Einstein Telescope Science Case

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& E.T. CDR 2019]

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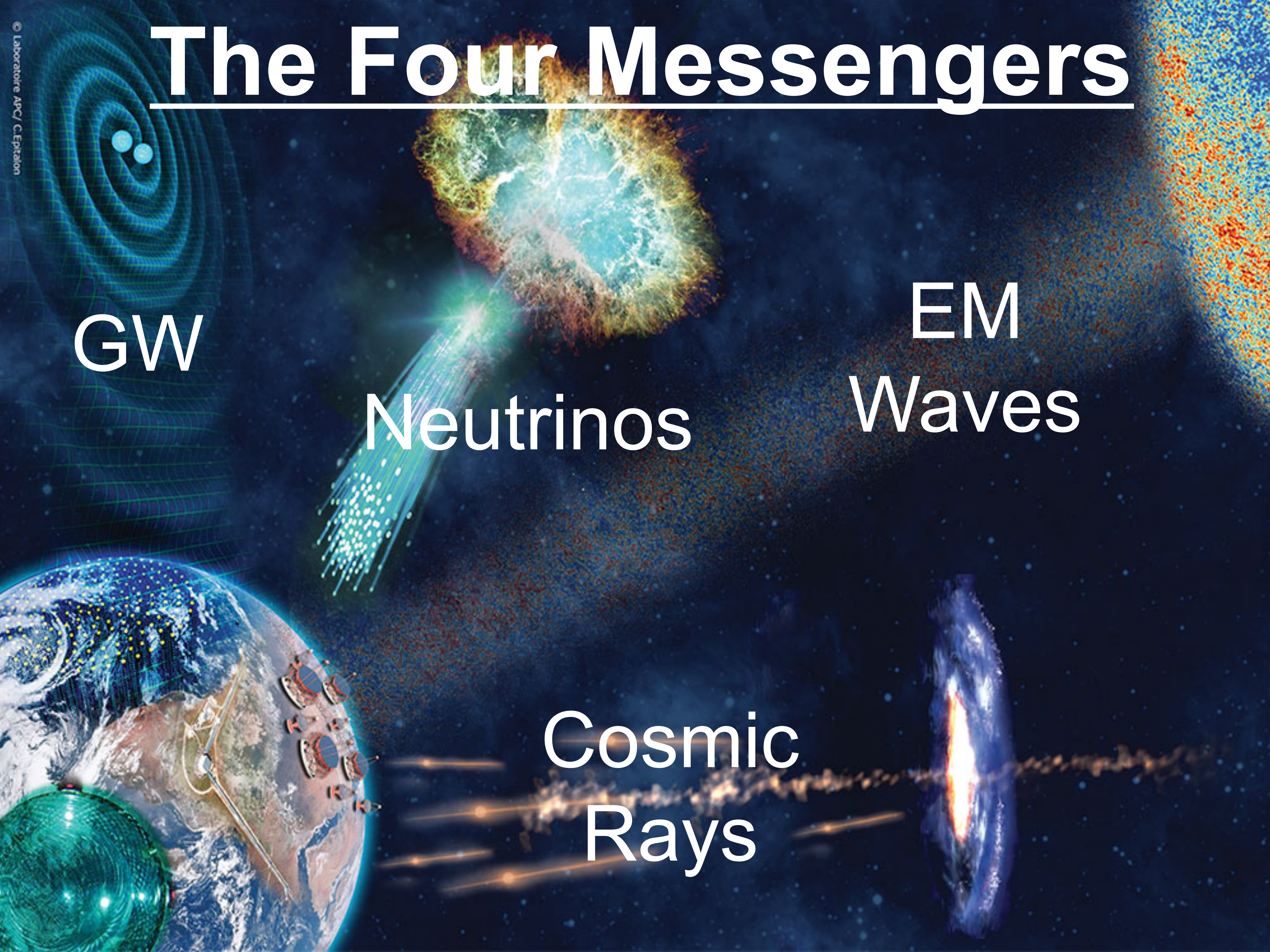
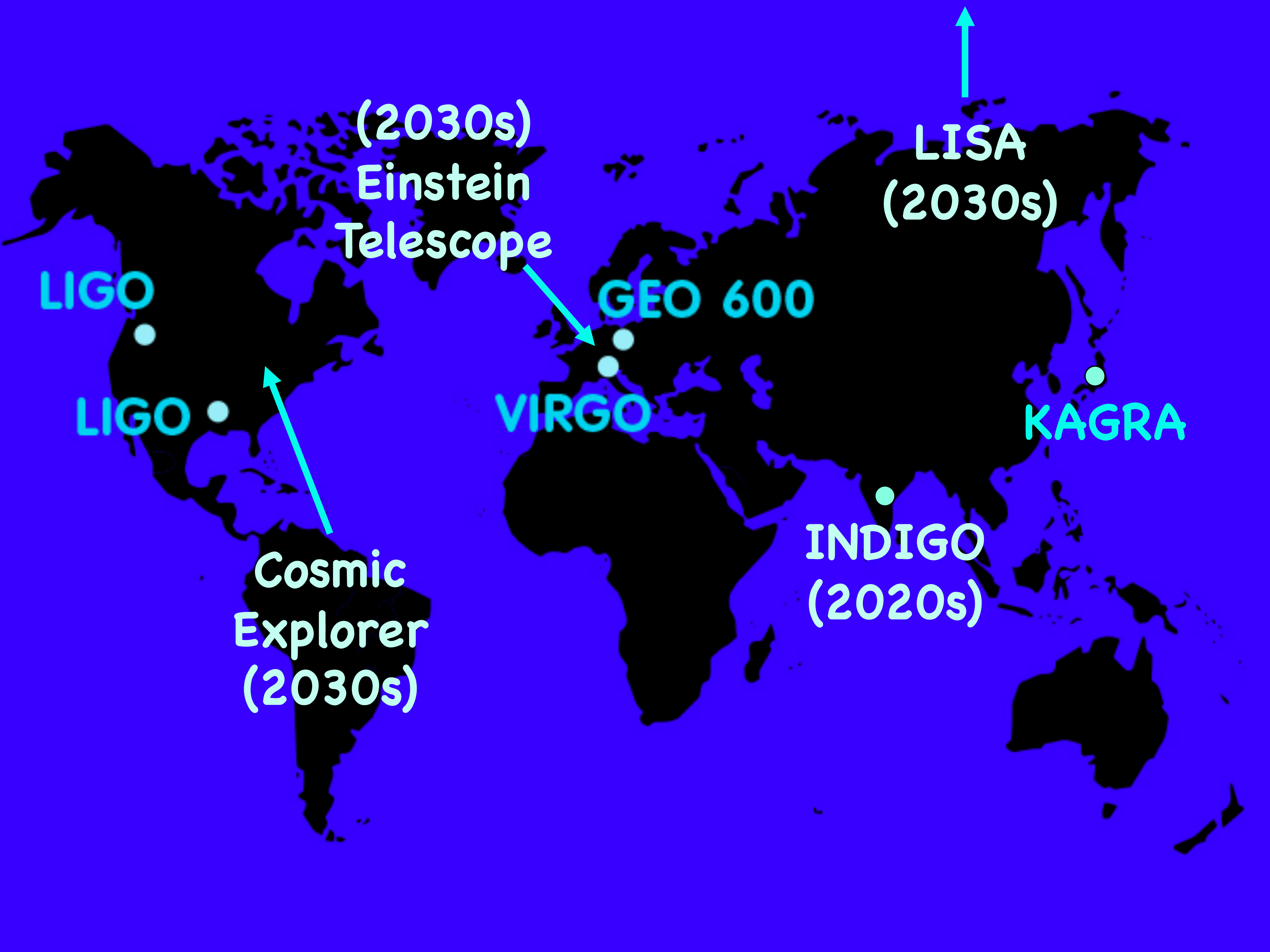
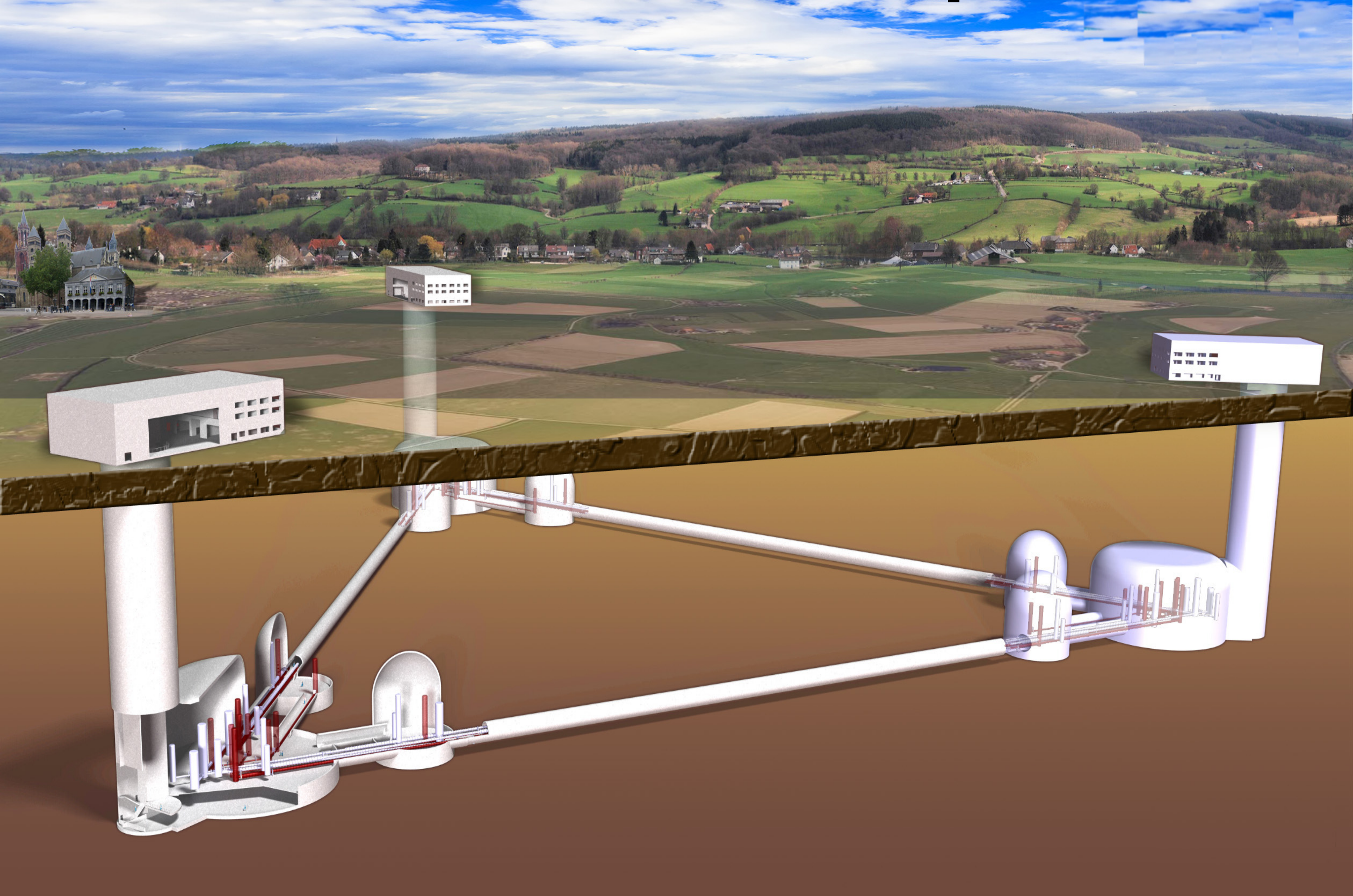
The Four Messengers



