Einstein Telescope

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MTA Wigner RCP

Wigner VIRGO Group and MGGL

International Conference on Precision Physics and Fundamental Physical Constants
10.06.2019.

Content

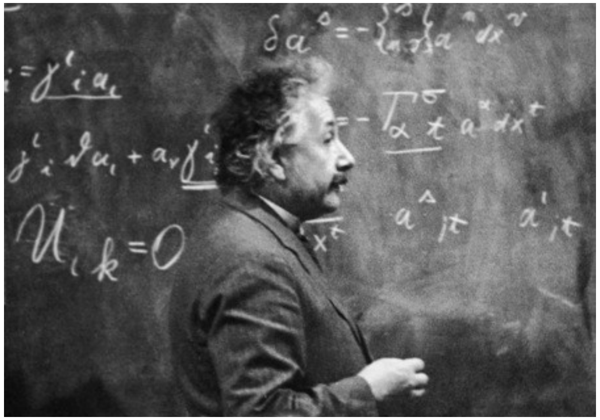
- 2g gravitational wave detectors

- 3g: Einstein Telescope (ET)

- New physics with ET

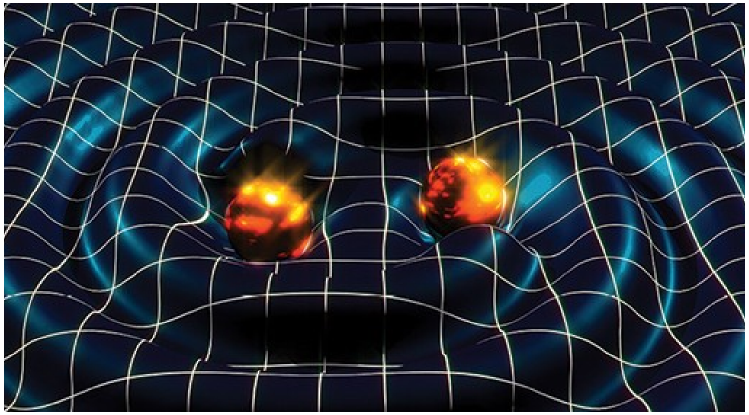
- Wigner group activities: site selection +

Ripples in spacetime



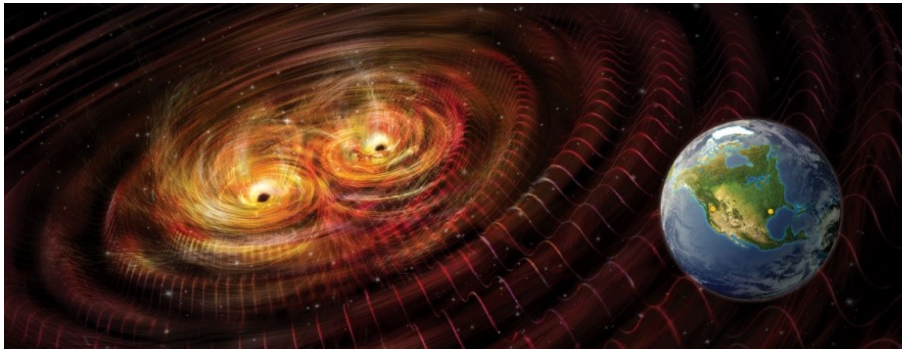
- General relativity, connects the curvature of spacetime with the matter content, its motion and properties

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$



- Gravitational waves, change of gravitational field, ripples of spacetime, propagating with the speed of light

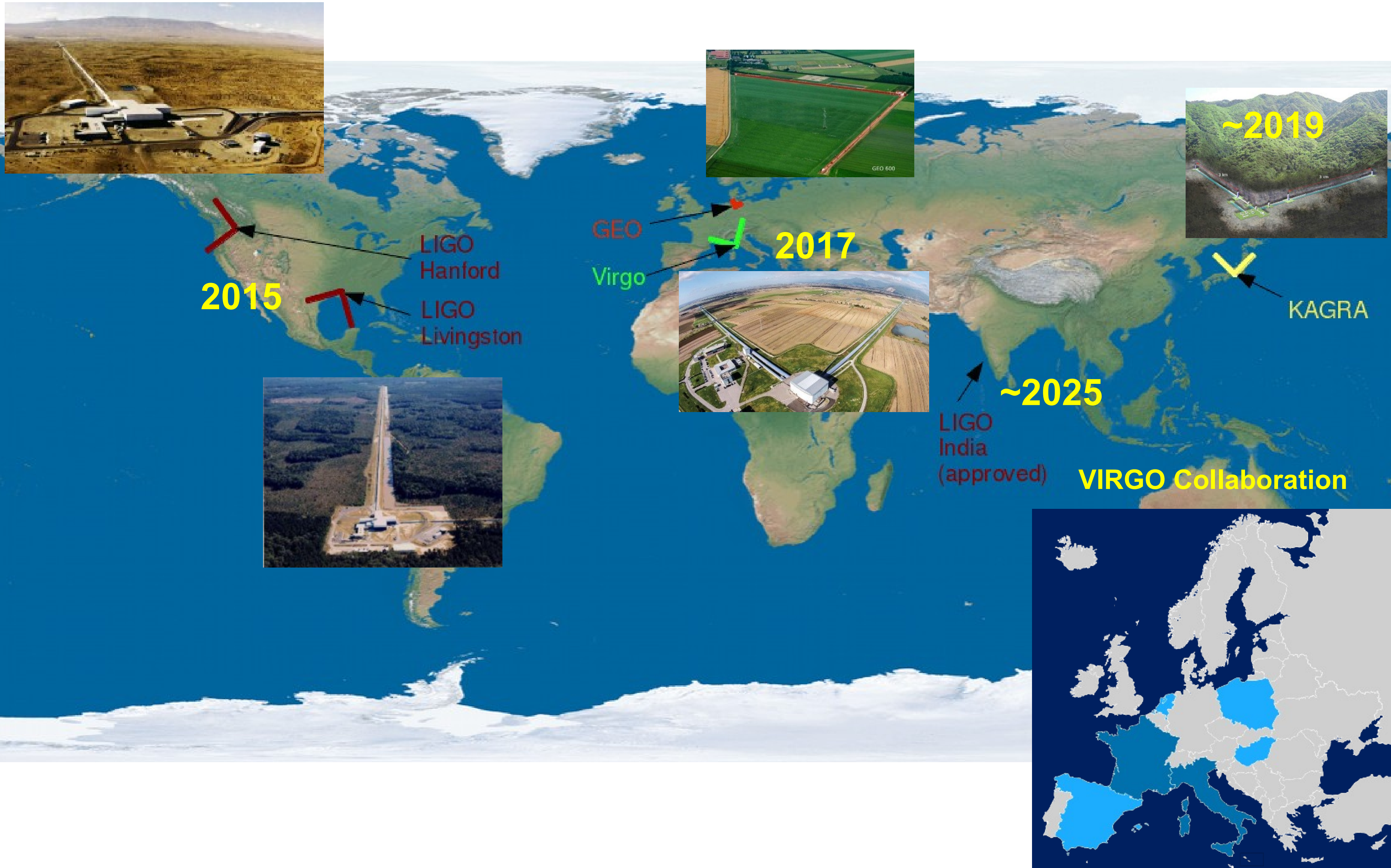
- Linear approximation, far from the source GWs are described as the perturbation of the flat metric



$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

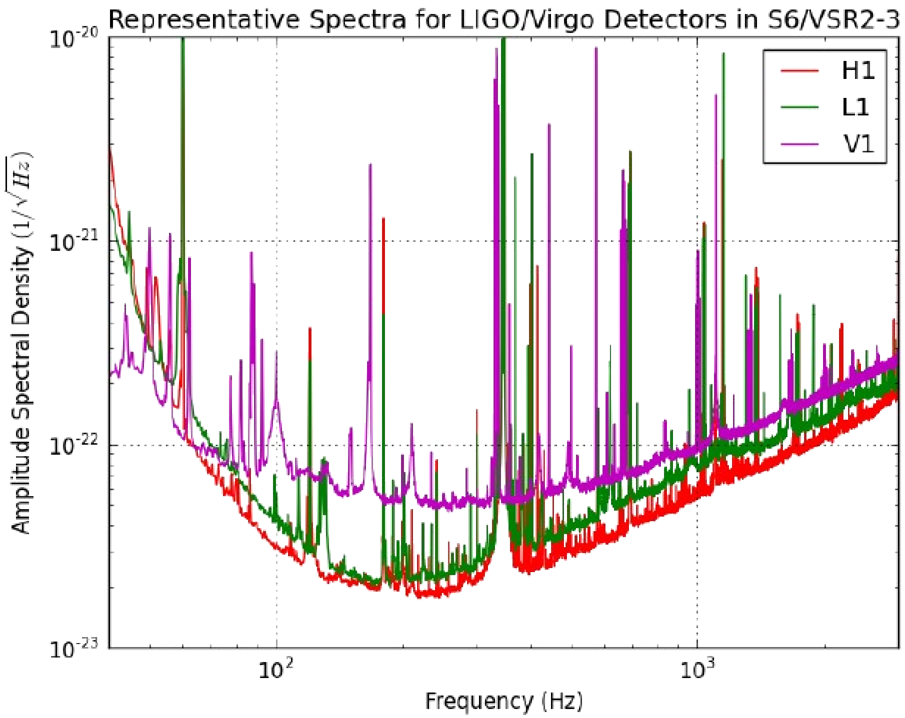
$$\eta^{\rho\sigma} h^{\mu\nu}{}_{,\rho\sigma} = -16\pi\tau^{\mu\nu}$$

