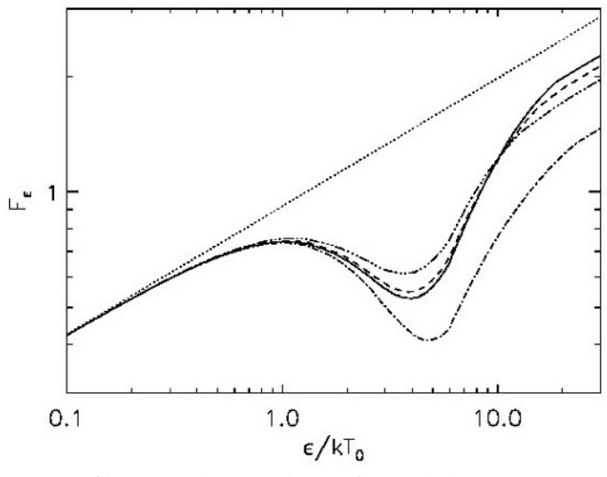
Sub-pc to milli-pc separations

In a gas-rich environment: formation of a circumbinary disc

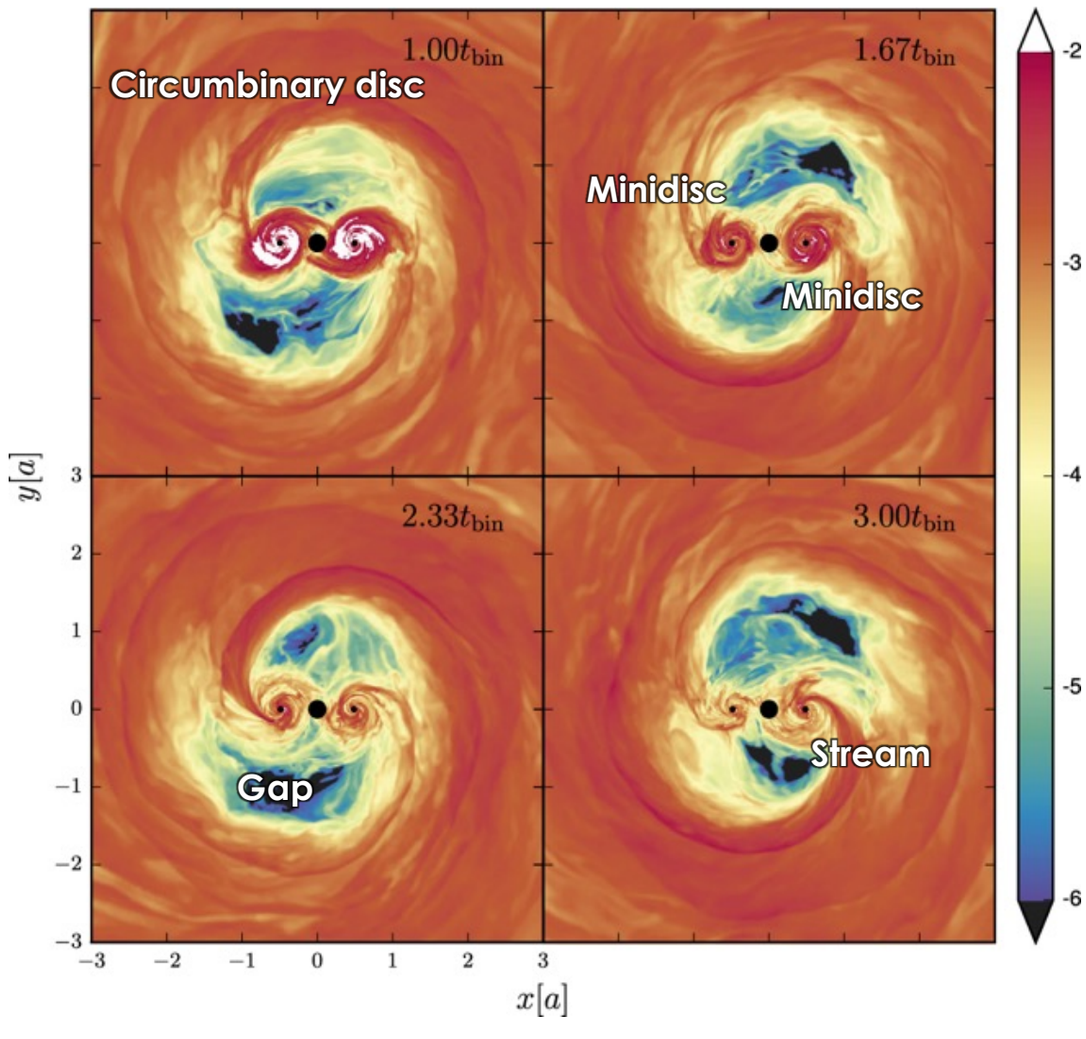


EM counterparts to MBH mergers: *precursors*

- Possible periodicities in the light curve
- Double peaked emission line profiles (Doppler shift caused by binary motion)
- Gaps in the spectrum
- Shocks when streams hit the edges of mini-discs



