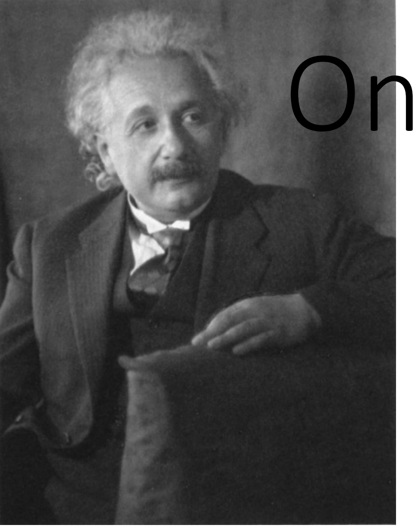
Einstein Telescope

The 3rd generation Gravitational Wave observatory

Michele Punturo

On behalf of the nascent ET collaboration

One century of research, study and R&D

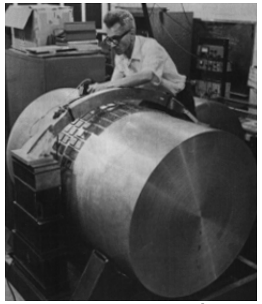


1915 GR

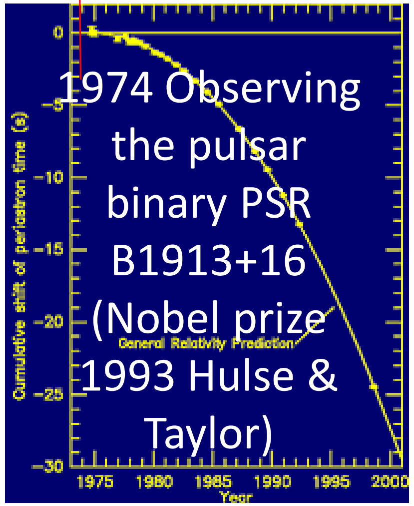
1916-1918 GW

1937 GW correct equation

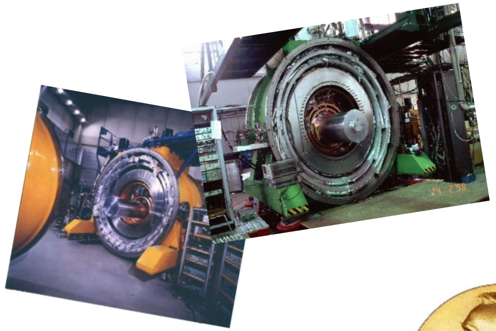
1957 GW are transporting energy



1966 J.Weber: beginning of the experimental era



1974 Observing the pulsar binary PSR B1913+16 (Nobel prize 1993 Hulse & Taylor)



’80-’90: Cryogenic resonant bars

1986: B.Schutz (standard sirens), PPN templates …

1993

INFN

1994: approval of the Virgo experiment

1999+ Templates: EOB, Numerical relativity

1999+ beginning of LIGO and Virgo (+4y) operations

Final targets?

2015: beginning of aLIGO operativity: GW detection

2017 beginning of Advanced Virgo operativity: GW from BNS

t

2015-2017: Scientific revolution

- The detection of GW has been a huge scientific achievement, result of a century of efforts, but actually it is the beginning of a new era in the observation of the Universe
- The discoveries announced by LIGO and Virgo are crucial milestones in Science:
  - GW150914:
    - the first direct detection of GW. Confirmation of the Einstein's prediction of GW. Discovery/Confirmation of the existence of stellar mass black holes. Birth of the experimental physics of the gravitation in strong field and of the astrophysics of stellar mass black holes
  - GW170814:
    - The first detection in a network of 3 GW detectors of GW emitted by the coalescence of black holes. The first test of GW polarisation. The birth of the gravitational wave astronomy and astrophysics thanks to the localisation capability.
  - GW170817:
    - The first detection of the GW emitted by the coalescence of two Neutron Stars. Test of GR versus alternative theories of gravity. The birth of the multi-messenger astronomy and astrophysics with GW

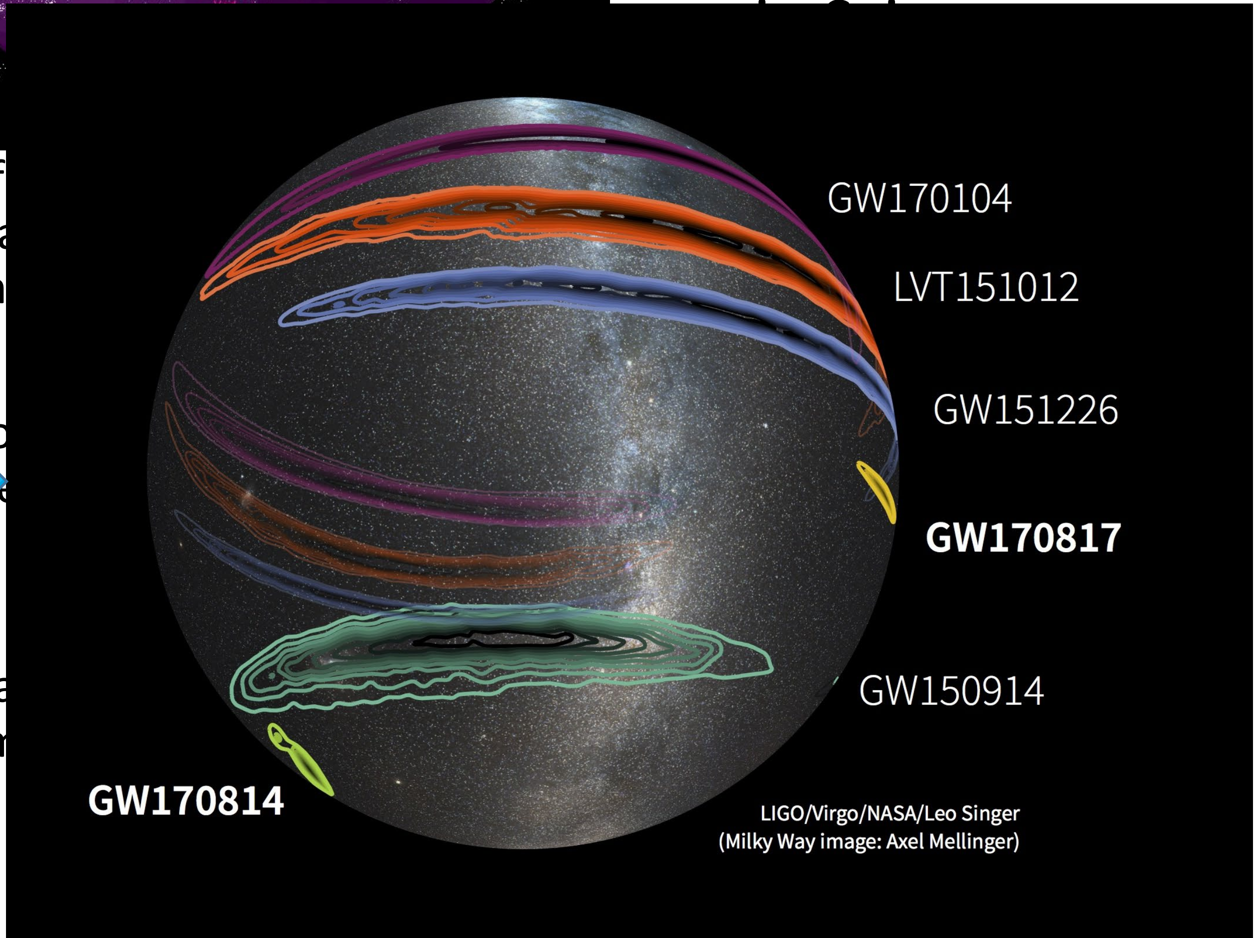
How it has been possible?

2015-2017: Scie

- The detection of GW has been a hug... ...esult of a century of efforts, but actually is the beginnin... ...vation of the Universe
- The discoveries announced by LIGO ...
  - GW150914: LIGO VIRGO
    - the first direct detection of GW. Confirmation of ... Discovery/Confirmation of the existence of stella... the gravitation in strong field and of the astroph...
  - GW170814: LIGO VIRGO
    - The first detection in a network of 3 GW detecto... The first test of GW polarisation. The birth of the ... to the localisation capability.
  - GW170817: LIGO VIRGO
    - The first detection of the GW emitted by the coa... alternative theories of gravity. The birth of the m...

New generation of detectors with largely improved sensitivity

3 detectors with comparable sensitivity



Network of GW detectors

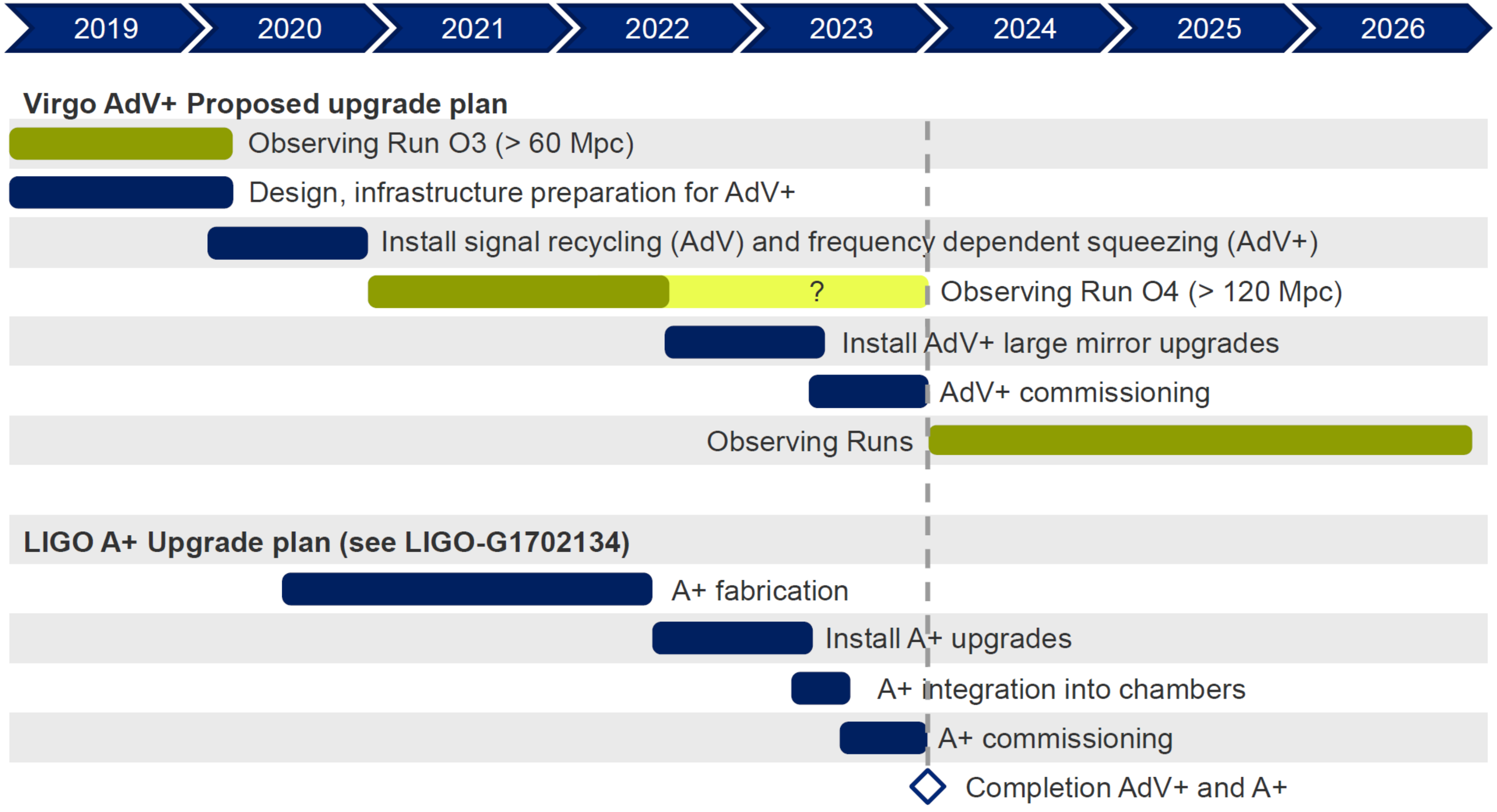
LIGO Scientific Collaboration:
- 1263 collaborators (including GEO)
- 20 countries
- 8 computing centres
- ~1.5 G$ of total investment

Virgo Collaboration:
- 343 collaborators
- 8 countries
- 5 computing centres
- ~0.42 G€ of total investment

KAGRA Collaboration:
- 260 collaborators
- 12 countries
- 5 computing centres
- ~16.4 G¥ of construction costs

Short term evolutions

Five year plan for observational runs, commissioning and upgrades

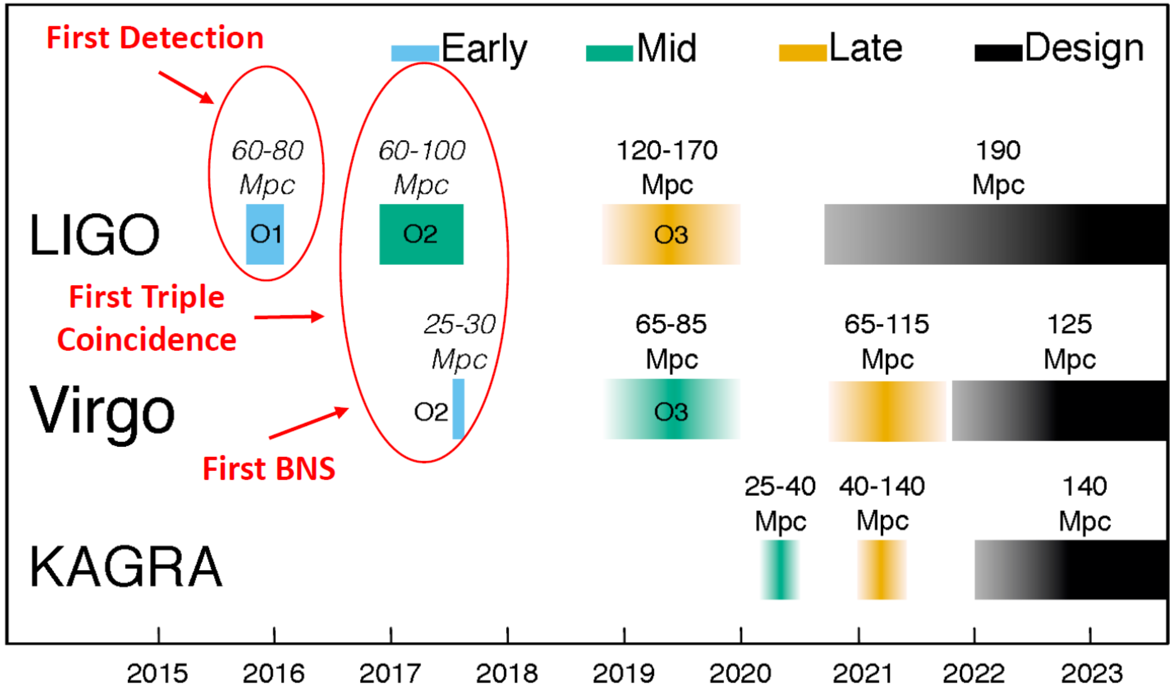


Note: duration of O4 has not been decided at this moment

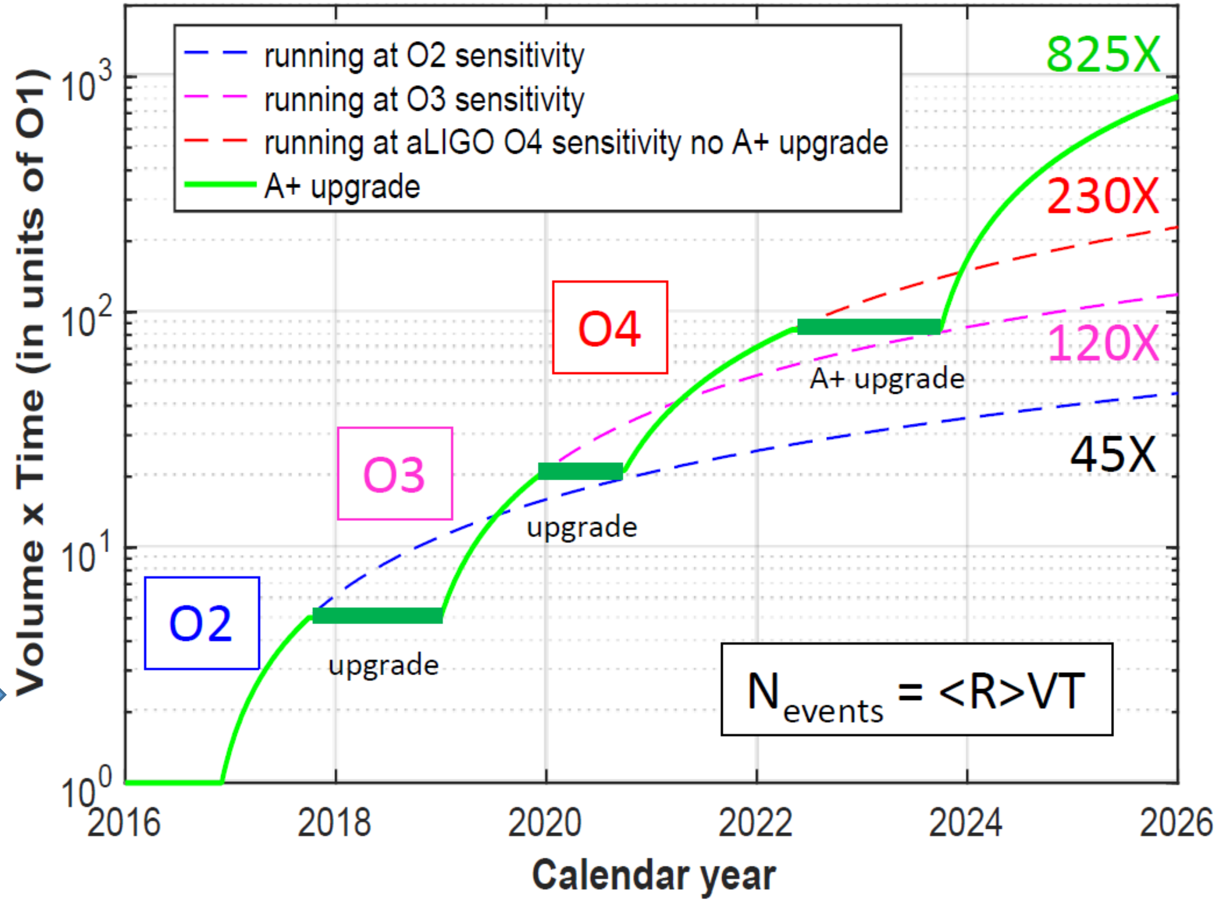
VIR-0943A-17

Plans for LIGO-KAGRA-Virgo runs

arXiv: 1304.0670v4 KAGRA & LIGO & VIRGO



Binary Neutron Stars Events



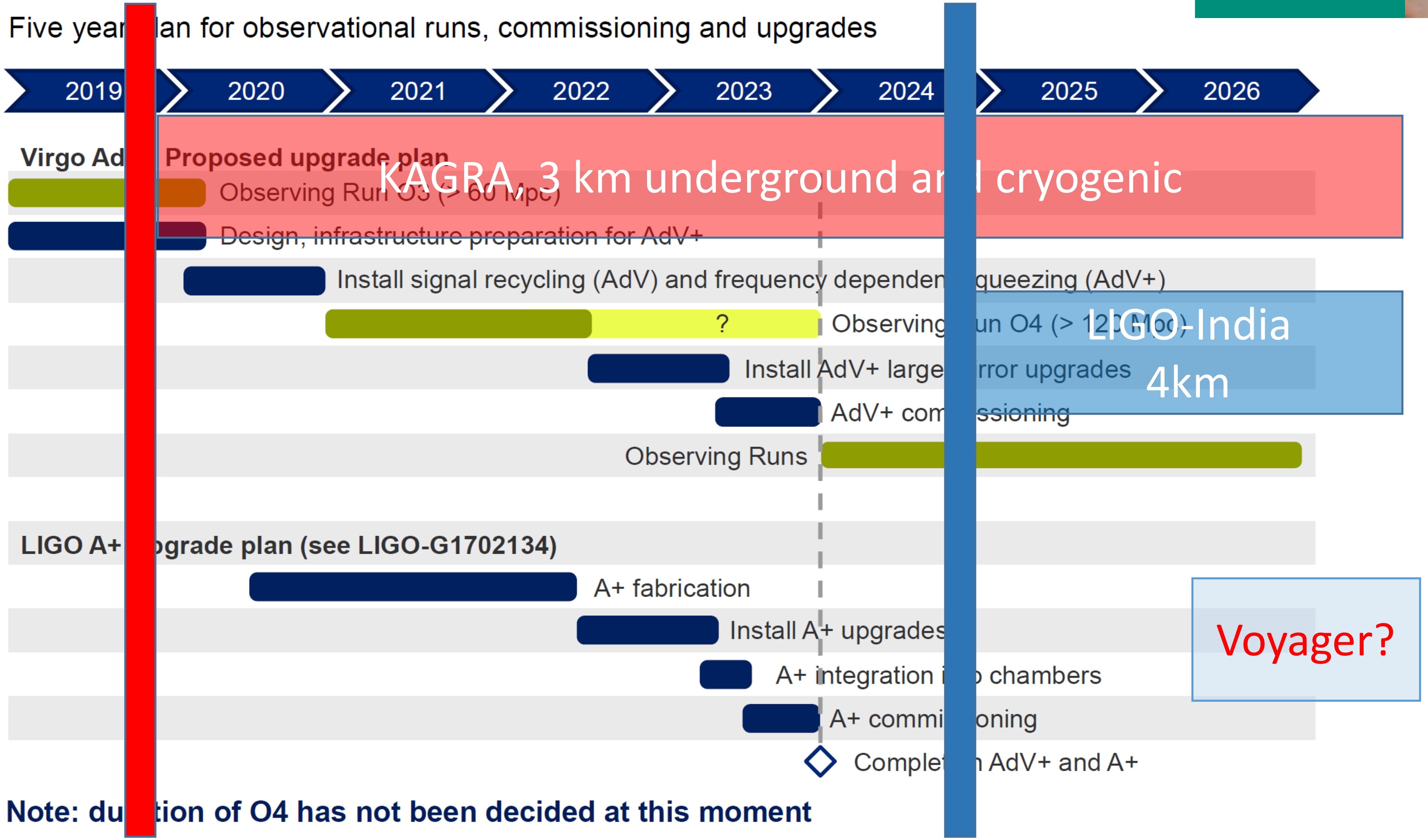
HEPP physicists?

Luminosity $\mathcal{L}$

Branching ratio $\mathcal{R}$

- <R> average astrophysical rate
- V volume of the universe probed → (Range)^3
- T coincident observing time

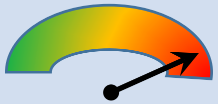
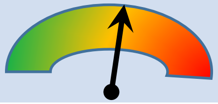
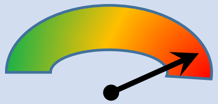
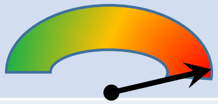
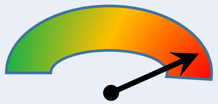
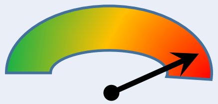
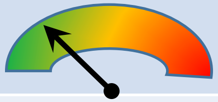
Short term evolutions



VIR-0943A-17

2029 outlook

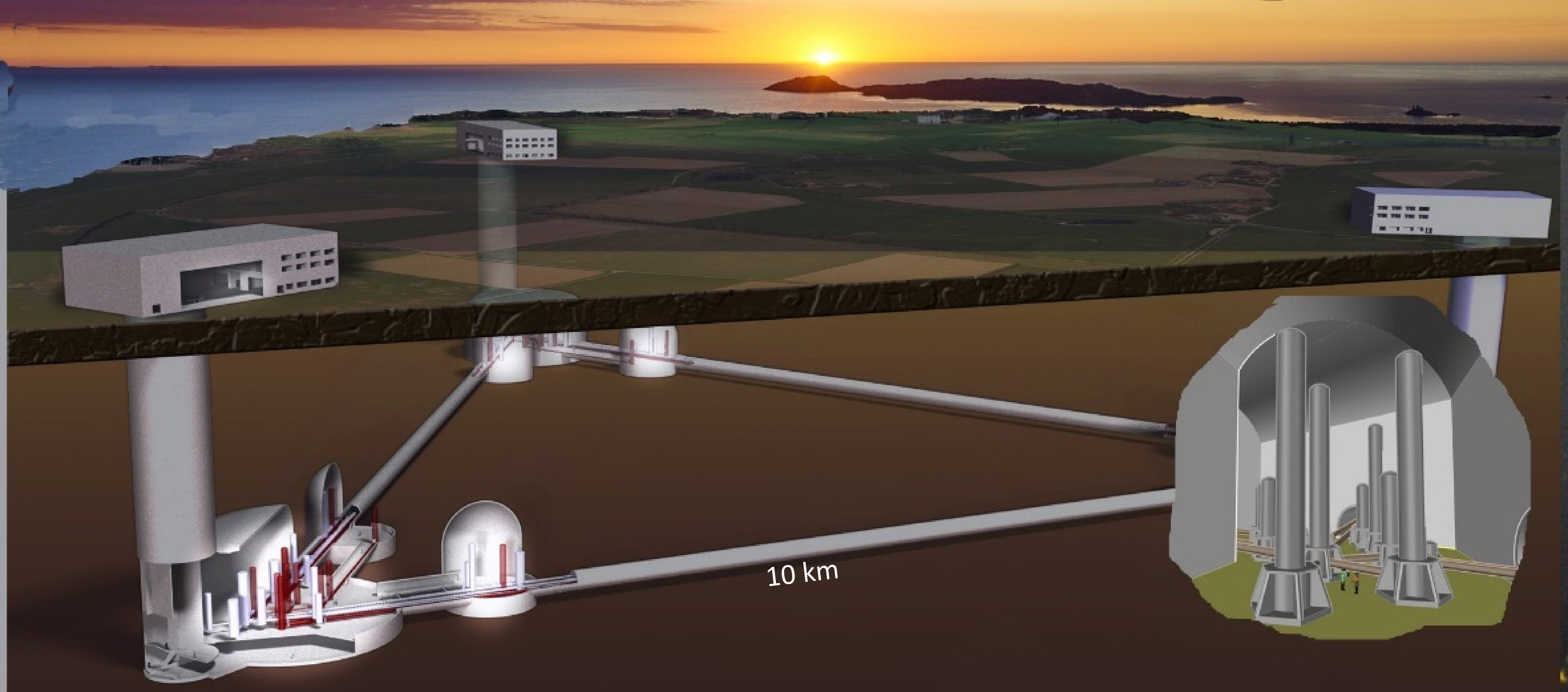
- In 2029 we will have a really heterogeneous 2.xG network
  - The concepts of “obsolescence” and “limit of the infrastructure”, that are driving the quest for new research infrastructures (rather more than a new detector) apply differently to the different continents

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

How to keep a scientific relevance in Europe?