2g detectors worldwide

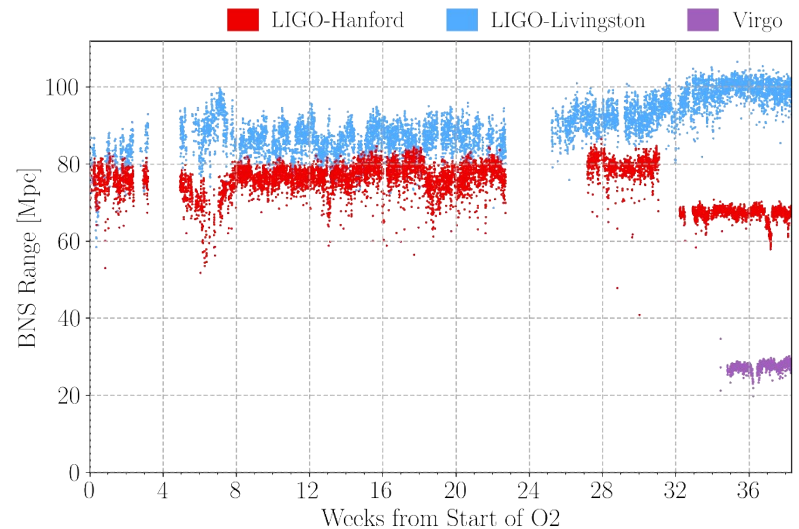


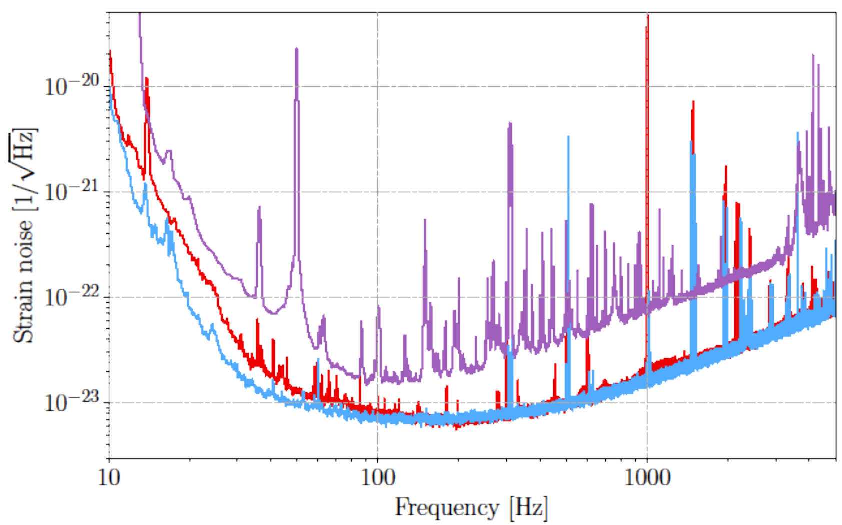
Sensitivity of GW detectors

- Sensitivity of first (2009 - 2010) and second (2017) generation detectors



Scientific Runs S1 – S6

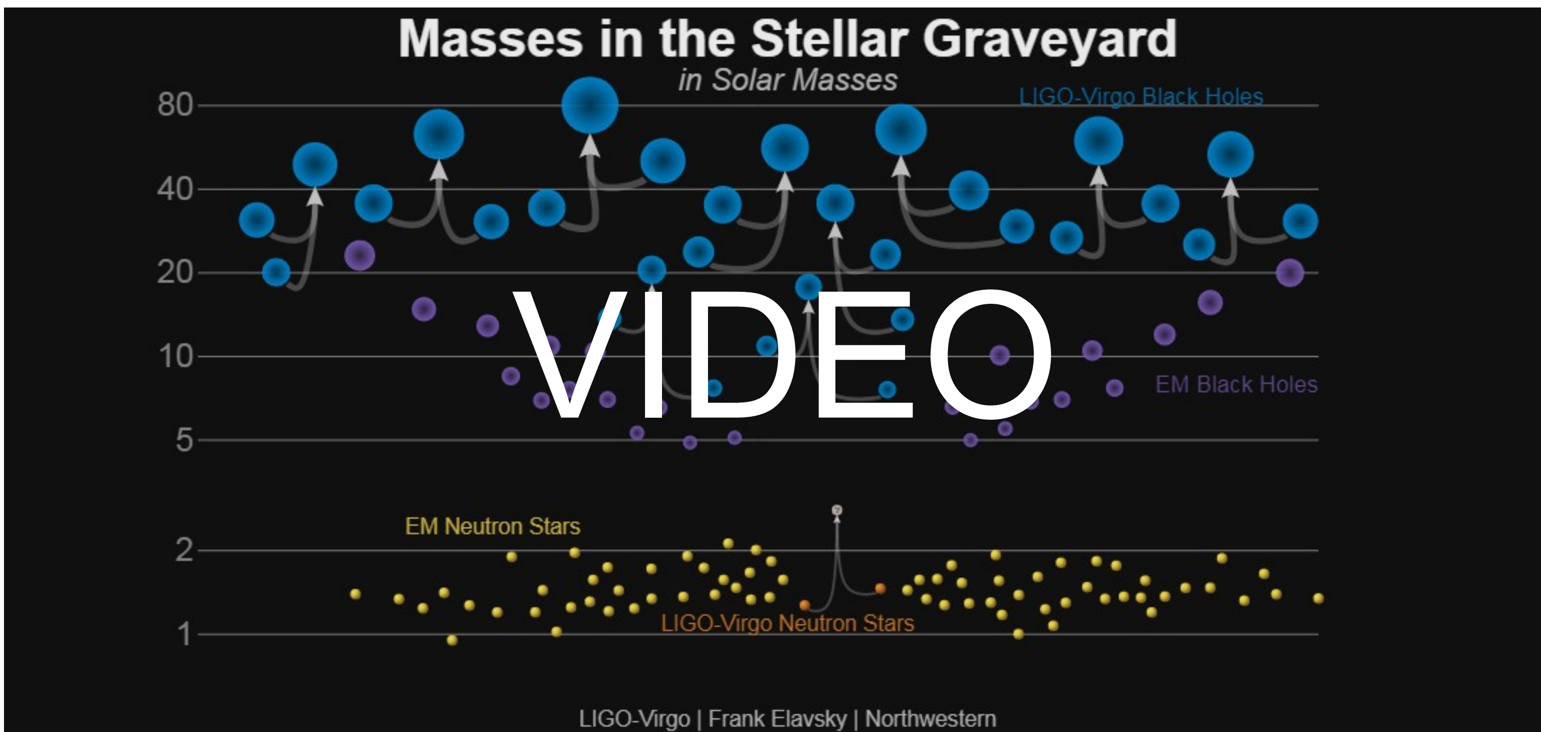




Observation Runs O1 – O2

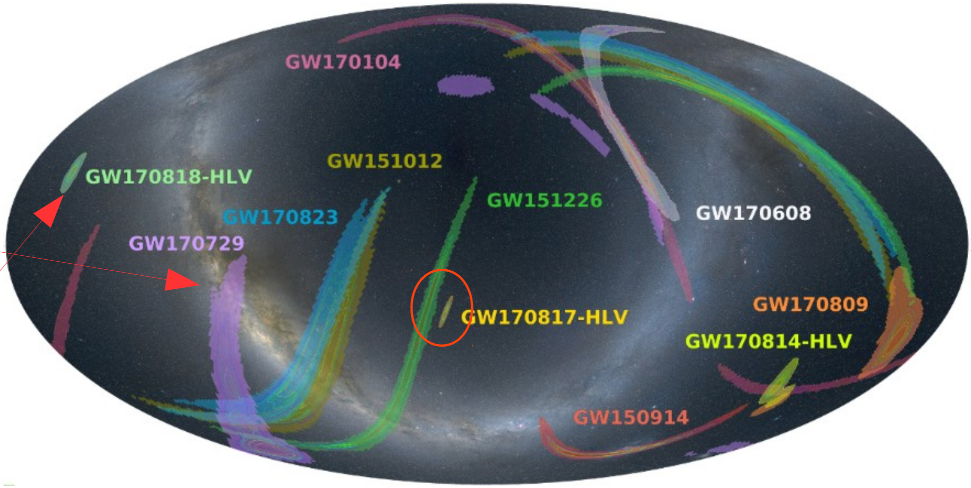
GW observations

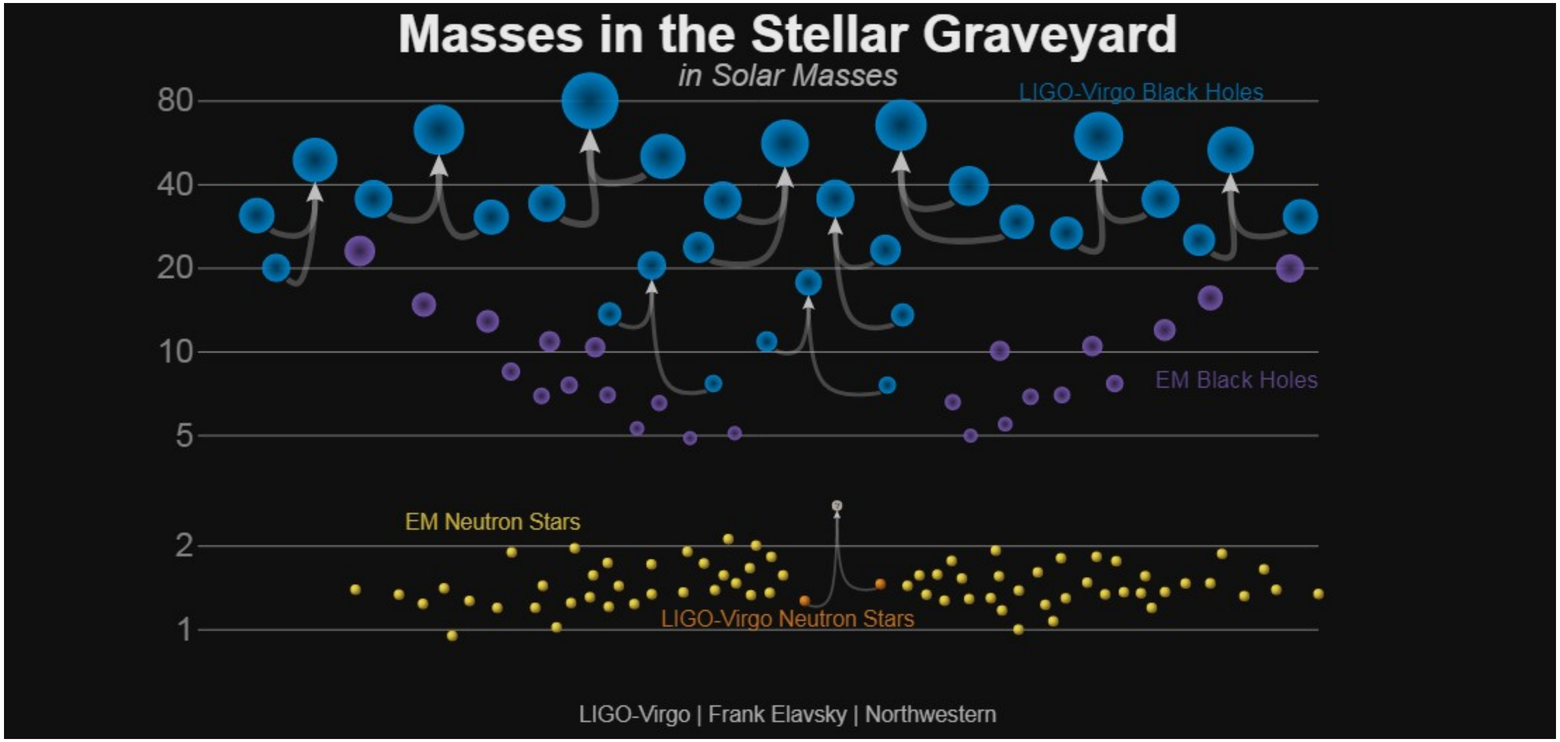
- 11 confident detections in O1 and O2, 1 BNS and 10 BBH, 11 marginal triggers
  - Total mass 18.6 – 85.1 $M_\odot$
  - Distance 40, 320 – 2750 Mpc
  - 1 detection / 15 days of data searched



GW observations

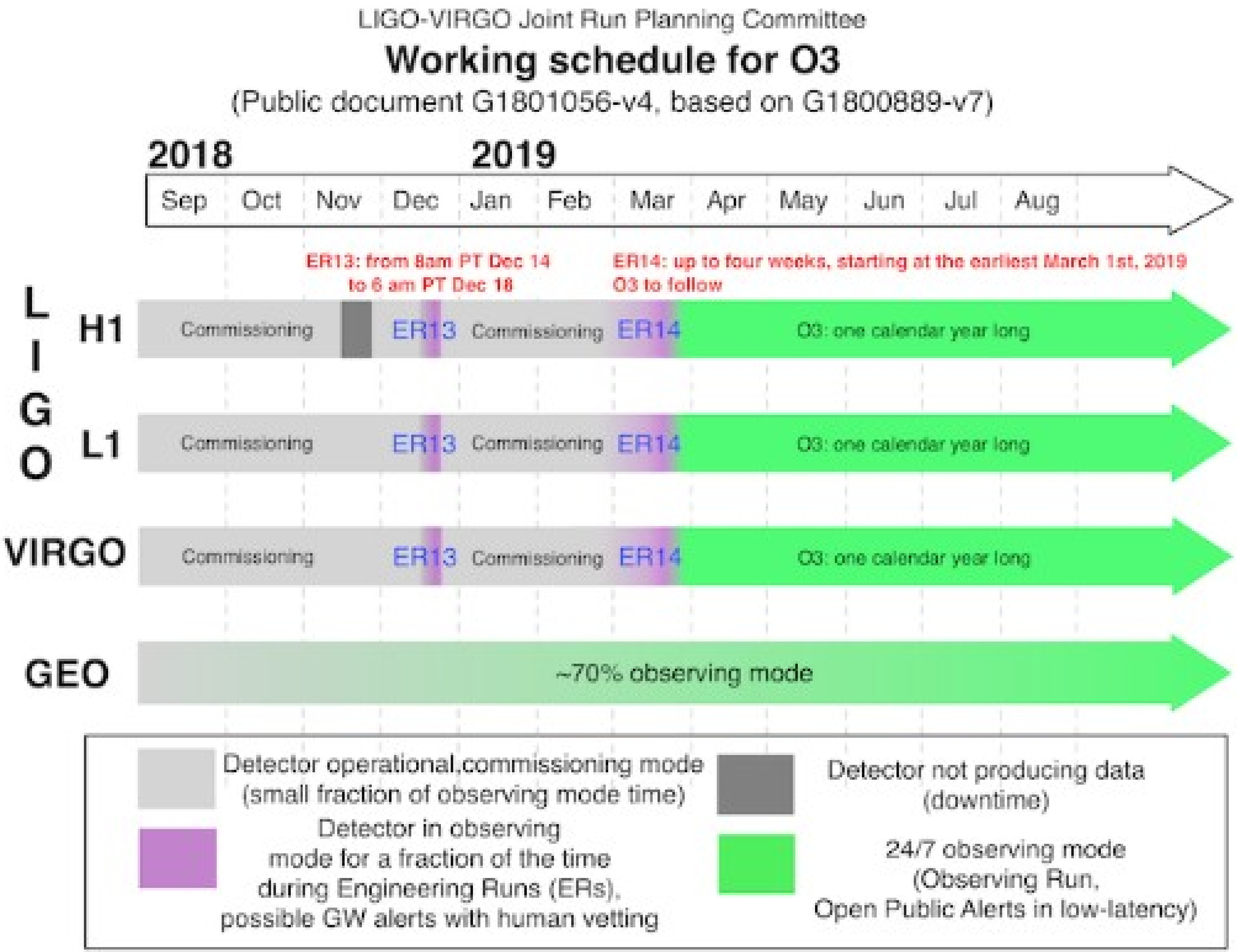
- GW170729 the most massive 80 $M_\odot$ and distant 1250 Mpc GW source
- GW170818 best localized 39 sq^2 BH source