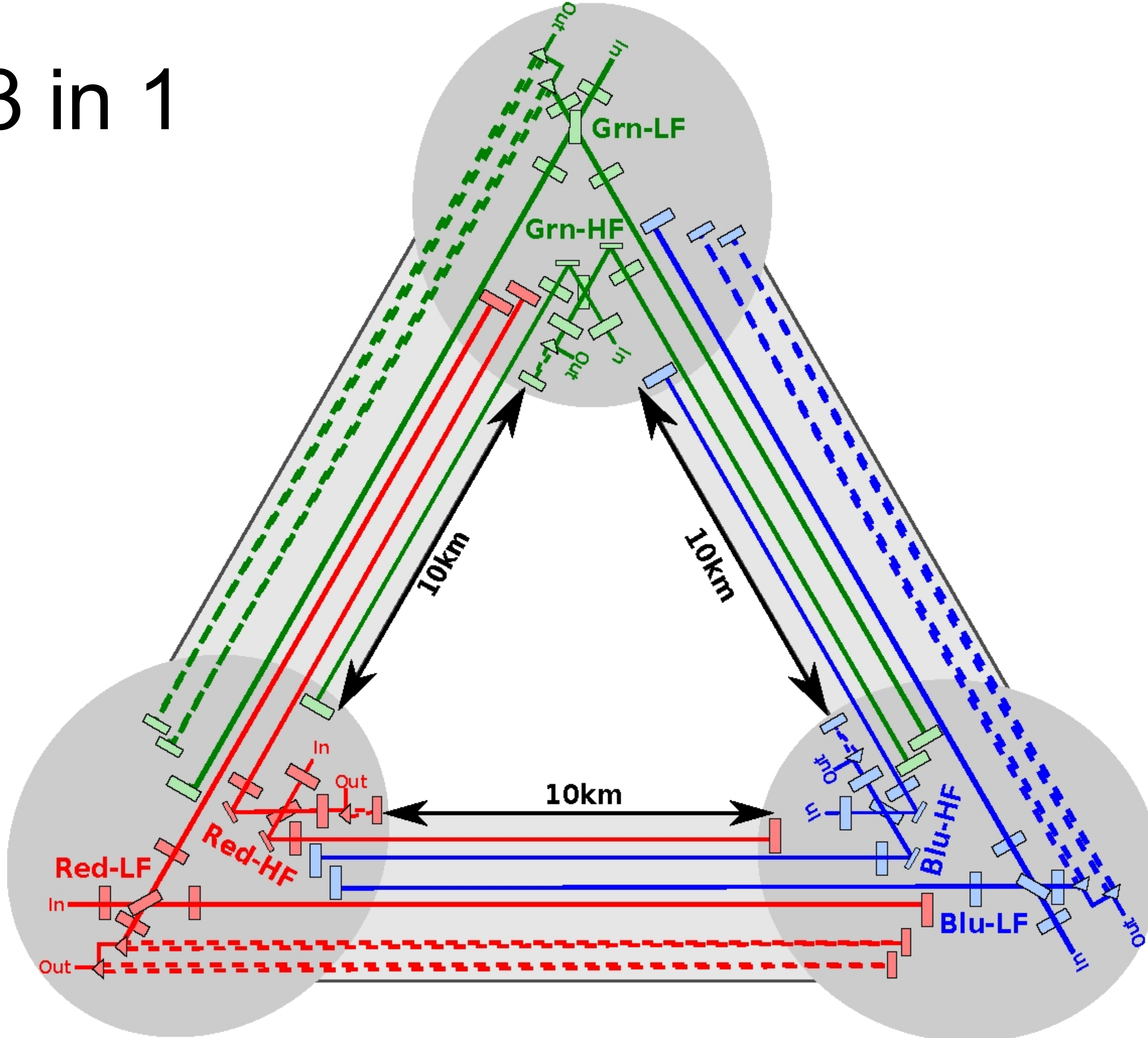


(2030s)
Einstein
Telescope
LISA
(2030s)
LIGO
LIGO
GEO 600
VIRGO
KAGRA
INDIGO
(2020s)
Cosmic
Explorer
(2030s)

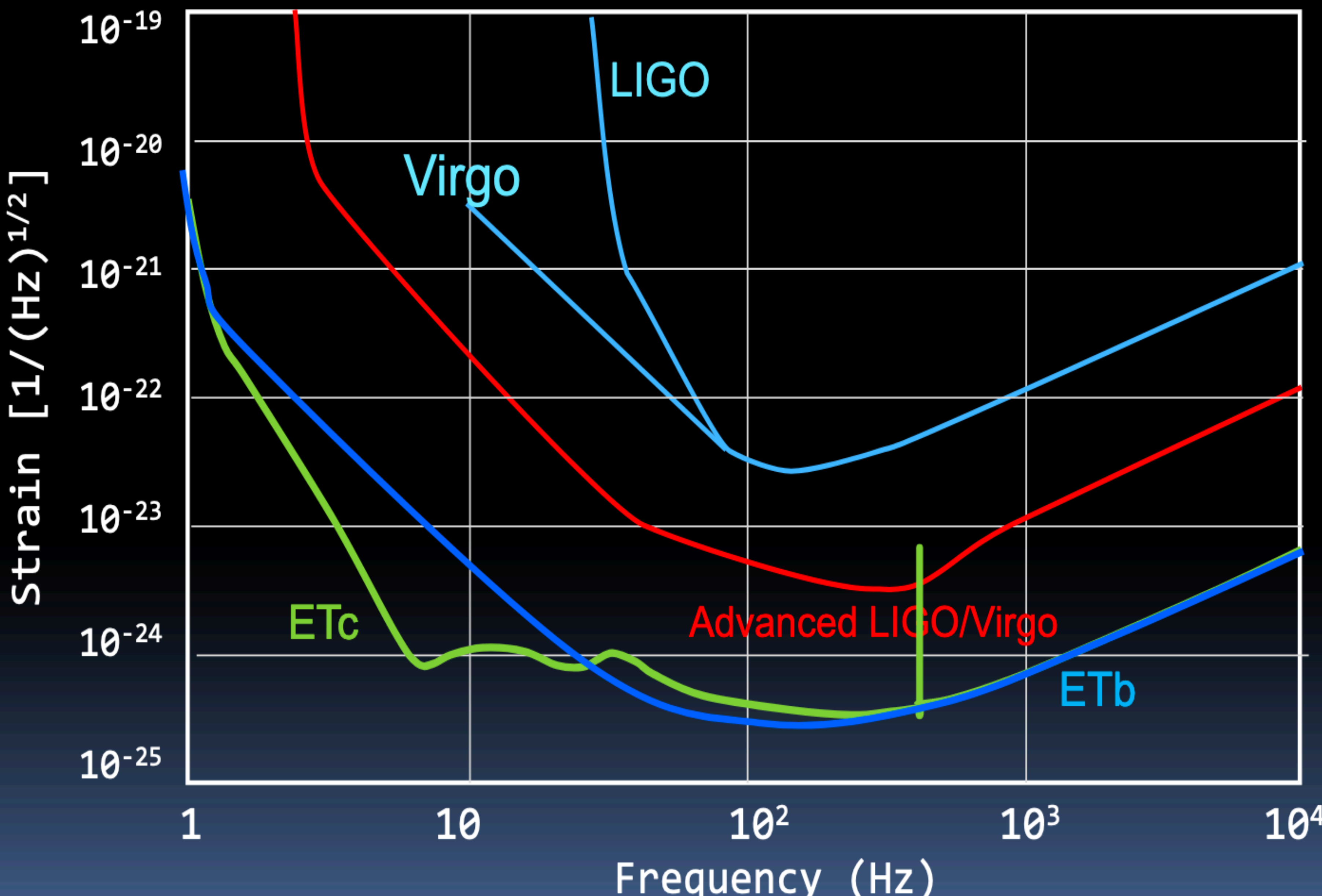
Einstein Telescope



3 in 1



Sensitivity ET vs LIGO



Horizon and SNR of ET vs LIGO

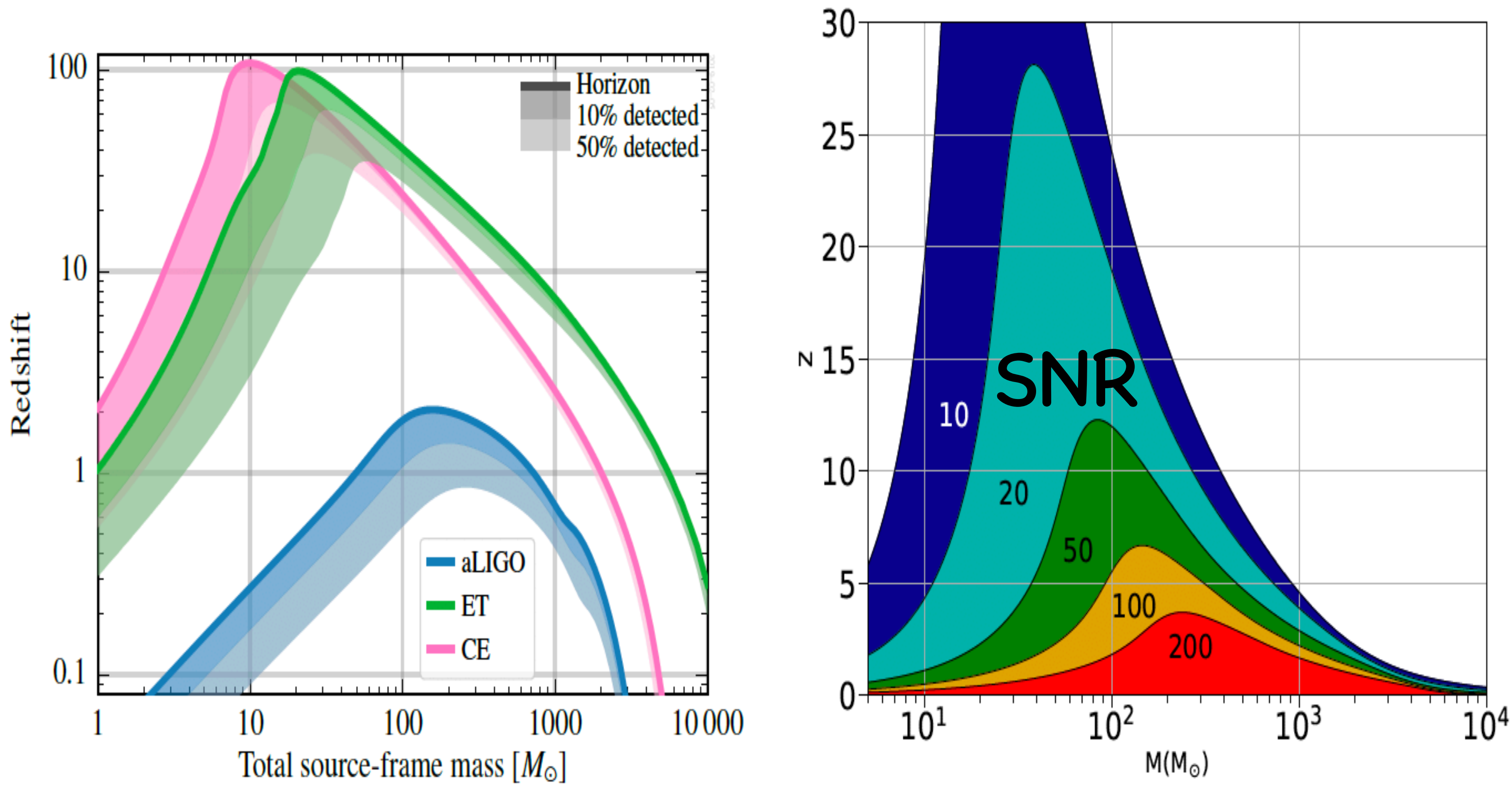


Figure 1. Left: astrophysical reach for equal-mass, nonspinning binaries for Advanced LIGO, Einstein Telescope and Cosmic Explorer (from ref. [22]). Right: lines of constant signal-to-noise ratio in the (total mass, redshift) plane, for a network of one ET and two CE detectors. The curves shown assume equal-mass binary components (figure courtesy by M. Colpi and A. Mangiagli).

Main Scientific Objectives

- Fundamental Physics and tests of GR
  - Nature of Gravity and Compact Objects
  - Black Holes and the nature of Dark Matter
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  - Stochastic Backgrounds
  - Cosmological parameters

