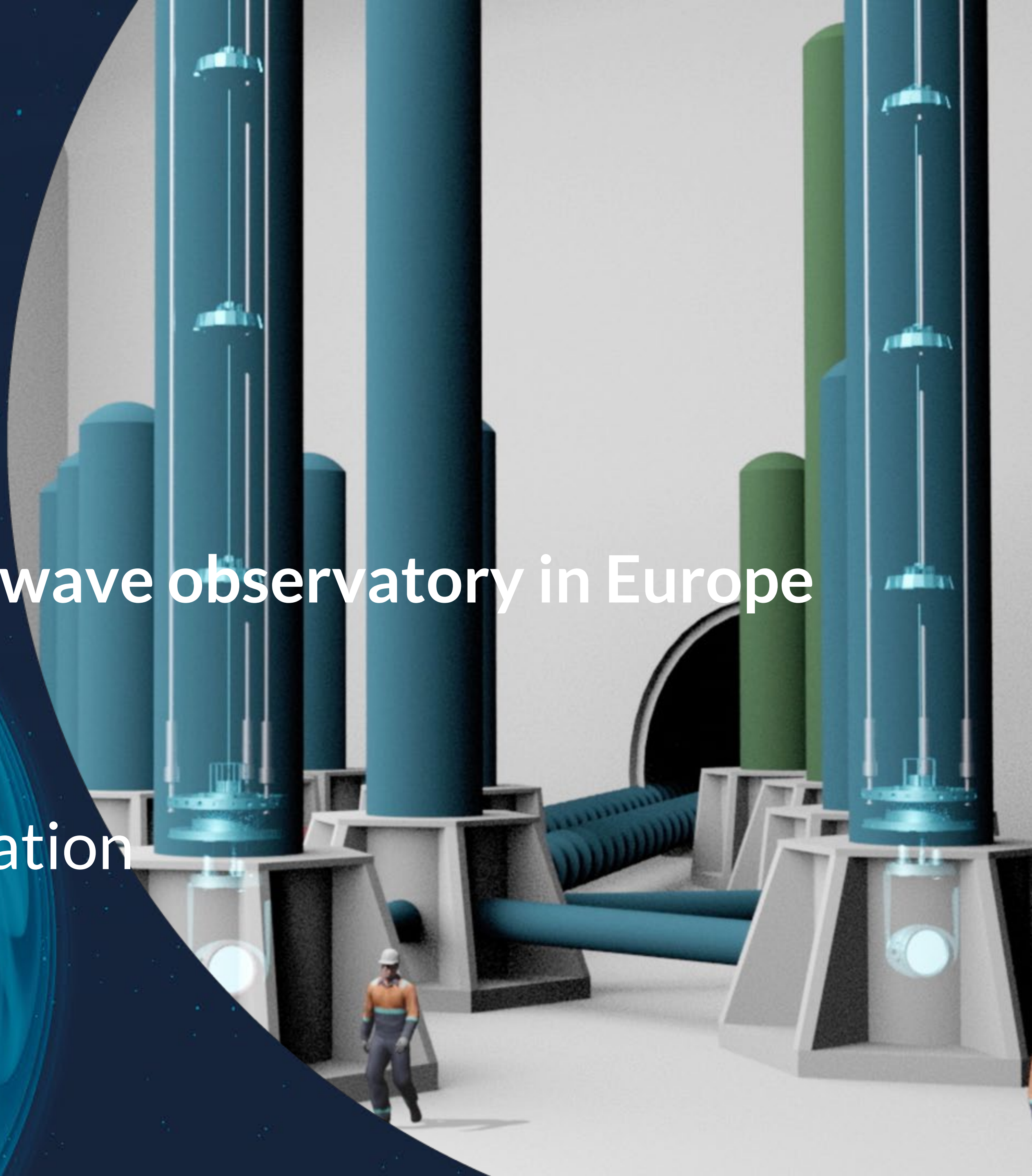
EINSTEIN TELESCOPE

CERN Colloquium, 30/11/2023

Einstein Telescope:
a next-generation gravitational wave observatory in Europe

Michele Punturo
INFN, spokesperson ET collaboration



INFN
Istituto Nazionale di Fisica Nucleare

(A.Einstein 1915)

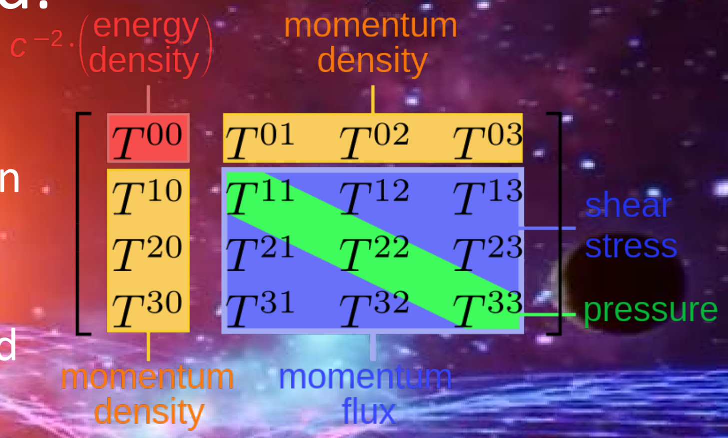
Einstein 's field equations

- In General Relativity the relation between gravity, mass distribution and spacetime curvature is expressed by the equations of field:

Effect of the deformation → $G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$ ← Cause of the deformation

$G_{\mu\nu} \equiv R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R$

$\frac{8\pi G}{c^4} \approx 2 \times 10^{-43} N^{-1}$

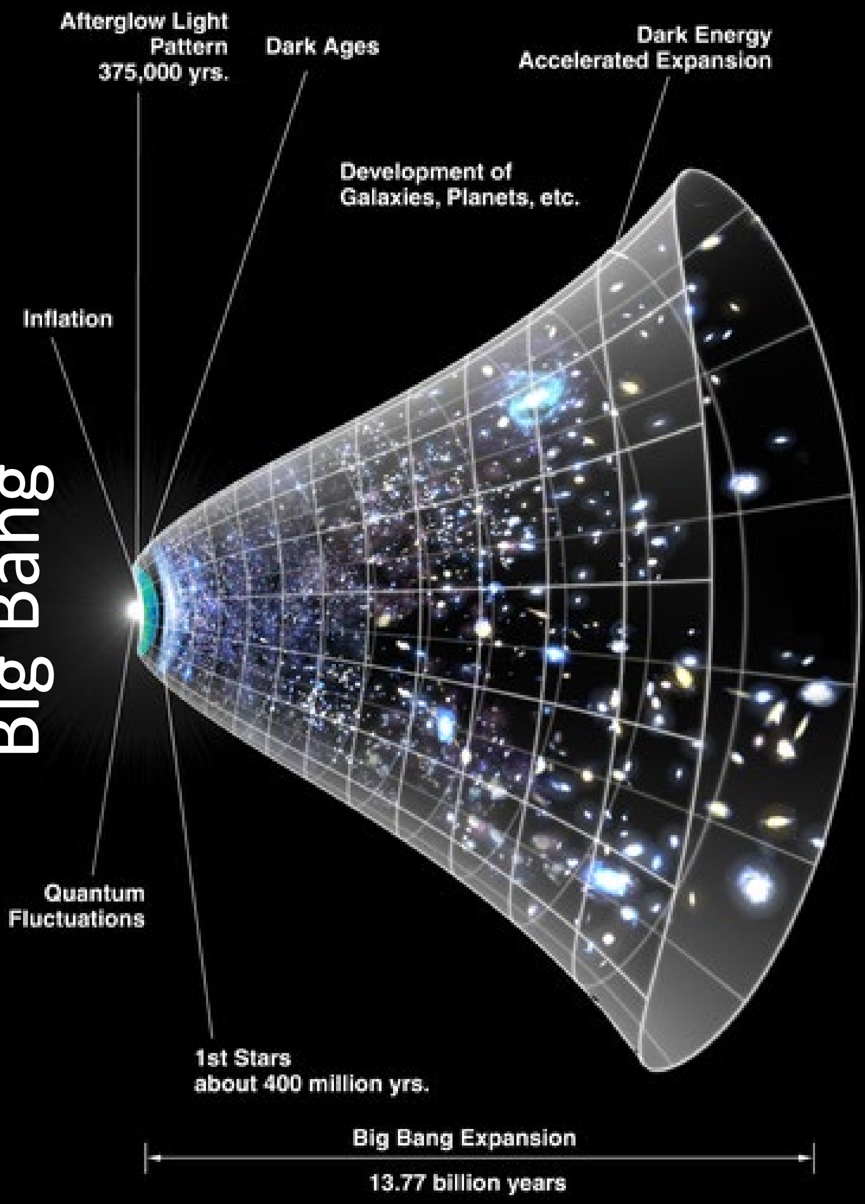


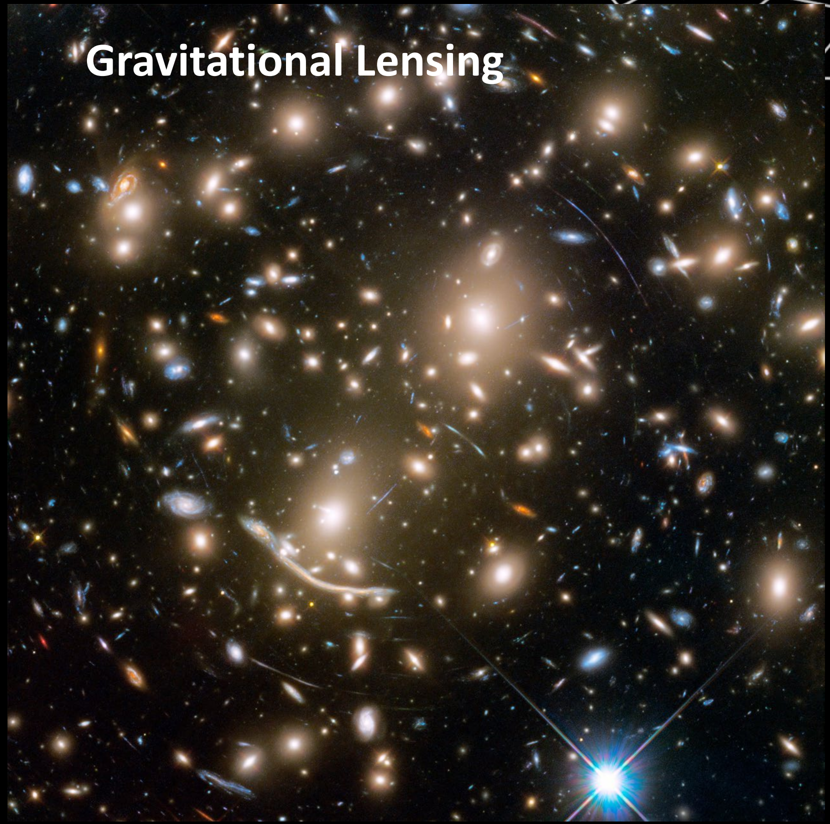
"Matter tells spacetime how to curve and curved spacetime tells matter how to move"

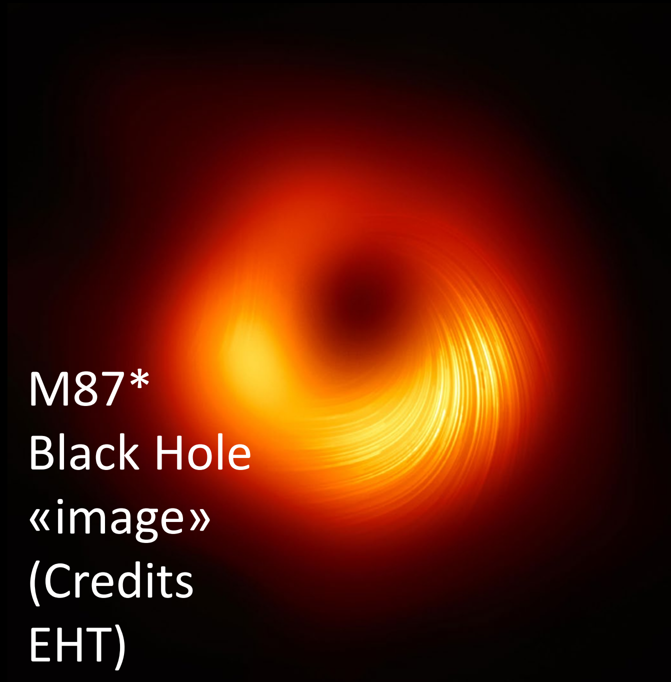
- Very naïf interpretation:
  - Let consider spacetime as an elastic medium: $(k_{el} \sim c^4/_{8\pi G})$
    - Spacetime is a very stiff elastic medium :
      - Very energetic phenomena, determine small curvature of the space-time

The GR Universe

Big Bang







M87*
Black Hole
«image»
(Credits
EHT)

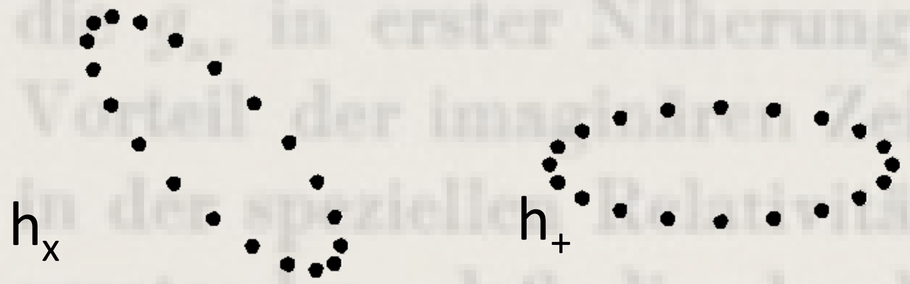
The Gravitational Waves

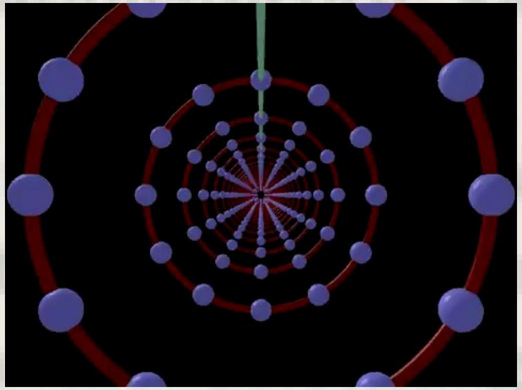
- In 1916, Albert Einstein published the first attempt to linearise the field equation in weak field condition $\left(g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}; \left|h_{\mu\nu}\right| \ll 1\right)$ obtaining the wave equation of the Gravitational waves

$$\left(-\frac{1}{c^2}\frac{\partial^2}{\partial t^2} + \nabla^2\right)\bar{h}_{\mu\nu} = \kappa\, T_{\mu\upsilon}\ ; \quad \kappa = -\frac{16\pi G}{c^4}$$

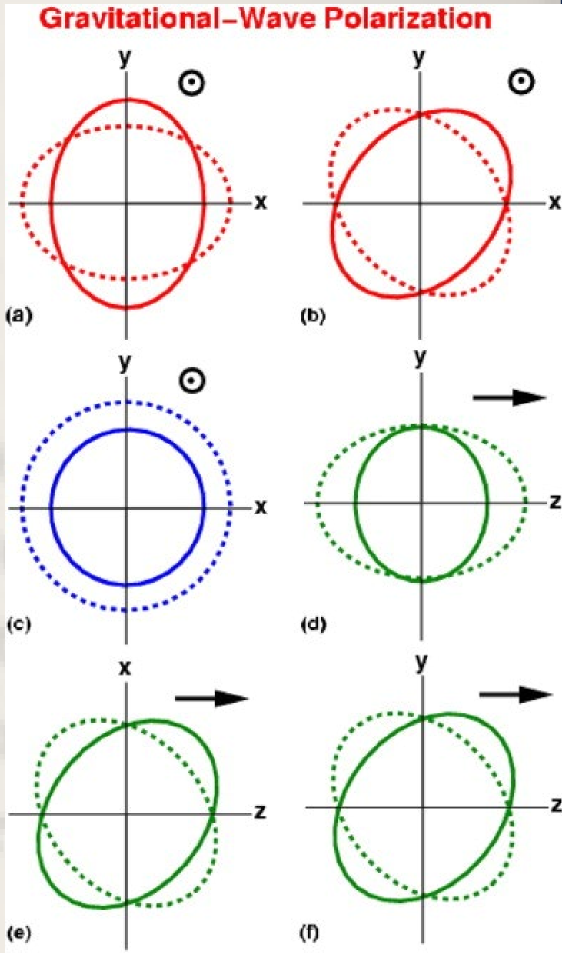
Far from matter: $T_{\mu\upsilon} = 0 \rightarrow \left(-\frac{1}{c^2}\frac{\partial^2}{\partial t^2} + \nabla^2\right)\bar{h}_{\mu\nu} = 0$

- In GR, the GW have 2 polarisations, h_+ and h_x and causes tidal deformations of the space-time





Note: This is due to the special Transverse Traceless gauge selected in GR. Other gravitational theories have up to 6 polarizations



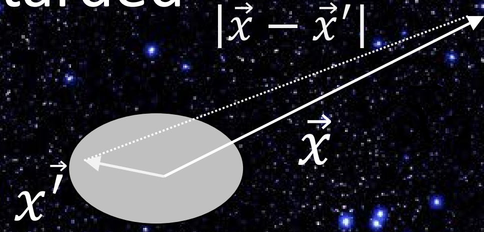
GW sources

- Starting from the linearized theory. The field equations in this case are

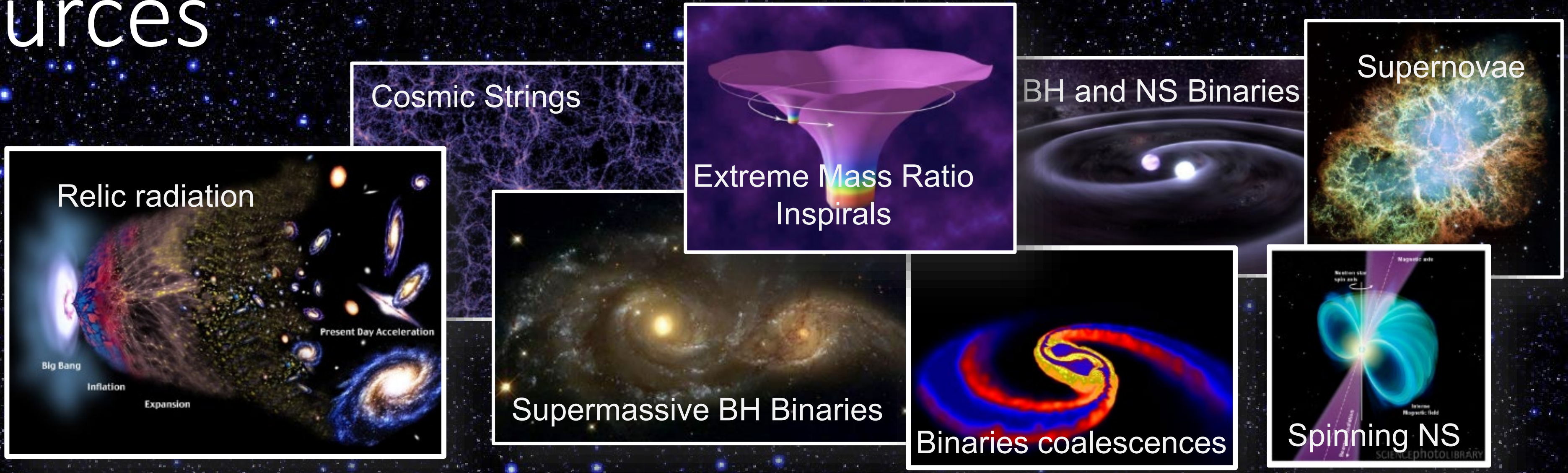
$$\Box \bar{h}_{\mu\nu} = -\frac{16\pi G}{c^4} T_{\mu\nu} = \kappa T_{\mu\nu} \quad \text{where} \quad \kappa \equiv \frac{16\pi G}{c^4}$$

- In a flat space approximation, far from the source that is generating GW, and having slow variations *v/c<<1*, the equation of field can be solved using the retarded potentials like in EM

$$\bar{h}^{\mu\nu}(t,\vec{x}) = -\frac{\kappa}{4\pi} \int \frac{T^{\mu\nu}\left(t - |\vec{x} - \vec{x}'|, \vec{x}'\right)}{|\vec{x} - \vec{x}'|} d^3x'$$



GW sources



- Expanding it in multipolar terms: Quadrupole, Octupole, …
- Arresting the series to the quadrupole term we obtain:

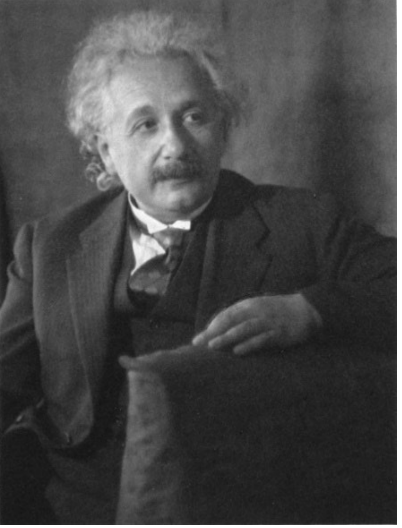
$$\left|h_{kl}^{TT}(t,\vec{x})\right|_{quad} = -\frac{\kappa}{8\pi r}\frac{1}{3}\ddot{Q}_{kl}^{TT}(t-r/c) = \frac{1}{r}\frac{2G}{c^4}\frac{1}{3}\ddot{Q}_{kl}^{TT}(t-r/c)$$

1/r

$1.6\times10^{-44}\ m^{-1}kg^{-1}s^{2}$

$$Q^{kl} = \int_V (3x'^k x'^l - r'^2\delta_l^k)\rho(\overrightarrow{x'})d^3x'$$

One century of research, study and technological developments

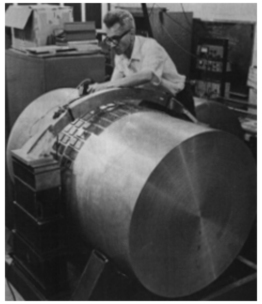


1915 GR

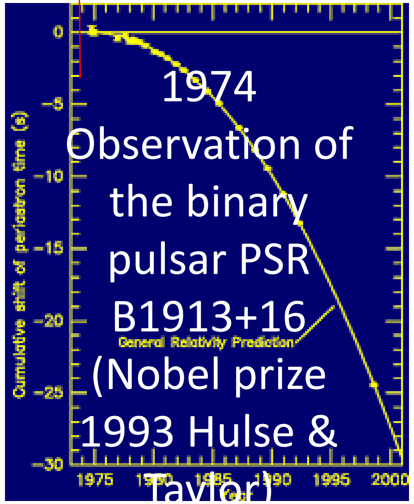
1916-1918 GW

1937 «On gravitational waves» A.Einstein N.Rosen

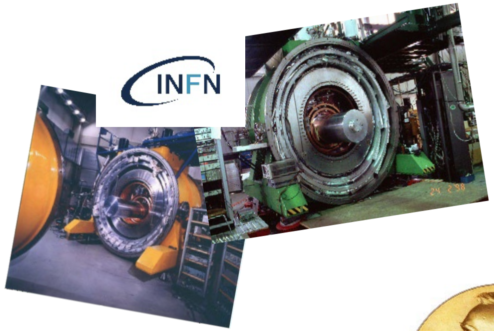
1957 GW carries energy and momentum: it modifies macroscopic objects



1966 beginning of the experimental era on GW with J.Weber



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



’80-’90: Cryogenic Resonant Bars

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

1993

1994: Virgo project formal approval

1999+ Templates: EOB, Numerical relativity

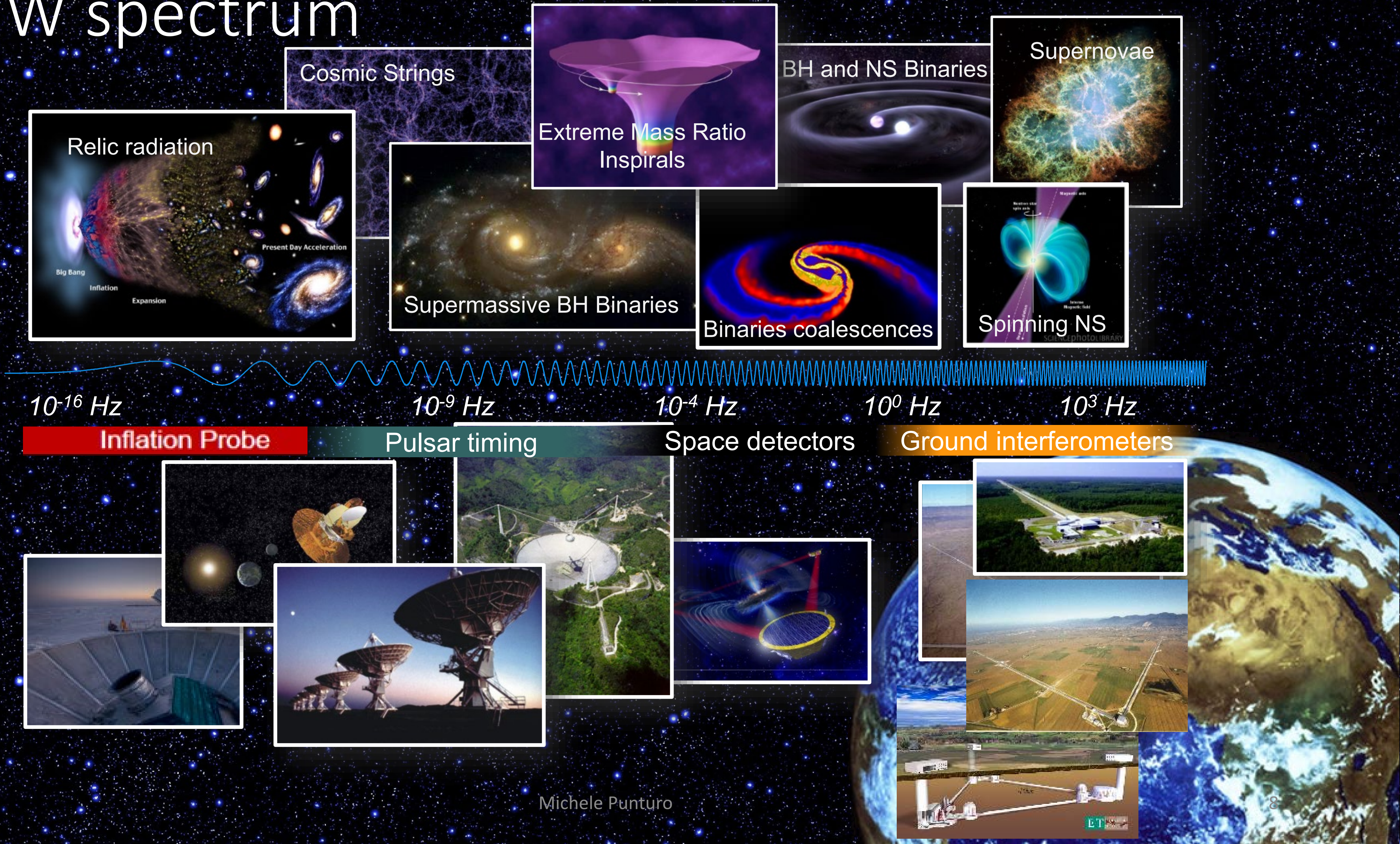
1999+ Beginning LIGO interferometer operations (Virgo +4y)

