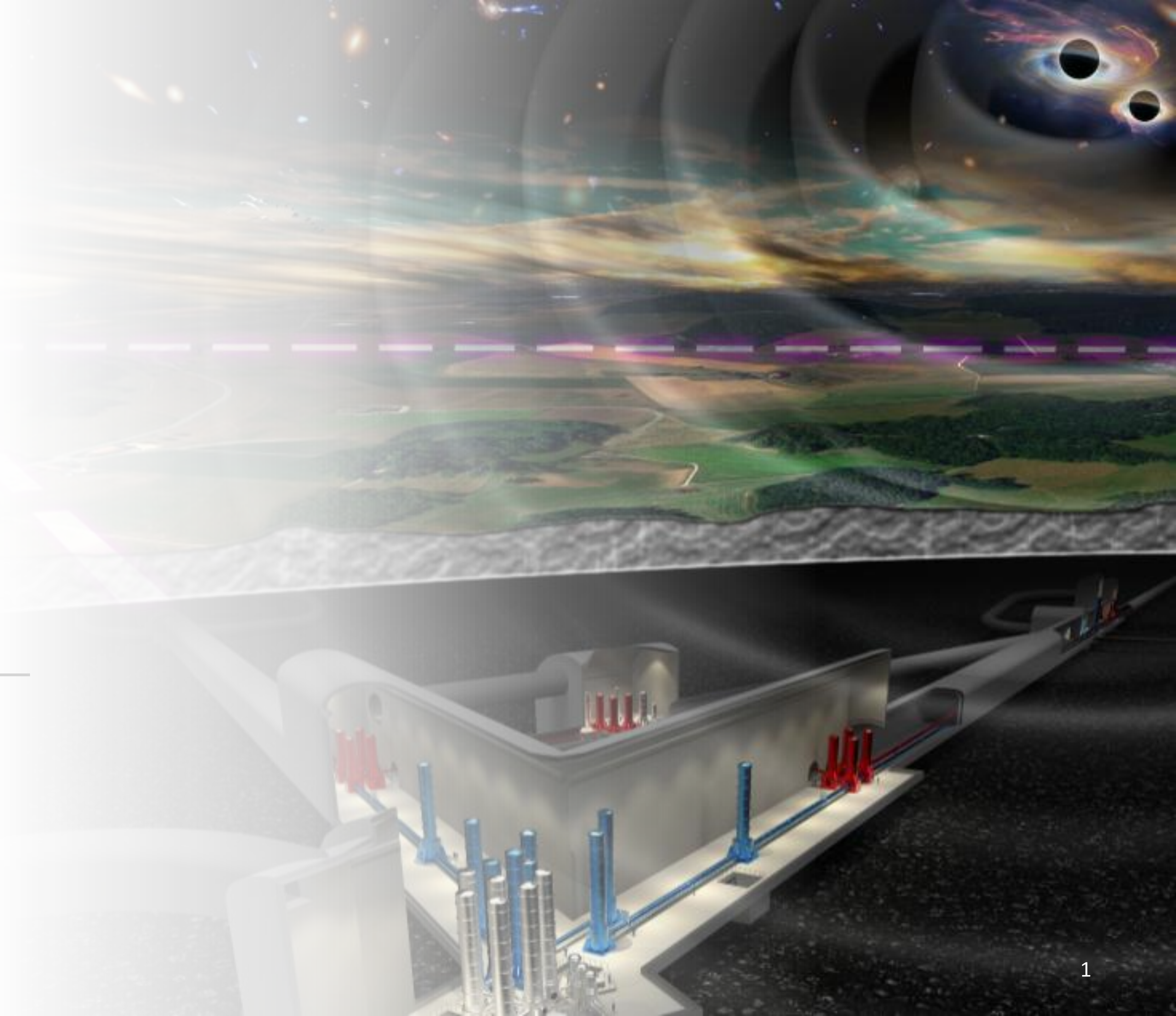
Einstein Telescope
Status of the project
@RICAP 2022 - Rome



