

The Einstein Telescope: an oversized strain gauge

ICE webinar "Listening to the Universe: Civil Engineering
for the Einstein Telescope"

Patrick Werneke

Einstein Telescope Organisation

September 30, 2026

Introduction Patrick Werneke

- Background: aeronautical engineering and business administration
- > 33 years @Nikhef: Dutch National Institute for Subatomic Physics

1993 – 2008 | Nikhef / ATLAS / CERN

- 15 years working on the ATLAS experiment, including 3 years based at CERN.

2009 – 2023 | Nikhef

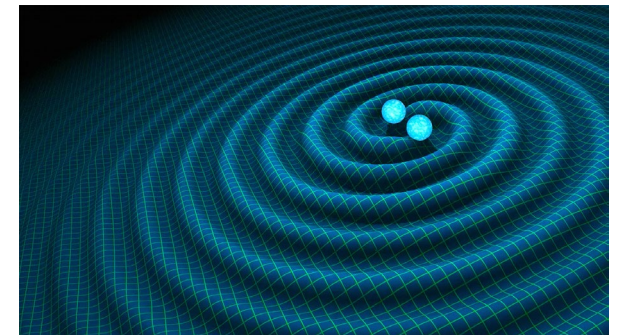
- 15 years as Head of the Mechanical Technology Department

2022 – Present | Einstein Telescope Organisation

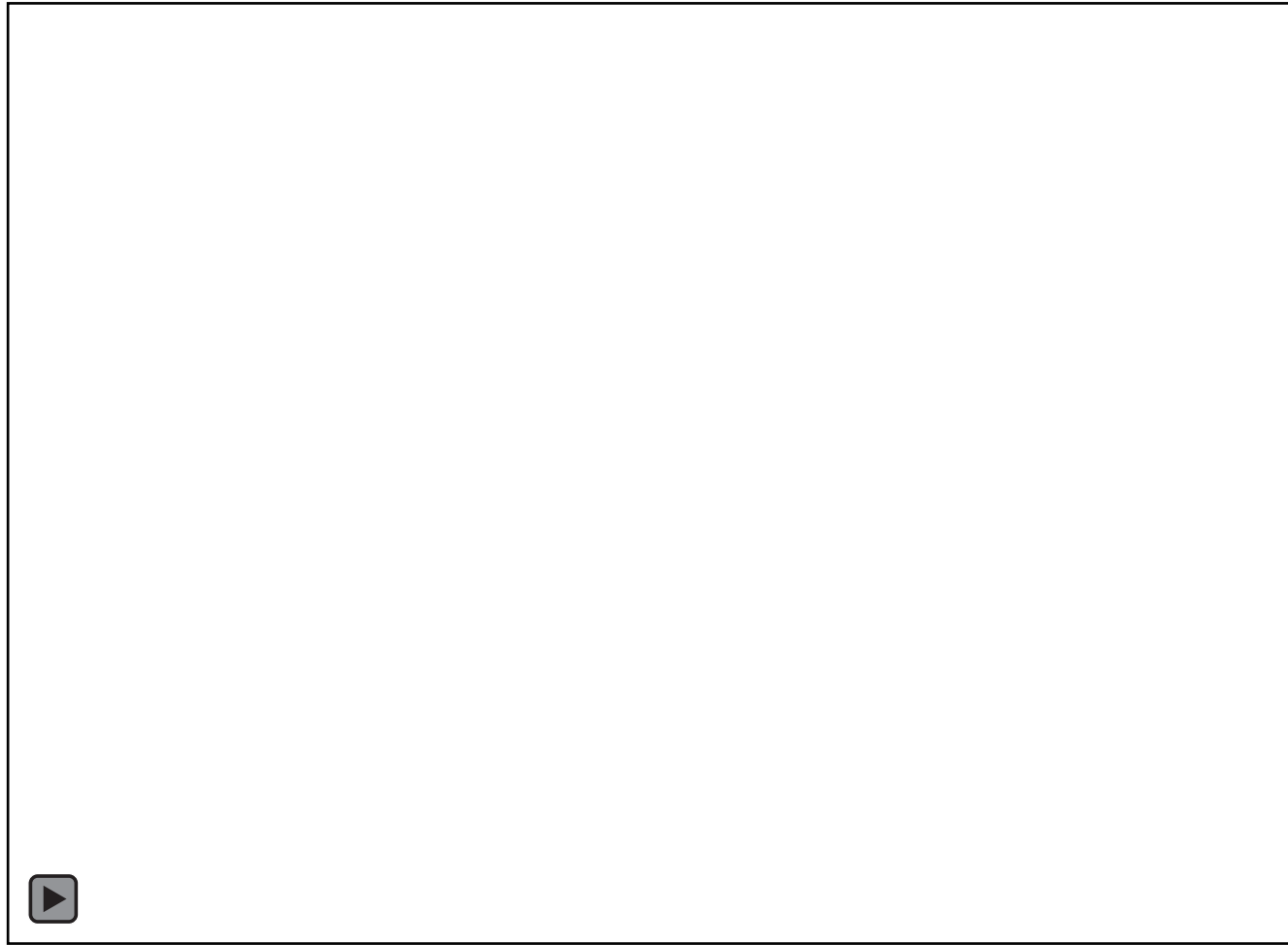
- For the past four years, Head of the Engineering Department



