Einstein Telescope and the world of binaries

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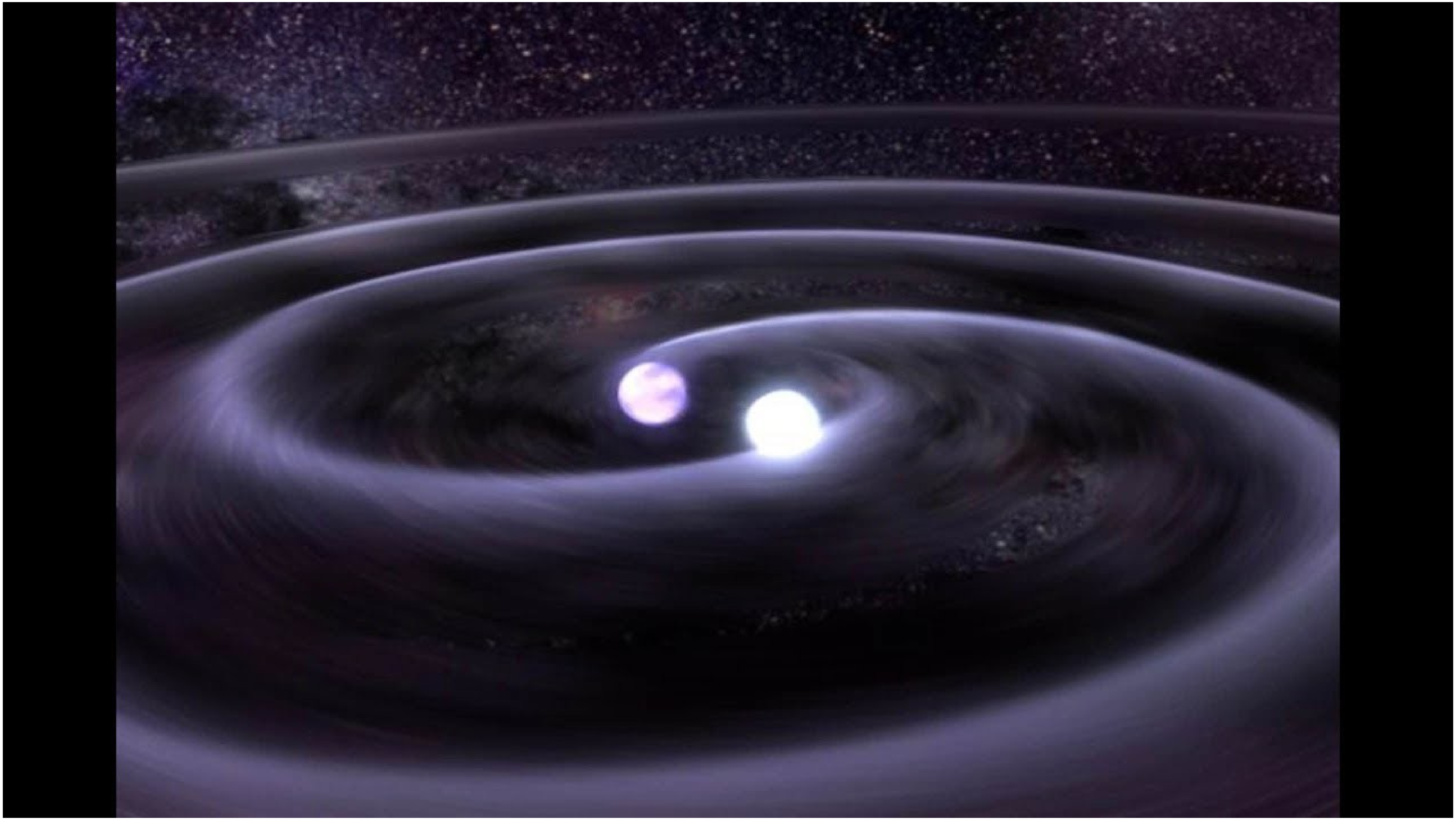
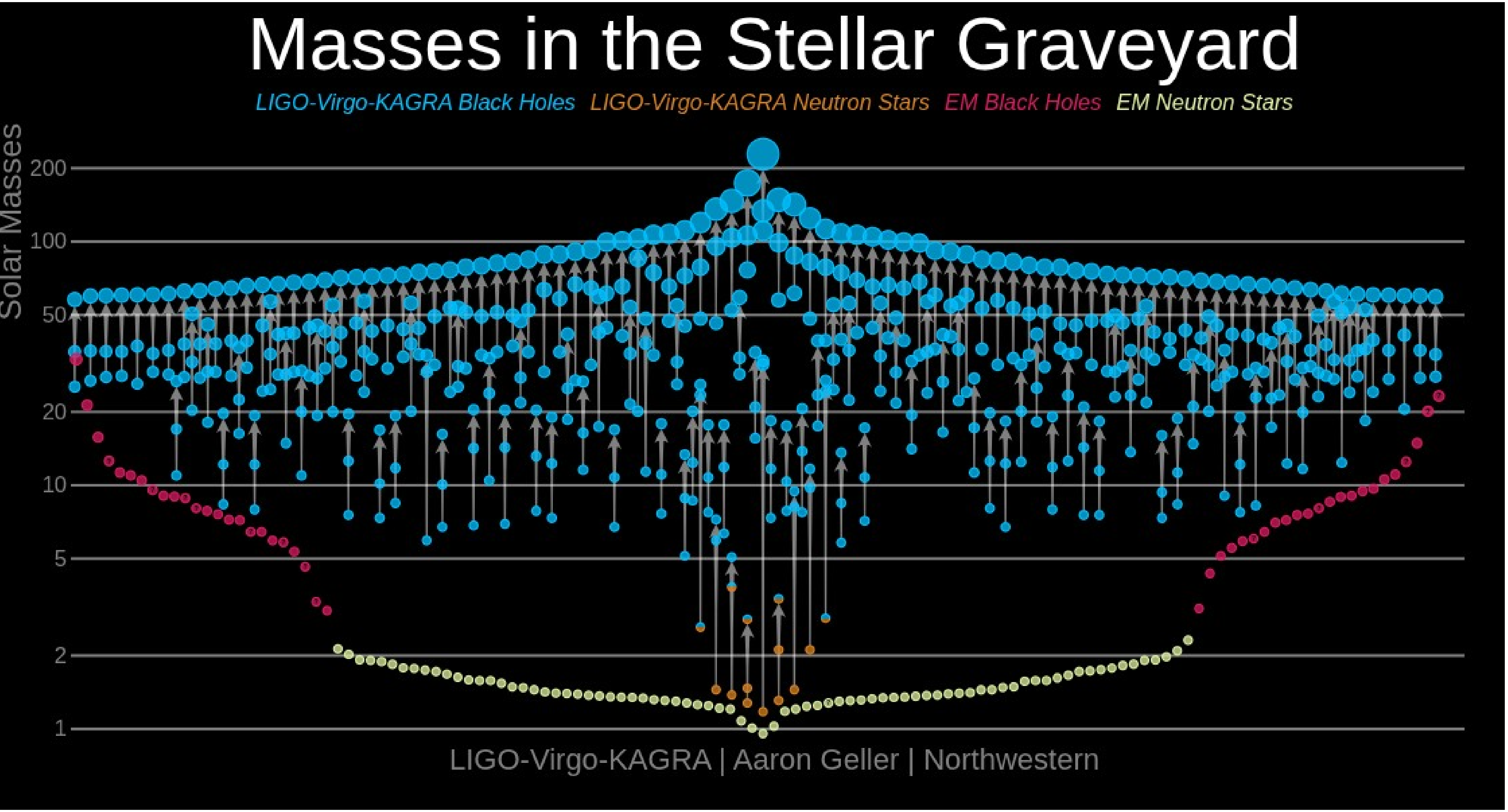
OBSERWATORIUM ASTRONOMICZNE UNIWERSYTETU WARSZAWSKIEGO

Compact object binaries



Observations



The merger rate densities

- BBH estimate $R = 17 - 45 \mathrm{Gpc}^{-3} \mathrm{yr}^{-1}$
- BNS estimate $R = 13 - 1900 \mathrm{Gpc}^{-3} \mathrm{yr}^{-1}$
- BHNS estimate $R = 7.4 - 320 \mathrm{Gpc}^{-3} \mathrm{yr}^{-1}$
- The local supernova rate ~ $10^5 \mathrm{Gpc}^{-3} \mathrm{yr}^{-1}$
- The BH formation rate is ~ $10^4 \mathrm{Gpc}^{-3} \mathrm{yr}^{-1}$
- About 1 black hole in a 100-1000 ends up in a merging binary
- Similarly NS: 1 in 100-1000 is in a merging binary!