Risk: Obsolescence and limits of the European Infrastructures in a 20 years timeline

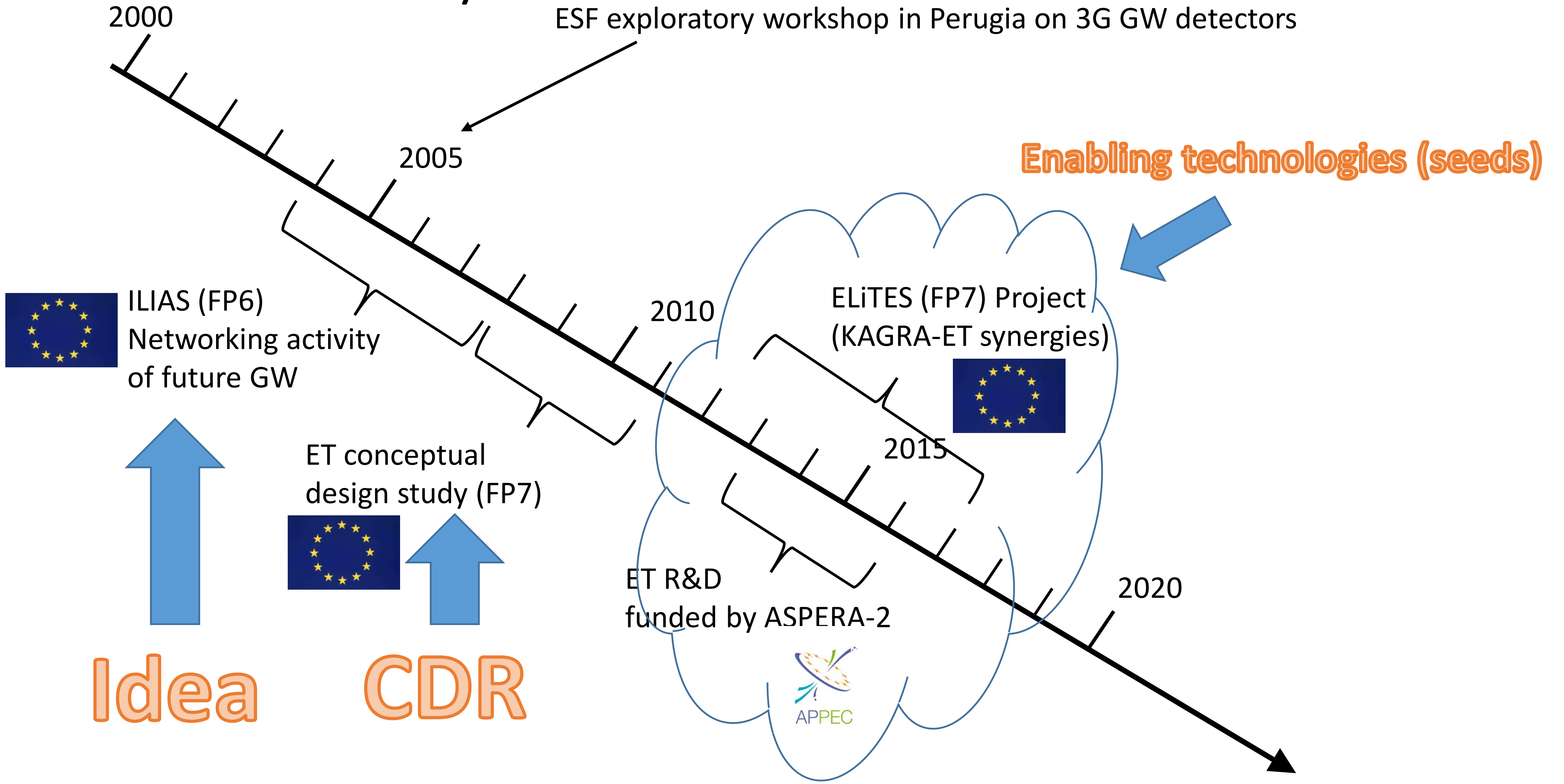
The Einstein Telescope



The 3G/ET key points

- ET is THE 3G new GW observatory
  - 3G: Factor 10 better than advanced (2G) detectors
  - New:
    - We need a new infrastructures because
      - Current infrastructures will limit the sensitivity of future upgrades
      - In 2030 current infrastructures will be obsolete
  - Observatory:
    - Wide frequency, with special attention to low frequency (few HZ)
      - See later
    - Capable to work alone (characteristic to be evaluated in the international scenario)
      - (poor) Localization capability
      - Polarisations (triangle)
      - High duty cycle: redundancy
    - 50-years lifetime of the infrastructure
      - Compliant with the upgrades of the hosted detectors

ET history

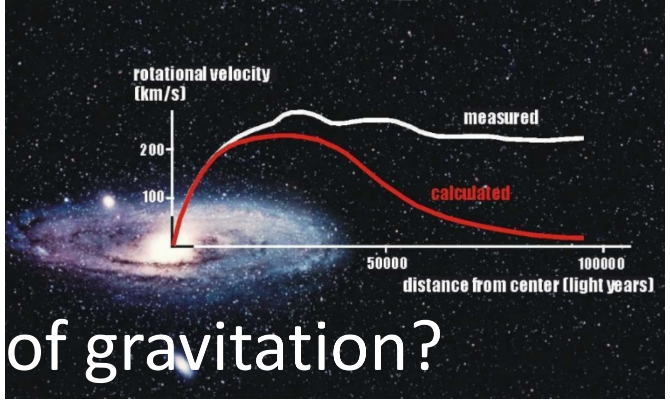

2000
ESF exploratory workshop in Perugia on 3G GW detectors
2005
Enabling technologies (seeds)
ILIAS (FP6)
Networking activity
of future GW
2010
ELiTES (FP7) Project
(KAGRA-ET synergies)
2015
ET conceptual
design study (FP7)
ET R&D
funded by ASPERA-2
APPEC
2020
Idea
CDR

ET: Science targets

Some of the questions addressed by GW (AdV+, ET)

- Fundamental questions in Gravity: **HEPP** Fundamental interactions, Dark matter, dark 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** Inflation, additional interactions, dark matter
  - Axions and ultralight particle through the evaluation of the consequences of new interactions, their impact on two bodies mechanics, in population and characterisics of BHs, NSs
- Probing the EOS of neutron stars **HEPP** Nuclear physics, quark-gluon plasma
- Exotic objects and phenomena (cosmic strings, exotic compact objects: boson stars, strange stars/gravastars, …)
- Cosmology and Cosmography with GWs **HEPP** Cosmology
- Accurate Modelling of GW waveforms
- GW models in alternative theory of gravitation **HEPP** Cosmology
- The population of compact objects discovered by GWs is the same measured by EM? Selection effects on BHs and NSs?
- What is the explosion mechanism in Supernovae? **HEPP** Nuclear physics
- What is the history of SuperMassive black holes?
- GW Stochastic Background? Probing the big bang? **HEPP** Cosmology, inflation
- Multimessenger Astronomy in 3G? **HEPP** Astroparticle, GRB, Neutrino Physics

Some of the fundamental questions



- Is Einstein's General Relativity THE theory of gravitation?
  - Test of GR
  - Polarisations
  - Mass of the "graviton"
- Do we need Dark Matter?
  - Wimps, Axions or black holes?

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \Rightarrow G_{\mu\nu} = \frac{8\pi G}{c^4}\left(T_{\mu\nu} + T_{\mu\nu}^{DM}\right)$$

$T_{\mu\nu}^{WIMP}$ $T_{\mu\nu}^{axion}$ $T_{\mu\nu}^{BH}$

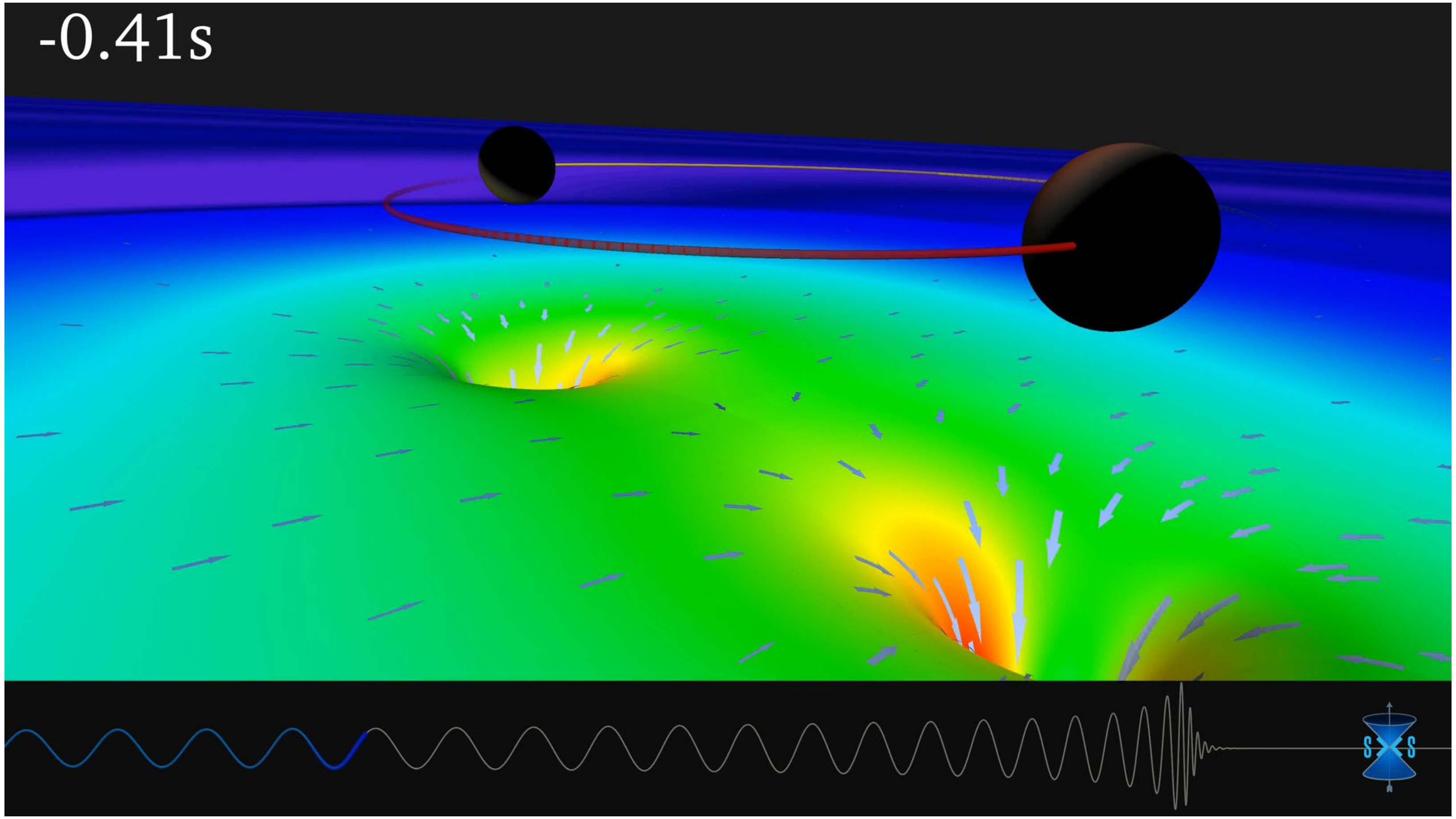
- Do we need Dark Energy?
  - Alternative theories of Gravity

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

Alternative theories of Gravity

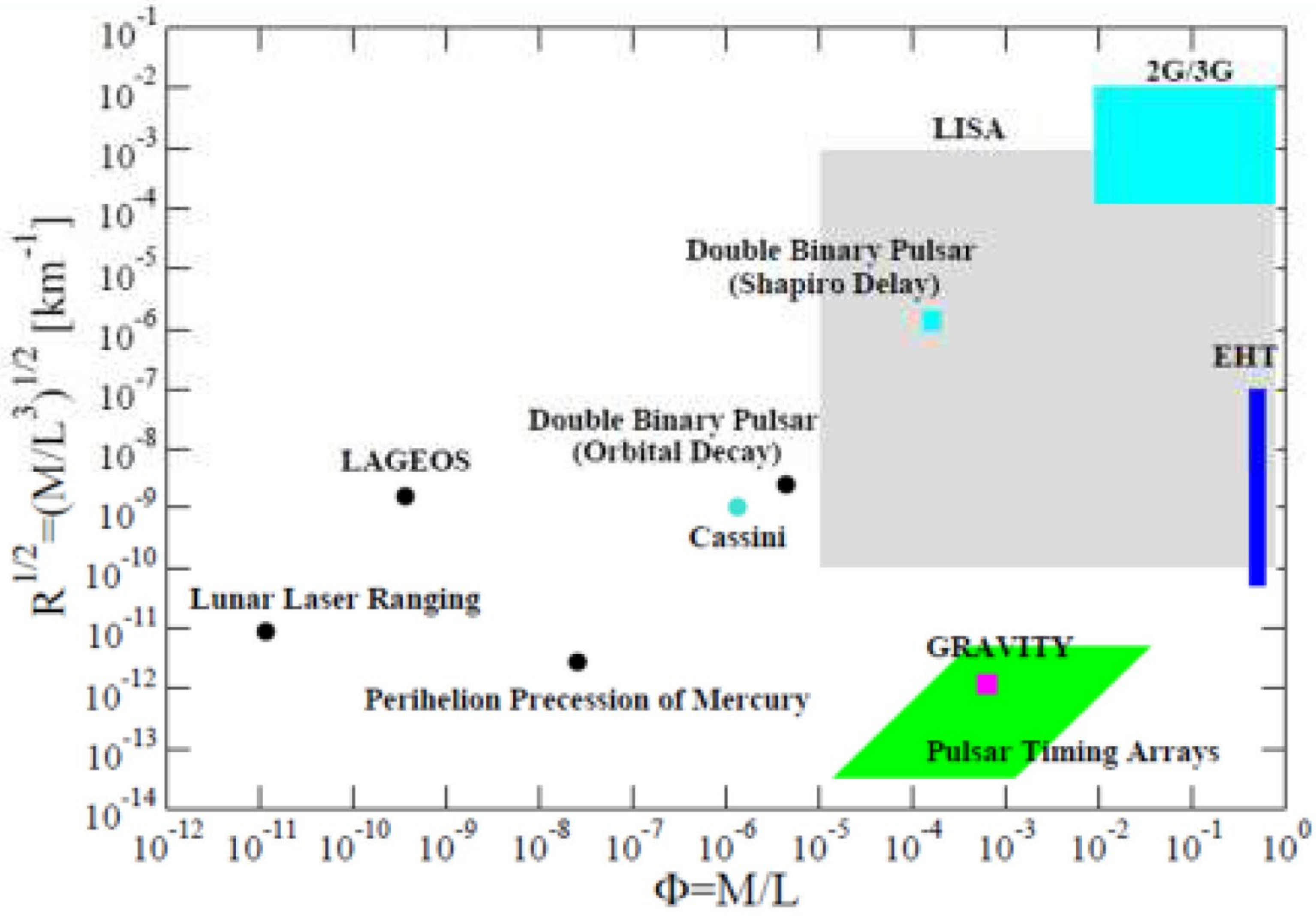
- Are Neutron Stars "strange"?
  - EOS of NS

GW150914 … e BBH coalescences



Probing GR in strong field conditions

- BBH coalescences allow to test GR in strong field conditions



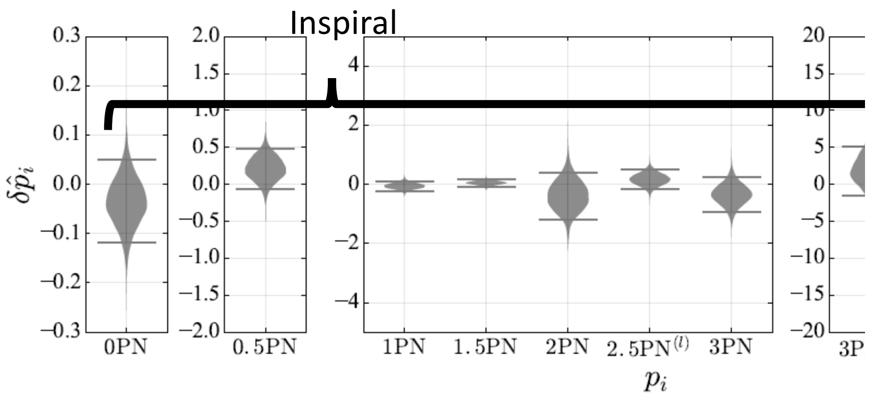
Yunes N. et al.
Phys. Rev. D 94, 084002 (2016)
Edited by ET science case team

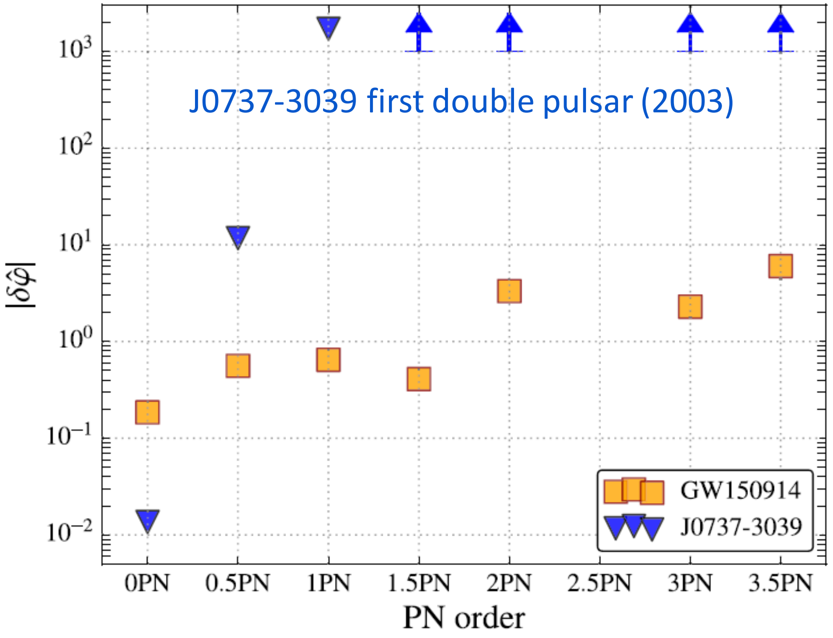
Test of GR: PN approximation

- Going in strong field regime, allow to constrain eventual discrepancies with respect to PN approximation of the GR
- BBH template

$$\Psi(f) = 2\pi f t_c - \varphi_c - \frac{\pi}{4} + \sum_{j=0}^{7} \left[\psi_j + \psi_j^{(l)} \ln f \right] f^{(j-5)/3},$$

$$\psi_j \rightarrow (1 + \delta p_j)\psi_j$$

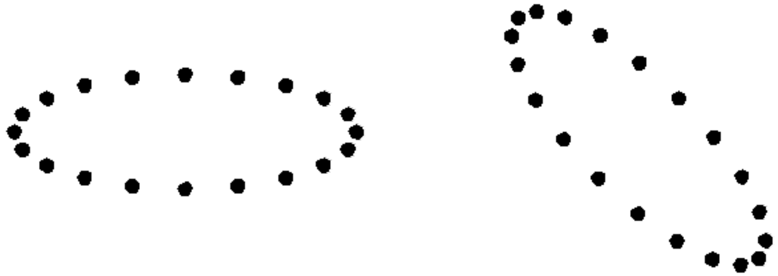


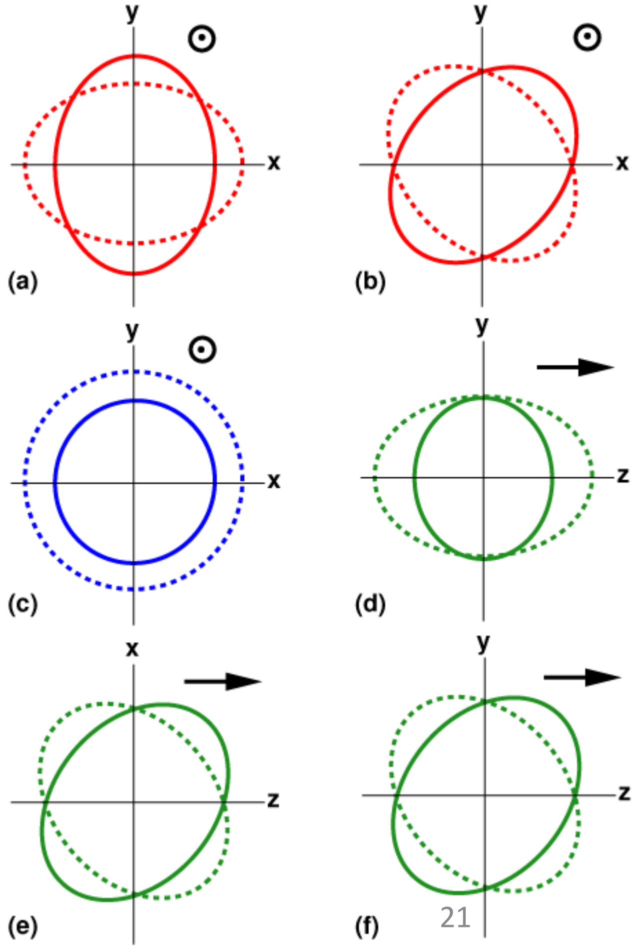


B. P. Abbott et al. (LIGO Scientific and Virgo Collaboration)
Phys. Rev. Lett. 118, 221101 – supplement material

Alternative theories of Gravity: polarisations

- GR predicts a tensorial nature of GW with two polarisations
  - Alternative theories of gravity could predict extra polarisations of GW (up to 6)

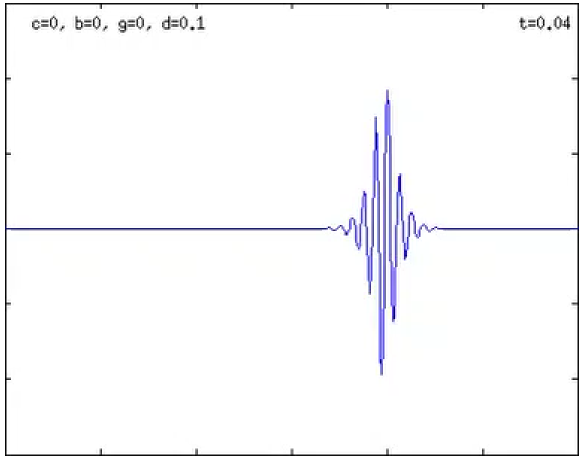




- Present and future GW detectors are setting stringent limits
  - GW170814:
    - Thanks to the presence of Virgo has been possible the evaluate the contribution of extra polarisations in the detected GW resulted disfavoured

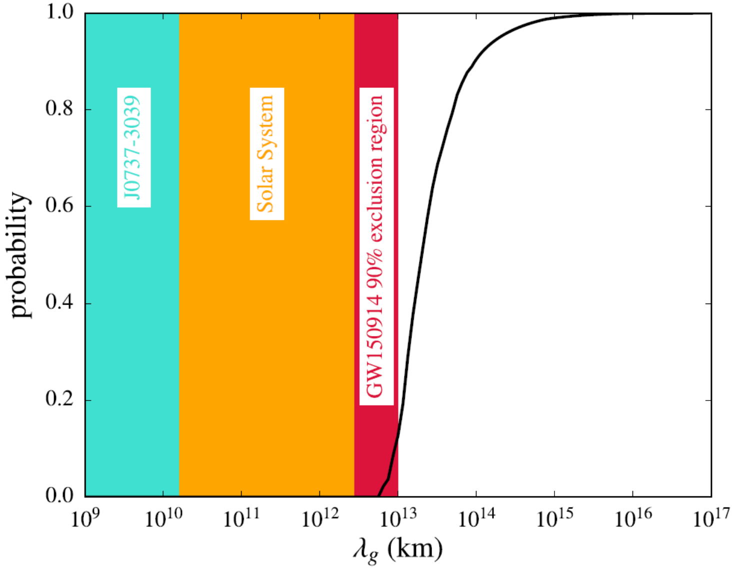
Is the Graviton massless?

- If the graviton has mass>0 the GW propagates slowly and with dispersion



- Dispersion relation: $E^2 = p^2c^2 + m_g^2c^4$
- $\lambda_g = h/(m_g c)$
- Thanks to **GW170104**, measured at about 3 billions of light years it is possible to set an upper limit:

$$\lambda_g > 1.6\times10^{13}\,km \Rightarrow \quad m_g < 7.7\times10^{-23}\,eV/c^2$$



Citation: C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016) and 2017 update

γ (photon) $\qquad I(J^{PC}) = 0,1(1^{--})$

γ MASS

Results prior to 2008 are critiqued in GOLDHABER 10. All experimental results published prior to 2005 are summarized in detail by TU 05.

The following conversions are useful: $1\text{ eV} = 1.783\times10^{-33}\text{ g} = 1.957\times10^{-6}\ m_e$; $\bar{\lambda}_C = (1.973\times10^{-7}\text{ m})\times(1\text{ eV}/m_\gamma)$.

VALUE (eV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
$<1\ \times10^{-18}$		[1] RYUTOV 07		MHD of solar wind

Multimessenger Astronomy and Fundamental Physics

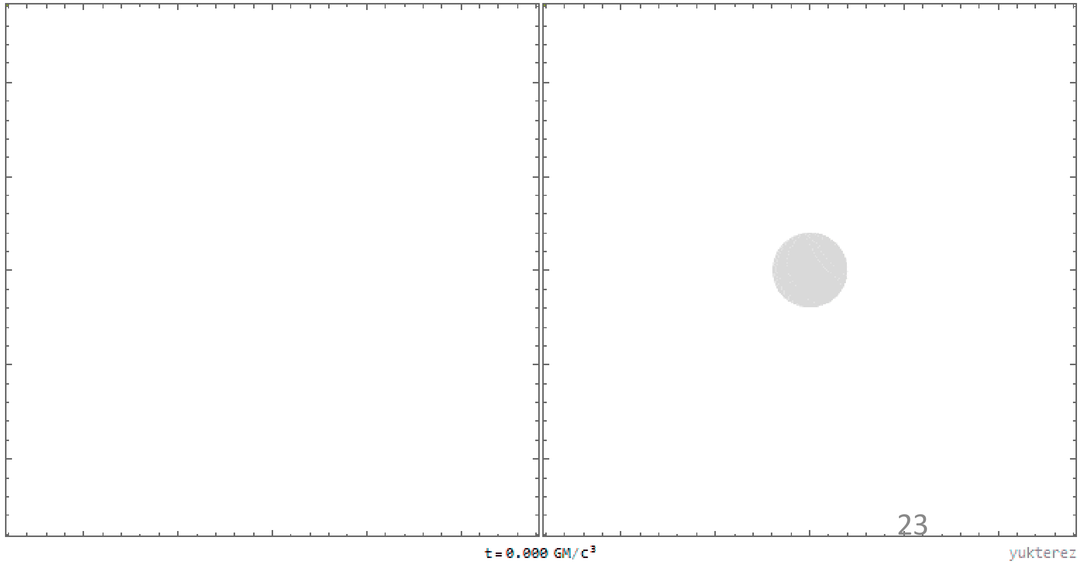
- The beginning of the multimessenger astronomy, marked by GW170817 allowed several fundamental physics tests
  - Constrain the difference of speed between γ and GW: $-3\times10^{-15} \leq \frac{v_{GW}-v_{\gamma}}{v_{\gamma}} \leq 7\times10^{-16}$
  - Test the equivalence principle and discard families (tensor-scalar) of alternative theories of gravity
    - Shapiro effect predicts that the propagation time of massless particles in curved spacetime, i.e., through gravitational fields, is slightly increased with respect to the flat spacetime case:

$$\delta t_{\mathrm{S}} = -\frac{1+\gamma}{c^3}\int_{\mathbf{r}_{\mathrm{e}}}^{\mathbf{r}_{\mathrm{o}}} U(\mathbf{r}(l))dl,$$

$\mathbf{r_o}$ observation point
$\mathbf{r_e}$ emission point
U(**r**) gravitational potential

$$-1.2\times10^{-6} \leq \gamma_{\mathrm{GW}} - \gamma_{\mathrm{EM}} \leq 2.6\times10^{-7}$$

- The γ factor parametrises the coupling of the density energy with the curvature; in the Einstein General Relativity $\gamma_{GW} = \gamma_{EM} = 1$



Dark Energy and Dark Matter after GW170817

GW170817 had consequences for our understanding of Dark Energy and Dark Matter

GWs: many models of modified gravity ruled out!