Antonino Chiummo - EGO

On behalf and with the contributions of

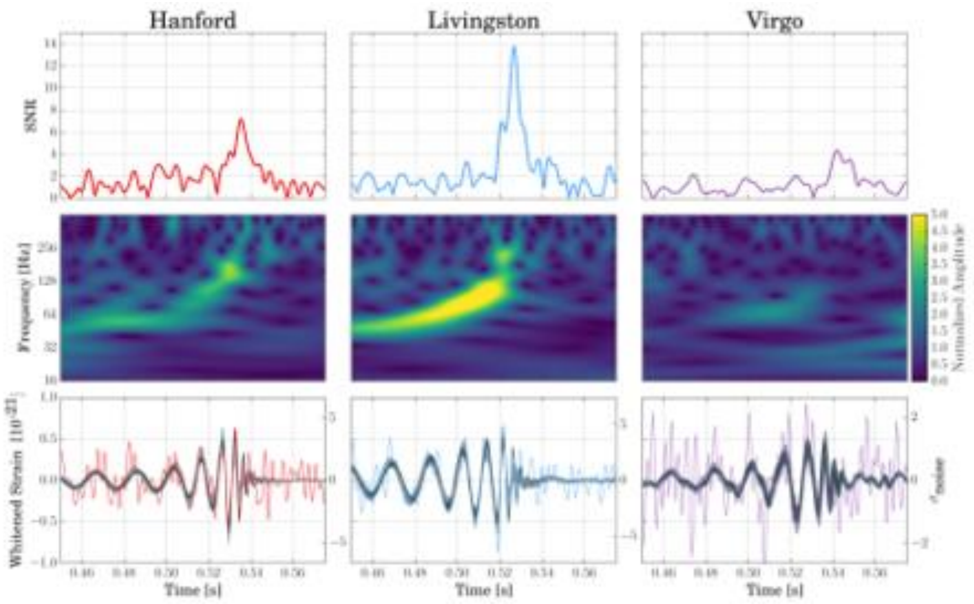
The ET Collaboration

EGO EUROPEAN GRAVITATIONAL OBSERVATORY

ET long path

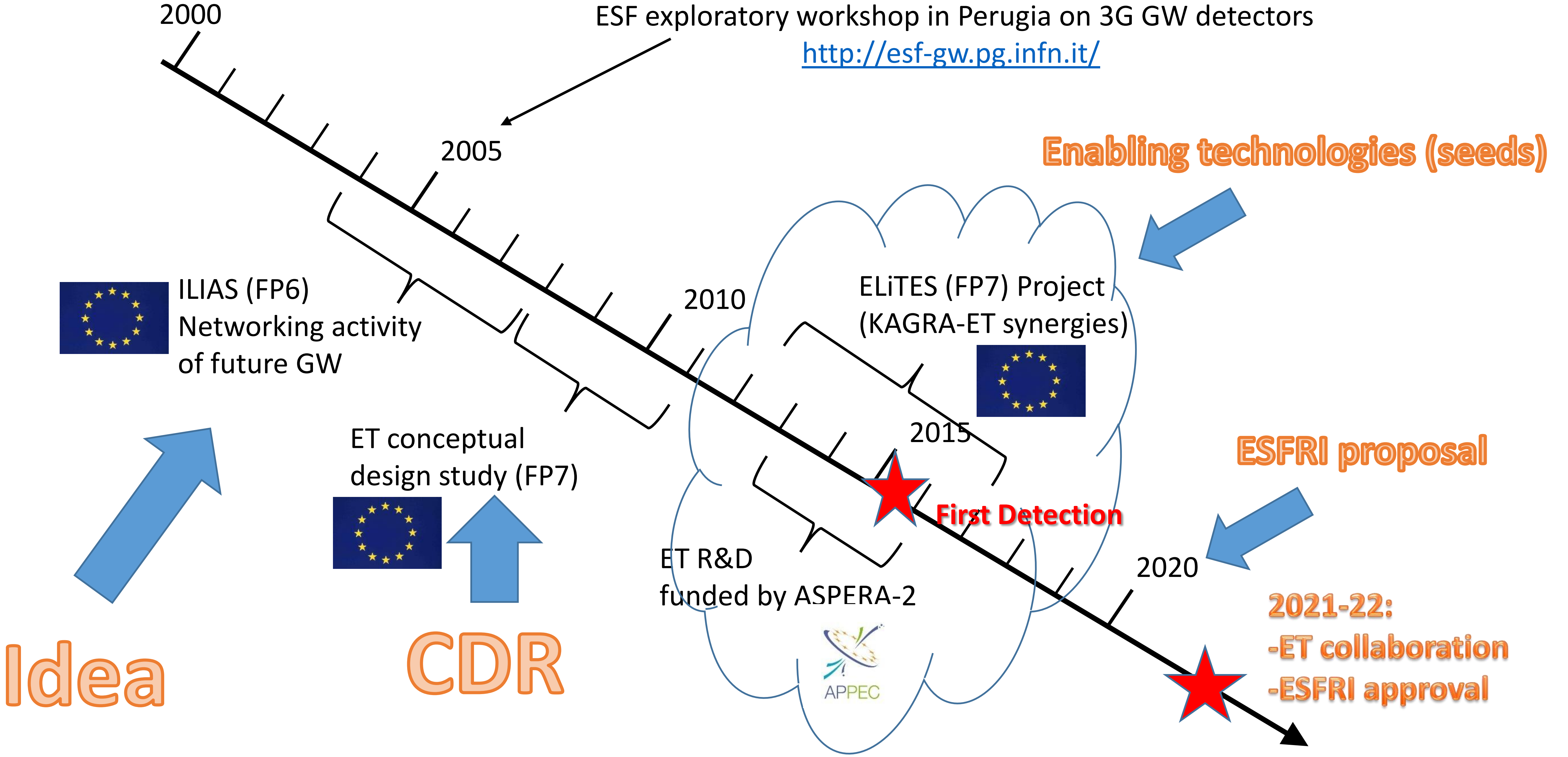
- After the groundbreaking detections of Gravitational Waves by the LIGO/Virgo Collaborations, the design of the third generation of gravitation wave interferometric antennas has gained a substantial interest and momentum
- The Cosmic Explorer in the US and the European Einstein Telescope are the instruments which will take the legacy of the current generation and further advance the reach of the GW antennas, both in terms of explored Universe and of type of accessible sources.
- ***But ET visionary work started well before, when no detection had still provided solid ground to GW Astronomy***

14 August 2017
First triple coincidence
LIGO/Virgo



See also M. Mantovani talk on Virgo status:
https://agenda.infn.it/event/29838/contributions/176707/

ET long path


2000
ESF exploratory workshop in Perugia on 3G GW detectors
http://esf-gw.pg.infn.it/
2005
2010
2015
2020
ILIAS (FP6)
Networking activity
of future GW
ET conceptual
design study (FP7)
ET R&D
funded by ASPERA-2
APPEC
ELiTES (FP7) Project
(KAGRA-ET synergies)
First Detection
Enabling technologies (seeds)
ESFRI proposal
2021-22:
-ET collaboration
-ESFRI approval
Idea
CDR

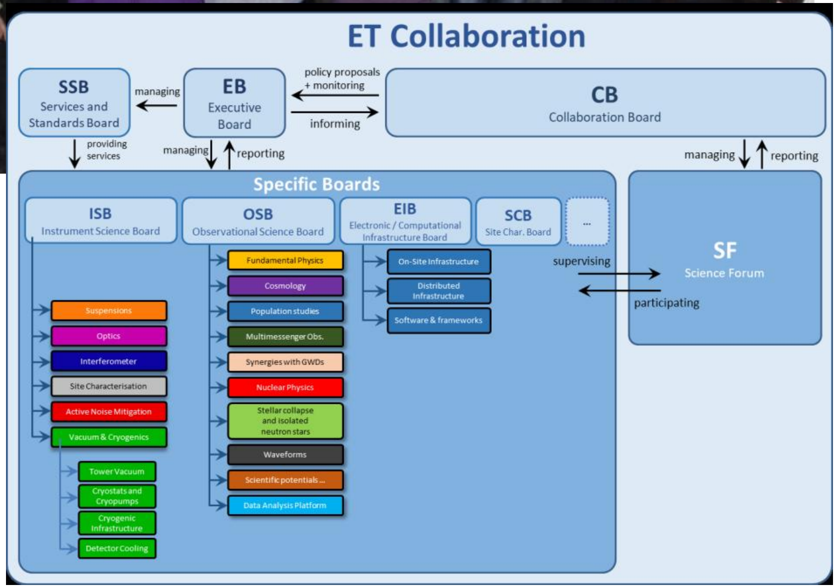
ET Collaboration

- ❑Born at the XII ET Symposium in Budapest (2022)