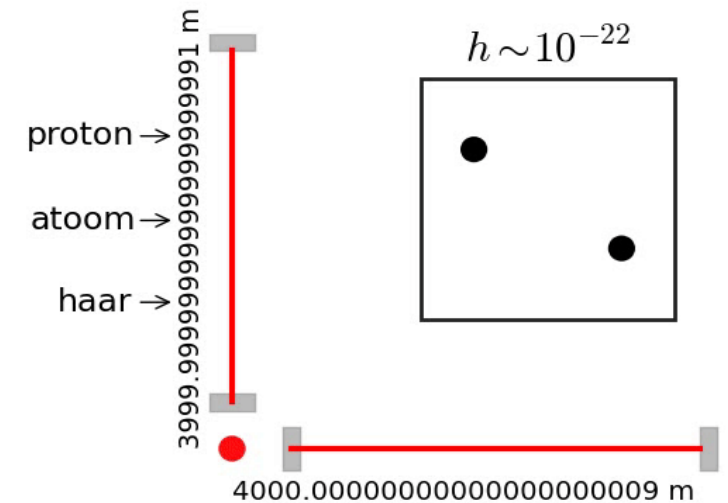
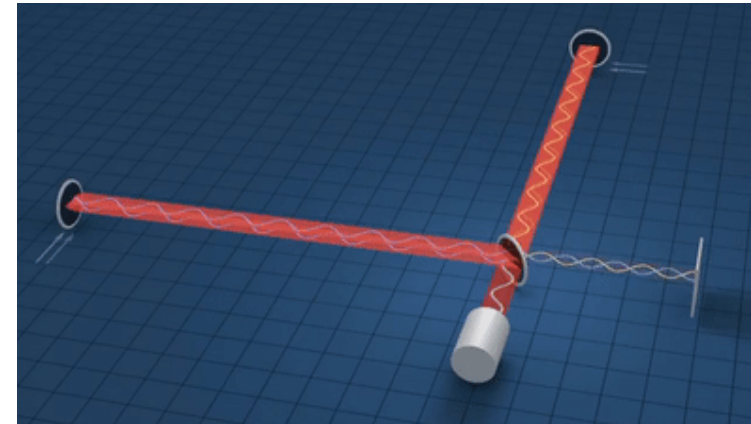
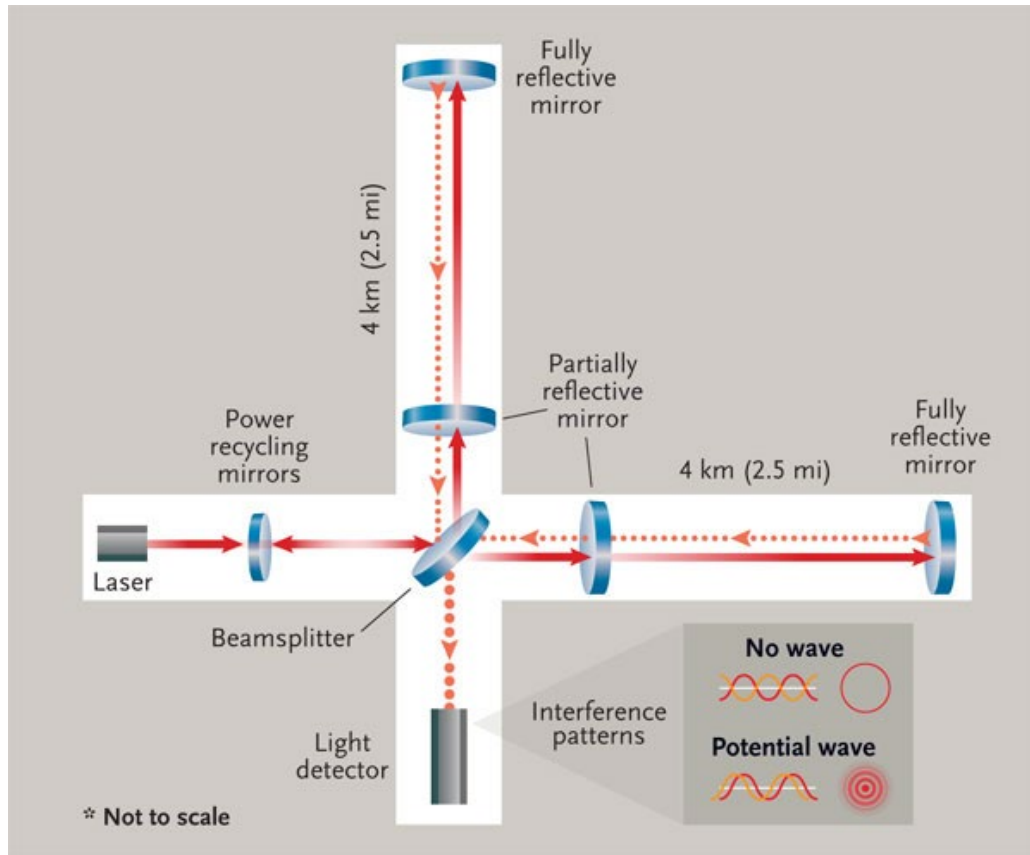
Gravitational Waves