	Viable after GW170817 ($c_g=c$)	Not Viable after GW170817 ($c_g \neq c$)
Horndeski	General Relativity	Quartic/quintic Galileon
	Quintessence/K-essence	"Fab-Four"
	K-mouflage	de Sitter Horndeski
	Brans-Dicke/f(R)	$G_{\mu\nu}\phi^{;\mu}\phi^{;\nu}$, Gauss-Bonnet
Beyond H.	DHOST with $A_1=0=B_i=G_5$	DHOST with $A_1\neq0$ or $B_i\neq0$ or $G_5\neq0$
	Derivative Conformal	Quintic GLPV

Also, e.g.,
- Massive gravity

Also strongly affected:
- Vector Dark Energy
- Einstein Aether theories
- Some sectors of Horava gravity
- TeVeS
- MOND-like theories
- Generalized PROCA theories

See, e.g., Ezquiaga & Zumalacarregui '17; Baker et al. '17; Creminelli & Vernizzi '17

Nicola Bartolo, private communication

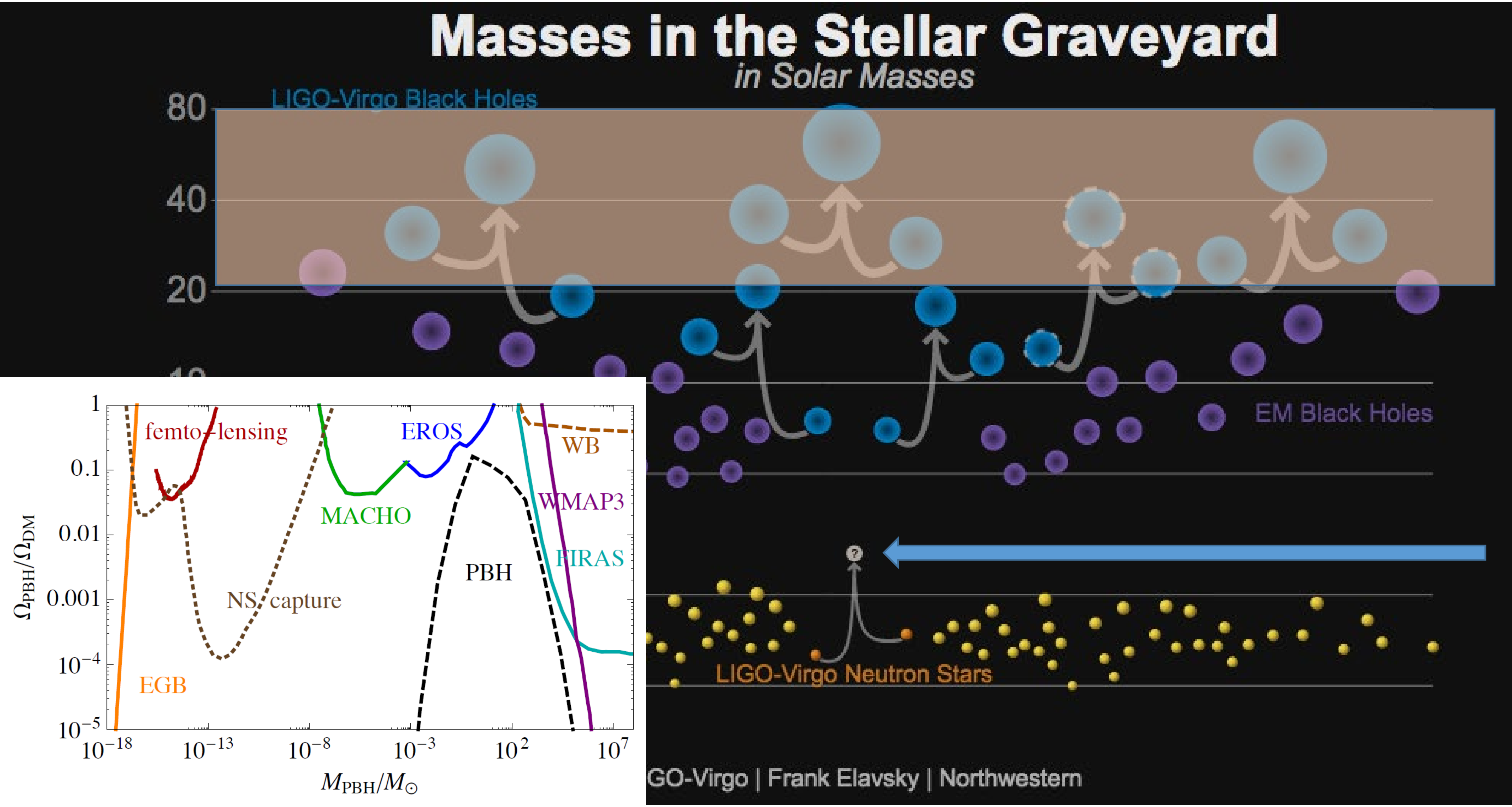
Ok, the Dark Matter paradigm seems strengthened

But what kind of Dark Matter?

$$G_{\mu\nu} = \frac{8\pi G}{c^4}\left(T_{\mu\nu} + T_{\mu\nu}^{DM}\right)$$

$$T_{\mu\nu}^{WIMP} \qquad T_{\mu\nu}^{axion} \qquad T_{\mu\nu}^{BH}$$

LIGO-Virgo detections



New family of BH?

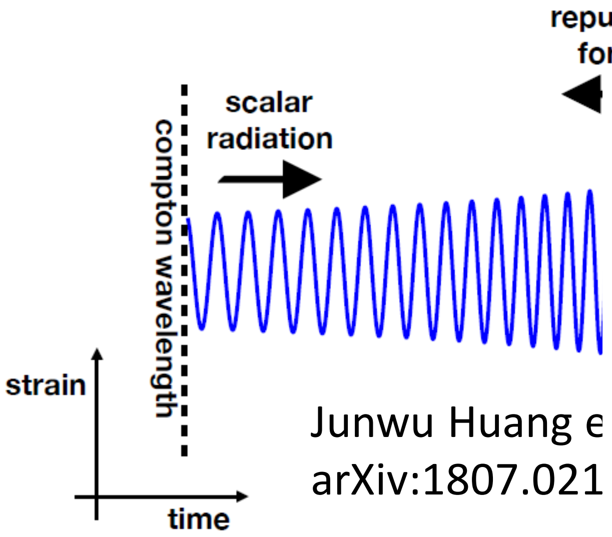
A BH or a Hypermassive NS in the mass gap?

Juan García-Bellido 2017 J. Phys.: Conf. Ser. 840 012032

Axions and GW

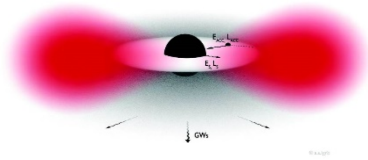
- Axions or, in general, light scalar fields are a possible extension of the Particle standard model and they could be a component of the dark matter or dark energy
  - Axions could provide an inflation mechanism
- What GW could tell about Axions?

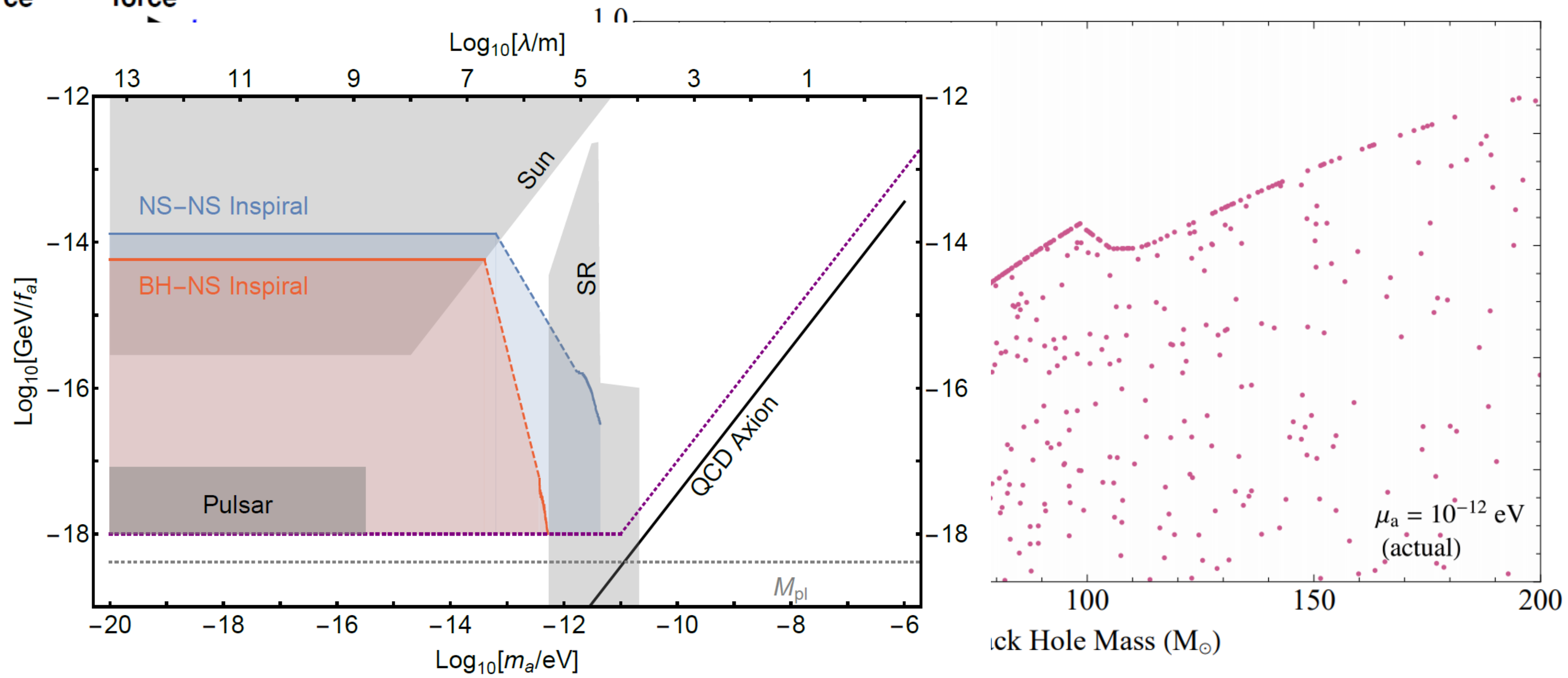
BNS coalescence



Junwu Huang e
arXiv:1807.021

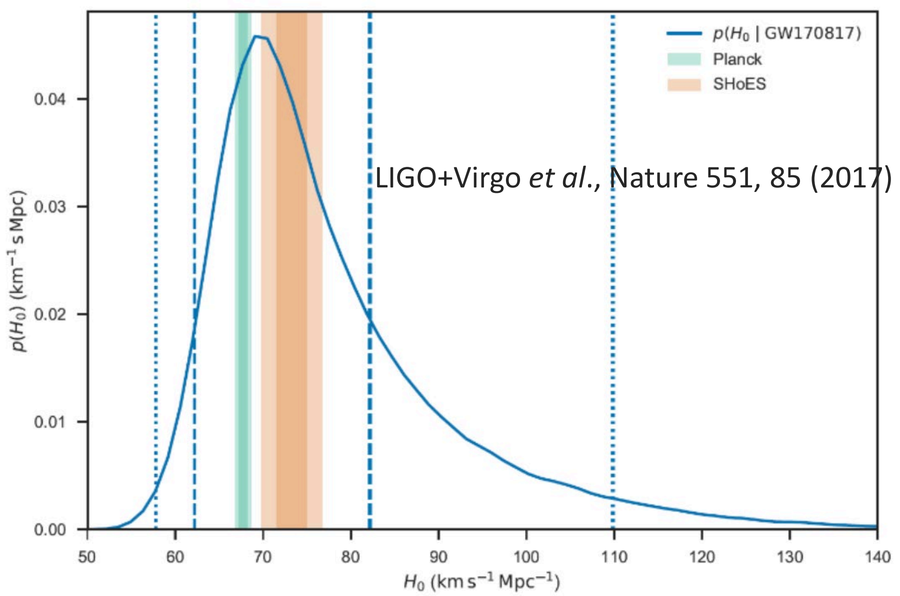
BH superradiance





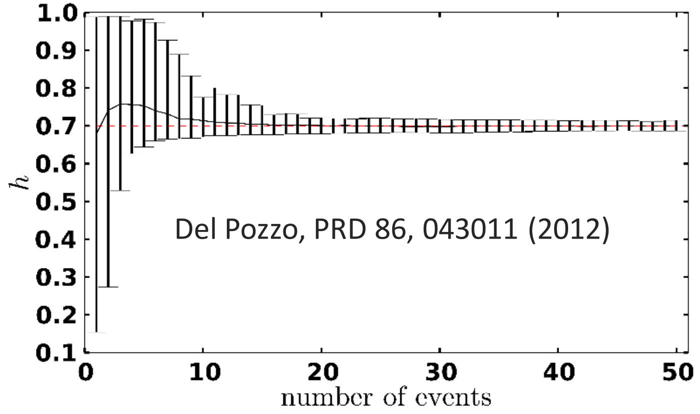
Cosmology with GW

- GW by coalescence of compact bodies are standard ~~candles~~ sirens
- GW170817 has been the first taste of the potential of the multimessenger astronomy in cosmology:
  - Measure of the Hubble constant with an independent method $H_0 = 70.0^{+12.0}_{-8.0}\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$

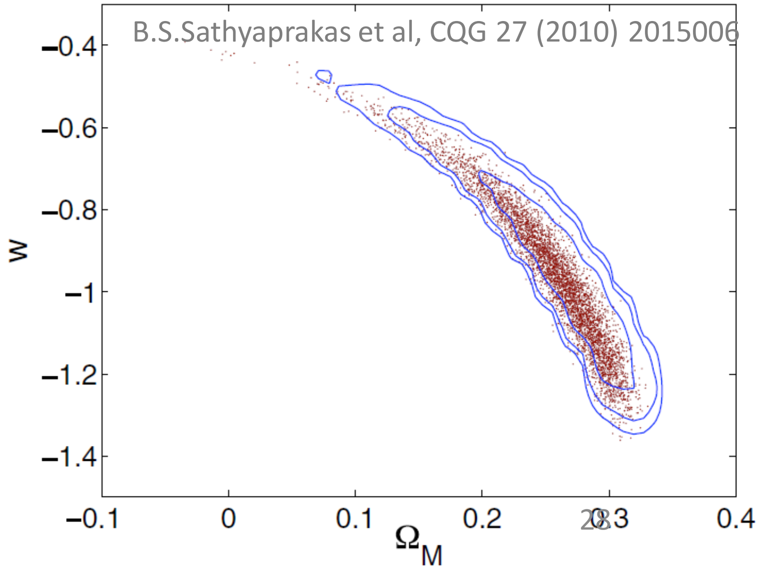


LIGO+Virgo *et al.*, Nature 551, 85 (2017)

- ET will reveal thousands of BNS coalescence:
  - Test of the cosmological model



Del Pozzo, PRD 86, 043011 (2012)

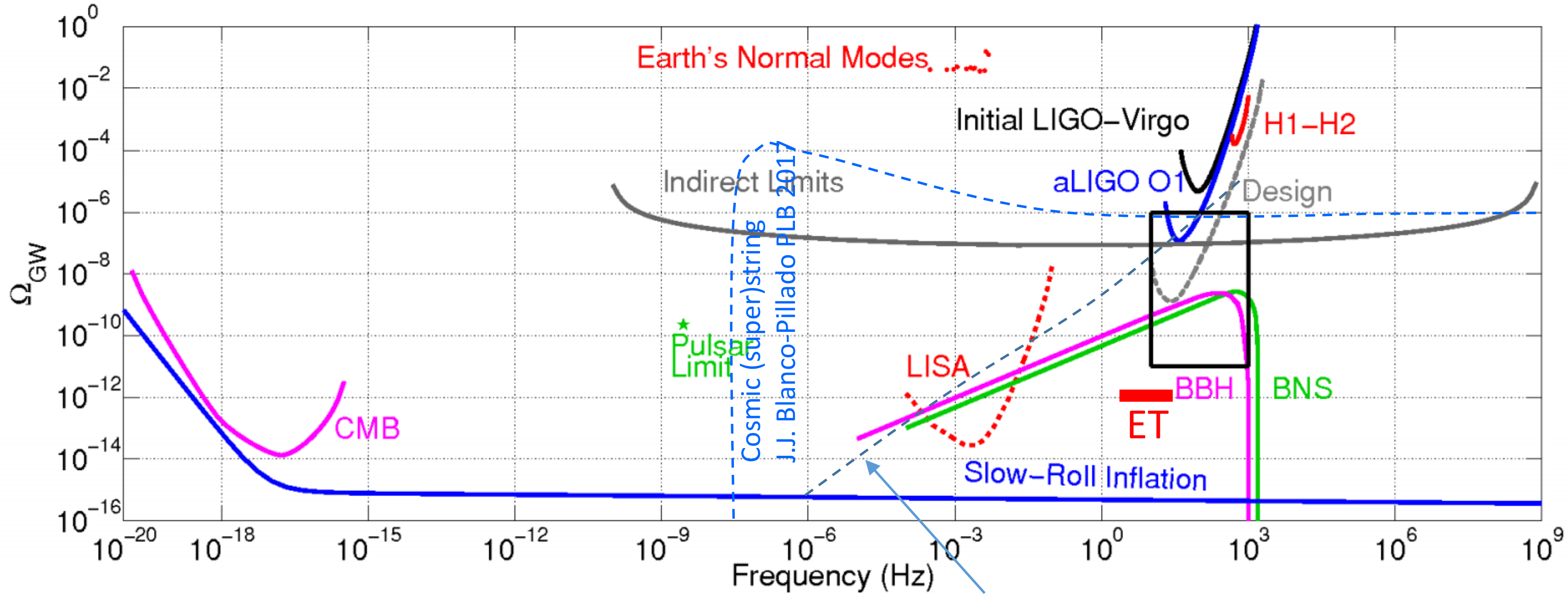


B.S.Sathyaprakas et al, CQG 27 (2010) 2015006

$$D_L(z) = \frac{c(1+z)}{H_0}\int_0^z \frac{dz}{\left[\Omega_M(1+z)^3 + \Omega_\Lambda(1+z)^{3(1+w)}\right]^{1/2}}$$

GW Stochastic Background and inflation

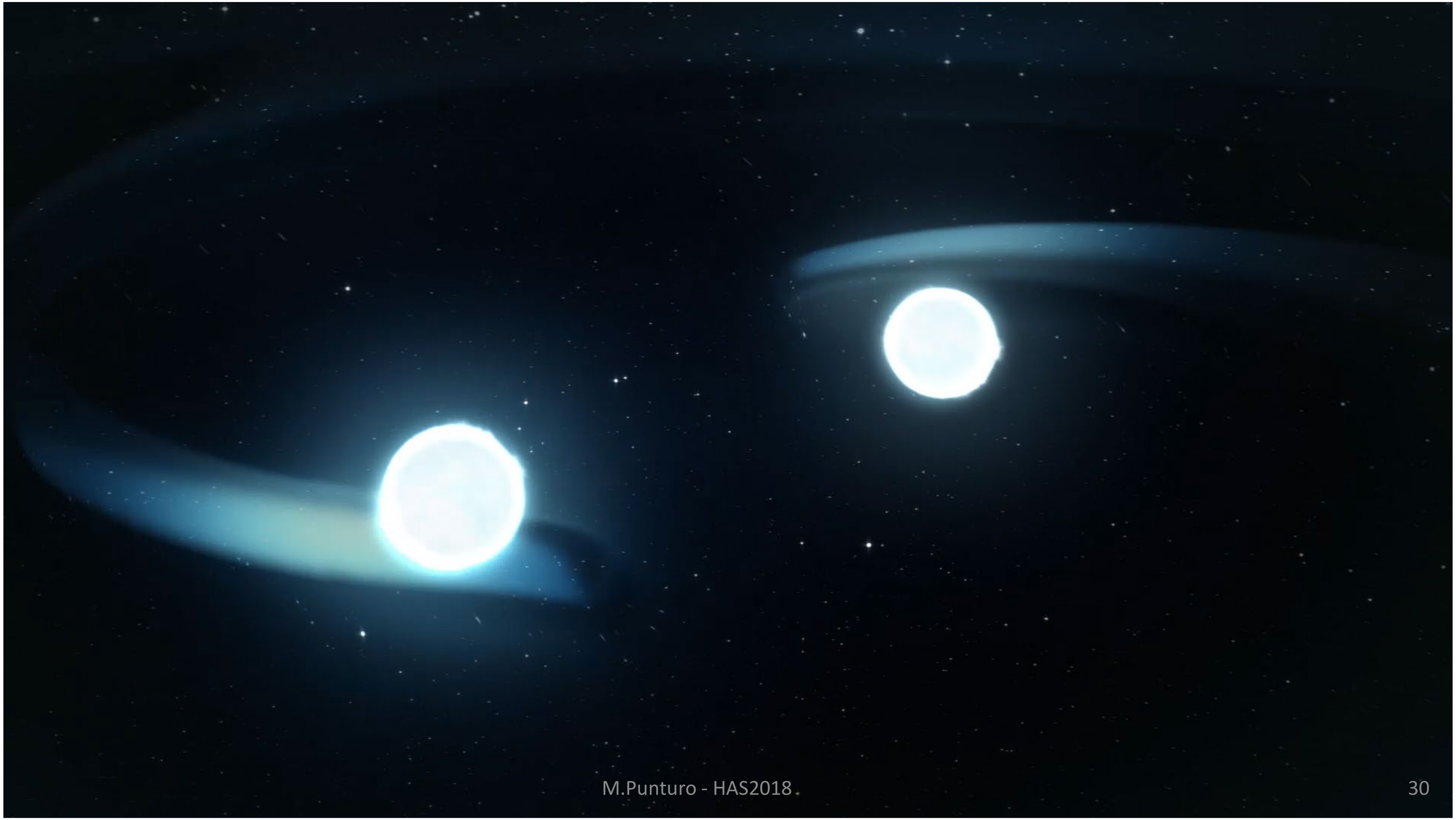
- Inflation, reheating, preheating models could be distinguishible in the GW stochastich background in case of some blue-shift mechanism
  - information on: new additional degrees of freedom, interactions and/or new symmetry patterns underlying high energy physics of early universe



Abbot, B.P. et al, Phys Rev Lett 118 (12), 2017, 121101

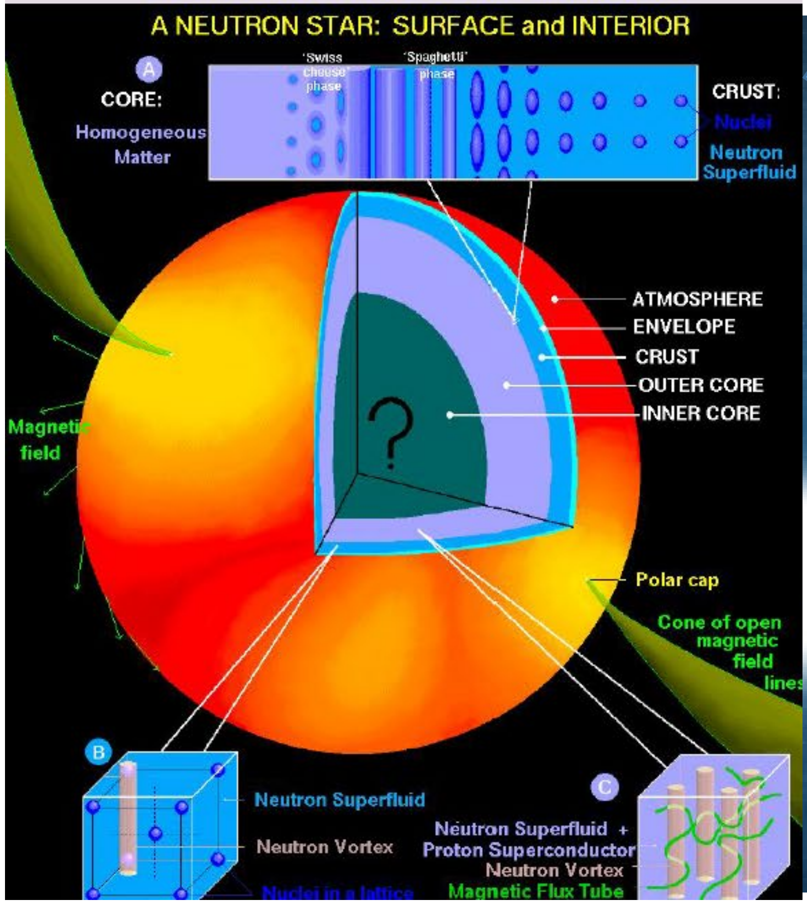
Axion inflation
(see for example V. Domcke arXiv:1704.03464)

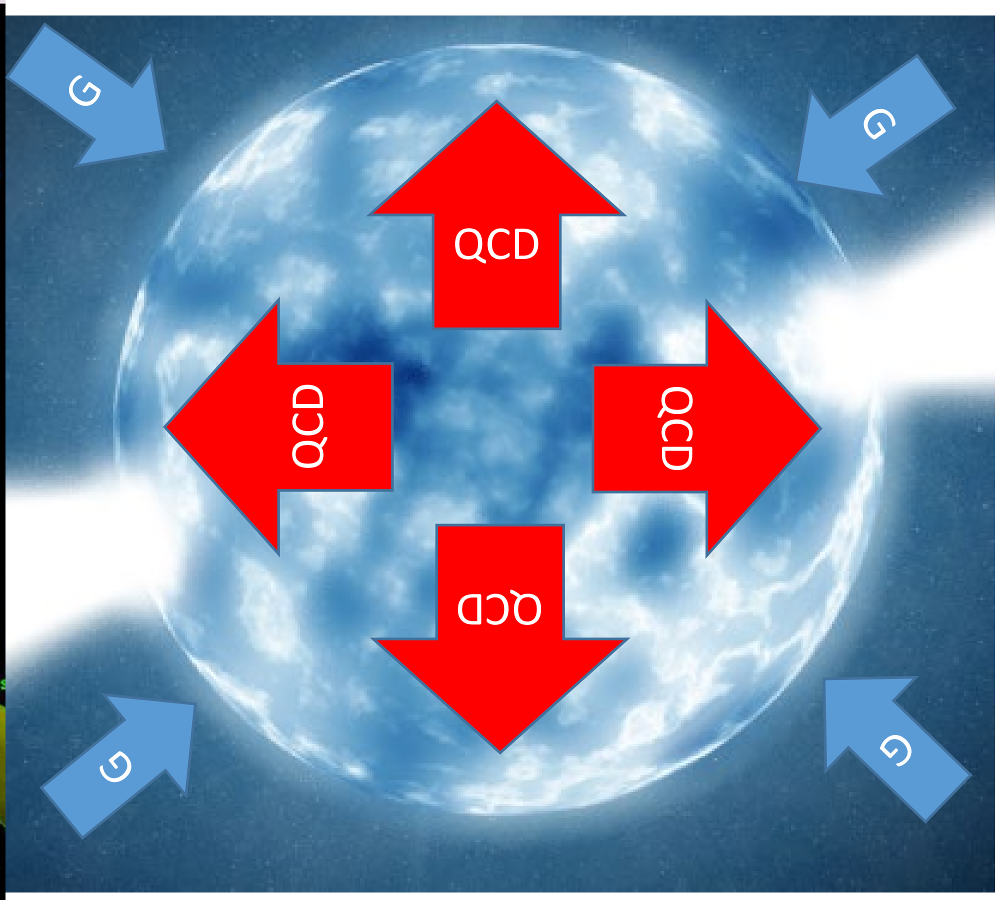
Our Collider

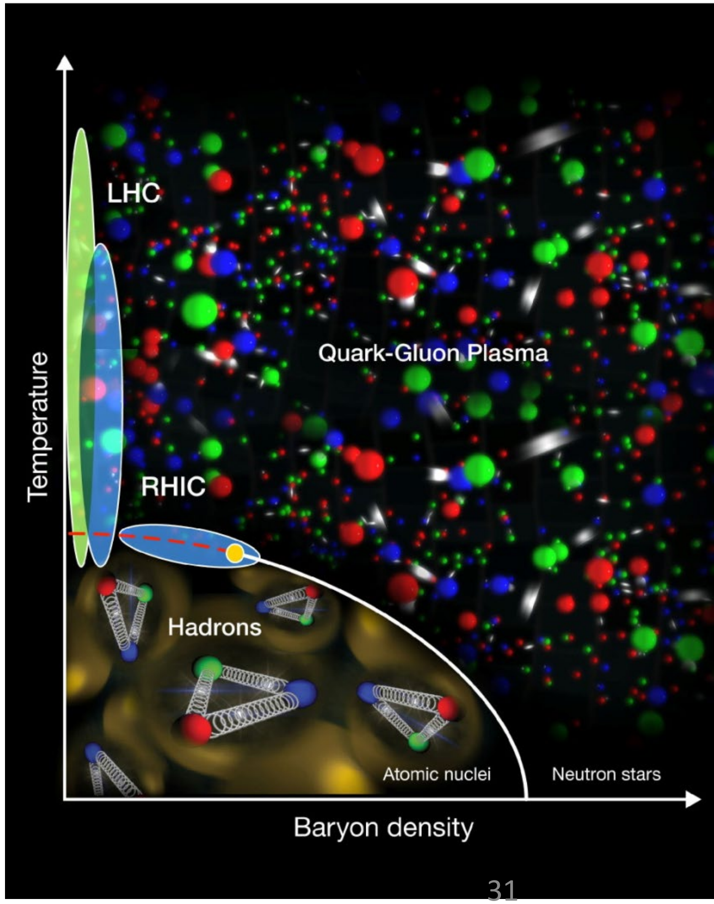


Neutron Star is a nuclear physics lab

- Neutron stars are an extreme laboratory for nuclear physics
  - The external crust is a Coulomb Crystal of progressively more neutron-reach nuclei
  - The core is a Fermi liquid of uniform neutron-rich matter (“Exotic phases”? Quark-Gluon plasma?)

