

EINSTEIN
TELESCOPE

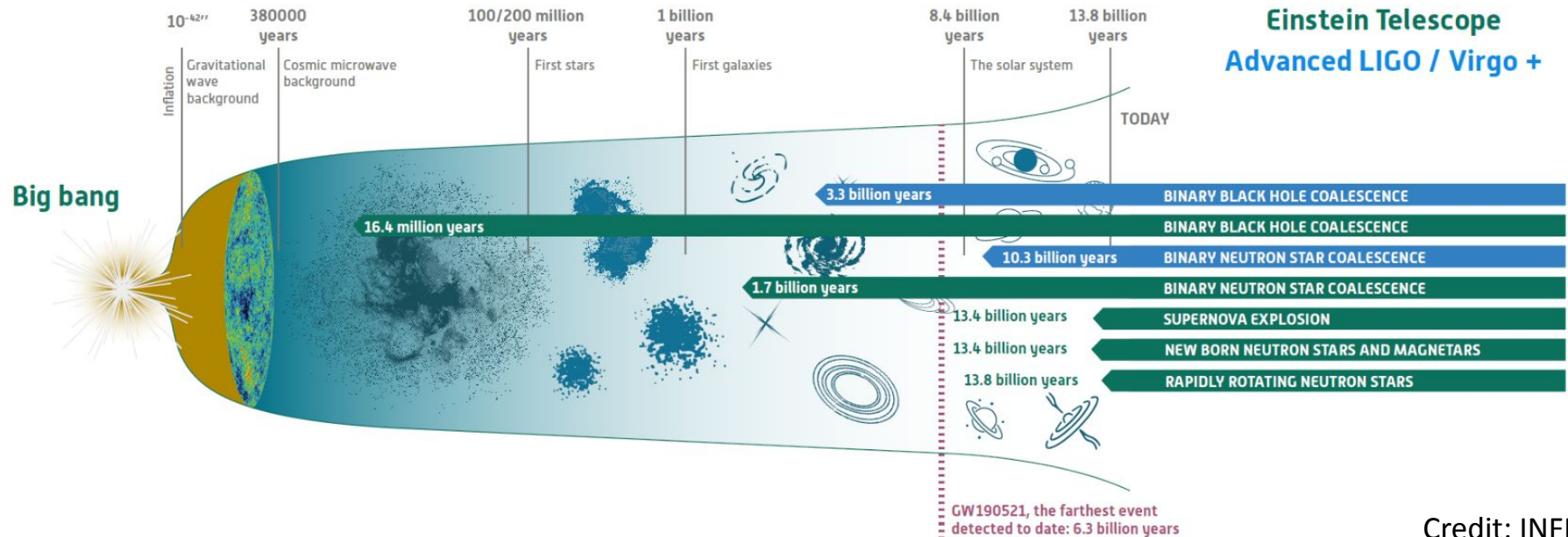
Einstein Telescope, pushing the outer limits of gravitational waves detection

Angélique Lartaux
on behalf of the ET collaboration

OePG-CMD-Graz2026 - 21 September 2026

Introduction to Einstein Telescope

- A **precision instrument** for gravitational wave sources in the nearby Universe
- A **discovery machine** investigating back to the dark ages of the Universe

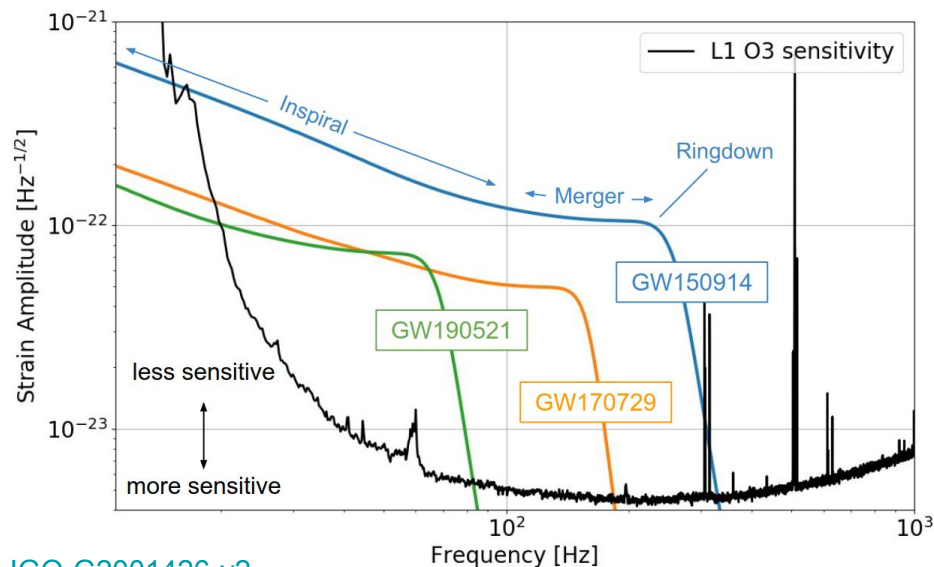


Credit: INFN

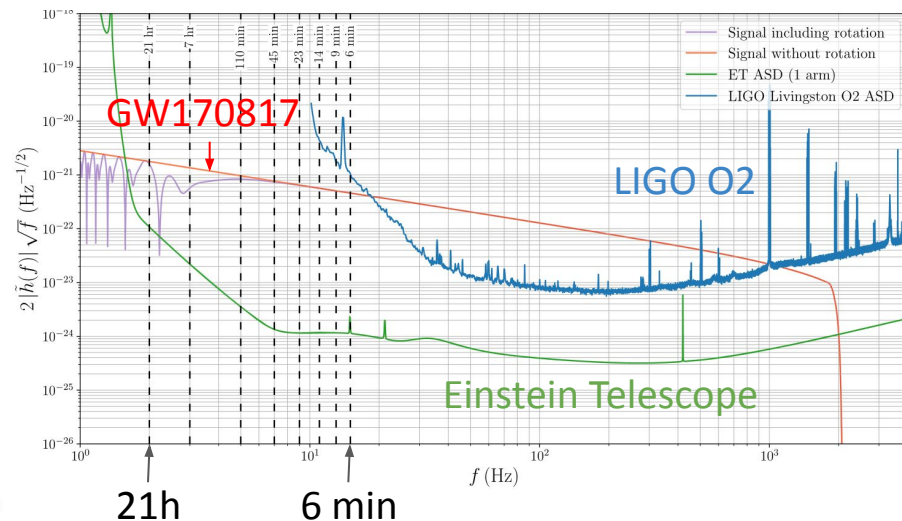
Instrumental requirements from science targets (1/3)

- Increasing the sensitivity to low frequencies...

Higher masses correspond to lower frequency GW emission



Early warning for Binary Neutron Star mergers to alert the community

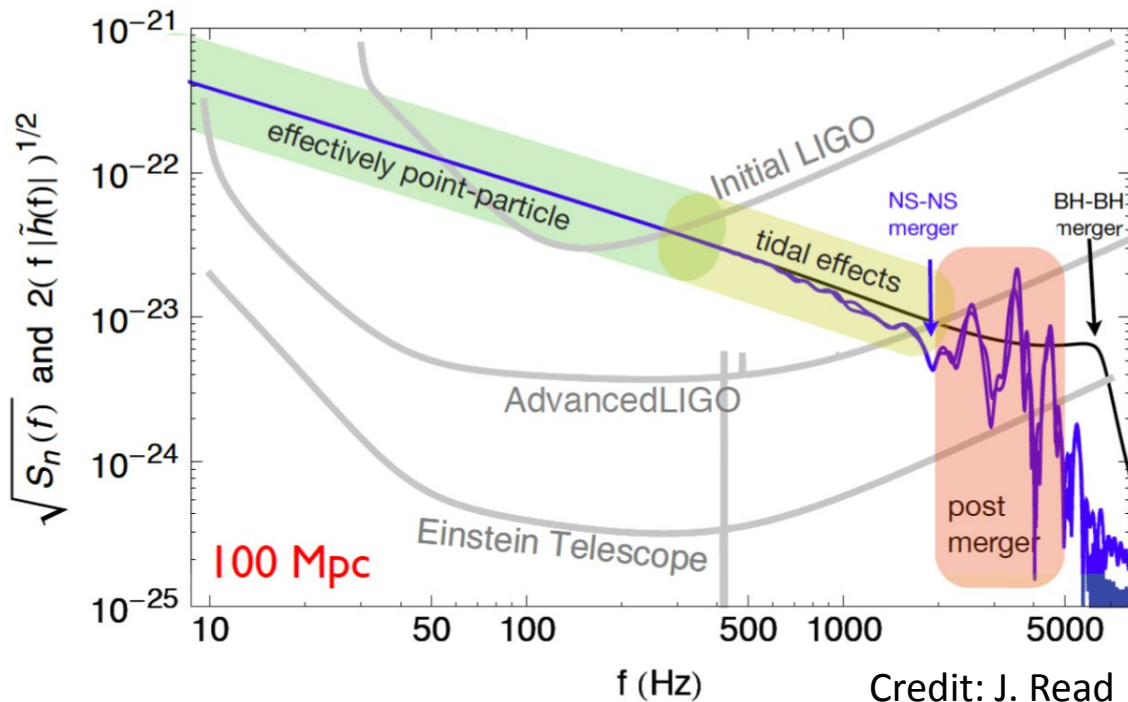


[LIGO-G2001426-v2](#)

[Francesco Iacovelli et al 2022 ApJ 941 208](#)

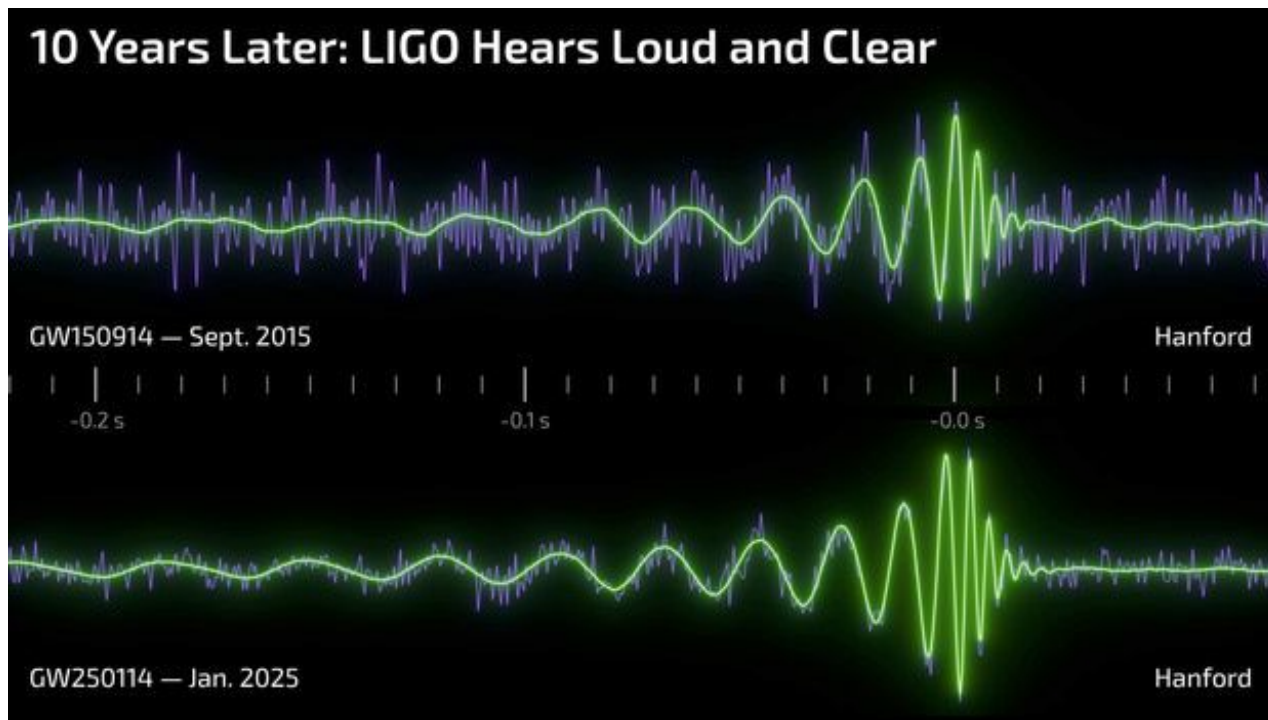
Instrumental requirements from science targets (2/3)