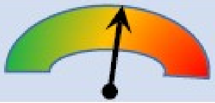
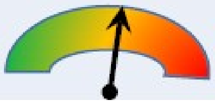
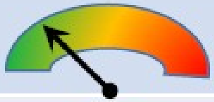
BH or a hypermassive NS

Observation plan



Observatories in the next 10 years

- Heterogeneous network of observatories
- Obsolescence / limits of the instruments
- Quest for new research infrastructures / more than a new detector

Continent	Detector	Obsolescence	Limits
America	LIGO H1		
	LIGO L1		
Europe	GEO600		
	Virgo		
Asia	KAGRA		
	LIGO India		

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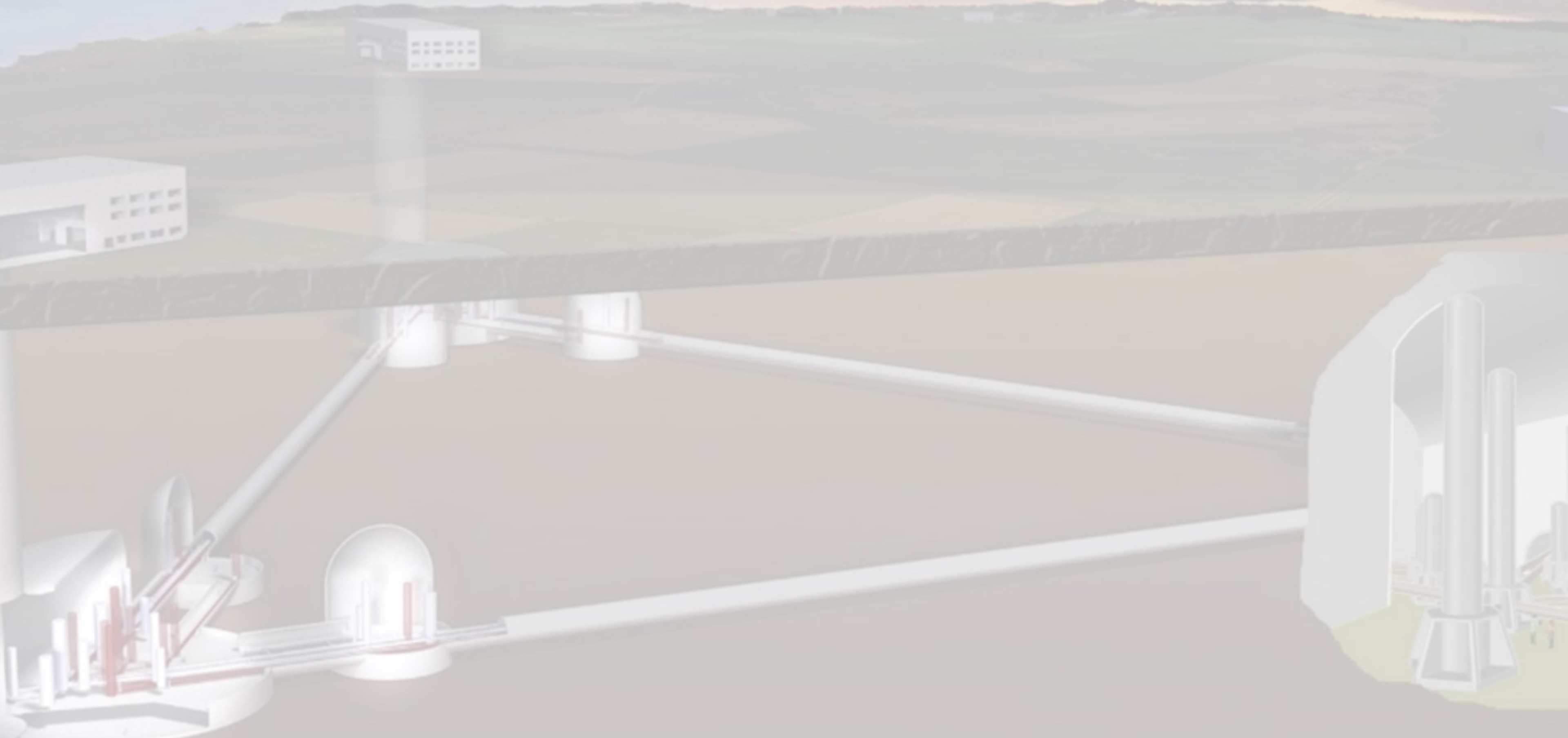
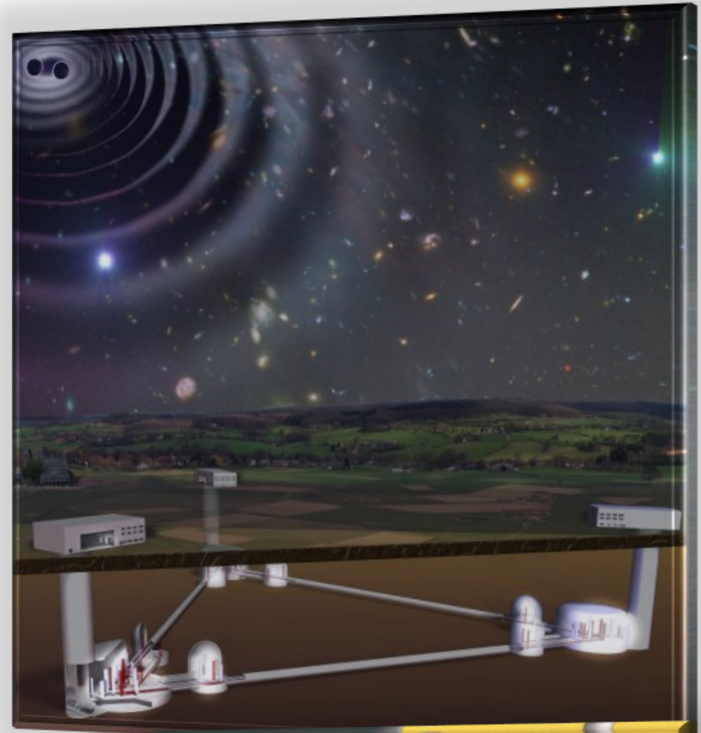
- 3g: Einstein Telescope (ET)

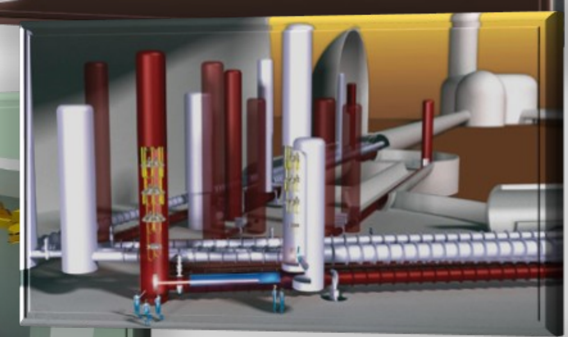


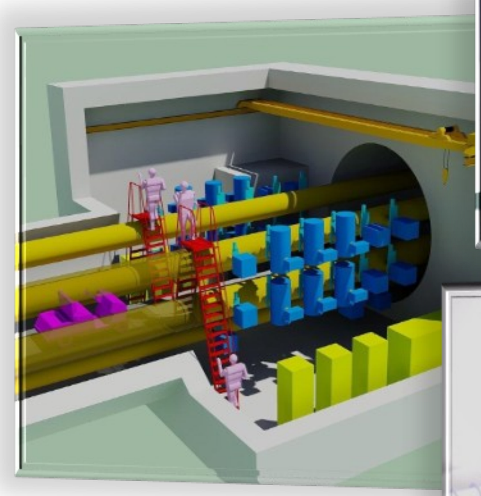
ET EINSTEIN TELESCOPE

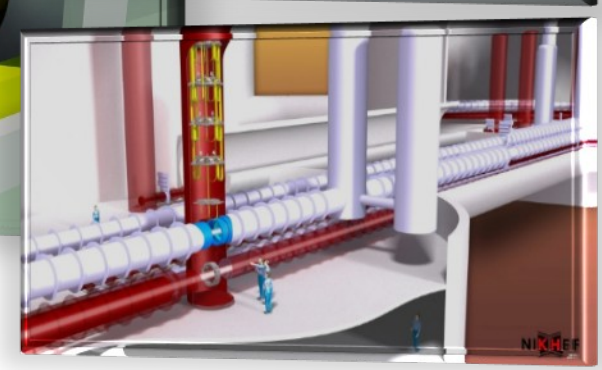
3G / ET

- Scientific relevance in Europe
- 3G new observatory / infrastructure ET
- 10x better sensitivity compared to 2G (1000x more BH observations)
- Wide frequency, special attention to low frequency
- Capable to work alone
  - Localization capability
  - Polarizations
  - High duty cycle / redundancy
- 50 years lifetime





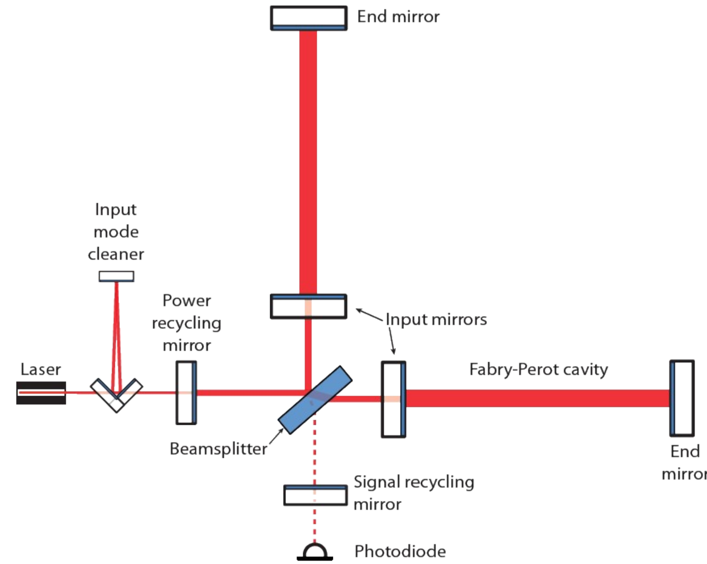




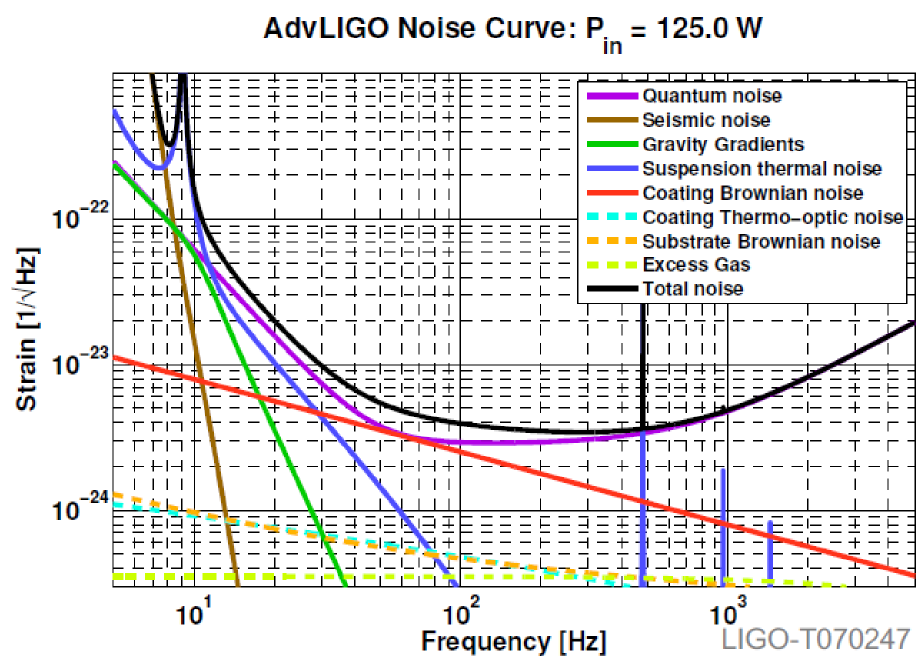
www.et-gw.eu

Evolution of interferometers

- 2nd generation, VIRGO, LIGO
  - Dark fringe operation
  - Power recycling
  - Fabry-Perot arm cavities
  - Input mode cleaning
  - Signal recycling
  - Squeezed light
  - Suspension systems (passive, active)