The rate implications

- The supernova rate density

$$R_{SN} \approx 10^5 \mathrm{Gpc}^{-3} \mathrm{yr}^{-1}$$

- The production of NSNS mergers must be very efficient
- Total GW luminosity density in the sky from NSNS mergers

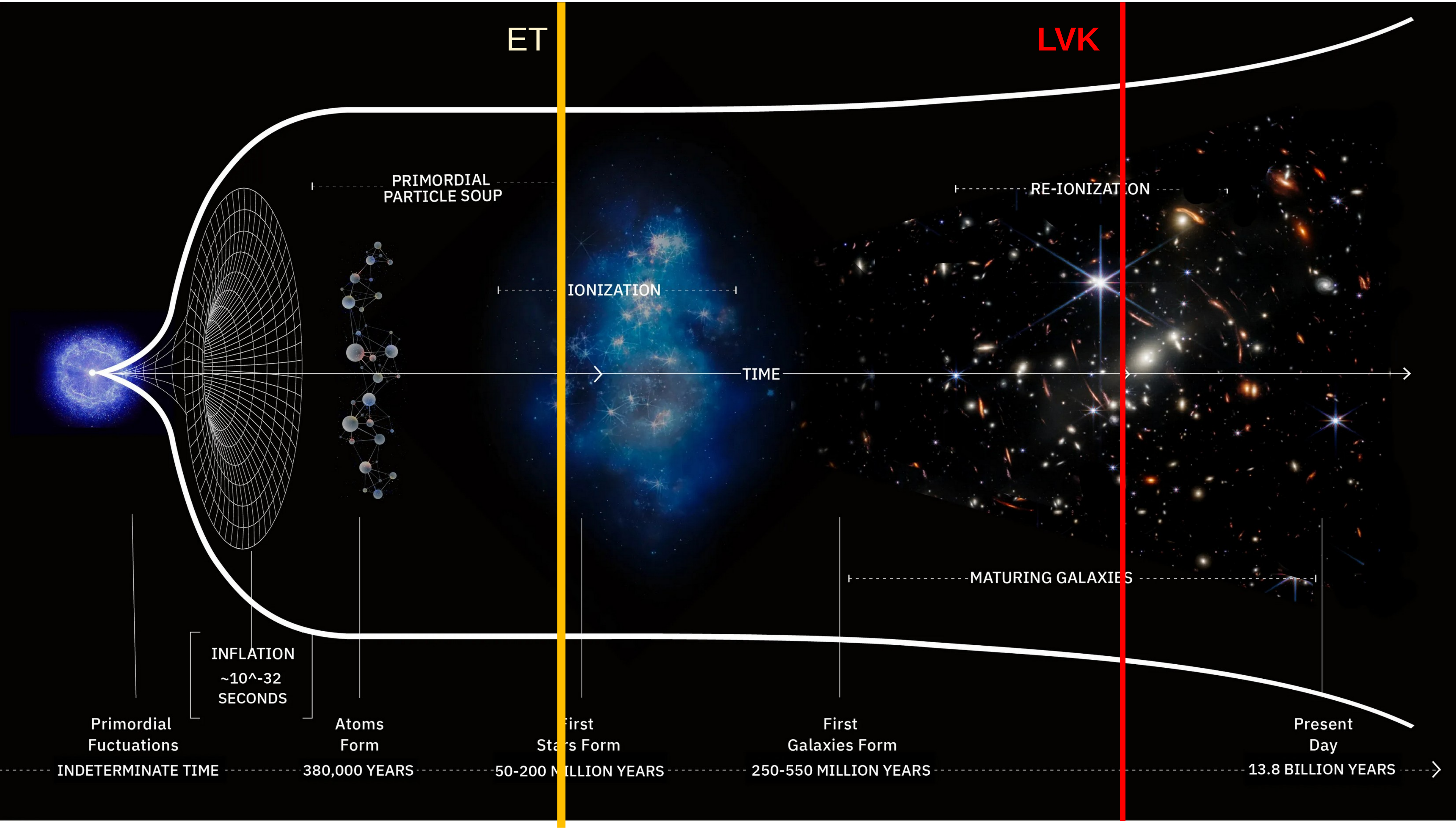
$$\mathcal{L}_{GW} = 1560 \frac{0.025 M_{\odot} c^2}{3.1 \times 10^7 \mathrm{s}} \approx 2.5 \times 10^{48} \mathrm{ergs}^{-1} \mathrm{Gpc}^{-3}$$

- The luminosity density of BHBH mergers is about 10 times larger

- EM luminosity density of all galaxies:

$$\mathcal{L}_{EM} \approx 10^{50} \mathrm{erg\,s}^{-1} \mathrm{Gpc}^{-3}$$

ET vs current instruments

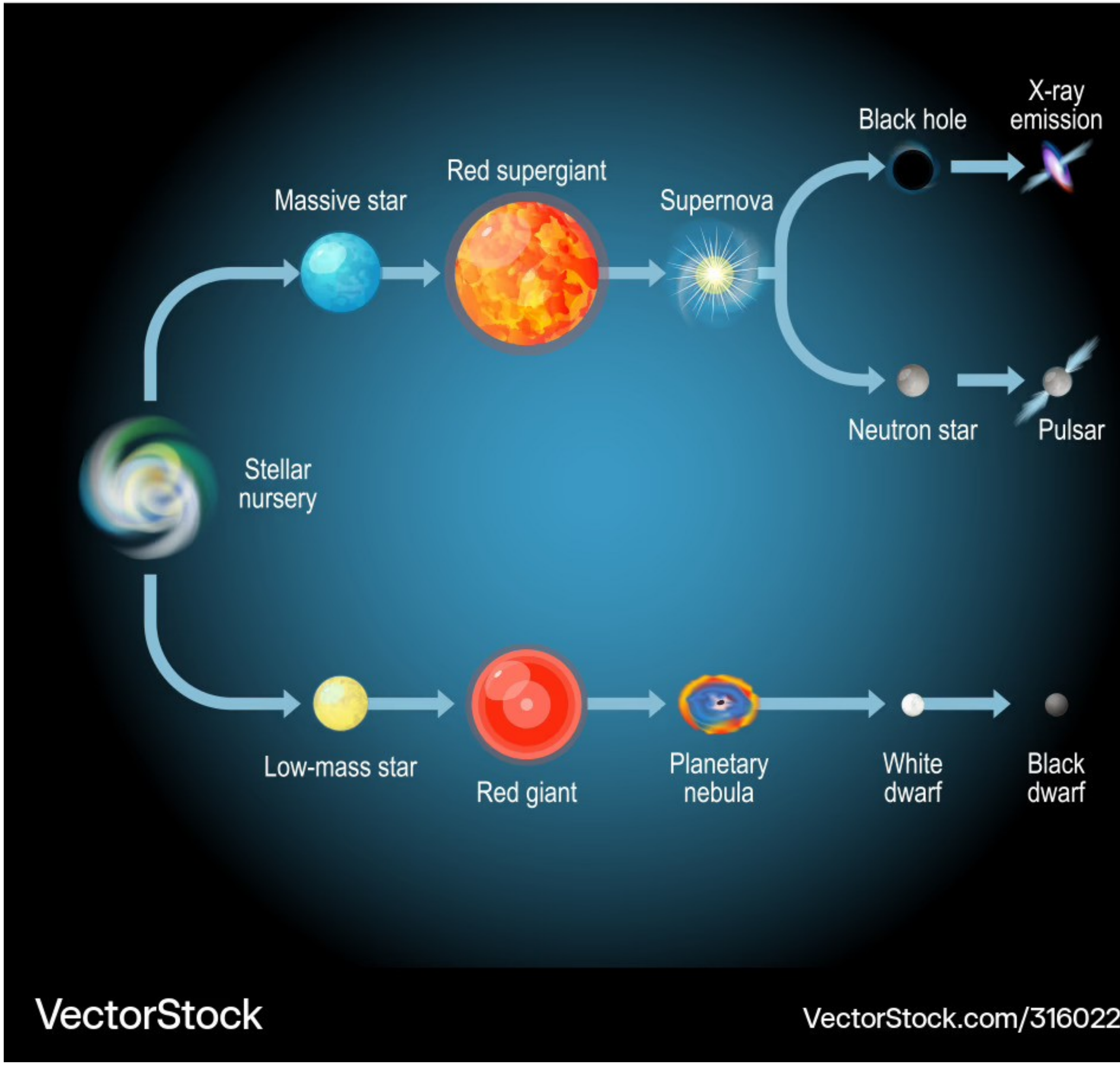


ET detection rates

- There is a supernova rate in the Universe every 0.1 to 1 second
- The coalescence rate is 100-1000 times lower
- ET will monitor the entire Universe
- We will detect a coalescence every 2 to 20 minutes

Where do they come from - the size problem

Stellar evolution

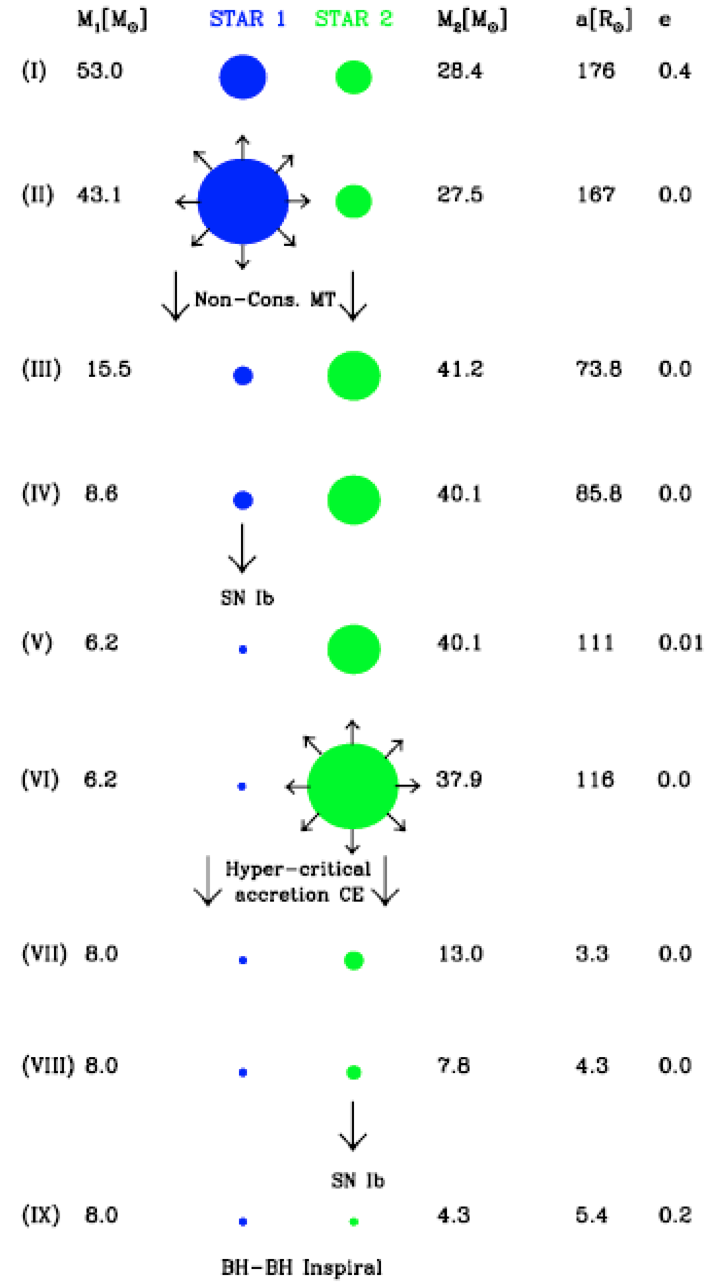


A binary BH contracting under the emission of GWs can not have large orbit than about 30 Rsun to merge in the Hubble time!

First solution

- Make BH binaries in normal stellar evolution galaxies
- Typical stellar environment
- Spins should be slightly aligned
- Making BH above 70 Msun difficult

Isolated evolution
- comon envelope ~!



Second solution

Make BH binaries in dense stellar regions.

Binaries and stars can collide and exchange partners.

Avoid the stellar size problem by partners exchange.

Advantage – easy way to produce compact binaries

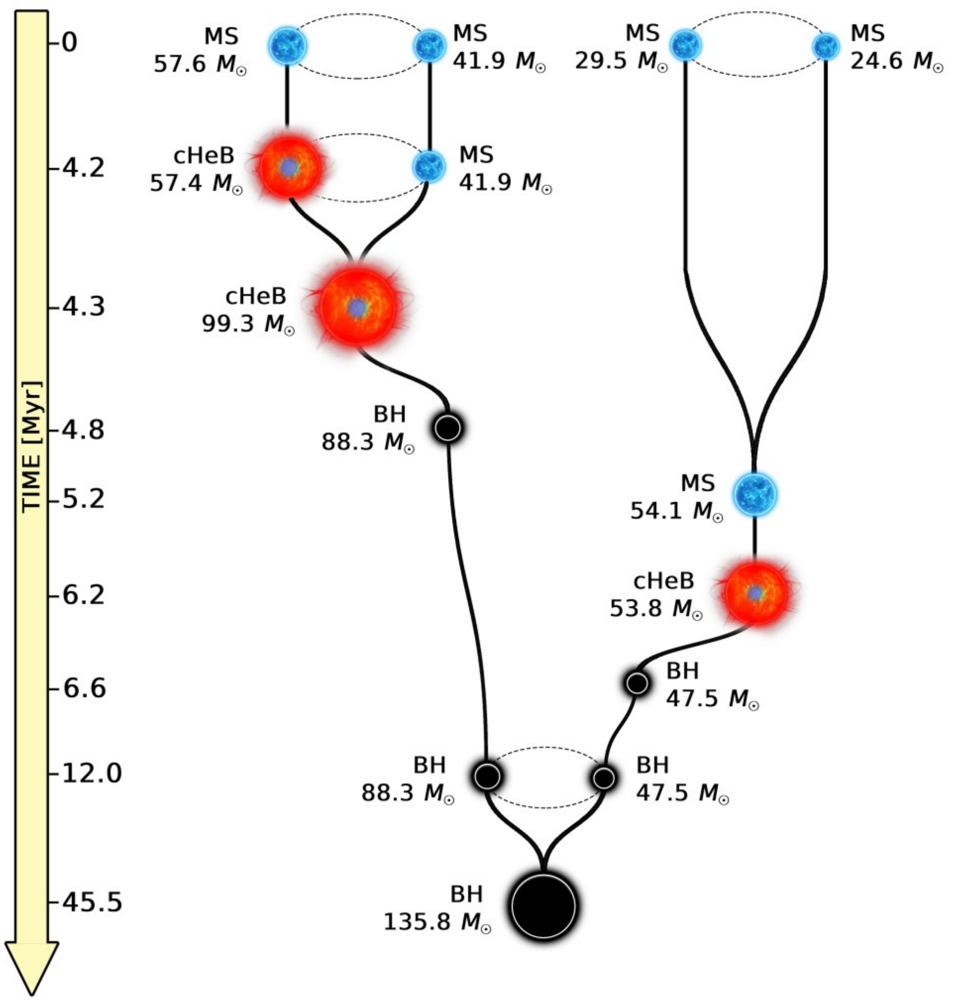
Disadvantage – only a small fraction of stellar mass in clusters