- Increasing the sensitivity to low frequencies... and also to high frequencies



Instrumental requirements from science targets (3/3)

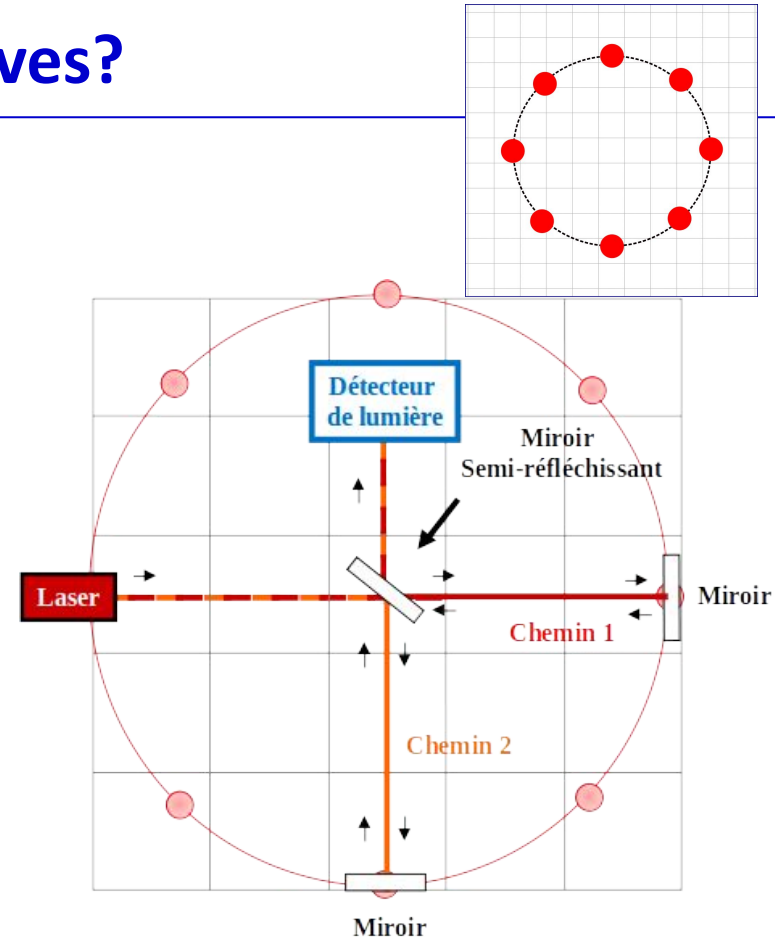
- Having better signal-to-noise ratio for tests of General Relativity



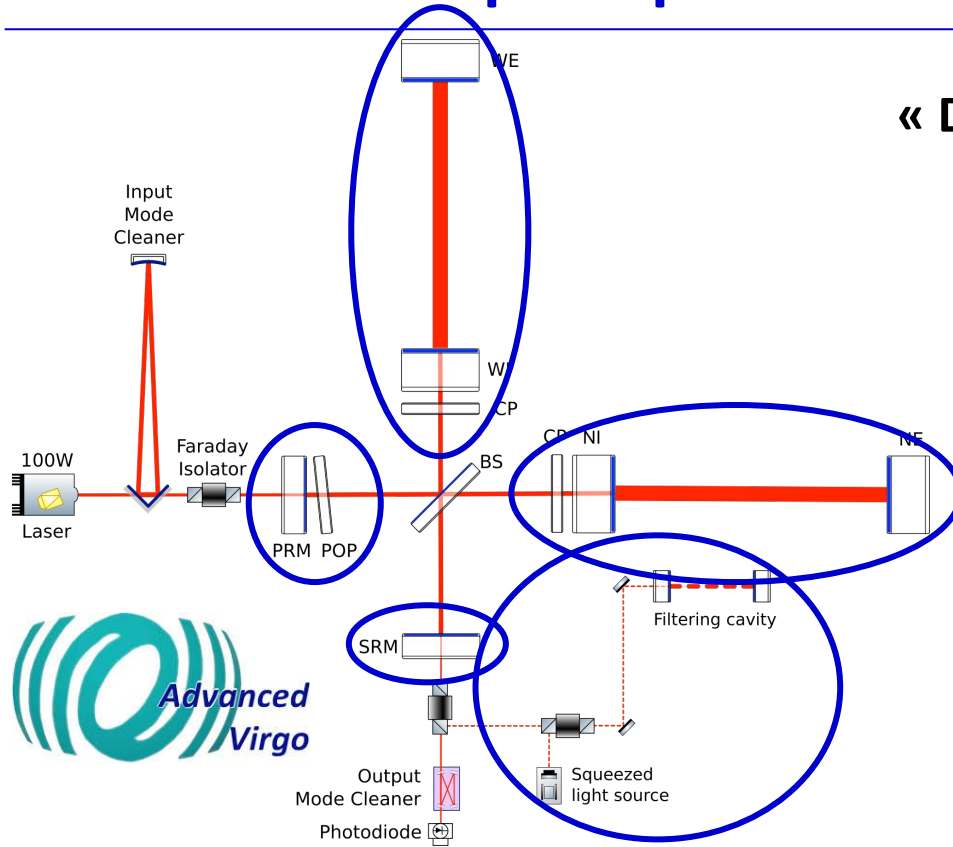
Credit: LIGO /
J. Tissino
(GSSI) / R. Hurt
(Caltech-IPAC)

How can we detect gravitational waves?

- Gravitational waves cause a distortion of spacetime, involving **contraction and stretching in two orthogonal directions** within the plane perpendicular to the direction of wave propagation
- **Michelson interferometer** is a well adapted instrument to measure tiny orthogonal deformations
- Sensitive to deformation thousands to millions time smaller than a proton



Interferometer principle



« Dual recycled » Michelson interferometer

- Fabry-Perot cavities in the arms to increase the optical path length
- Power recycling (operation close to dark fringe)
- Signal recycling to increase signal-to-noise ratio
- Quantum noise reduction



Common challenges

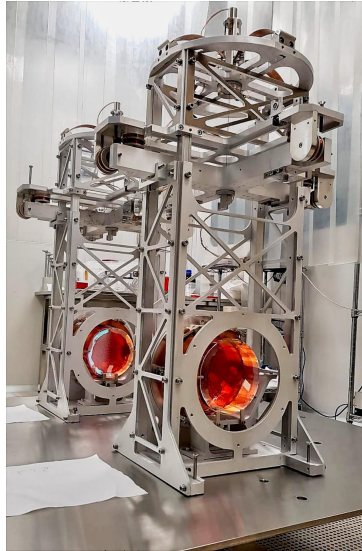
- To reach the required sensitivity, ground based gravitational wave detectors must be isolated from their environment, with state-of-the-art optics

Vacuum



~ 10 000 m³ of
vacuum at 10⁻⁹ mbar

Suspensions



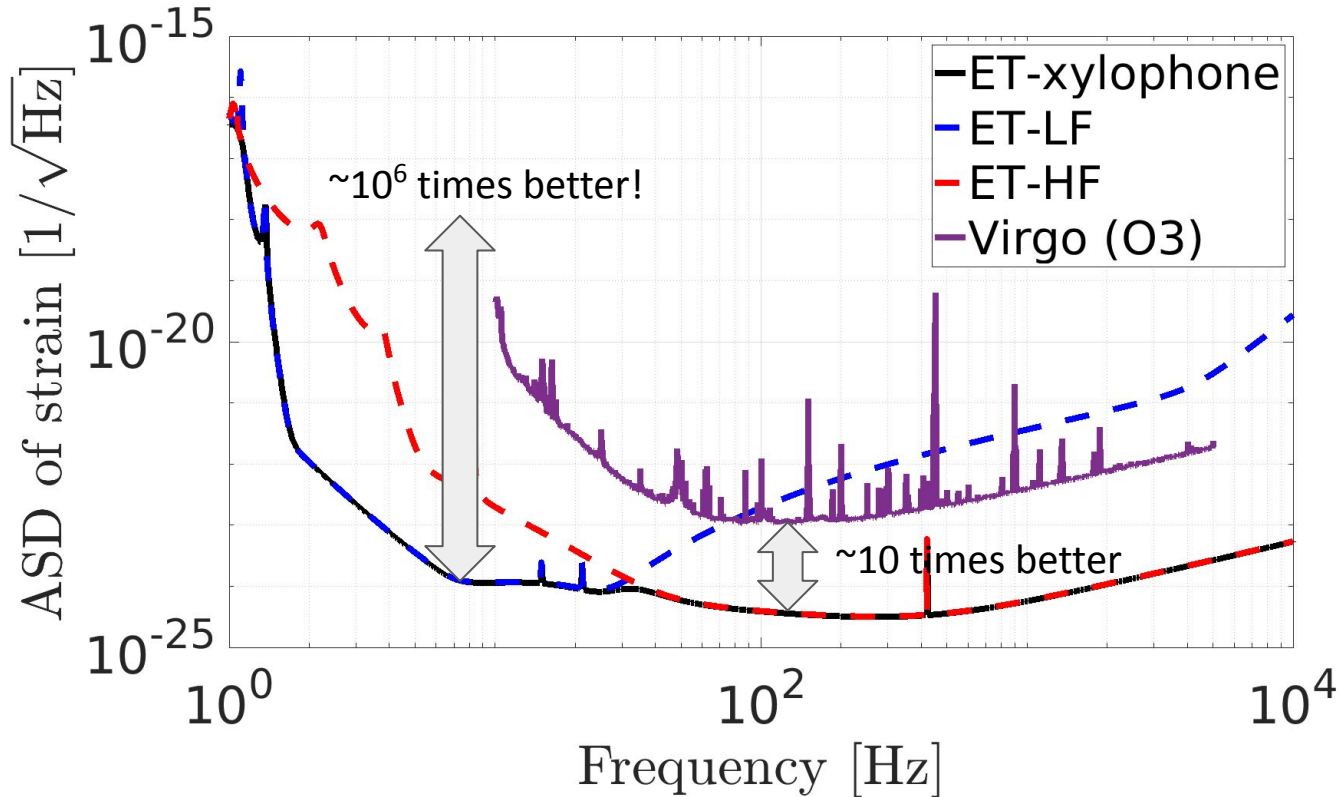
7 pendulum
stages to
reduce to
reduce by a
factor 10¹⁴ the
movements
from the
ground

Mirrors



Surface area accurate to within 5
atoms, less than 10 ppm not reflected

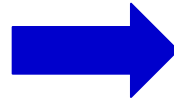
Instrumental challenges - Sensitivity improvement