2015: Beginning operations aLIGO: GW discovery

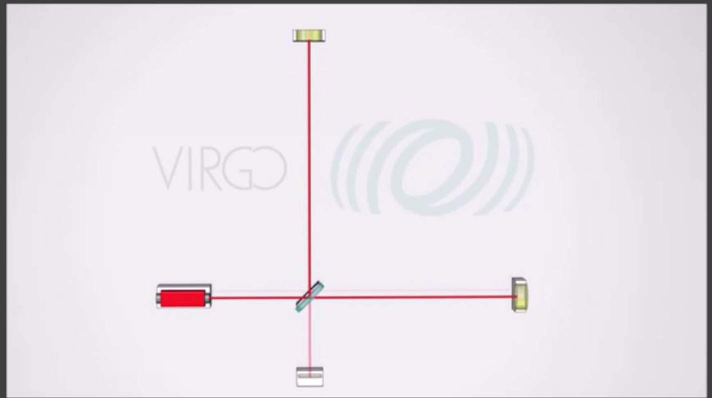
2017 Beginning operations Advanced Virgo: GW from BNS coalescence

t

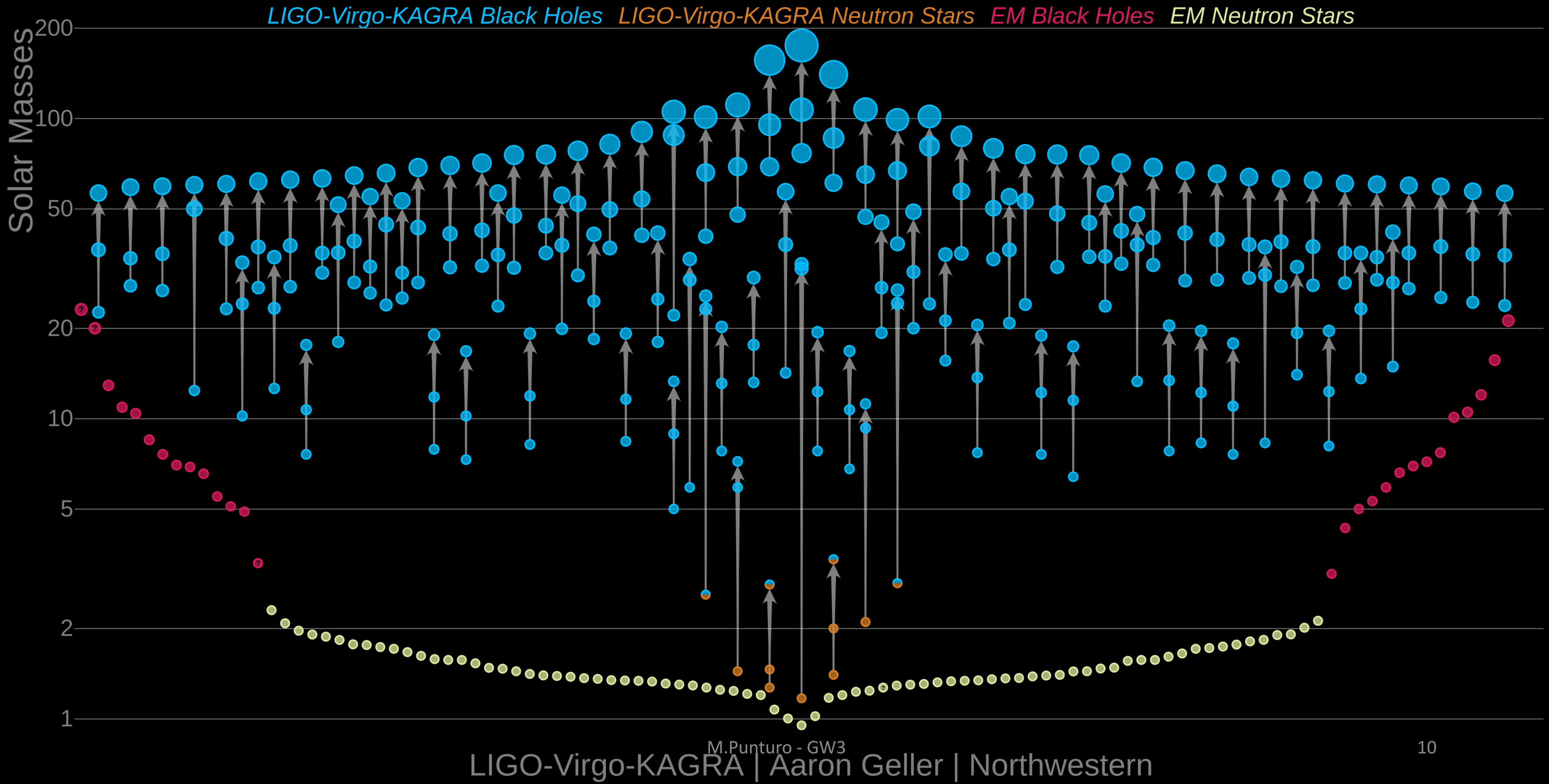
The GW spectrum

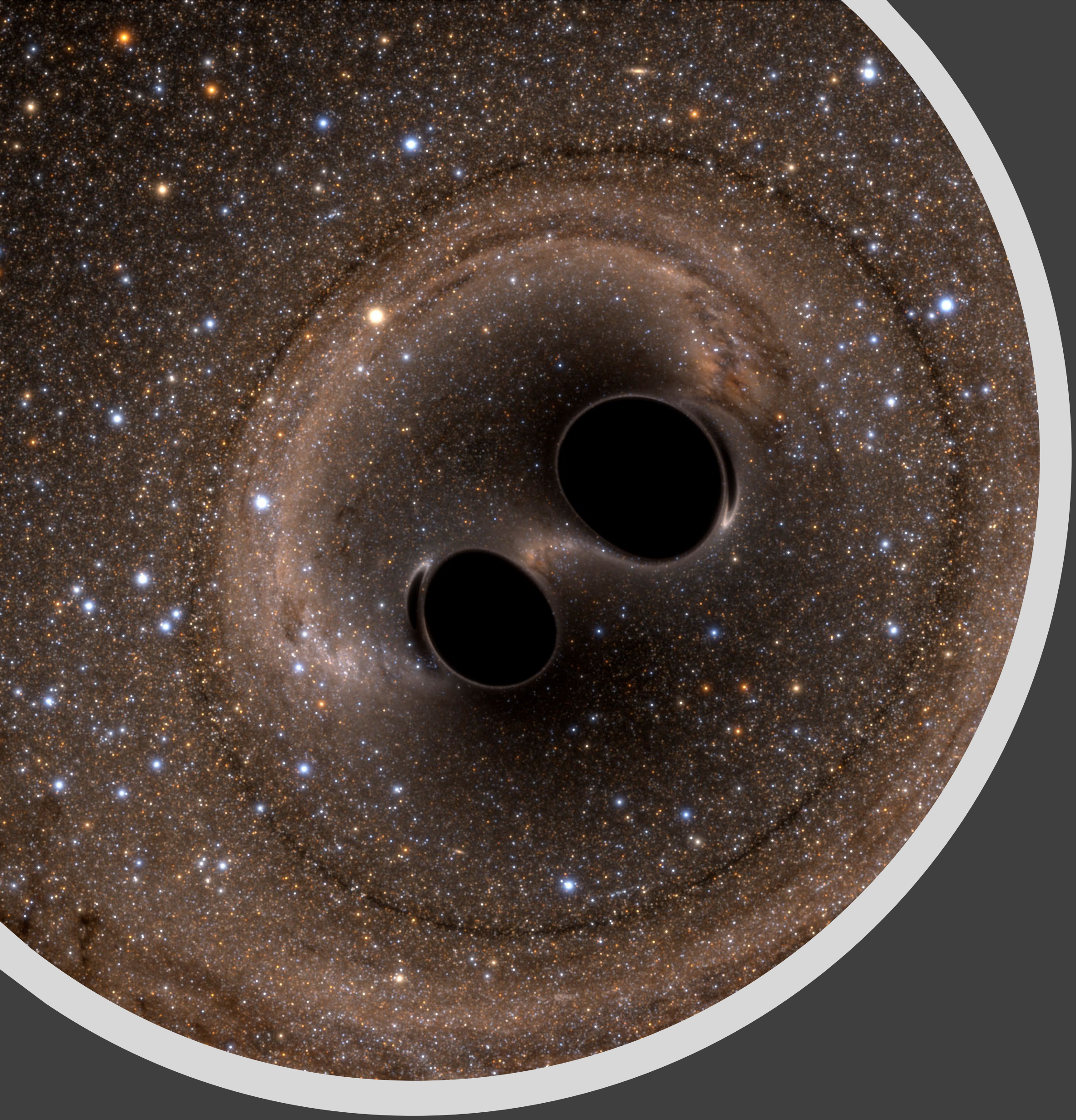


Current GW detectors



Masses in the Stellar Graveyard





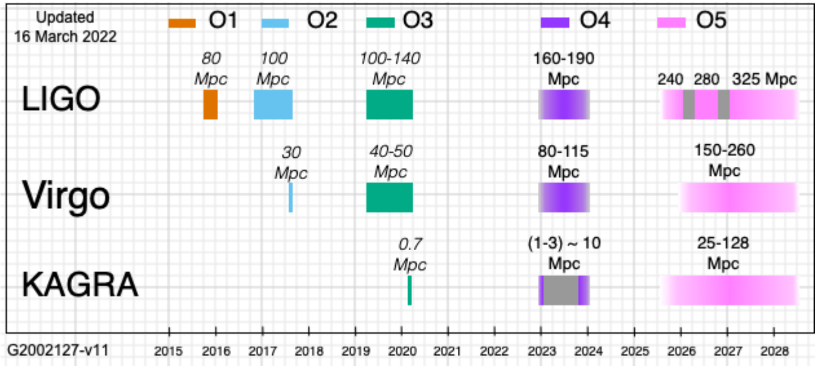
Monumental successes of the Advanced detectors

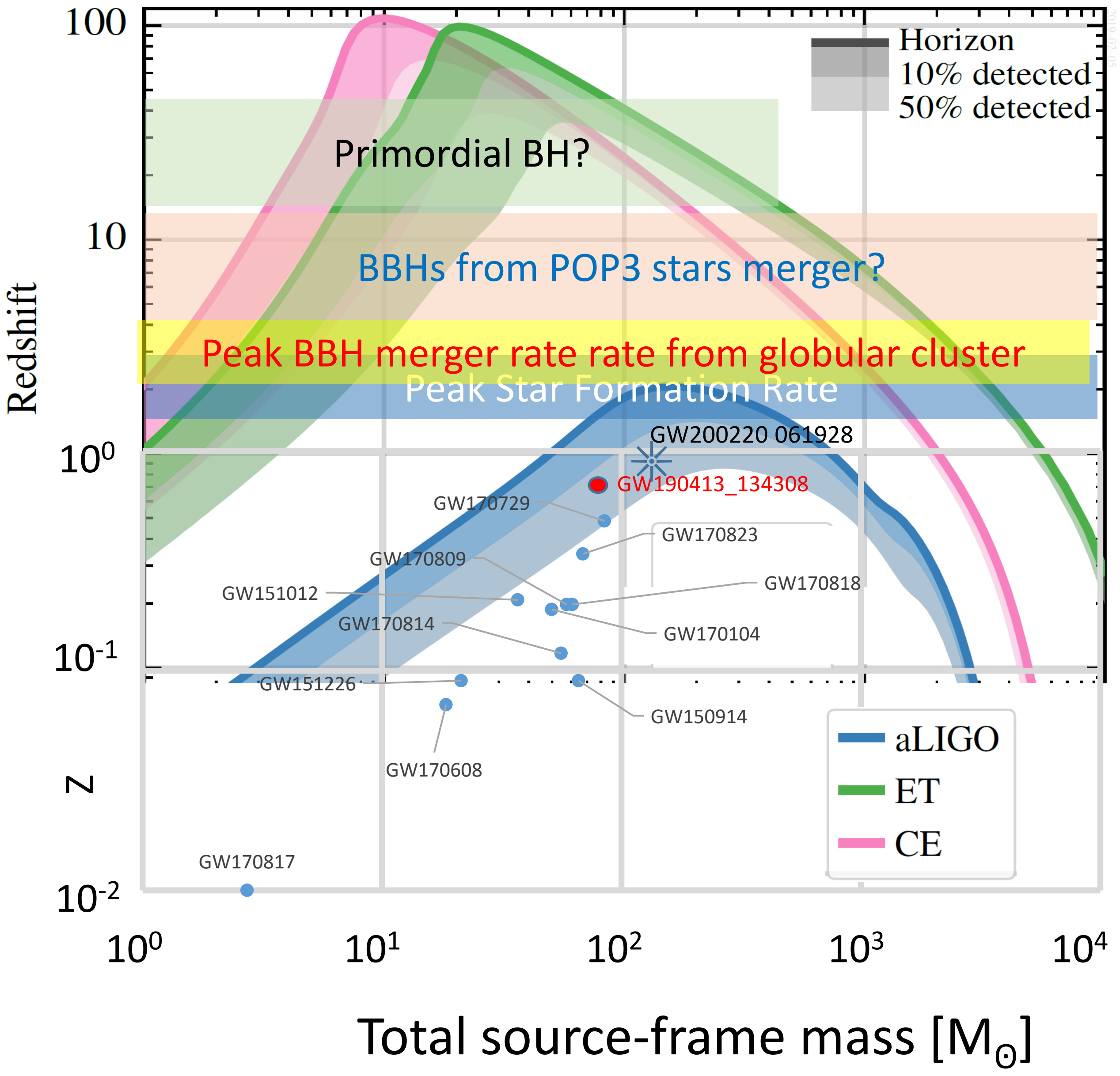
- First detection of GWs from a BBH system (GW150914)
  - Physics of BHs
- First detection of GWs from a BNS system (GW170817)
  - Birth of the multimessenger astronomy with GWs
  - Costraining EOS of NS
- Localisation capabilities of a GW source
- Measurement of the GW propagation speed
- Test of GR
- Alternative measurement of H_0
- GW polarisations
- Intermediate mass black hole (GW190521)

OK, all done?

- aLIGO and AdV achieved awesome results with a sensitivity poorer than the nominal one
- When they will reach or over-perform their nominal (updated) sensitivity, can we exploit all the potential of GW observations?

- 2nd generation GW detectors will explore the local Universe, even in their post-O5 configuration, initiating precision GW astronomy, but to have cosmological investigations a factor of 10 improvement in terms detection distance is needed





3G ground-based detectors will be required to access the high redshift Universe

Detection distance of GWD

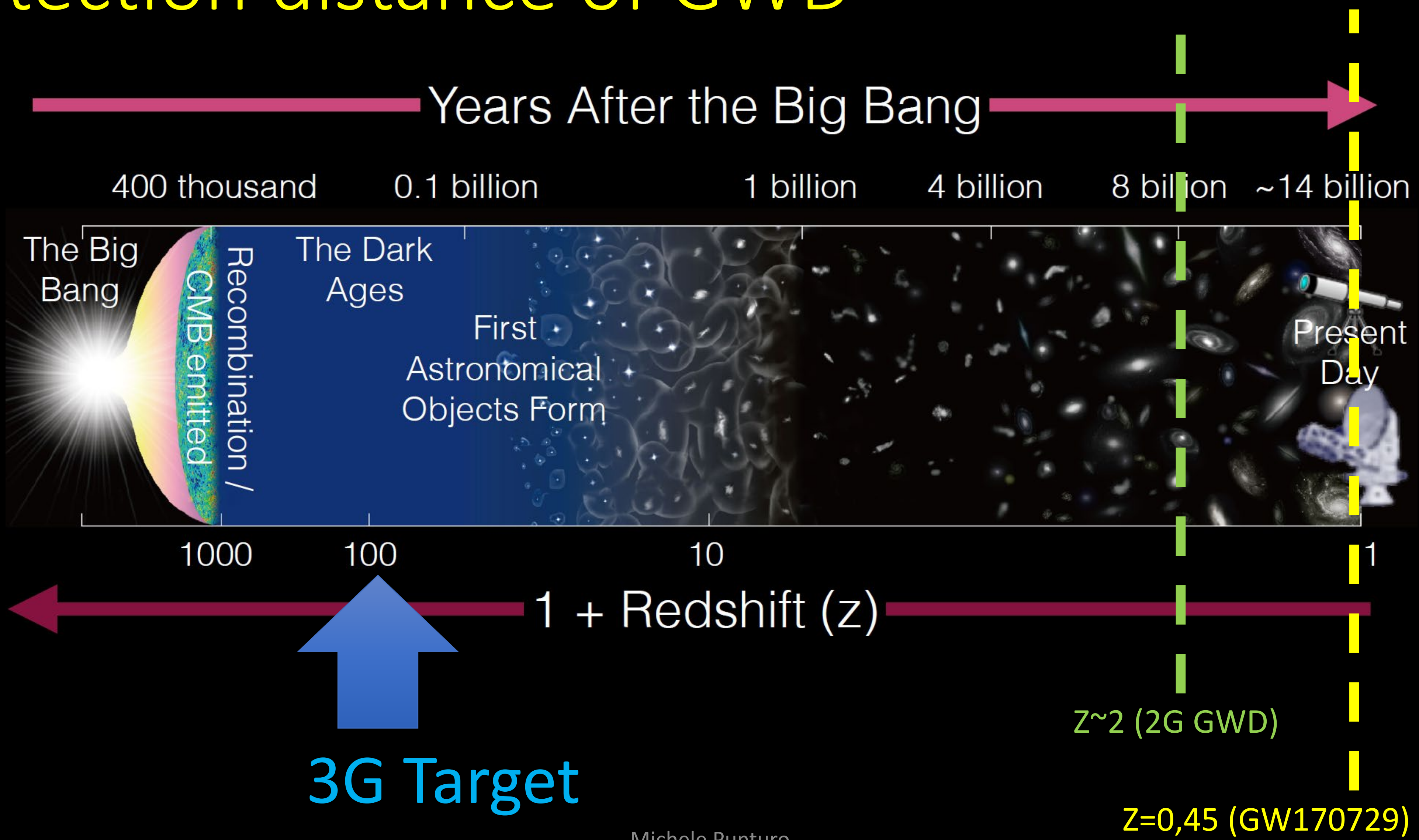
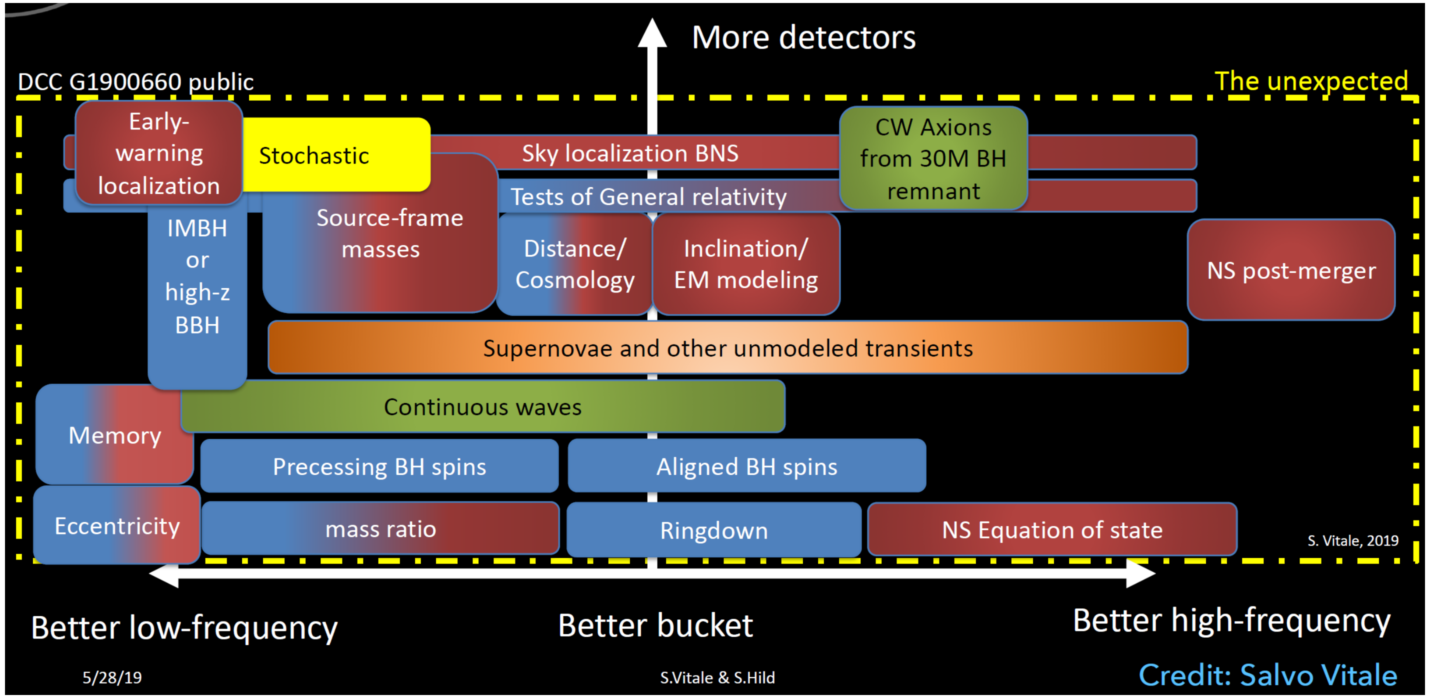


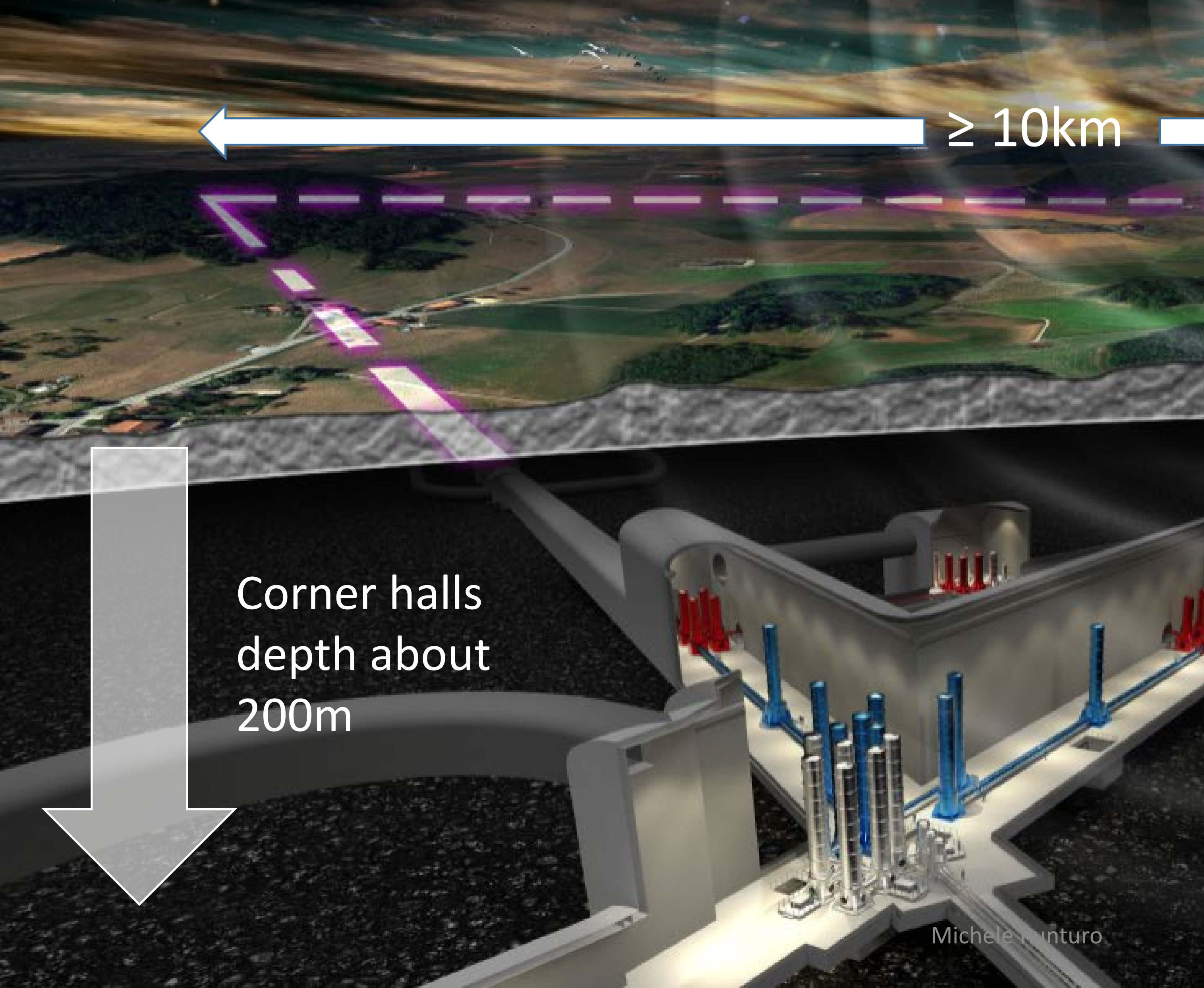
Image credit: NAOJ/ALMA http://alma.mtk.nao.ac.jp/

Where to look for new physics?