Characteristic:

– random spin directions

- possibility of masses above 70Msun

Cluster evolution
- exchanges



Third solution

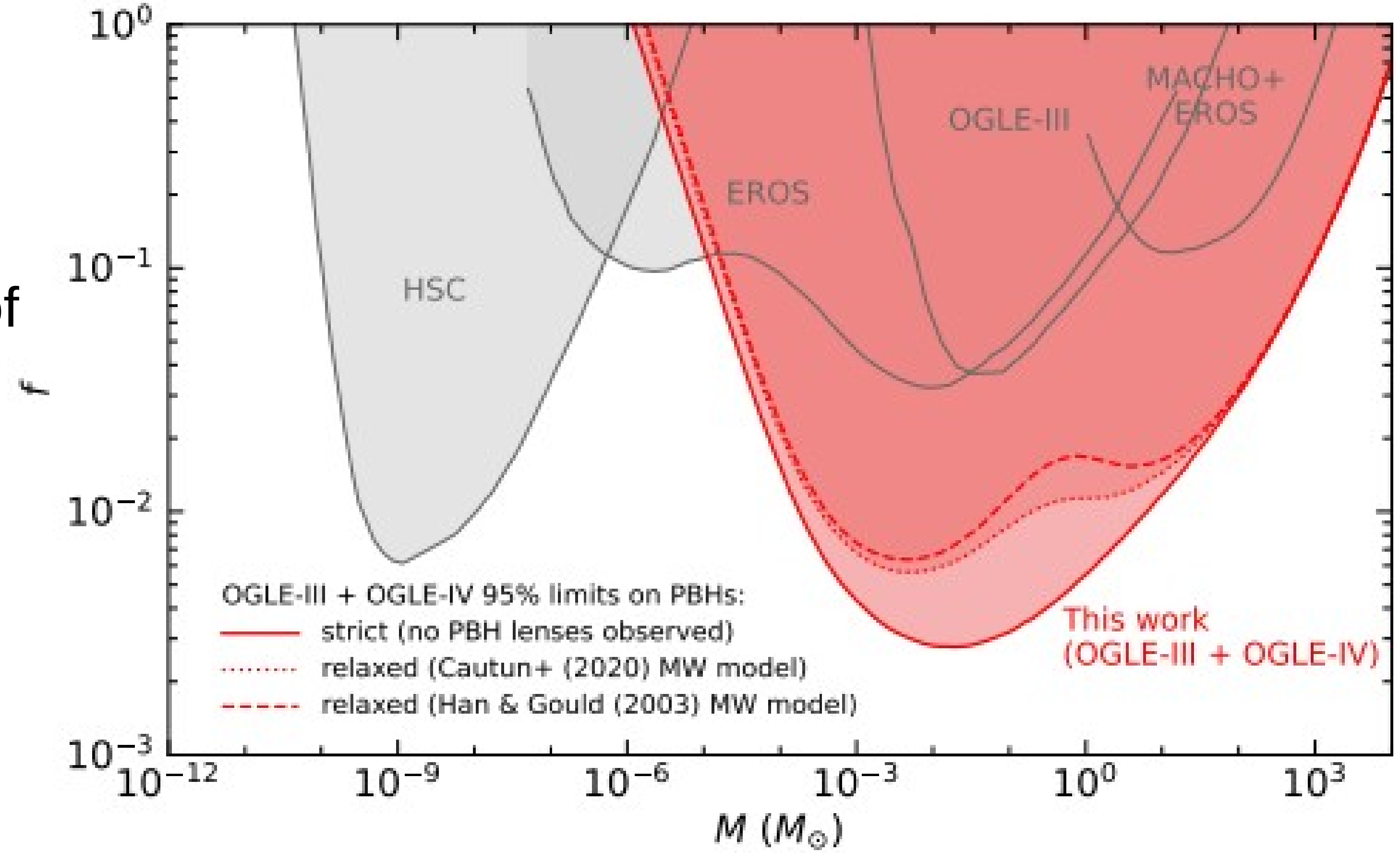
Primordial binaries

Density strongly constrained by lensing

Unclear mechanism of pairing and formation of binaries

Rate should peak at very high redshift

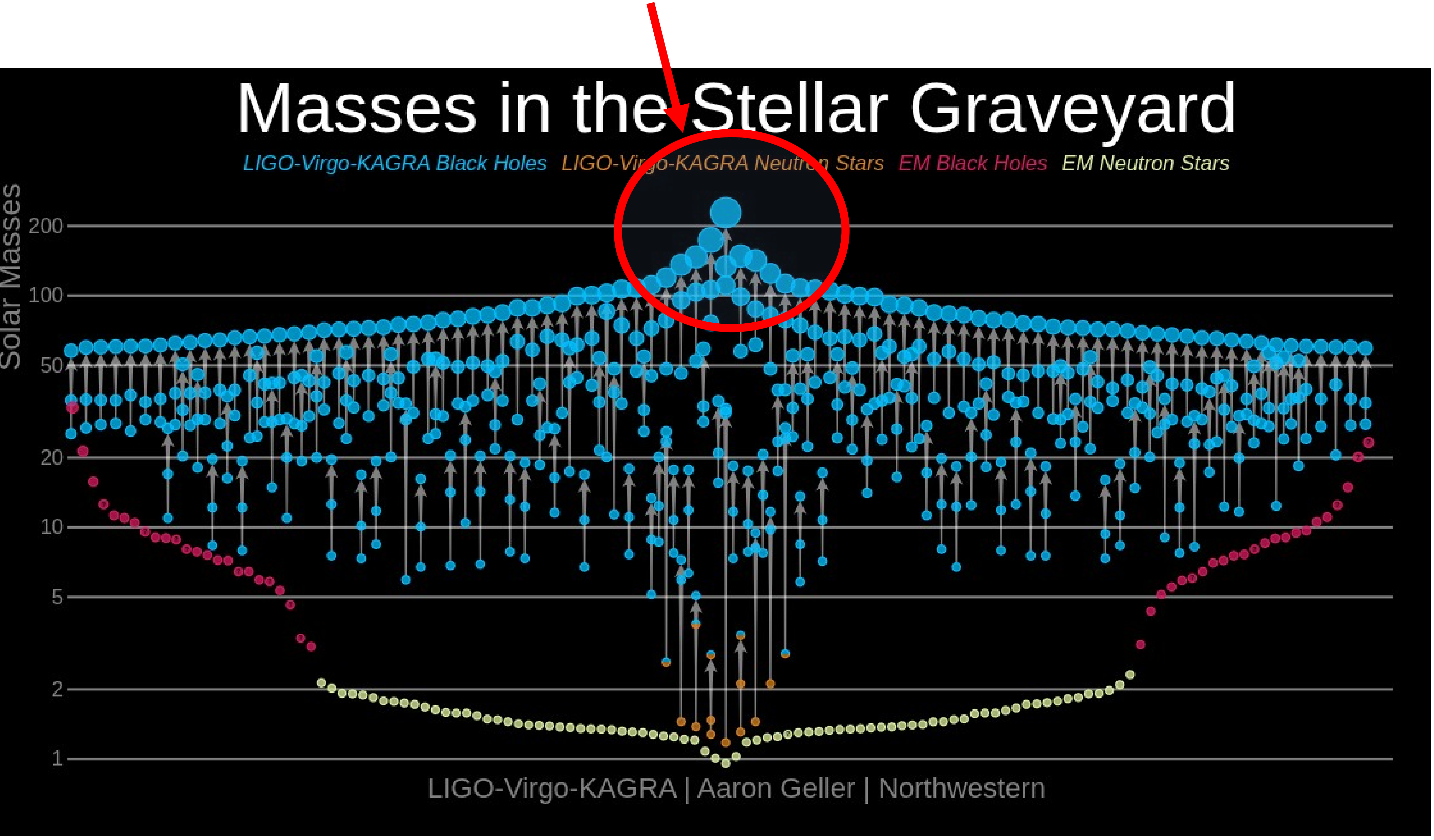
The only known way to form BH with mass below 1Msun



How will ET help?