Instrumental requirements - Key elements

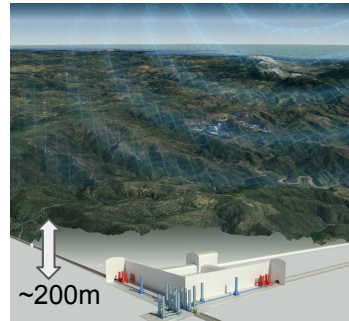
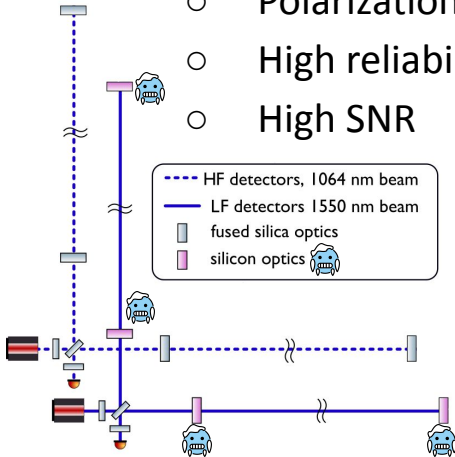
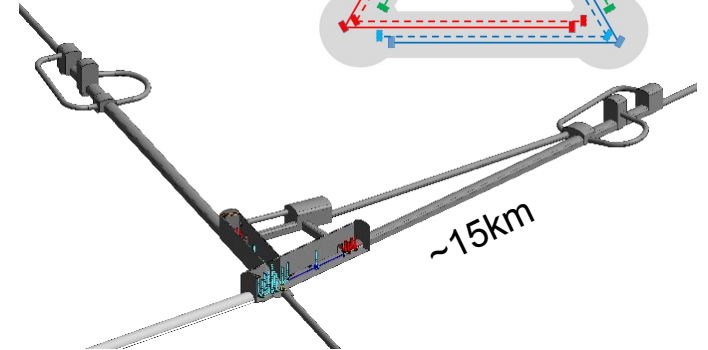
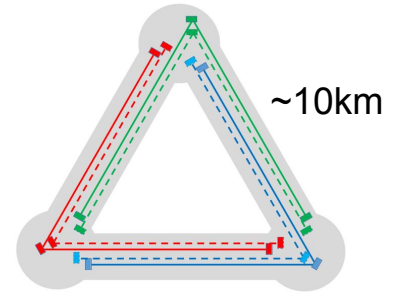
● Requirements

- Wide frequency range
- Low-frequency sensitivity
- Localization capability
- More uniform sky coverage
- Polarization disentanglement
- High reliability (high duty cycle)
- High SNR



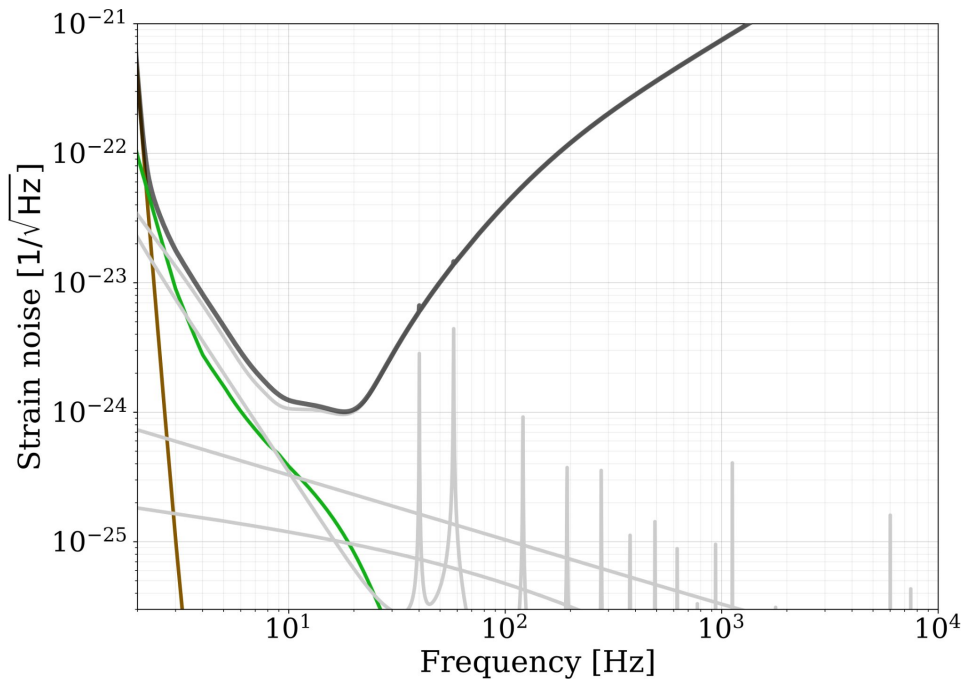
● Design specifications

- Longer arms (10-15km)
- Xylophone (multi-interferometer) design
- Cryogenic
- Underground
- Triangular or 2L

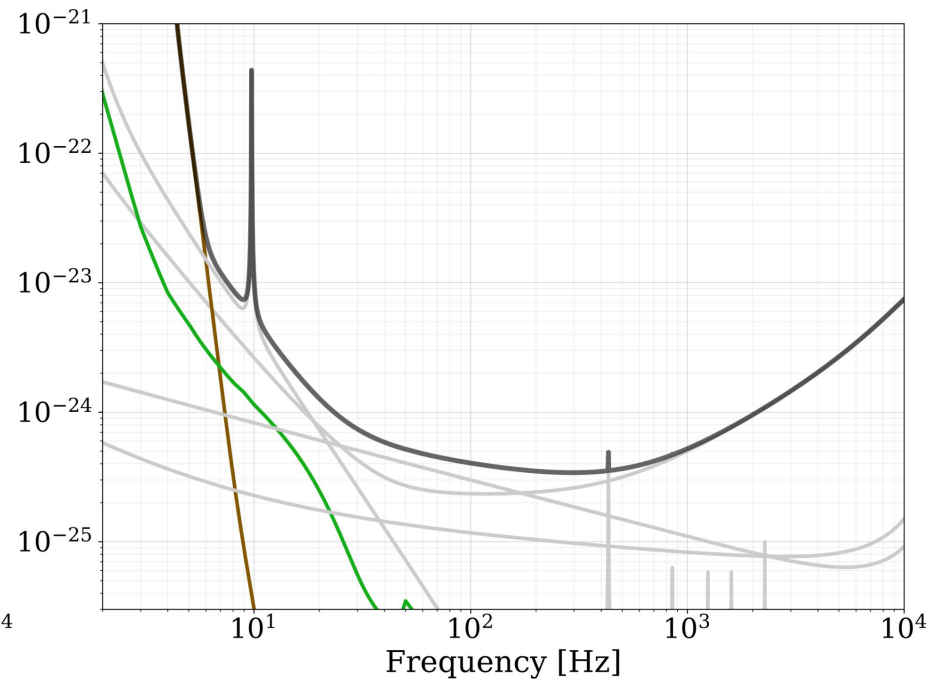


Sensitivity curves

Underground operation



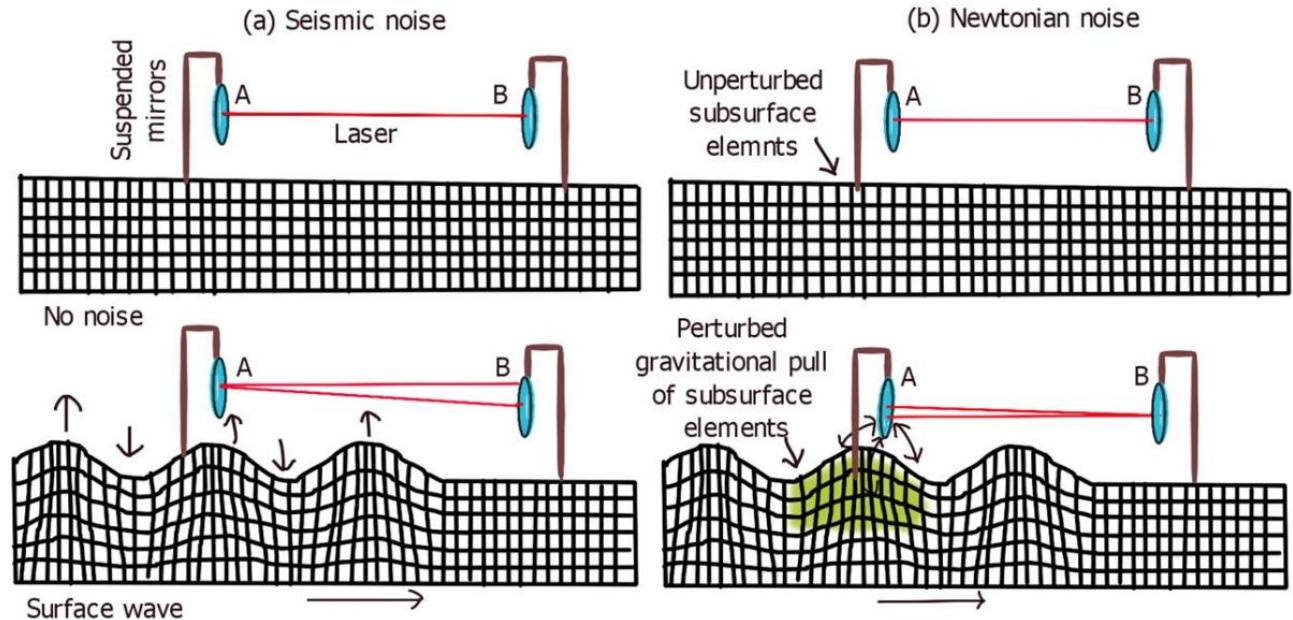
Low-frequency detector



High-frequency detector

Newtonian noise

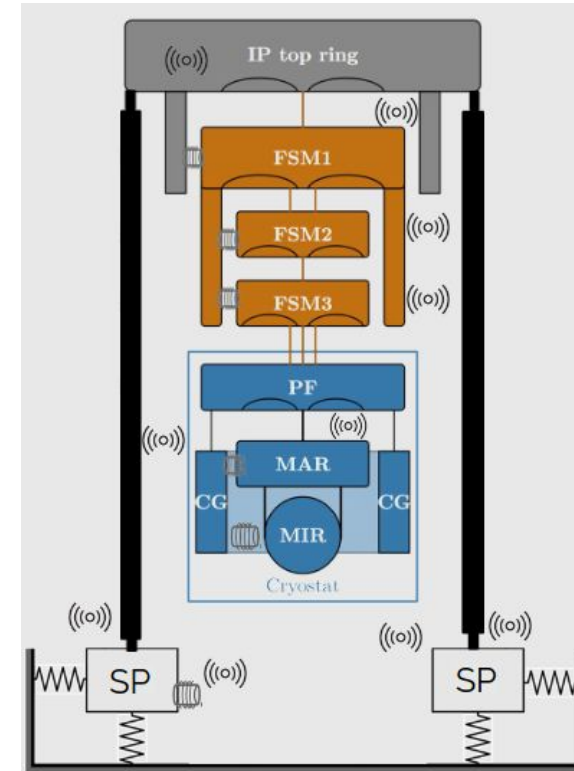
- It was shown that a seismic tiltmeter has the maximal coherence of all types of seismic sensors with NN produced by a field of Rayleigh waves
- A single tiltmeter would allow us to fully cancel NN from Rayleigh waves



From L. Errico [presentation](#)