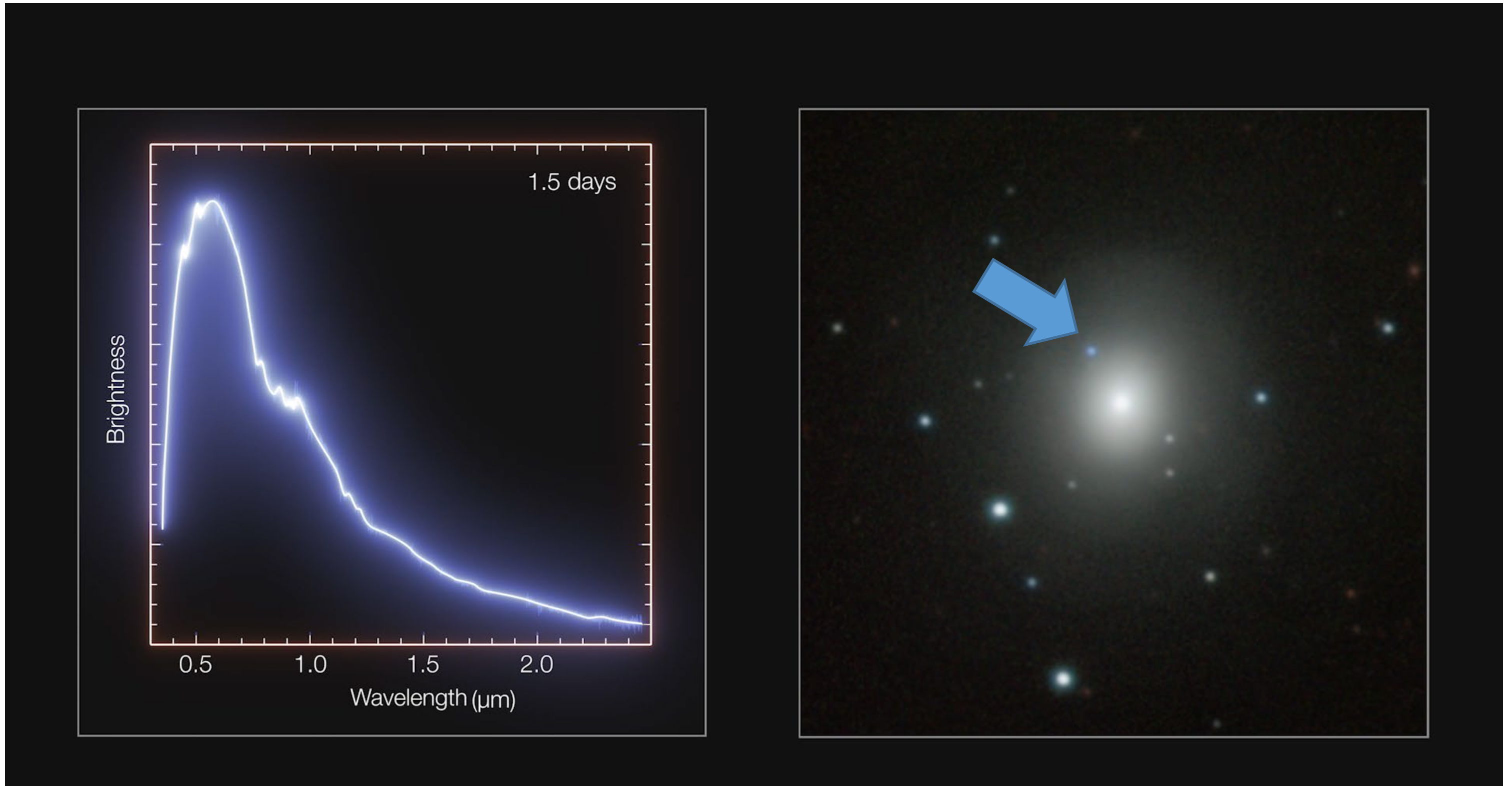






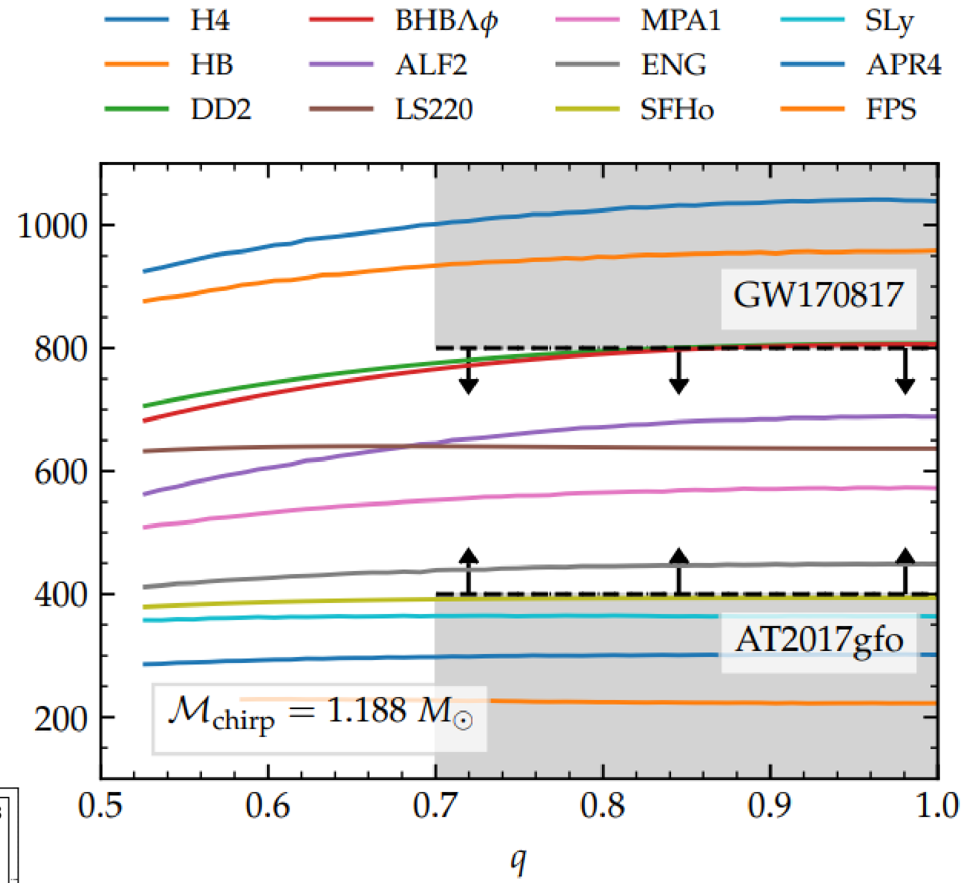
GW170817: Nuclear Physics “experiment”

- The collision of two NS in GW170817 has been a complex nuclear physics experiment, where it has been possible
  - The accurate measure the mass and radius of the NS through the tidal deformation of the star → Constrain the EOS
  - To observe the production of heavy elements through r-processes

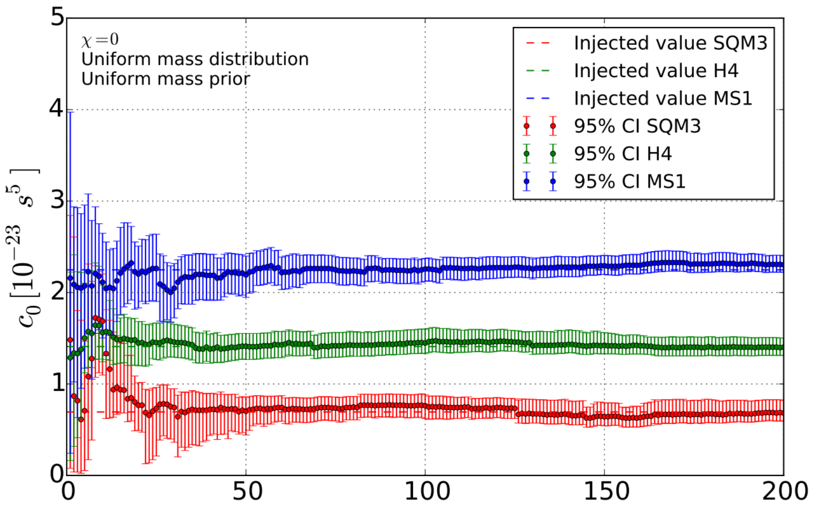


Constraining the NS EOS

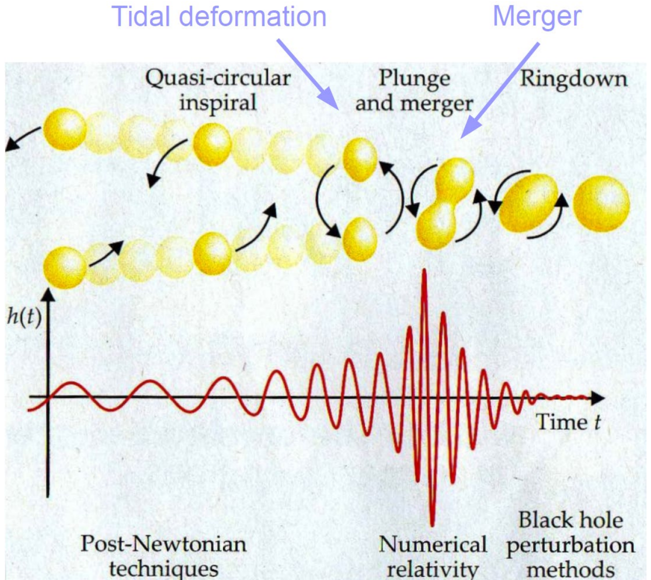
- Measuring the tidal deformation through the dephasing in the GW signal is possible to constrain the EOS of the NS
- Adding the em information helps to impose more stringent constrain
  - Knowing the EOS it is possible to describe the status of the matter in the over-critical pressure condition in the NS



D. Radice et al. (APJ Letters, 852, 2, 2018),



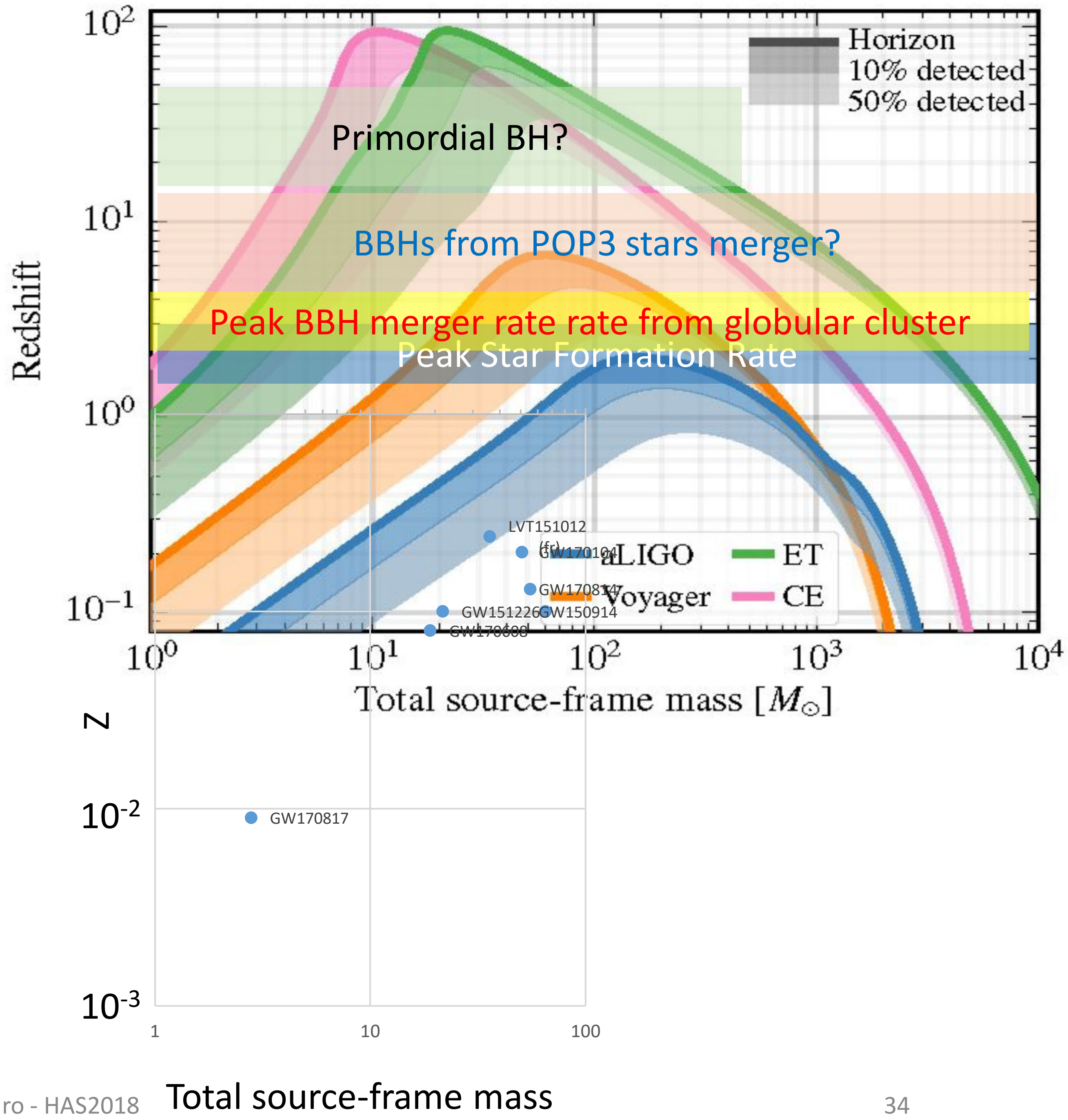
M. Agathos et al, Phys. Rev. D 92, 023012 (2015)



OK, all done?

- aLIGO and AdV achieved awesome results with a reduced sensitivity
- When they will reach or over-perform their nominal sensitivity can we exploit all the potential of GW observations?

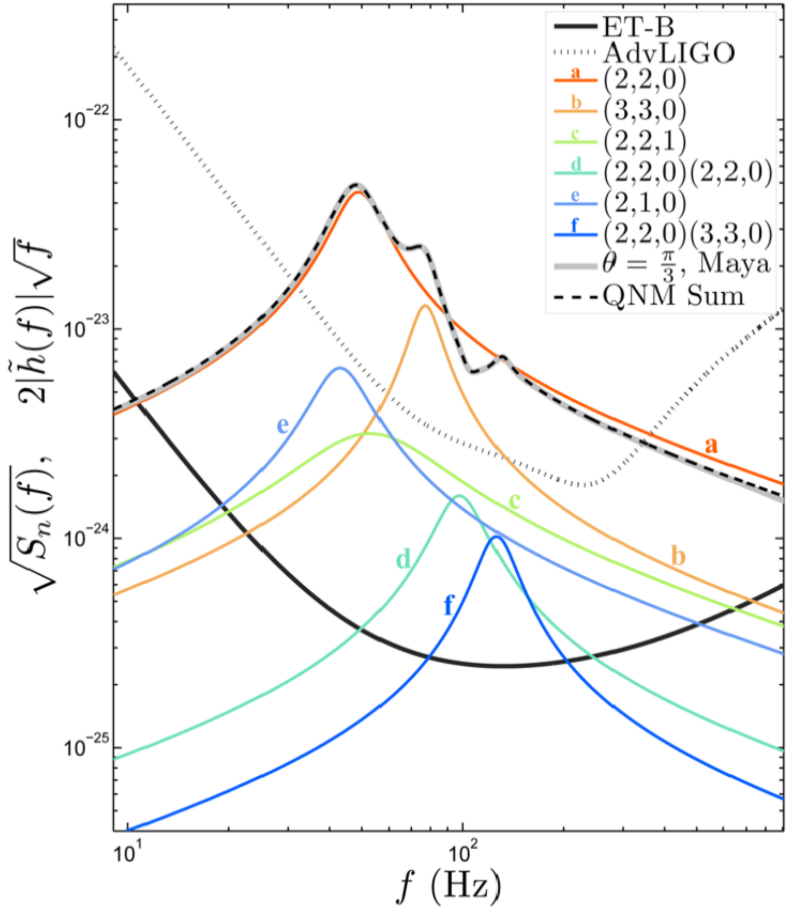
- 2nd generation GW detectors will explore local Universe, initiating the precision GW astronomy, but to have cosmological investigations a factor of 10 improvement in terms detection distance is needed



Extreme gravity

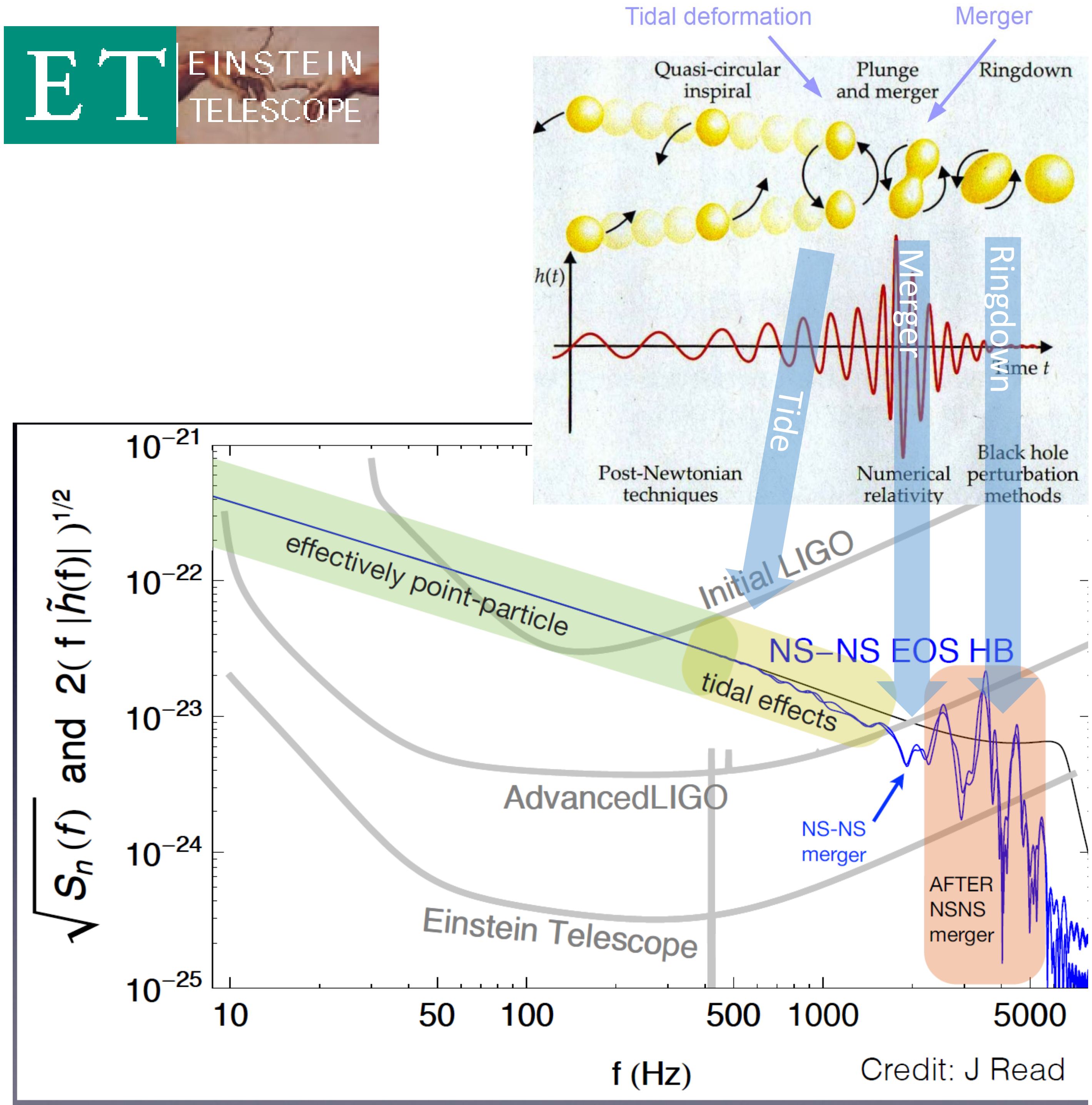
- But, are the massive objects seen by aLIGO and AdV really GR-BBH?
  - Unable to disentangle the QNM
  - Do exotic compact objects (Boson stars, strange stars) exists?
  - Do singularities and event horizons really forms?

350 Msun binary @ 100 Mpc



London et al. 2014

Structure of a Neutron Star

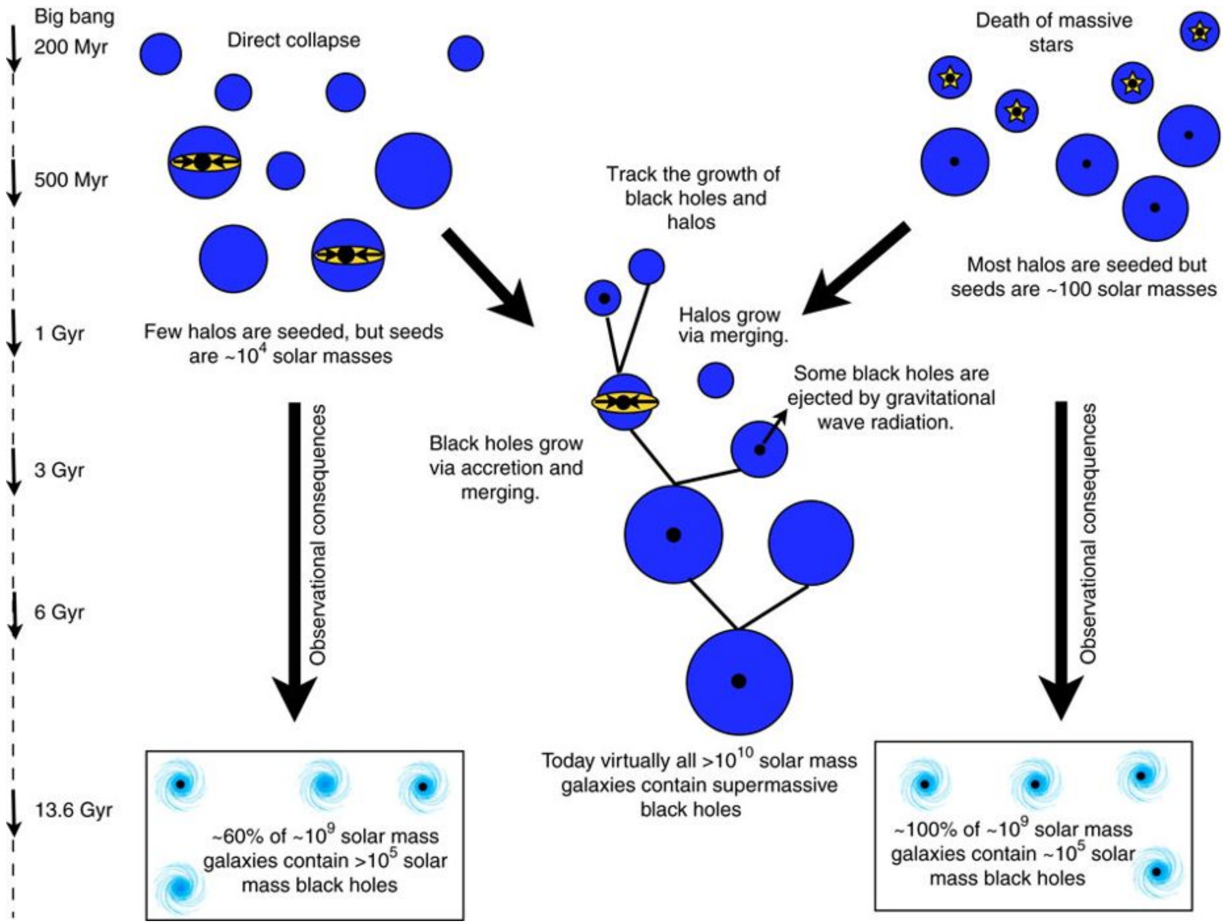


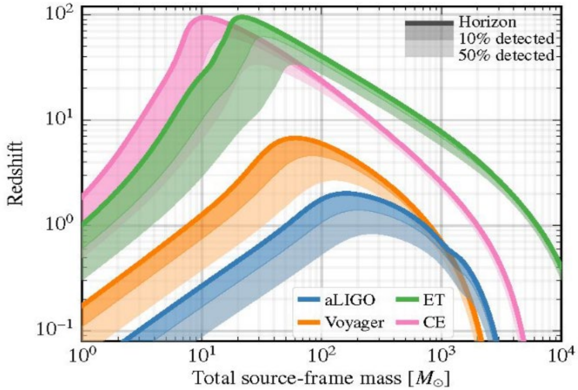
Stephen Fairhurst
ET meeting 27-28 March 2017

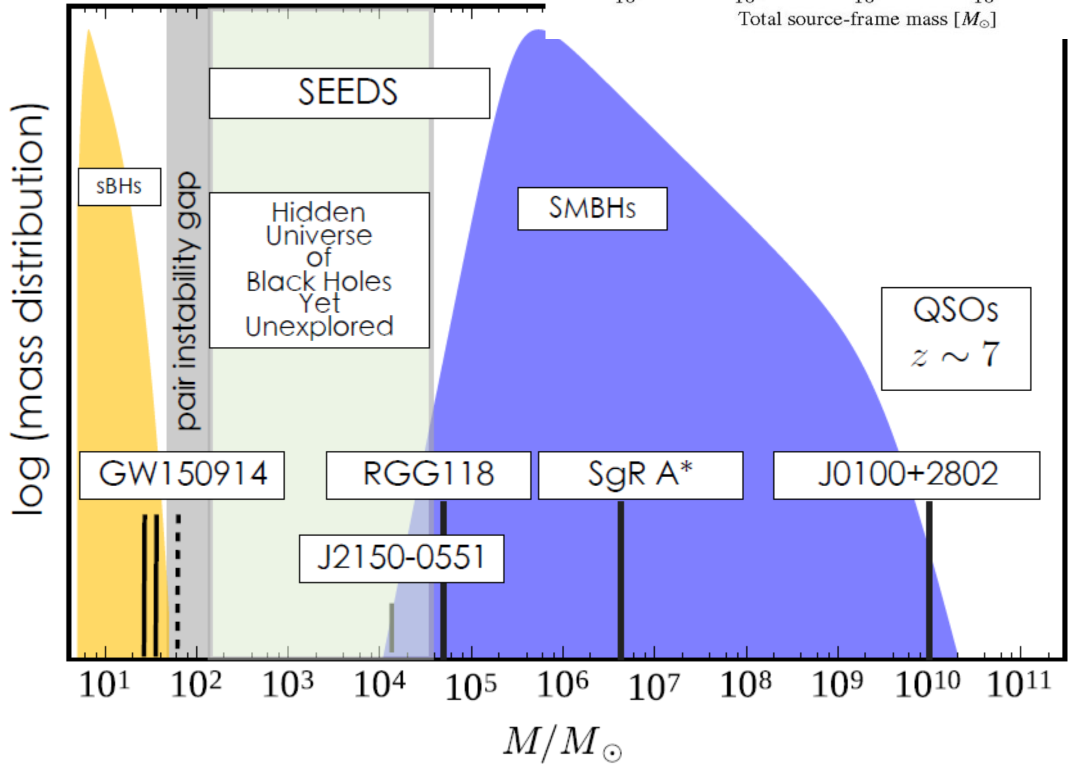
Low frequency?