2 black holes colliding and emitting a gravitational wave



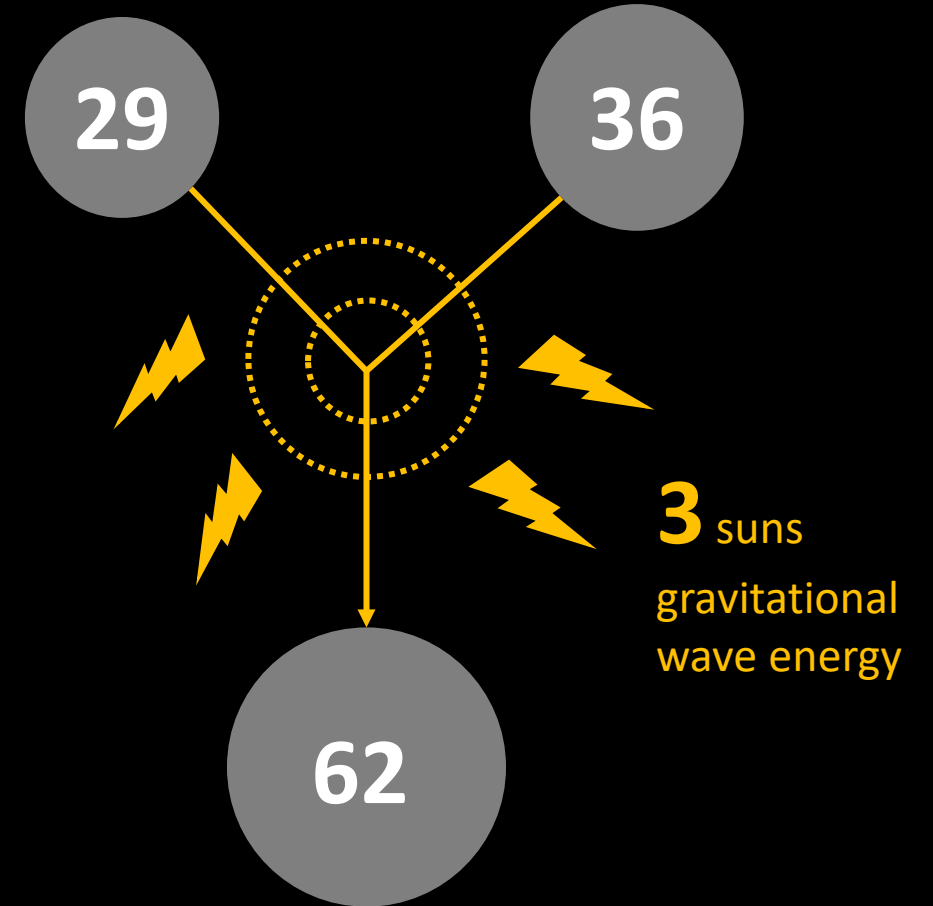
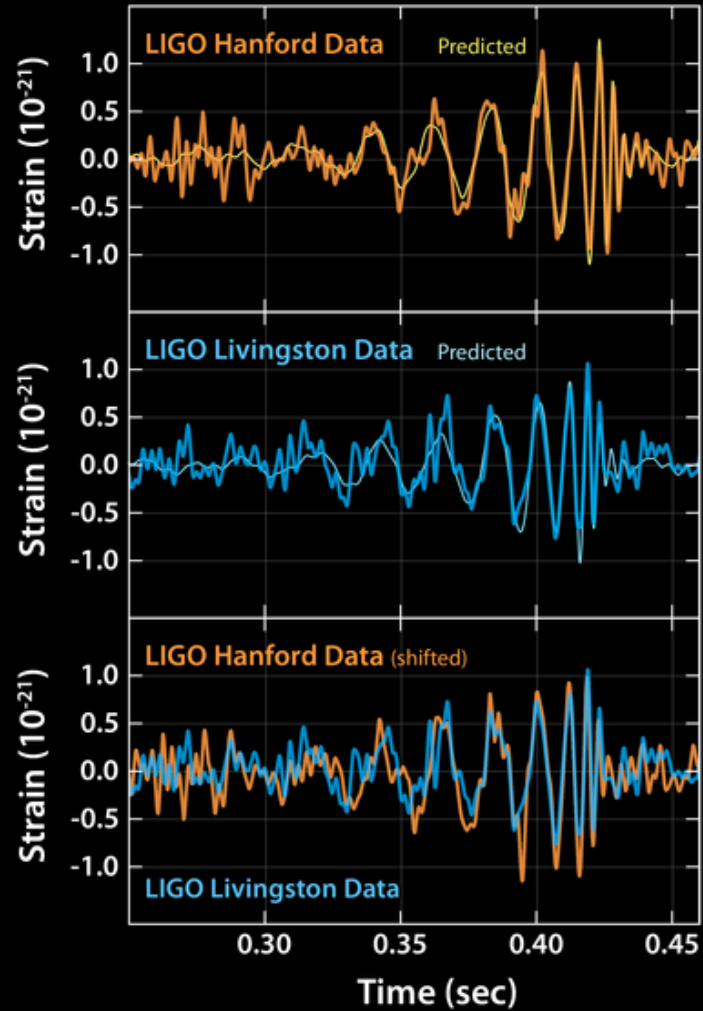
Detection of Gravitational Waves