Suspension system

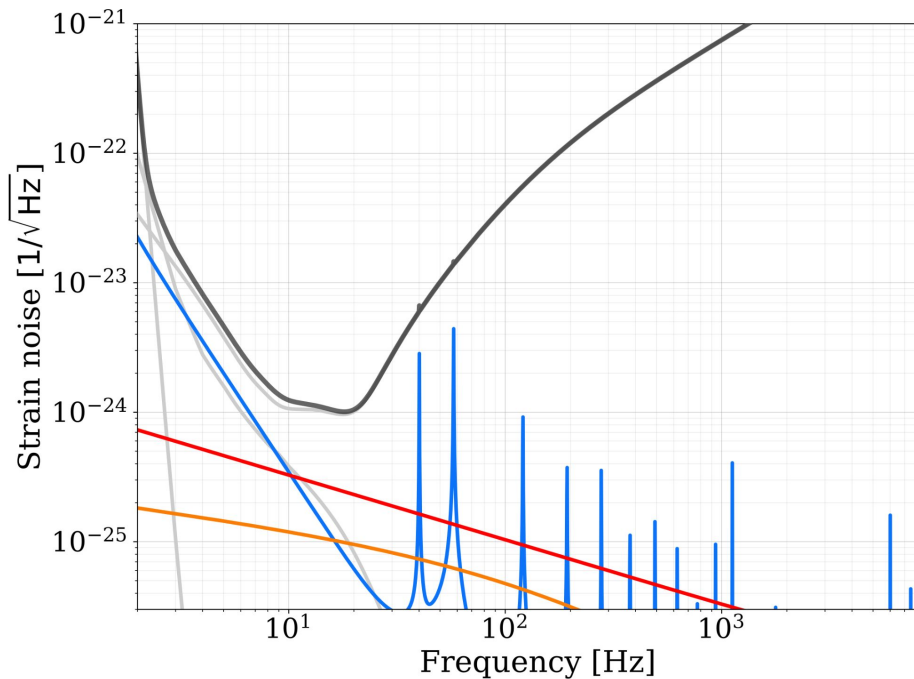
- Active and Passive pre-attenuation stage
- Mechanical Filter Chain
- Payload
- Sensors, Actuators and their driving electronics boards



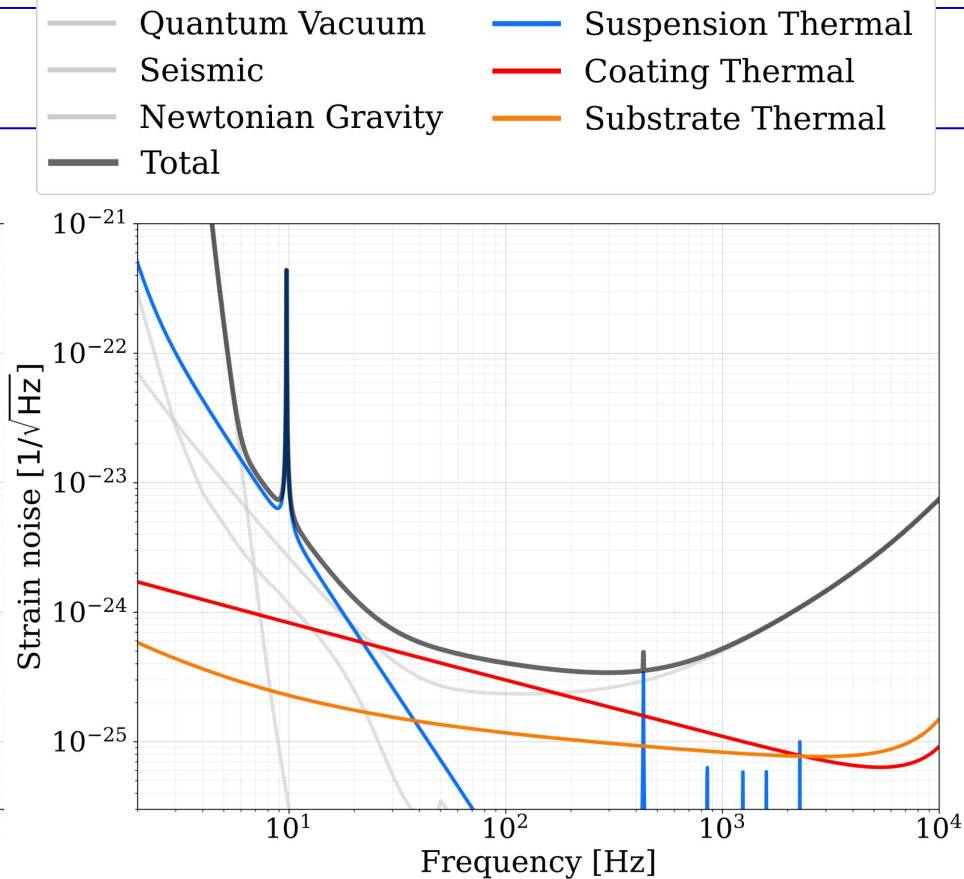
From R. Cornelissen and J. Docherty [presentation](#)

Sensitivity curves

Cryogenics operation

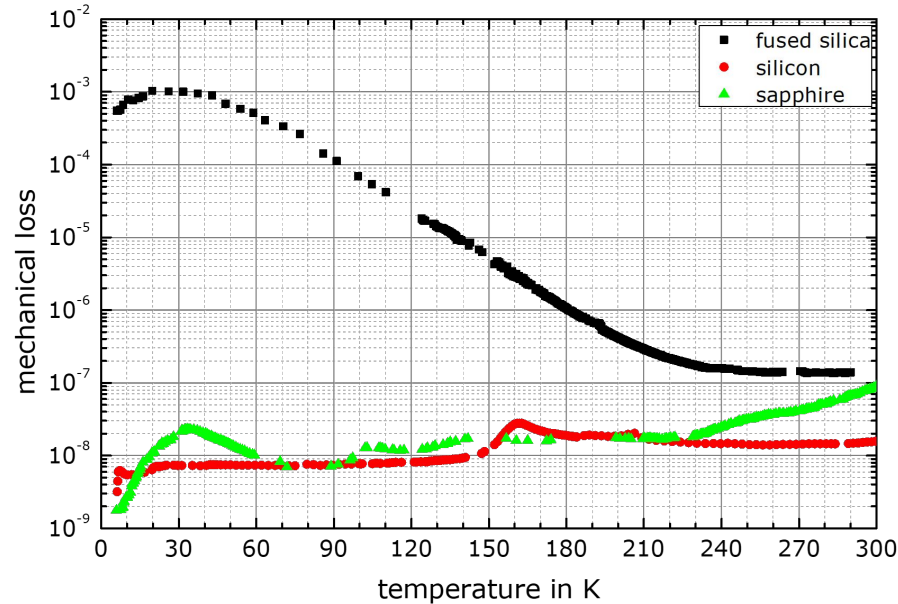


Low-frequency detector



High-frequency detector

Cryogenics challenges - mirror substrate



R. Nawrodt et al. 2009, Proceedings of ICEC22-ICMC2008

From L. Silenzi [presentation](#)

Sapphire

Already used at 1064 nm in KAGRA, shows challenges in inhomogeneities, birefringence and size availability

Silicon

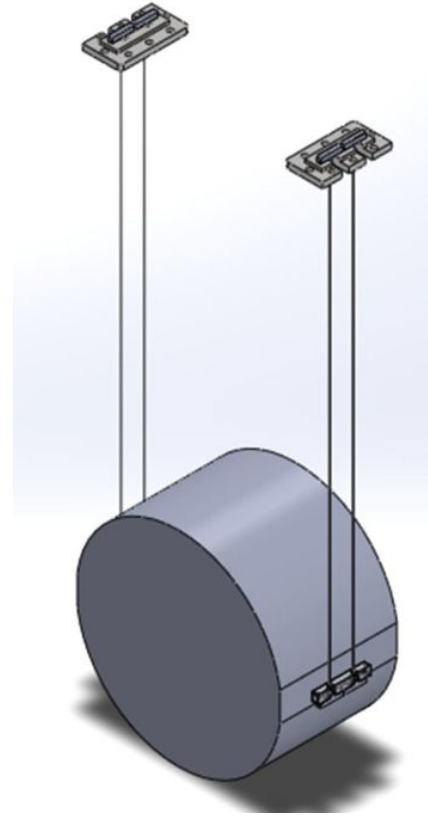
Low optical absorption requires very pure material, i.e. float zone (FZ) silicon or magnetically-stabilized Czochralski silicon.

But high-purity material not available in such large size. Challenges:

- ❖ **make large material purer**, optimizing the fabrication process
- ❖ **make pure material larger**, optimizing the process or with composite test masses

Cryogenics challenges - cooling

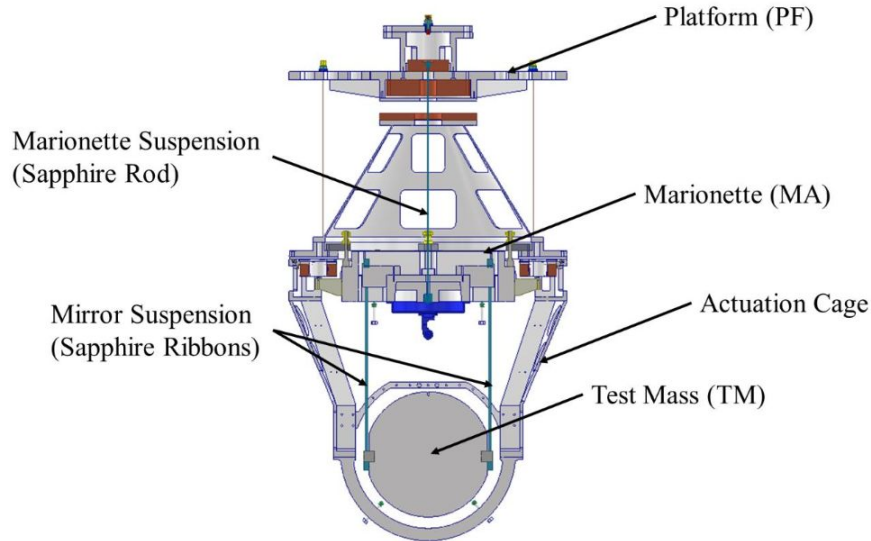
- Thermal noise from suspensions, mirror substrate and coating impact the position of the mirror seen by the laser
- The cooling of a 200 kg test-mass hosted by an 800 kg articulated structure at few K **IS NOT** a technological challenge
- Cooling-down with mechanical constraints impacting on the structural dynamics of the payload and then on the control noise reflected on its position is a **BIG CHALLENGE**
- Cooling-down a test-mass that is indeed a mirror that is a core optical element of an interferometer is a **BIG CHALLENGE**



Adapted from [E. Majorana presentation](#)