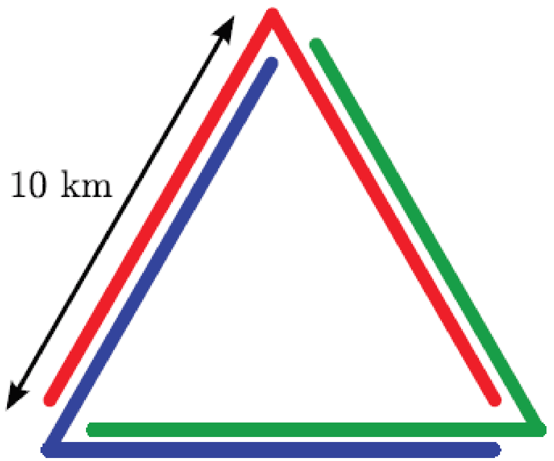


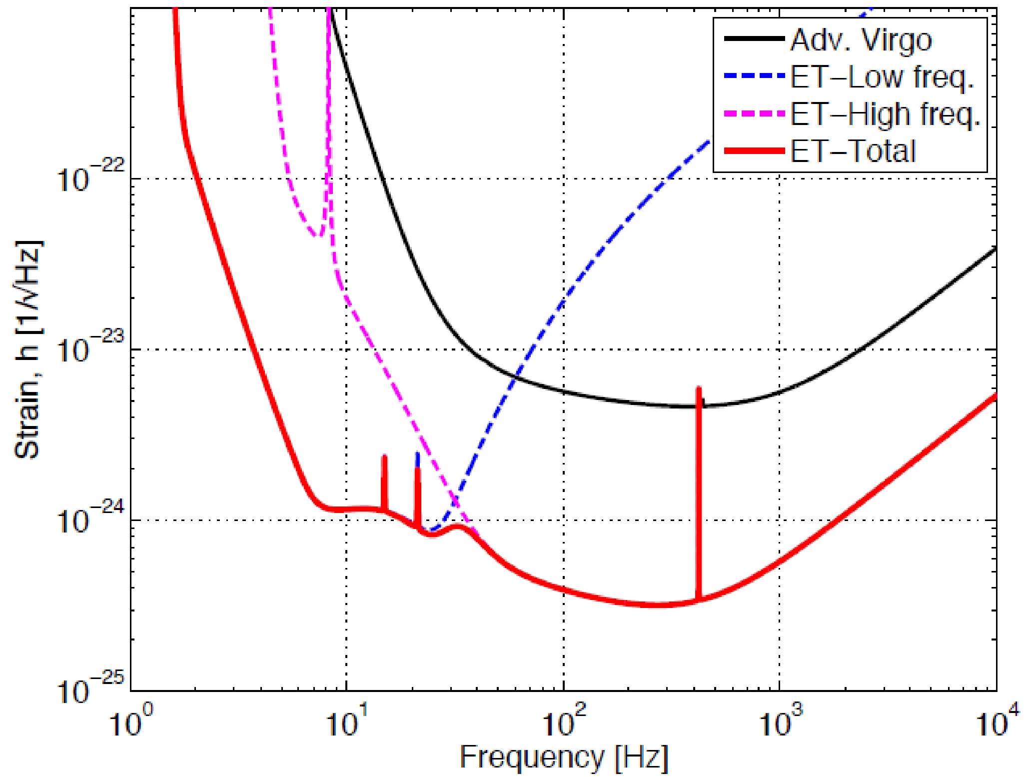
- 3rd generation, e.g. ET, 10 x sensitivity improvement Design Study 2011
  - Larger laser, 125 W → 500 W
  - Bigger mirrors, 30 kg → 210 kg
  - Longer arm, 3,4 km → 10 km
  - Cooling, 290 K → 20 K
  - Underground operation



Standalone observatory

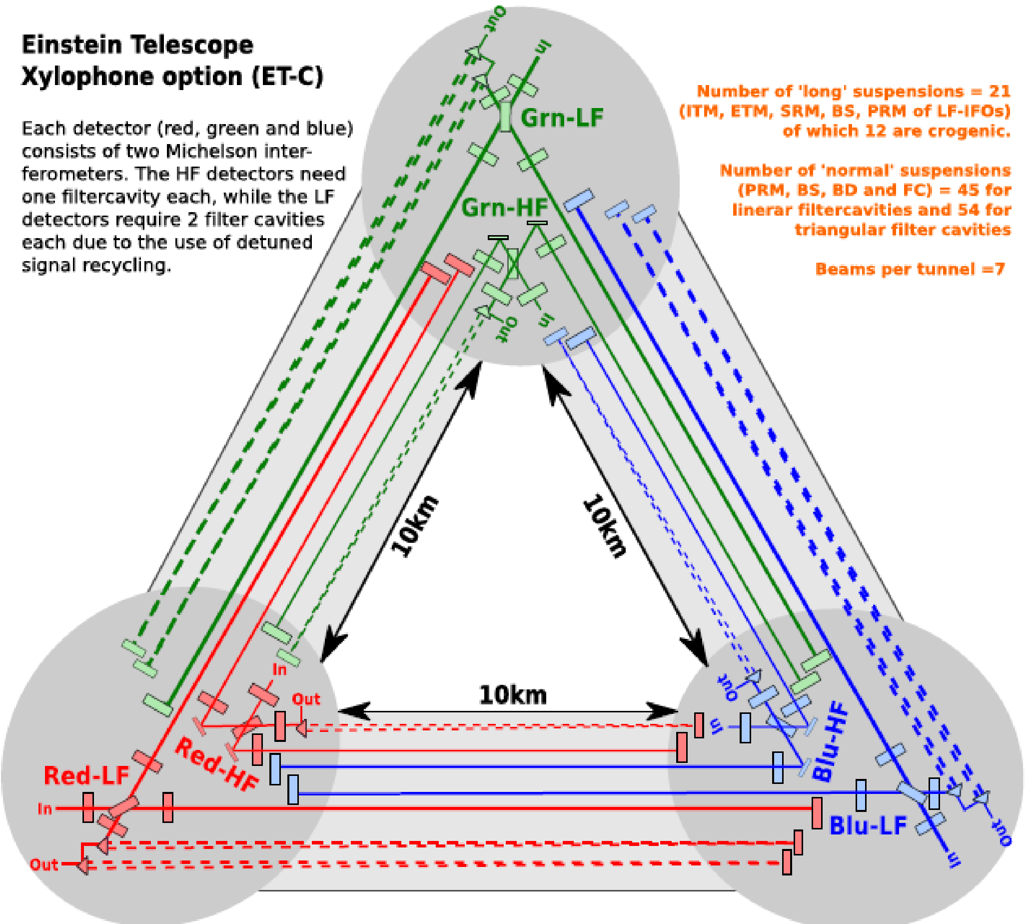
- Improving at low and high frequencies with a single detector
- LF: cold mirrors ↔ HF: more laser power
- Split the detection band with 2 specialized instruments





Standalone observatory

- Start with a single – xylophone – detector
- Add a second one to resolve polarization
- Add a 3rd one for null stream and redundancy



ET timeline

ET project roadmap (APPEC):

- 2018-19 formation of ET collaboration (LoI signatures, ...)
- 2019-20 ESFRI (European Strategy Forum on Research Infrastructures)
  roadmap proposal (WG telecon).
  - Site selection parameters (Italy, ~~Hungary~~, The Netherlands)
  - Several options xylophone vs. L shape: Cosmic Explorer, ~~LIGO Voyager~~
- 2022 Site selection (technical and political)
- 2023 Full technical design report. Here the design options are frozen.
- Cost definition
- 2025 Infrastructure realization (excavation, etc..)
- 2030-31 end of infrastructure construction, beginning of installation
- 2032+ installation, comissioning, operation

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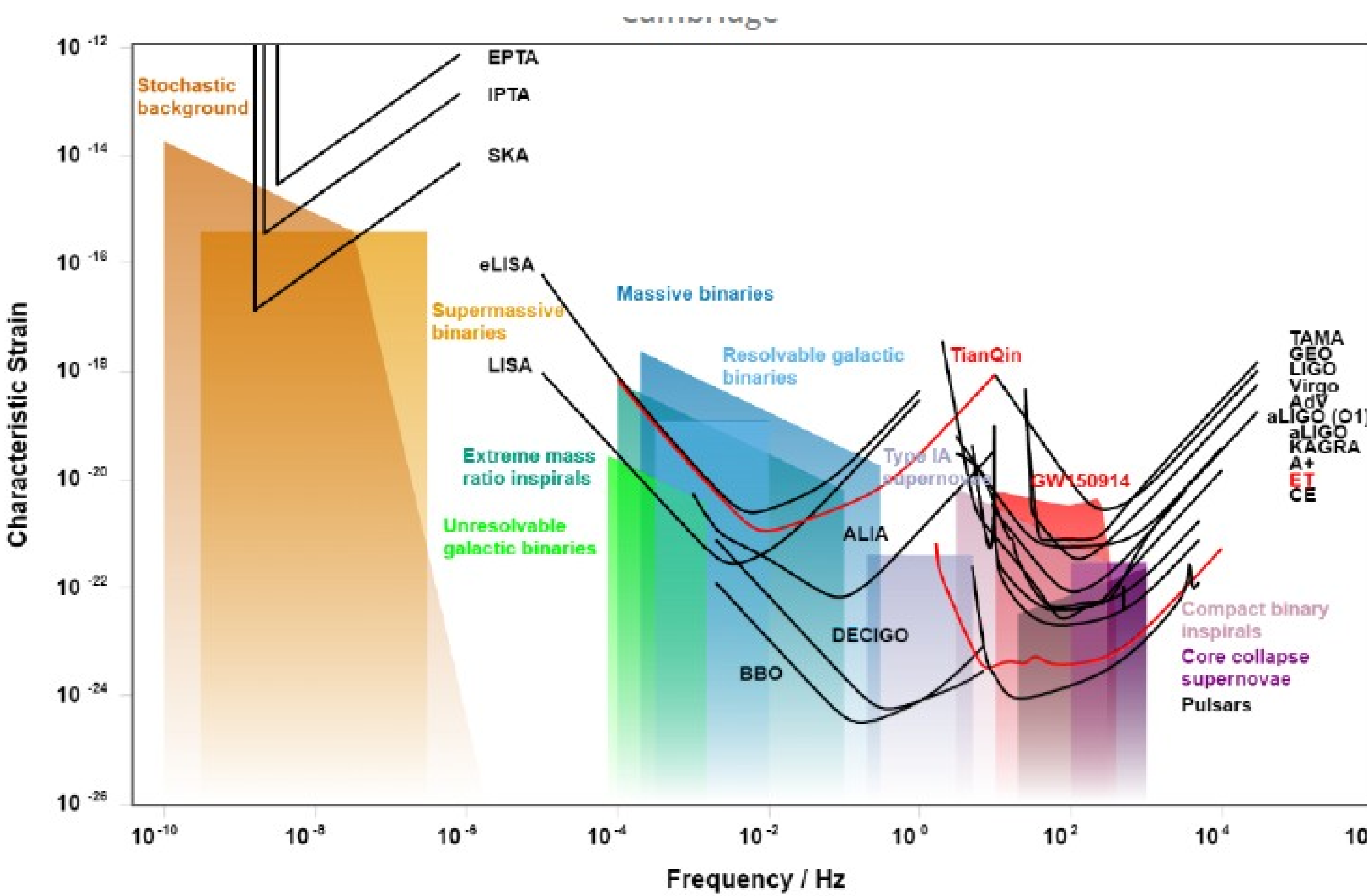
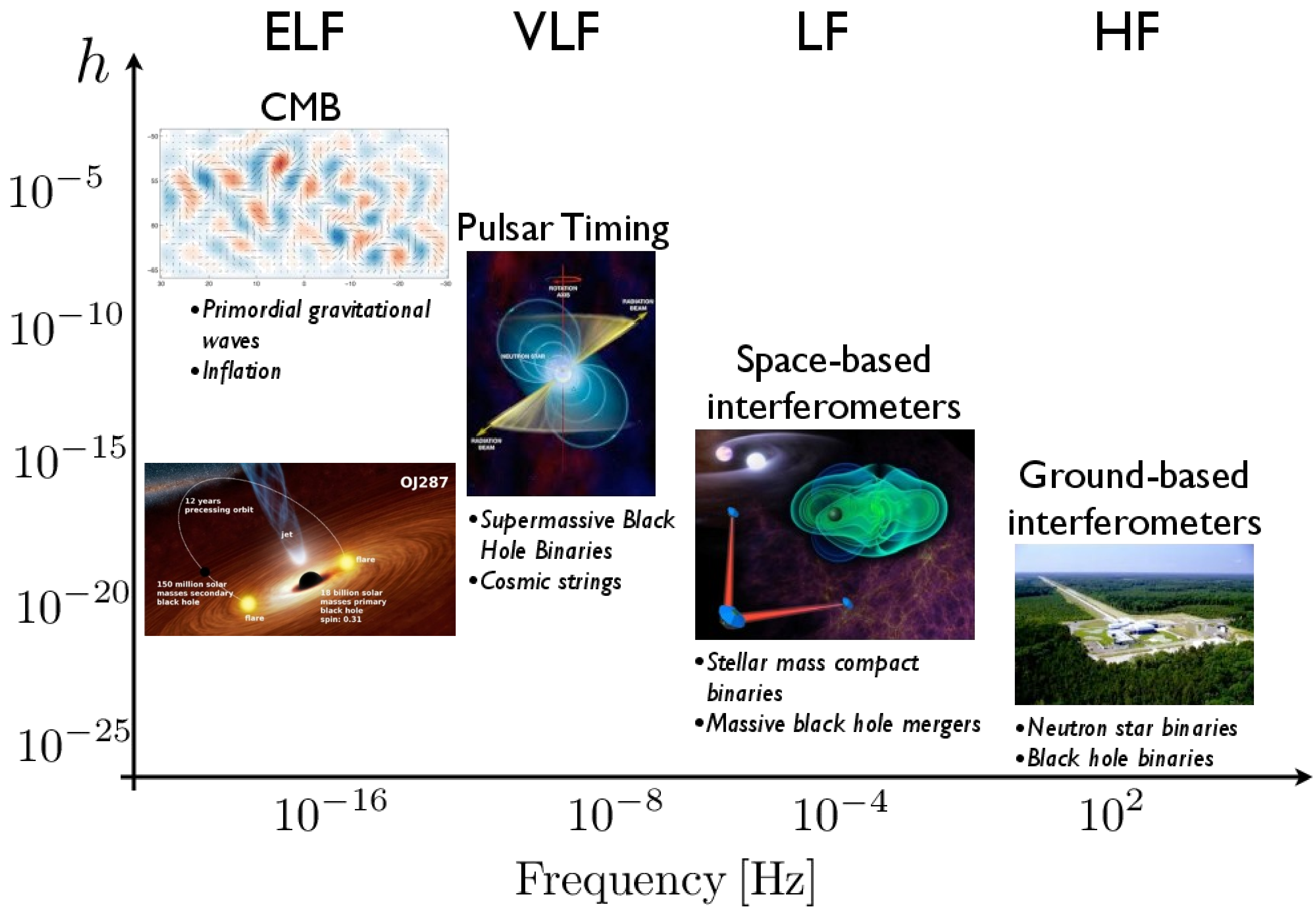
- New physics with ET