- Terrestrial interferometric detectors have access roughly to the [few, few×10^3] Hz frequency interval of the GW signal
- GW sources produce signals in different GW ranges
- Discovery machines must have the widest possible frequency range
- Precision measurement machines should have the best sensitivity
- 3G GW observatories must have both



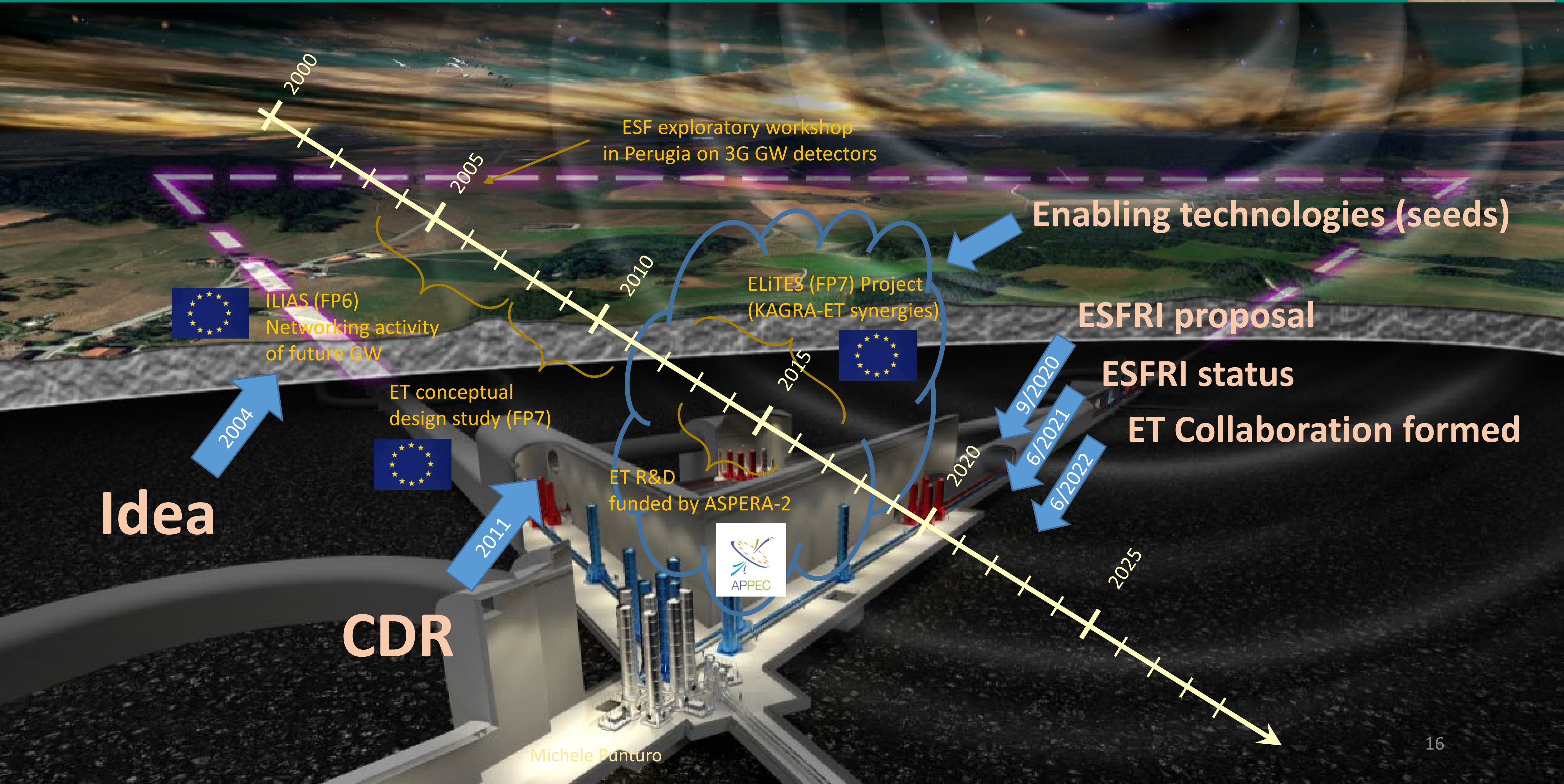
Einstein Telescope (ET)

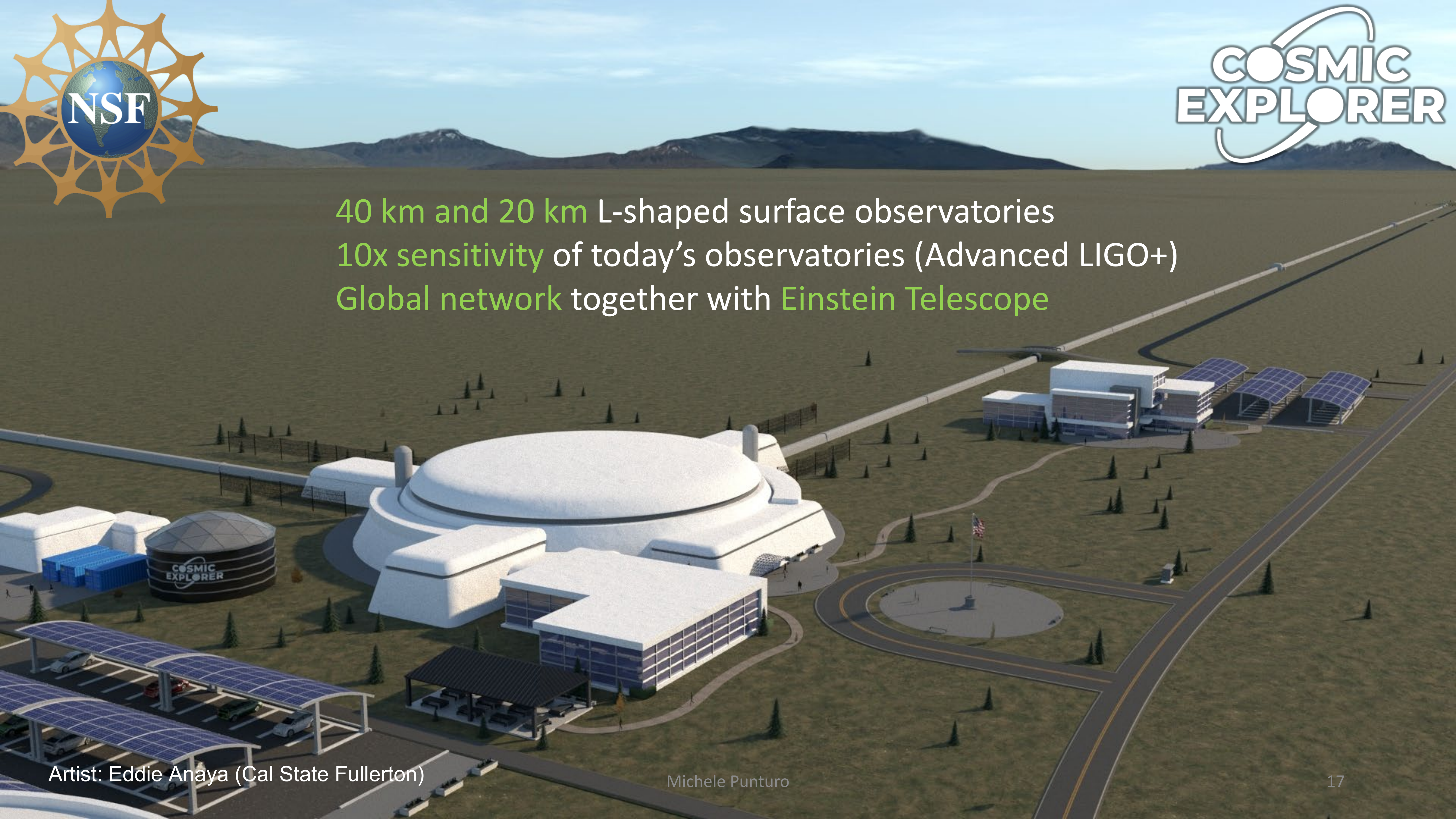


ET pioneered the idea of a 3rd generation GW observatory:

- A new infrastructure capable to host future upgrades for decades without limiting the observation capabilities
- A sensitivity at least 10 times better than the (nominal) advanced detectors on a large fraction of the (detection) frequency band
- A dramatic improvement in sensitivity in the low frequency (few Hz – 10Hz) range
- High reliability and improved observation capability
- Polarisation disentanglement

ET: a long path





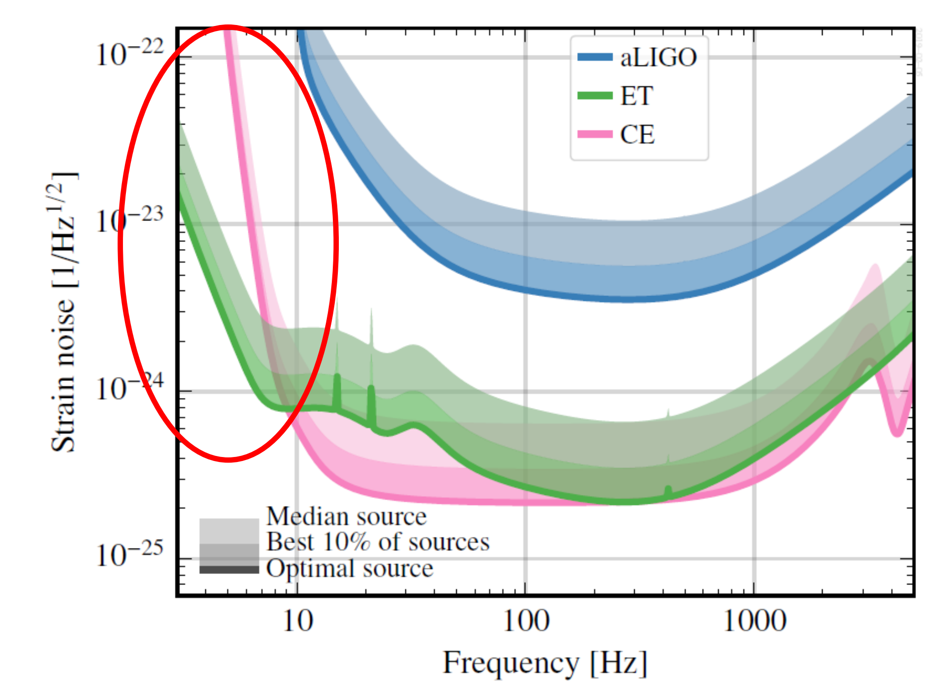
40 km and 20 km L-shaped surface observatories

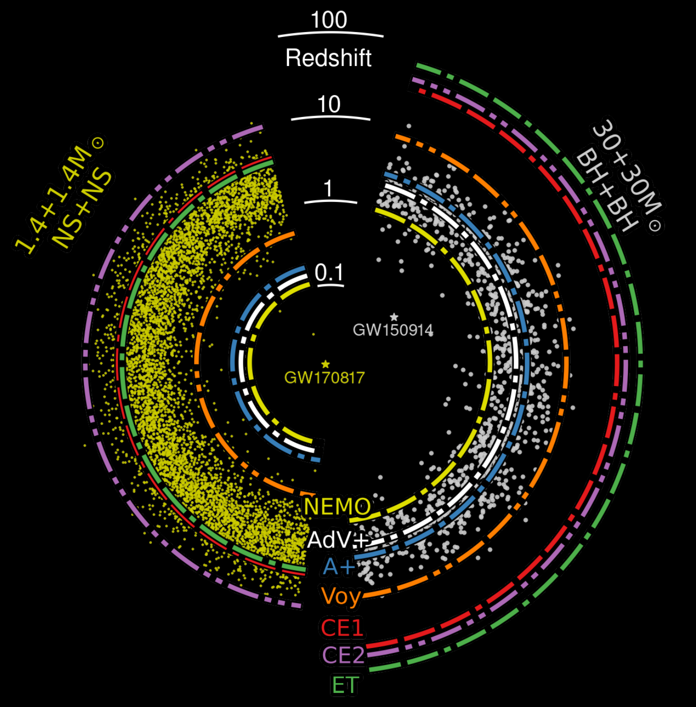
10x sensitivity of today’s observatories (Advanced LIGO+)

Global network together with Einstein Telescope

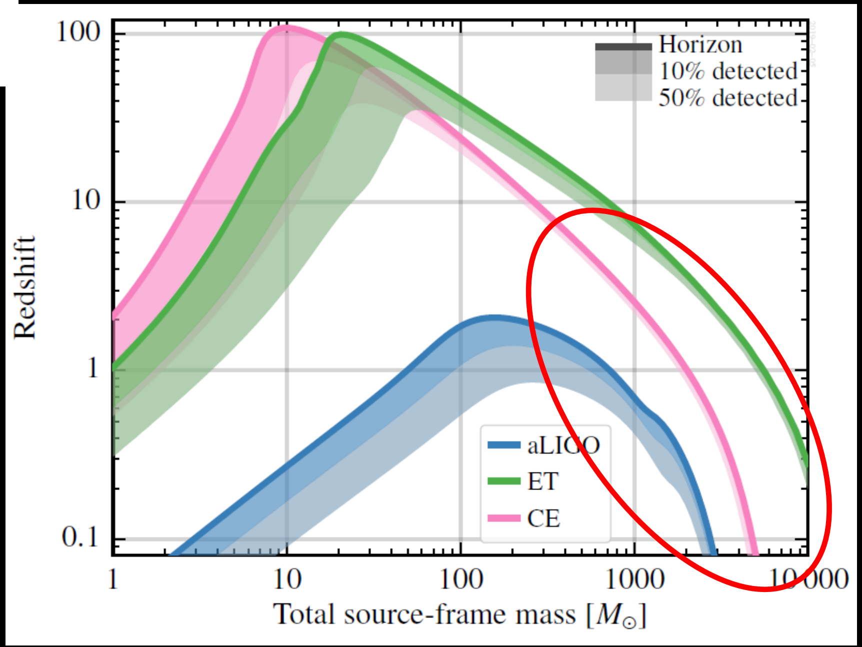
Artist: Eddie Anaya (Cal State Fullerton)

Observation performance of ET & CE





- BBH up to z~50-100
- 10^5 BBH/year
  - Masses $M_T \gtrsim 10^3\ M_\odot$
- BNS to z~2
  - 10^5 BNS/year
  - Possibly O(10-100)/year with e.m. counterpart
- High SNR



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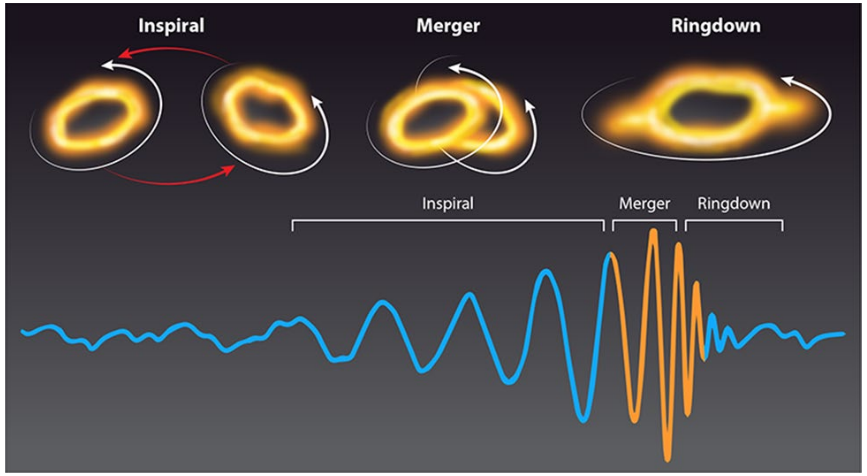
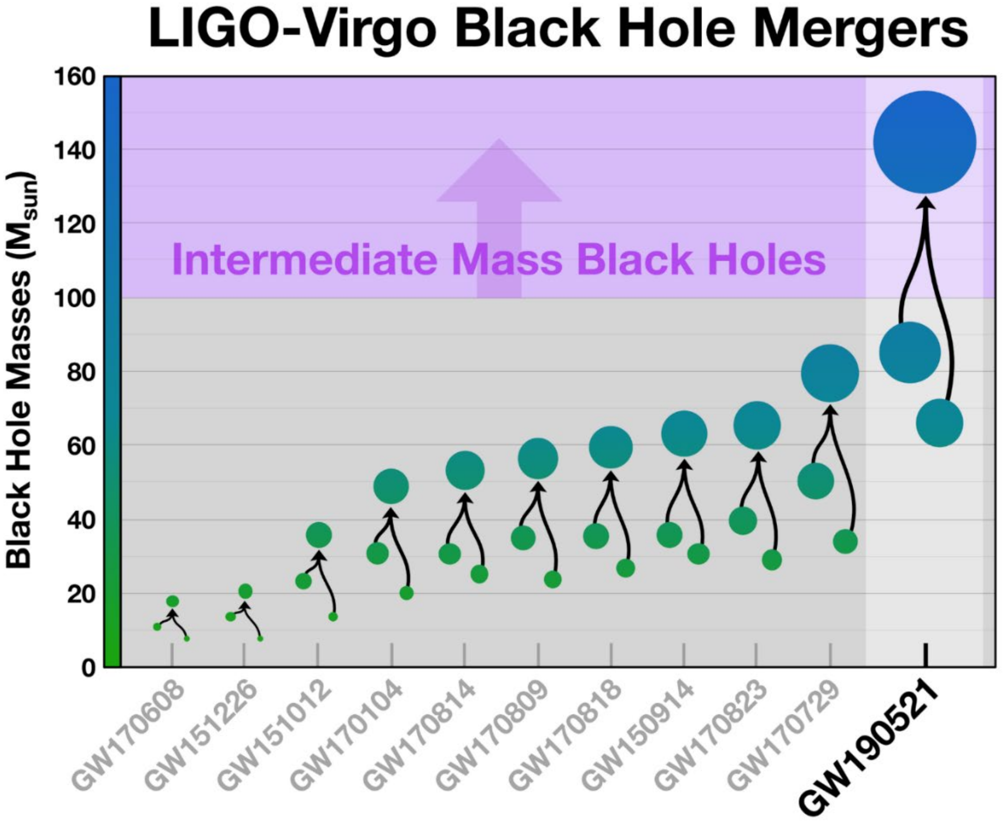
Why low frequency focus?

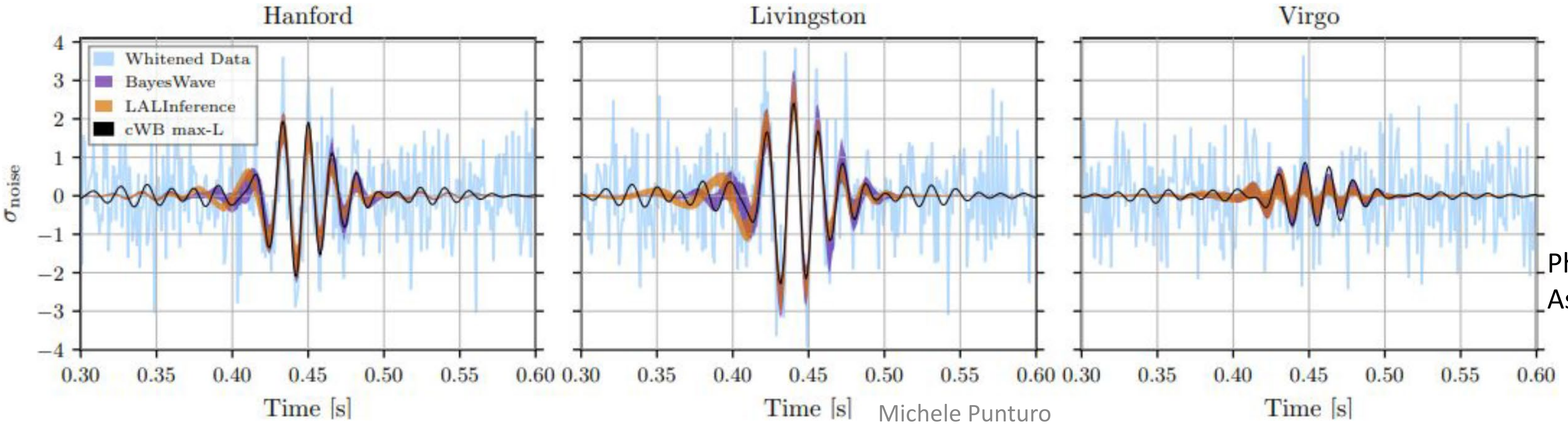
GW190521

$M_1 = 85^{+21}_{-14} M_\odot$, $M_2 = 66^{+17}_{-18} M_\odot$
at $z \sim 0.82$ (5.3Gpc)
Remnant $M_f = 142^{+28}_{-16} M_\odot$

- Very special event:
  - M_1, a black hole that should not exist
  - M_f, the first IMBH ever seen



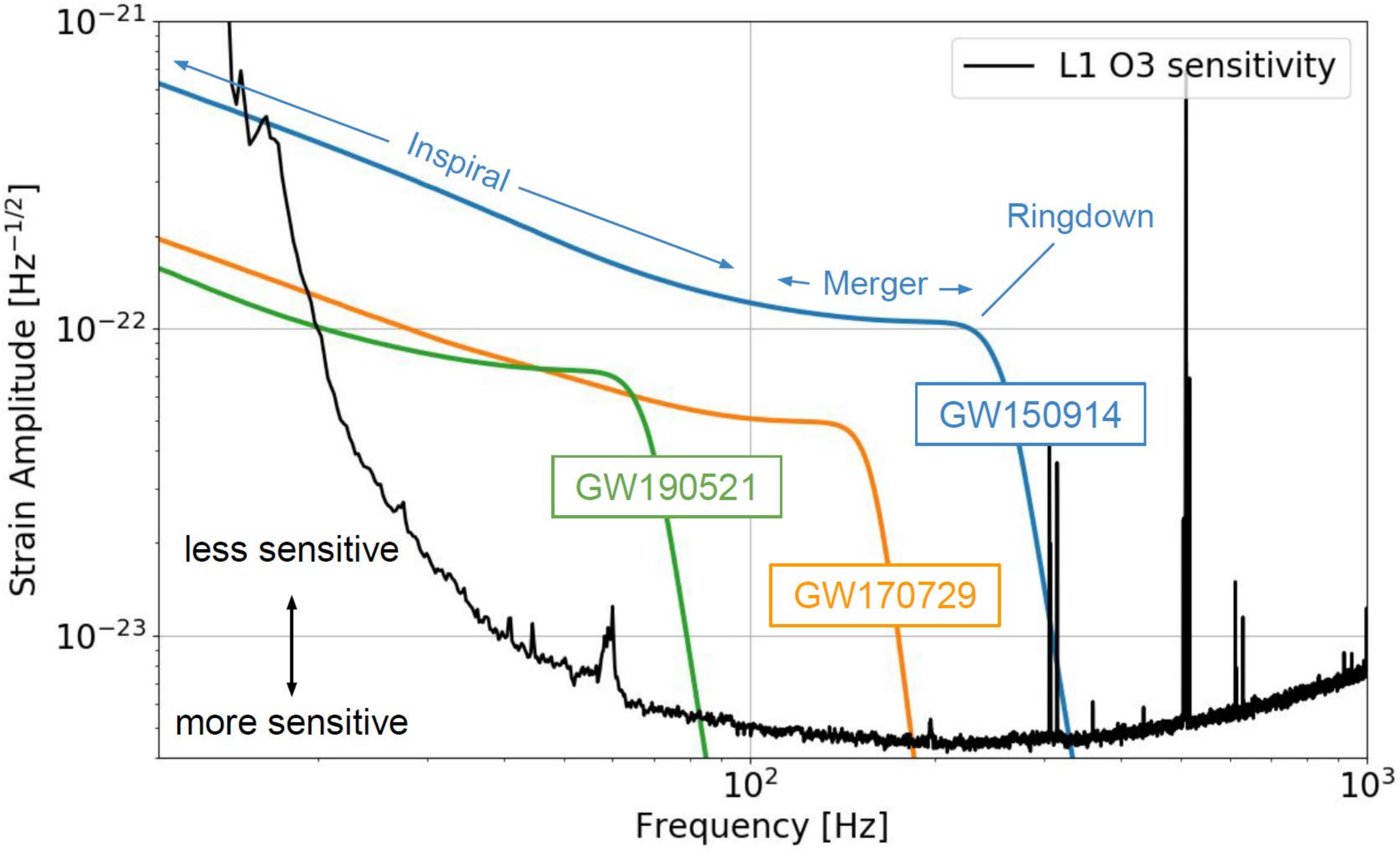




Where is the chirp?