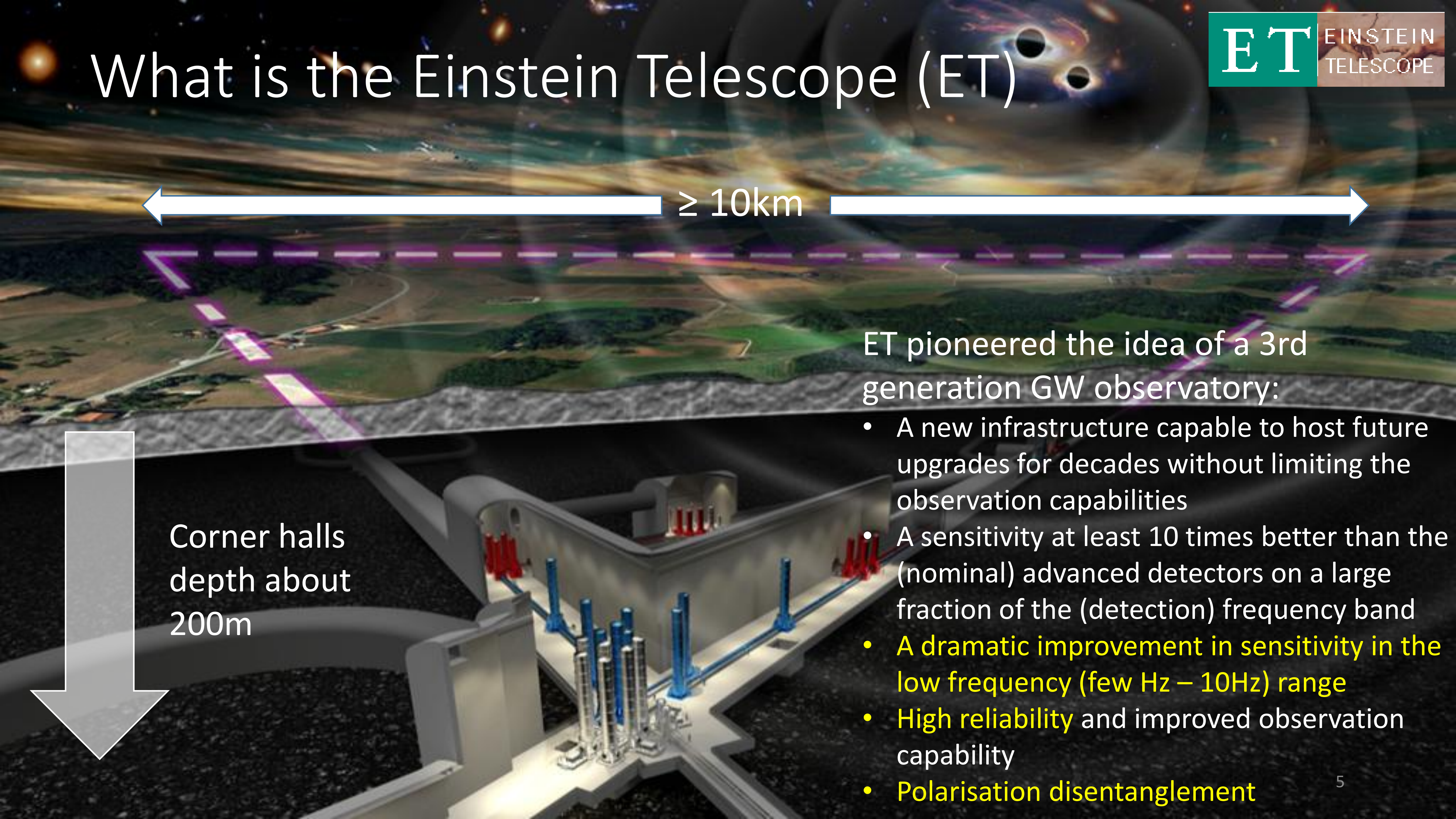
- ❑80 Research Units from Europe and Asia Institutions

- ❑More than 1200 members

Bylaws available on ET TDS:
https://apps.et-gw.eu/tds/ql/?c=16220



What is the 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 Science Case in a nutshell