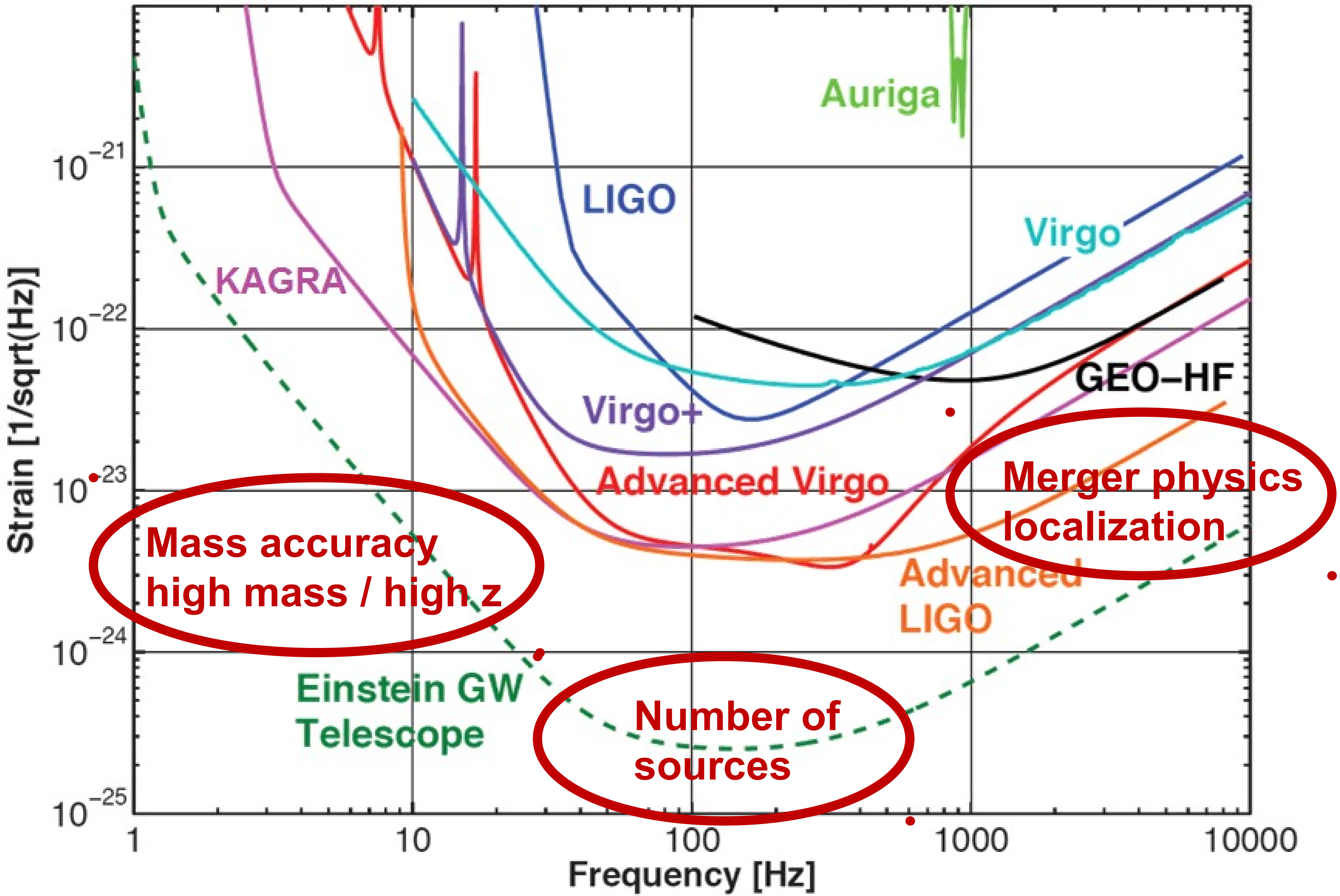


Characteristic Strain
Frequency / Hz
Stochastic background
EPTA
IPTA
SKA
eLISA
LISA
Supermassive binaries
Massive binaries
Resolvable galactic binaries
Extreme mass ratio inspirals
Unresolvable galactic binaries
TianQin
Type IA supernovae
GW150914
ALIA
DECIGO
BBO
TAMA
GEO
LIGO
Virgo
AdV
aLIGO (O1)
aLIGO
KAGRA
A+
ET
CE
Compact binary inspirals
Core collapse supernovae
Pulsars

GW / multi-messenger astronomy



Sensitivity improvement



Questions addressed by GWs

- Fundamental questions in Gravity:
  - New/further tests of GR
  - Exploration of possible alternative theories of Gravity
  - How to disprove that Nature black holes are black holes in GR (e.g. non tensorial radiation, quasi normal modes inconsistency, absence of horizon, echoes, tidal deformability, spin/induced multipoles
- Fundamental questions in particle physics

  Axions and ultralight particle through the evaluation of hte consequences of new interactions, their impact on two bodies mechanics, in population characteristics, of Bhs, Nss
- EOS of neutron stars
- GW models in alternative theories of gravitation
- Te population of compact objects discovered by GWs is the same measured by EM? Selection effects on BHs and NSs?
- Explosion mechanisms in Supernovae?
- History of supermassive black holes?
- GW stochastic background? Probing the big bang?
- Multimessenger astronomy in 3G?

Questions addressed by GWs

- Fundamental questions in Gravity: **HEPP: dark matter, energy**
  - New/further tests of GR
  - Exploration of possible alternative theories of Gravity
  - How to disprove that Nature black holes are black holes in GR (e.g. non tensorial radiation, quasi normal modes inconsistency, absence of horizon, echoes, tidal deformability, spin/induced multipoles

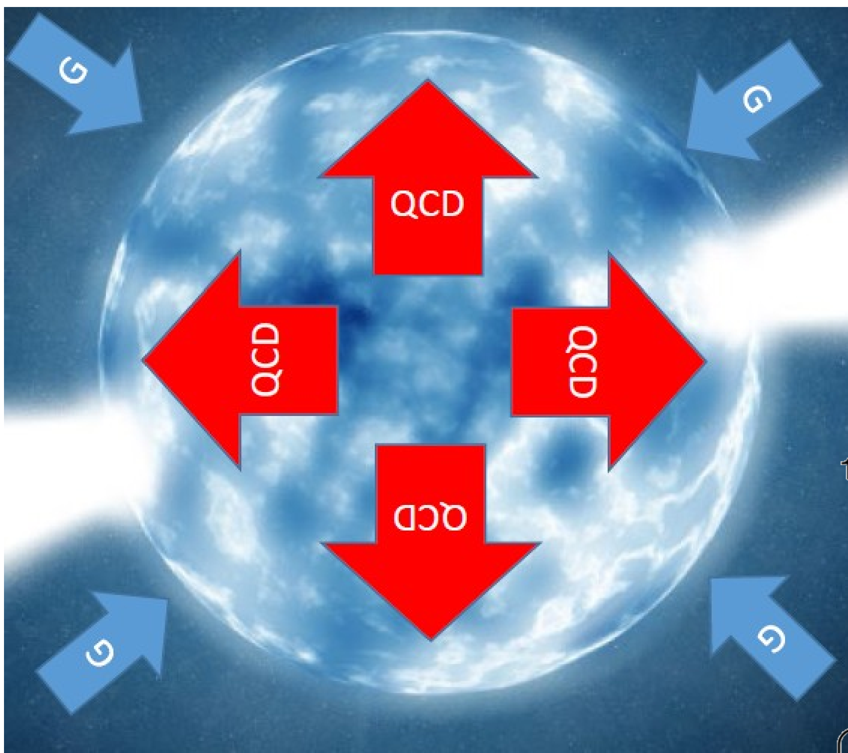
- Fundamental questions in particle physics **HEPP: dark matter, inflation, 5th forces**