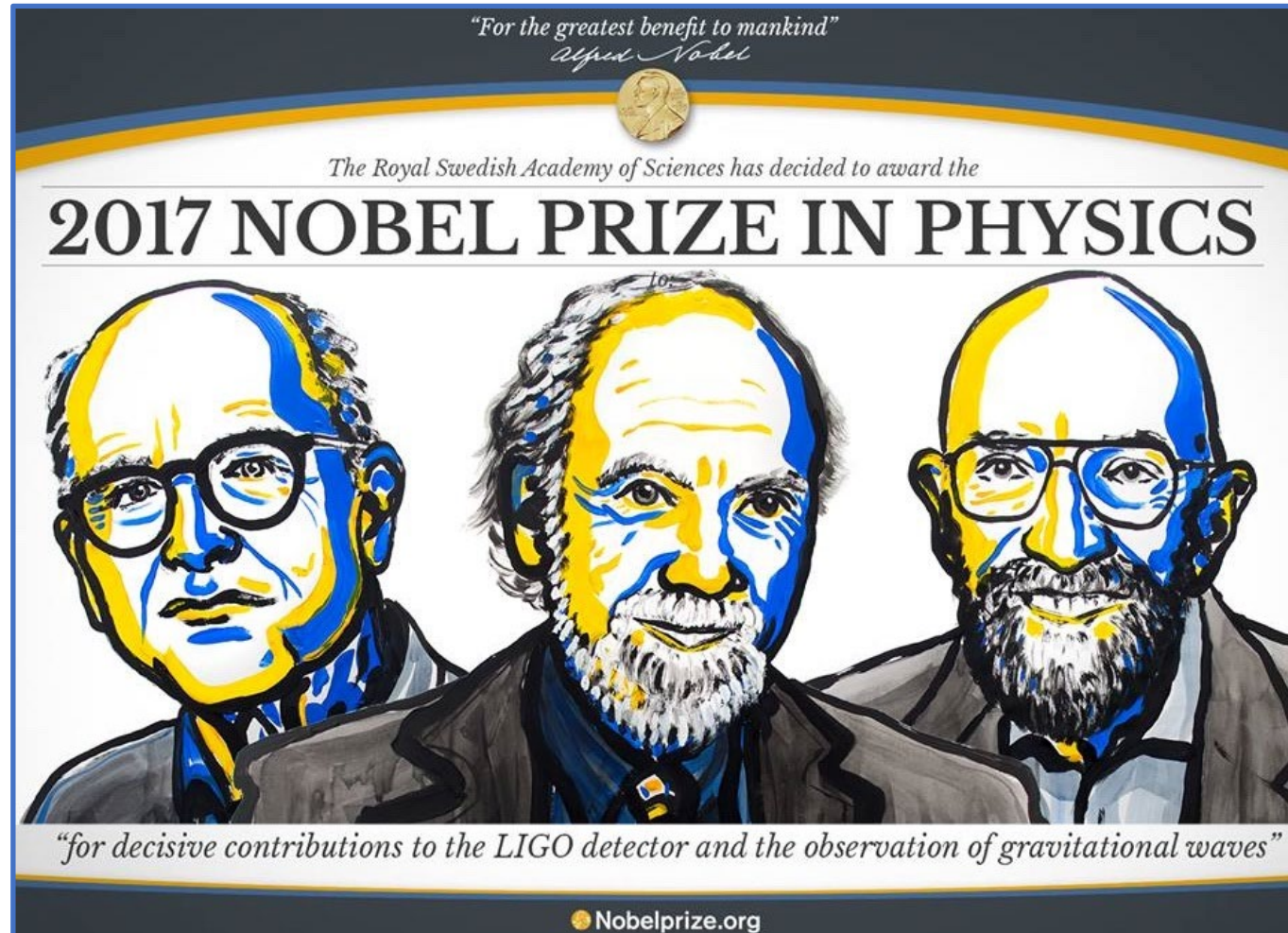
22 decimal places. This means that it can detect differences in distance ten thousand times smaller than the size of the protons in an atomic nucleus.