Seeds and Supermassive Black Holes

- Supermassive Black Holes (SMBHs) are present at the center of many galaxies:
  - What is their history? How they formed? What are the seeds?



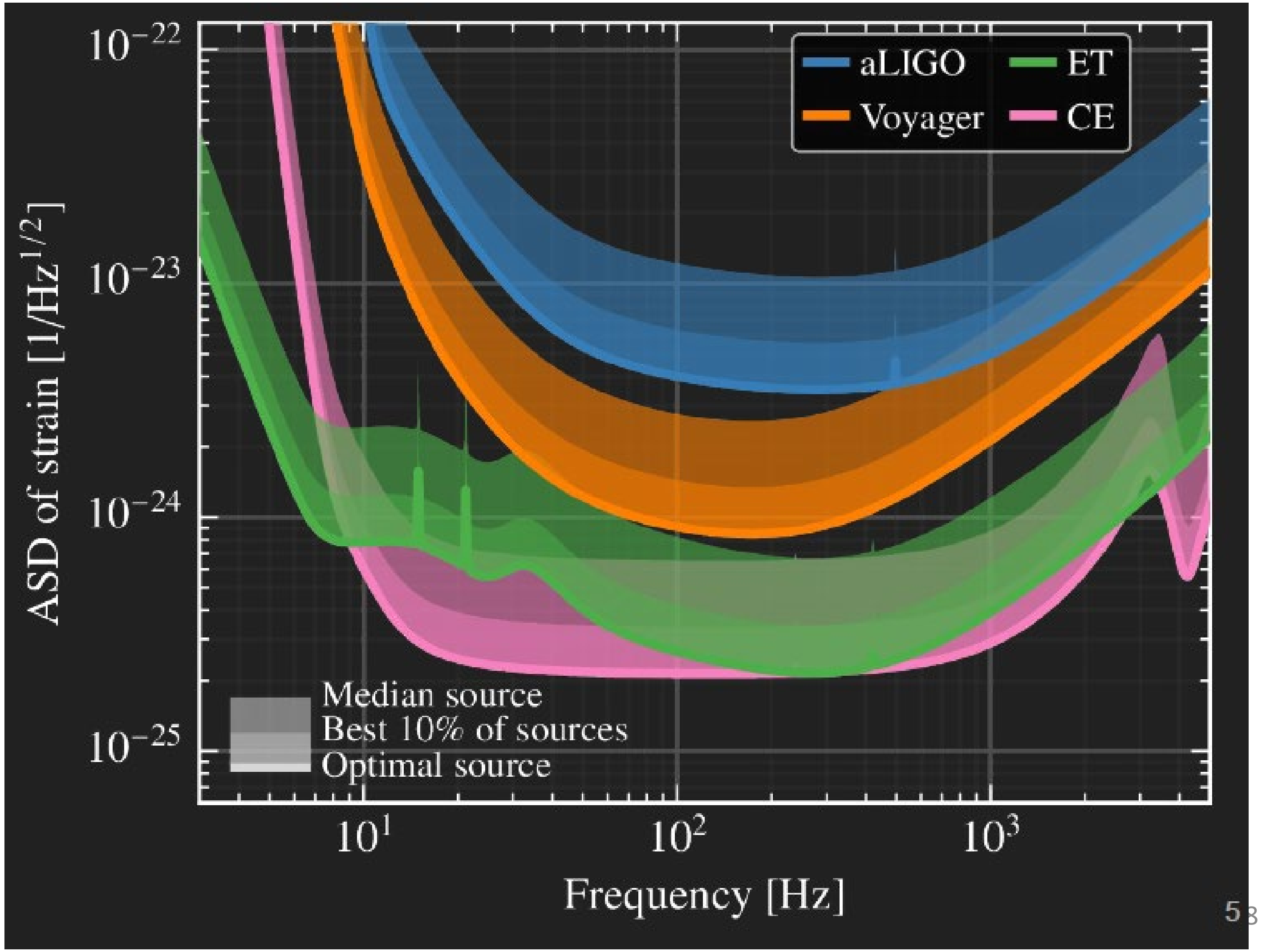


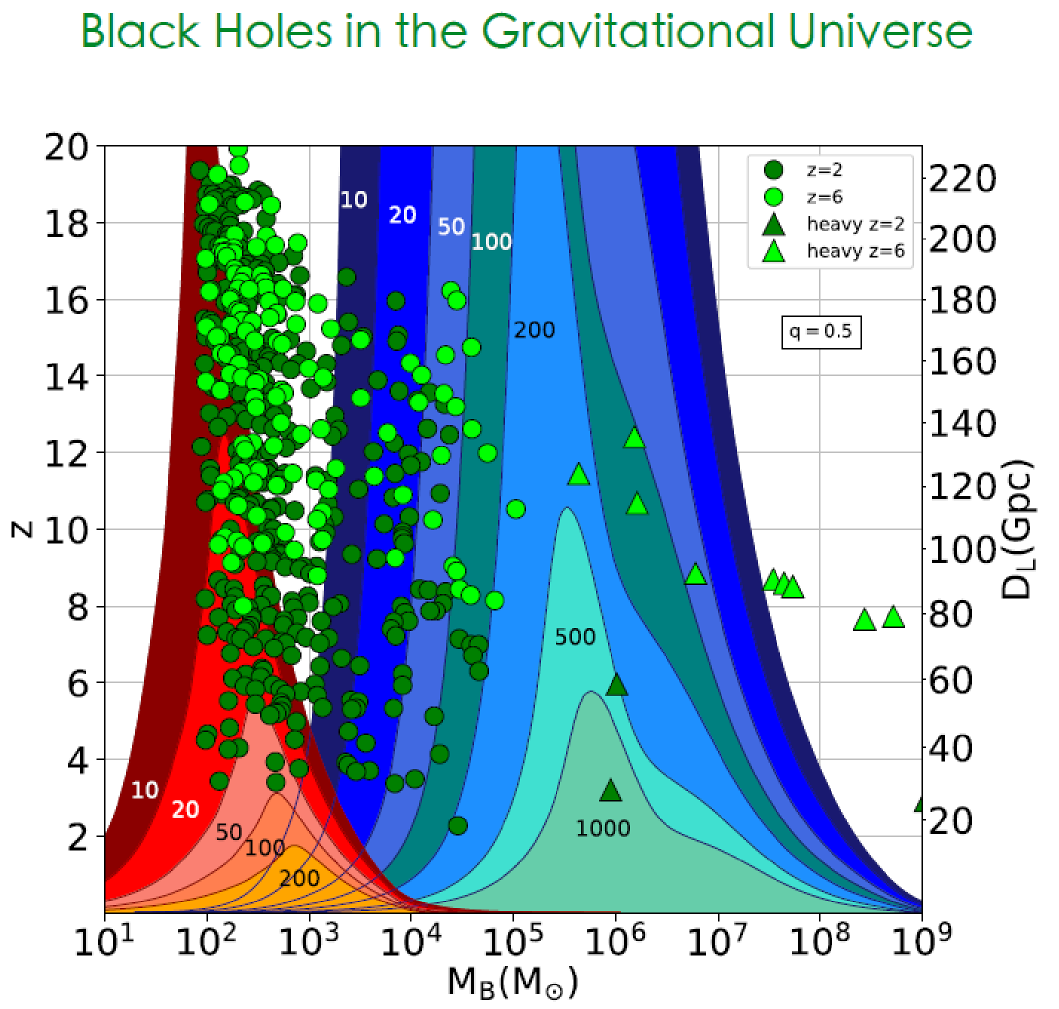


Seeds and Supermassive Black Holes

EINSTEIN TELESCOPE

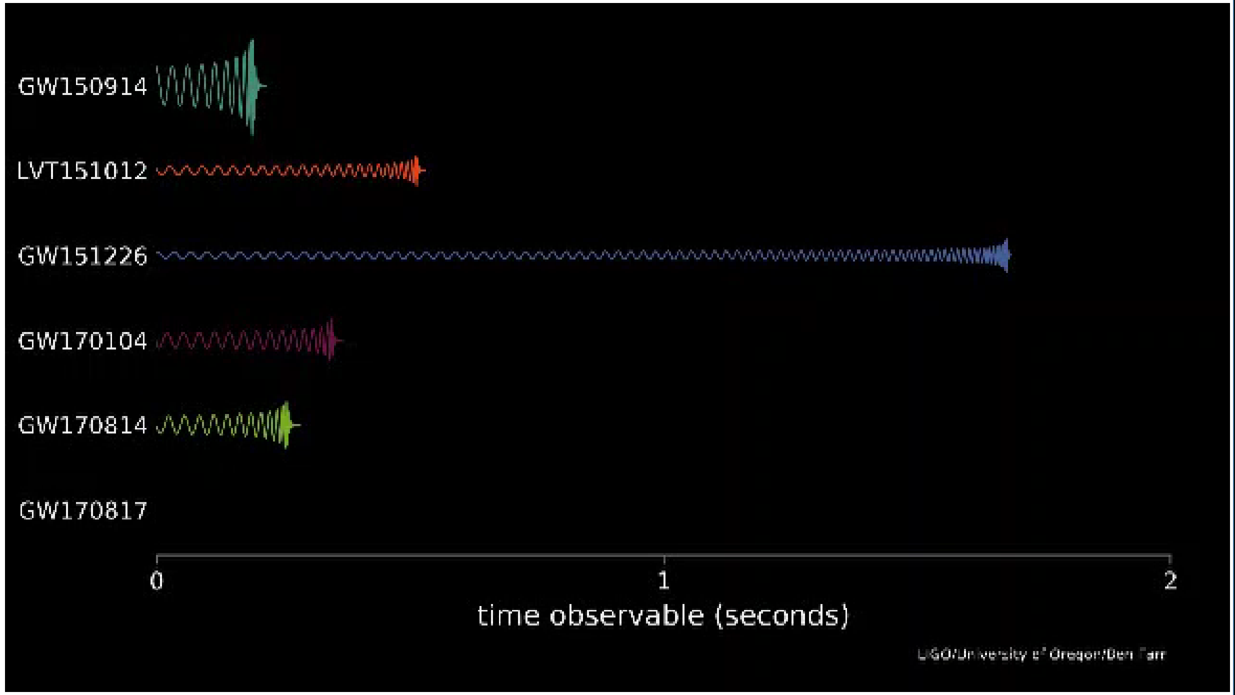
- LISA will detect the coalescences of SMBHs, but what about the seeds?

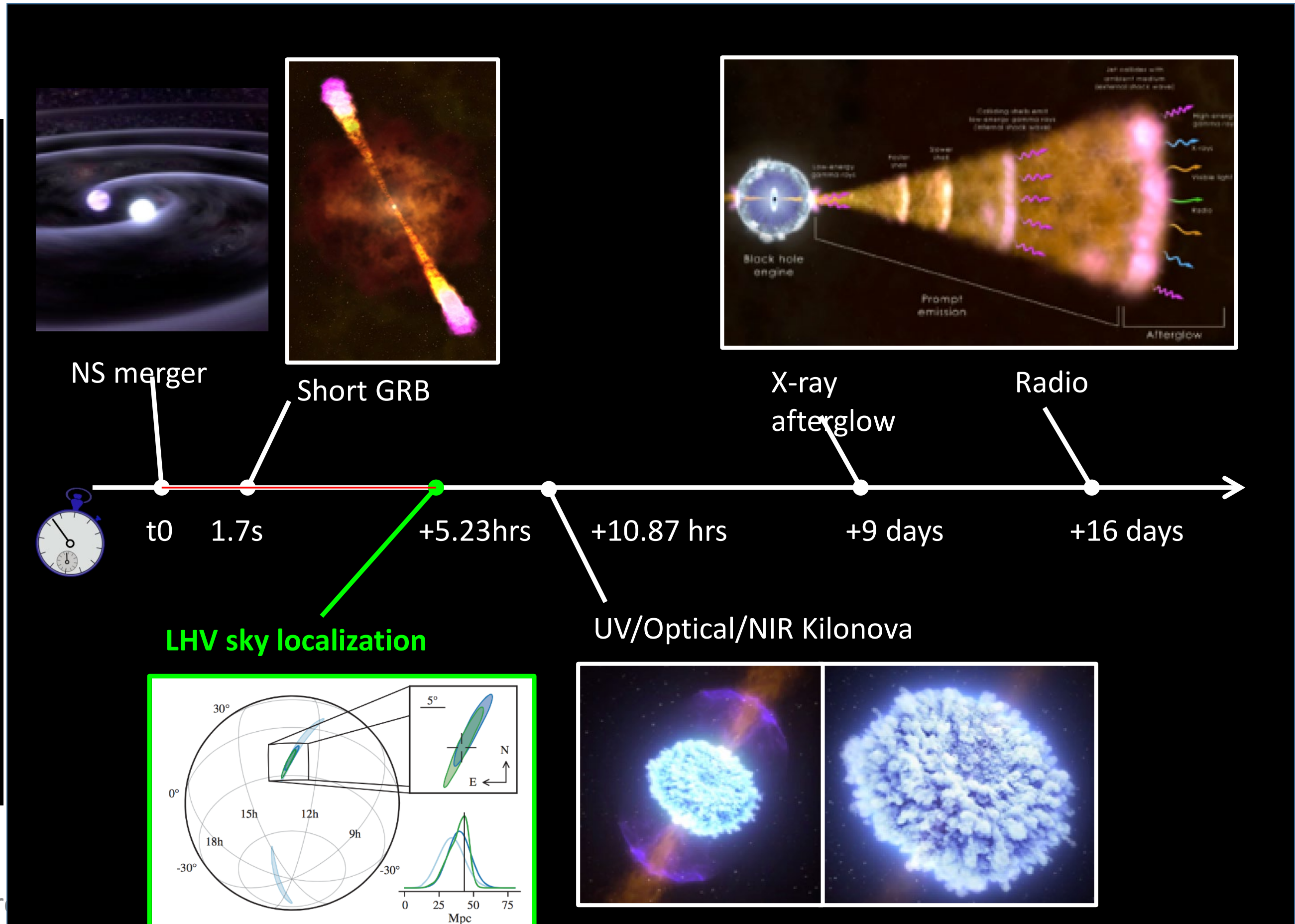




Low frequency: Multi-messenger astronomy

- GW are the only messenger that transport information before the event is occurred
- GW170817 is present in LIGO/Virgo outputs for dozens of seconds, but the trigger to telescopes is arrived with a certain delay

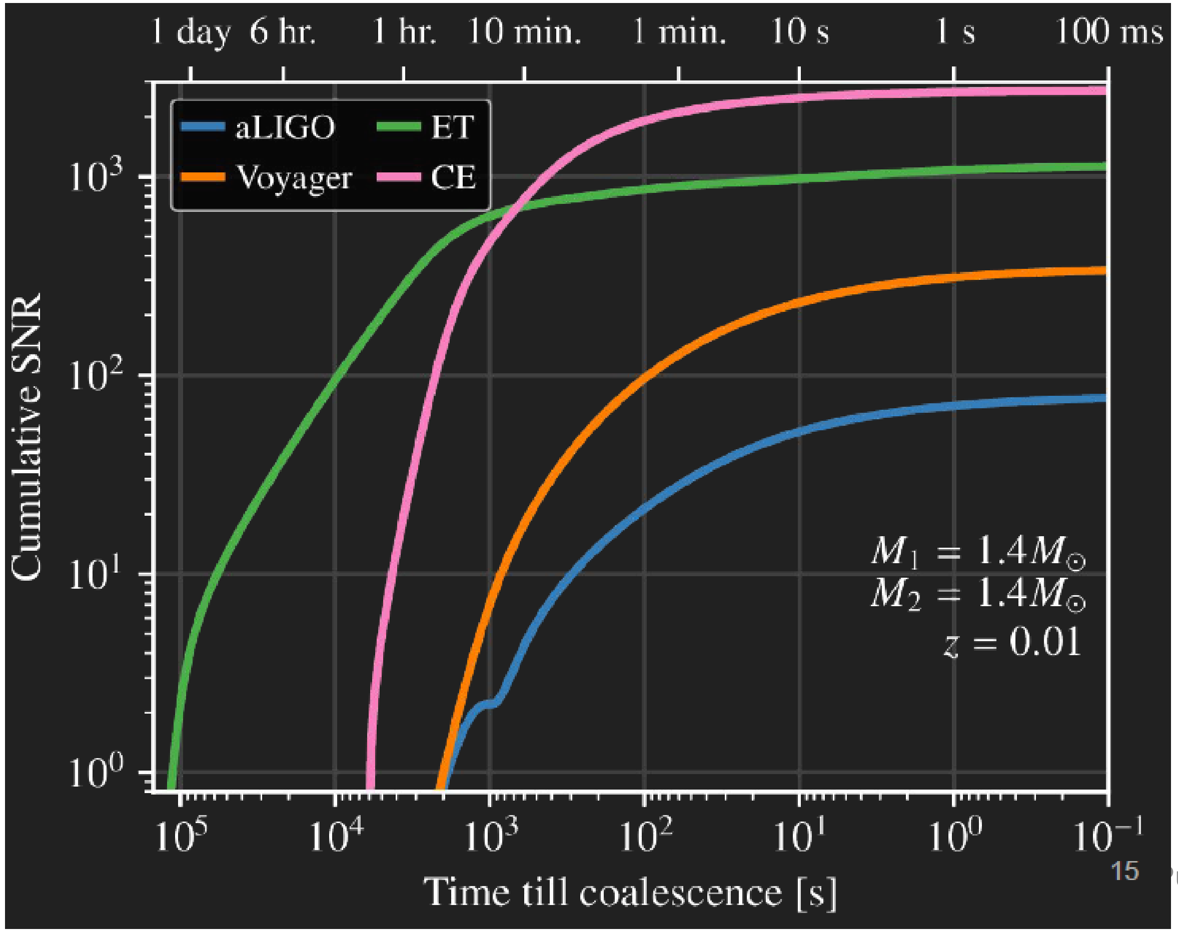


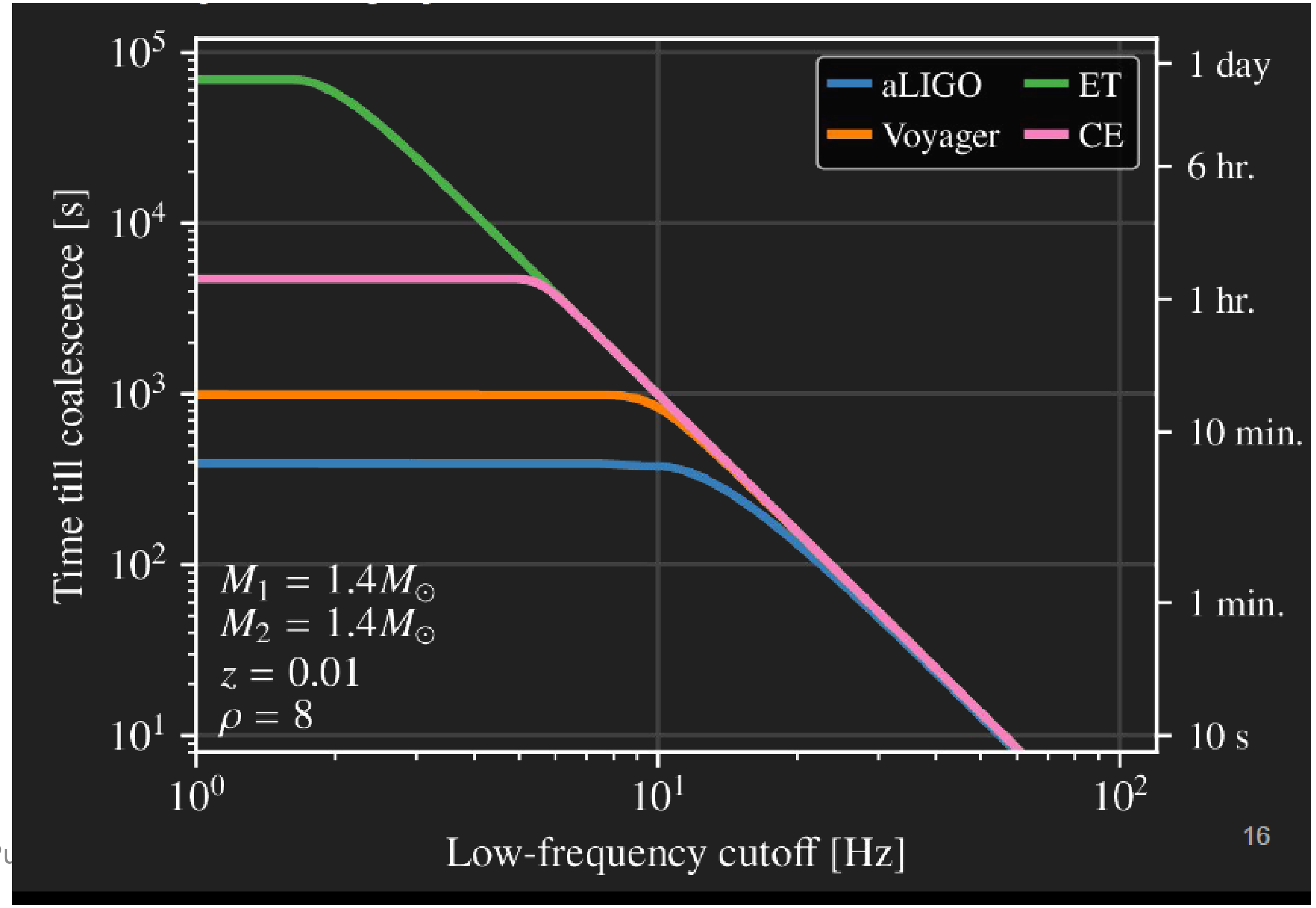


LVC + astronomers, ApJL, 848, L12

Low frequency: Multi-messenger astronomy

- If we are able cumulate enough SNR before the merging phase, we can trigger e.m. observations before the emission of photons
- Keyword: low frequency sensitivity:





Realising ET
Where we are?

The European context

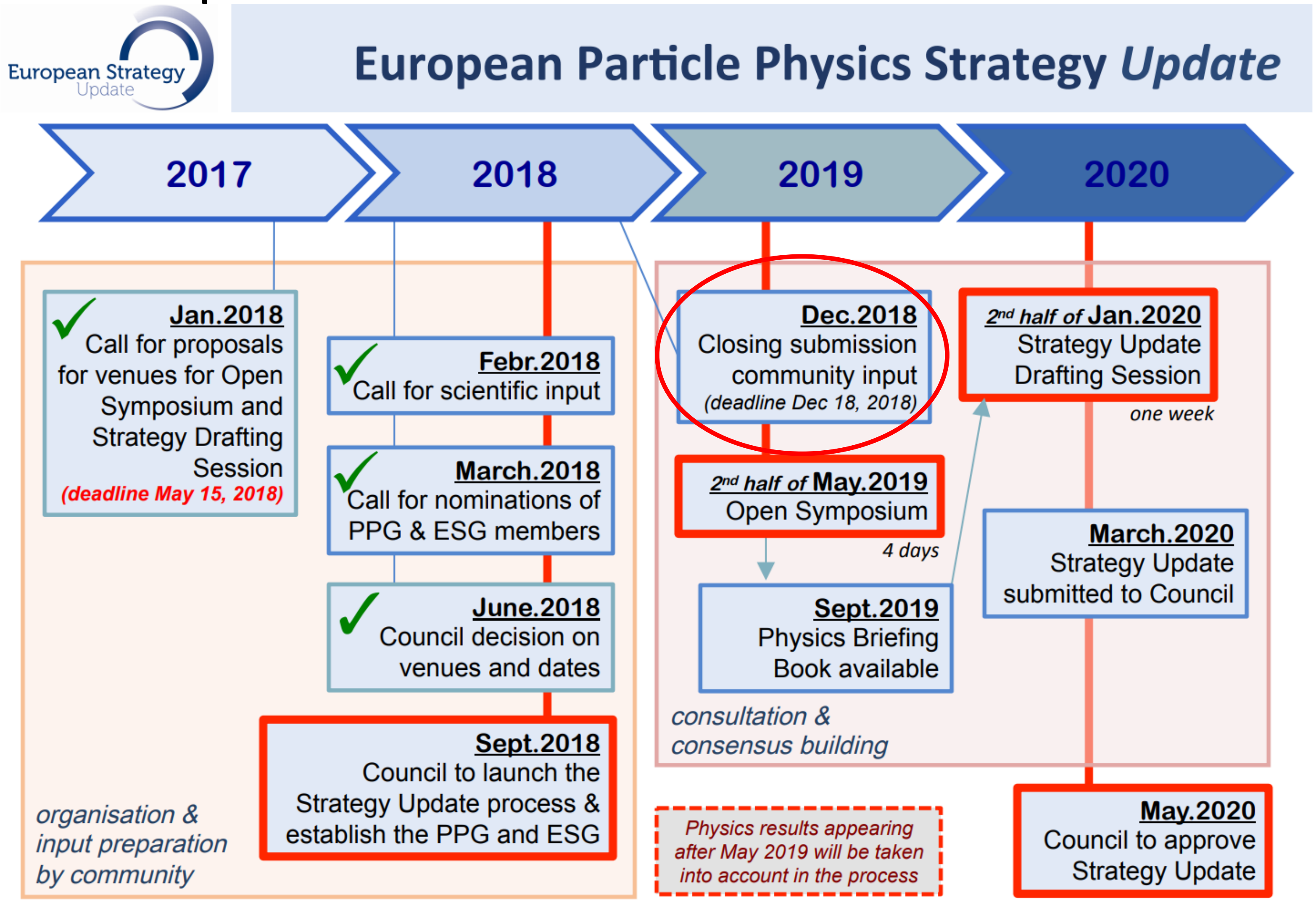
ET: project roadmap

ET EINSTEIN TELESCOPE

- ET has a clearly defined project roadmap, presented to APPEC:
  - 2018-2019 Form the ET collaboration
  - 2019-2020 ESFRI roadmap
    - In Apr 2019 ET and the GW GRI (Global Research Infrastructure) will be presented as case study to the G7 body GSO (Group of Senior Officer)
    - We need to define the site selection parameters before to submit the proposal
      - The requirement to be compliant with alternative design options (Δ vs L) could be a crucial point
  - 2022 Site Selection
    - Technical/political activity
    - Requirements need to be compared with the site characteristics through an intense experimental activity in the next 3 years
  - 2023 Full Technical Design Report ← Here, the design options are frozen
  - Cost definition
  - 2025 Infrastructure realization start (excavation, ….)
  - 2030 -2031 end of infrastructure construction, beginning of installation
  - 2032+: installation / commissioning / operation