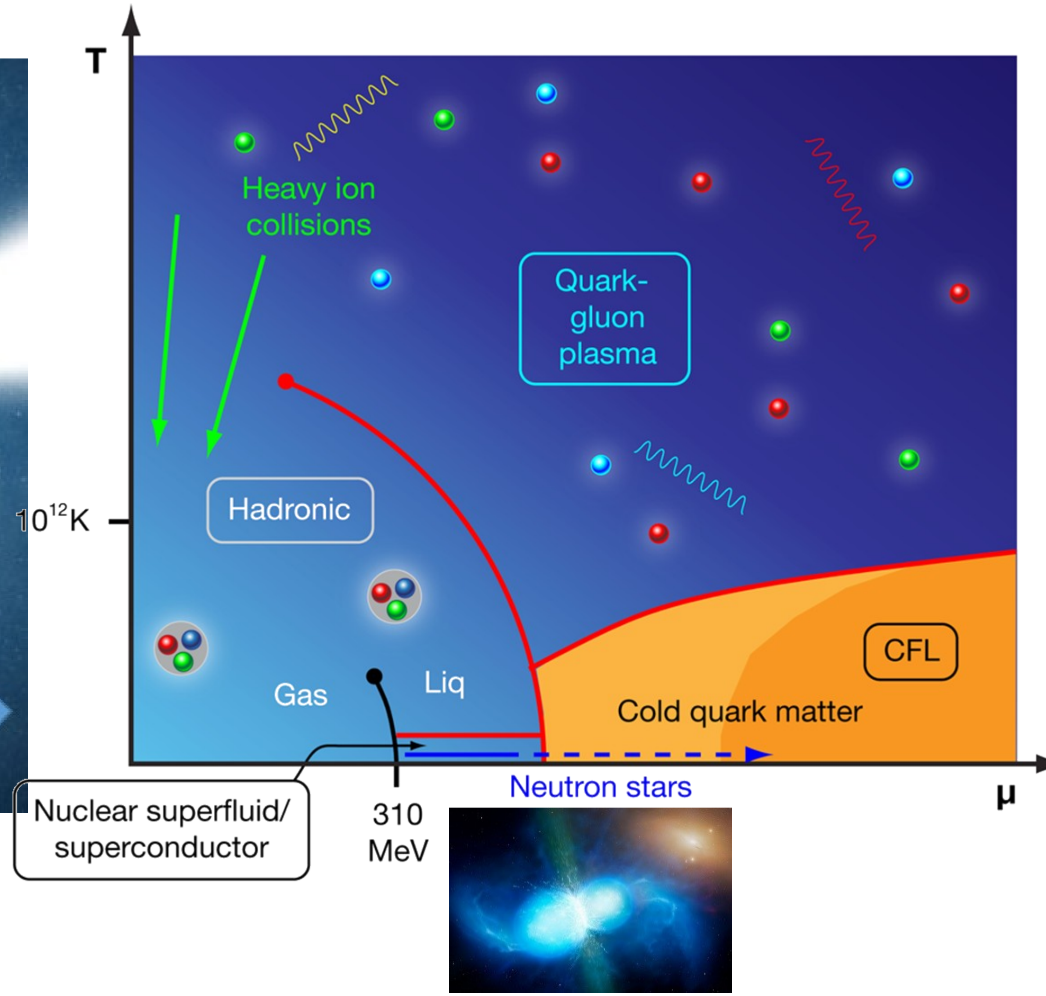
  Axions and ultralight particle through the evaluation of the consequences of new interactions, their impact on two bodies mechanics, in population characteristics, of Bhs, Nss

- EOS of neutron stars **HEPP: nuclear physics, QGP**
- GW models in alternative theories of gravitation
- Te population of compact objects discovered by GWs is the same measured by EM? Selection effects on BHs and NSs?
- Explosion mechanisms in Supernovae? **HEPP: astrophysics**
- History of supermassive black holes?
- GW stochastic background? Probing the big bang? **HEPP: cosmology**
- Multimessenger astronomy in 3G?

Neutron Stars

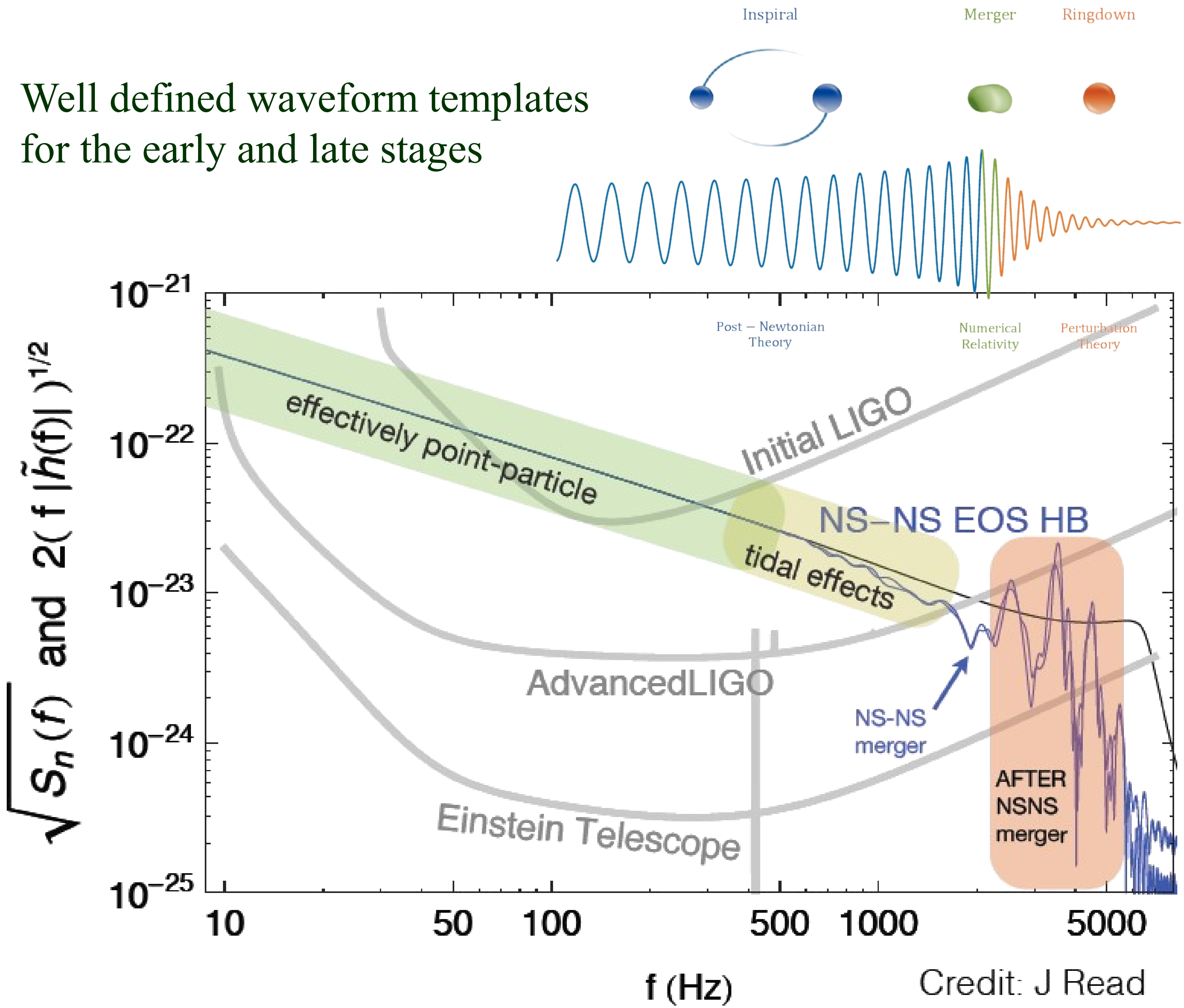
- Neutron stars are extreme labs for nuclear physics
- EOS and tidal deformability / Love number





Binary coalescences

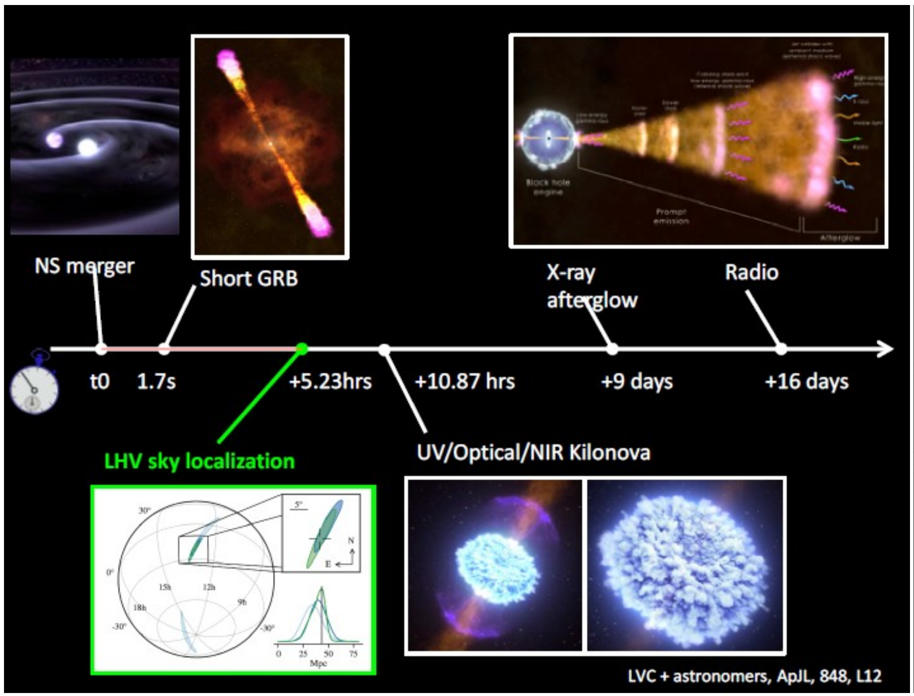
- Well defined waveform templates for the early and late stages

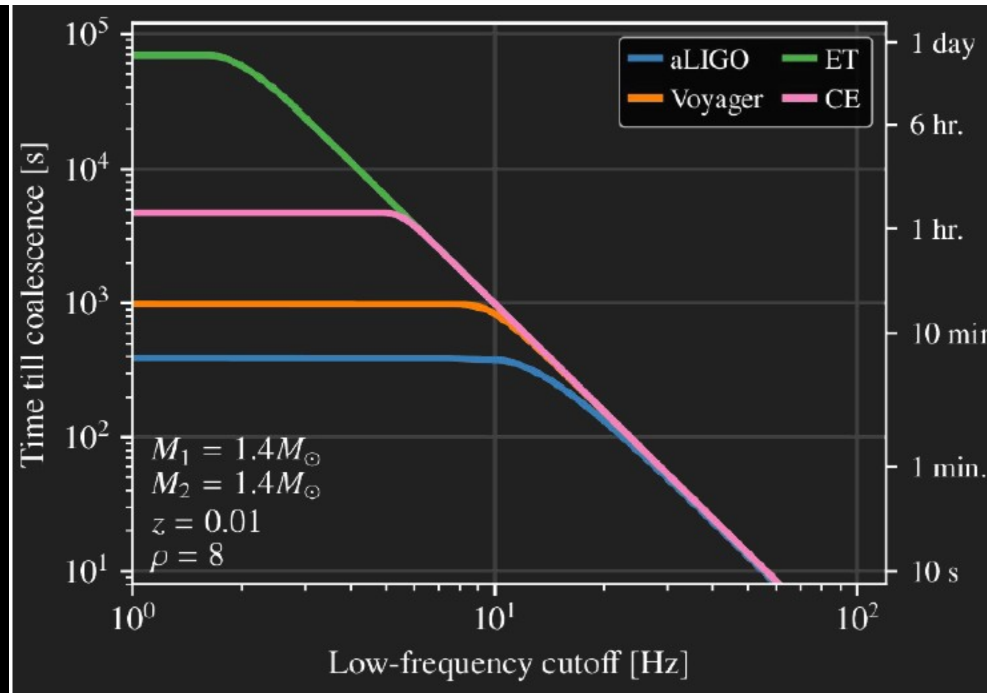


Credit: J Read

Low frequency – multi-messenger astronomy

- GWs are the only messengers to bring information before coalescence
- Early warning of EM observatories
- Low frequency sensitivity is a key factor