FIRST DETECTION – GW150914

14 September 2015

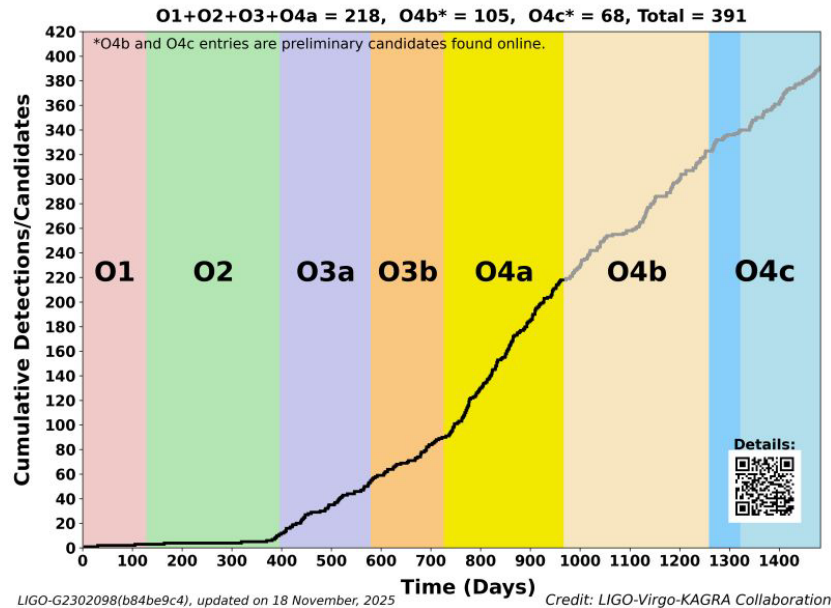


2017 Nobel Prize

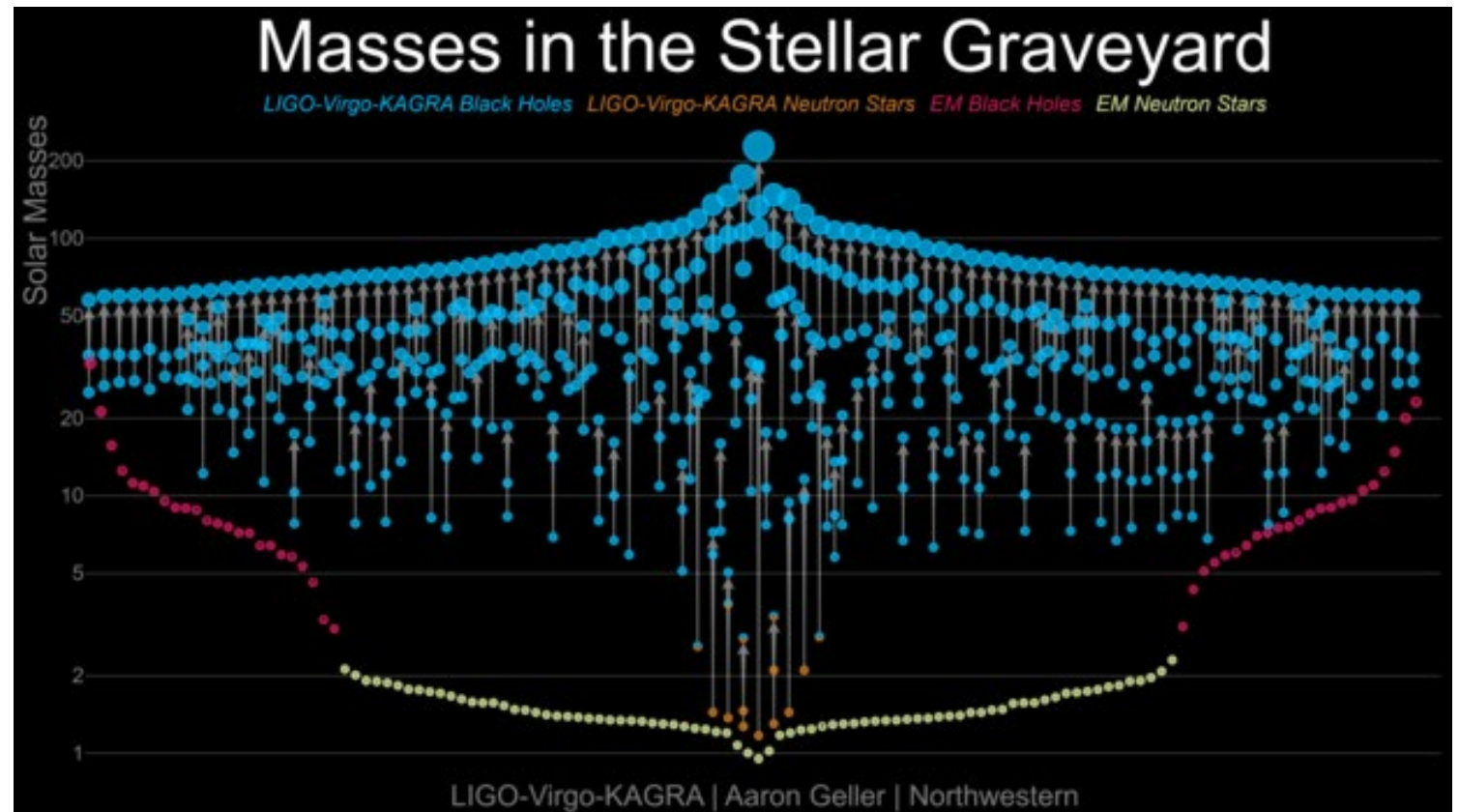


- Rainer Weiss
- Barry Barish
- Kip Thorne

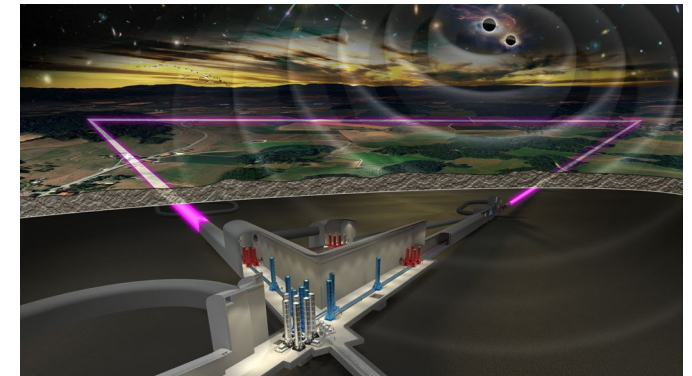
Frequent observations of binary coalescences

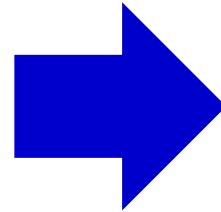


About one signal
detected per week!