Probing Gravity at all scales

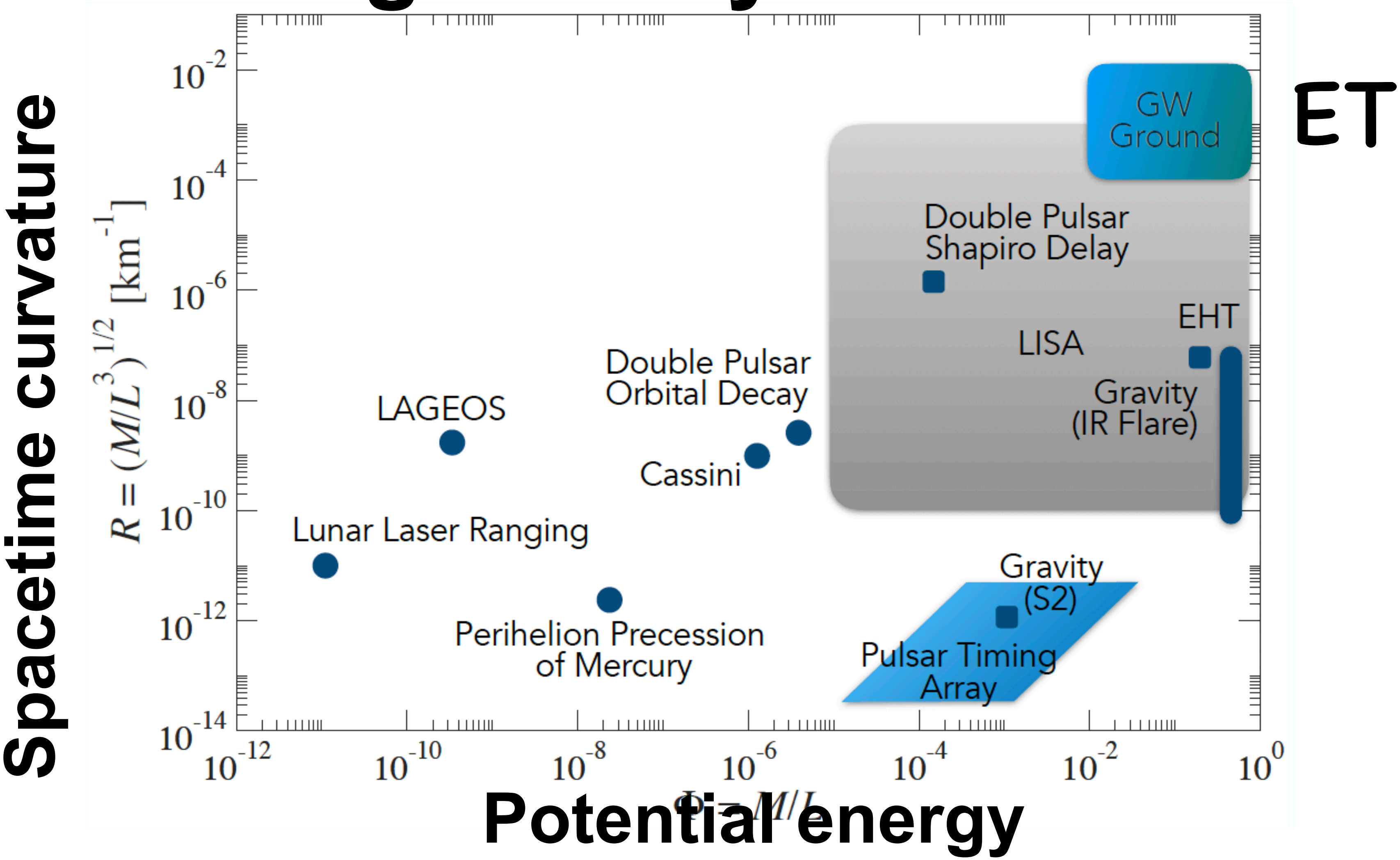
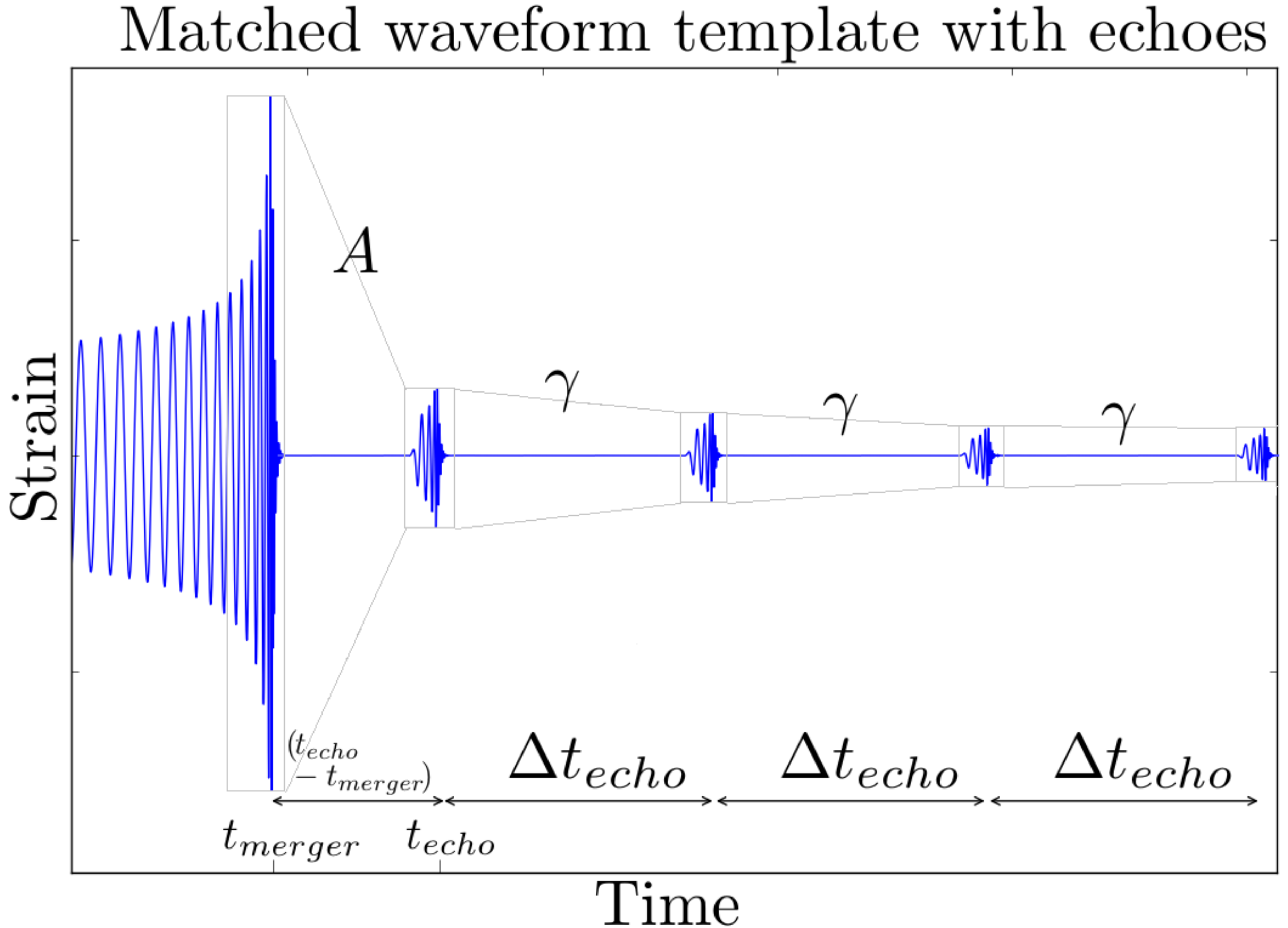
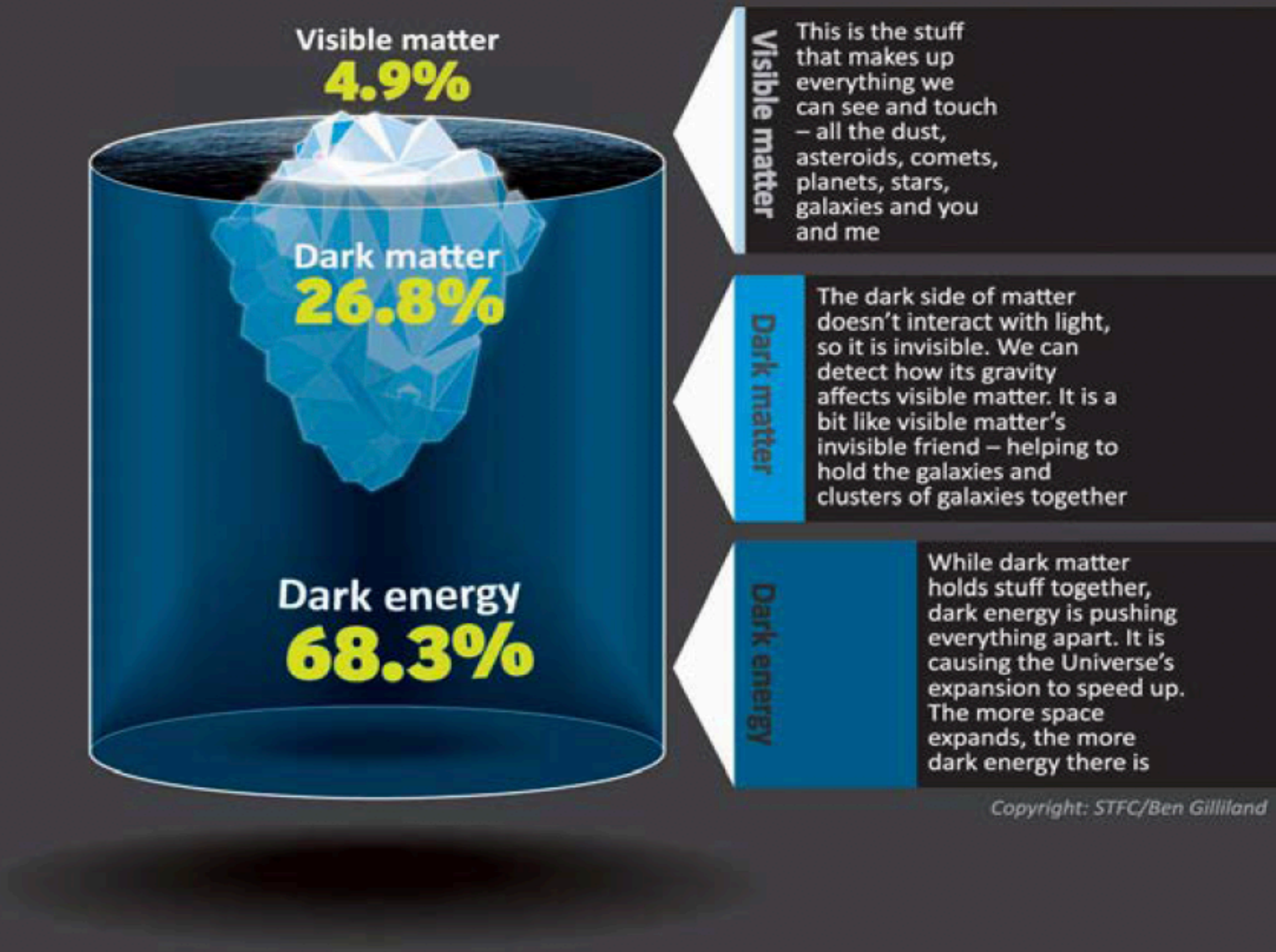


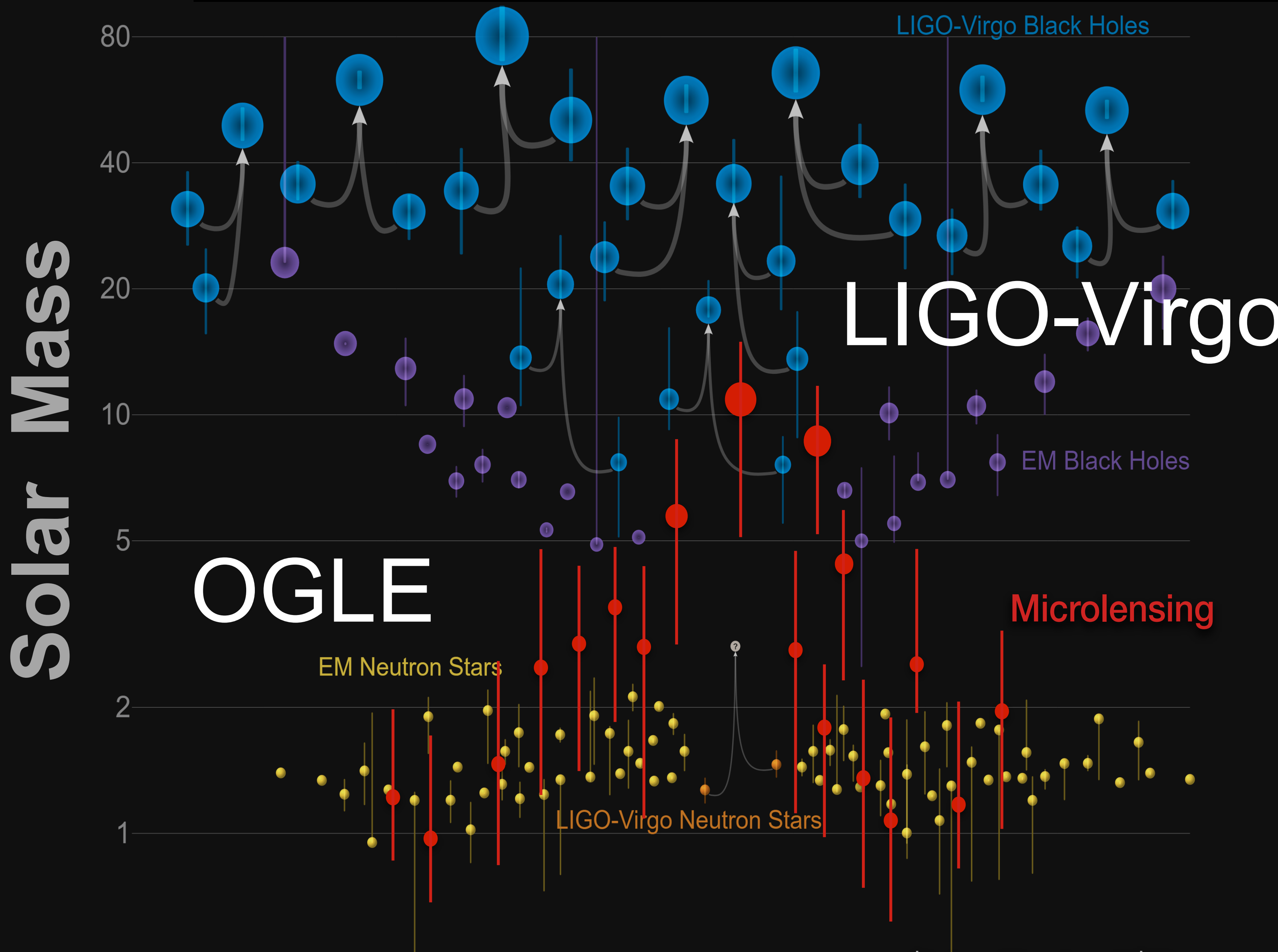
Figure 8. Probing gravity at all scales: illustration of the reach in spacetime curvature versus potential energy targeted by different kinds of observations. M and L are the characteristic mass and length involved in the system or process being observed. The genuinely strong-field dynamics of spacetime manifests itself in the top right of the diagram. The label EHT refers to the Event Horizon Telescope. From ref. [86].