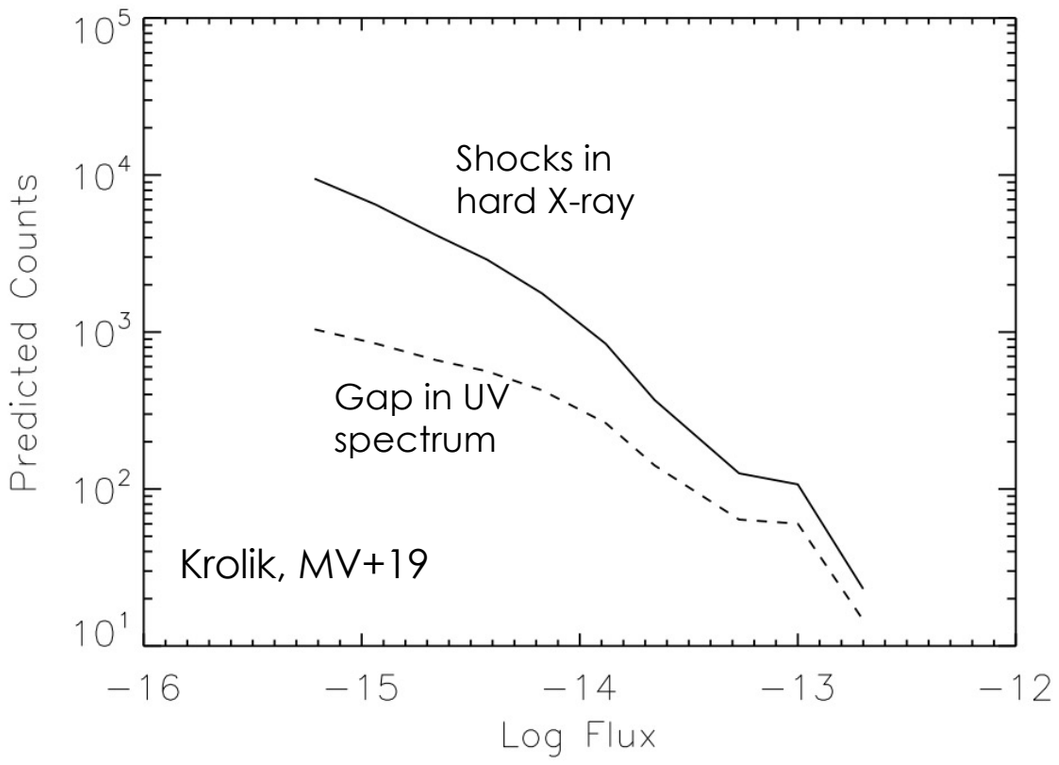
e.g.,Armitage & Natarajan 02; MacFadyen & Milosavljevic 08; Bogdanovic+08; Dotti+08, Cuadra+09; Sesana+12; Roedig+12; Shi+12; Noble+12; D'Orazio+13; D'Ascoli+19