European Strategy on Particle Physics

- Stimulate the reciprocal interest between GW and HEPP communities

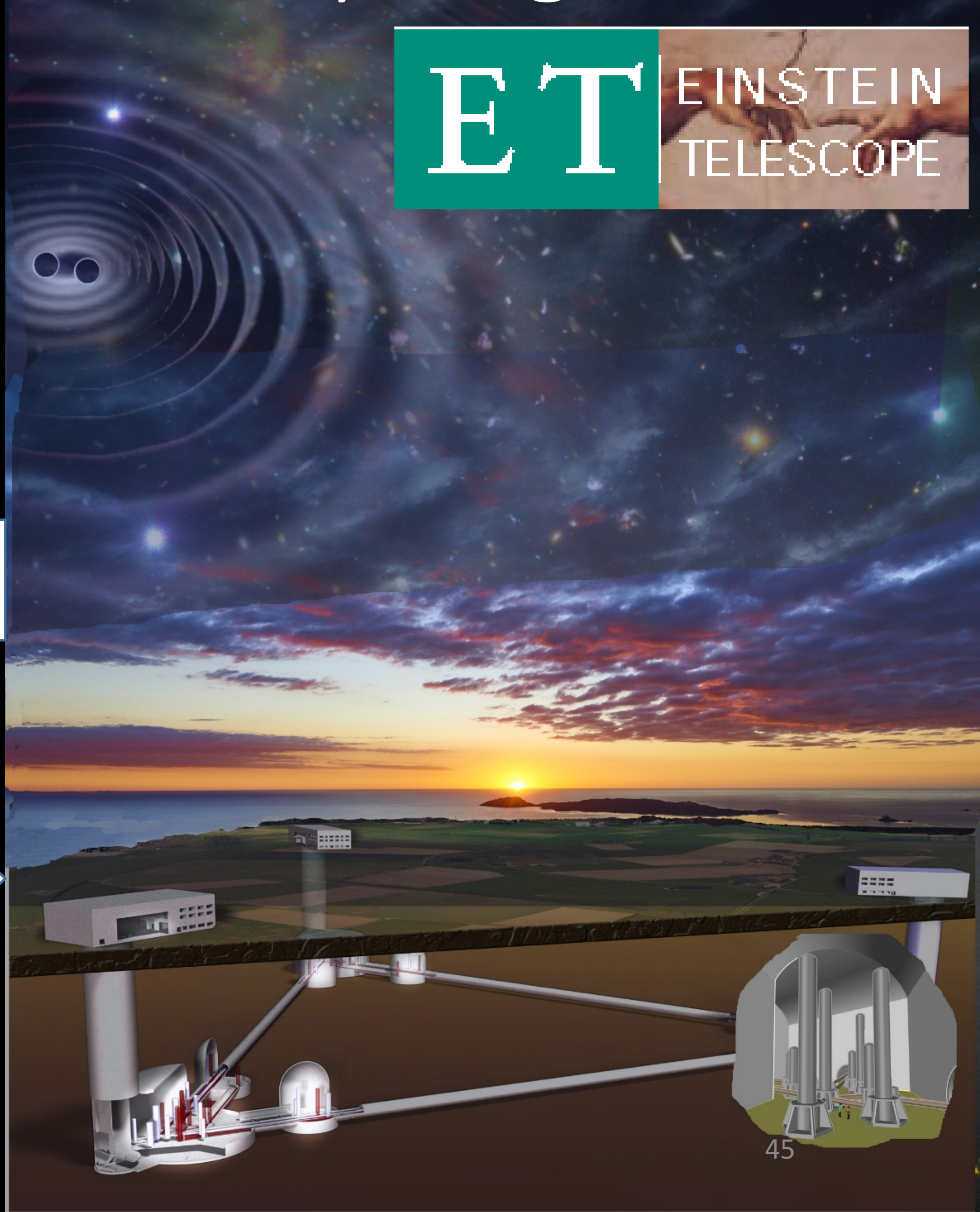


HEPP and GW physics similitudes & synergies

- Synergies
  - There are strong synergies in the Physics and Technologies in the two fields
  - Physics: GW → HEPP
  - Technology: HEPP → GW

Physics

Technology

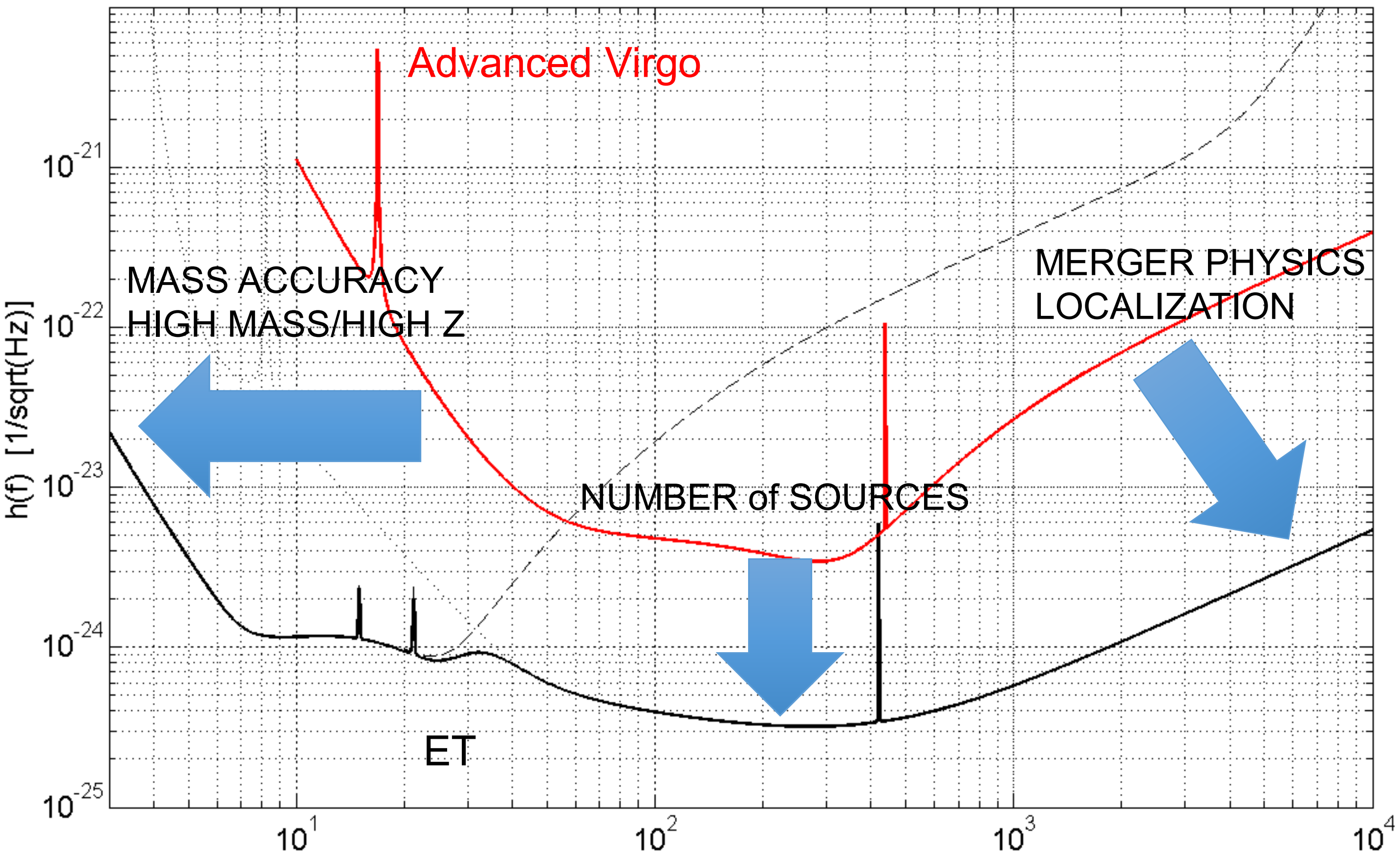


Technologies HEPP → GW

- Current and future GW detectors can hugely benefit of the technologies developed at CERN for HEPP
- ET needs from CERN/HEPP:
  - Underground infrastructures
    - Civil Engineering
  - Cryogenics (~10K)
    - Large, underground plants, low noise
      - Controls, Safety, handling
  - Vacuum ($<10^{-10}$ mbar)
    - ET, the largest volume under vacuum
      - Controls, safety, handling
  - Material and surface science
    - Special materials, surface treatments
  - Electronics/Data acquisition
    - Monitoring, timing, high rate DAQ
  - Computing
    - Data handling, computing methods, GRID, GPUs

Enabling Technologies

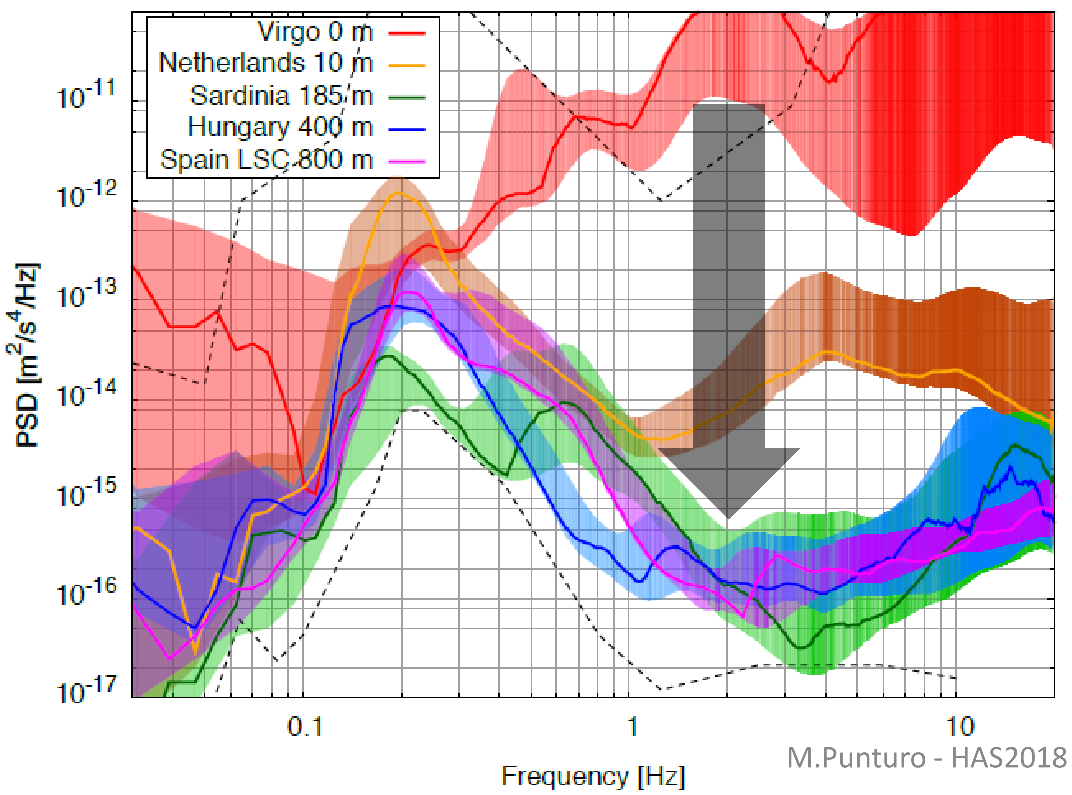
SENSITIVITY GOAL: ~×10 better



Widening the band: low frequency

- Low frequency limitation for GW detectors is given by the seismic noise and Newtonian noise
  - Both can be reduced going underground

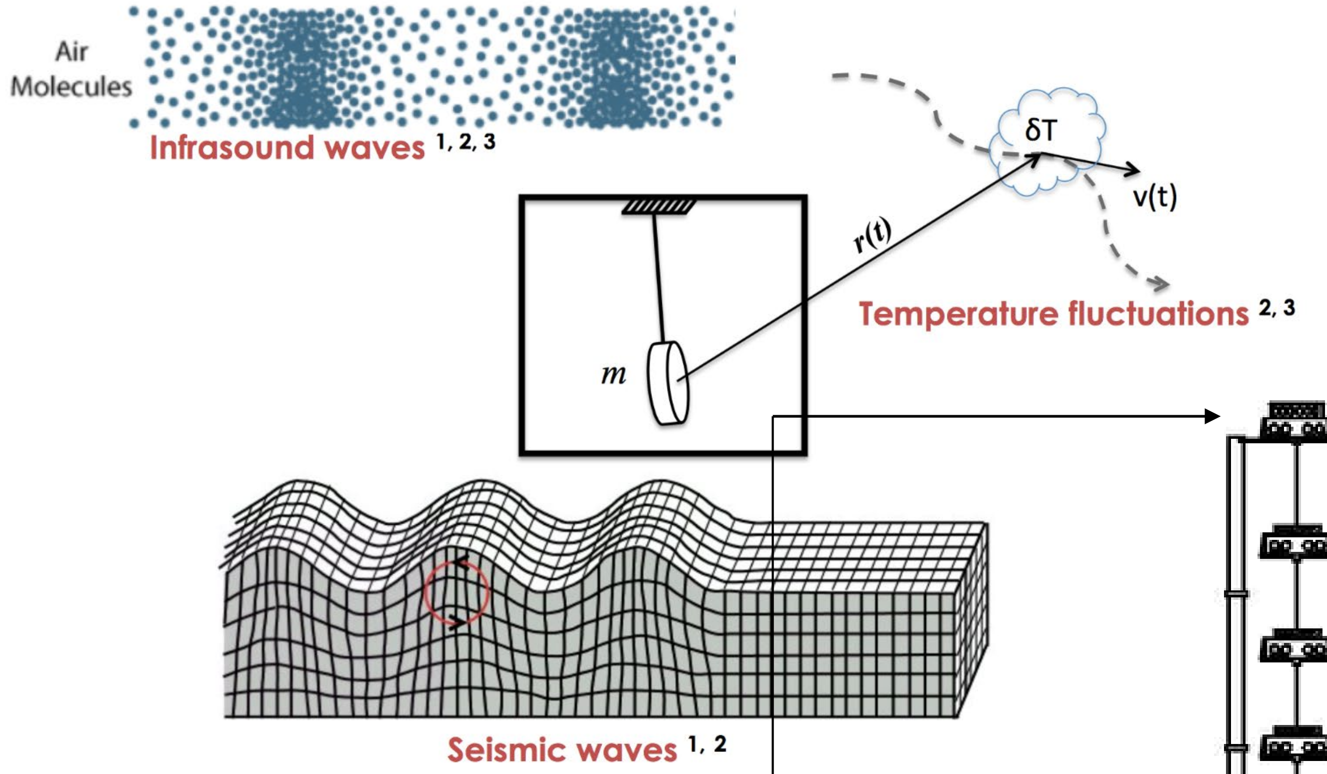
Horizontal spectral motion at various sites



noise at 2 Hz reduced by ~2 orders of magnitude

ET design study

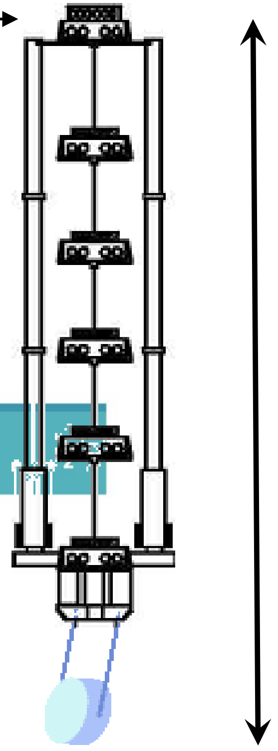
Newtonian Noise



[1] Saulson Phys. Rev. D **30**, 732, [2] J. Harms Terrestrial Gravity Fluctuations,
[3] Creighton CQG. **25** (2008) 125011, C.Cafaro, S. A. Ali arXiv:0906.4844 [gr-qc]

NEWTONIAN NOISE

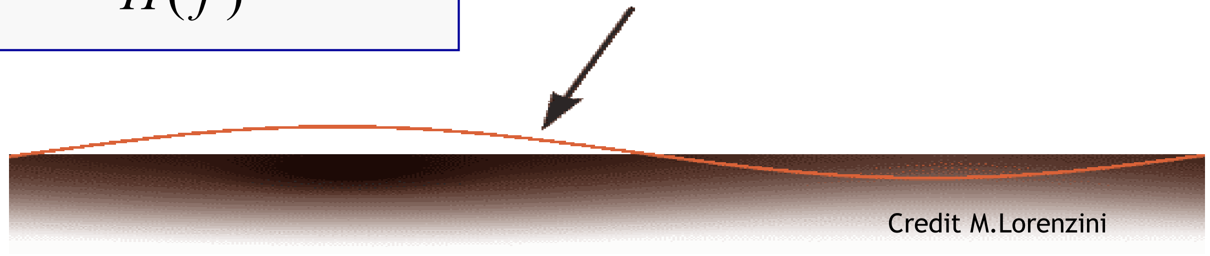
$$\tilde{h}(f) = const. \times \frac{G\rho_0}{H(f)} \cdot x_0(f)$$



Virgo ~ 9m

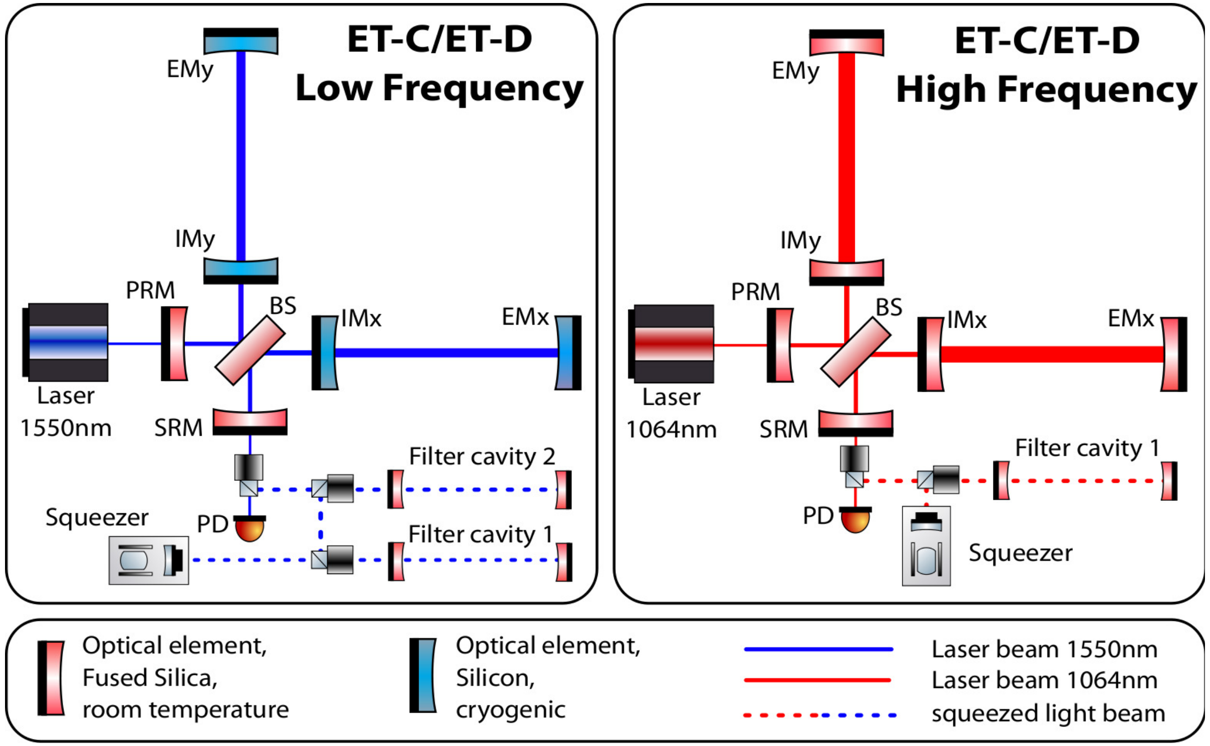
ET ~ 17m ?

Huge impact on the infrastructure cost: Enabling Technology!

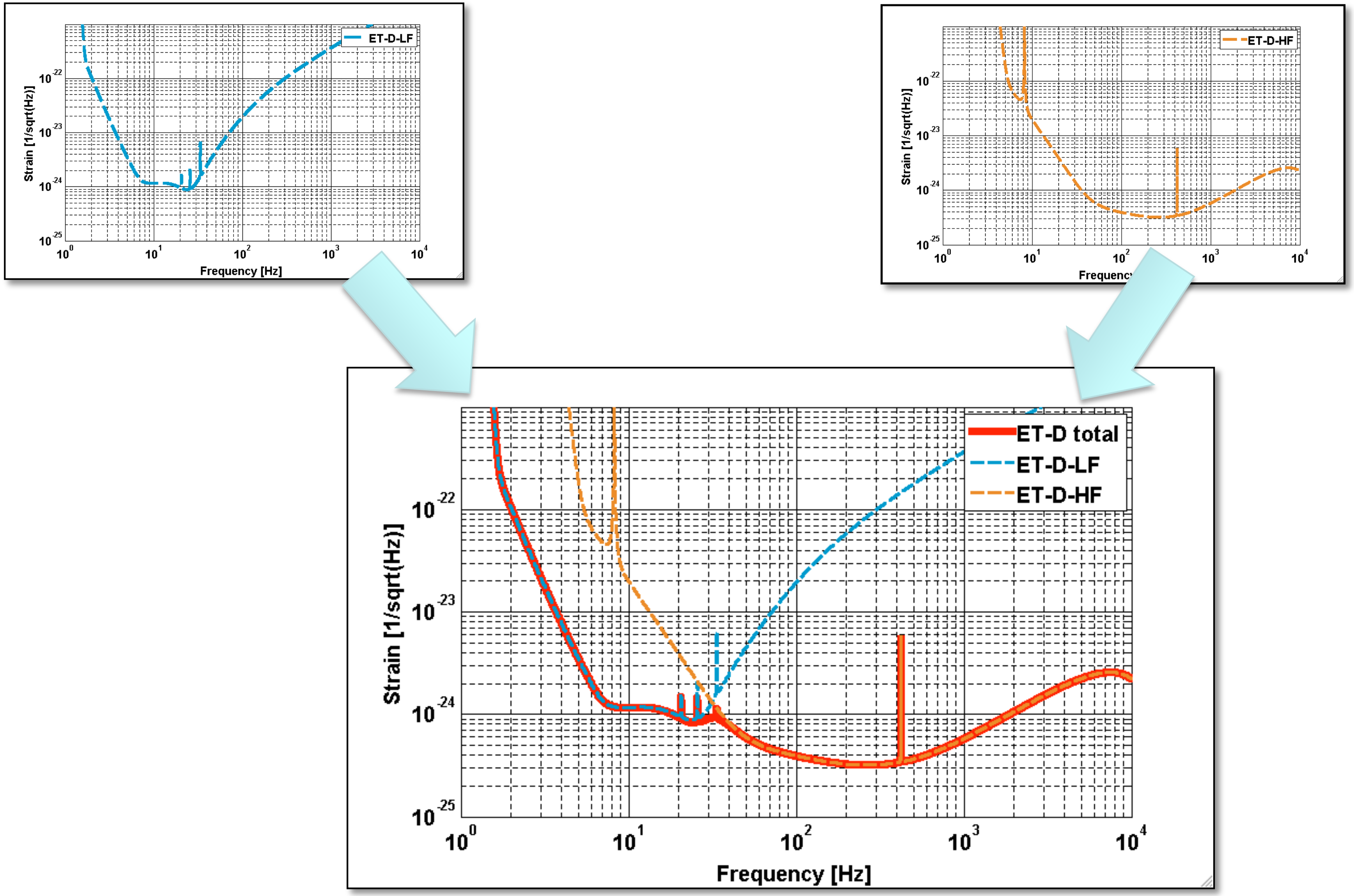


WIDEN THE BAND: XYLOPHONE

- Improving al low and high frequency with a single detector is very challenging
  - HF requires more laser power
  - LF requires cold mirrors
- Idea: split the detection band over 2 “specialized” instruments



Xylophone principle



Technologies

- The main ingredients are:
  - Size: 10km vs 3km
  - Xylophone design: ET-LF, ET-HF

- ET-LF:
  - Underground
  - Cryogenics
  - Silicon (Sapphire) test masses
  - Large test masses
  - New coatings
  - New laser wavelength
  - Seismic suspensions
  - Frequency dependent squeezing

- ET-HF:
  - High power laser
  - Large test masses
  - New coatings
  - Thermal compensation
  - Frequency dependent squeezing

Cryogenics

- ET design asks for 10-20K operation temperature
  - How to cool down without introducing vibrational noises?
  - How to cool down without polluting the mirrors?
  - How to cool down in a way compatible with the commissioning activities? (KAGRA bad experience)
  - How to realise cryostats having a reduced footprint
    - Impact on the infrastructure cost due to special cross-compatibility between the different interferometers
- Collaboration with KAGRA is a "must"

Enabling technologies

Cryogenic Materials

- Silicon indicated as first choice material (Sapphire as backup solution)
  - Best thermal noise behavior at low temperature
  - Small thermal expansion coefficient (zero) at low temperature
  - “Transparent” at $\lambda \geq 1550$nm
  - Heavily used in industry
- Question marks:
  - Test Masses:
    - Large size samples (r~30cm, M~300kg) are produced through *Czochralski* grown method
      - High optical absorption (hundreds of ppm)
    - Few ppm absorption seems possible with Float Zone method grown samples, but small size samples are produced
    - Magnetic Czochralski samples promise to solve this dilemma
  - Payload:
    - Suspensions in Silicon fibers/ribbons?
      - How to produce them?
      - What are the effective performances (thermal noise, thermal conductibility, ….)?
    - How to assemble the payload through (silicate) bonding?
  - Mirrors:
    - Coatings @ cryogenic Temperature
      - Materials
      - Nano-layers, amorphous / crystalline structure, …

Enabling technologies

Enabling technologies

Squeezing

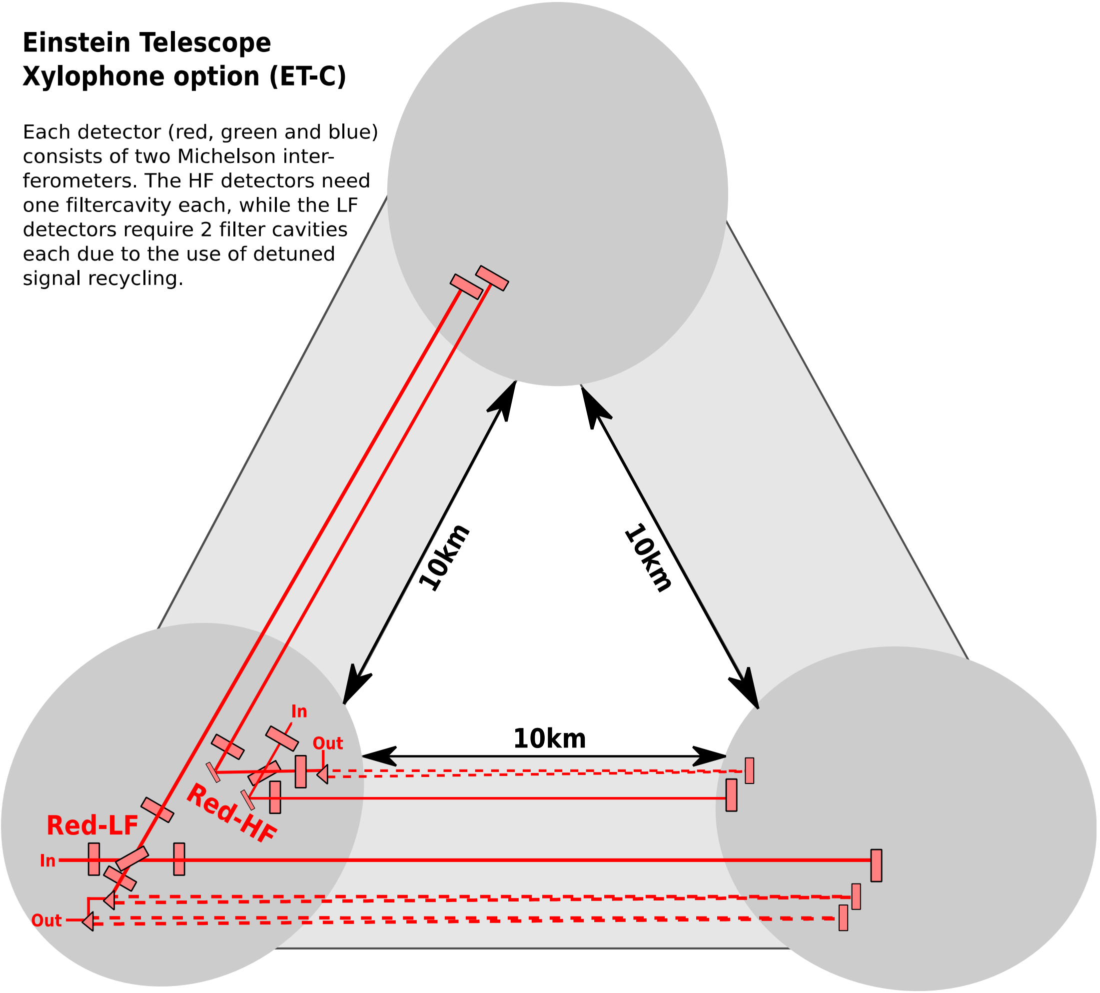
- The frequency dependent squeezing is used both by ET-LF and ET-HF
  - In the ET-LF interferometer requirements are quite stringent
    - Long filtering cavities are imposed by optical requirements
    - Short filtering cavities are suggested by infrastructural constraints
      - Optical design and simulation is necessary to find the optimal compromise