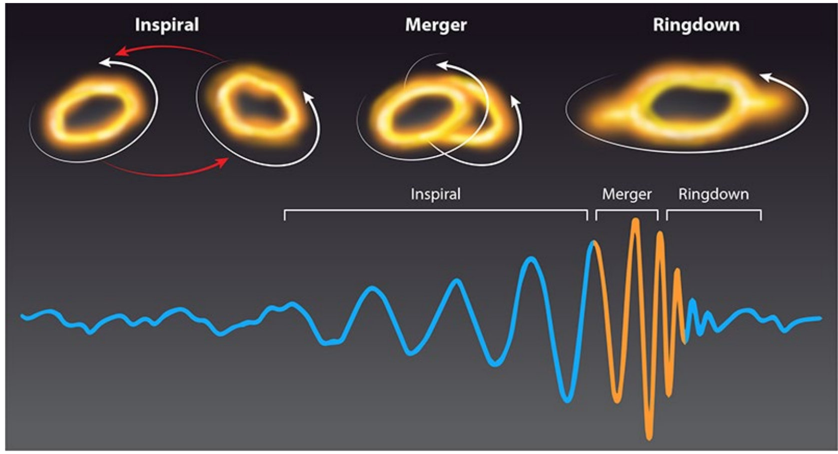
Phys. Rev. Lett. 125, 101102 (2020)
Astrophys. J. Lett. 900, L13 (2020)

GW190521: LIGO-Virgo sensitivity to the BBH merger



- Higher masses correspond to lower frequency GW emission

(Top) Kip Thorne; (Bottom) B. P. Abbott *et al.*; adapted by APS/Carin Cain



ET Science in a nutshell

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ASTROPHYSICS

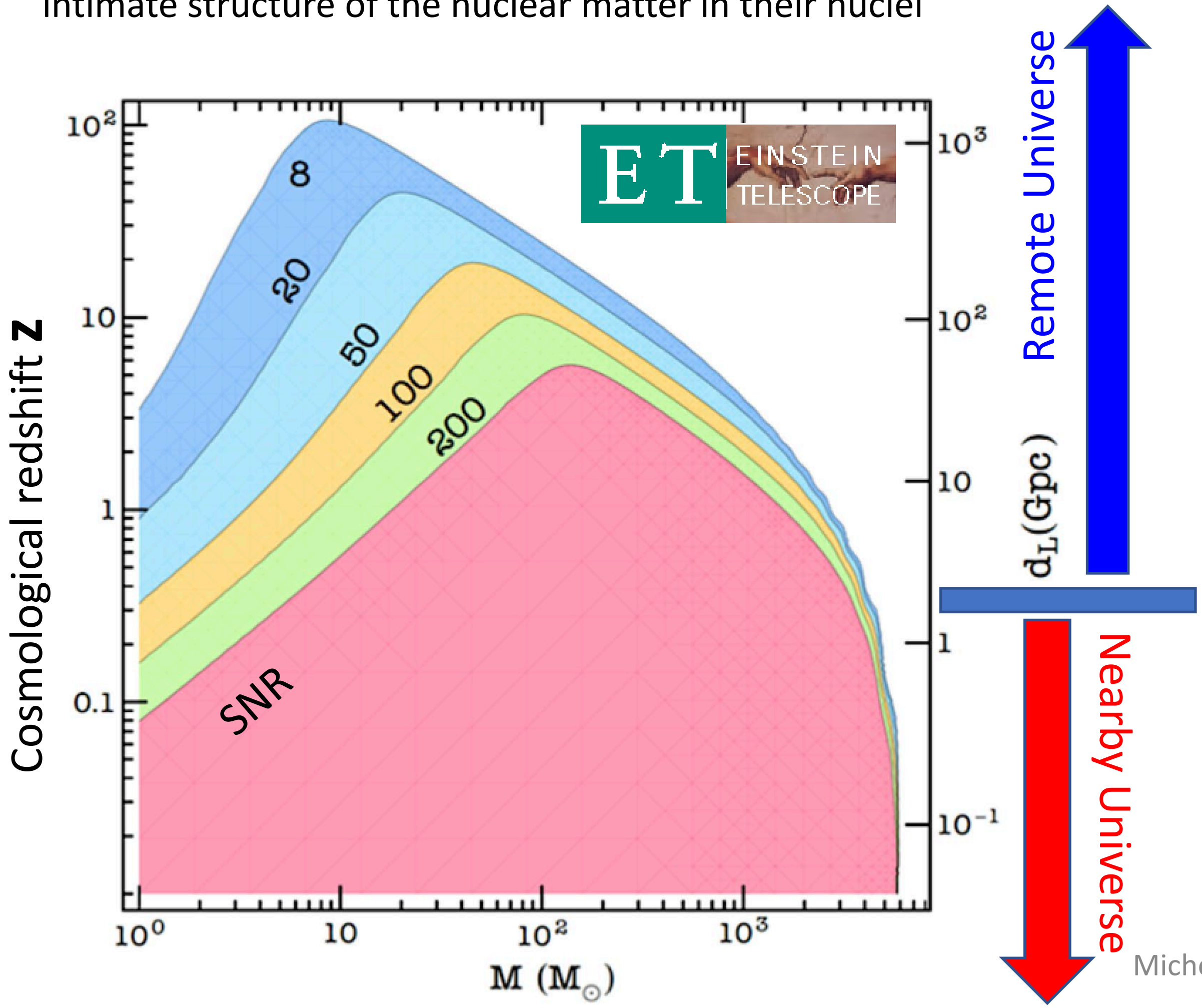
- **Black hole properties**
  - origin (stellar vs. primordial)
  - evolution, demography
- **Neutron star properties**
  - interior structure (QCD at ultra-high densities, exotic states of matter)
  - demography
- **Multi-band and -messenger astronomy**
  - joint GW/EM observations (GRB, kilonova,...)
  - multiband GW detection (LISA)
  - neutrinos
- **Detection of new astrophysical sources**
  - core collapse supernovae
  - isolated neutron stars
  - stochastic background of astrophysical origin

FUNDAMENTAL PHYSICS AND COSMOLOGY

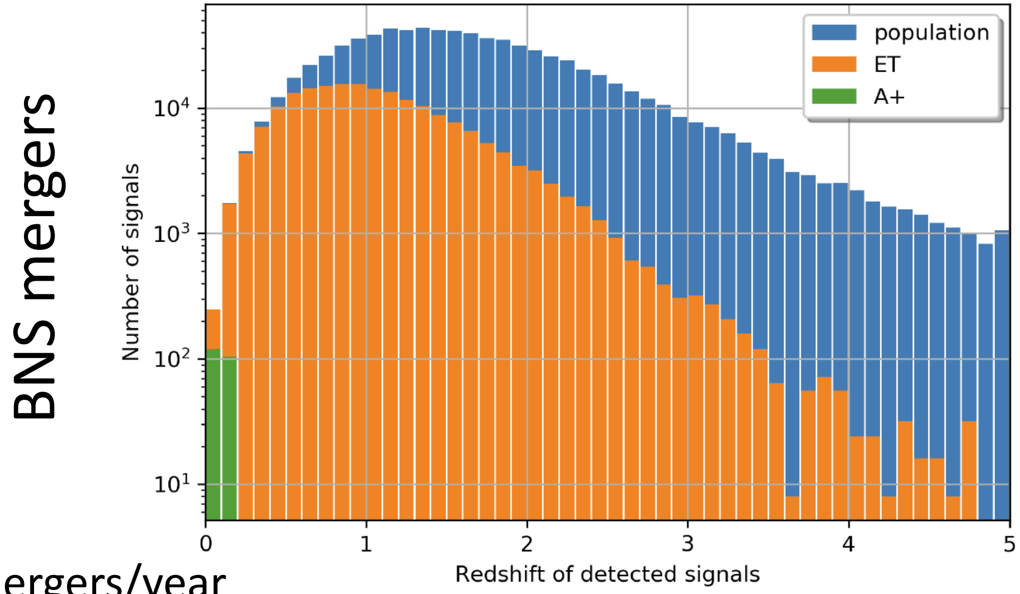
- **The nature of compact objects**
  - near-horizon physics
  - tests of no-hair theorem
  - exotic compact objects
- **Tests of General Relativity**
  - post-Newtonian expansion
  - strong field regime
- **Dark matter**
  - primordial BHs
  - axion clouds, dark matter accreting on compact objects
- **Dark energy and modifications of gravity on cosmological scales**
  - dark energy equation of state
  - modified GW propagation
- **Stochastic backgrounds of cosmological origin**
  - inflation, phase transitions, cosmic strings

ET Science in a nutshell

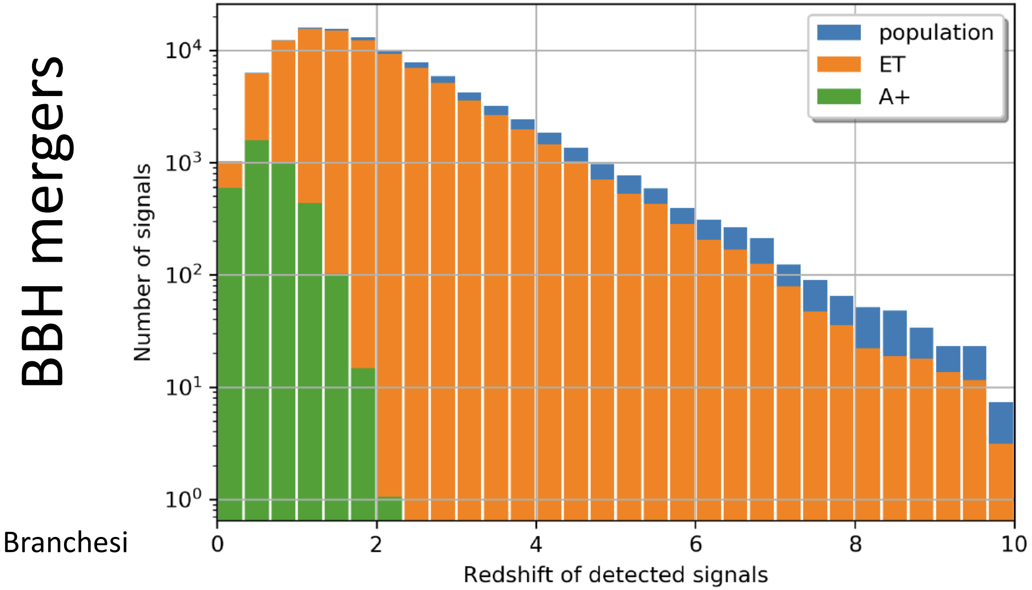
- ET will explore almost the entire Universe listening the gravitational waves emitted by black hole, back to the dark ages after the Big Bang
- ET will detect, with high SNR, hundreds of thousands coalescences of binary systems of Neutron Stars per year, revealing the most intimate structure of the nuclear matter in their nuclei



Compact Object Binary Populations



O(10^5) mergers/year



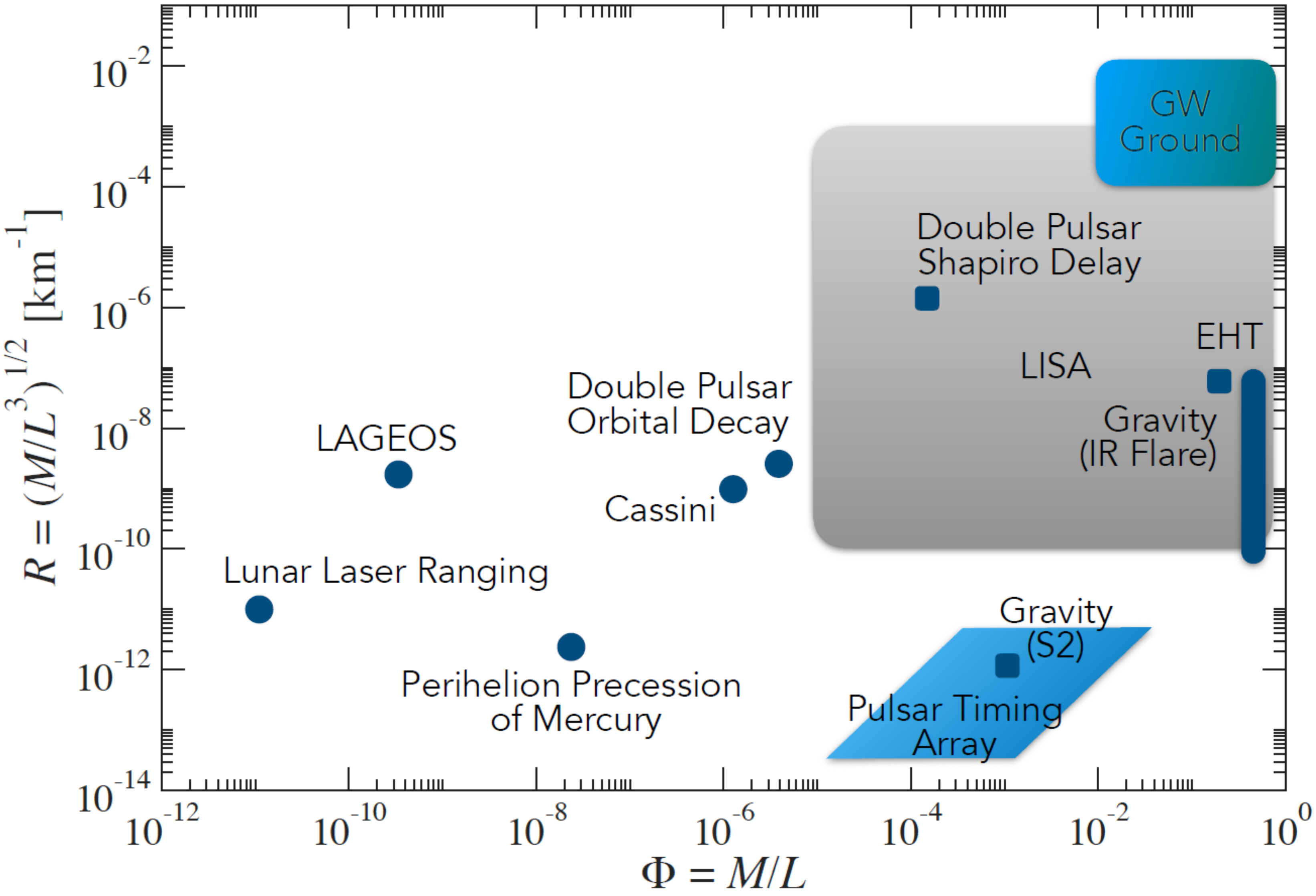
Michele Punturo

Credit: M.Branchesi

GWs are probing GR in strong field conditions

- BBH coalescences allow to test GR in strong field conditions

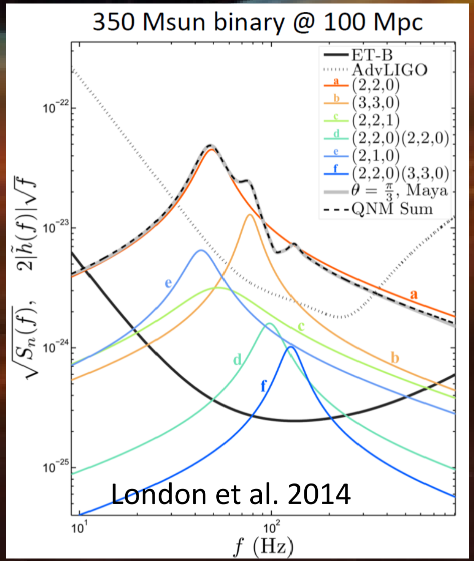
Yunes N. et al.
Phys. Rev. D 94, 084002 (2016)
Edited by ET science case team



GW Science with ET

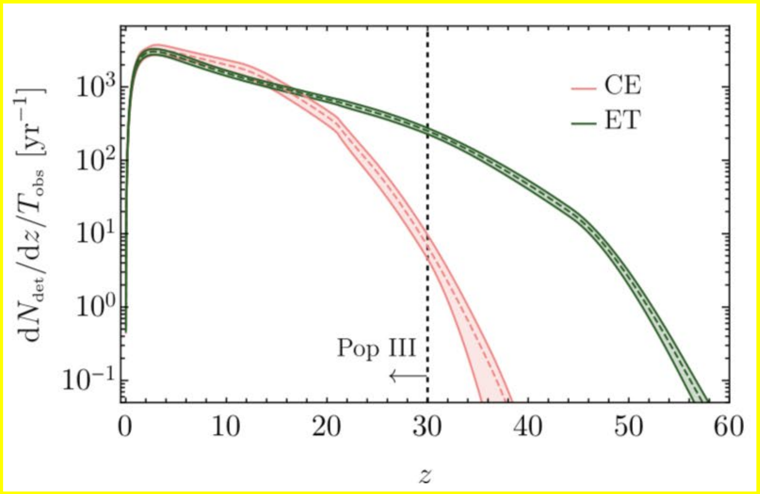
Extreme Gravity conditions

- In GR, no-hair theorem predicts that BHs are described only by their mass and spin (and charge)
  - However, when a BH is perturbed, it reacts (in GR) in a very specific manner, relaxing to its stationary configuration by oscillating in a superpositions of quasi-normal (QN) modes, which are damped by the emission of GWs.
  - A BH, a pure space-time configuration, reacts like an elastic body → Testing the "elasticity" of the space-time fabric
  - Exotic compact bodies could have a different QN emission and have echoes.



Primordial Black Holes

- ET (and CE) will detect BBH well beyond the SFR peak z~2
  - comparing the redshift dependence of the BH-BH merger rate with the cosmic star formation rate to disentangle the contribution of BHs of stellar origin from that of possible BHs of primordial origin: any BBH merger at z>30 will be of primordial origin.



Cosmology, Cosmography, Hubble constant measurement

- In high-mass ratio events from either neutron star-black hole or double black hole binaries, significant energy in the higher-order modes can break the distance-inclination angle degeneracy since the polarization modes have a different dependence on the inclination angle.
- In some golden case the host galaxy can be identified and then the redshift can be obtained without an em counterpart

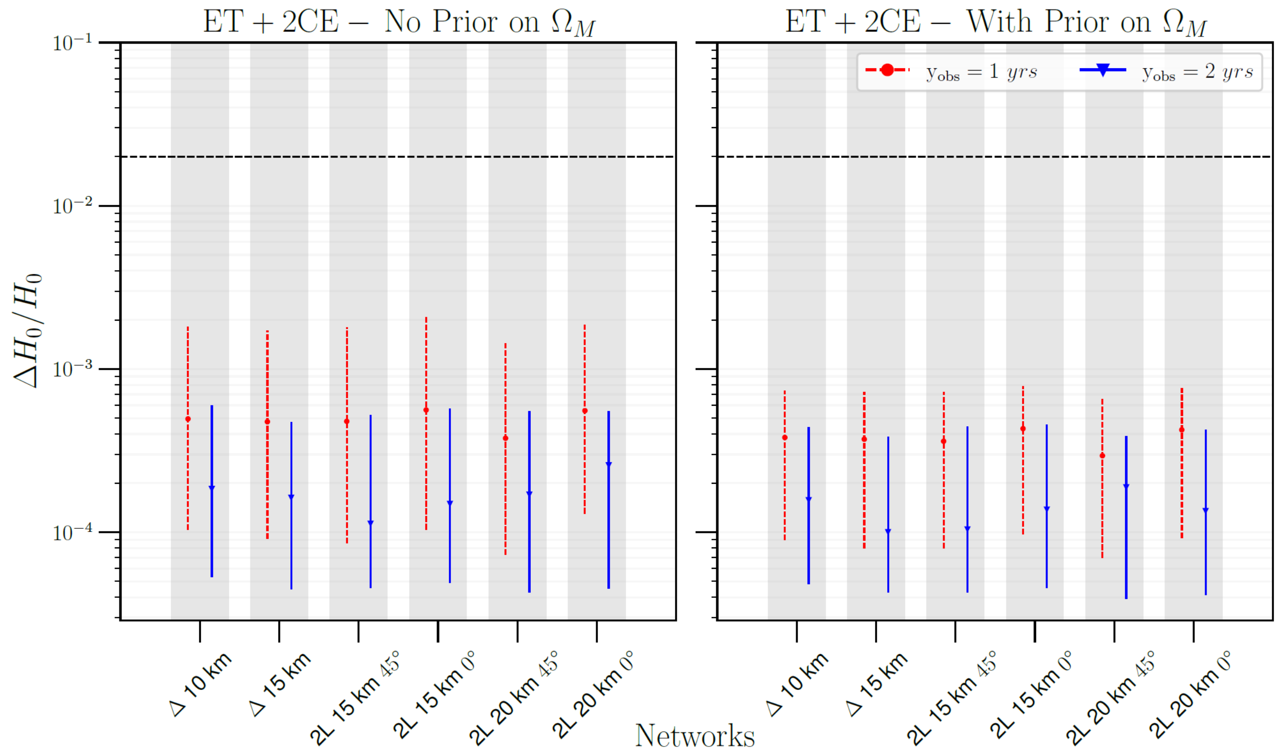
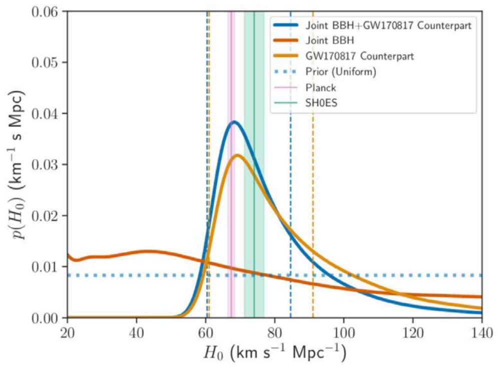


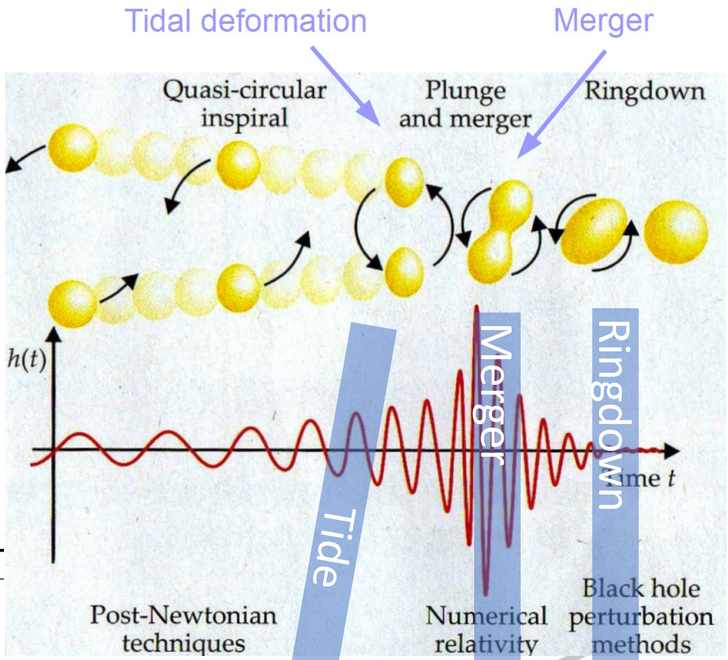
Figure 60: The accuracy with which the Hubble constant can be measured by different detector networks by high-mass ratio binary black holes, with events corresponding to 1 and 2 yrs of observation time picked randomly from the 10-year catalog of BBH events located within $z = 0.1$. In the left plot, H_0 is measured with no prior imposed on the dark matter energy density Ω_M, while for the right plot we assume a gaussian prior with a width of 0.017. The markers show the median value of the fractional error in H_0 and the error bars denote the 68% confidence region.