ASTROPHYSICS

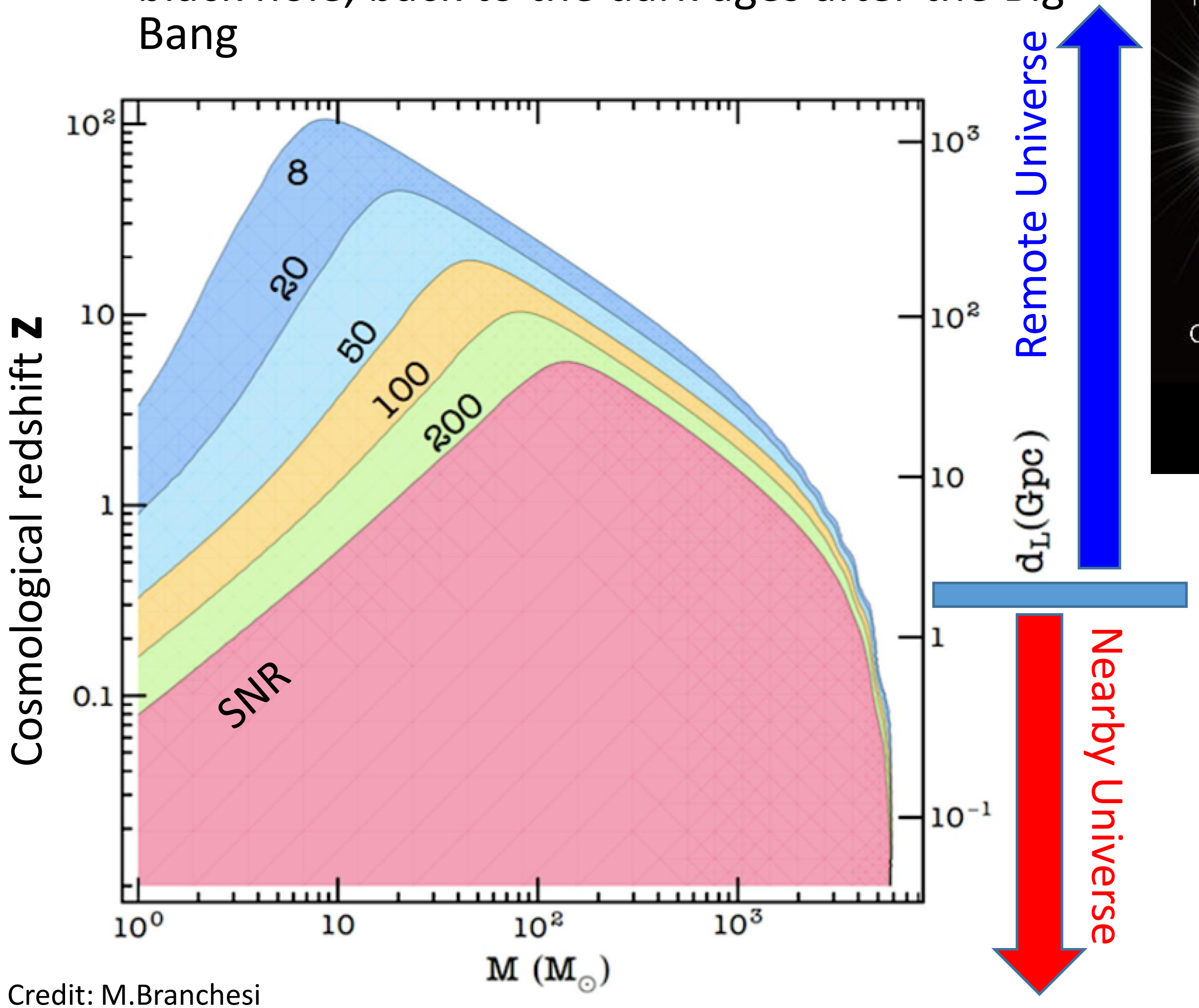
- **Black hole properties**
  - origin (stellar vs. primordial)
  - evolution, demography
- **Neutron star properties**
  - interior structure (QCD at ultra-high densities, exotic states of matter)
  - demography
- **Multi-band and -messenger astronomy**
  - joint GW/EM observations (GRB, kilonova,...)
  - 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

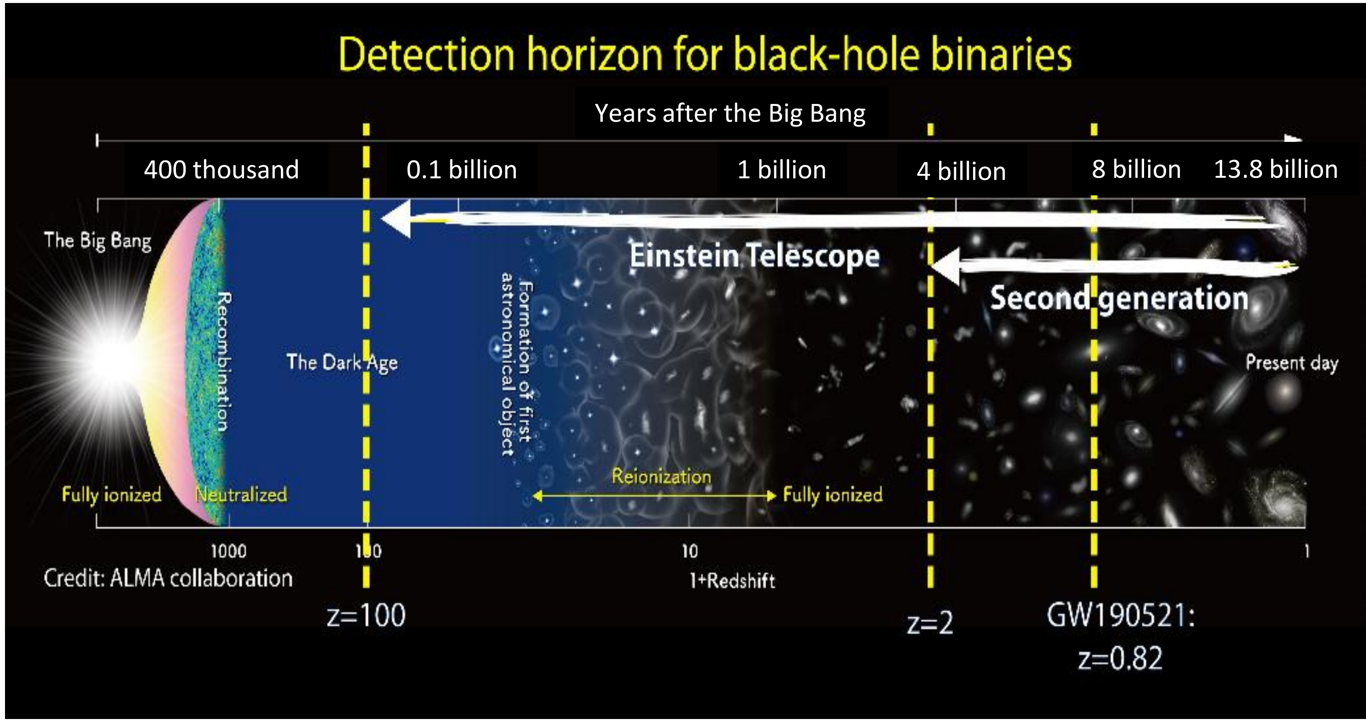
- **The nature of compact objects**
  - near-horizon physics
  - tests of no-hair theorem
  - exotic compact objects
- **Tests of General Relativity**
  - post-Newtonian expansion
  - strong field regime
- **Dark matter**
  - primordial BHs
  - axion clouds, dark matter accreting on compact objects
- **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: double nature

- ET will be a new discovery machine:
  - ET will explore almost the entire Universe listening the gravitational waves emitted by black hole, back to the dark ages after the Big Bang