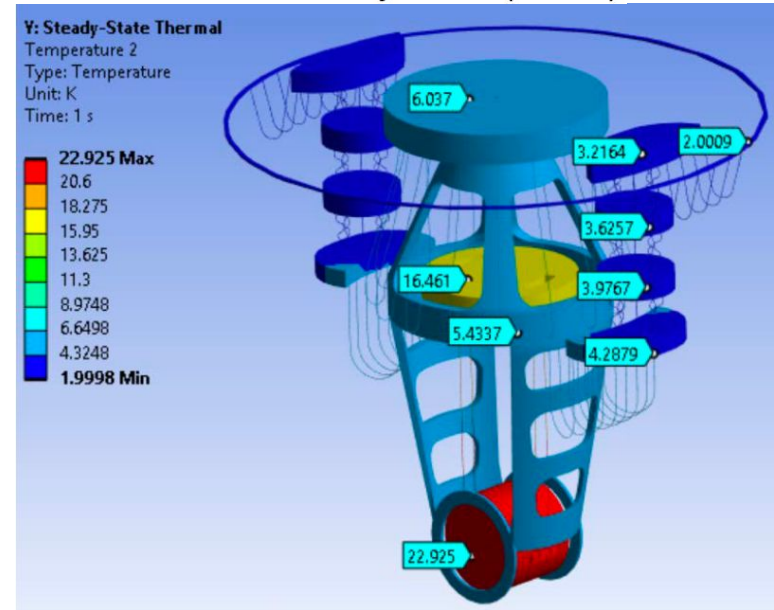
Cryogenics - Baseline payload design

Heat extracted via the 4 wire suspensions:
Cristals made of Silicon or Sapphire



From [F. Ricci presentation](#)

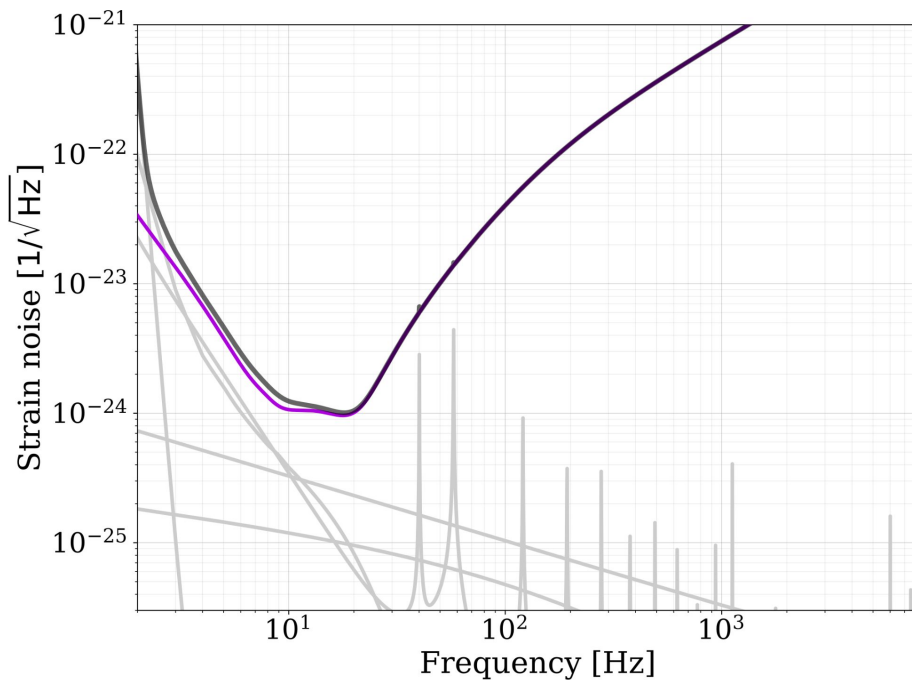
- Application of 2 K heat sink
- Payload connection via heat link vibration isolation systems (HLVIS)



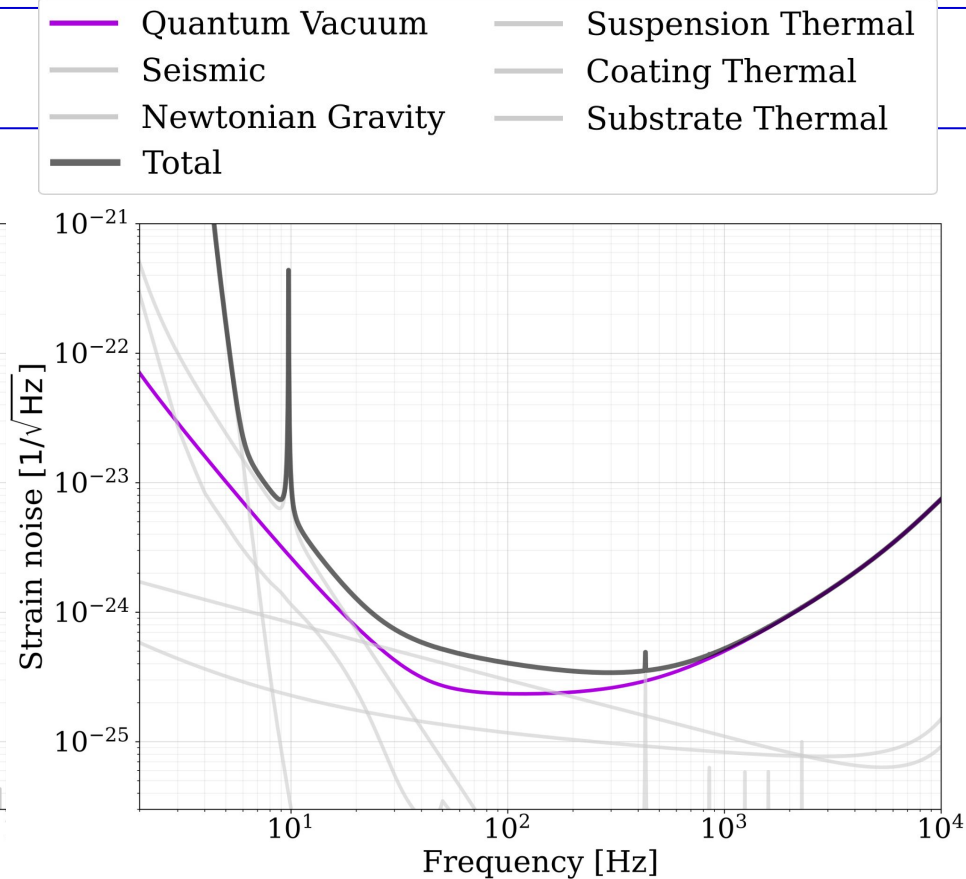
From [S. Grohmann presentation](#)