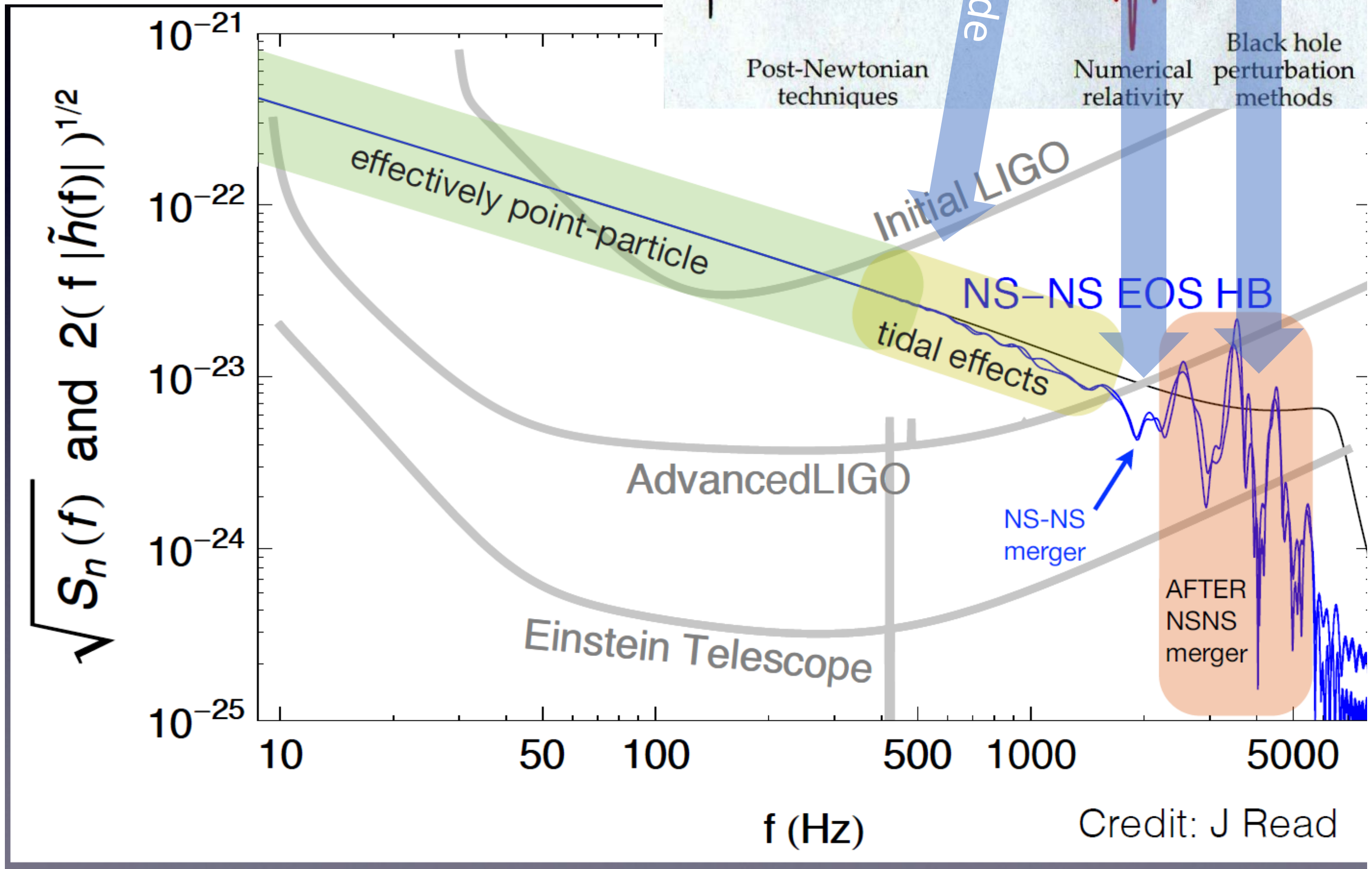


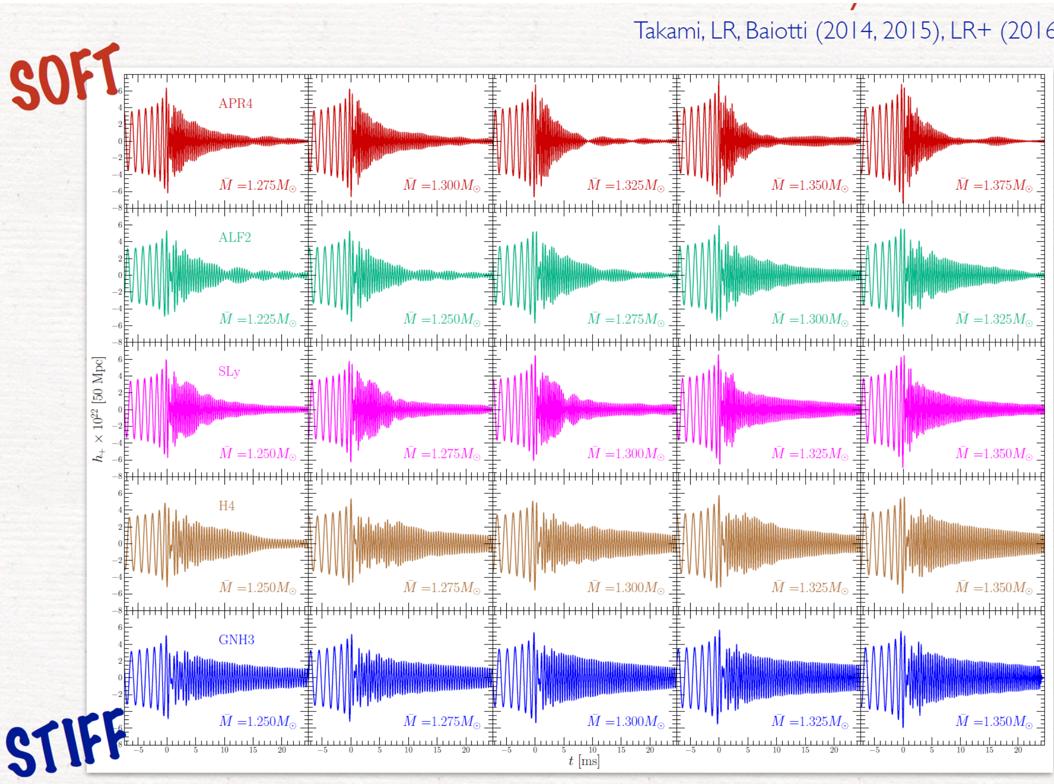
$H_0 = 68^{+14}_{-7}$ km s^{-1} Mpc^{-1}

Structure of a Neutron Star

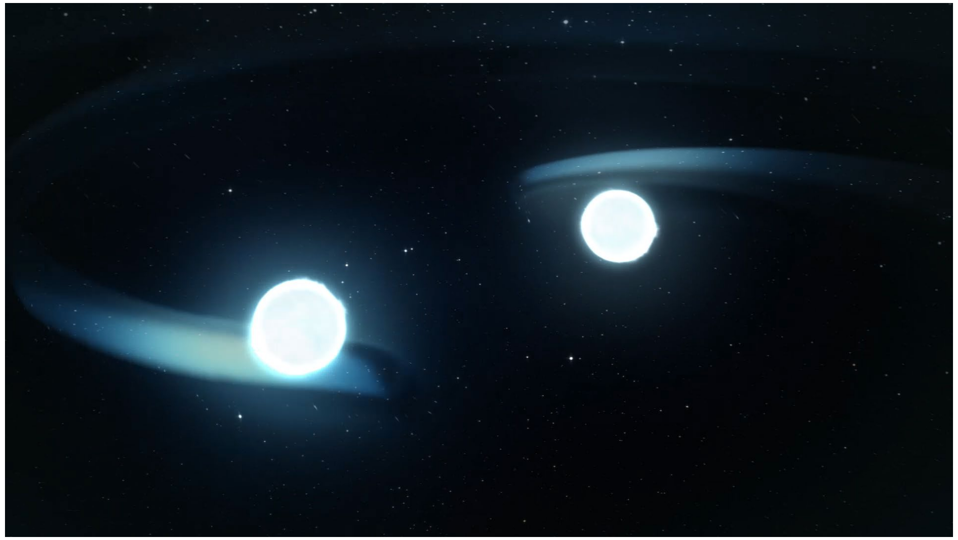
Stephen Fairhurst
ET meeting 27-28 March 2017



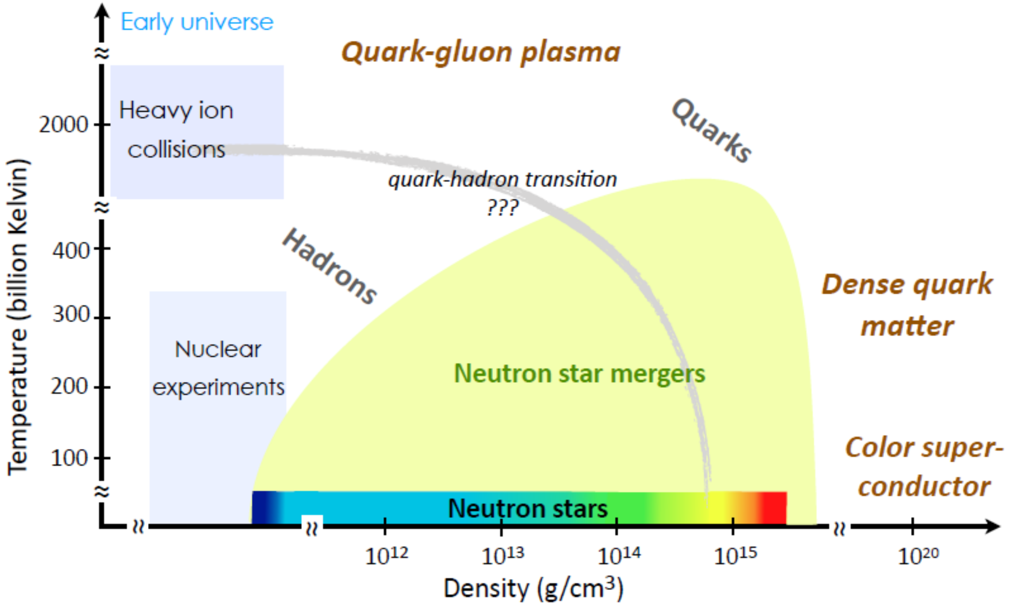




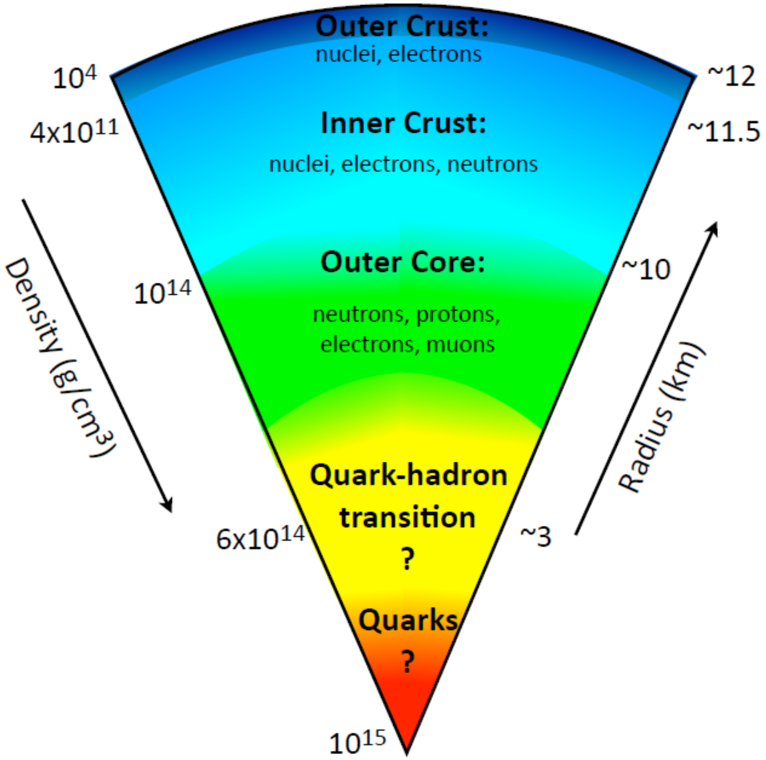
GW Science with ET



- 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?)

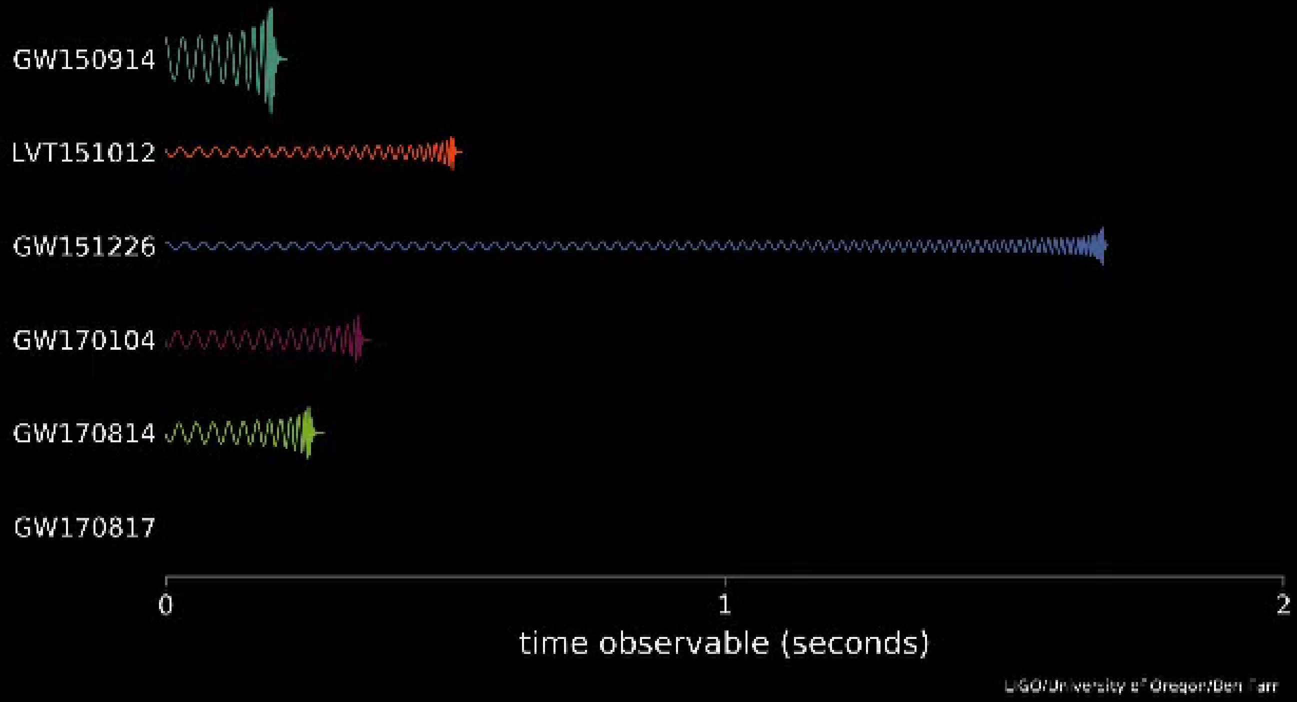


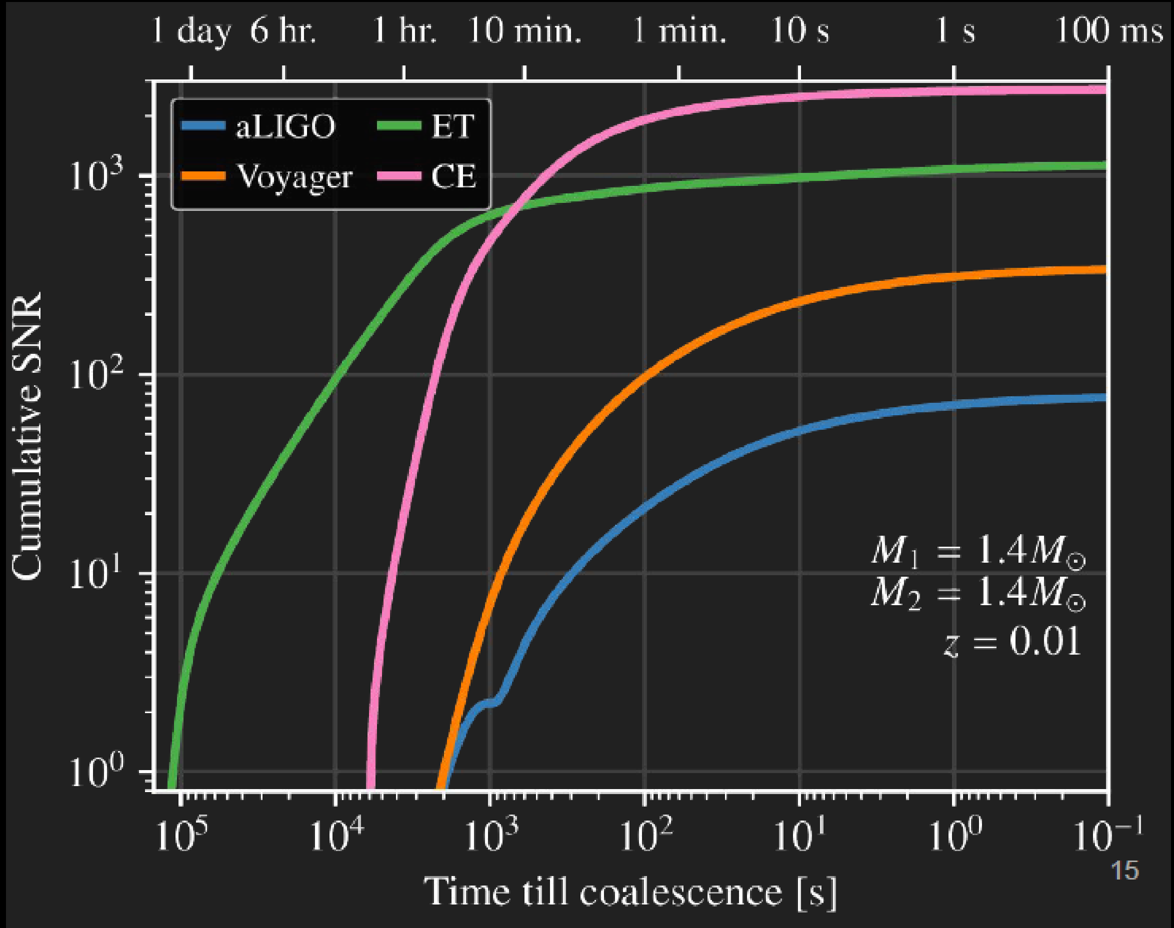
- Tidal deformation from the dephasing in the GW signal → constrain the EOS of the NS.
- EM information → more stringent constrain.
- EOS describes the status of the matter in the over-critical pressure condition.



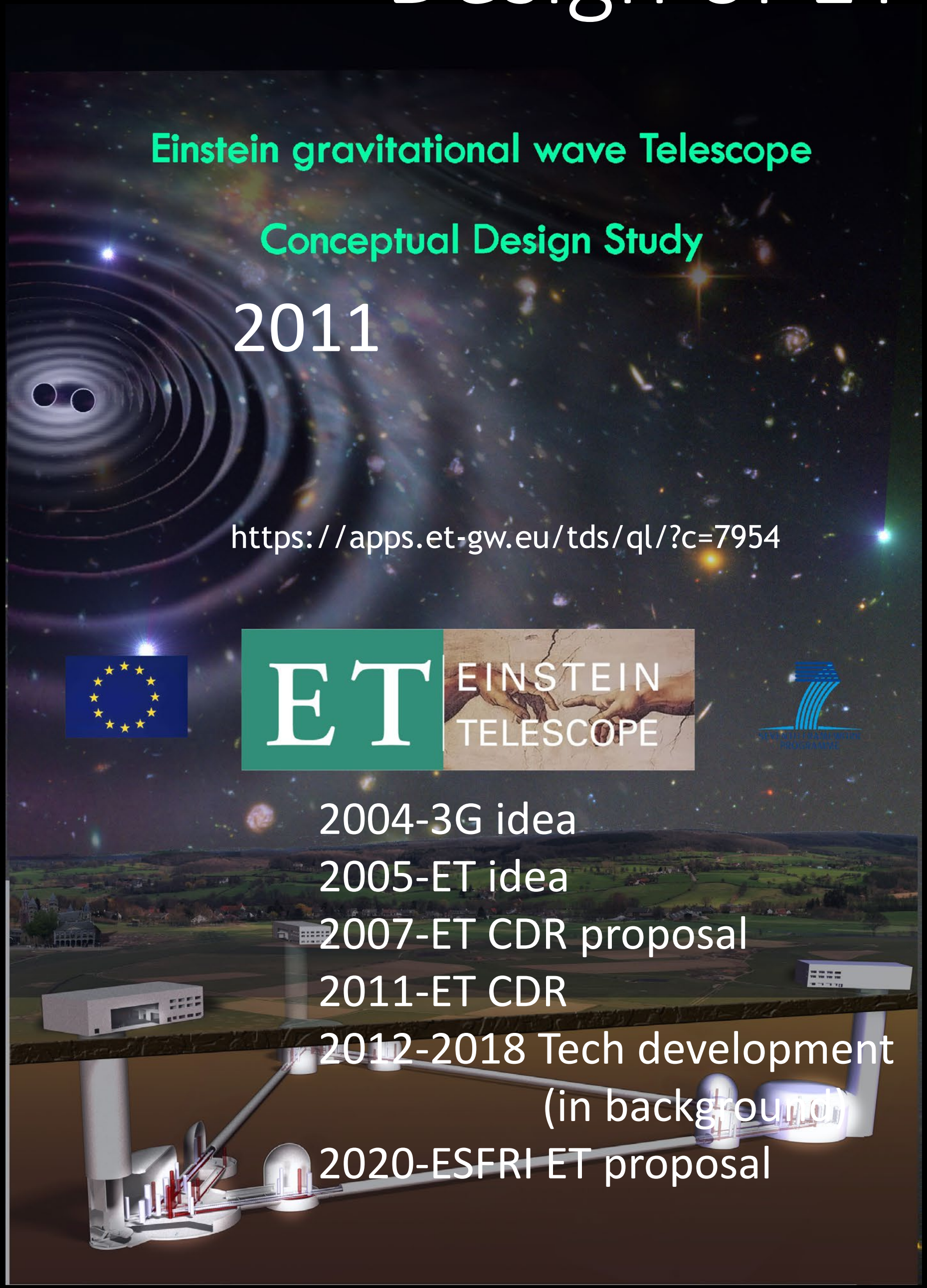
Low frequency: Multi-messenger astronomy

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



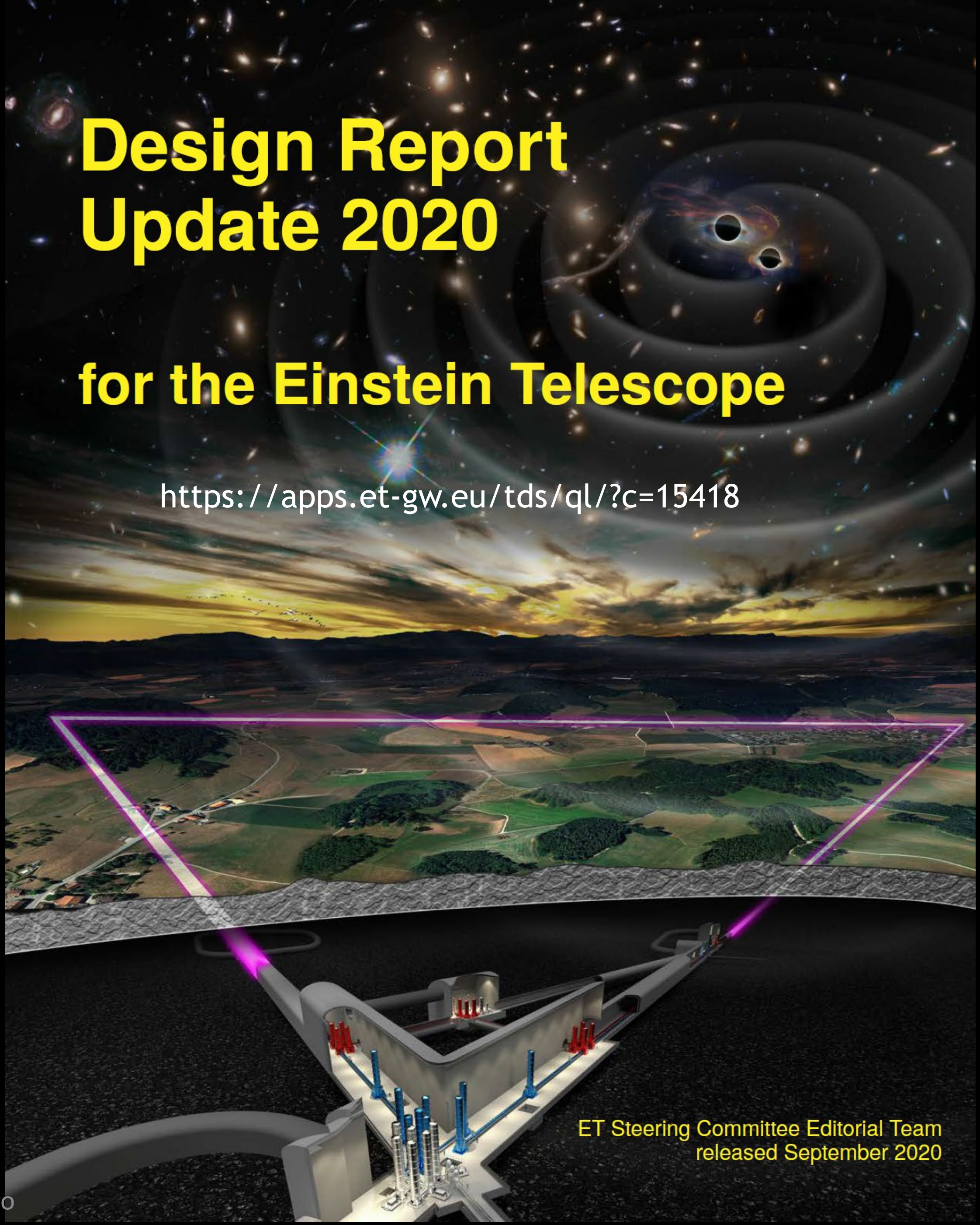


Design of ET

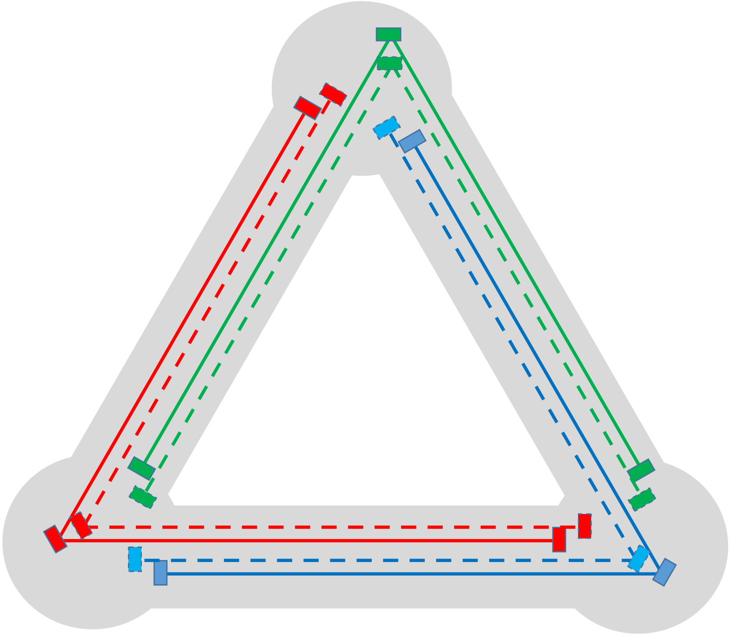


2004-3G idea
2005-ET idea
2007-ET CDR proposal
2011-ET CDR
2012-2018 Tech development (in background)
2020-ESFRI ET proposal

ESFRI



ET key elements

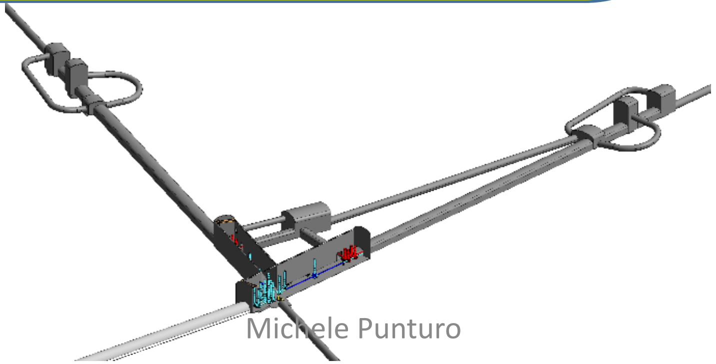


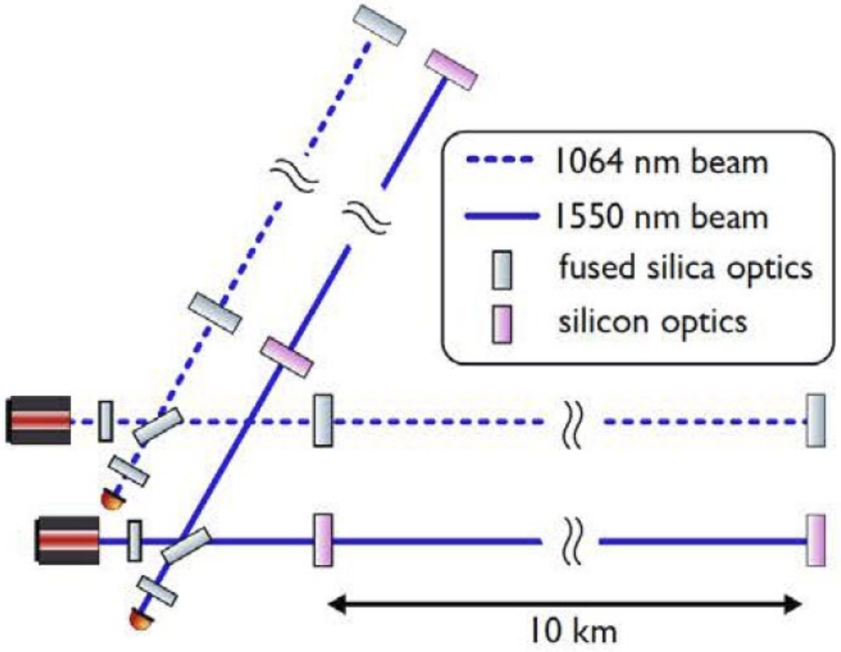
Requirements

- Wide frequency range
- Massive black holes (LF focus)
- Localisation capability
- (more) Uniform sky coverage
- Polarisation disentanglement
- High Reliability (high duty cycle)
- High SNR

Design Specifications

- Xylophone (multi-interferometer) Design
- Underground
- Cryogenic
- Triangular shape
- Multi-detector design
- Longer arms





ET design: Δ or (two) L

In the last two of years, the collaboration started the evaluation of the best configuration for ET, considering the alternative of two L configuration (as LIGO, Cosmic Explorer) to maximize the science return and reduce risks.