Credit: M.Branchesi



- ET will be a precision measurement observatory:
  - 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

Credit: M.Punturo

ET Science in a nutshell: Multi-Messenger

-Obvious collaboration with other 3G and 2G GW detectors

-But due to the unprecedented sensitivity of the ET antenna, most of the GW events will provide trigger to EM detectors also in the undesirable case of stand-alone configuration

-The pointing capability for BNS, for instance, will be ensured by the fact that the GW signal will be persistent for order of days: the modulation of the Earth rotation will provide some pointing capability

- much more in the Science Case paper: https://arxiv.org/abs/1912.02622


Science Case for the Eins
Telescope

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Marica Branchesi,[g,h] Sebastien Clesse,[i,j] Ste
Juan García-Bellido,[k] Stefan Grimm,[g,h] Jan
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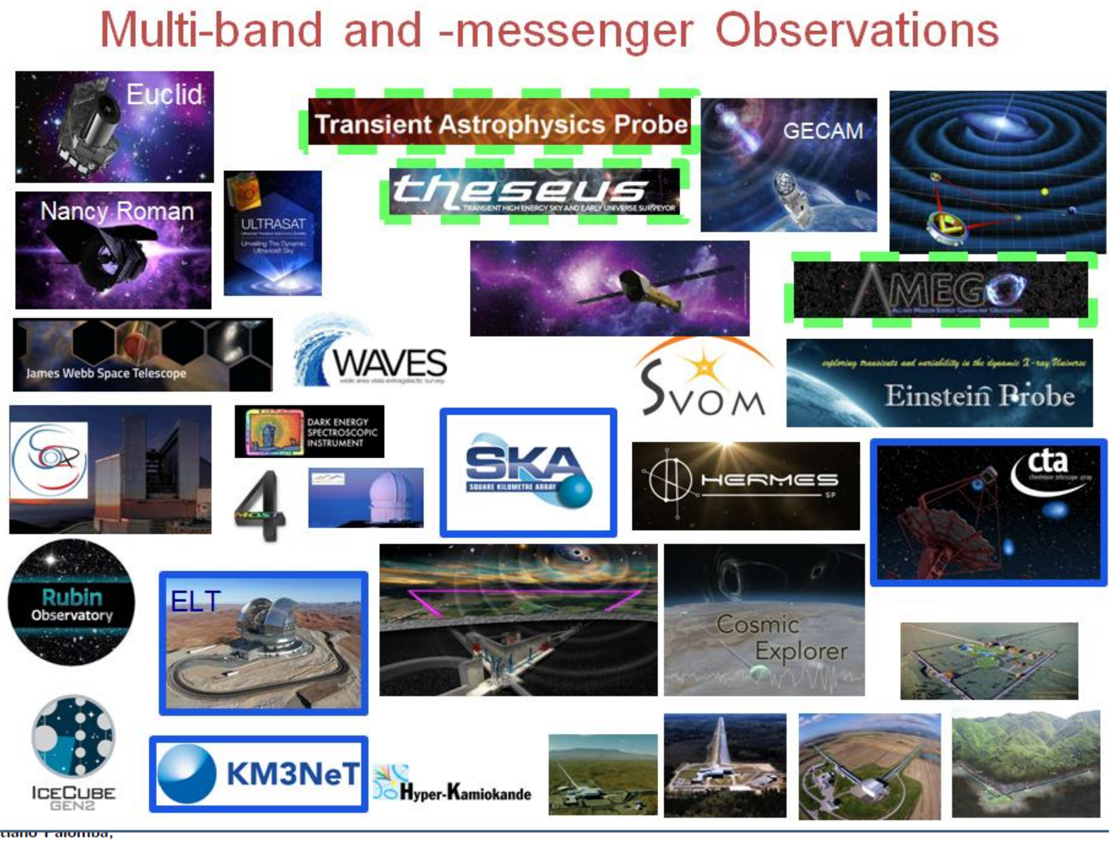
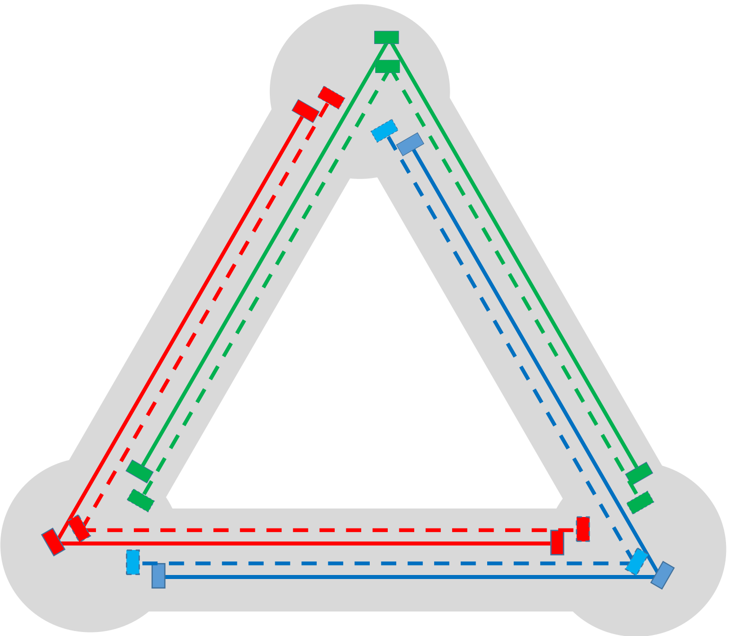
arXiv:1912.02622v4 [astro-ph.CO] 24 Mar 2020