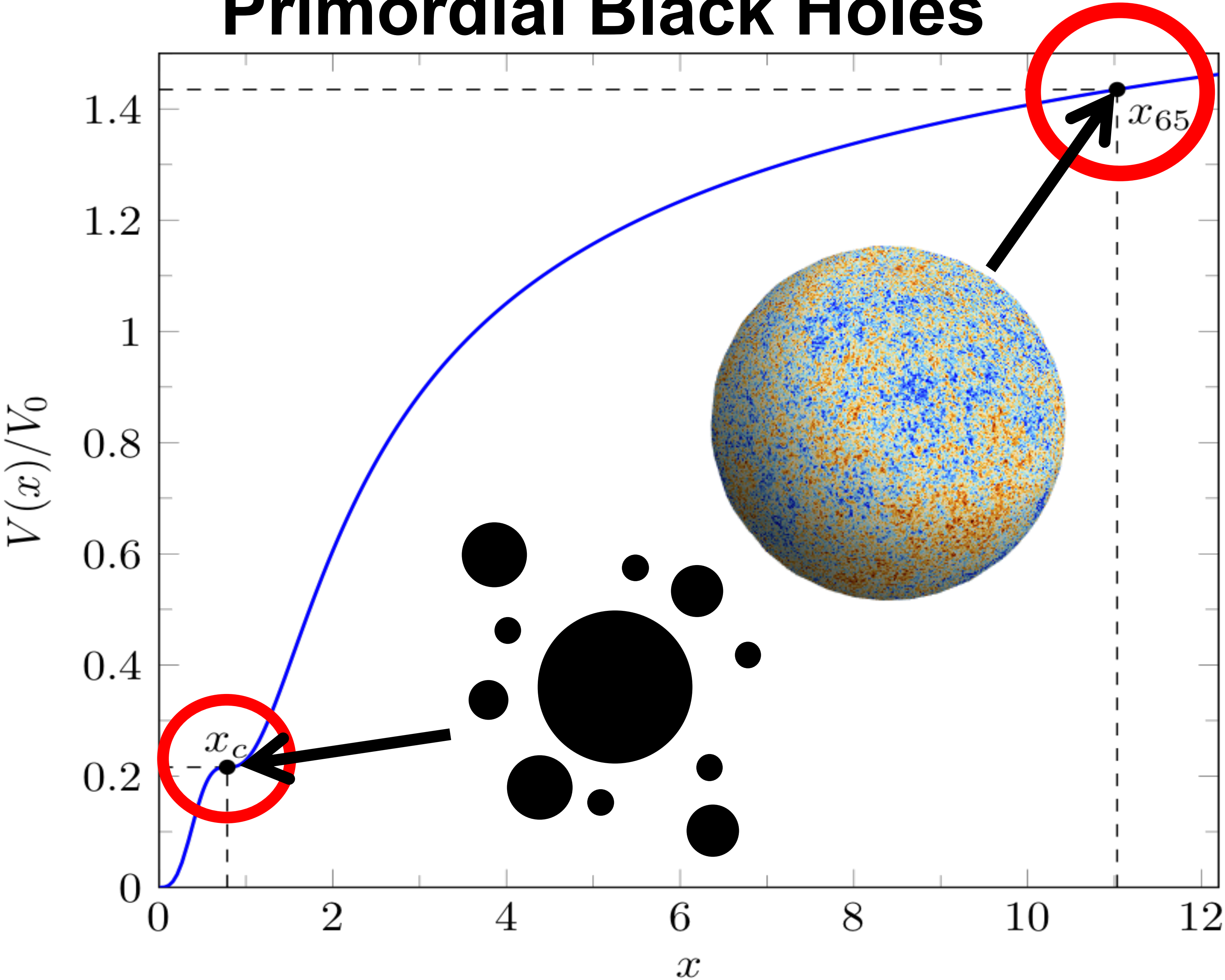
Matched waveform template with echoes
Strain
Time
A
γ
γ
γ
$(t_{echo} - t_{merger})$
Δt_{echo}
Δt_{echo}
Δt_{echo}
t_{merger}
t_{echo}


Visible matter
4.9%
Dark matter
26.8%
Dark energy
68.3%
Visible matter
This is the stuff that makes up everything we can see and touch – all the dust, asteroids, comets, planets, stars, galaxies and you and me
Dark matter
The dark side of matter doesn't interact with light, so it is invisible. We can detect how its gravity affects visible matter. It is a bit like visible matter's invisible friend – helping to hold the galaxies and clusters of galaxies together
Dark energy
While dark matter holds stuff together, dark energy is pushing everything apart. It is causing the Universe's expansion to speed up. The more space expands, the more dark energy there is

Black Holes and Neutron Stars

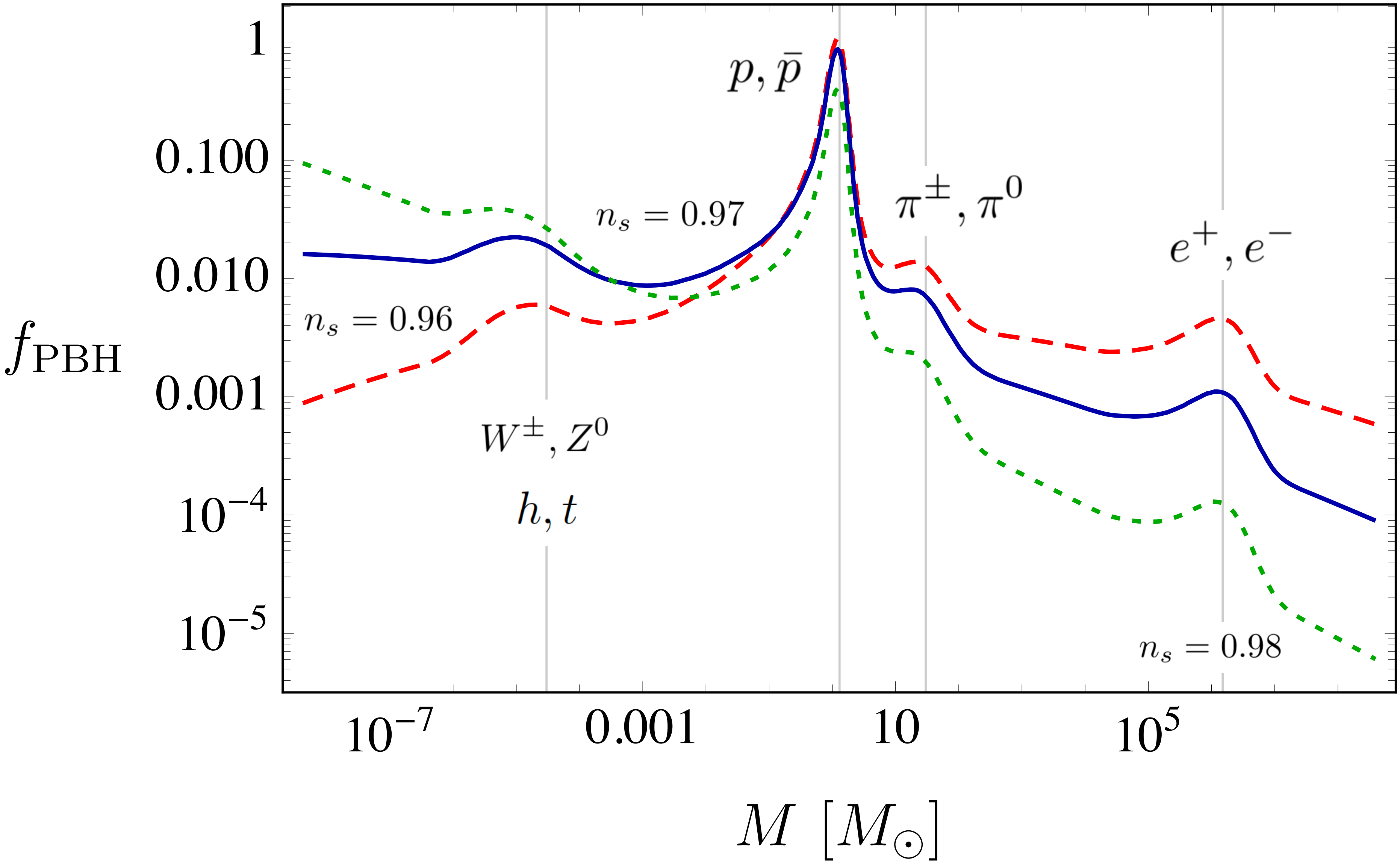


Primordial Black Holes



PBH mass spectrum

Carr, Clesse, JGB, Kühnel (2019)



PBH mass spectrum

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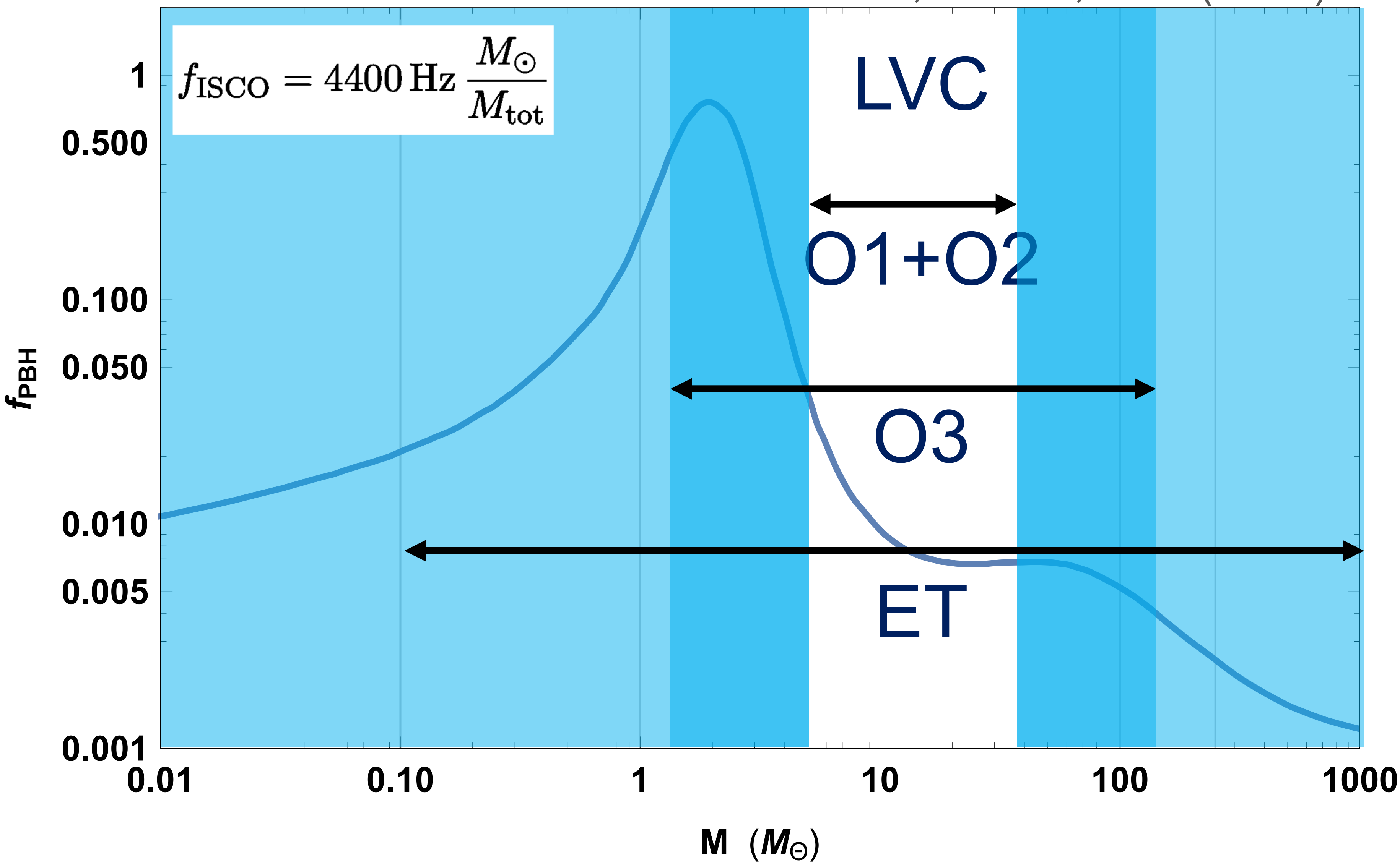