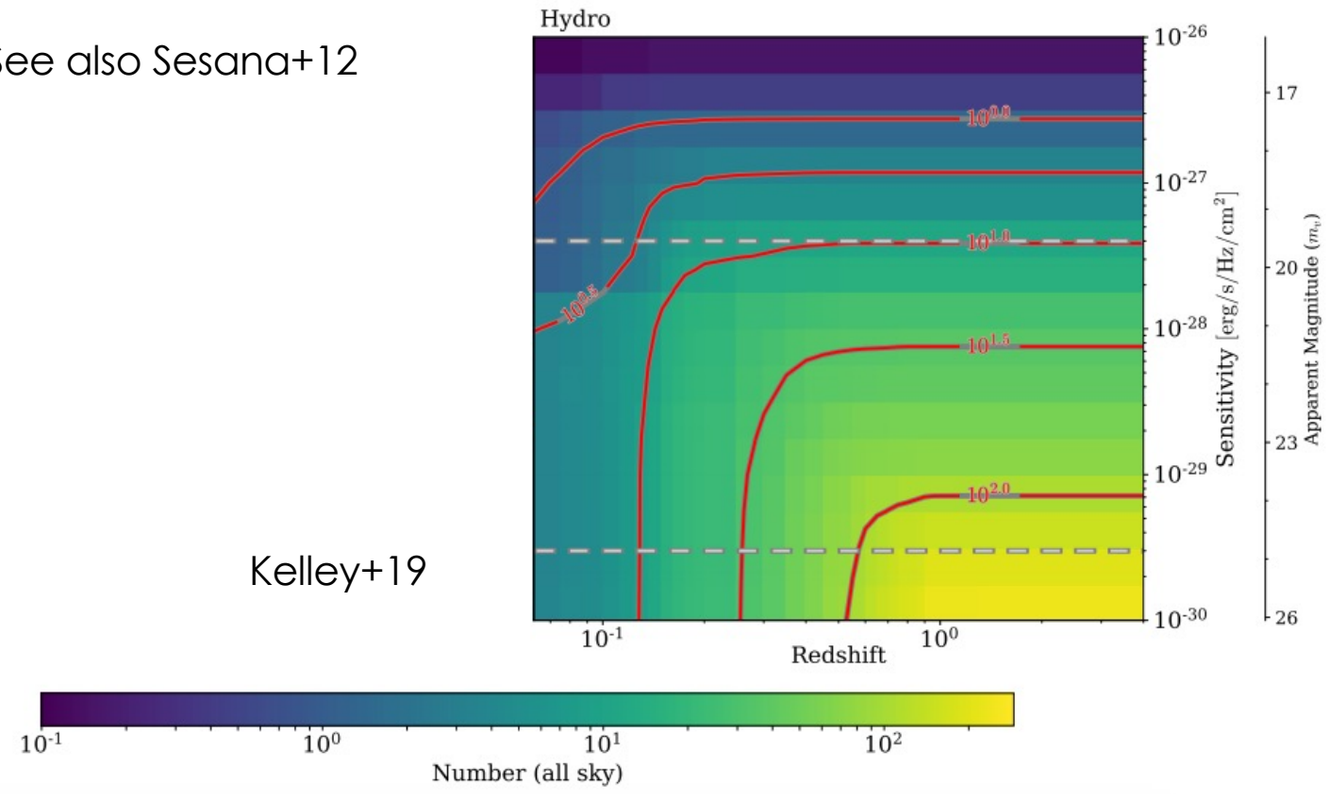
EM counterparts to MBH mergers: *precursors*

Hydrodynamical cosmological simulations ~(100 Mpc)^3 box: masses, mass ratios, accretion rates of MBH binaries

- Gaps in the spectrum
- Shocks when streams hit the edges of mini-discs
- Possible periodicities in the light curve