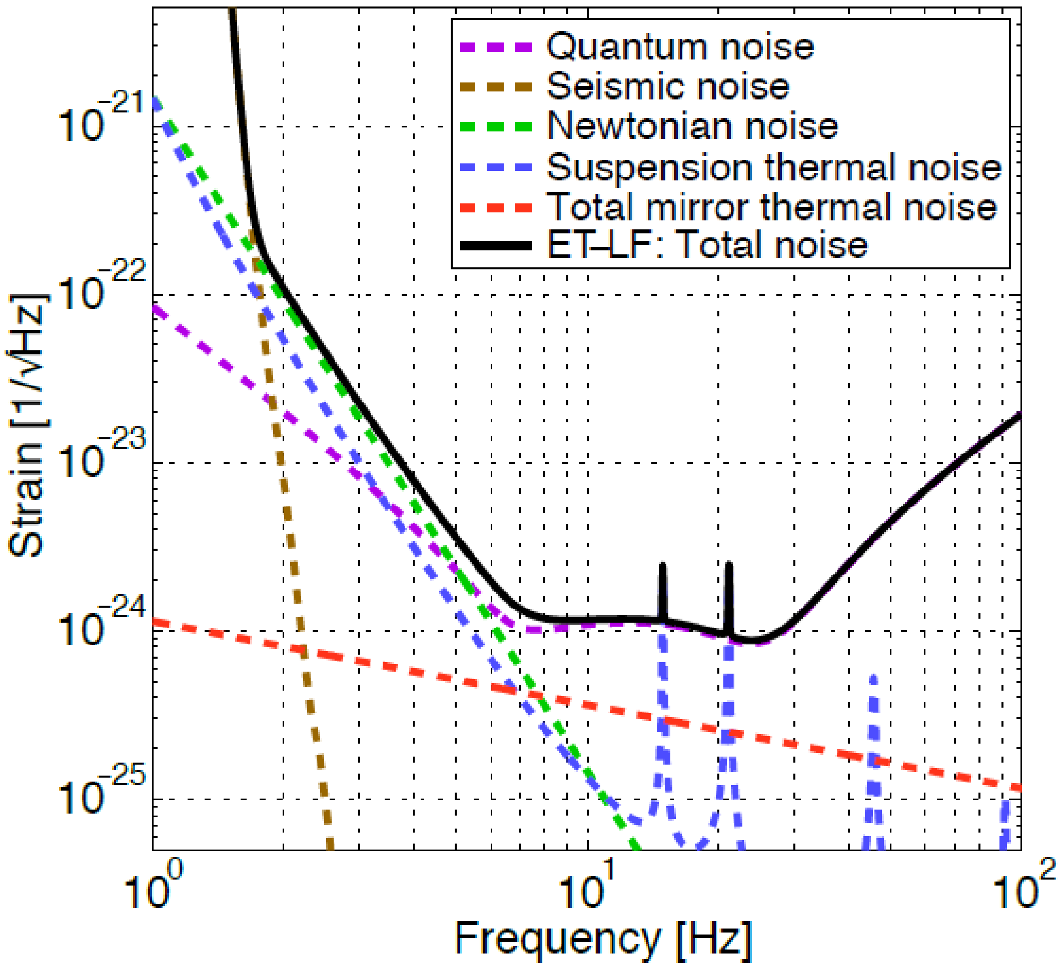




- Wigner group activities:
  - wave forms, pn calculations
  - site selection
  - Newtonian noise, material models
  - Eötvös balance

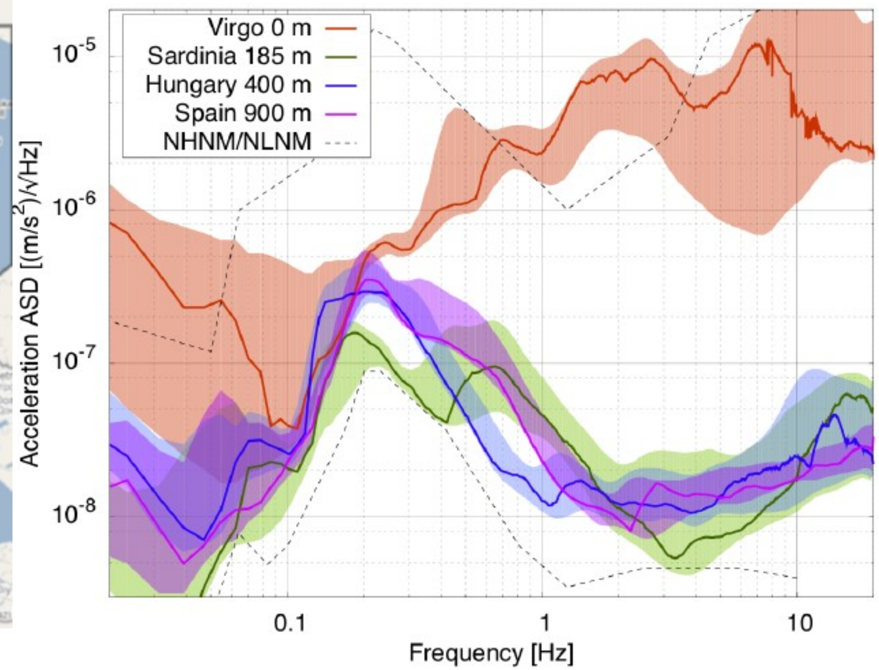
Low frequencies: seismic and Newtonian noise

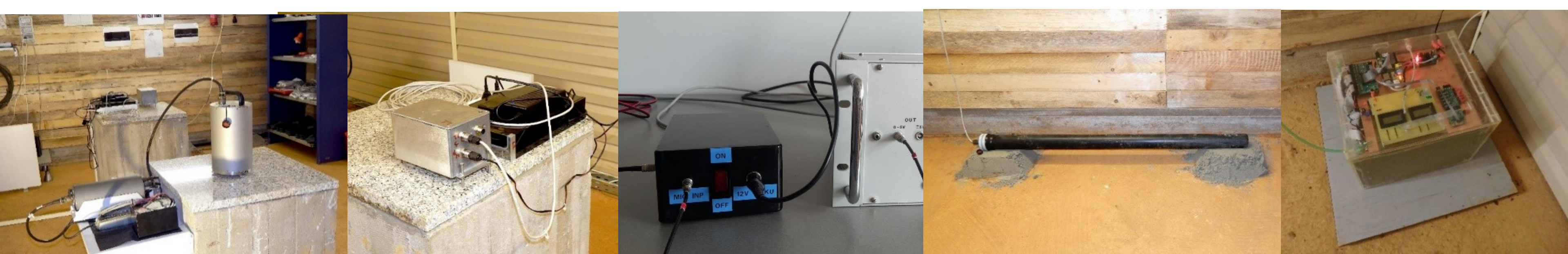
Active damping for newtonian noise and for seismic below 4 Hz
Maximum passive damping: 10 Hz, 10^{15}x



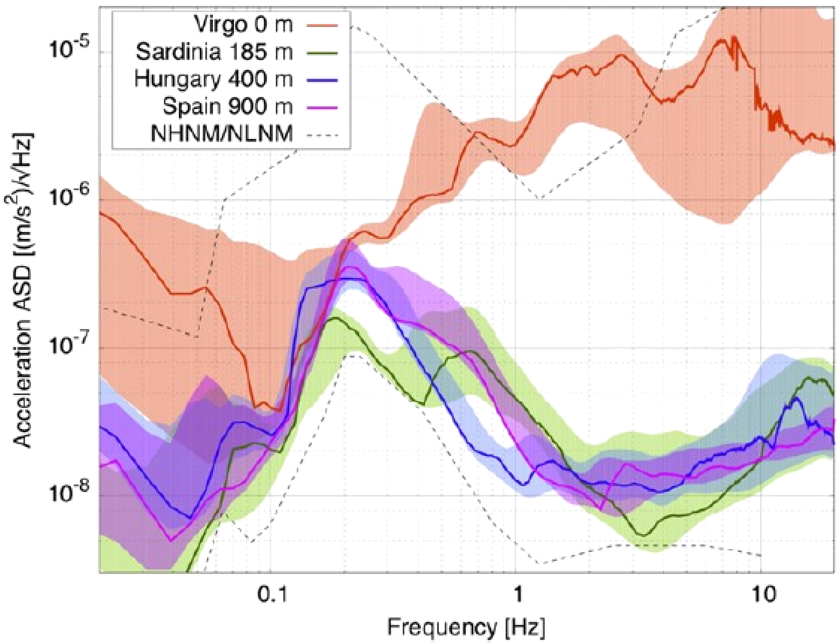
ET site selection

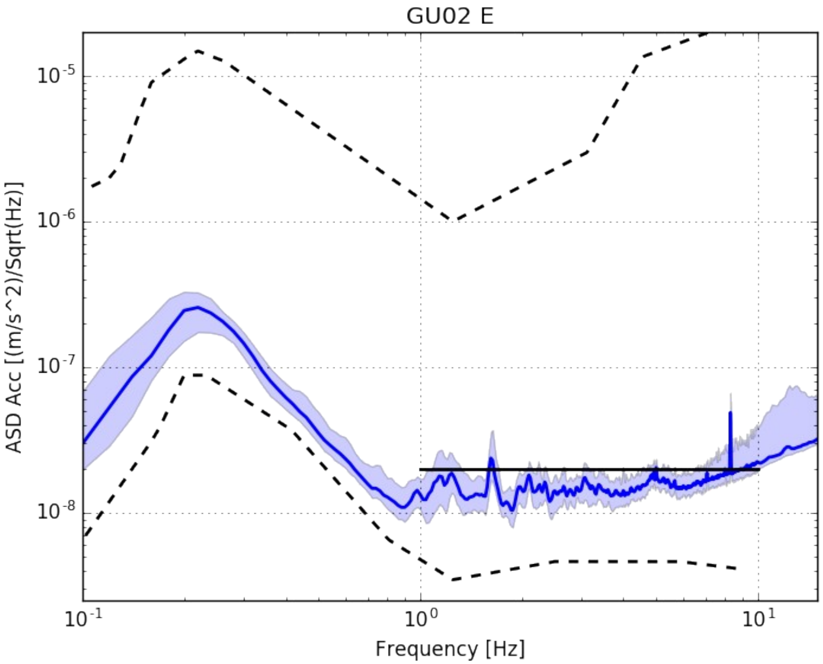
- European effort, 3 candidates based on original studies
- Long-term measurements: Mátra Gravitational and Geophysical Laboratory





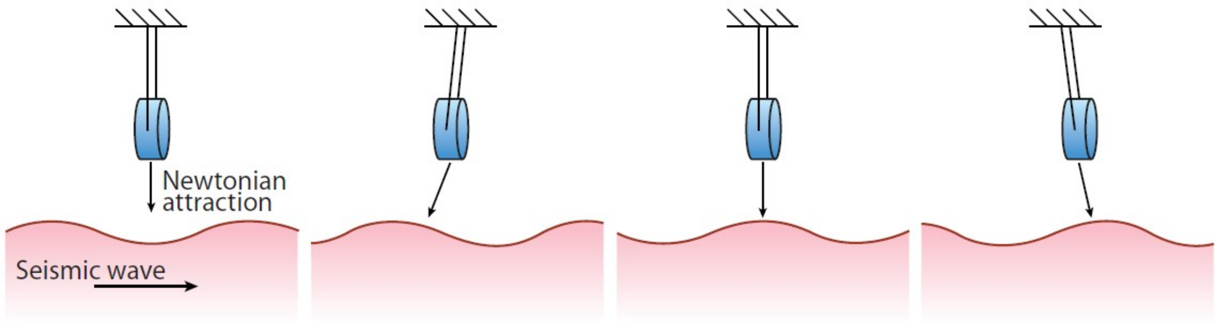
Optimal noise level





- Left: Baker et.al. (2015), short term, Right: Somlai et.al. (2018), 2 weeks
- Plotted: Acceleration ASD, 10 – 90 percentiles (stripe), and the mode (line)
- Cumulative characteristics, rms_{2Hz}
  - Beker et.al. (2011): 0.082 nm (5 days)
  - Somlai et.al. (2018): 0.083 nm (2 weeks)

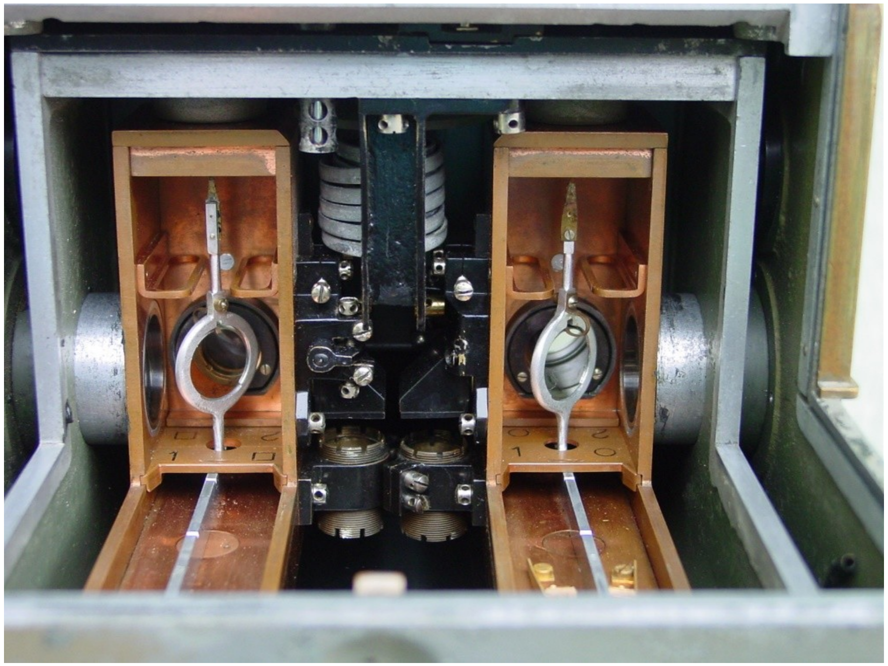
Newtonian noise



What is a rock?