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Black Hole Binaries

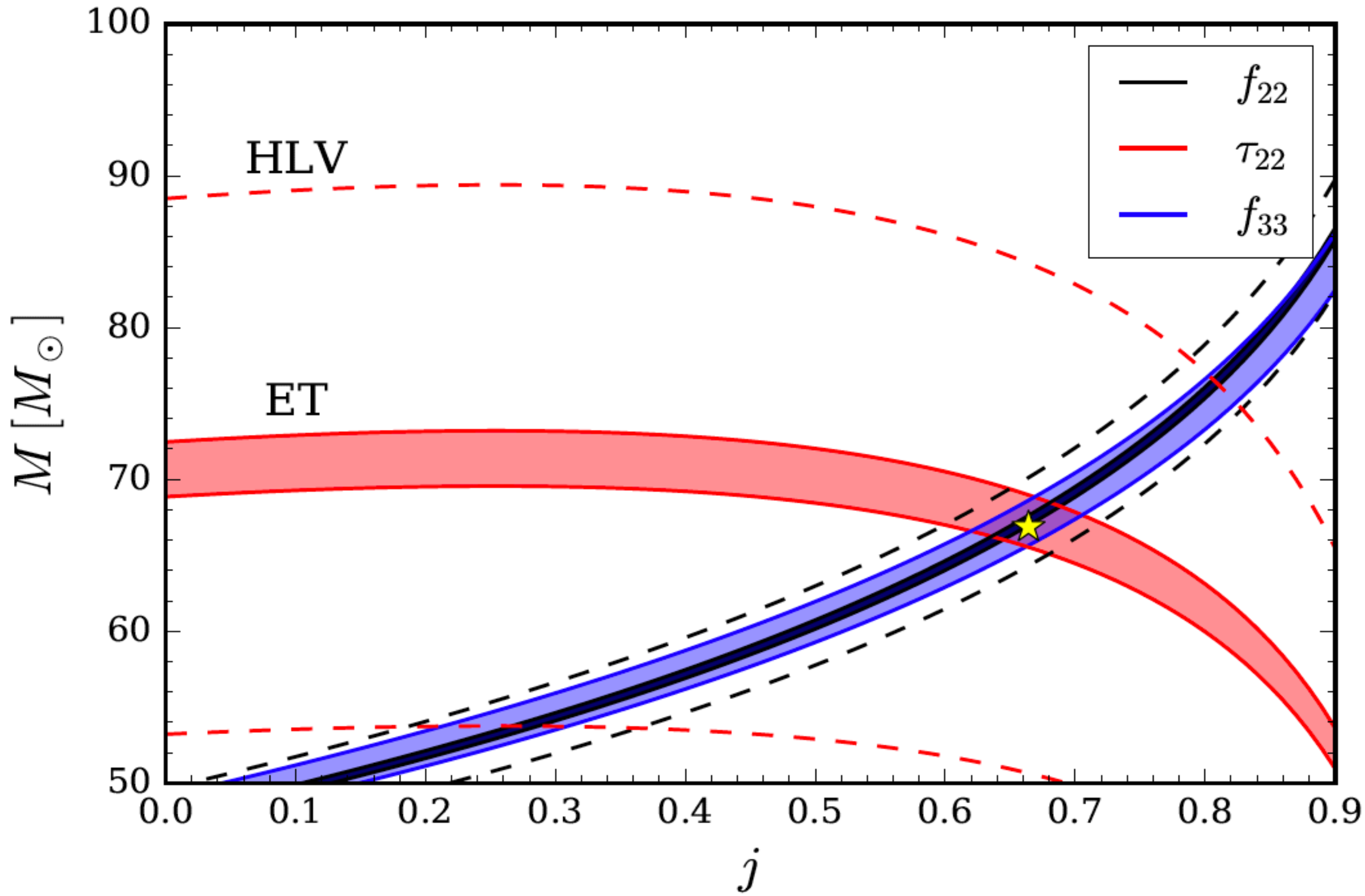


Figure 9. Testing the nature of black holes by using two quasi-normal modes and checking that the characteristic frequencies f_{22} and f_{33} and the damping time τ_{22} are consistent with each other, given that for ordinary black holes these can only depend on two numbers, namely the final mass M and final spin j. The estimates are for the "ringdown" of the remnant black hole arising from a binary similar to the source of GW150914. The dashed curves marked HLV are the 95% confidence regions one would obtain from Advanced LIGO-Virgo, while the colored bands are for ET. The star indicates the true values of M and j. Figure adapted from ref. [89].

Binary Neutron Stars Mergers

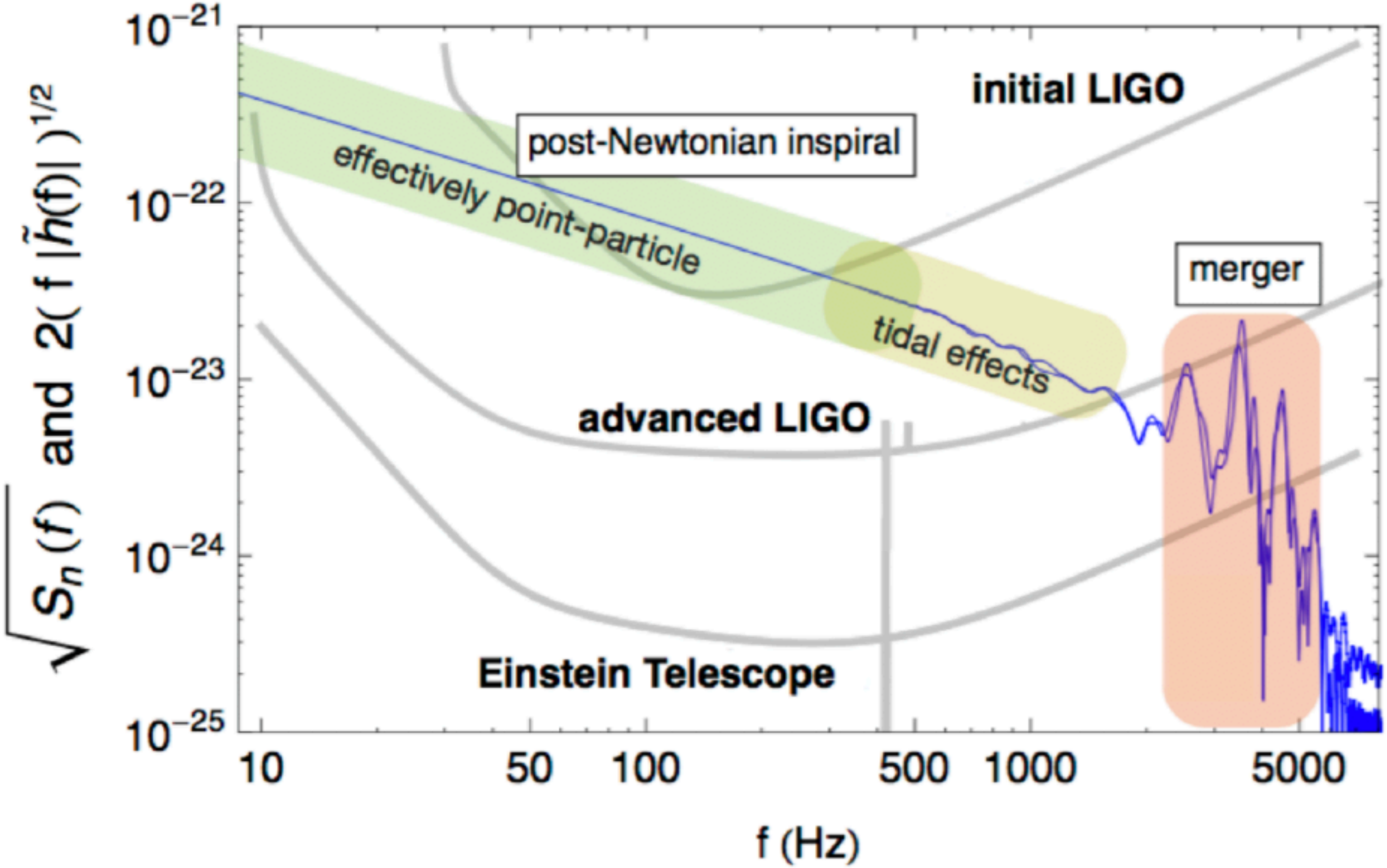
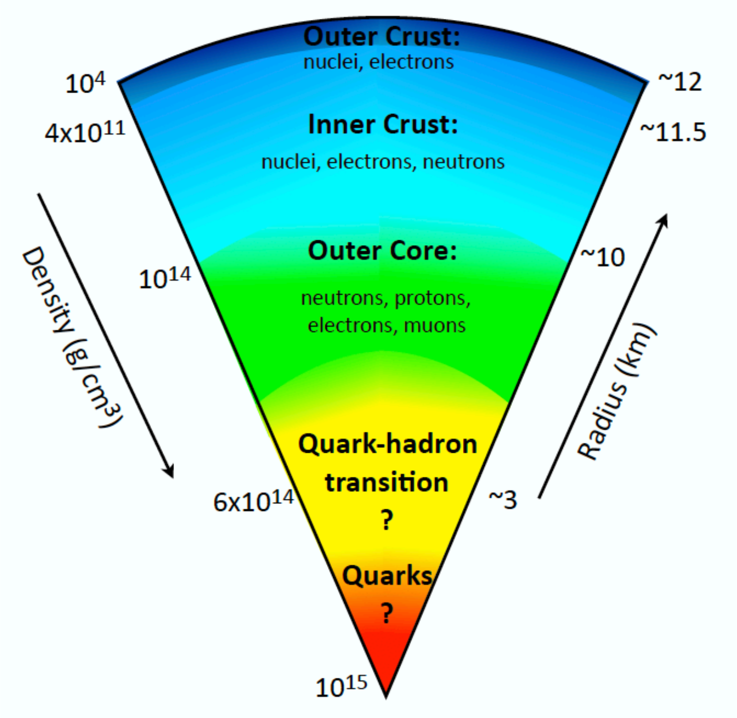


Figure 4. Gravitational wave signal from a NS-NS merger at a distance 100 Mpc, as it sweeps across the detector-accessible frequency range. Figure from [37] (adapted from an original figure by J. Read, based on data from [38]).