Sensitivity curves

Quantum Noise Reduction

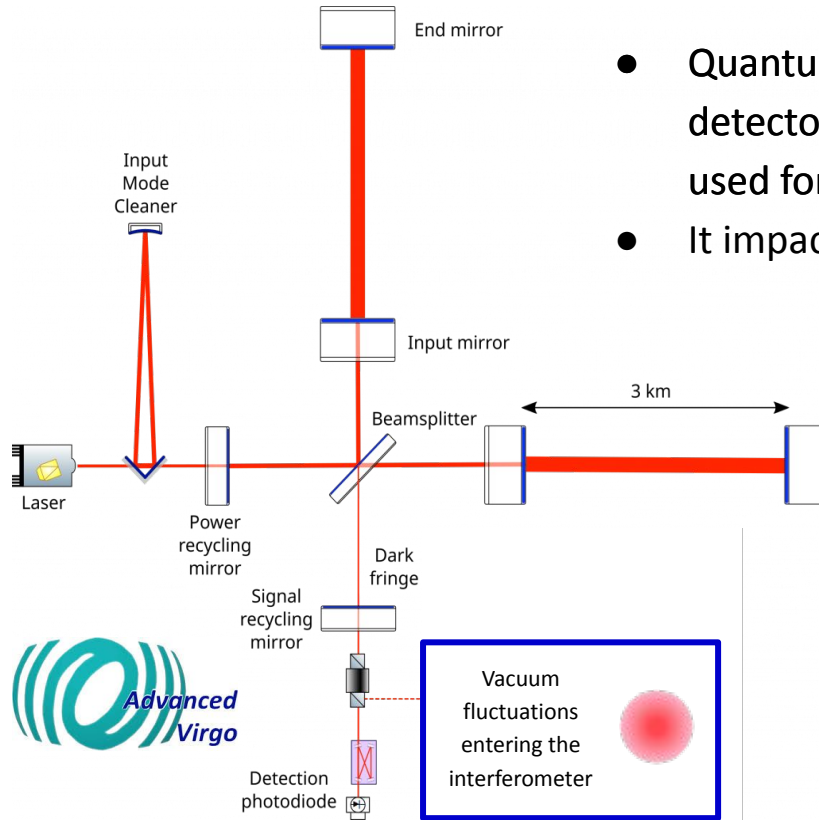


Low-frequency detector

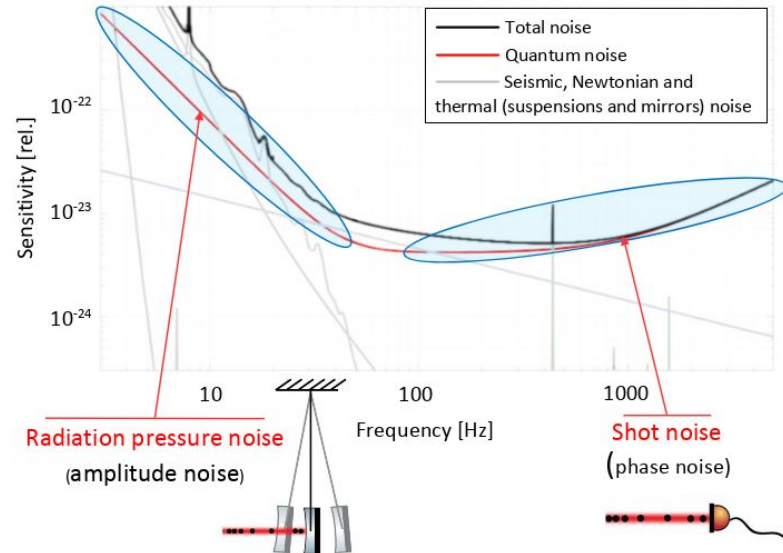


High-frequency detector

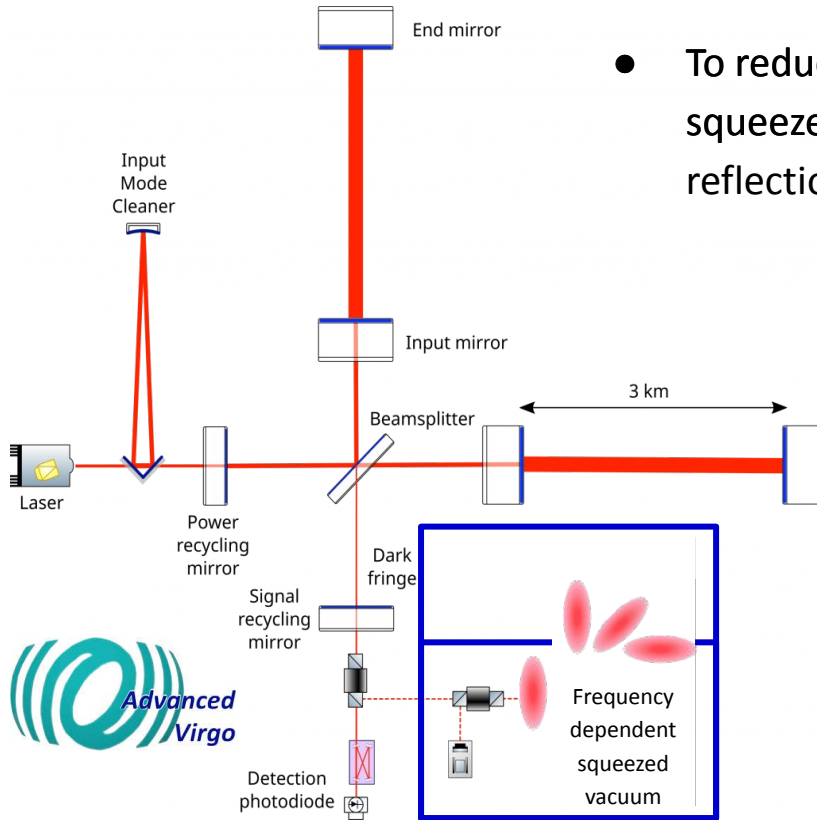
Quantum Noise Reduction - Introduction



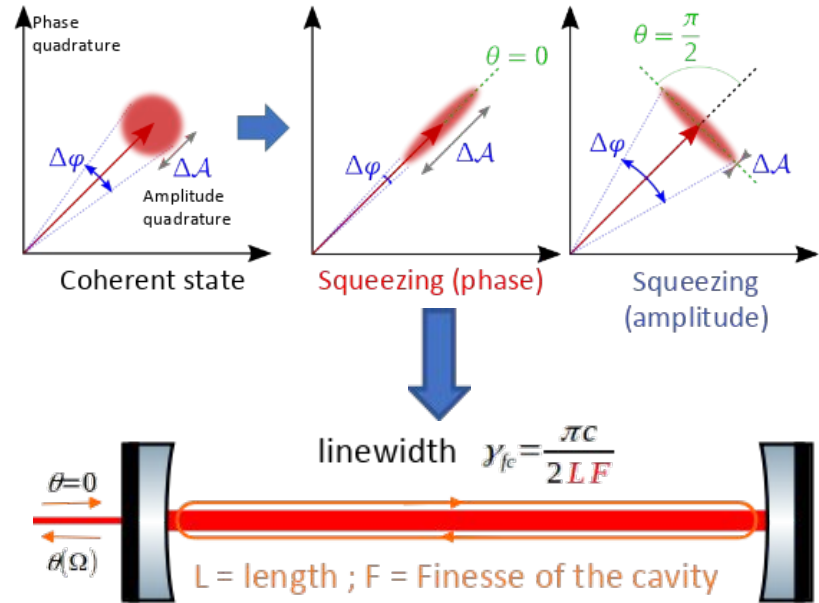
- Quantum noise arises from vacuum fluctuations entering the GW detector through its output port and interfering with the light used for GW detection.
- It impacts the interferometer sensitivity through two ways:



Quantum Noise Reduction - Squeezing

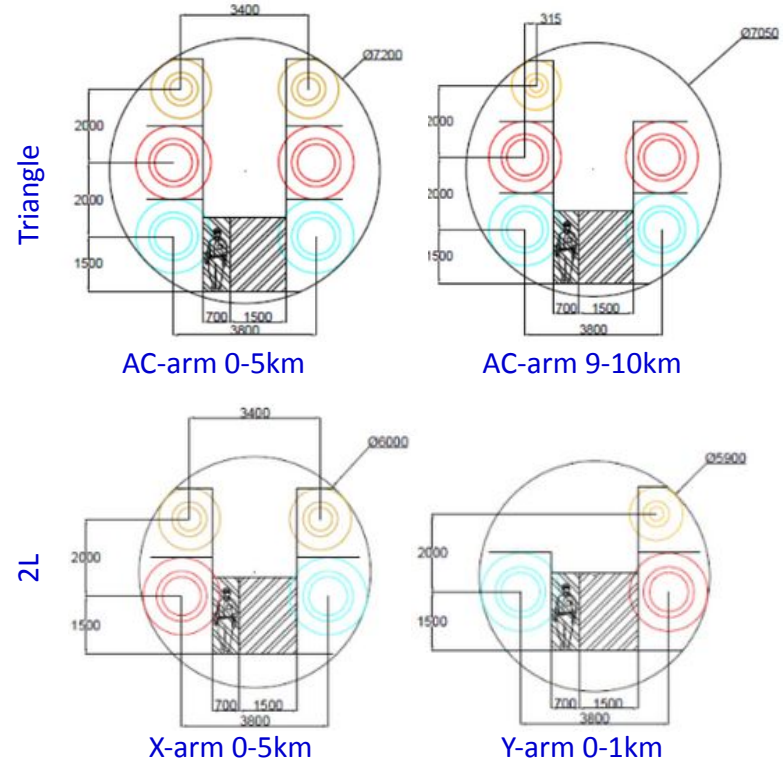
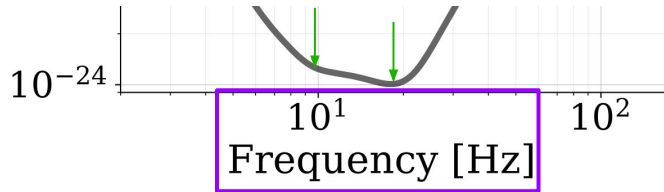


- To reduce quantum noise we replace the coherent vacuum with squeezed vacuum states of light made frequency dependent by reflection on optical resonator(s)



Quantum Noise Reduction - Squeezing for Einstein Telescope

- High-Frequency detector:
 - Squeezing similar to LIGO-Virgo
 - Wavelength = 1064nm
 - 1 filter cavity of 1km
- Low-Frequency detector:
 - Wavelength = 1550 nm (due to cryogenics operation)
 - 2 filters cavities of 5 km each
 - 2 dips at low frequencies on LF sensitivity curve



M. Majoor

And many other instrumental challenges

- Scattered light
- High power stable laser
- Vacuum
- Active Noise Mitigation
- Interferometer Sensing and Control
- Environmental monitoring
- ...

Conclusion

- Einstein Telescope is the next generation of European gravitational wave detector foreseen to operate for half of the century
- The science targets are multifold (see the ~900 pages of the "Blue book" [JCAP03\(2026\)081](#))
- The gain in sensitivity wrt LIGO-Virgo-KAGRA is tremendous and rely on many complementary technologies:
<https://www.youtube.com/watch?v=gPZYDwLYTI>
- The Einstein Telescope Collaboration keeps growing!

Thank you!

Back-up material

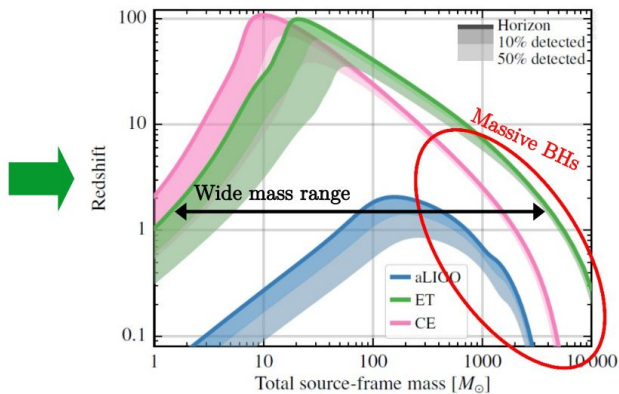
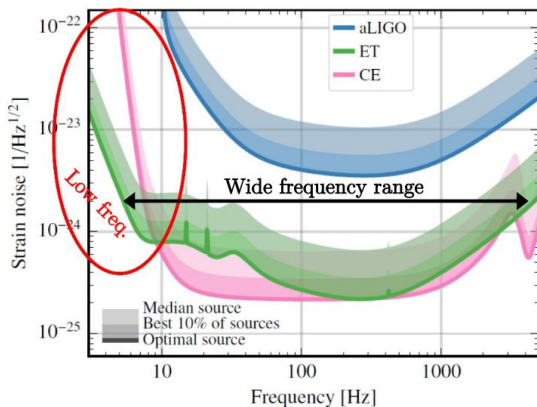
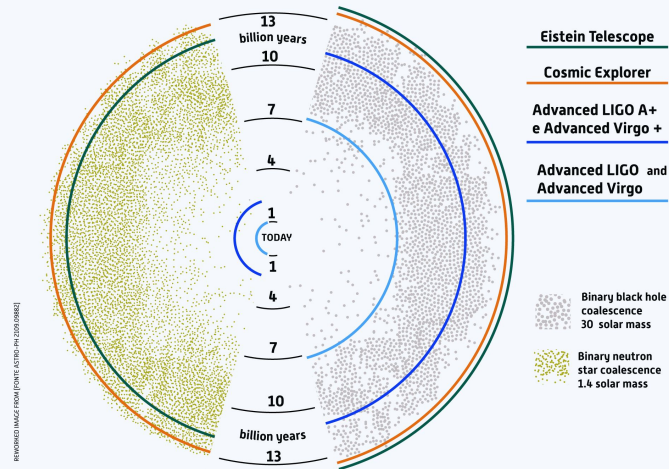
sources



Observation performances

Einstein Telescope and Cosmic Explorer

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





ET: large scale and complex infrastructure

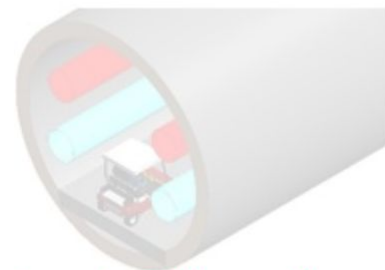
Underground observatory

Pro:

- Access to the low frequency:
 - 2-10Hz for ET
 - Reduction of the seismic and Newtonian Noise
 - Suppression of the atmospheric Newtonian Noise and of the wind impact
 - Reduction of the anthropogenic noise
 - Magnetic
 - Acoustic
 - Vibration
- Easier compatibility with the urbanization of the hosting region
 - Europe is generally a strongly urbanized continent
- Landscape impact

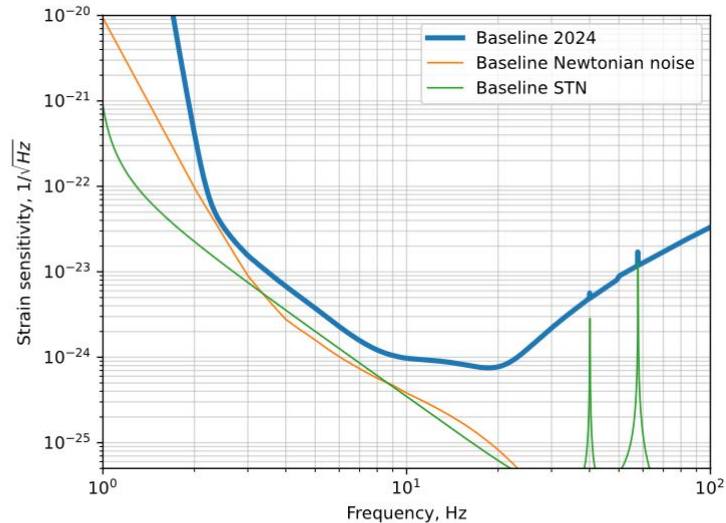
Cons:

- Costs
- Challenging civil engineering (>30km of tunnels, large caverns...)
- Time needed to build it
- Limited possibility to upgrade the civil infrastructure in a medium-long term timeline
- More difficult operating environment in all the observatory phases (construction, integration, commissioning, maintenance and upgrade)

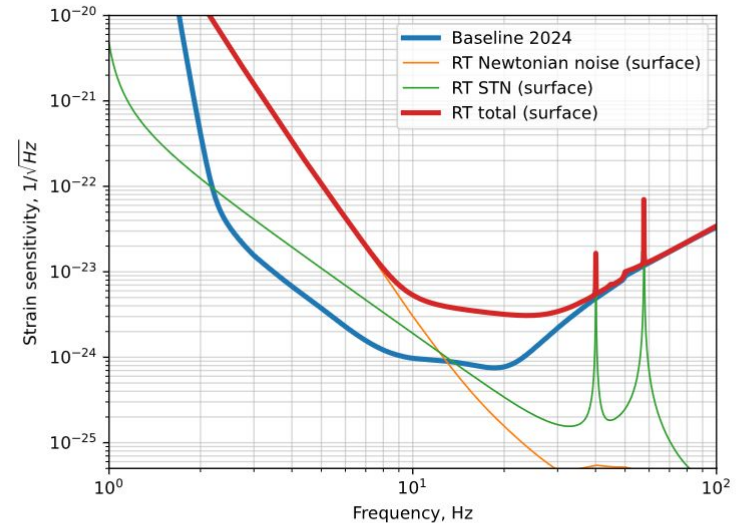


Limiting noise contributions to ET-LF sensitivity

- Baseline cryogenic LF



- Comparison (RT, surface)