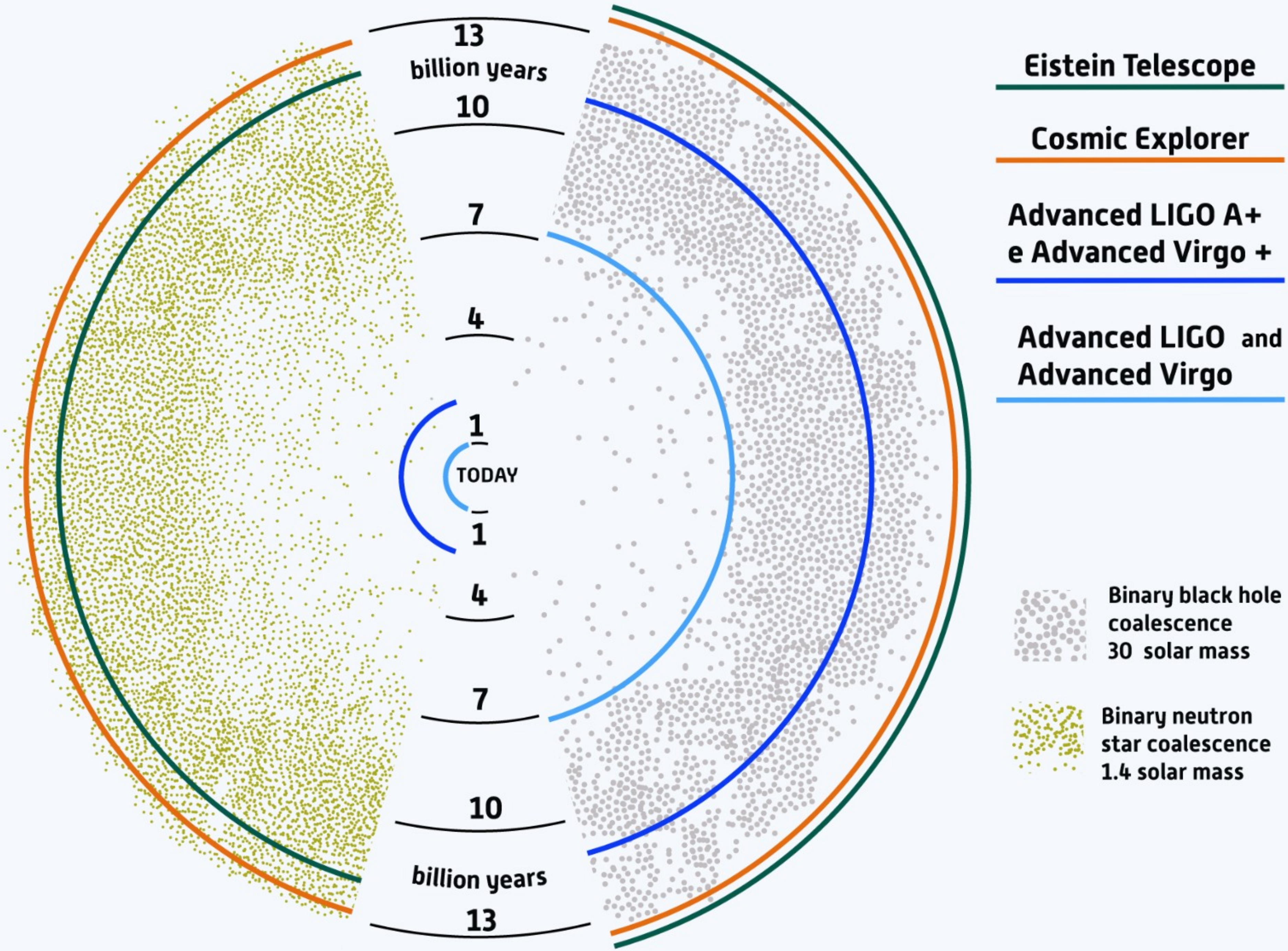
- Detailed spin detection
- Precise rate estimate
- Masses – spins of hierarchical mergers

The IMBH binaries



IMBH binaries

- Origins:
  - Population III ?
  - Clusters – hierarchical mergers ?
  - Primordial – almost ruled out
- ET LF – crucial to understand the origin and properties of IMBHs



REWORKED IMAGE FROM [FONTE ASTRO-PH 2109.09882]

Binaries as astrophysical tools

- Cosmology
- Fundamental physics
- Testing Genral Relativity

Cosmology

- Why binaries are standard sirens (GW version of standard candles)?

  $E_{GW} \propto M, \;\; t_{merger} \propto M$

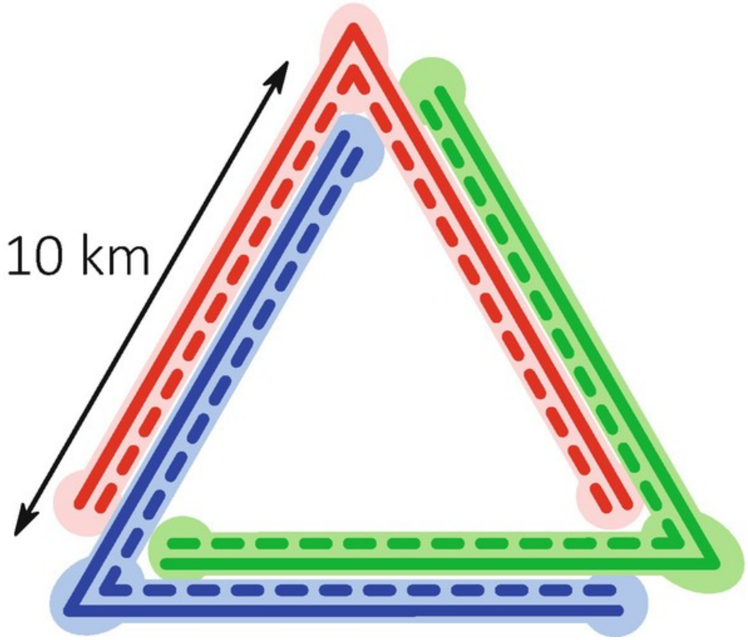
  $L_{GW} \propto E_{GW}/t_{merger}$ ~const

- Anisotropy of radiation
- Amplitude and rate of frequency change bth relate to redshifted chirp mass
- Need redshift estimate to construct Hubble diagram!