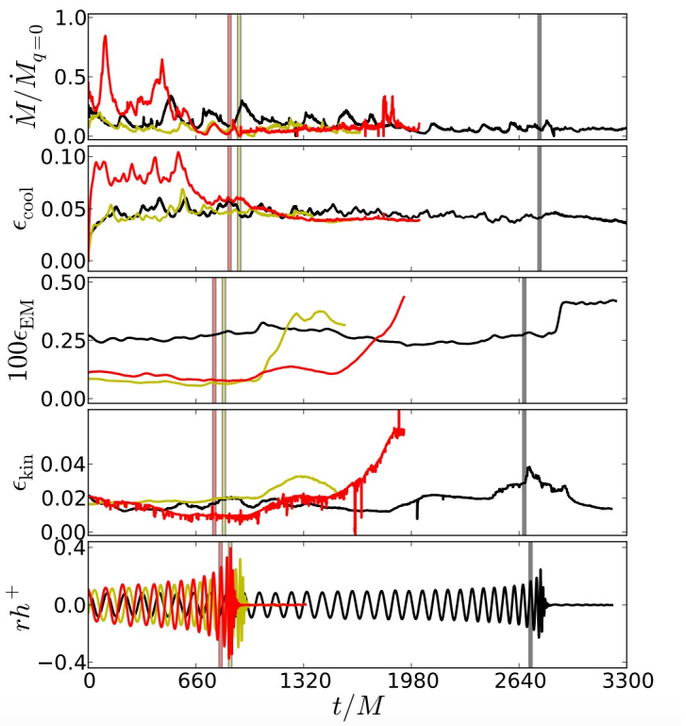


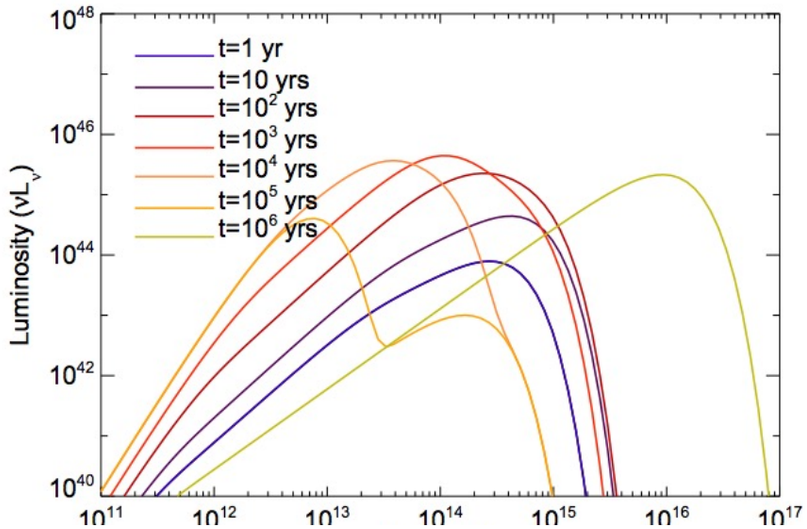
See also Sesana+12

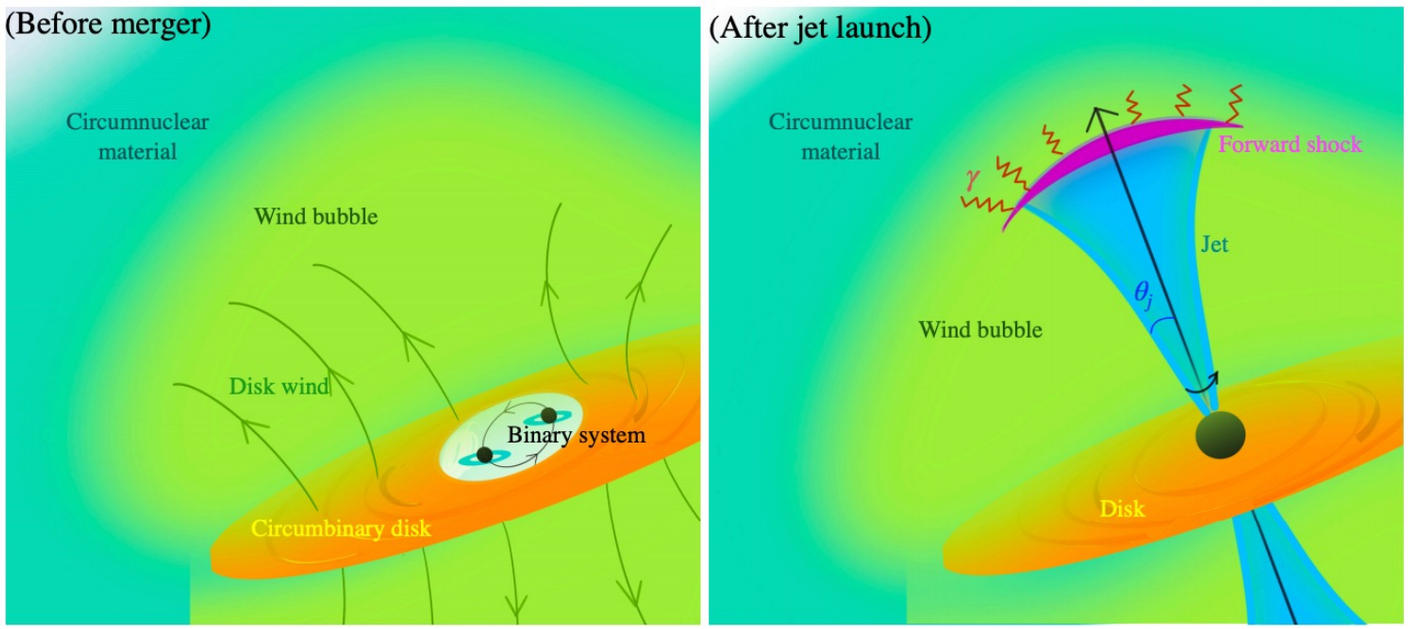


EM counterparts to MBH mergers: *afterglows*

- Burst at merger as gas plows in from gap
- Perturbed discs
- Effect of recoils
- Dual/single jets