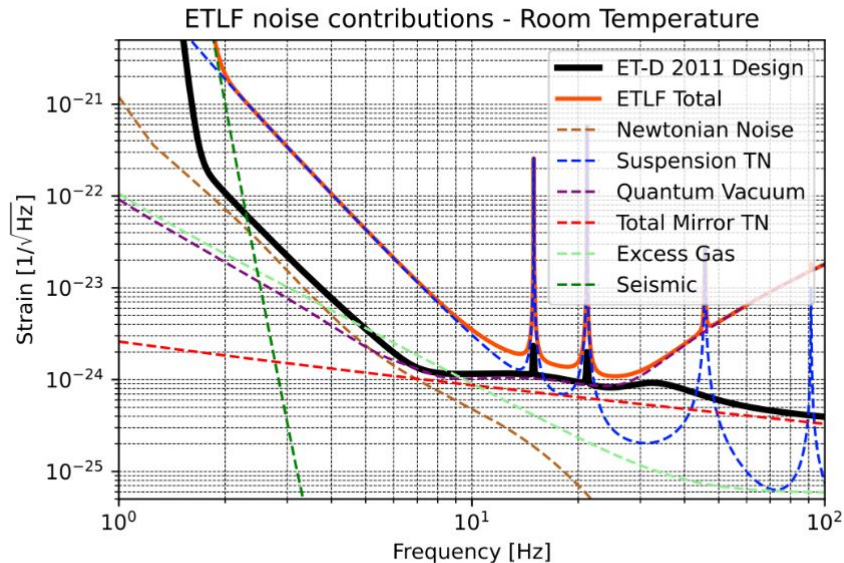
Figures based on ET-Noise Budget Gitlab - PyGwinc Code (29.05.2025) - <https://gitlab.et-gw.eu/et/isb/interferometer/ET-NoiseBudget>

The underground installation and the cryogenic operation are two sides of the same coin

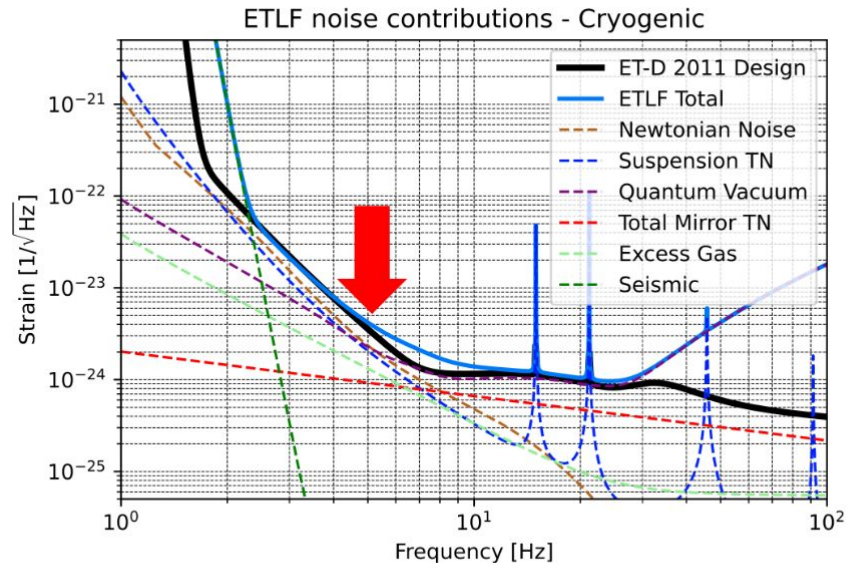
A strong motivation to implement cryogenics in ET

Cryogenics contributes to a significant increase of sensitivity at low frequency

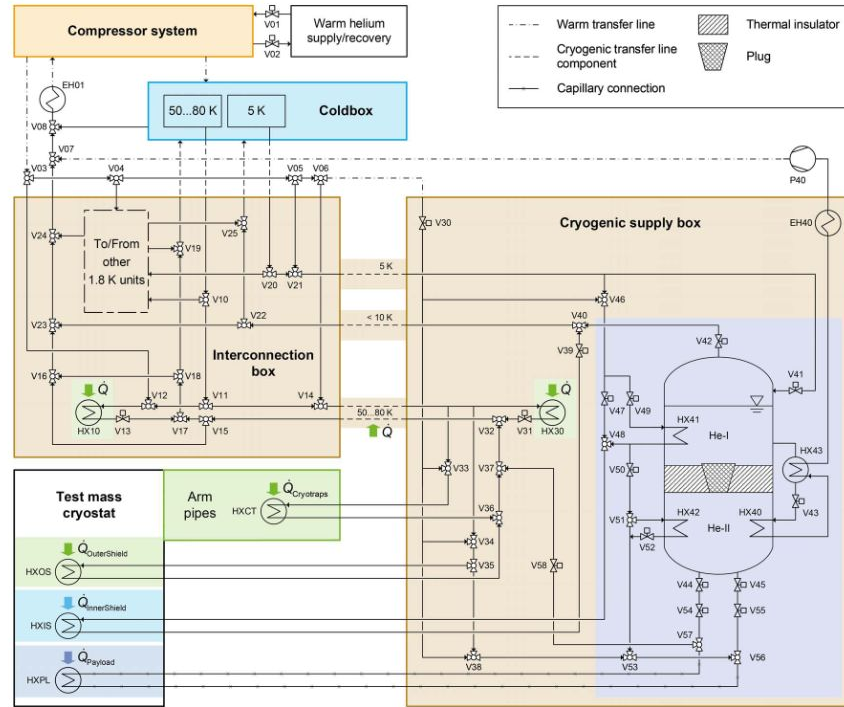
Room-Temperature ET-LF



Cryogenic ET-LF



Cryogenic infrastructure concept [*]



- No underground LN₂ (safety)
- One He refrigerator at each vertex
 - (Remote) surface compressors
 - Underground coldbox
 - Interconnection box to several cryogenic supply boxes (1 for each tower/cryostat)
 - Up to c. 500 m long transfer lines
 - 1-phase cooling for 80 K cryopumps/outer shields
 - 1-phase cooling for 10 K baffles, 5 K inner shields and 3.7 K cryopumps
 - He-II payload cooling/inner shield



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

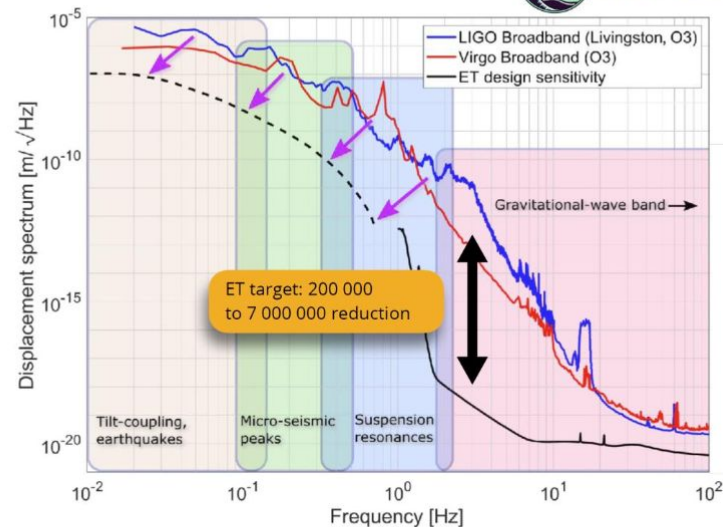
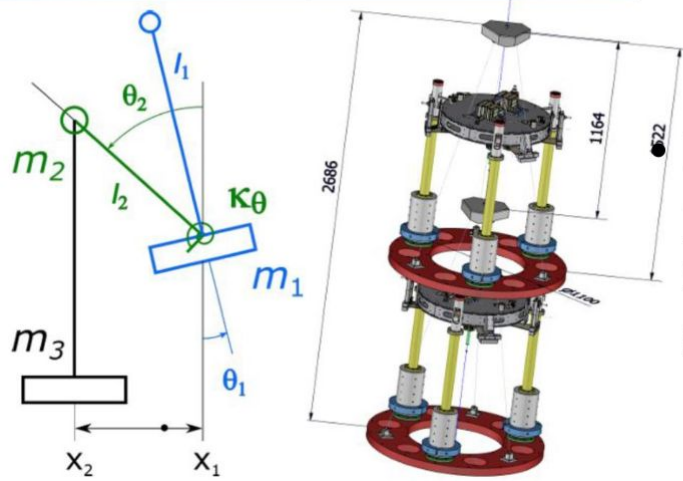
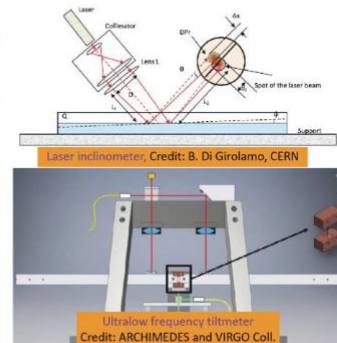
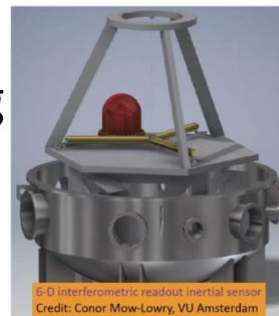
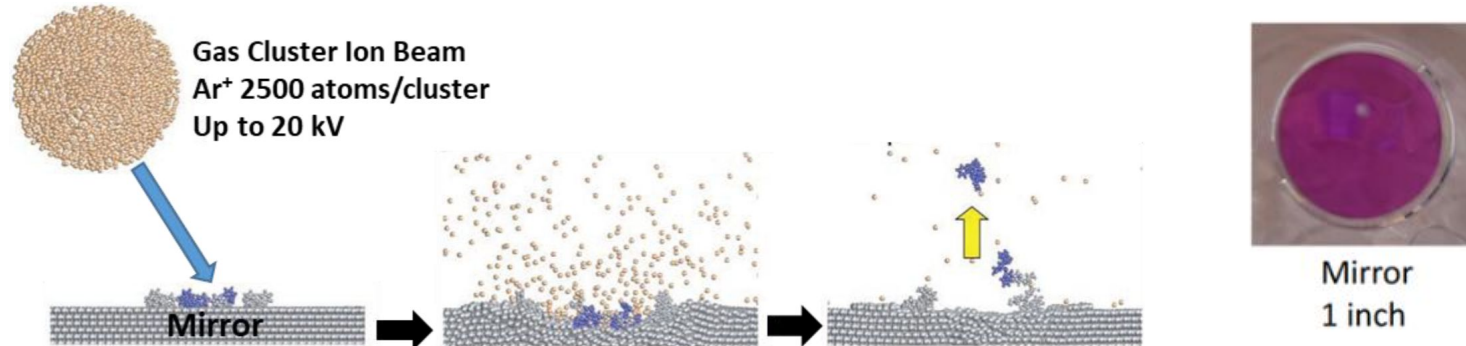