Enabling technologies

EINSTEIN TELESCOPE

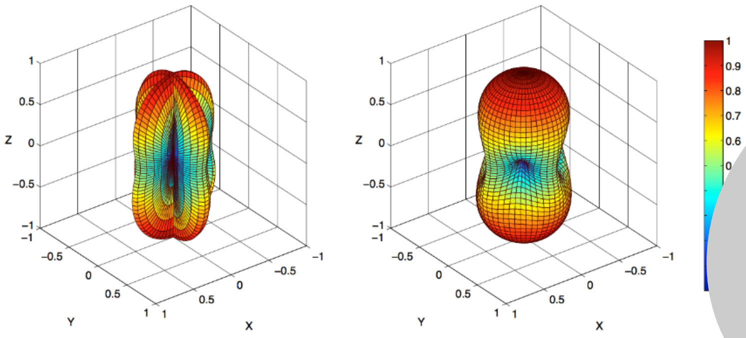
STAND-ALONE OBSERVATORY

- Start with a single (xylophone) detector



STAND-ALONE OBSERVATORY

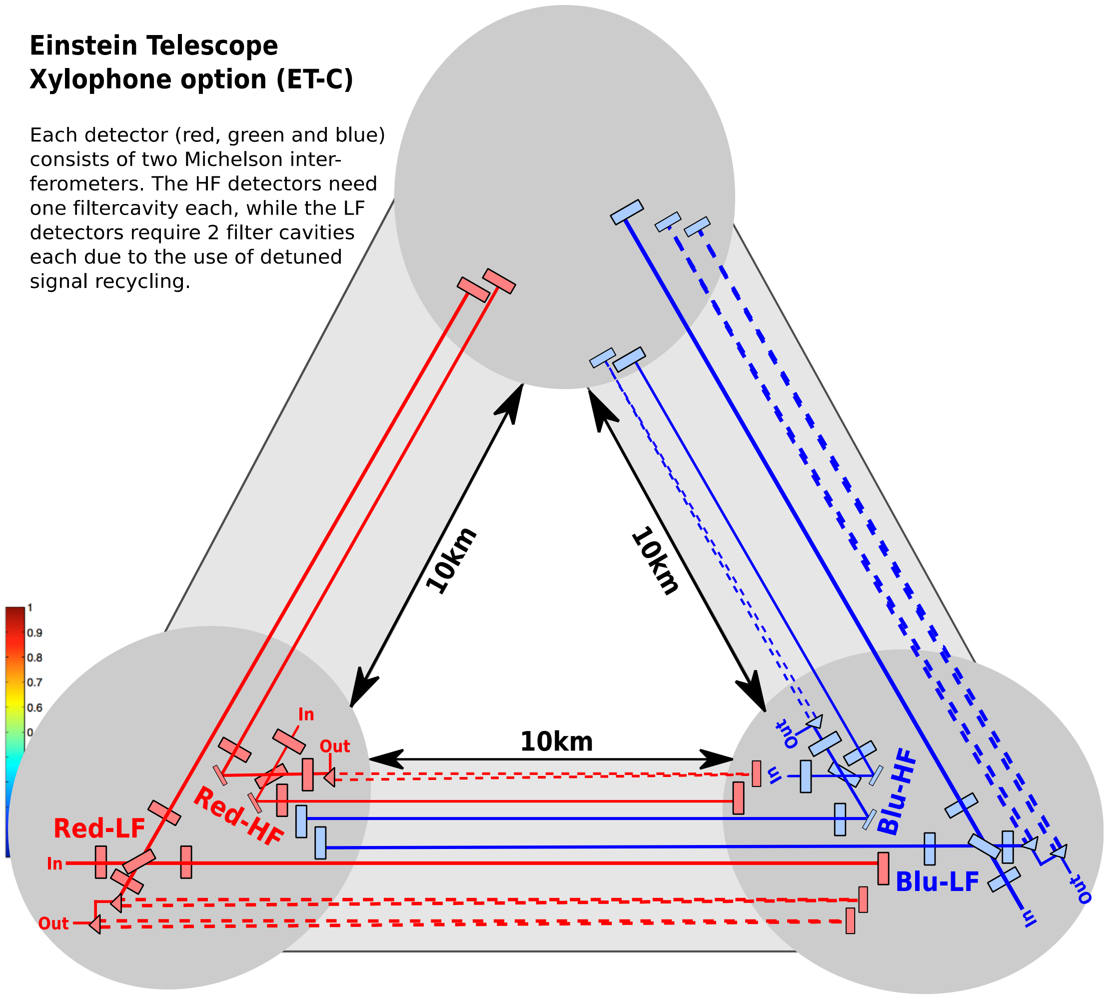
- Start with a single (xylophone) detector
- Add a second one to fully resolve polarizations



Antenna pattern for a polarized GW: simple “L” (left) vs Triangle (right)

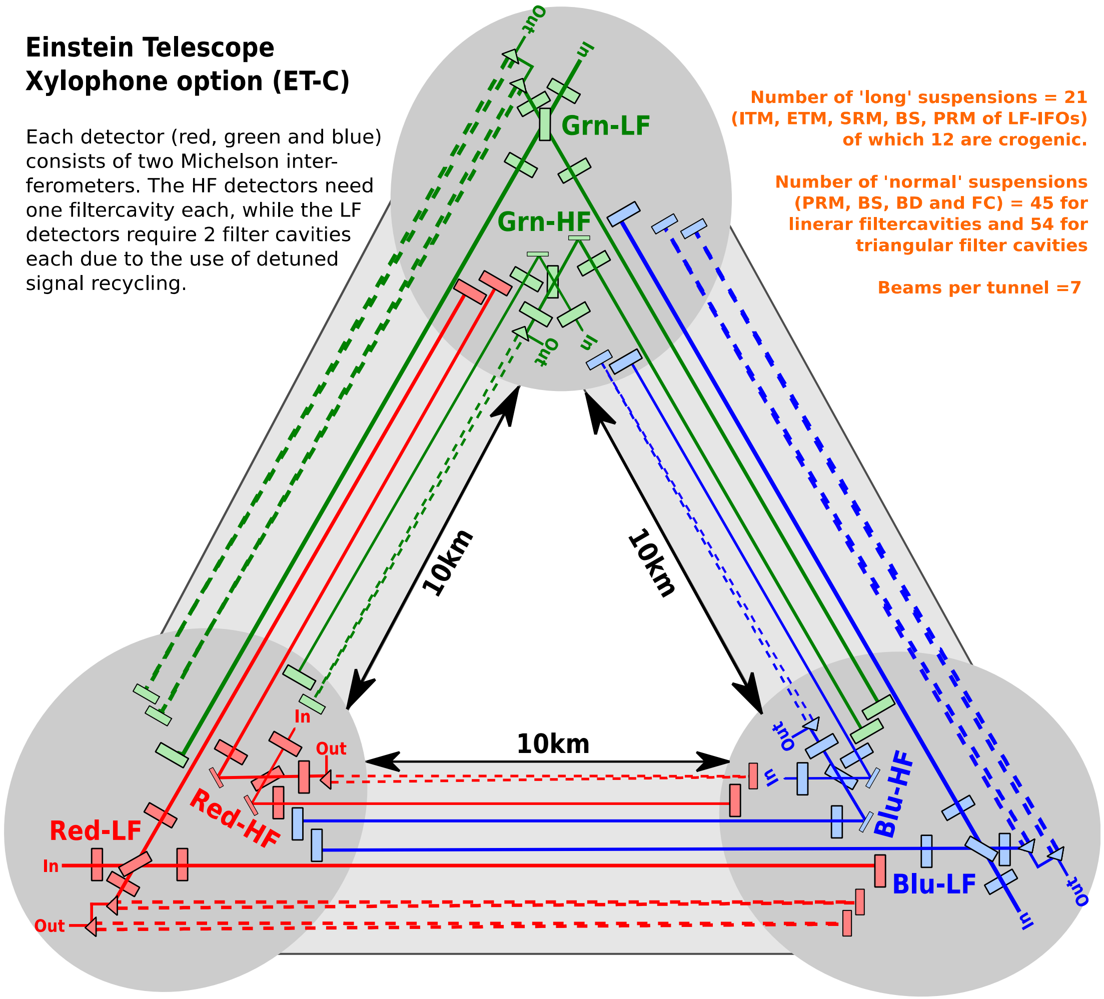
Einstein Telescope Xylophone option (ET-C)

Each detector (red, green and blue) consists of two Michelson interferometers. The HF detectors need one filtercavity each, while the LF detectors require 2 filter cavities each due to the use of detuned signal recycling.



STAND-ALONE OBSERVATORY

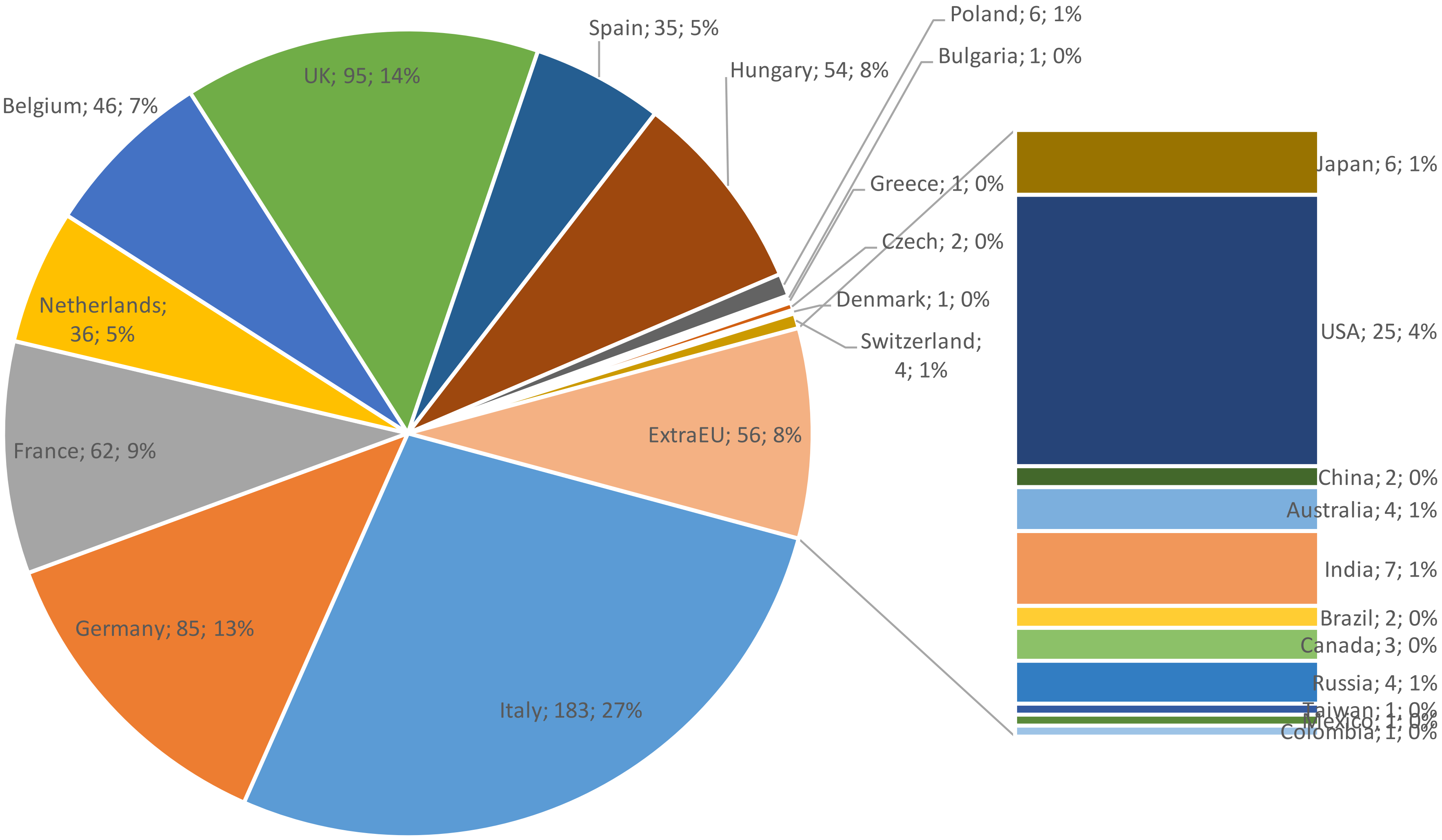
- Start with a single (xylophone) detector
- Add a 2nd one to fully resolve polarization
- Add a 3rd one for null stream and redundancy



Organisation

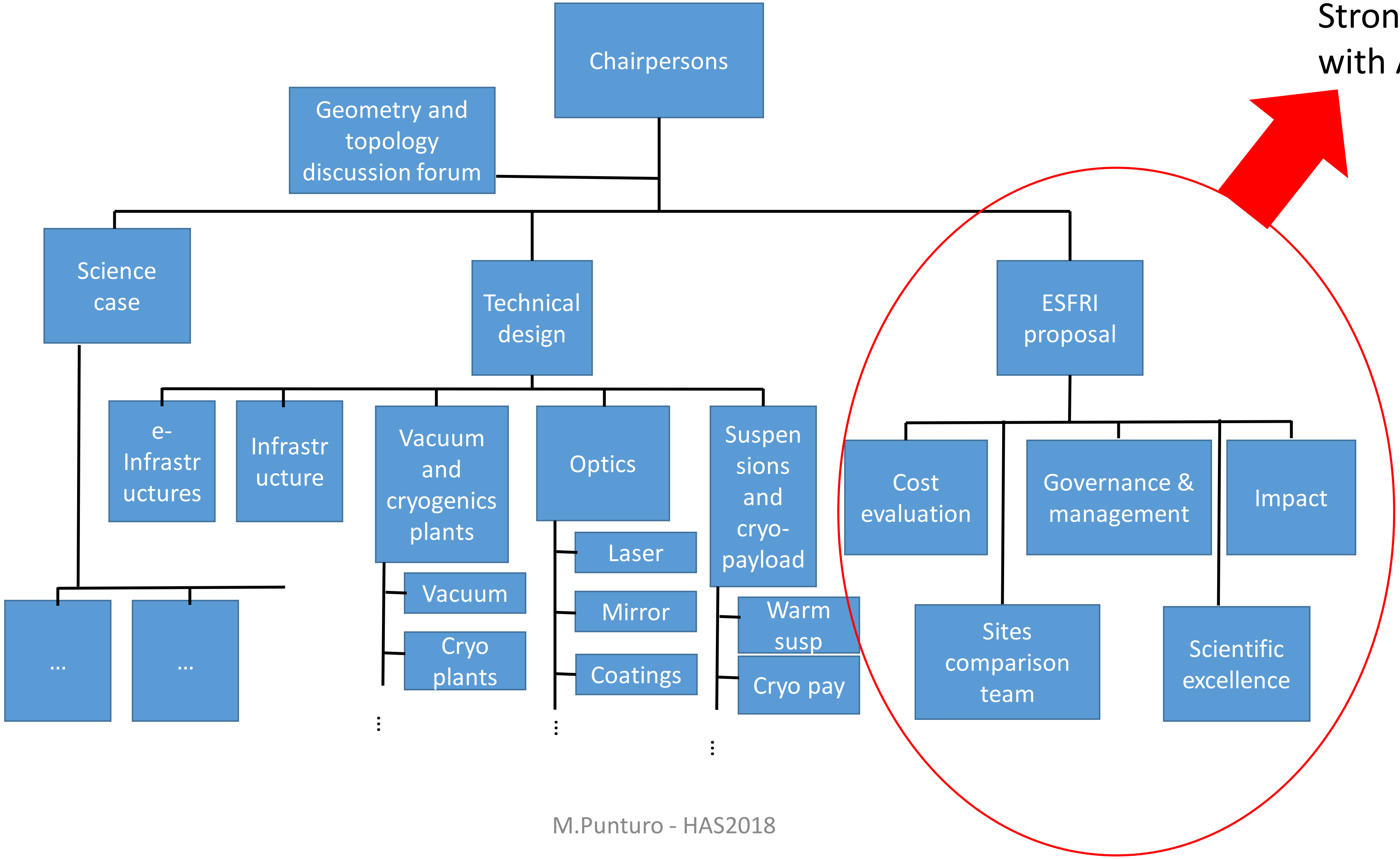
ET collaboration: Letter of Intent

- Addressed to all the scientists and engineers interested to the 3G GW science and technology
- The signatories (667 persons, the 31st of October) probably will become the future members of the ET collaboration



http://www.et-gw.eu/index.php/letter-of-intent

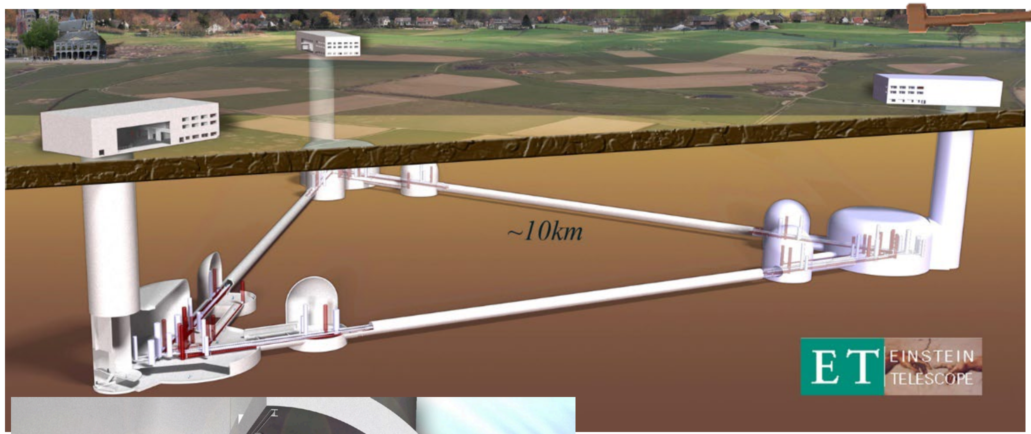
The Executive Board

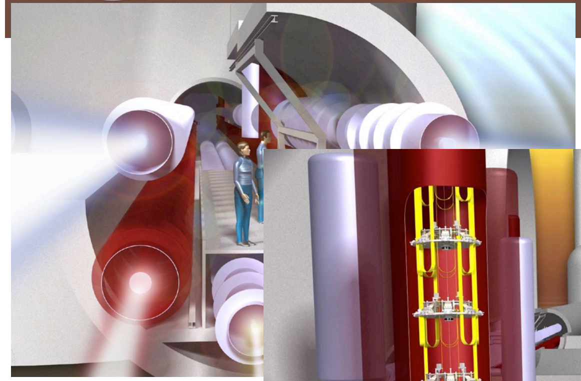


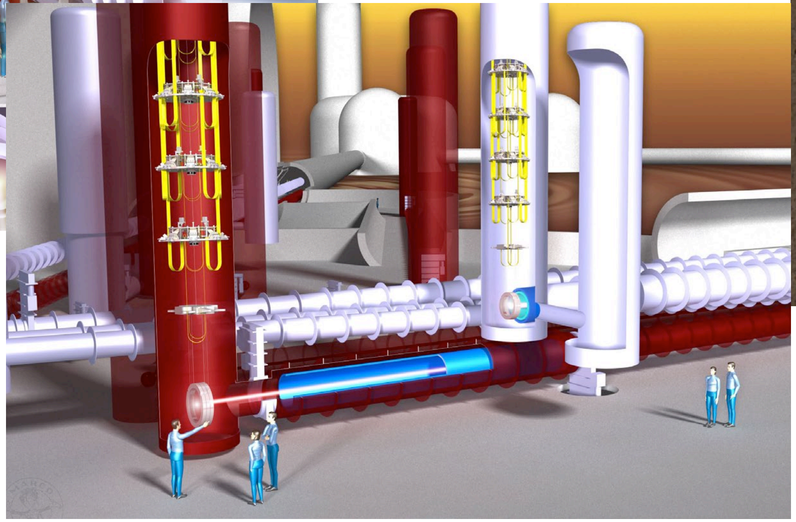
Strong interaction with APPEC

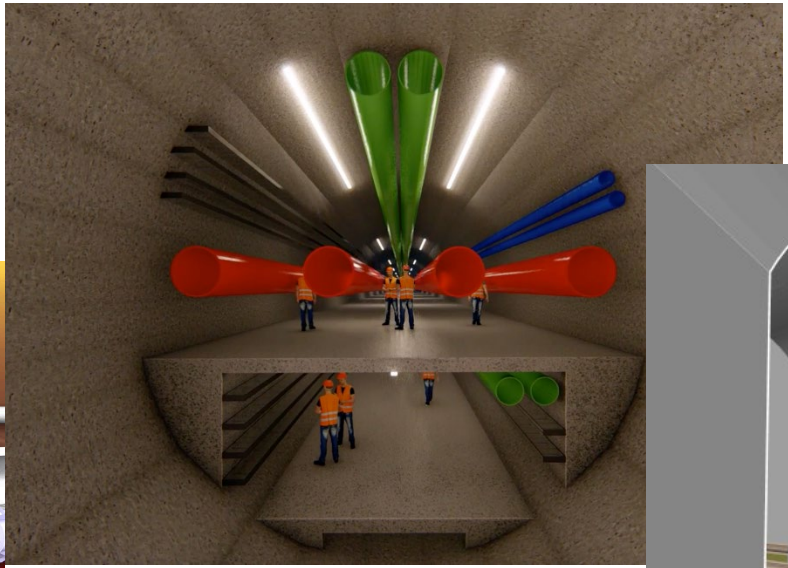
From the conceptual to the technical design

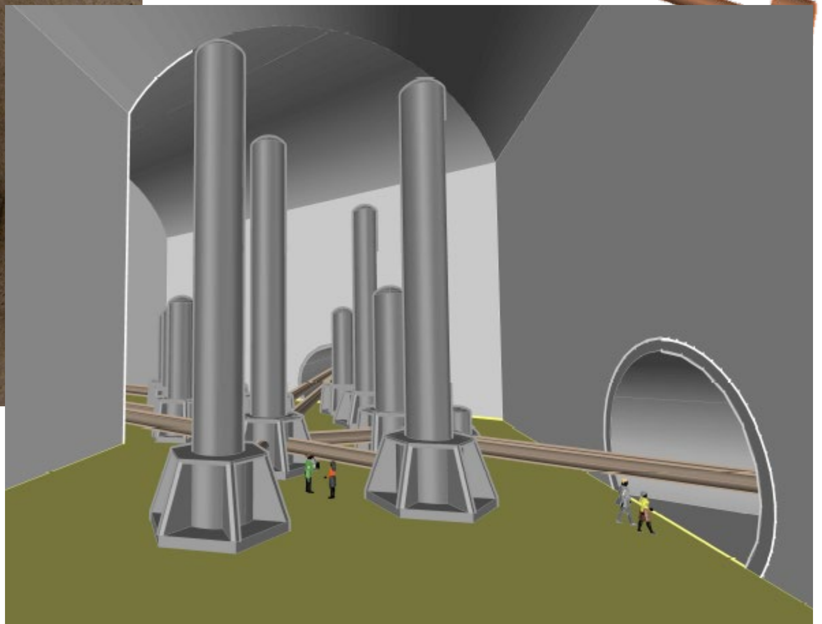
- Currently our efforts are addressed to transform the ET infrastructure concept in a project