Neutron Stars and QCD phases



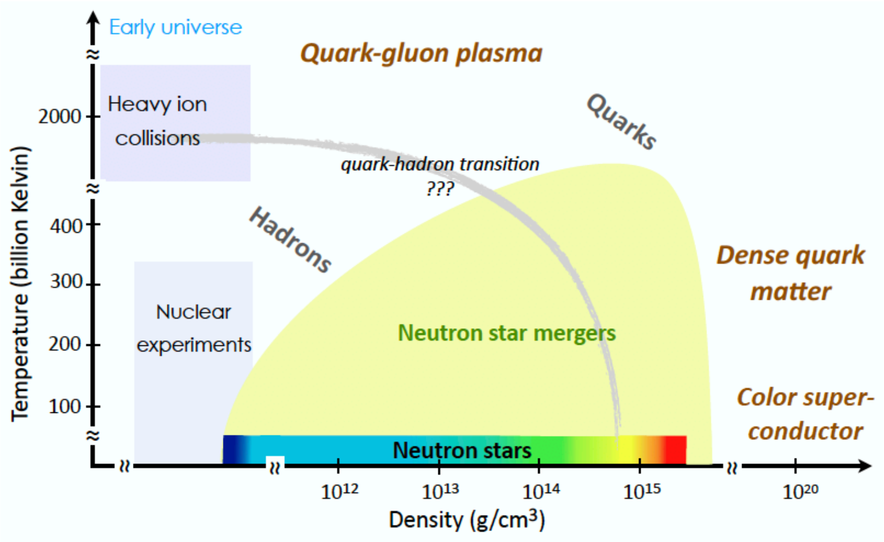
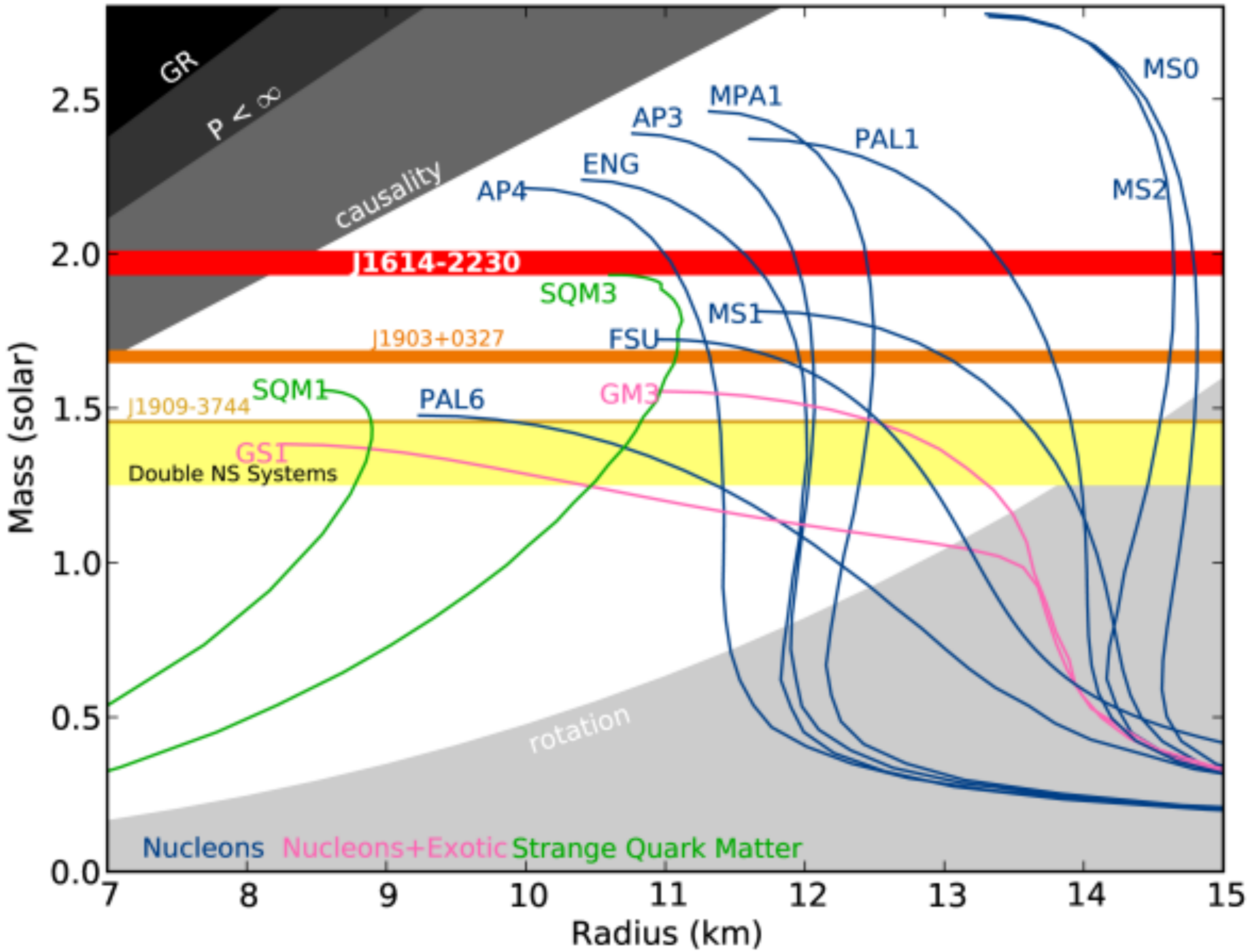
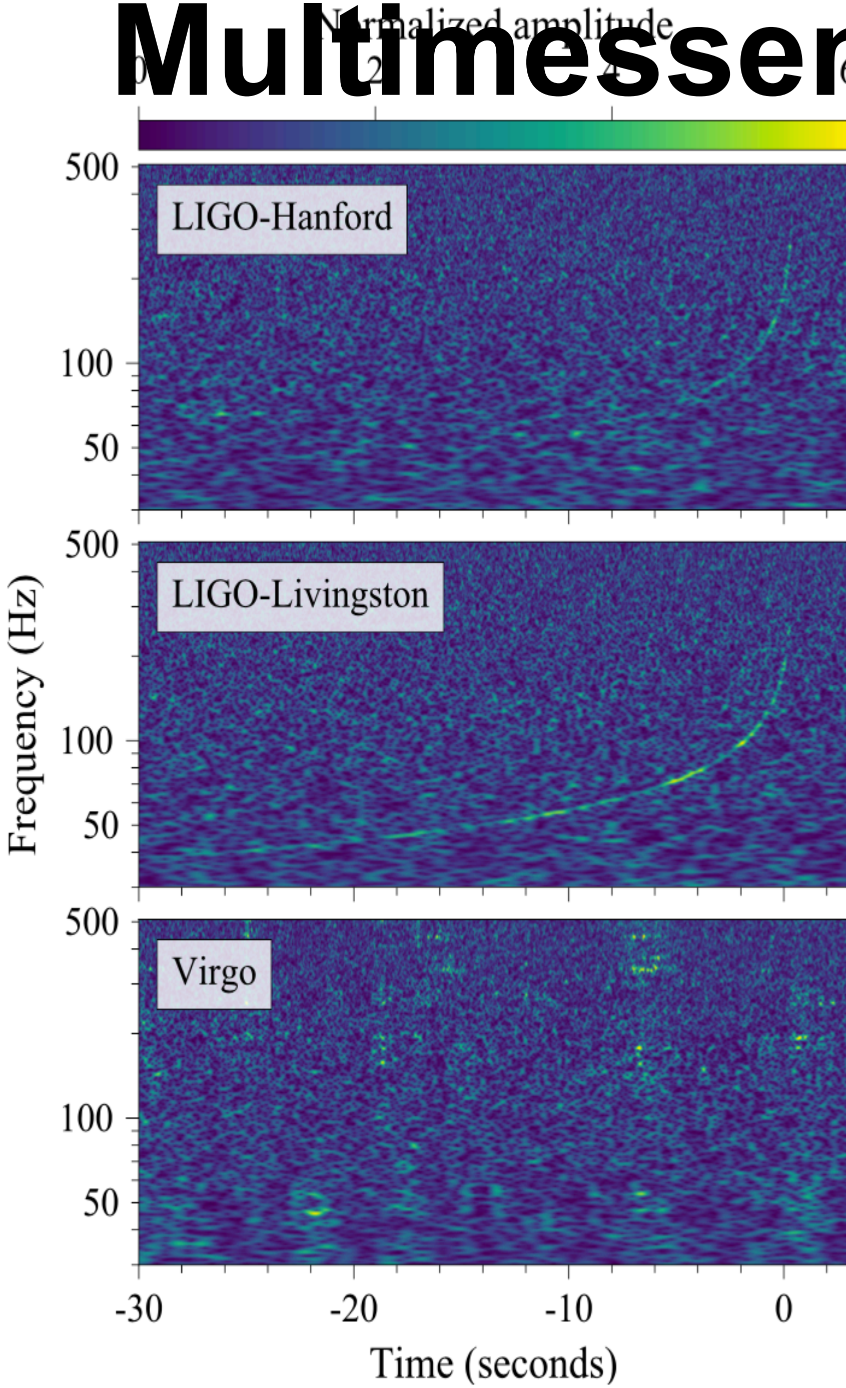


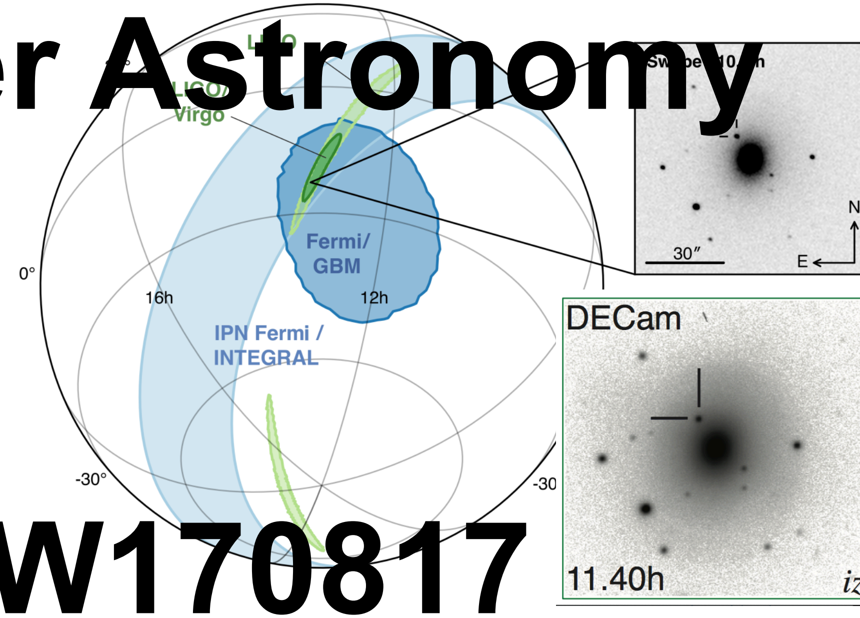
Figure 3. Left: Conjectured interior structure of a neutron star. Right: Matter encountered in neutron stars and binary mergers explores a large part of the QCD phase diagram in regimes that are inaccessible to terrestrial collider experiments.