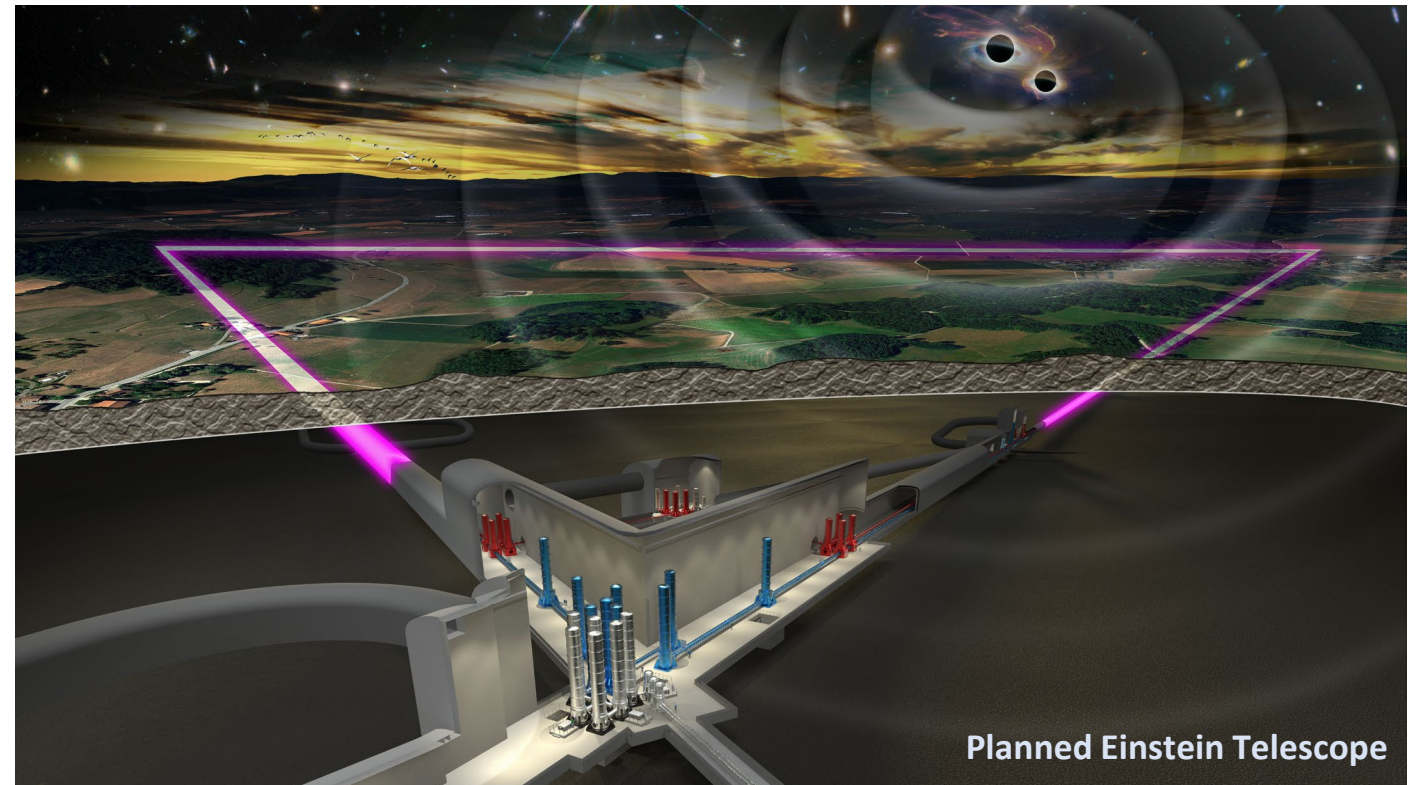


The Einstein Telescope Detector



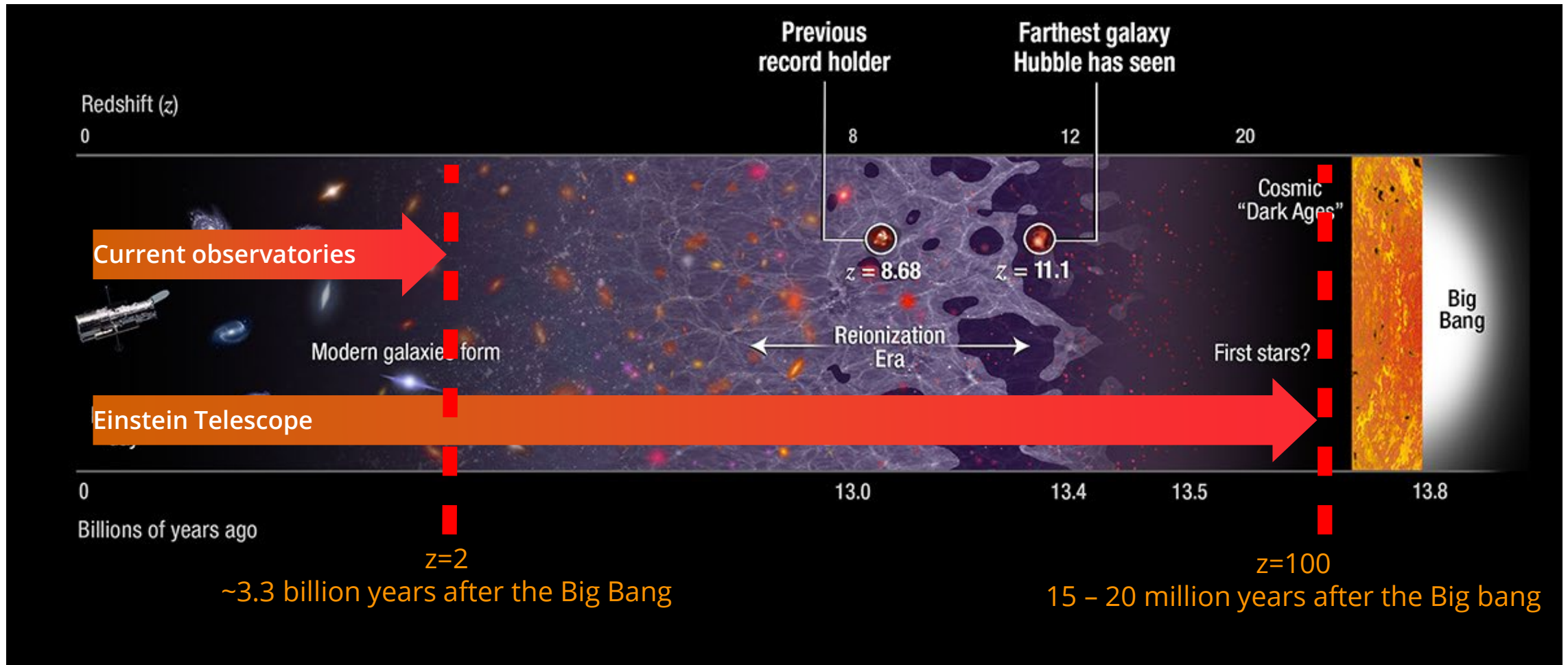


From the science case of ET

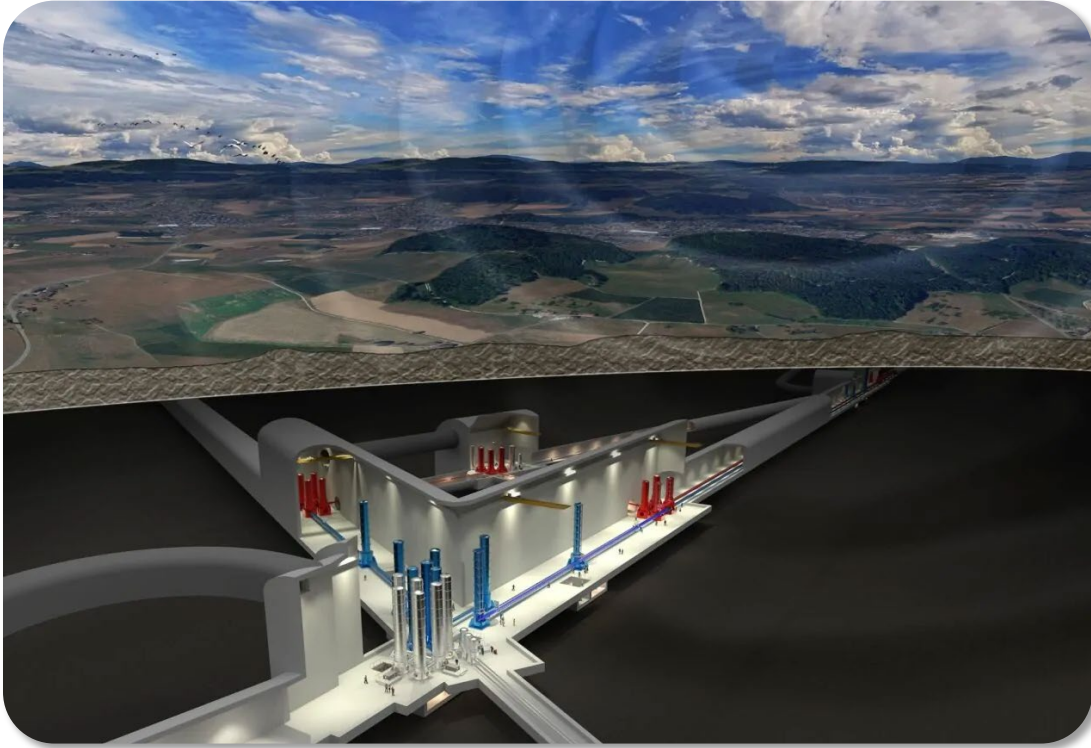


Current detectors observe about one signal per week.
ET will observe about 100.000 to 1.000.000 binary black