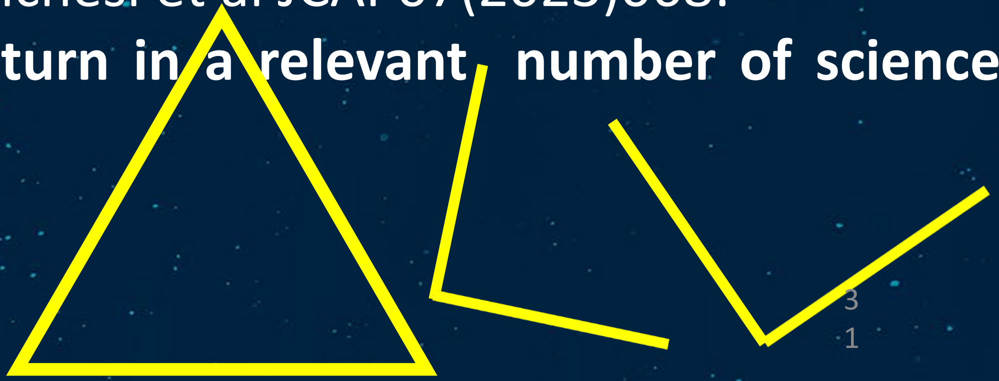
Since 2011 (CDS, triangle configuration) the situation drastically changed:

- ❑ First detections, GTWC-3 catalog → BH population → new evolution models;
- ❑ Science case developed;
- ❑ Know-how with advanced (L) detectors;
- ❑ International scenario (+ Cosmic Explorer in US);
- ❑ Two candidate sites strongly supported (and a potential third site…).

The collaboration is analyzing both configurations: **optimizing science return, differential risk assessment.**

First results on the science return published in Marica Branchesi et al JCAP07(2023)068:

The 2L 15 km geometry shows an improved science return in a relevant number of science targets



ET Enabling Technologies

- The multi-interferometer approach asks for two parallel technology developments:
  - **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

Parameter	ET-HF	ET-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10-20 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	45 cm/ 57 cm
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase (rad)	tuned (0.0)	detuned (0.6)
SR transmittance	10 %	20 %
Quantum noise suppression	freq. dep. squeez.	freq. dep. squeez.
Filter cavities	1×300 m	2×1.0 km
Squeezing level	10 dB (effective)	10 dB (effective)
Beam shape	TEM_{00}	TEM_{00}
Beam radius	12.0 cm	9 cm
Scatter loss per surface	37 ppm	37 ppm
Seismic isolation	SA, 8 m tall	mod SA, 17 m tall
Seismic (for $f > 1$ Hz)	$5 \cdot 10^{-10}\ \mathrm{m}/f^2$	$5 \cdot 10^{-10}\ \mathrm{m}/f^2$
Gravity gradient subtraction	none	factor of a few

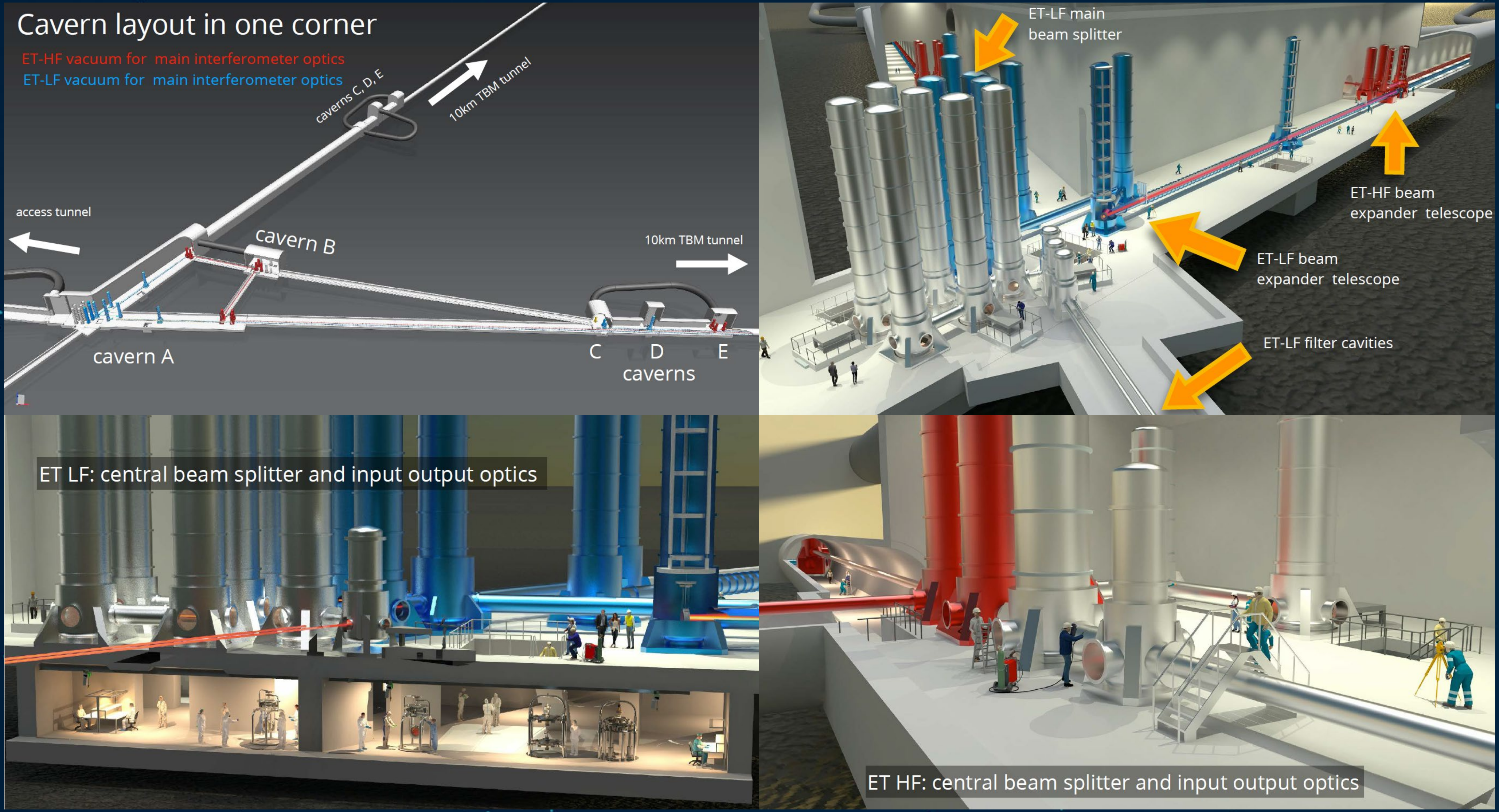
ET-LF enabling technologies:
- Challenging engineering
- New technology in cryo-cooling
- New technology in optics
- New laser technology
- High precision mechanics and low noise controls
- High quality opto-electronics and new controls

ET-HF enabling technologies:
- Evolved laser technology
- Evolved technology in optics
- Highly innovative adaptive optics
- High quality opto-electronics and new controls

ET EINSTEIN TELESCOPE

INFN Istituto Nazionale di Fisica Nucleare

ET: large scale and complex infrastructure



Credit: A.Freise, 2020 XI ET Symposium

Challenging Engineering: key points

- **~30km of underground tunnels**
  - Safety (fire, cryogenic gasses, escape lanes, heat handling during the vacuum pipe backing)
  - Noise (creeping, acoustic noise, seismic noise, Newtonian noise)
  - Minimisation of the volumes, but preservation of future potential)
  - Water handling, hydro-geology and tunnels inclination
  - Cost
- **Large caverns**
  - In addition to the previous points:
  - Stability
  - Cleanliness
  - Thermal stability
  - Ventilation and acoustic noise

Of pivotal importance the CERN support in the role of Advisor on civil engineering

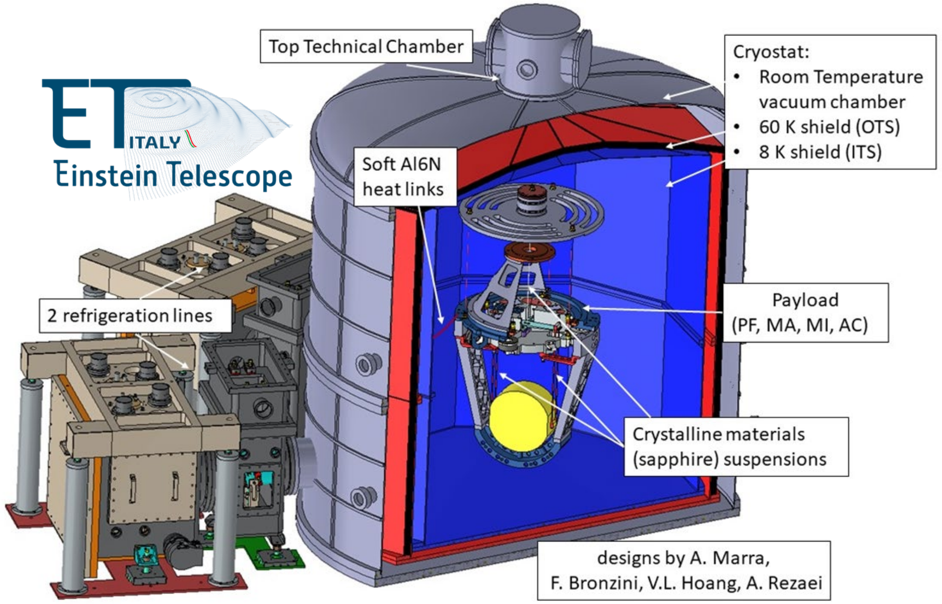
Deliverable	Description of civil engineering documents to be produced by ETO and reviewed and supported by CERN	Date
D1	Work Plan explaining the roadmap to produce the TDR	Q4 2023
D2	Review and Assessment document of existing information relevant for civil engineering	Q4 2023
D3	Requirements and specific objectives for the civil engineering tender documents for consultant(s) to develop civil engineering layouts/specifications and to produce cost/schedule report and risk analysis	Q2 2024
D4	Configuration of design tools (Geoprofiler, GIS data, BIM model etc.)	Q4 2024
D5	Structure of the TDR	Q1 2025
D6	TDR	Q4 2026

Challenges in Cryo-cooling

ET operative temperature ~10K

Key issues

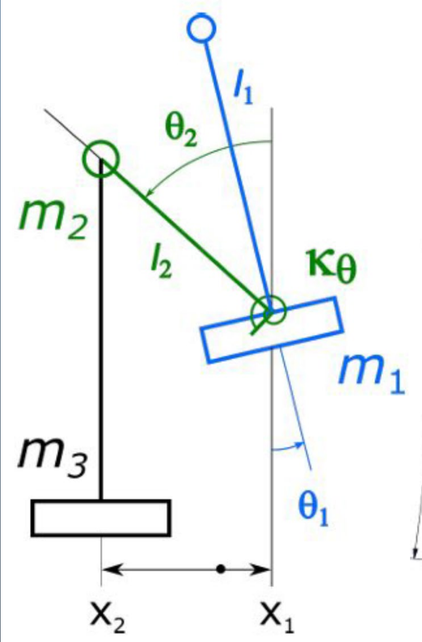
- Acoustic and vibration noises
- Laser absorption and heat extraction
- Cleanliness and contamination
- Cooling time (large masses, commissioning time, …)
- Infrastructures
- Technology (cryo-fluids or cryo-coolers)
- Materials
- Safety

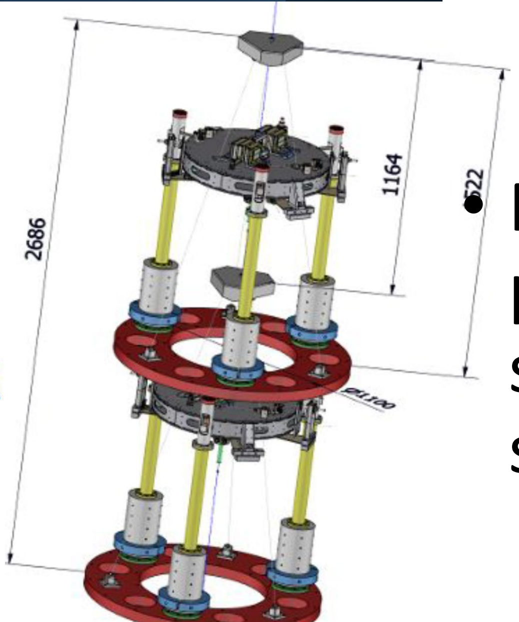


Amaldi Research Center in Rome

Low Frequency special focus

- Low noise site
- Underground infrastructure
- 17m tall seismic filtering suspensions
  - Large impact on cavern engineering and costs
- R&D in active-passive filtering systems and seismic sensors





Credits: A.Freise

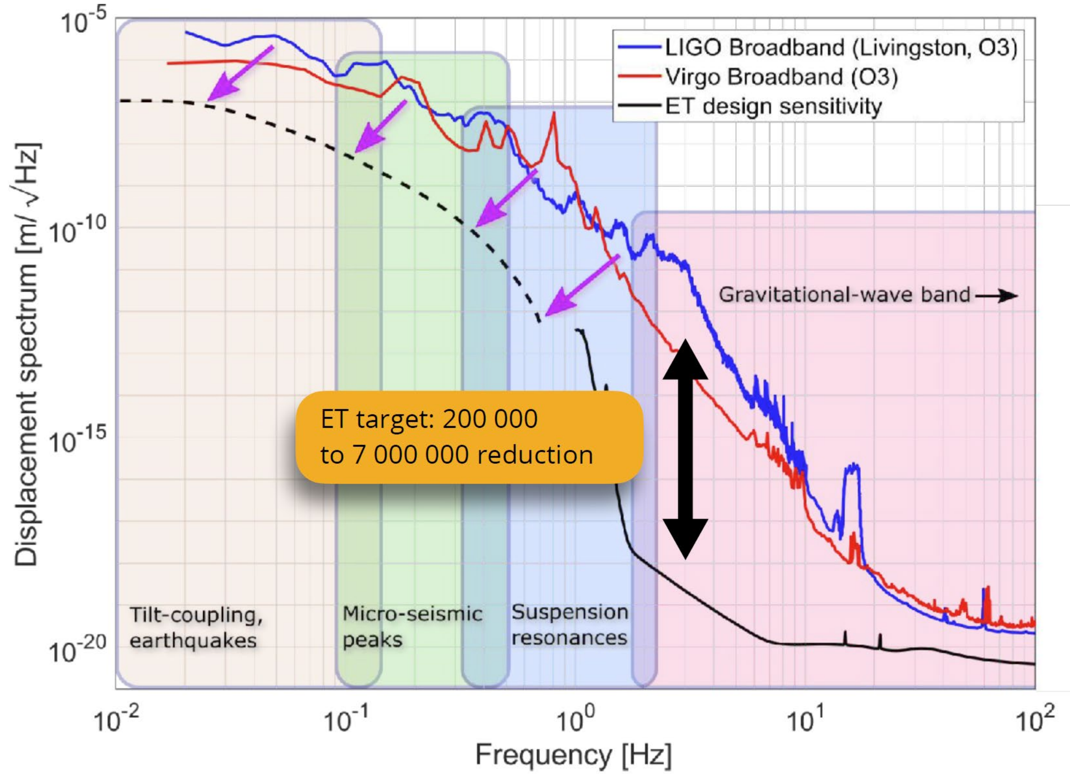
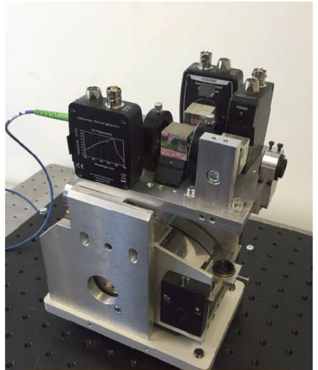
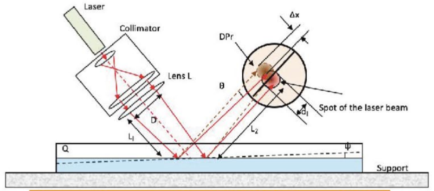


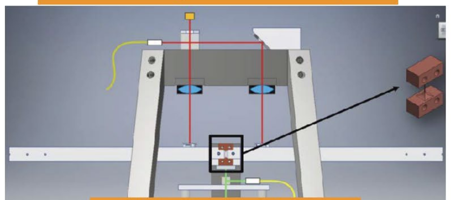
Image: Conor Mow-Lowry


6-D interferometric readout inertial sensor
Credit: Conor Mow-Lowry, VU Amsterdam

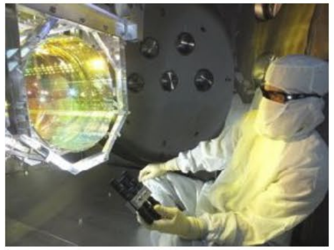

Low frequency seismometers
Credit: Christophe Collette, U. Liege

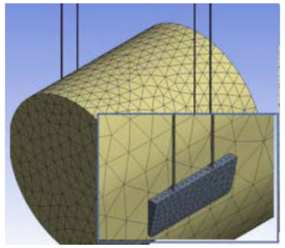


Laser inclinometer, Credit: B. Di Girolamo, CERN


Ultralow frequency tiltmeter
Credit: ARCHIMEDES and VIRGO Coll.

Credits: A.Freise



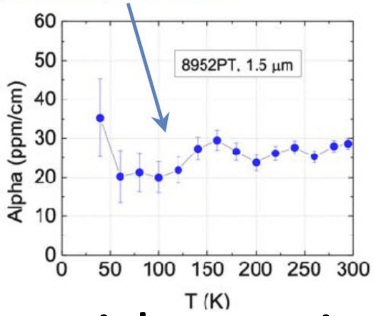


Advanced LIGO – 40 kg / ET 200 kg

Nikon SiO_2

Absorption of "best 45 cm" MCZ Si: 1.5um

Stanford/Glasgow/Berkeley/Caltech 2019



New Optics

- **Substrates Challenge:**
  - Substrate (ET-HF silica / ET-LF silicon) of 200 kg-scale, diam≥45cm, with required purity and optical homogeneity/abs.
  - Silicon Challenge:
    - Czochralski (CZ) method produced test masses could have the required size, but show absorption excesses due to the (crucible) contaminants
    - Float Zone (FZ) produced samples show the required purity, but of reduced size (20cm wrt ≥45cm required)
    - Magnetic Czochralski (mCZ) could be the possible solution?
- **Coating Challenge:**
  - major challenge over recent years:
    - Amorphous dielectric coating solutions often either satisfy thermal noise requirement (3.2 times better than the current coatings) **or** optical performance requirement (less than 0.5ppm) – not both
    - AlGaAs Crystalline coatings could satisfy ET-LF requirements, but currently limited to 200mm diameter.

New Laser and Opto-Electronic Technology

Virgo and LIGO developed CW low noise lasers at 1064nm

- In ET-HF their evolution toward higher power will be investigated

In ET-LF we will use a different wavelength because of the Silicon test masses:

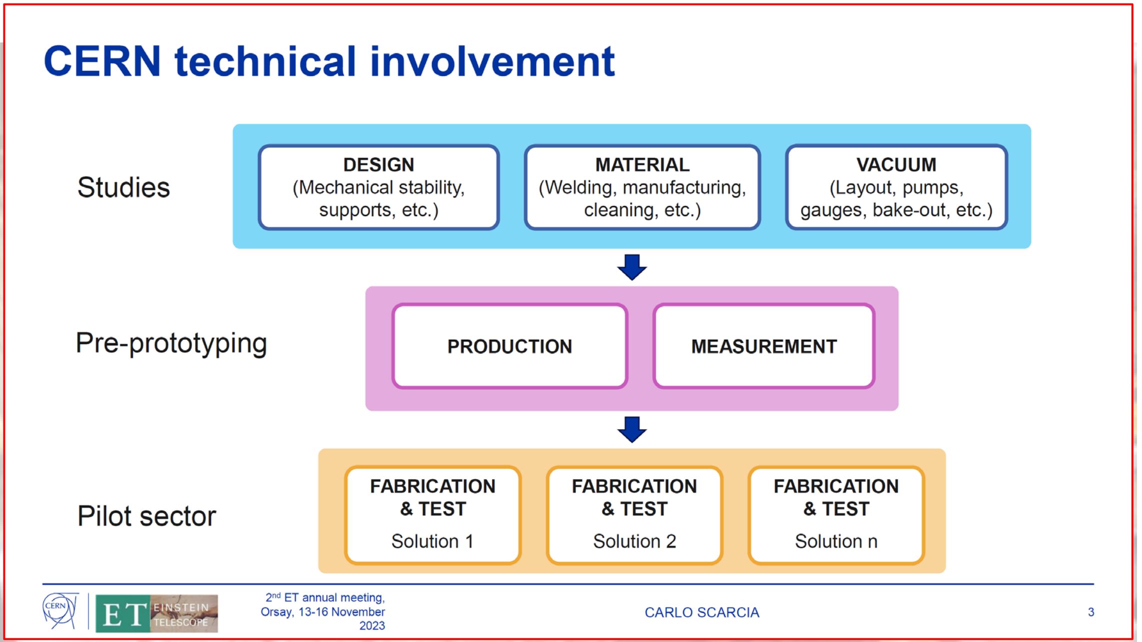
- λ=1.55μm or 2μm?