Neutron Star's mass and radius

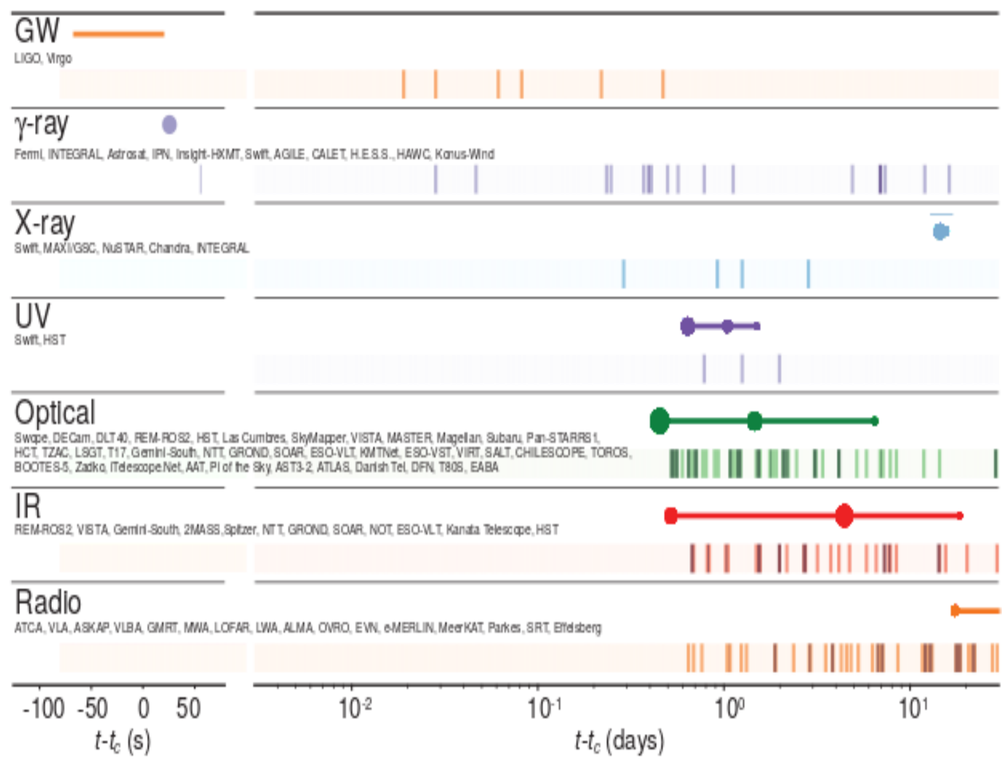


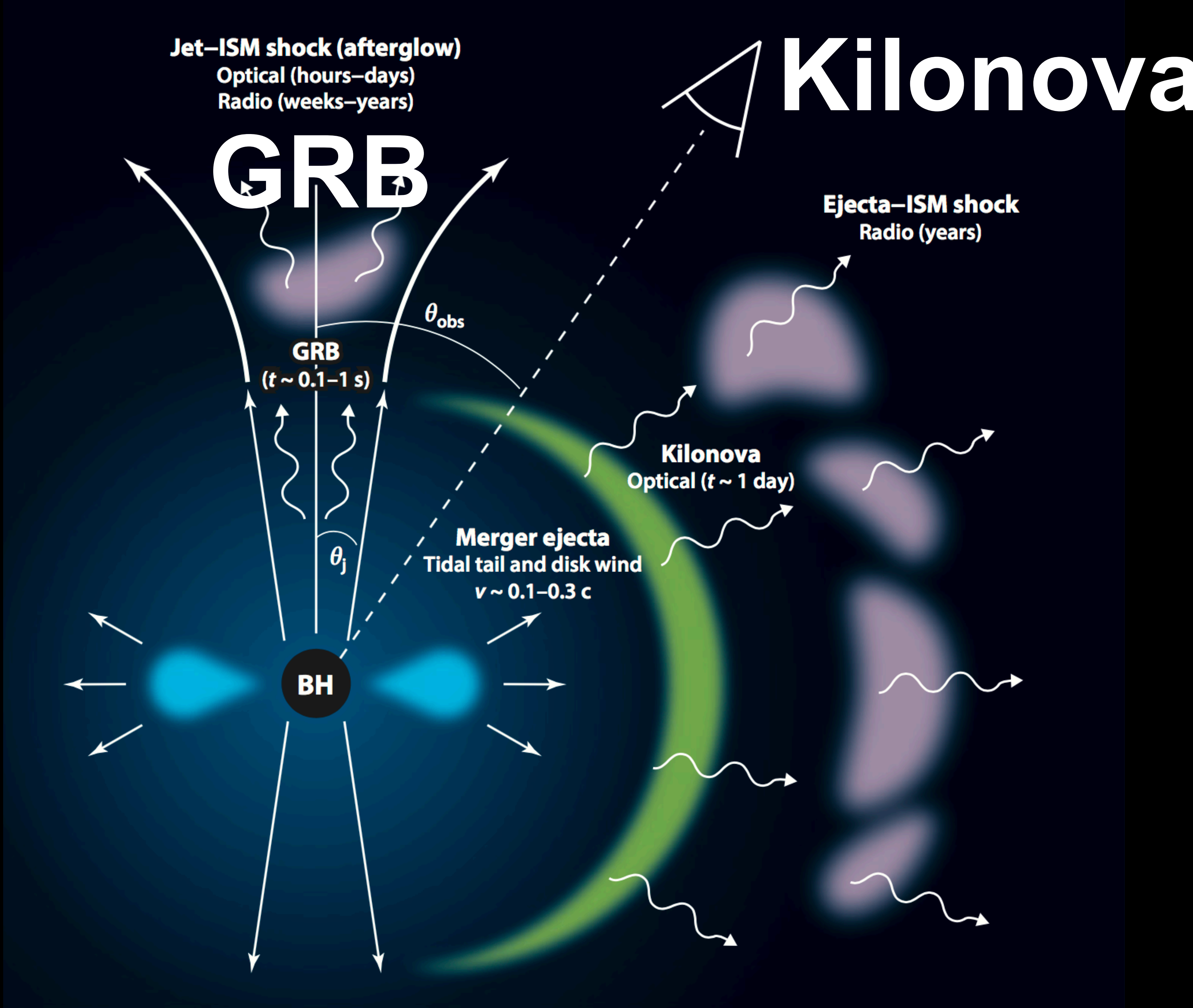
Multimessenger Astronomy





GW170817



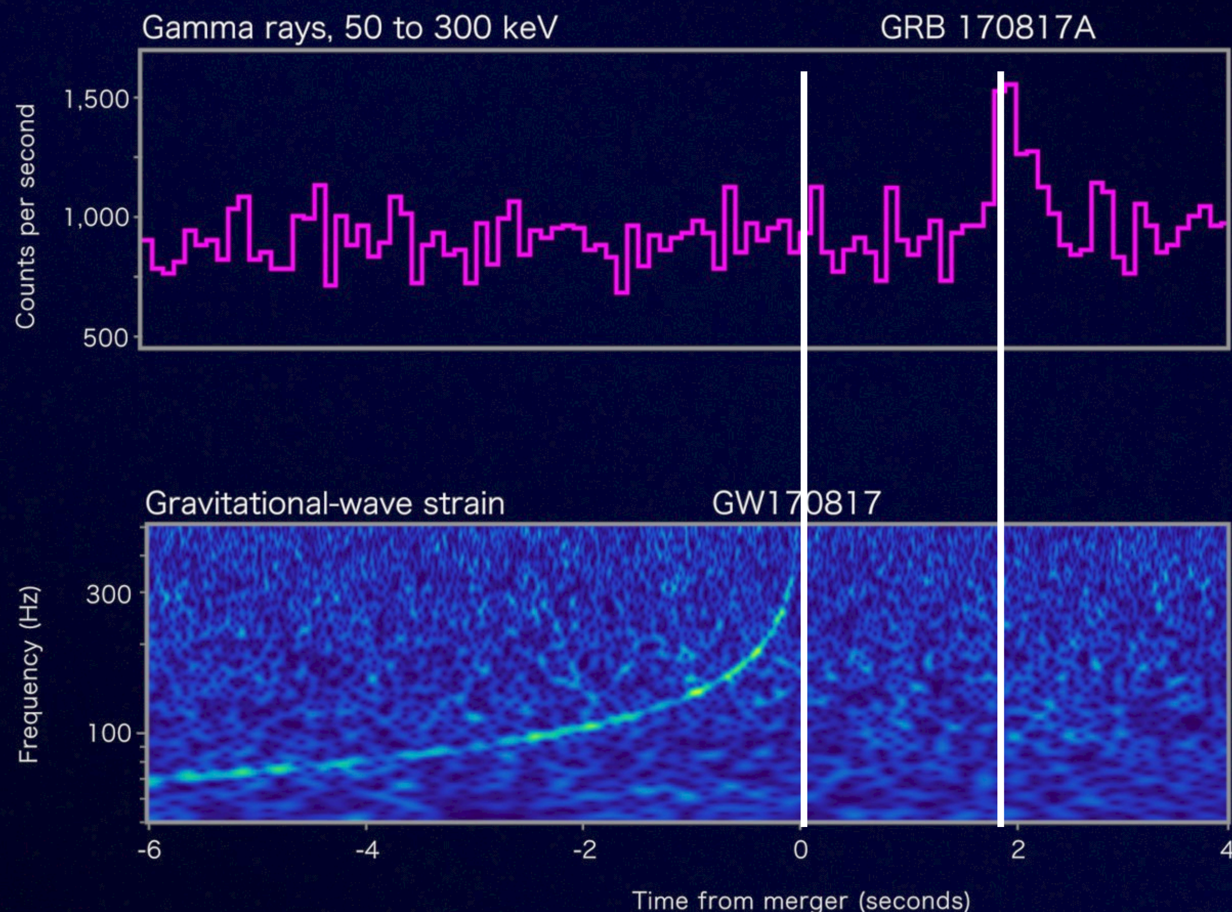

Kilonova
GRB
Jet–ISM shock (afterglow)
Optical (hours–days)
Radio (weeks–years)
Ejecta–ISM shock
Radio (years)
θobs
GRB
(t ~ 0.1–1 s)
Kilonova
Optical (t ~ 1 day)
Merger ejecta
Tidal tail and disk wind
v ~ 0.1–0.3 c
θj
BH

$c_{gw} = c_{em}$

(1.7 s in 144 Myrs)

Fermi

LIGO



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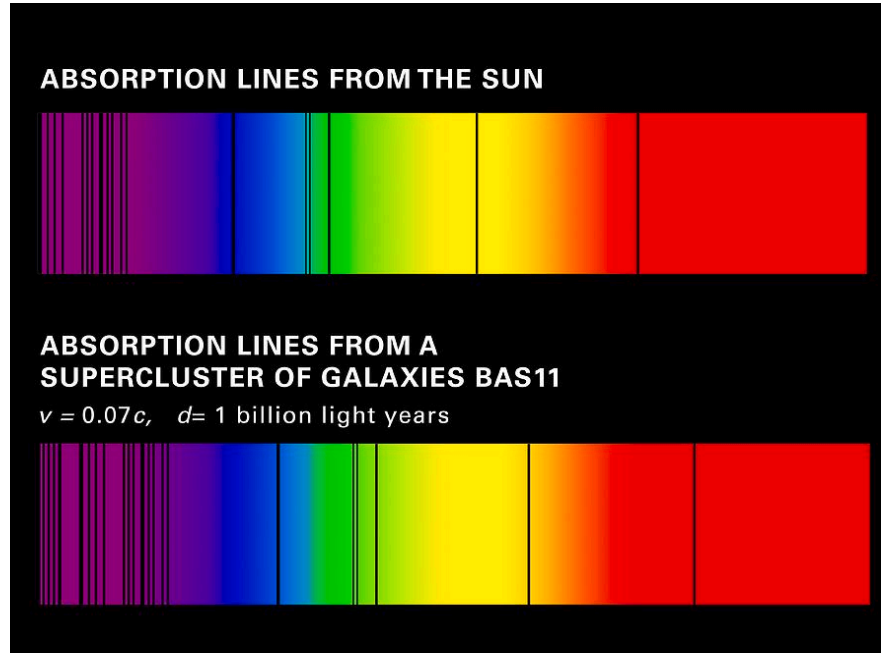
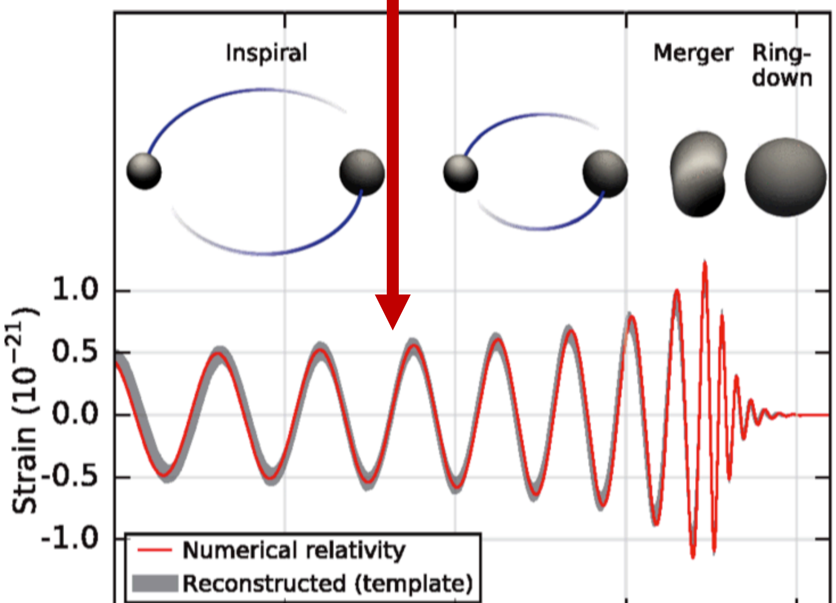
Universe Expansion

Hubble Law

$$H_0\, d_L = z$$

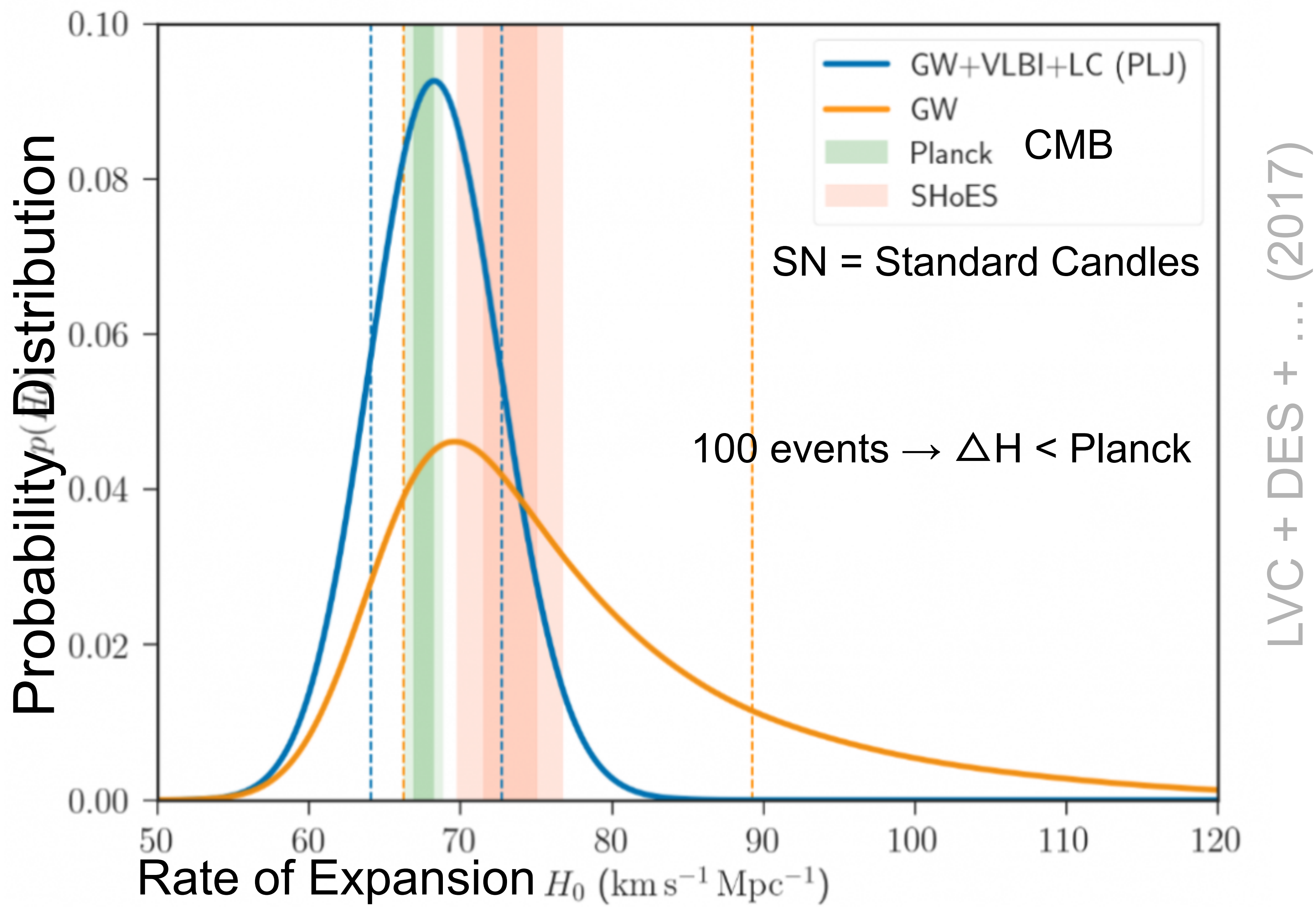




NGC4993

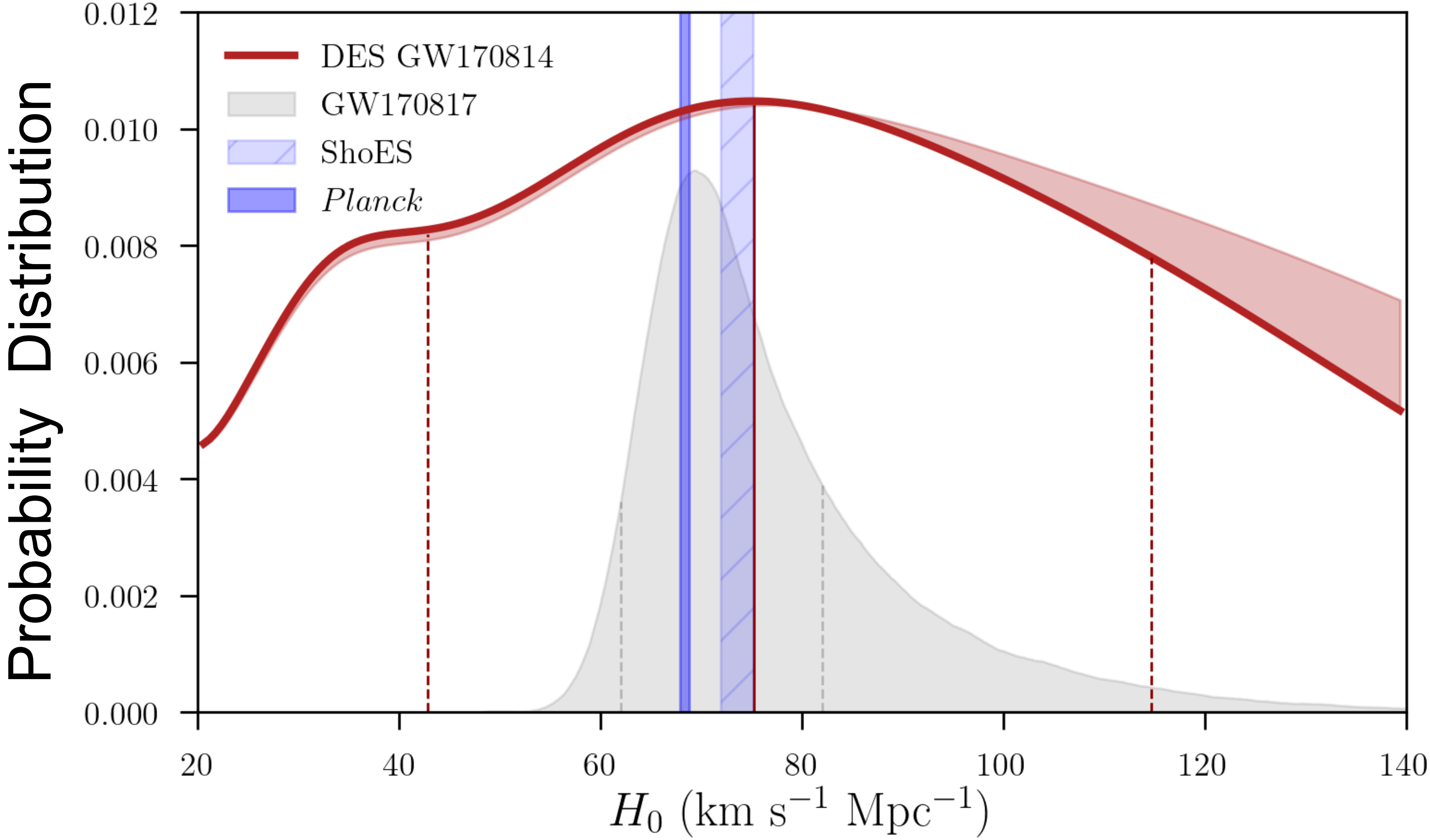
$$z = 0.009727$$

GW = Standard Sirens



GW = Dark Sirens

Soares-Santos, Palmese, JGB et al. (2019)