Breaking the degeneracy

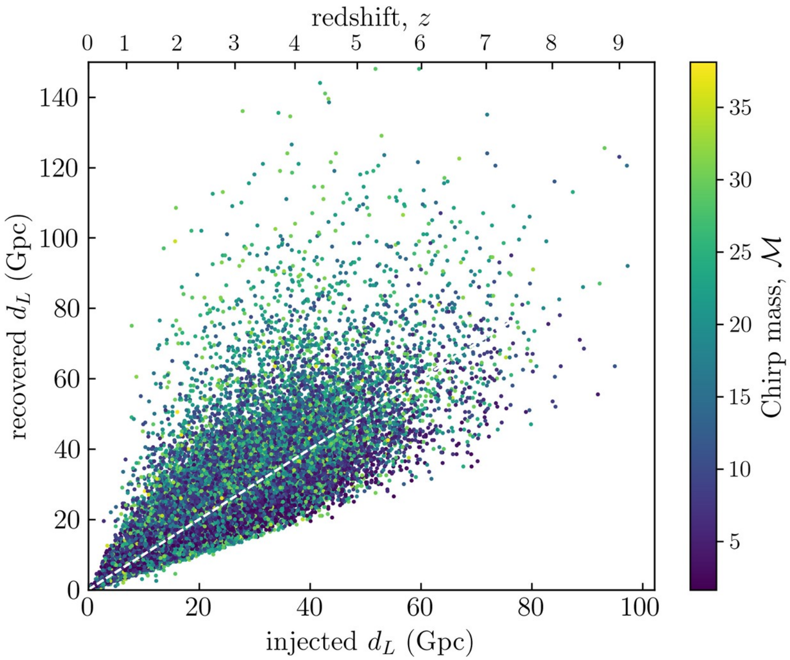
- Optical counterparts → redshift
- Known mass distribution → redshift
- Precise location and polarization to take care of anisotropy of GW radiation
- Statistical redshifts from a set of potential hosts

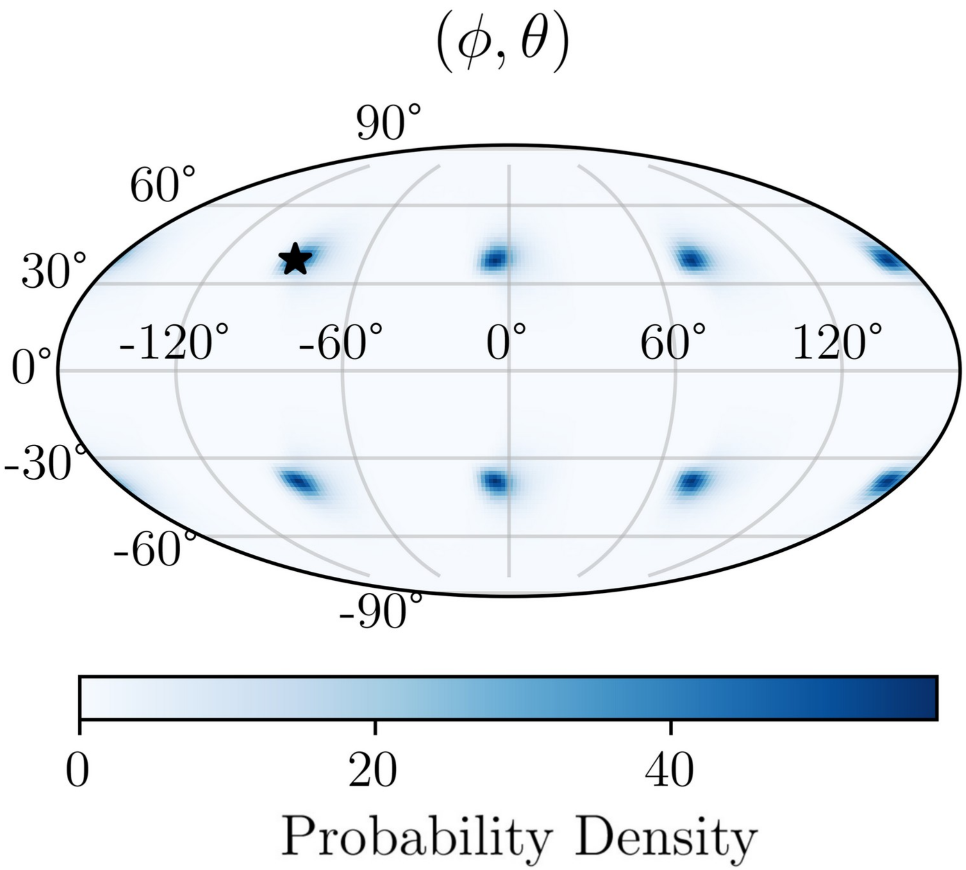
ET advantage



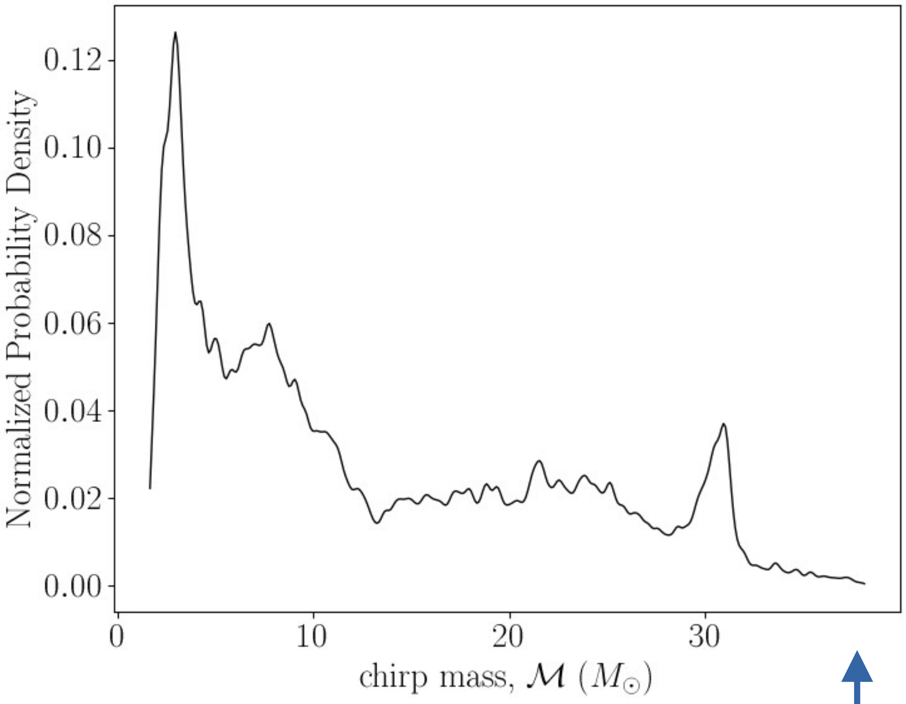
Three detectors:

Luminosity distance and constraints on sky position and polarization



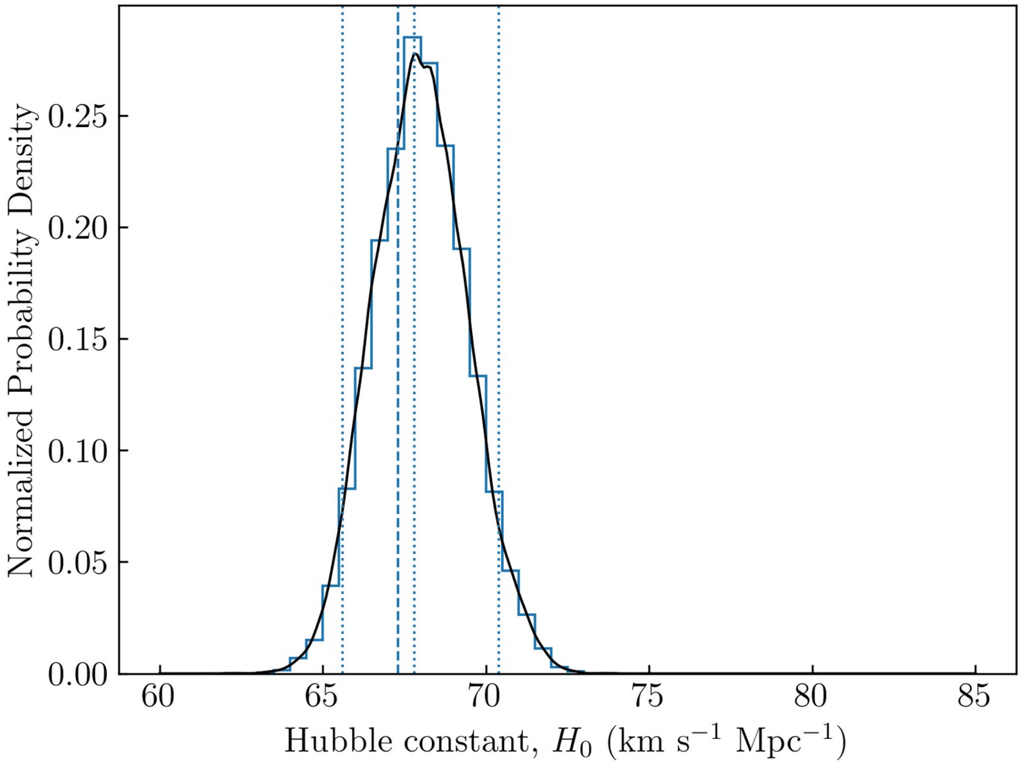


ET cosmology



Assuming known binary mass distribution

We can get Hubble constant with 3% accuracy with a few months of ET data



Fundamental physics – speed of gravity

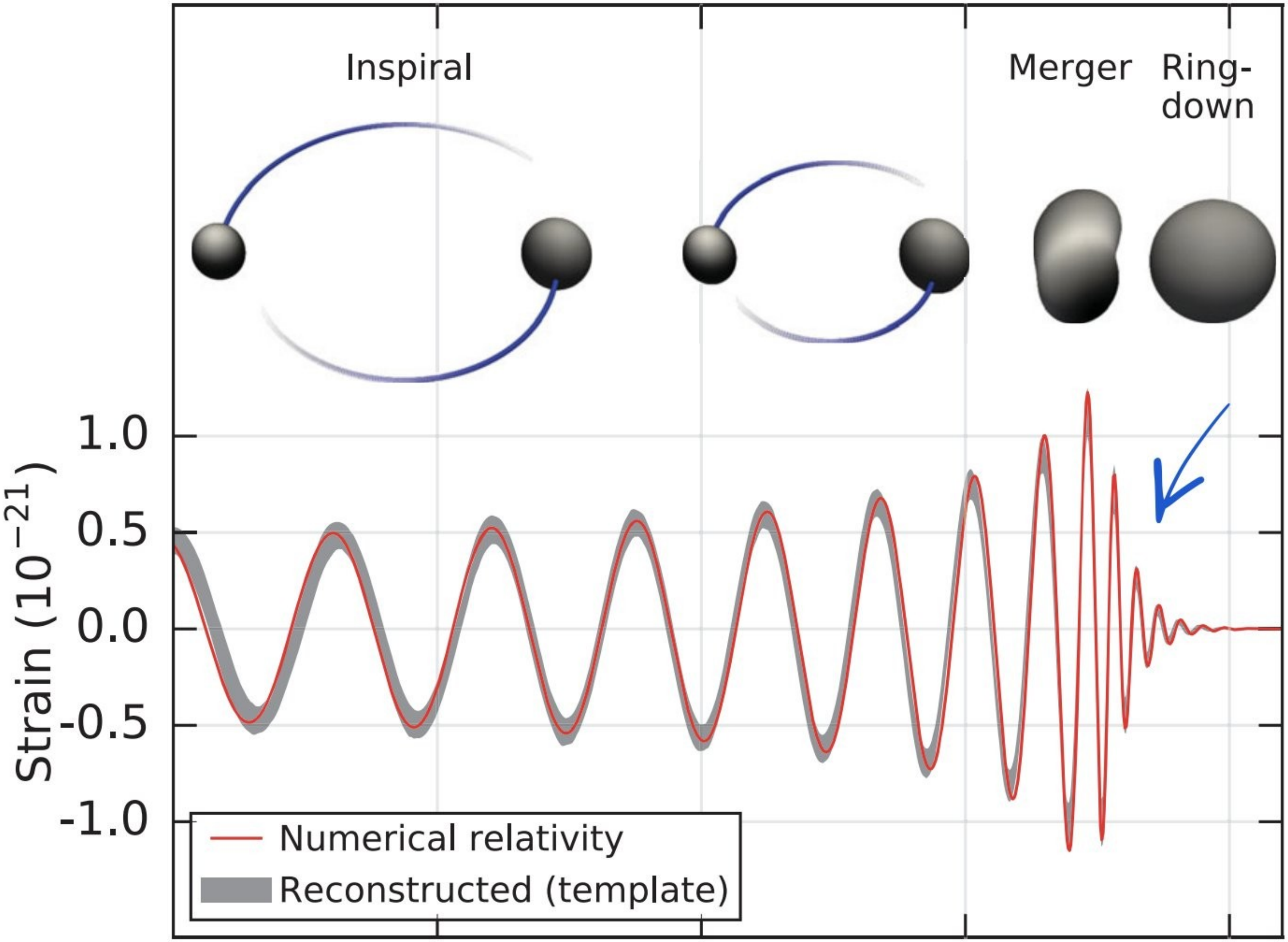
Delay between GW and EM signals

- Current limit

$$\frac{\delta v}{v} \approx 10^{-15}$$

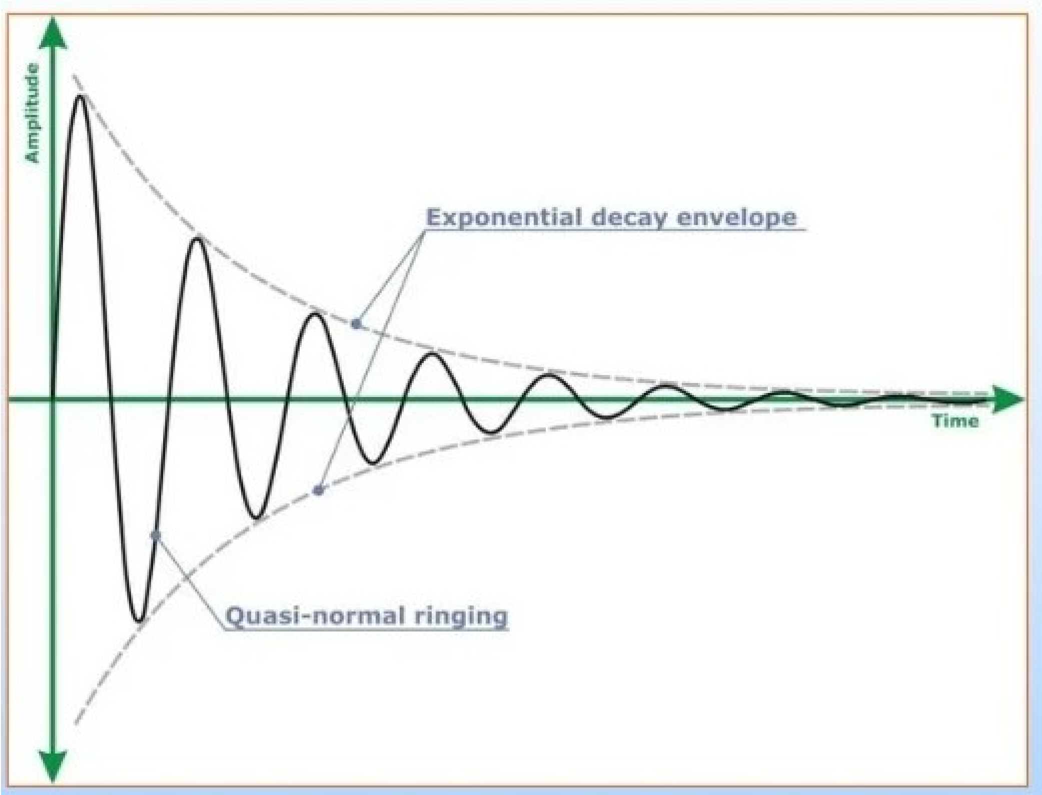
- ET limits from BNS mergers – up to 100 times better.