New electro-optic components:

- High quantum efficiency photodiodes
- Low absorption e.o.m.
- Low dissipation faraday isolators

Other relevant challenges

- Auxiliary optics, adaptive optics and thermal compensation of optical aberrations
- Precision mechanics, alignment and positioning
- **Vacuum** (*the largest volume under UHV in the World*):
  - More than 120km of vacuum pipes
    - ~1 m diameter, total volume 9.4×10^4 m^3
    - 5×10^{-11} mbar for H_2, 5×10^{-12} mbar for N_2, 10^{-11} for H_2O and less than 10^{-14} mbar for Hydrocarbons
  - Lifetime 50 years
  - Cost
  - Joint development with CERN involving ET and CE
- Low noise controls
- Computing
  - Computation intensive, not data intensive
- **Governance & Organisation**



https://cerncourier.com/a/cern-shares-beampipe-know-how-for-gravitational-wave-observatories

BEAMPIPES FOR GRAVITATIONAL WAVE TELESCOPES 2023

Beampipe know-how for GW observatories

The direct detection of gravitational waves (GWs) in 2015 opened a new window to the universe, allowing researchers to study the cosmos by merging data from multiple sources. There are currently four gravitational wave telescopes (GWTs) in operation: LIGO at two sites in the US, Virgo in Italy, KAGRA in Japan and GEO600 in Germany. Discussions are ongoing to establish an additional site in India. The detection of GWs is based on Michelson laser interferometry with Fabry–Perot cavities, which reveals the expansion and contraction of space at the level of ten-thousandths of the size of an atomic nucleus, i.e. 10^{-19} m. Despite the extremely low strain that needs to be detected, an average of one GW is measured per

Beam me up
The participants of the March workshop that was dedicated to vacuum technologies for

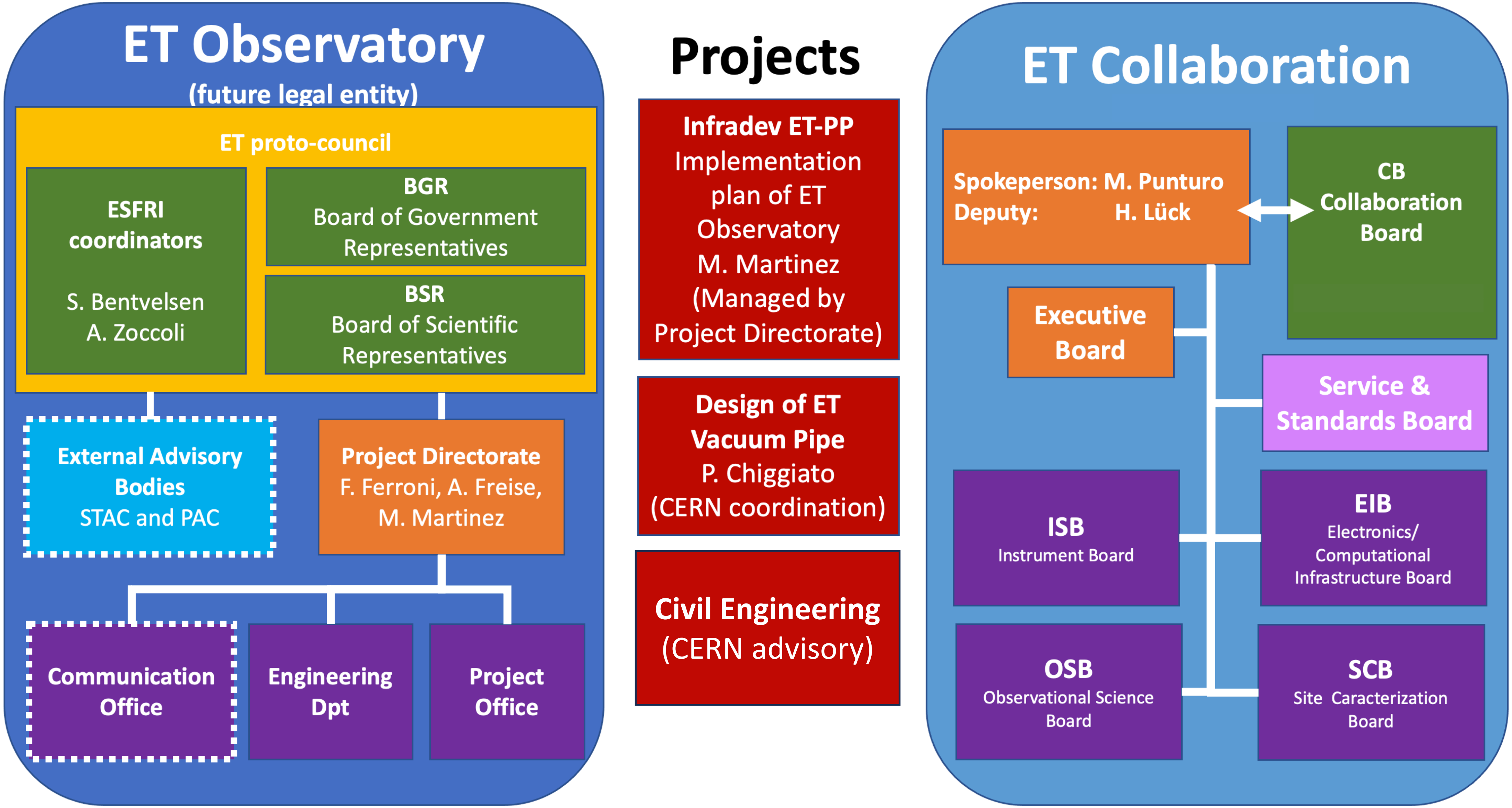
solutions were adopted, then the vacuum pipe system would amount to half the estimated cost of the CE and almost one-third of the ET, with underground civil engineering the dominant amount. Reducing the cost of vacuum systems

vacuum systems provided a starting point for the presentations of ongoing developments. To conduct an effective cost analysis and reduction, the entire process must be taken into account – including raw-material production and treatment,

Einstein Telescope in the ESFRI Roadmap

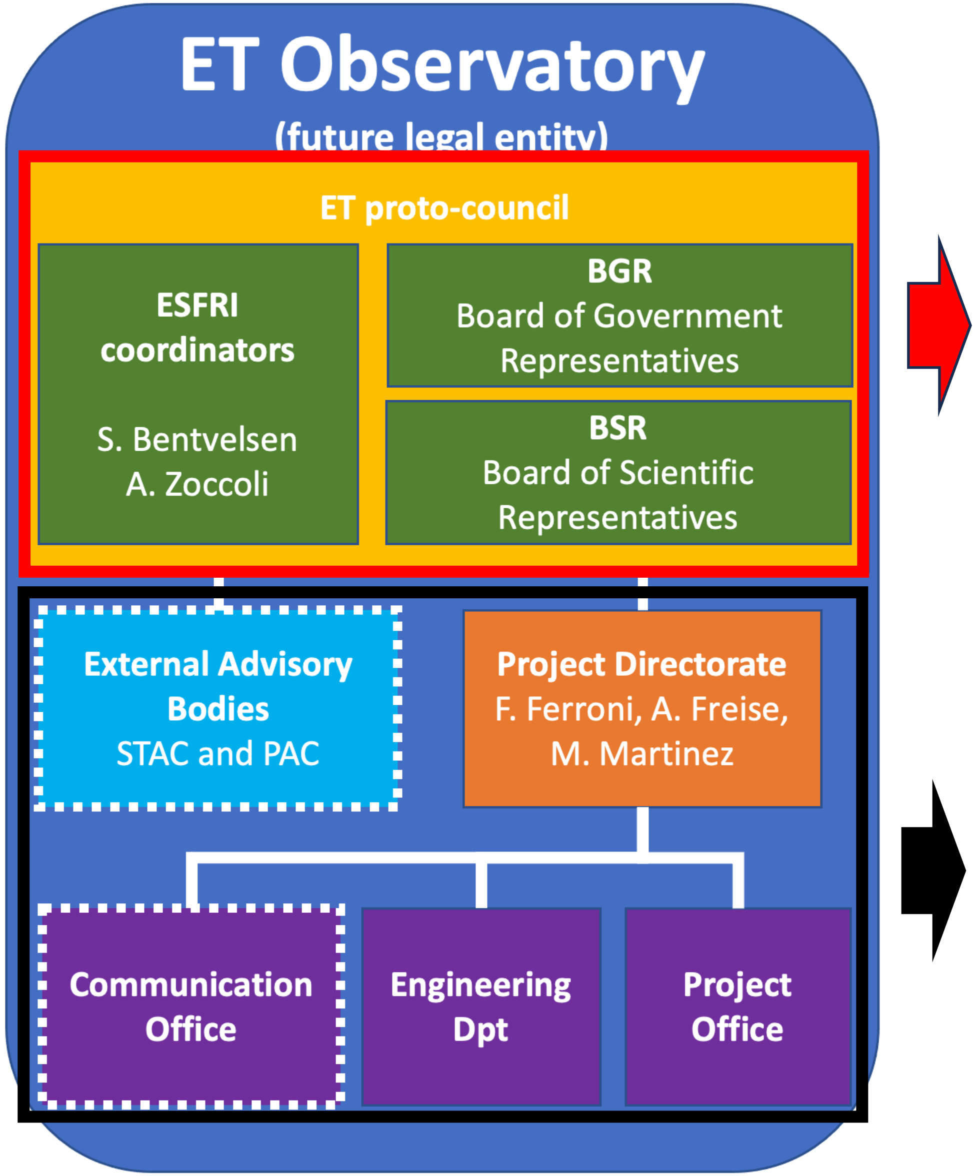
- ET entered the 2021 ESFRI roadmap update
- The ET proposal has been presented by the following countries: Italy, the Netherlands, Belgium, Spain and Poland
- The ET consortium is led by INFN and Nikhef
- The ET (current) governance has been structured according the following scheme

ET Current Organization



Simplified rapresentation by P.Verdier

ET Current Organisation

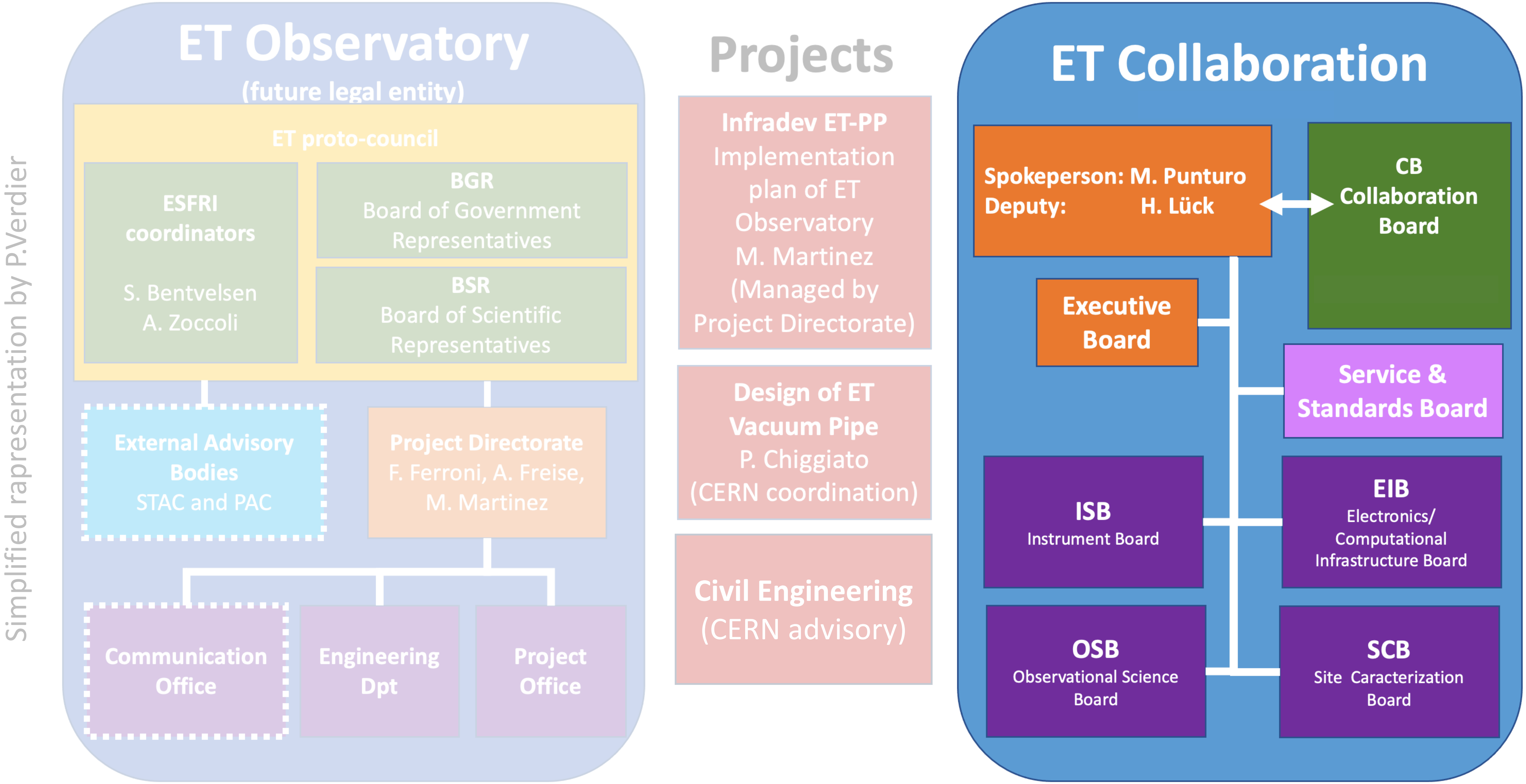


Temporary groups, working towards becoming the ET governing body, such as a Council. **Our most important link to governments and funding agencies** (Austria, Belgium, France, Italy, Netherlands, Poland, Spain, UK are members with Germany as observer).

An small but active organisation with the formal responsibility to realise ET. **A future legal entity for ET would be based on this structure.**

Credits: A. Freise

ET Current Organisation

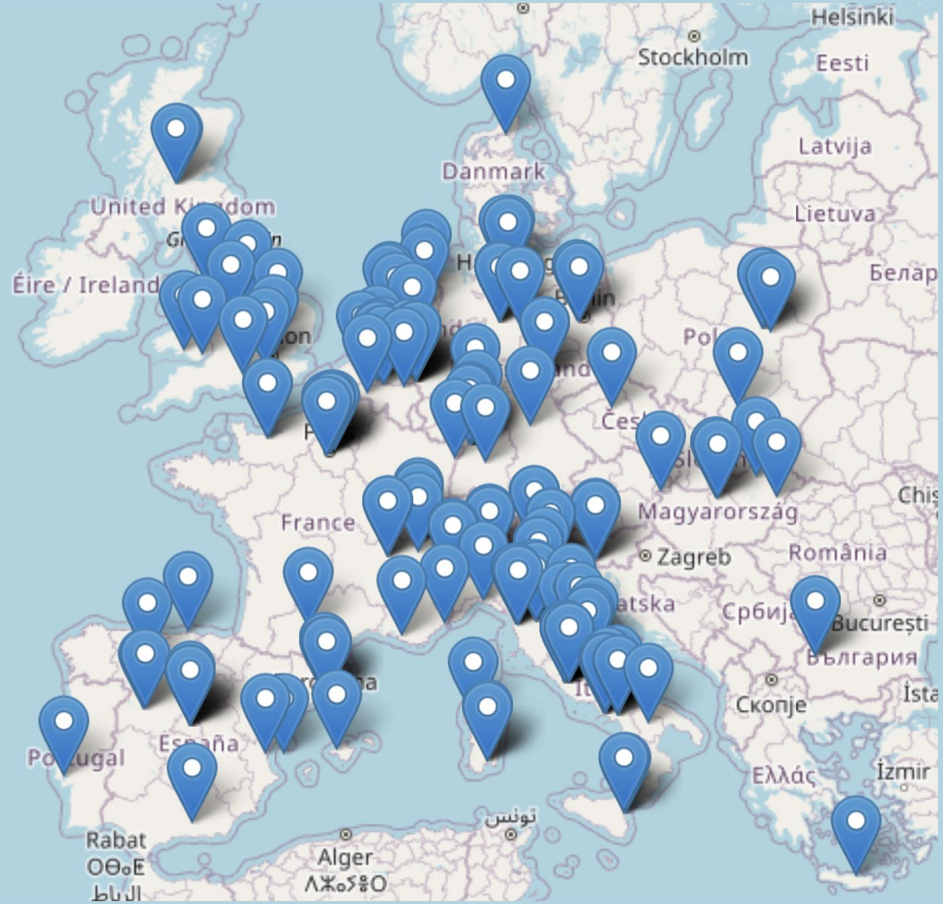


The Einstein Telescope Collaboration

ET EINSTEIN TELESCOPE

- 85 Research Units (+1 request pending)
- 1568 members (24/11/2023 15:29)
- Total: 226 Institutions
  in 25 Countries