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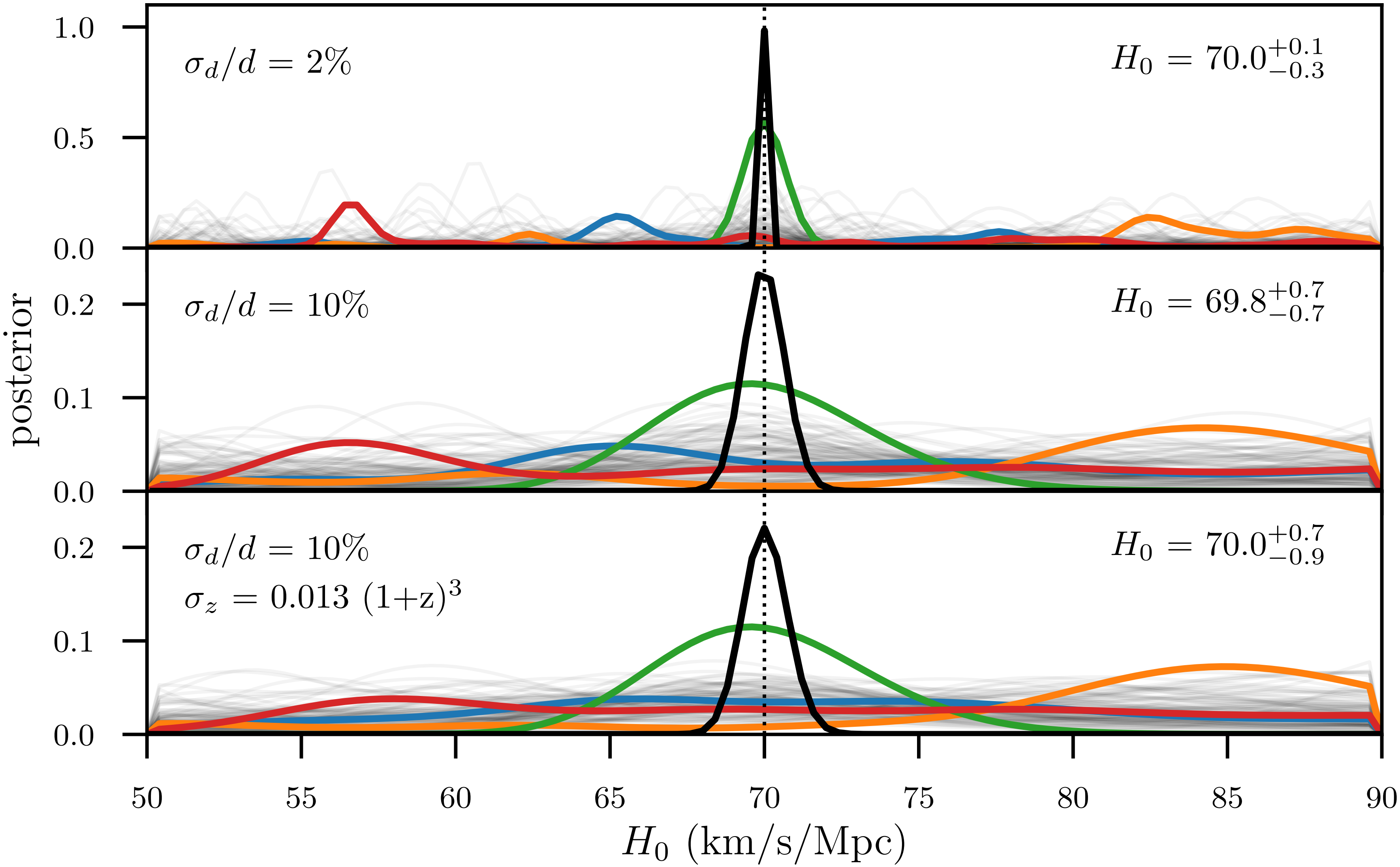
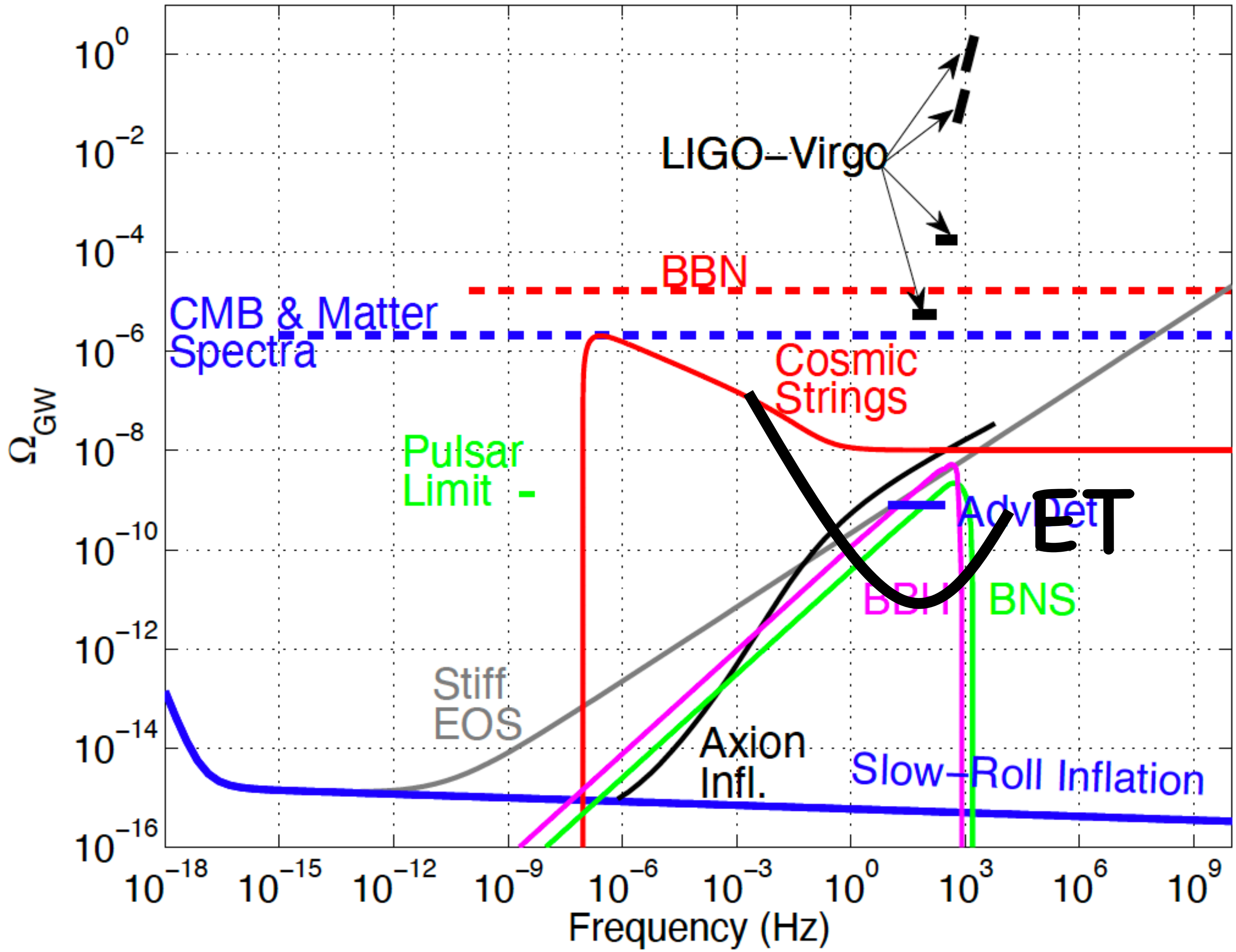


Stochastic Background GW

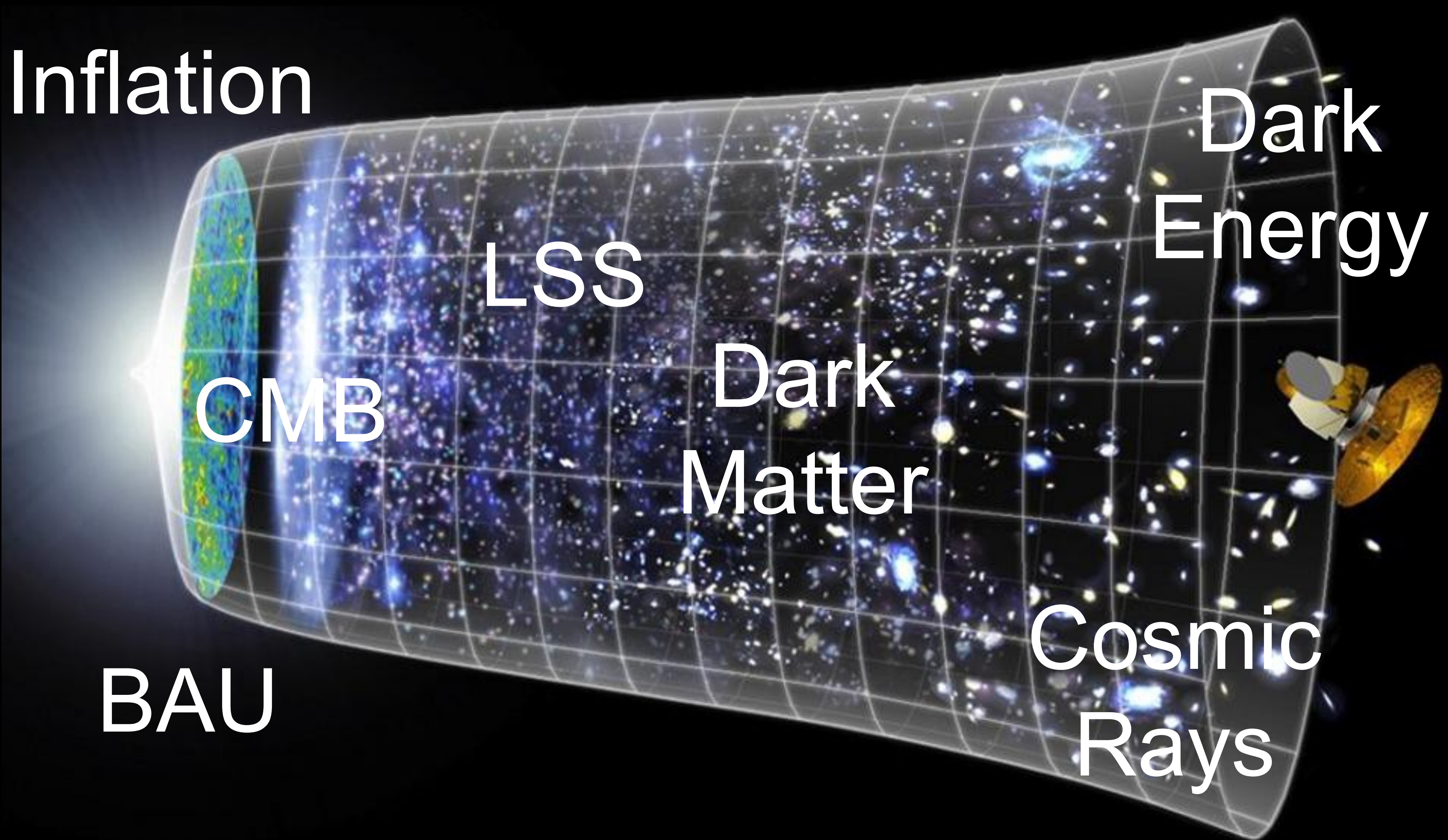


Conclusions

- Third Generation GW interferometers are inevitable. The question is when and where.

- The Science Case is very clear:
  - Fundamental Physics
  - Astrophysics
  - Cosmology

- How big is our community?
- Do we have the momentum?


Inflation
Dark
Energy
LSS
Dark
Matter
CMB
BAU
Cosmic
Rays