Image: Conor Mow-Lowry



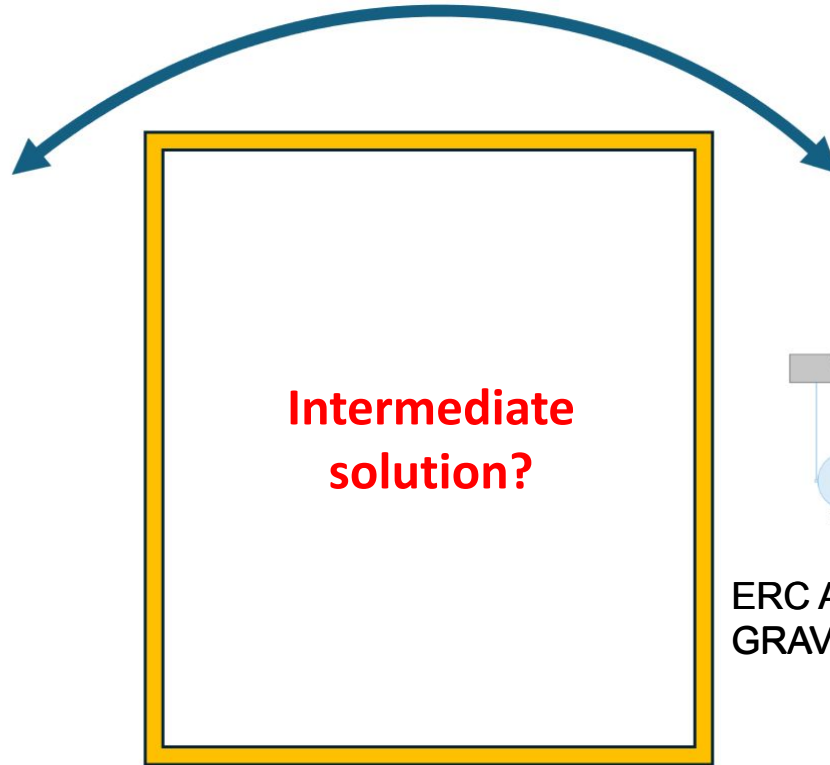
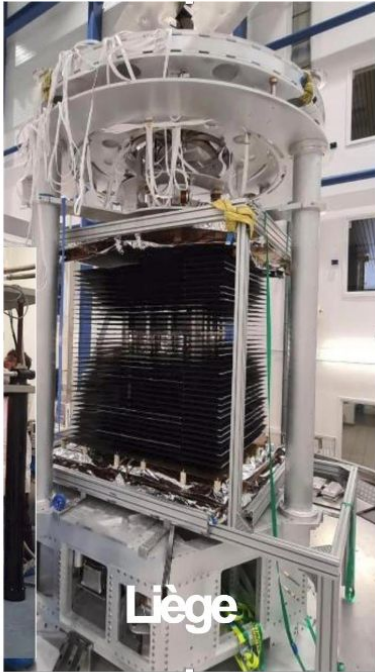
Cryogenics challenges - mirror cleaning

- KAGRA experience: Unstable cooling performance happened resulting in H₂O gas release -> **Frosting of mirrors**. Solution: Warm up and re-cooling for 3 months for recovery. ([GWADW presentation](#))
- Proposition at IJCLab to use Cluster Ion Beam for mirror defrosting, cleaning and discharging => first tests at room temperature on high quality coating substrates

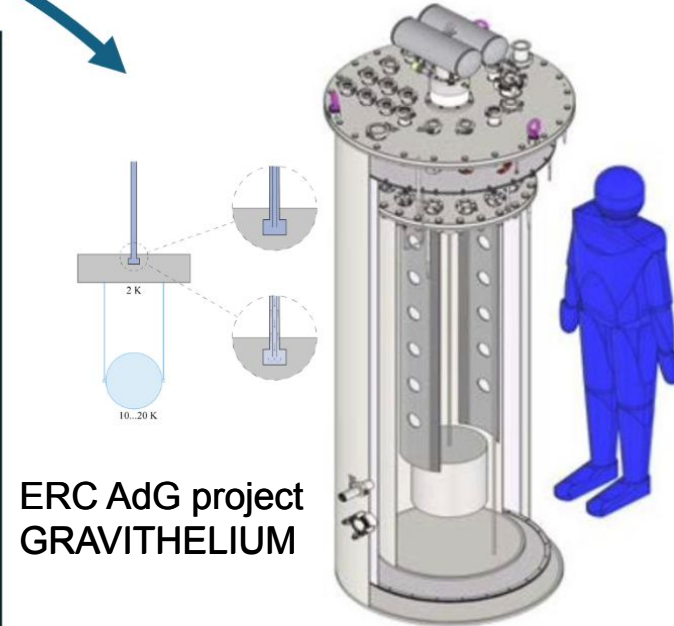


Cryogenics cooling R&D - Large scale prototypes

Ideally radiative non-contact



Ideally conductive contact



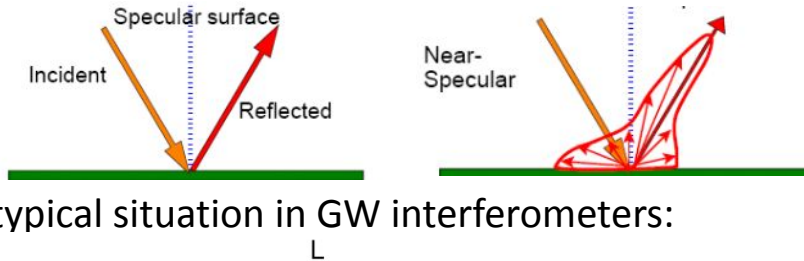
Karlsruhe

Adapted from [E. Majorana presentation](#)

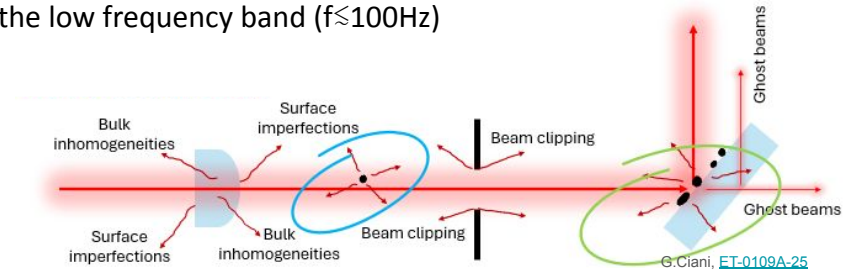
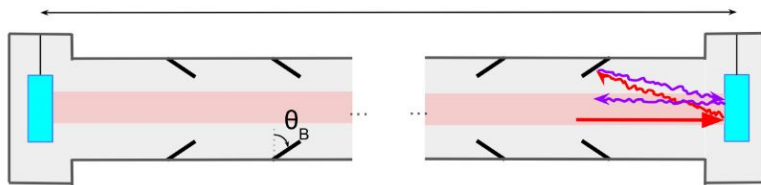
Scattered and Stray Light

Straylight:

- any photon that is scattered and do not follow the intended path
- consequences:
 - optical losses
 - photons recouple with random phase: excess noise in the low frequency band ($f \lesssim 100\text{Hz}$)



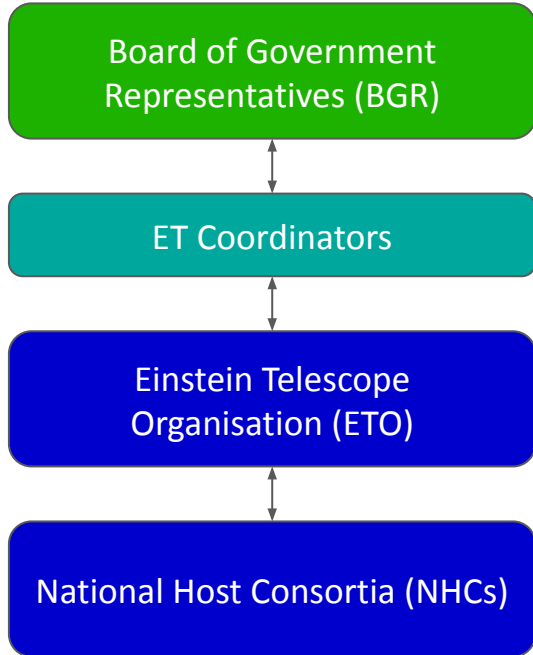
A typical situation in GW interferometers:



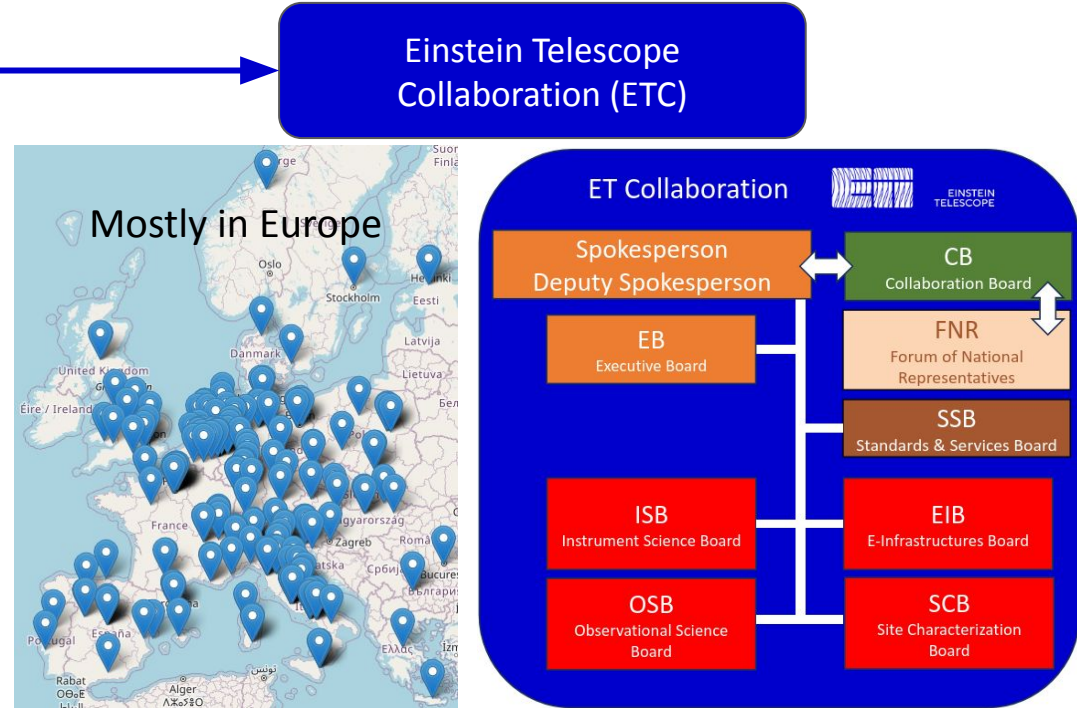
Stray light produced by a Test Mass reaches the pipe tube (or pipe baffle), is scattered back towards the TM and then again re-scattered into the main beam

Einstein Telescope Organisation and Collaboration

Project management



Science



Site and timeline

- Three sites formally candidates to host ET:
 - EMR Euregio, border region between Netherlands, Belgium and North Westfalia (Germany)
 - Lausitz, Saxony (Germany)
 - Sardinia (Italy)
- ET timeline is under review, 2026-2027 is crucial:
 - Sep-Oct 2026: Geometric comparison report by ET Organization
 - Dec 2026-June 2027: Call for tenders
 - Fall 2027: Site selection decision (after review by international panel)
 - 203X: Opening ET