- ET member database

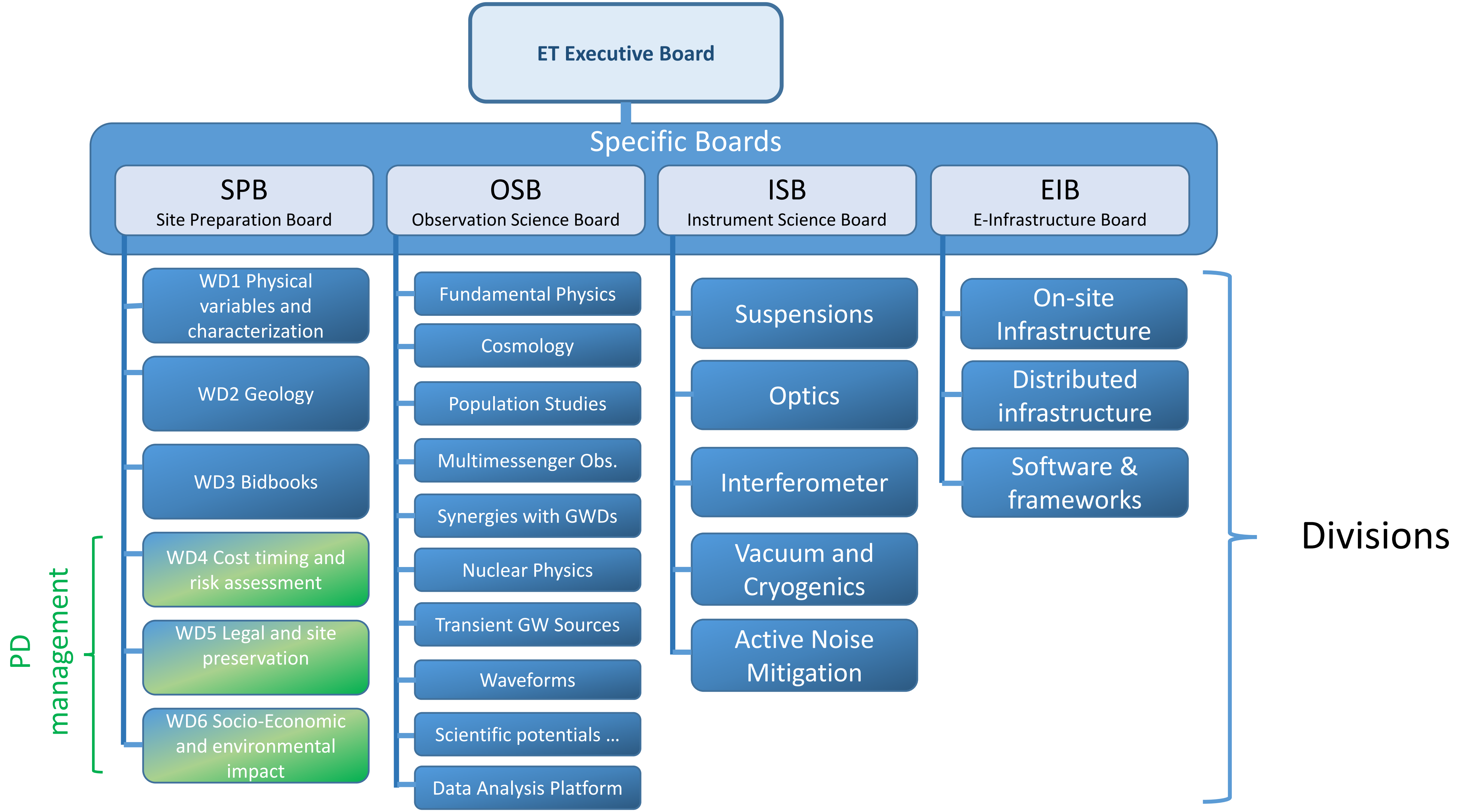


ET Member's affiliation map

ESFRI

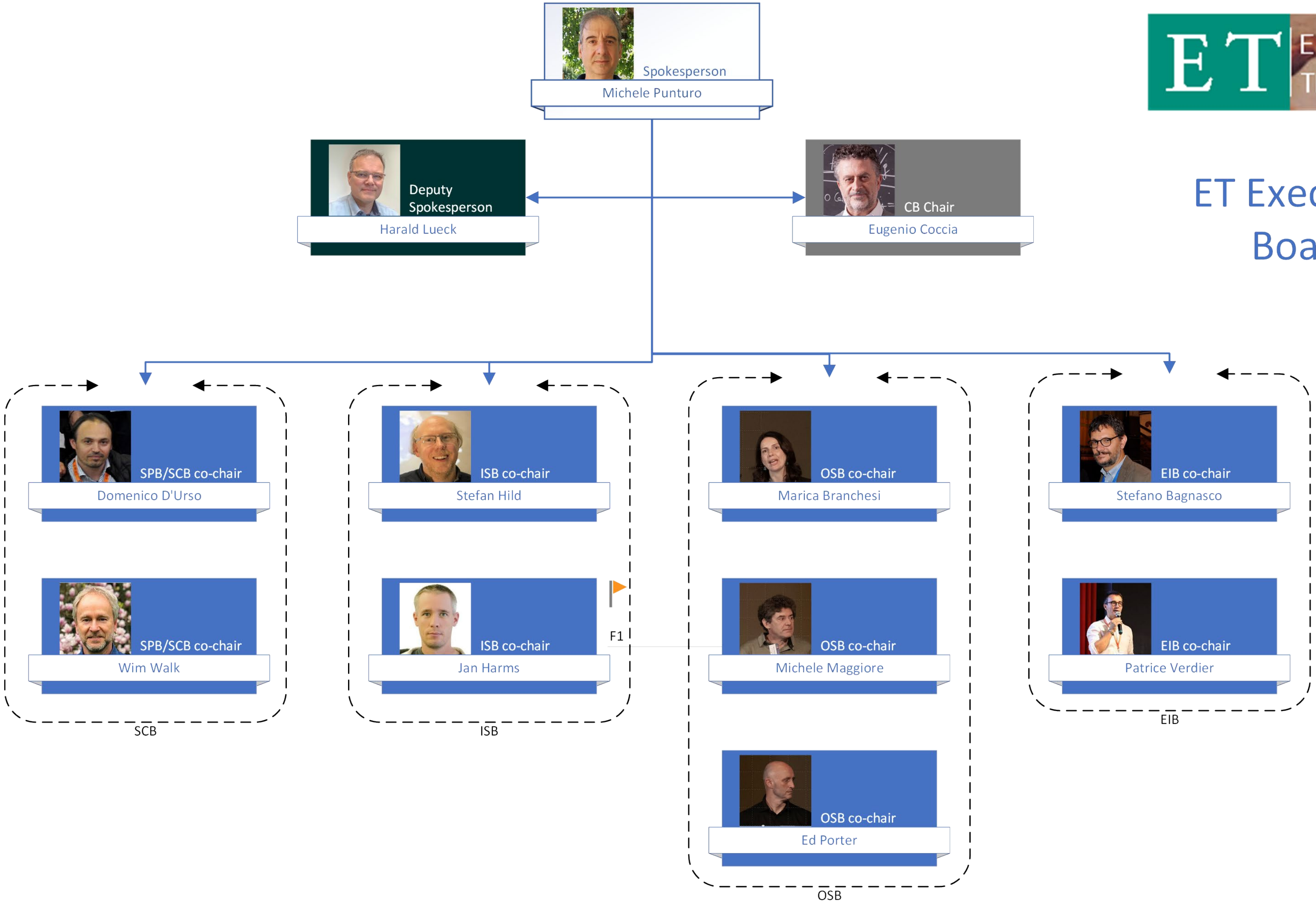
ET Specific Boards

EINSTEIN TELESCOPE



The Executive Board

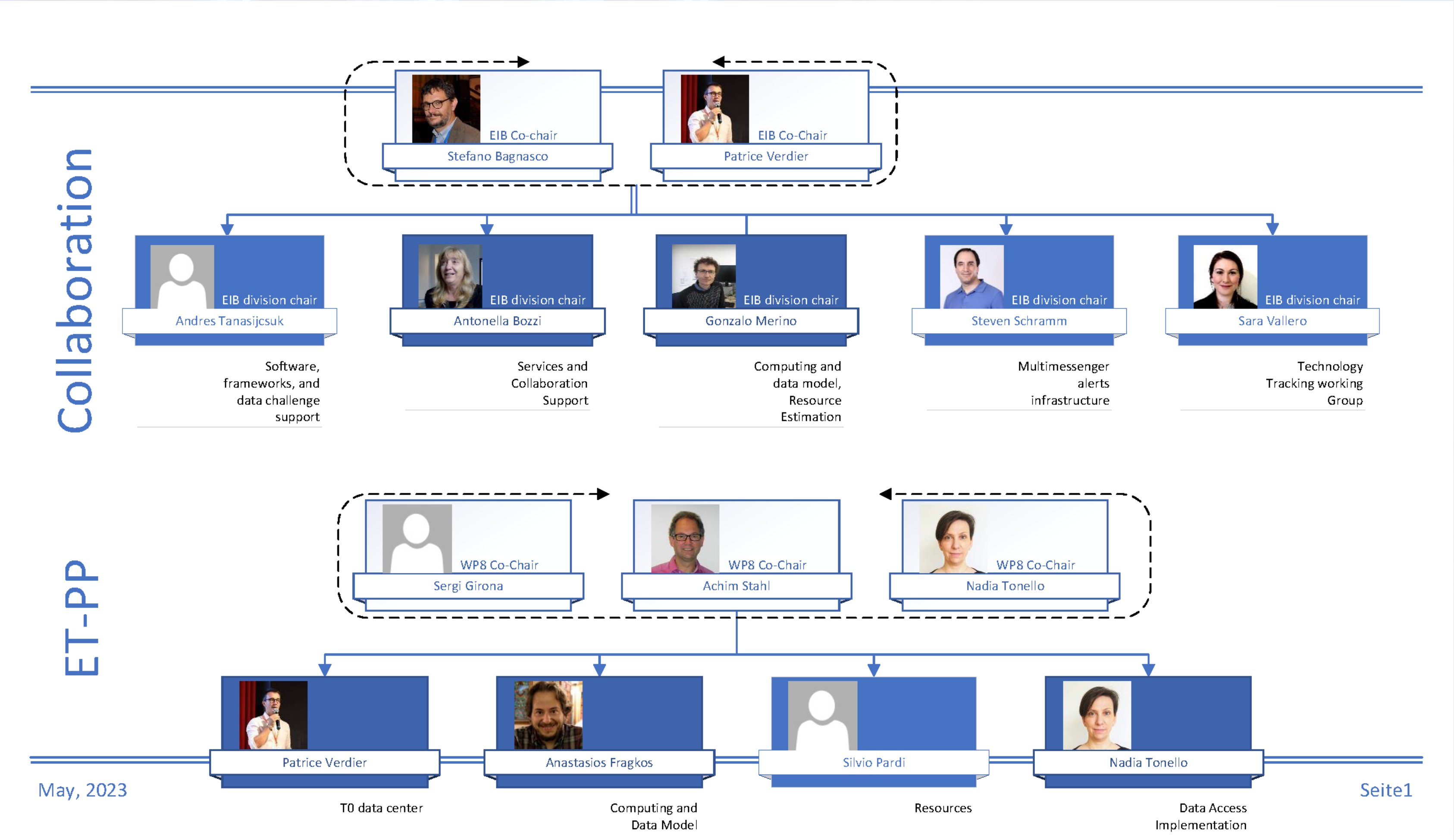
ET Executive Board



The Observational Science Board

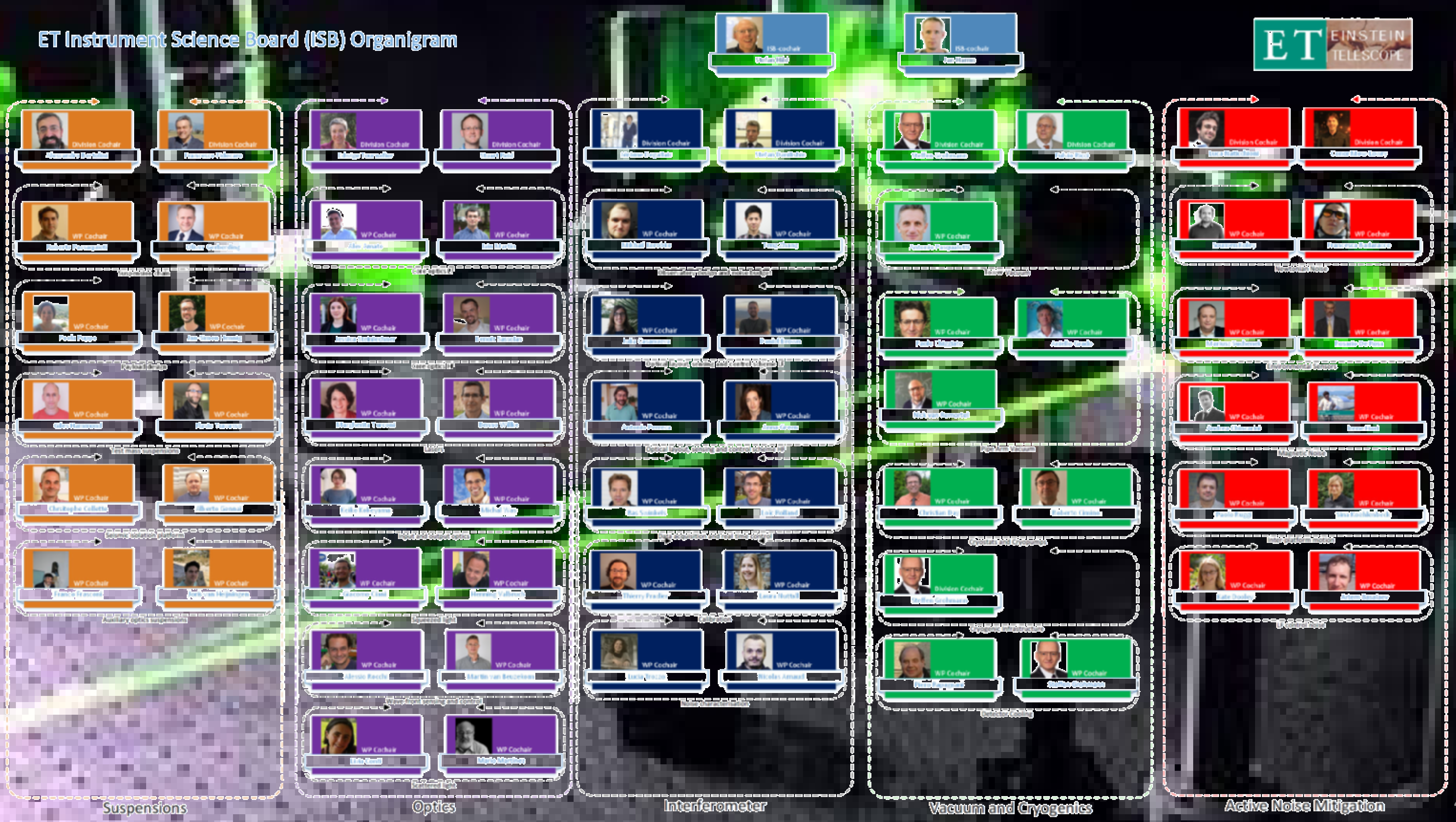
- Targets:
  - Update the ET science case (Blue Book)
  - Address the optimization of the science return of ET
  - Prepare the data analysis in ET
  - Strengthen the collaboration with all the partners in Multimessenger Astronomy

The e-Infrastructures Board



The mandate of the e-Infrastructure board is to design, create and operate an evolving, efficient and functional e-infrastructure environment at a reasonable cost.
Initially the focus is on the development of a Computing Model for the ET.

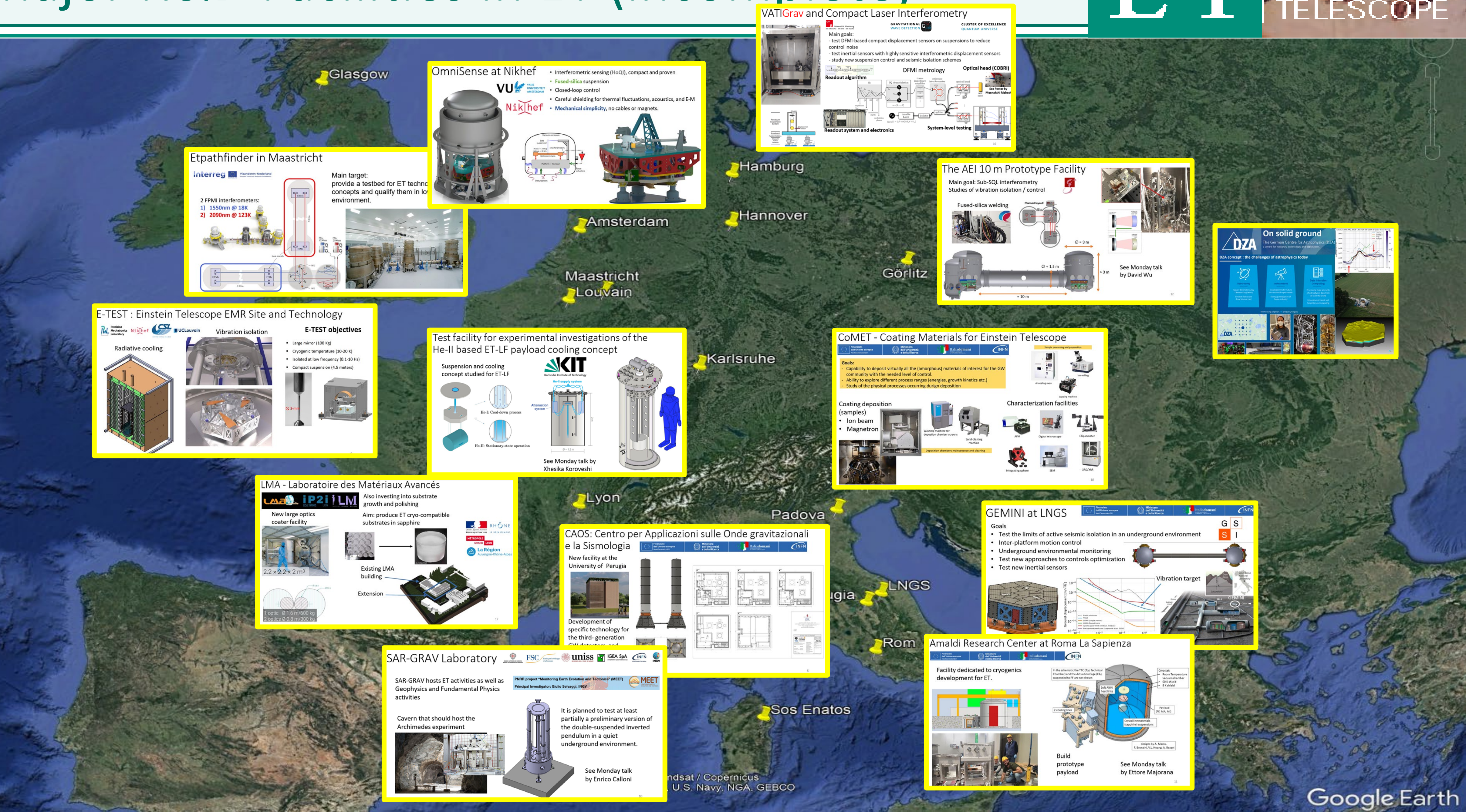
The Instrument Science Board



Major R&D Facilities in ET (incomplete)

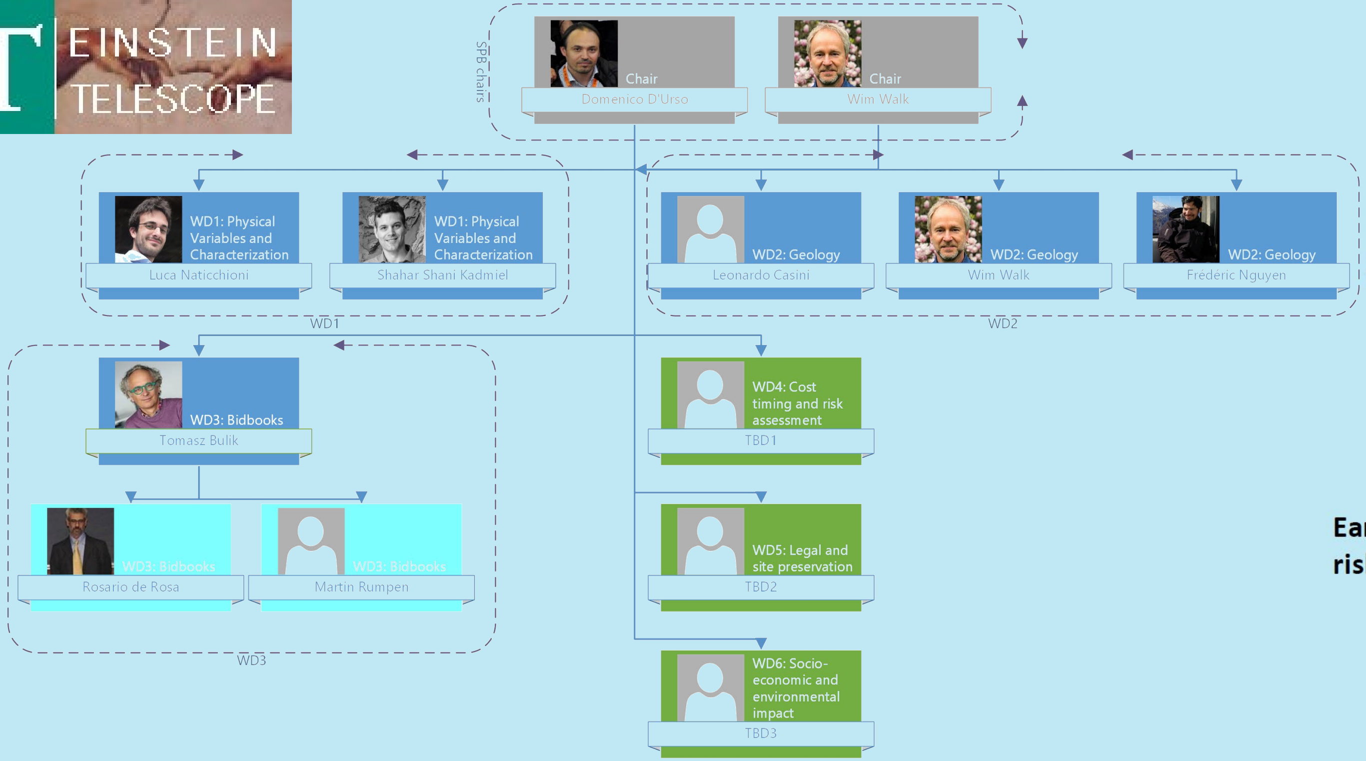
EINSTEIN TELESCOPE

From the XIII ET symposium, an incomplete selection of
thepresented large facilities



ET candidate sites

Site Characterization/ Preparation board



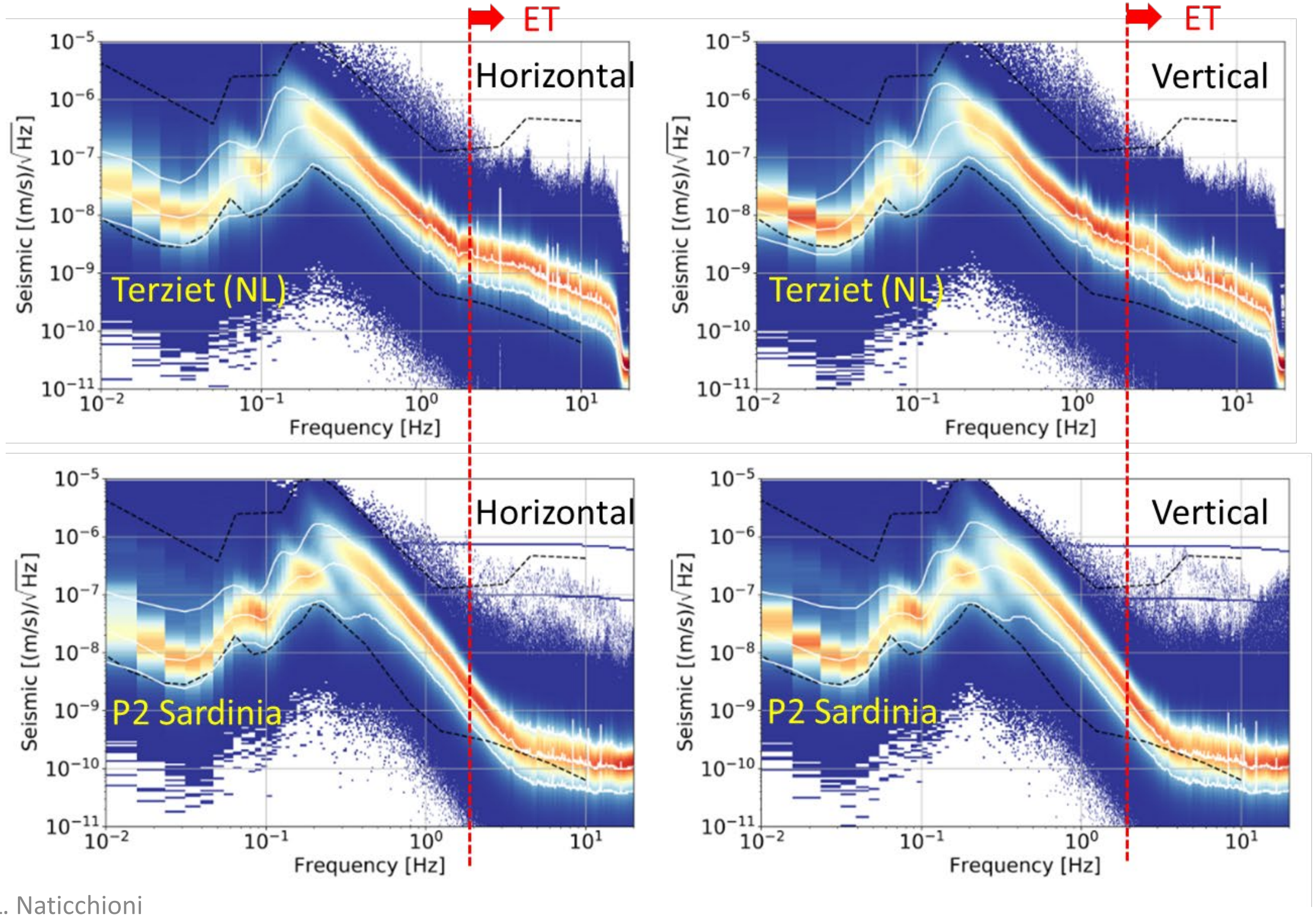
- Two sites officially candidate to host ET:
  - EMR EUregio, border region between Nederland, Belgium and Germany
  - Sardinia (Lula area, Barbagia)
- A third potential site is located in Saxony (Lusatia), still not official
- Overall site evaluation is a complex task depending on:
  - Geophysical and environmental quality
  - Financial and organization aspects
  - Services, infrastructures

Earthquake risk map

Sites comparison

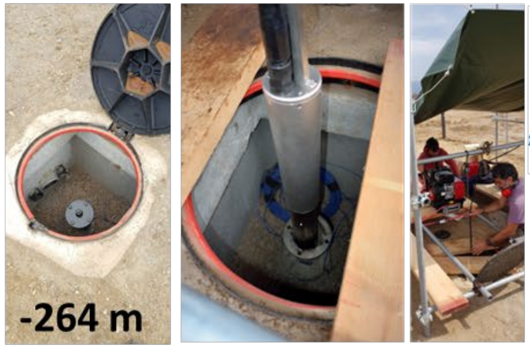
Borehole measurements comparison

+ a large set of other environmental noise sources measures (wind, magnetic, …)



EMR Terziet (NL) borehole

Sardinia P2 borehole

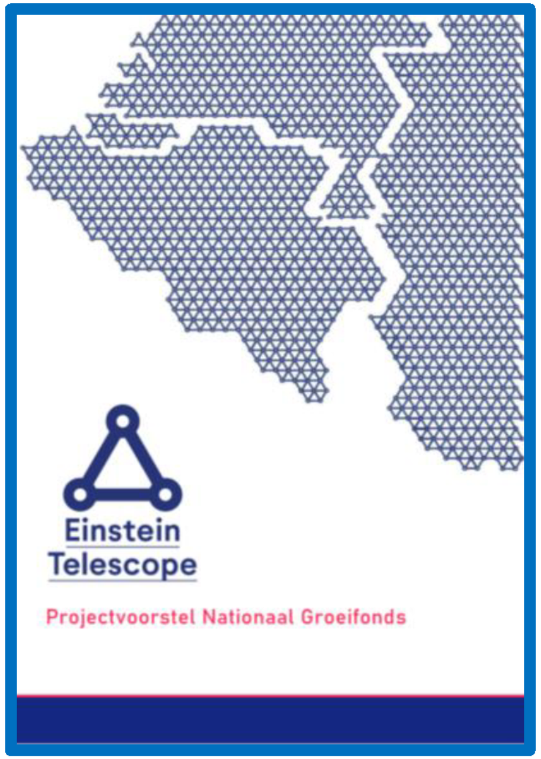


Credit L. Naticchioni

Einstein Telescope in Euregio Meuse-Rhine (EMR)

Connected institutions in:
Belgium,
Germany &
the Netherlands

Nationaal Groeifonds (the Netherlands)



Emphasis on potential socio-economic Impact

Submitted by OCW Ministry
(EZK Ministry support)

Supported by ~70 Dutch Industries/institutions

In October 2021 the Netherlands submitted large funding proposal within context of the '*Nationaal Groeifonds*'. Decision in April 2022.

Includes 42 M€ for geology, R&D & organization
as well as possible Dutch share towards ET realization

German Center for Astrophysics

DZA

Pressemitteilung

Forschung von Weltrang in der Lausitz

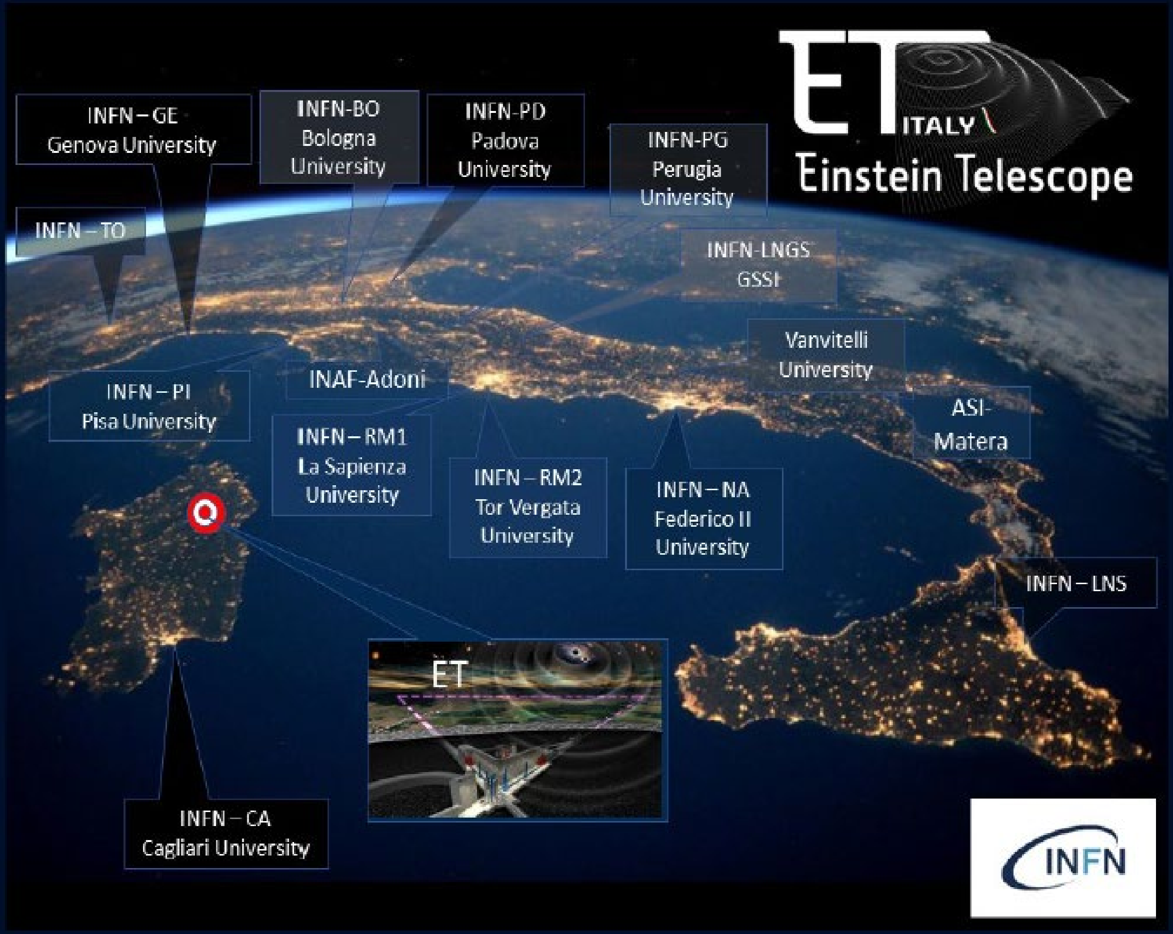
Deutsches Zentrum für Astrophysik – Forschung. Technologie. Digitalisierung. (DZA) gewinnt Wettbewerb zur Strukturförderung

Görlitz, 29.09.2022 Die Entscheidung im Wettbewerb „Wissen.schafft.Perspektiven“ ist getroffen: Mit dem Deutschen Zentrum für Astrophysik - Forschung. Technologie. Digitalisierung. (DZA) entsteht ein nationales Großforschungszentrum mit internationaler Strahlkraft, das ressourcensparende Digitalisierung vorantreibt, neue Technologien entwickelt, für Transfer sorgt und Perspektiven für die Region schafft – fest verwurzelt in der sächsischen Lausitz.

ETIC

Einstein Telescope Infrastructure Consortium

- ETIC is a project funded by the Italian Ministry for University and Research with 50M€ within the PNRR
- ETIC is lead by INFN and involves INAF, ASI and other 11 Universities
- It aims to:
    - Realize a network or research infrastructures, devoted to developing the ET enabling technologies and hosted in the laboratories of the ETIC partners
    - Realise a feasibility study of ET in Sardinia, key element of the Italian bidbook, including geotechnical and engineering studies



Candidatura Italiana

ET Italia: https://www.einstein-telescope.it/

https://www.governo.it/it/media/il-presidente-meloni-alla-presentazione-della-candidatura-italiana-einstein-telescope/22813

6/6/2023

Conclusions

- Experimental research in Gravitational Wave has just started with the monumental successes of Advanced LIGO and Advanced Virgo
- It has a bright future thanks to the huge science potential of this field
- A new generation of GW observatories is under preparation covering a wider frequency range and a much better sensitivity
- Einstein Telescope is now an ESFRI project supported by several European governments and agencies and funded by some of them
    - ET is now a CERN recognized experiment
- The next decades in GW research will be rich of expected and probably unexpected new findings