hole mergers per year! And many other new sources!

From the science case of ET

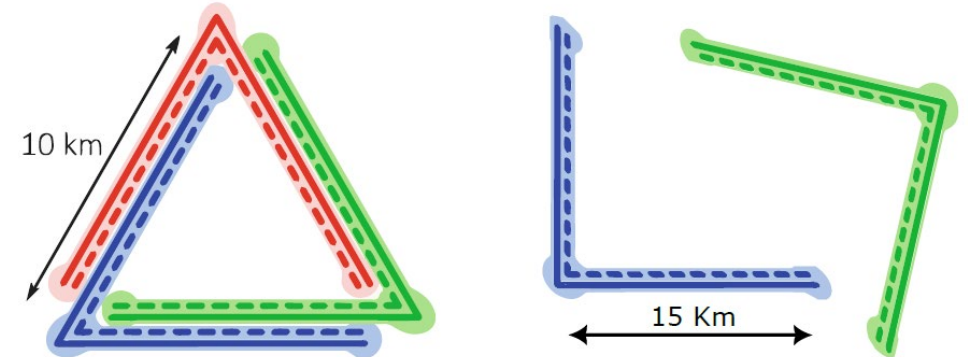


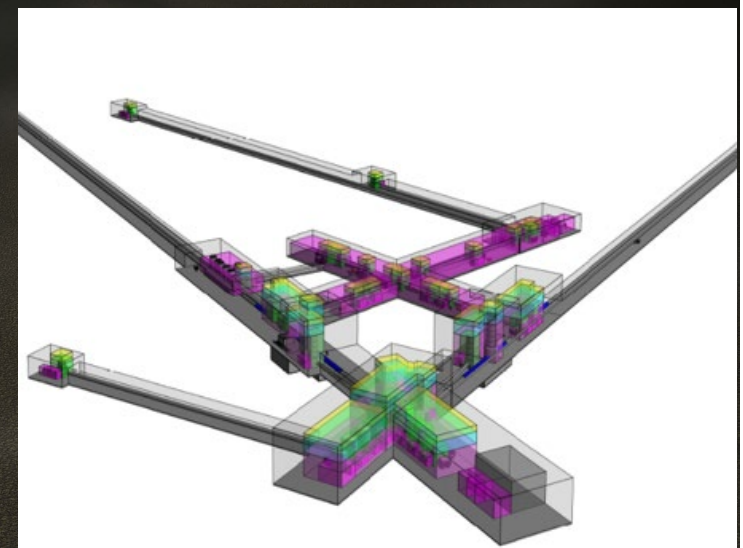
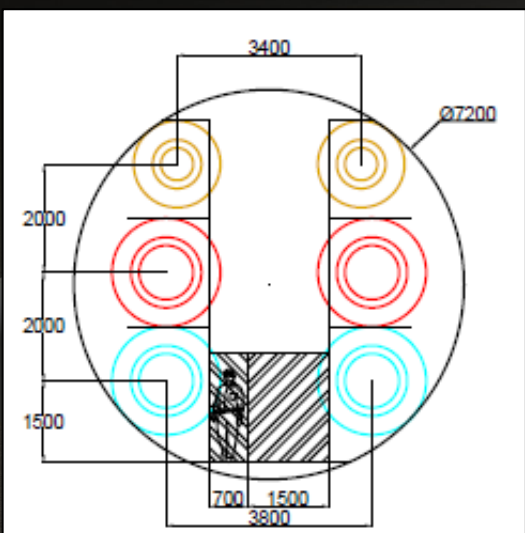
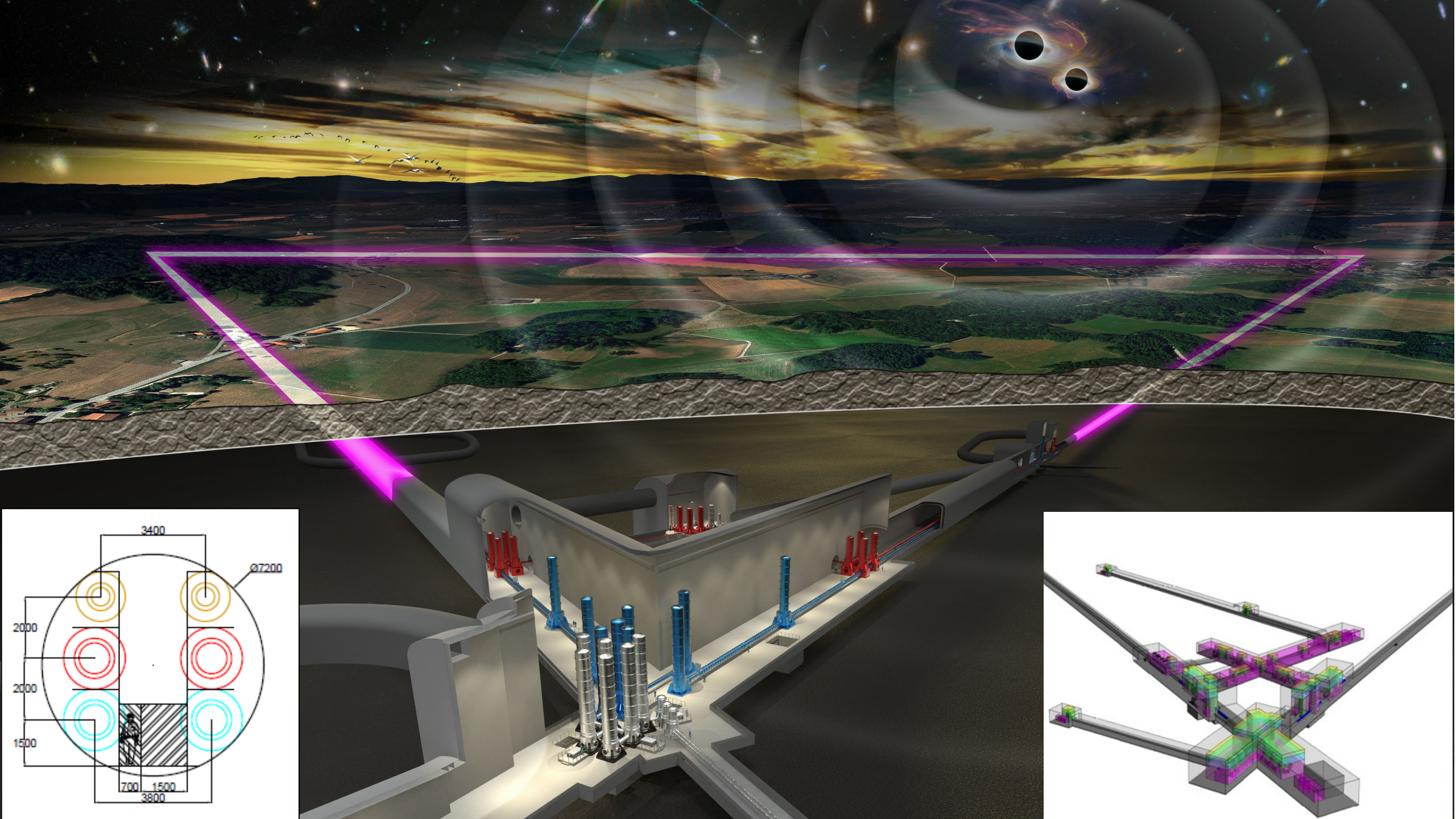
The Einstein Telescope a 3rd Generation GW Detector