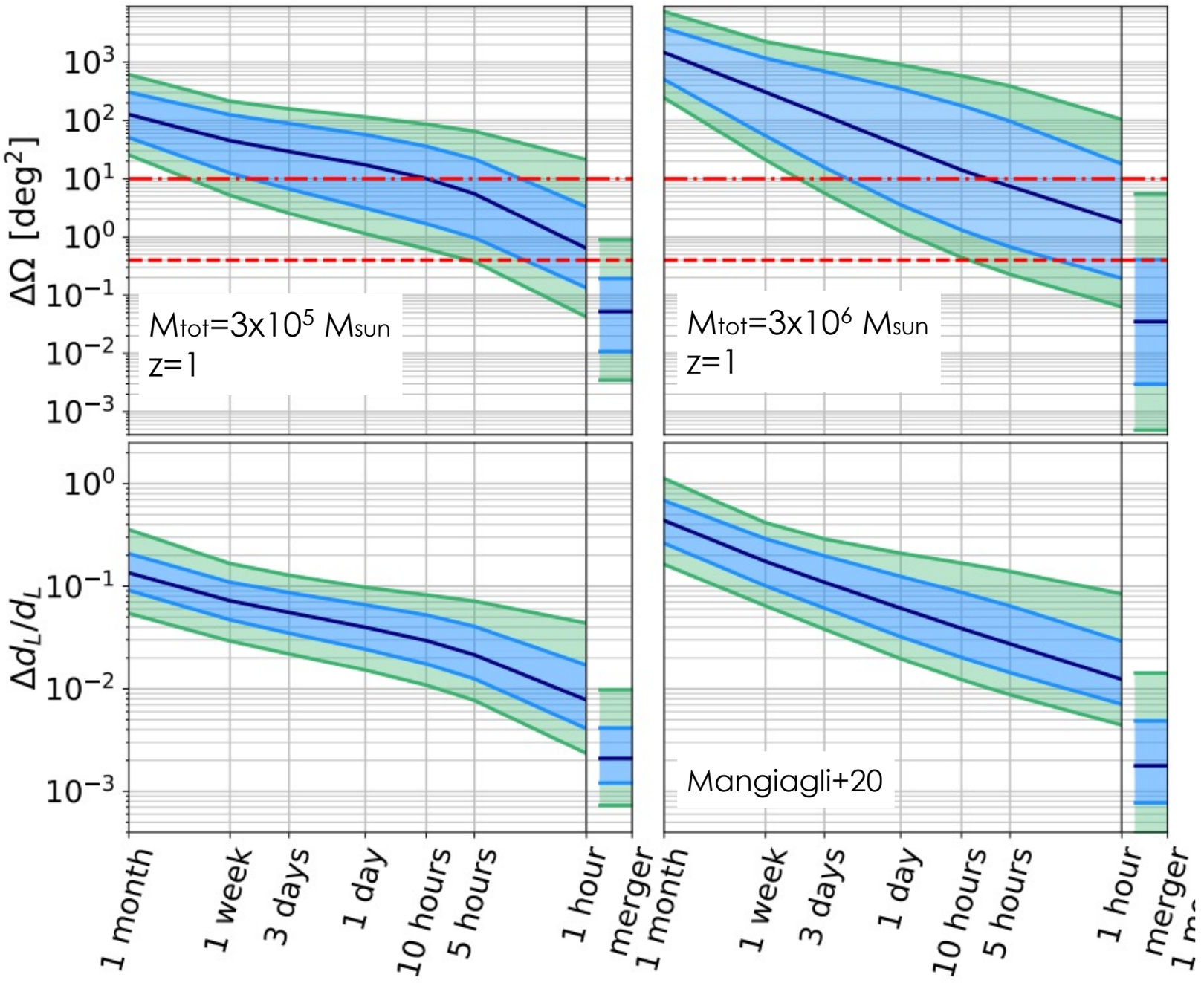






Armitage & Natarajan 02; Milosavljević & Phinney 05; Schnittman & Krolik 08; Palenzuela+10, Gold+14, Yuan+21 etc etc

EM counterparts to MBH mergers: *afterglows*



Sky localization improves with S/N => error box decreases as we get closer to the merger proper

EM counterparts to LISA's MBH mergers

By assuming f_{Edd}=1 we can have an optimistic estimate of the luminosities

Sources are faint but detectable with facilities expected to be around when LISA flies (ELT, ATHENA, SKA)

EM counterparts to PTA's MBH mergers

Binaries, not mergers! High MBH mass and low redshift => typically low f_{Edd}

Very poor sky localization (100s deg^2)

Summary

Rich multimessenger science with MBH binaries and mergers

LISA's MBHs expected (relatively) faint: 10^4-10^7 Msun massive black holes in 10^8-10^{10} Msun galaxies out to z>>>3

PTA binaries not well localized but close by and massive/bright

Synergies with ELT, ATHENA, LSST, SKA, WFIRST, etc etc etc