Fundamental physics – BH oscillations



Fundamental physics – BH oscillations

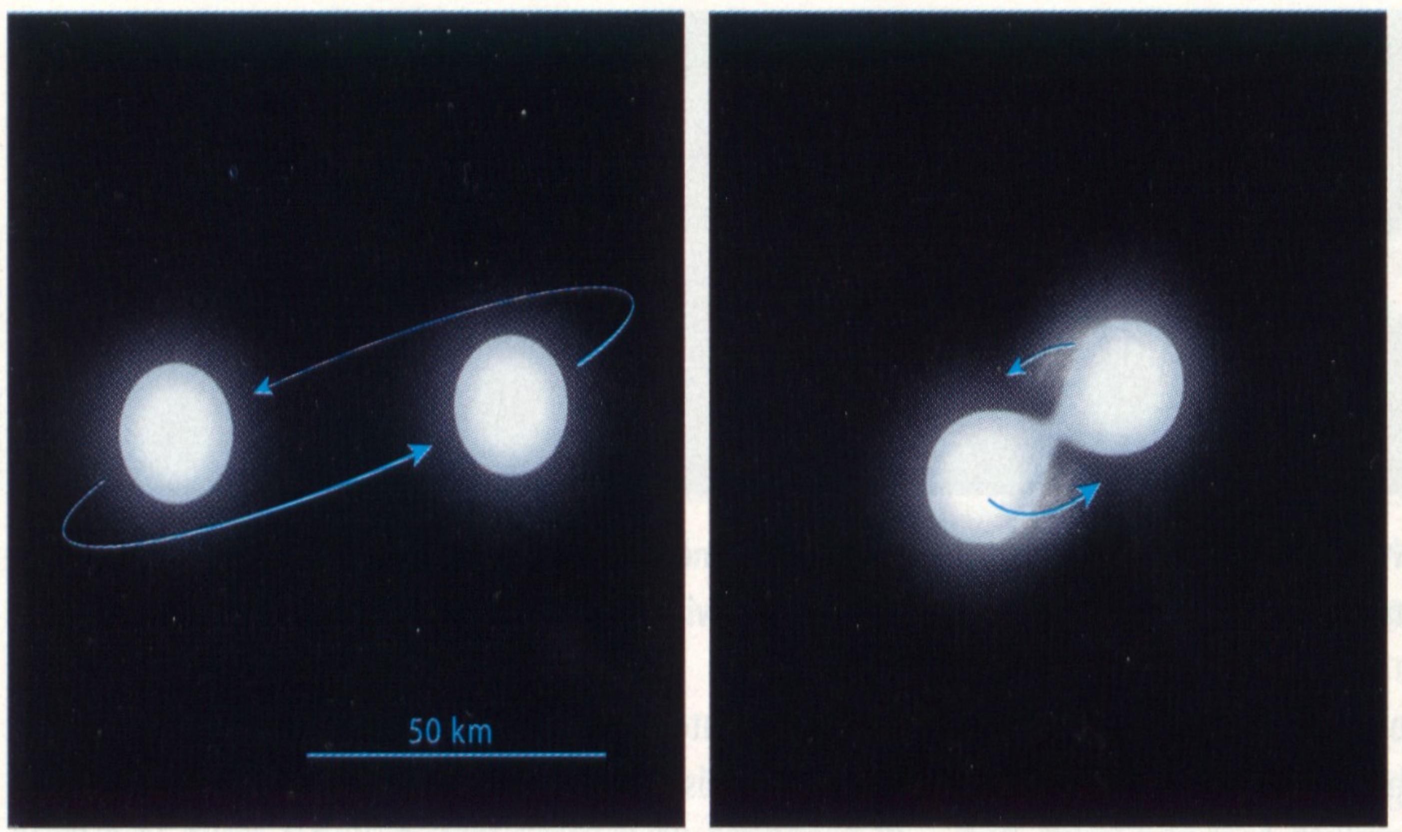
- Testing no-hair theorem
- Testing General Relativity
- ET – will be able to detect tens of nearby mergers with signals strong enough to see several harmonics!



Fundamental physics – dense matter

- Neutron star interiors – how to check them?
- EM – mass - radius relations
- GW mergers - squeezing neutron stars!

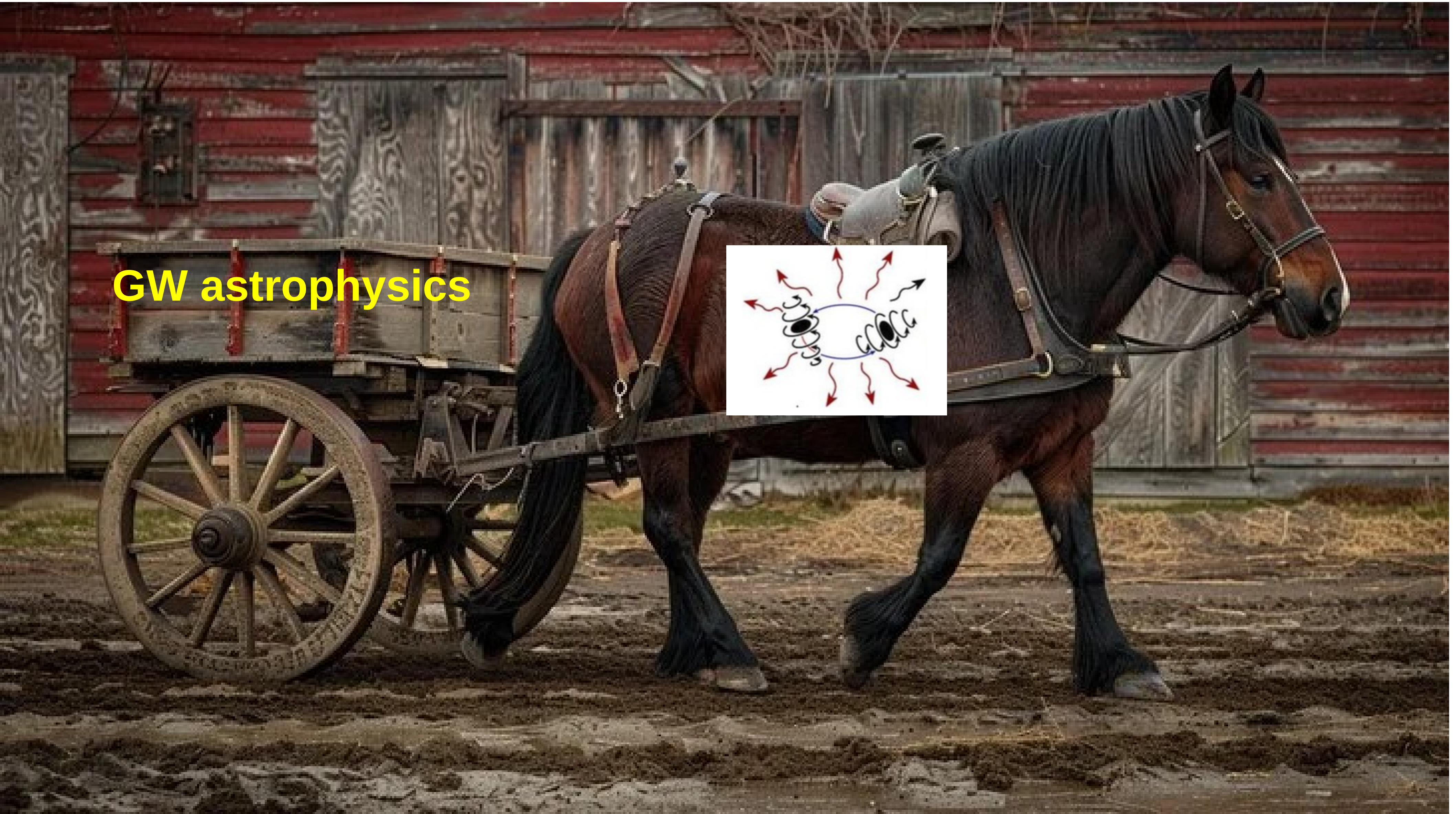
Neutron star deformability



Summary

- Binaries will be the base of GW astronomy.
- ET will uncover their origin and properties
- ET will enable to use them to answer questions on fundamental physics

Binaries – work horse of GW astronomy



Thank you!