Credits: M.Branchesi, M.Punturo

ET Design: key elements

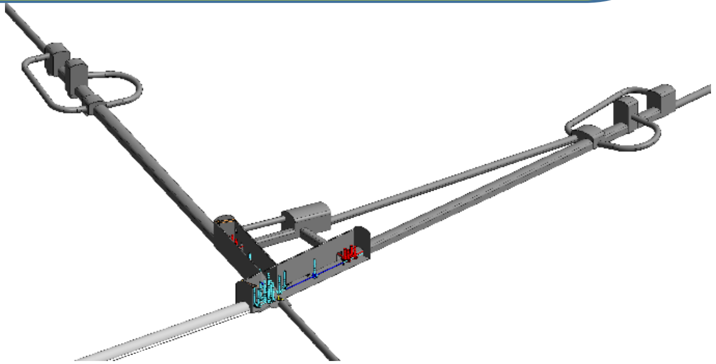


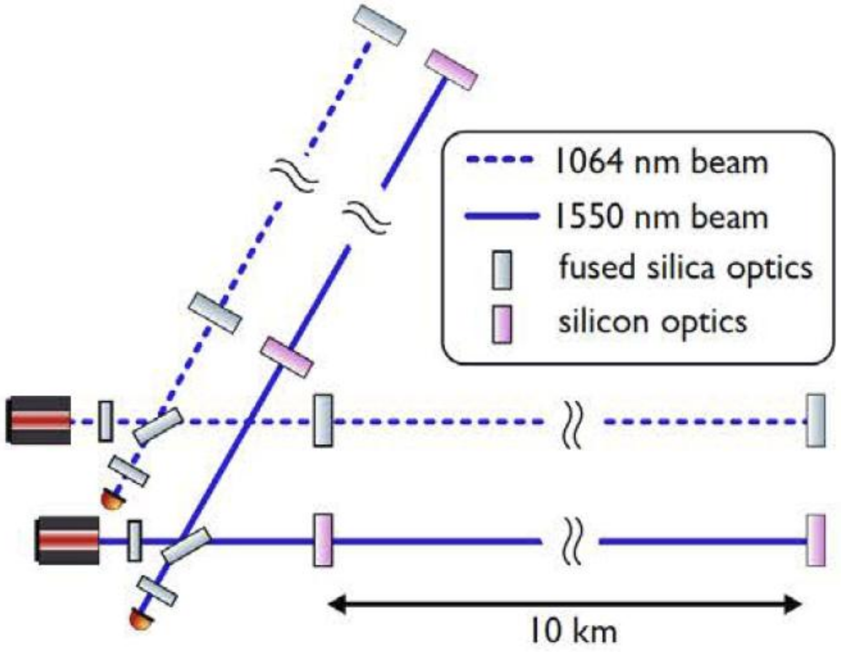
Requirements

- 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





EINSTEIN TELESCOPE

ET EINSTEIN TELESCOPE

ET TECHNOLOGY (MAIN) CHALLENGES

Challenging engineering

New technology in cryo-cooling

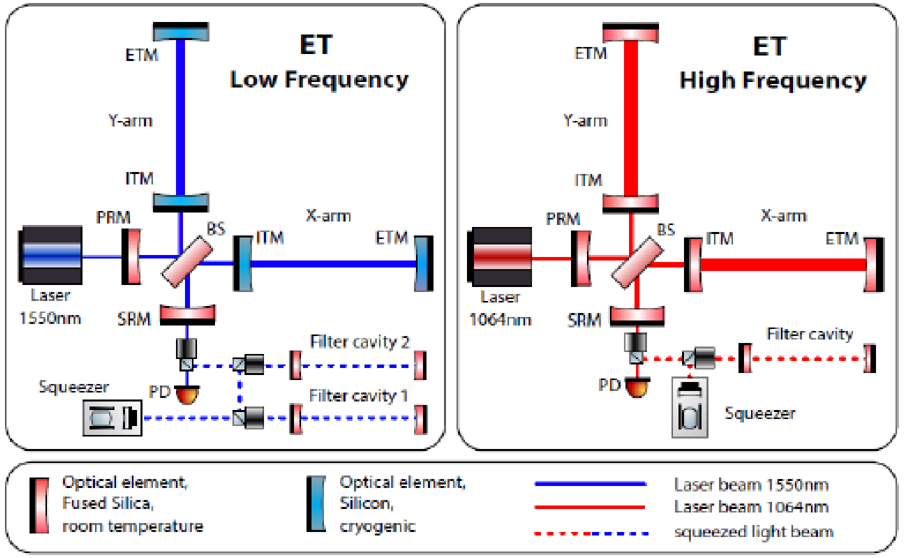
New technology in optics

New laser technology

High precision mechanics and low noise controls

High quality opto-electronics and new controls

- 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

Evolved laser technology

Evolved technology in optics

Highly innovative adaptive optics

High quality opto-electronics and new controls

Perhaps the most ambitious target for instrument science

LOW FREQUENCY NOISE

ET is not 10x better than 2nd gen detectors, it is million times better at 3Hz…

…and no gravitational wave detector to date has reached its design sensitivity at low frequencies

We need to systematically identify and mitigate LF noise

- RMS motion
- Achievable isolation
- Light scattering
- Angular controls
- Seismic platform and suspensions
- Environmental noise