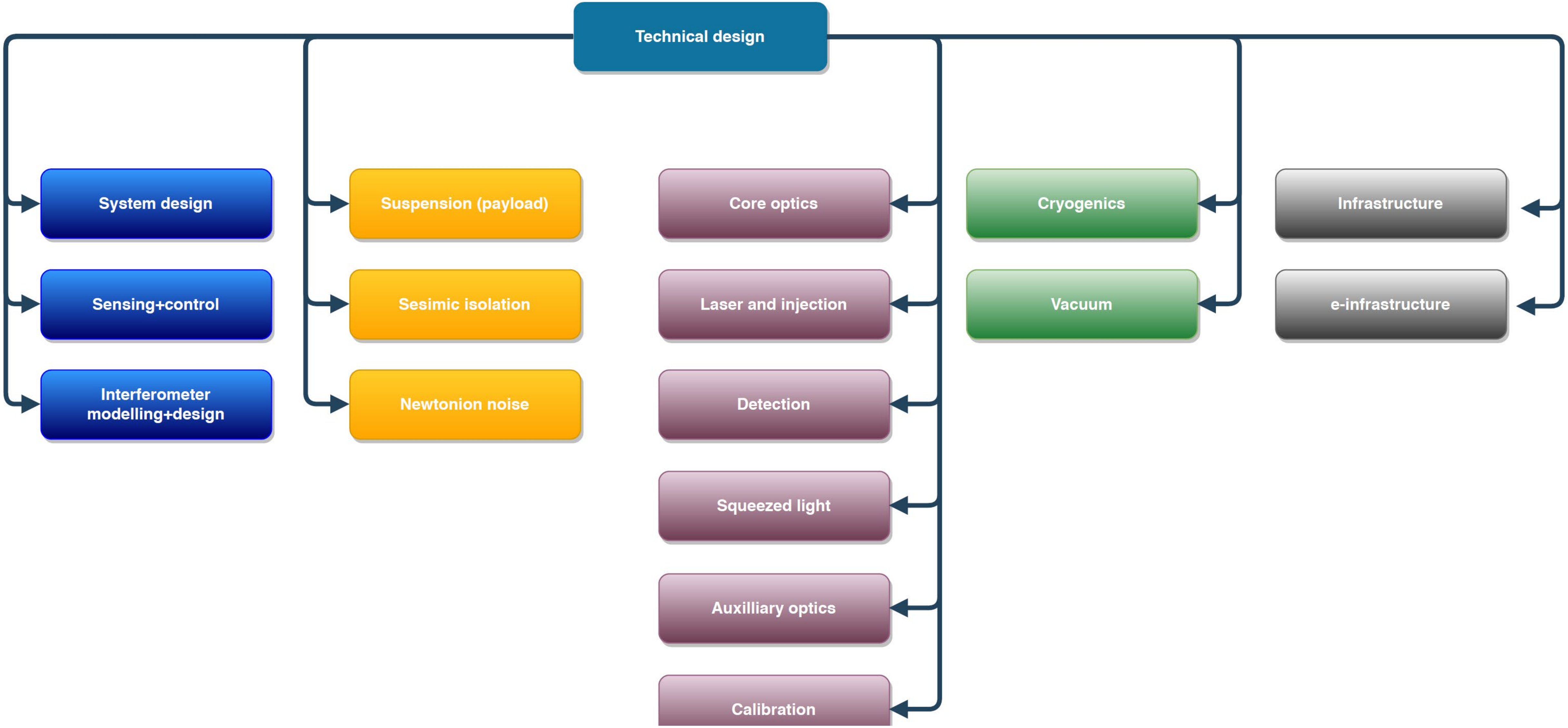








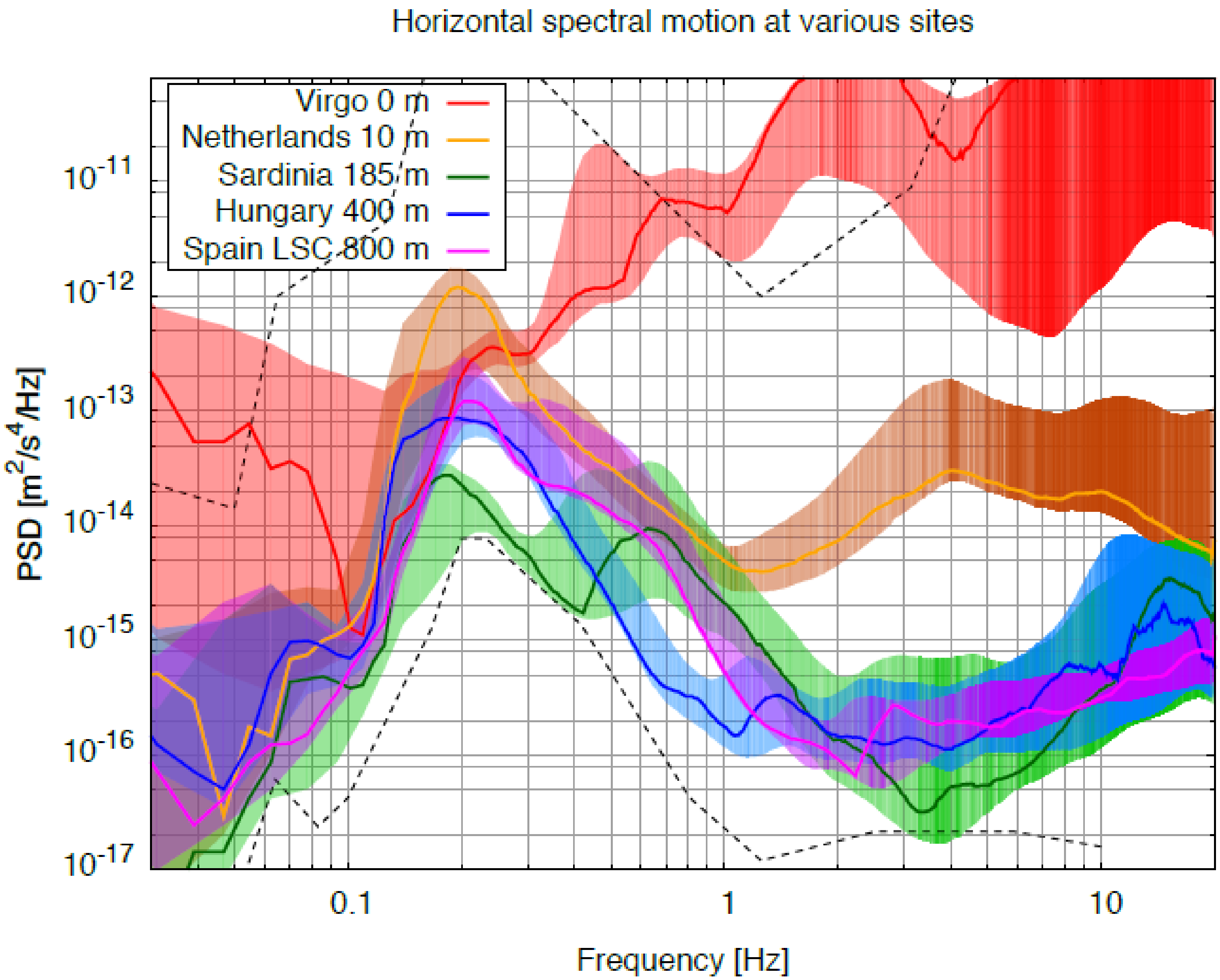
The Technical design Team



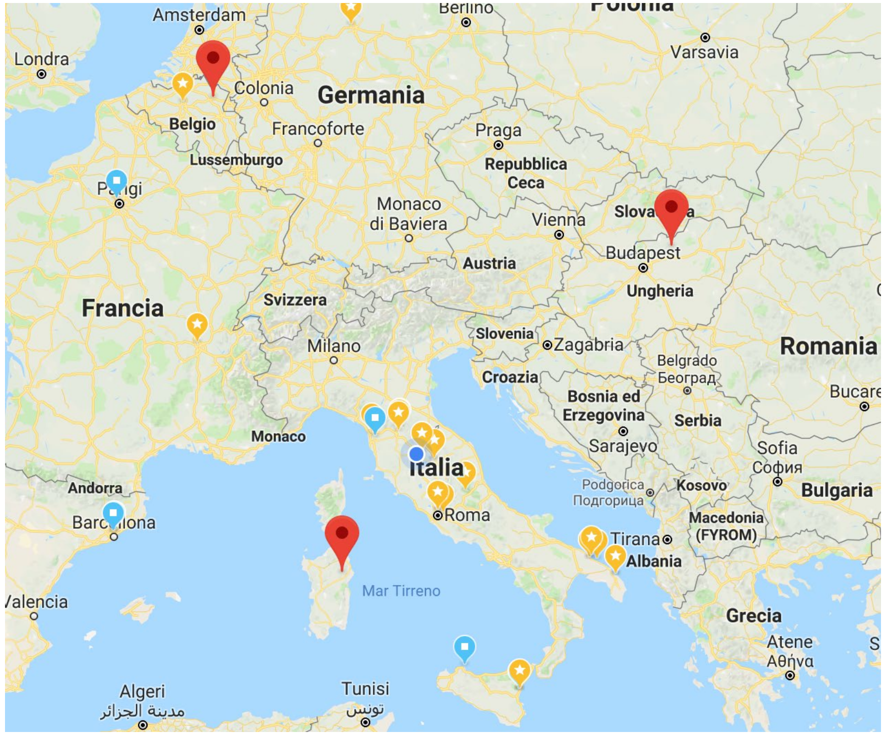
Site Selection

The European competition

ET site: 3 candidates



- What are the technical selection parameters?
- How the sites match these parameters?
  - Complete the site qualification

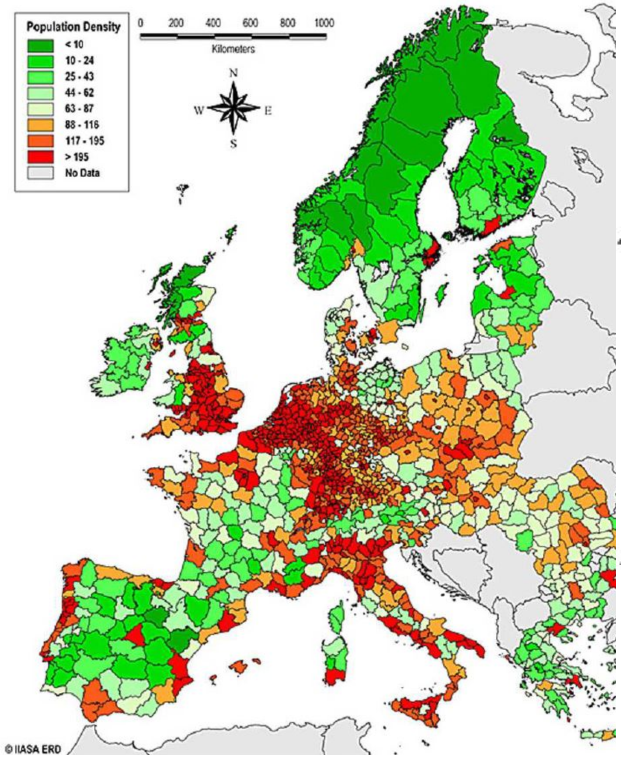


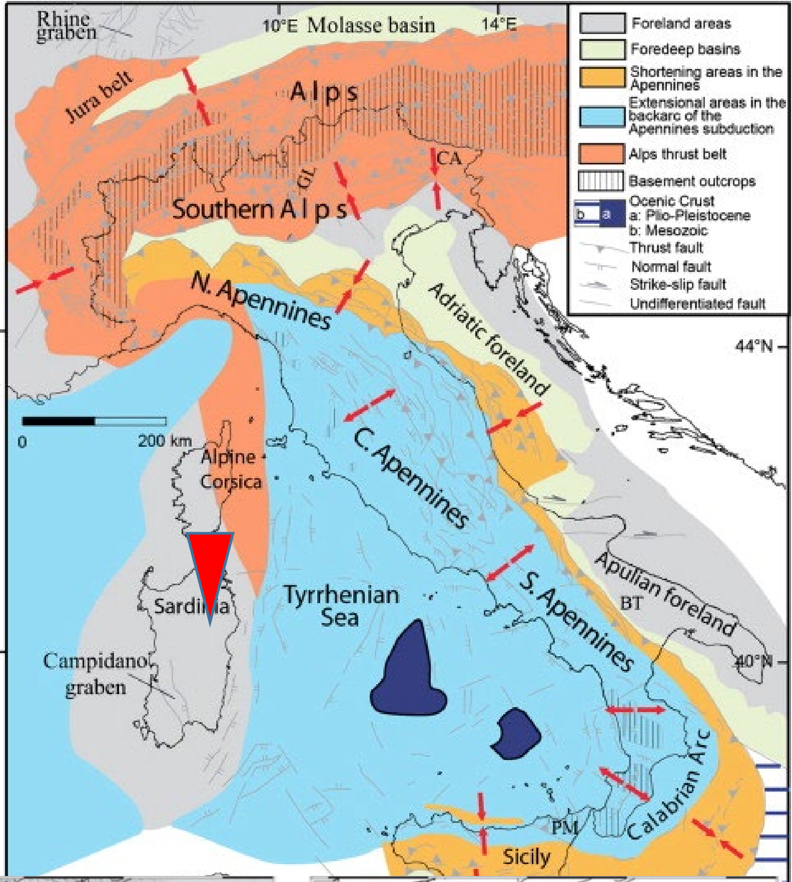
EUREGIO MEUSE-RHINE

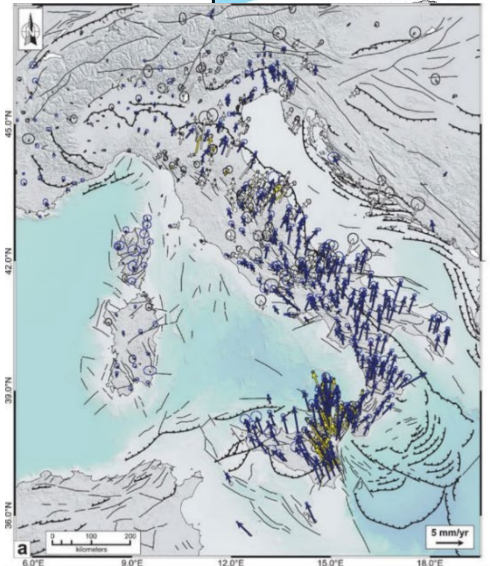
- A proposal to realize ET in the Limburg area
- A strong asset: a detector hosted by 3 countries (B-D-NL)
- Initial funding (4-6M€) by NL and B
- Site still to be qualified with a long and complete seismic measurement campaign (to be started in 2019)

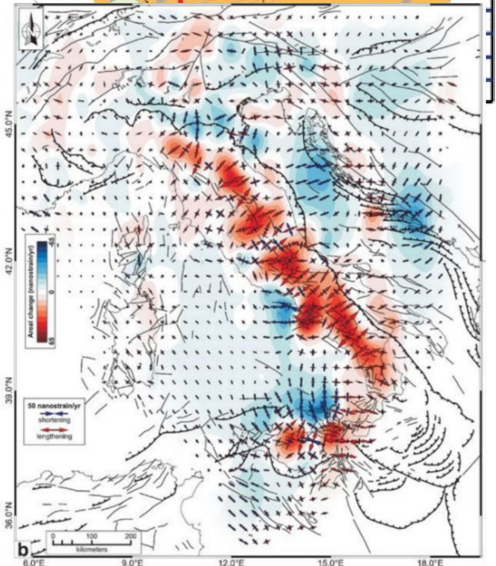
Sardinia - Italy

- Site (preliminarily) qualified with a long measurement campaign, published in CQG
- Very high quality geological, seismic, constructive and environmental characteristics
- Support of the Italian Government
  - 17 M€ promised to support AdV+ and the ET site candidature
    - 5.5M€ delivered in 2018
  - 1M€ delivered by Sardinia region
    - 2 M€ to be delivered soon



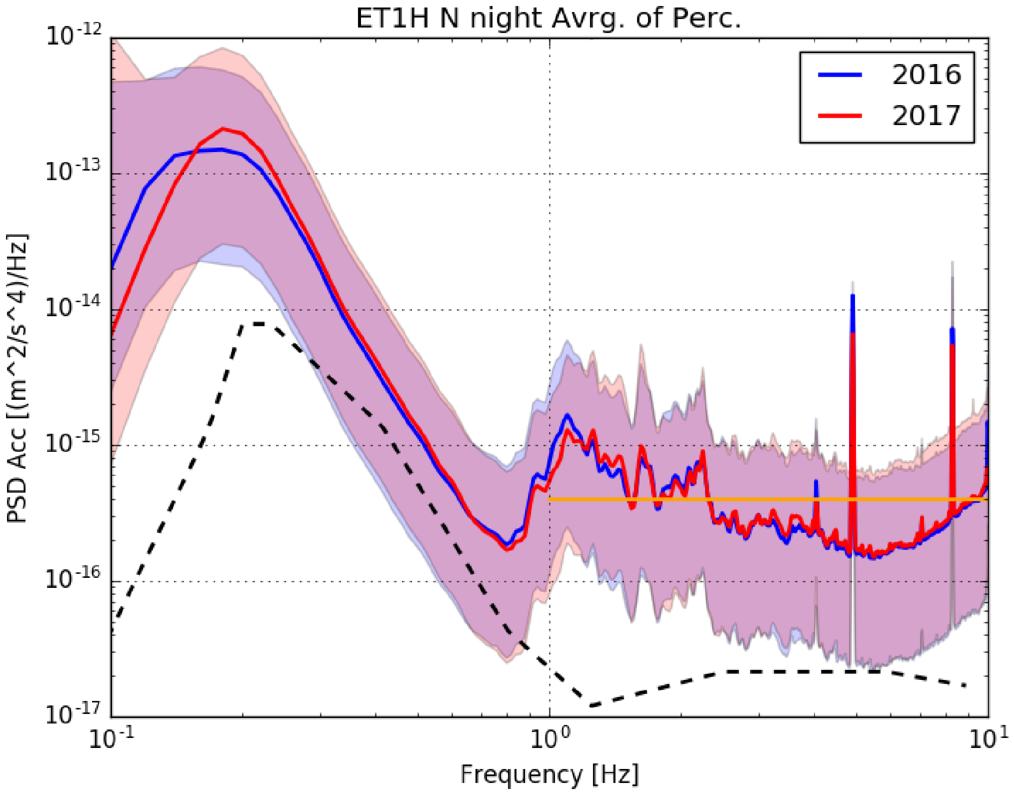






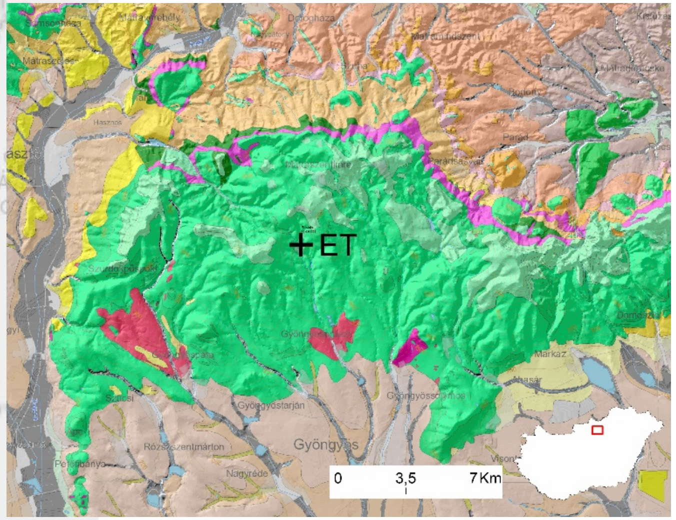
MATRA MOUNTAINS: Hungary

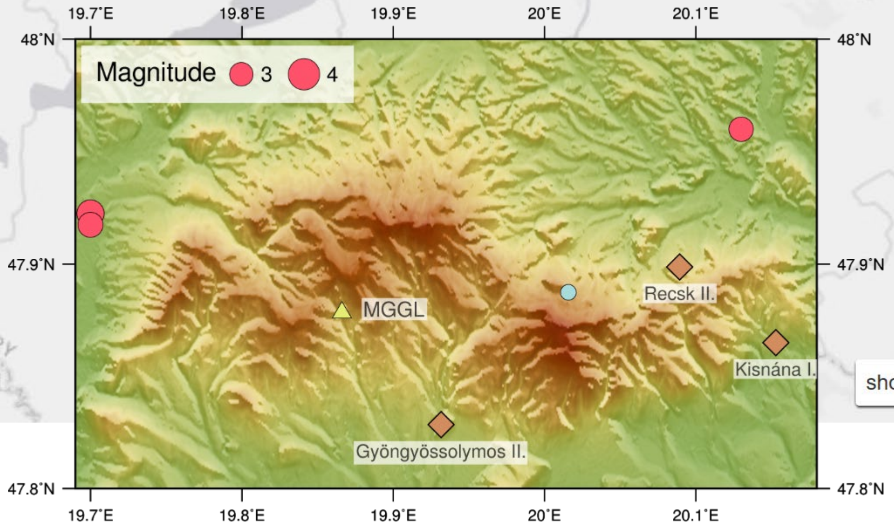
- Underground lab (-88m) realized and used for seismic measurements
- Two years of seismic data available (arXiv:1811.05198)

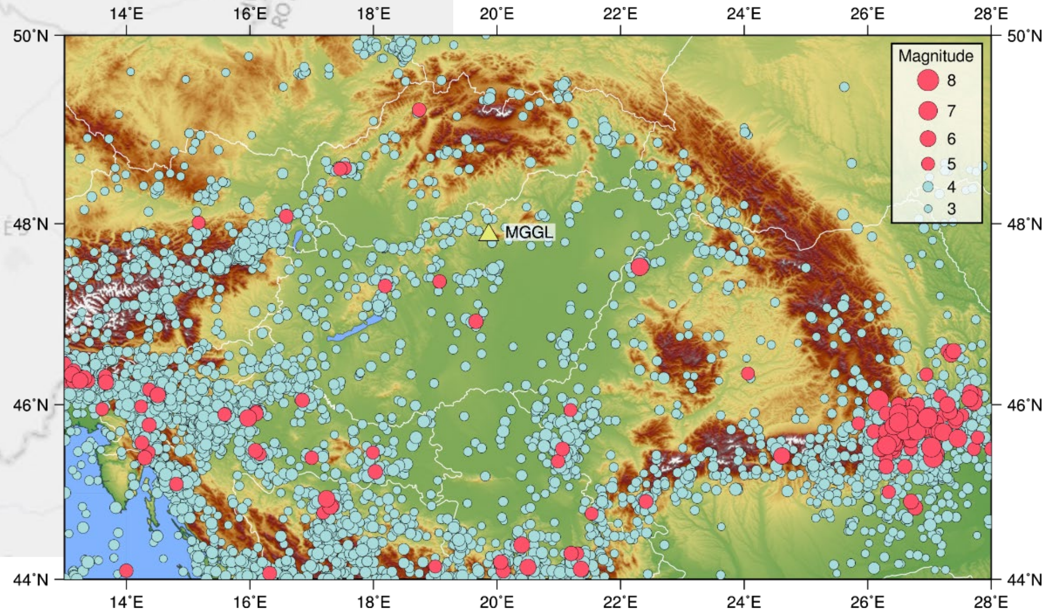


Natural and Anthropic seismicity

- Various andesite types from same geological era, limestone basis
- Local seismicity level
  - 3 earthquakes in the last 200 yrs
  - M = 3.5 (1879), 3.2 (1895), 3.1 (1980)
- Explosions nearby
  - 91 between 03.2016 – 12.2017



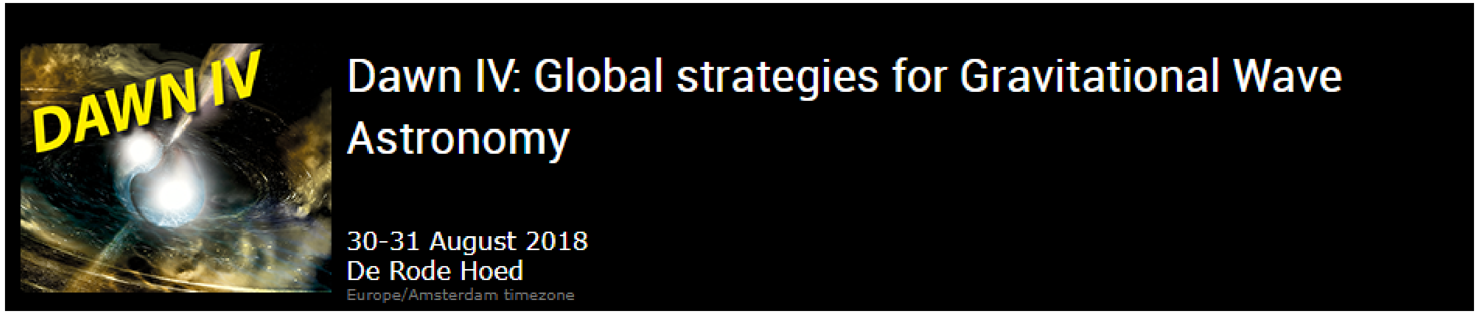




The International scenario

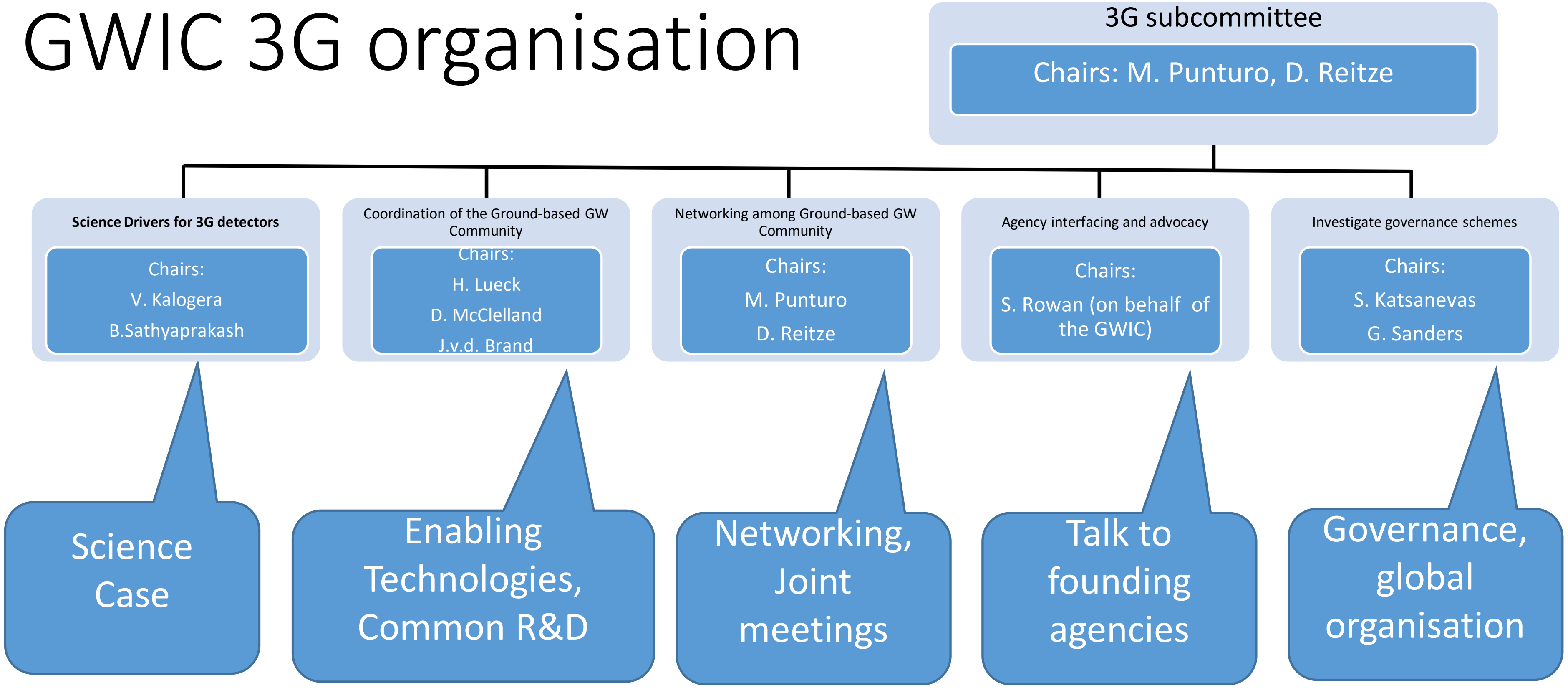
The international scenario

- The GW detection, the beginning of the GW multi-messenger astronomy and the acceleration of the ET project stimulated a worldwide excitation for the 3G detectors
- LIGO colleagues elaborated a 3G idea named Cosmic Explorer (CE)
  - In 2018 NSF funded a design study for CE, confirming the validity of the pioneer activity realised by the ET community and admitting a “10 years” delay with respect to ET
    - In August 2018 NSF organised a DAWN meeting dedicated to 3G in Europe



    - Participation of “delegates” of national funding agencies in Europe including CERN, that it is preparing the Particle Physics European Roadmap
    - *Sparkling* discussions on many aspects, but clear statement on the need of a global coordination

GWIC 3G organisation



https://gwic.ligo.org/3Gsubcomm/

GWIC 3G organisation

3G subcommittee
Chairs: M. Punturo, D. Reitze

- **Science Drivers for 3G detectors**
  Chairs:
  V. Kalogera
  B.Sathyaprakash
- Coordination of the Ground-based GW Community
  Chairs:
  H. Lueck
  D. McClelland
  J.v.d. Brand
- Networking among Ground-based GW Community
  Chairs:
  M. Punturo
  D. Reitze
- Agency interfacing and advocacy
  Chairs:
  S. Rowan (on behalf of the GWIC)
- Investigate governance schemes
  Chairs:
  S. Katsanevas
  G. Sanders

More than 200 scientists

- Seed Black holes
- Neutron Stars
- Compat binaries
- Cosmology
- Supernova
- Multi-messenger observations
- Extreme gravity
- Waveform models
- Detector networks

ET EINSTEIN TELESCOPE

3G Science case workshop

- Postdam, 1-2 October 2018
- Very exciting and scientifically interesting meeting
  - Science Case document that will be the input for
    - CERN roadmap (18th of December 2018)
    - Decadal Survey (18th of January 2019)
    - ET ESFRI proposal (Apr. 2020)

Conclusions

- ET is a frontier project on GW research
  - It is **the only** project that can guarantee a scientific relevance of Europe in the 2030 decade (terrestrial detectors)
  - It is paving the path toward 3G detectors
    - Its design is based on the hypothesis to be the only one 3G observatory
    - In case other 3G detectors/observatories will be realised in the world, ET design can be simplified keeping the same scientific potential, but reducing the complexity
  - A pan-European effort on its design, technology development and realisation is needed
  - The competition on the possible site in Europe is healthy because it stimulates activities and interest, but it must find a convergence in the first years of the next decade