What is a rock?

Jánossy Underground Physical Laboratory Eötvös balance measurements



- MTA Wigner RCP and BME
- Aim: Eötvös year, weak equivalence principle, <u>Newtonian noise</u>

„….still we are very much aware that the observations presented here were not made under the most favorable conditions, also, they are not the best that we believe are achievable with our instrument. But: „Ars longa vita brevis” - we have to content ourselves with having made a step forward.”

Handwritten draft of Roland Eötvös, 1909. (to be published)

Orosz István:
Eötvös Loránd

Thank you for your attention!

Eötvös Loránd

1848 – 1919

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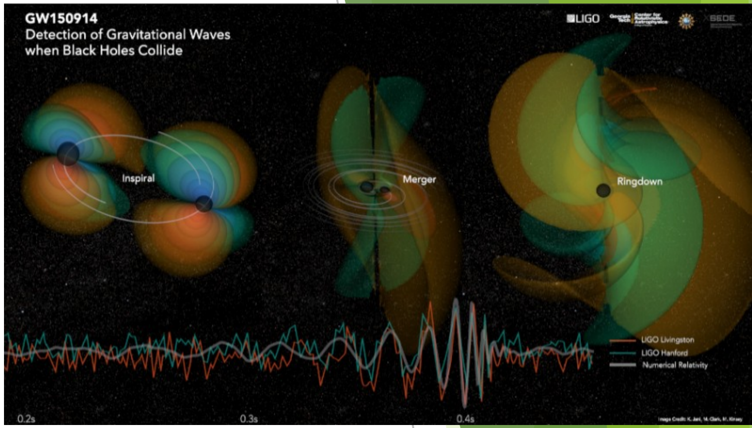
United Nations
Educational, Scientific and
Cultural Organization

Egyesült Nemzetek
Nevelésügyi, Tudományos és
Kulturális Szervezete

100th anniversary of Roland Eötvös (1848-1919), physicist, geophysicist, and innovator of higher education
Commemorated in association with UNESCO

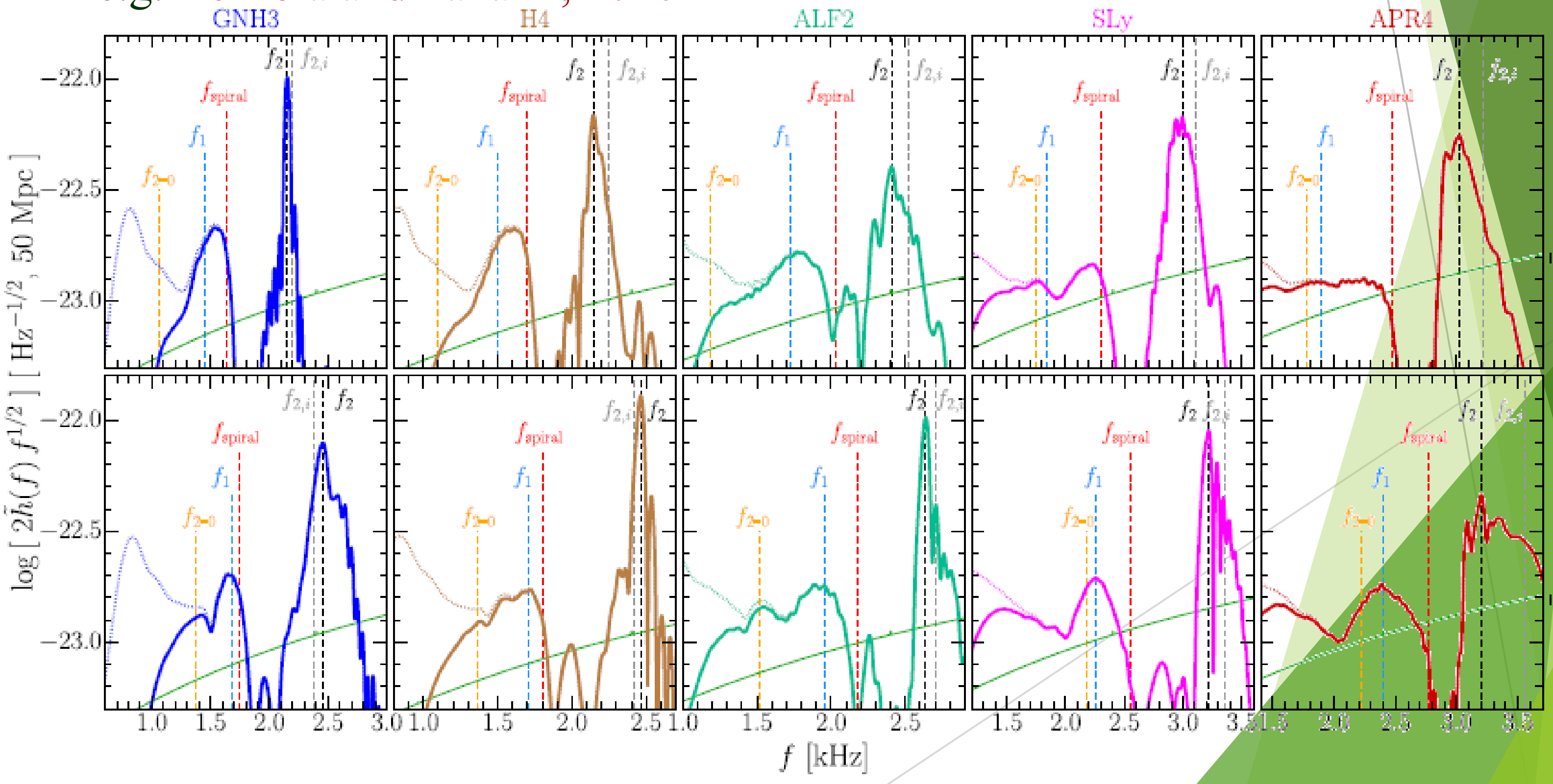
Eötvös Loránd (1848-1919) fizikus, geofizikus és a felsőoktatás megújítójának 100. évfordulója
Az UNESCO-val közösen emlékezve

Waveforms



- Numerical evolution
  e.g. LORENE, KADATH

- GR and hydrodynamics
  e.g. Rezzola and Takami, 2016



Waveforms

Favata, 2014

- Stationary Phase Approximation

$$\tilde{h}_{\rm T}(f) = \mathcal{A} f^{-7/6} e^{i\Psi_{\rm T}(f)}$$

- GW phase

$$\Psi_{\rm T}(f) = \phi_c + 2\pi f t_c + \frac{3}{128\eta v^5}\Big(\Delta\Psi^{\rm pp}_{\rm 3.5PN} + \Delta\Psi^{\rm spin}_{\rm 3PN} + \Delta\Psi^{\rm ecc.}_{\rm 2PN} + \Delta\Psi^{\rm tidal}_{\rm 6PN} + \Delta\Psi^{\rm tm}_{\rm 6PN}\Big)$$

- NS tidal love number: ~ few hundred

  for black holes: 0

$$\Delta\Psi^{\rm tidal}_{\rm 6PN} = -\frac{39}{2}\tilde{\Lambda} v^{10} + v^{12}\left(\frac{6595}{364}\delta\tilde{\Lambda} - \frac{3115}{64}\tilde{\Lambda}\right)$$

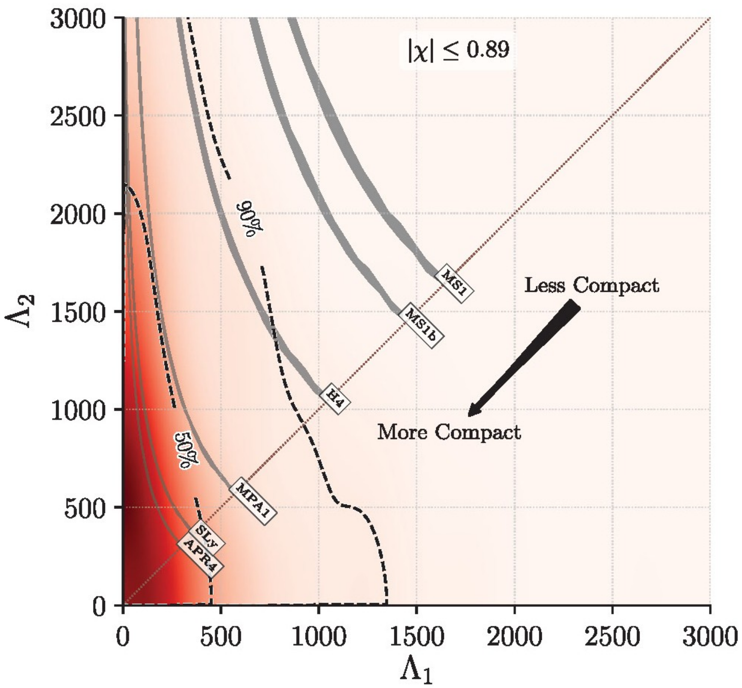
First BNS merger – GW170817

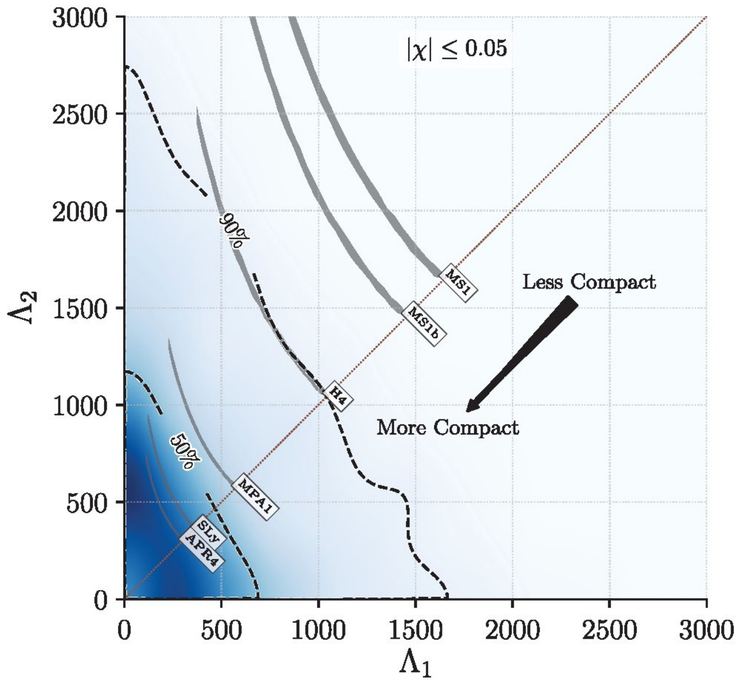
- The tidal field of the companion induces a mass-quadrupole moment

$$\Lambda = (2/3)k_2[(c^2/G)(R/m)]^5$$

- Tidal deformability
$\Lambda \sim$ quadrupole moment / external tidal field

- Measurements disfavor EOS that predict less compact stars





Observations with such delicate instruments should be made in a vibration-free environment which is also protected from temperature variations, and especiallz from the effects from of unilateral irradiation. Windowless chambers in basementts would fit those conditions best. Unfortunatelz no such chambers were available for us. Time was pressing so we had to be content with and observation room located at the second floor. Of the laboratory available to us and had two windows looking South. However, buildings on the opposite side cast their shadow on these windows during most of the day, also, they were obstructed by rolling curtains, this the room was kpet dark all the time. For even more complete protection even within the room a separate housing wwas built for each instrument, whose walls consisted of canvas sheets stretched on double frames, and the space between was filled with fine sawdust and sewn stitched blankets.

Since the room where we made our observations laz awaz from street trafic initially we had no reason to be worried about stronger vibratios, but unfortunately the circumstances deteriorated when a new construction was started in close vicinity during the observations

Although the results of observations show no significant influence of these circumstances, still we are very much aware that the observations presented here were not made under the most favorable conditions, also, they are not the best that we believe are achievable with our instrument. But: „Ars longa vita brevis” - we have to content ourselves with having made a step forward.