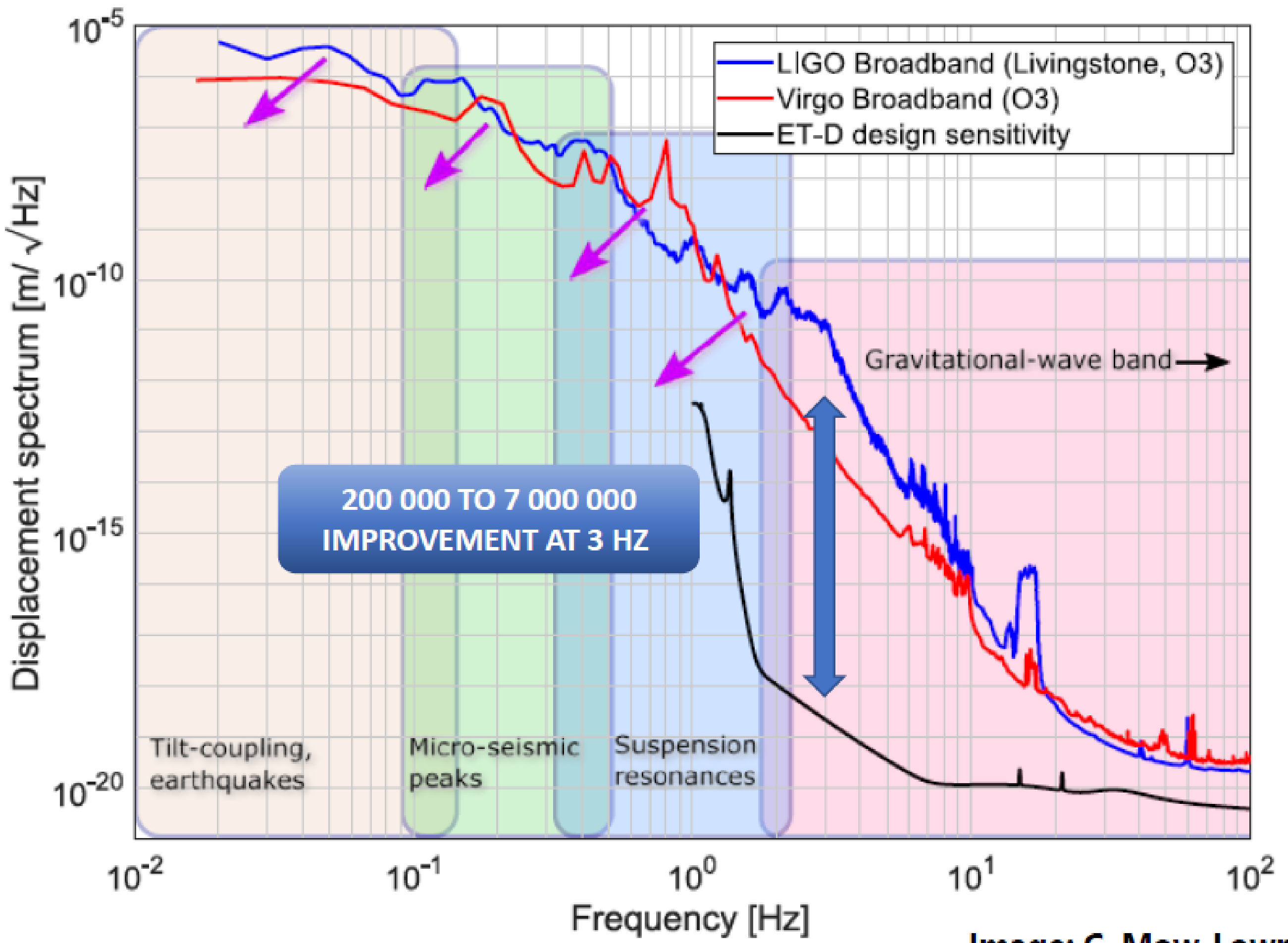
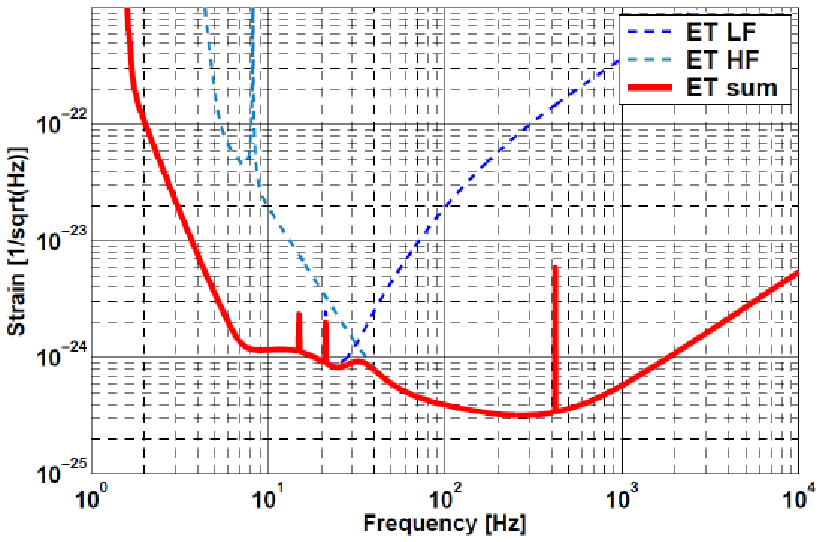


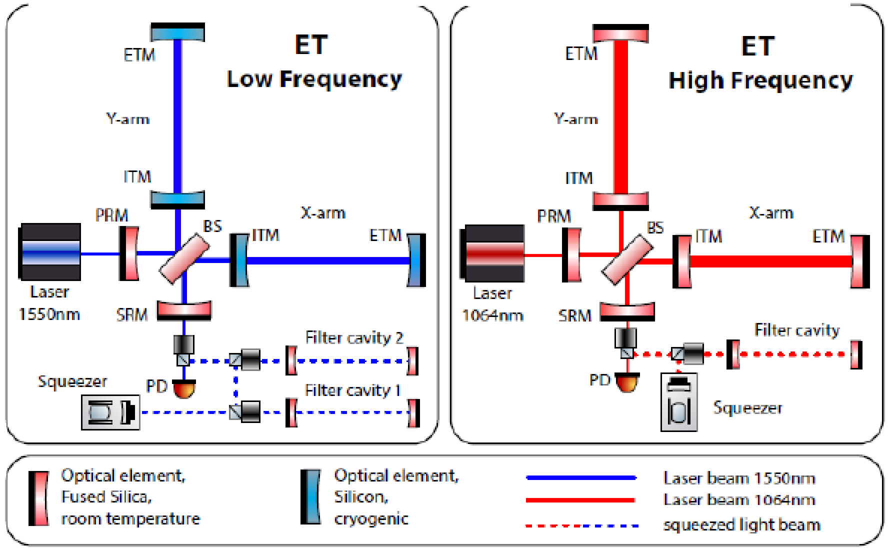
Image: C. Mow-Lowry

Challenging sensitivity target

ET BASELINE DESIGN

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 site(s)

- Currently there are two sites, in Europe, candidate to host ET:
  - The Sardinia site, close to the Sos Enattos mine
  - The EU Regio Rhine-Meusse site, close to the NL-B-D border
- A third option in Saxony (Germany) is under discussion

ET sites under characterisation

EINSTEIN TELESCOPE

Euregio Meuse-Rhine

- A 250-m deep borehole has been excavated and equipped
  - Seismic data under acquisition and analysis
- A set of other boreholes under excavation
- Extensive active and passive site characterisation with sensor arrays in 2021
- Good seismic noise attenuation given by the particular geological structure
- Characterisation funded through Interreg grants
- Large proposal for qualifying the site essentially approved to the Dutch government

Sardinia

- Long standing characterisation of the mine in one of the corners continuing
  - Seismic, magnetic and acoustic noise characterisation ongoing at different depth in the mine
- Underground laboratory under preparation (SarGrav)
- Two ~290m boreholes have been excavated, equipped and data taking is ongoing
- A set of other boreholes expected in 2022
- Intense & international surface investigations programme ongoing
- Characterisation funded on regional and national funds
- Large proposal for technology development and engineering design submitted to the Italian government

Next Step and Priorities

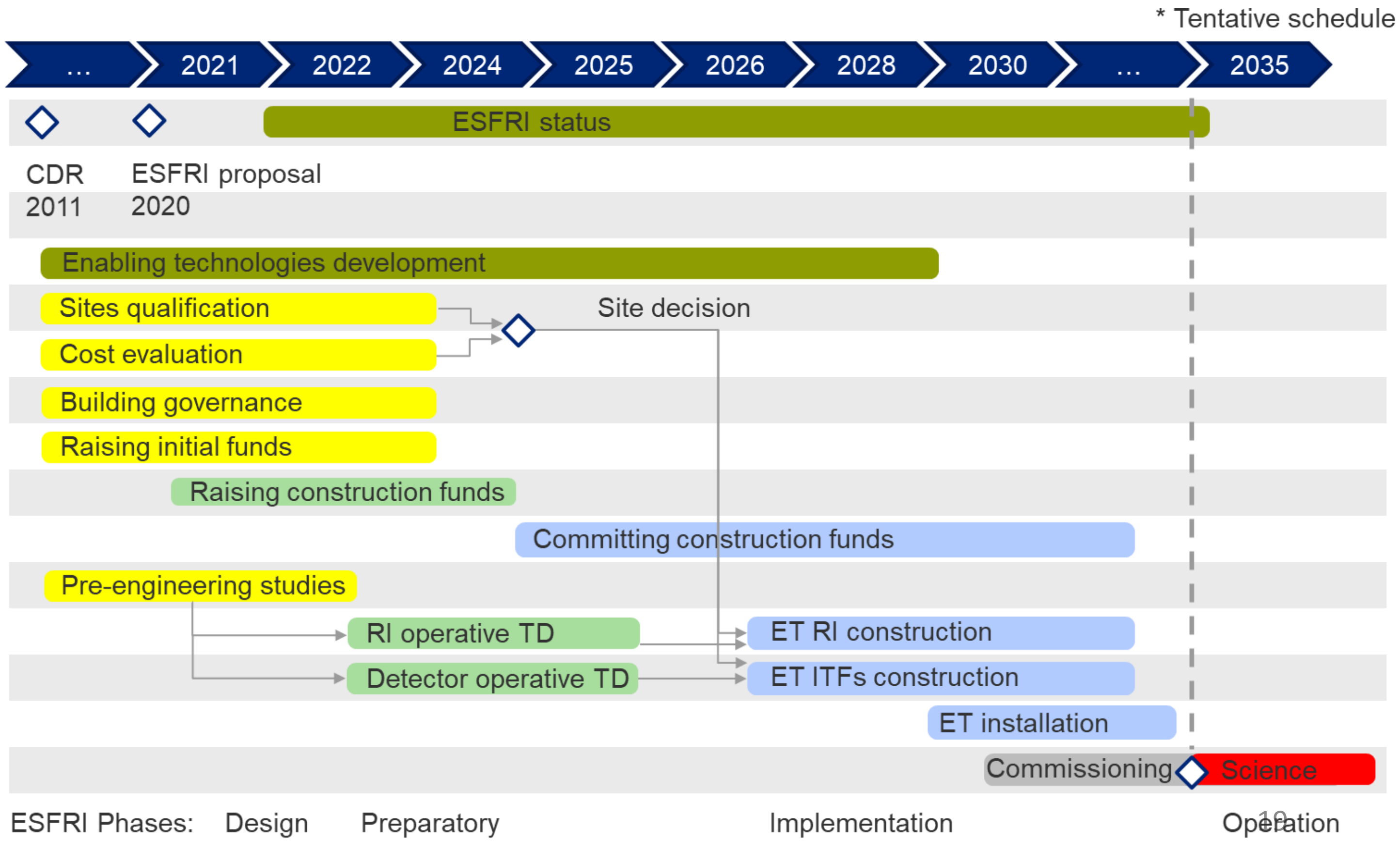
- What:
  - The Collaboration priorities are:
    - Collaboration Board:
      - Evaluation and admission of the RUs, voting mechanisms, completion of the bylaws, election of the CB chair, election of the spokesperson and deputy spokesperson
    - Executive Board
      - Define the interfaces and the integration level with the Project Office, Engineering department and Vacuum pipe team
      - Evolve the ET CDR in the detector TDR
      - Coordinate the definition and the development of the ET technologies
      - Complete the ET science book
      - Develop the tools

Next Step and Priorities

- Where:
  - Support the site selection procedure through the National Host Teams
  - The collaboration and the EB in particular have the duty to support the SPB/SCB in all the site characterization activities, defining the noise requirements, validating the analysis methods and tools, analyzing the impact of the site characteristics on the ET science performance

Next Step and Priorities

- When:
  - This is one of the most critical point of the current ET status.
  - The ET roadmap has been proposed in the ESFRI document:
  - ET milestones and deliverables have been partially revisited in the INFRA-DEV proposal
  - TDR deliverability is affected by the timing declared in the CERN document for the vacuum pipe
  - It is urgent, and we just started it with the PO, to analyze all the activities and their interfaces to define correctly the timing



Conclusions

- ET is a huge enterprise, with a potentially dramatic increase of GW Scientific revenue
- The interest of large community and the actions of a reduced set of scientists pushed it through more than a decade
- In the last few years ET acquired a large momentum and now it is a global scale project: on June 2022 the ET collaboration was estabilished
- Sinergy with the european authorities at government level is being achieved, funds are arriving
- Active collaboration with the other third generation project (Cosmic Explorer) is a key factor, but ET can produce great science also in stand-alone configuration
- Multi-messenger Astronomy will be greatly enhanced, possibly a prioritazion of triggers will be needed due the big number of GW signals

Thank you for your attention