- ET-Low Frequency (LF): 3 Hz – ≈ 30 Hz
- ET-High Frequency (HF): ≈ 30 Hz – 10 kHz
- Underground: ≈ 250 m
- Circulating laser power: 18 kW (LF), 3 MW (HF)
- Mirror mass: 211 kg (LF), 200 kg (HF)
- Mirror substrate: Si (LF), fused silica (HF)
- Cryogenics: 10 – 20 K (LF) + cryo pumps
- Ultra-High Vacuum; $< 10^{-10}$ mbar

--- HF detectors, 1064 nm beam
— LF detectors 1550 nm beam

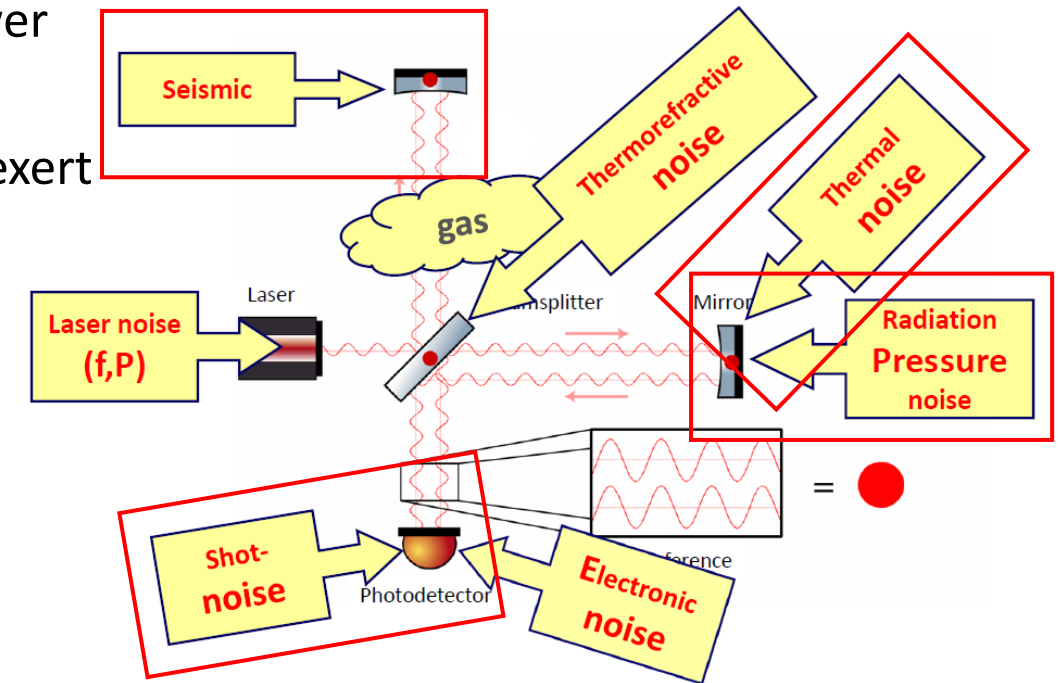




Fighting Noise Sources

Fundamental and technical noise sources limit the sensitivity of ET:

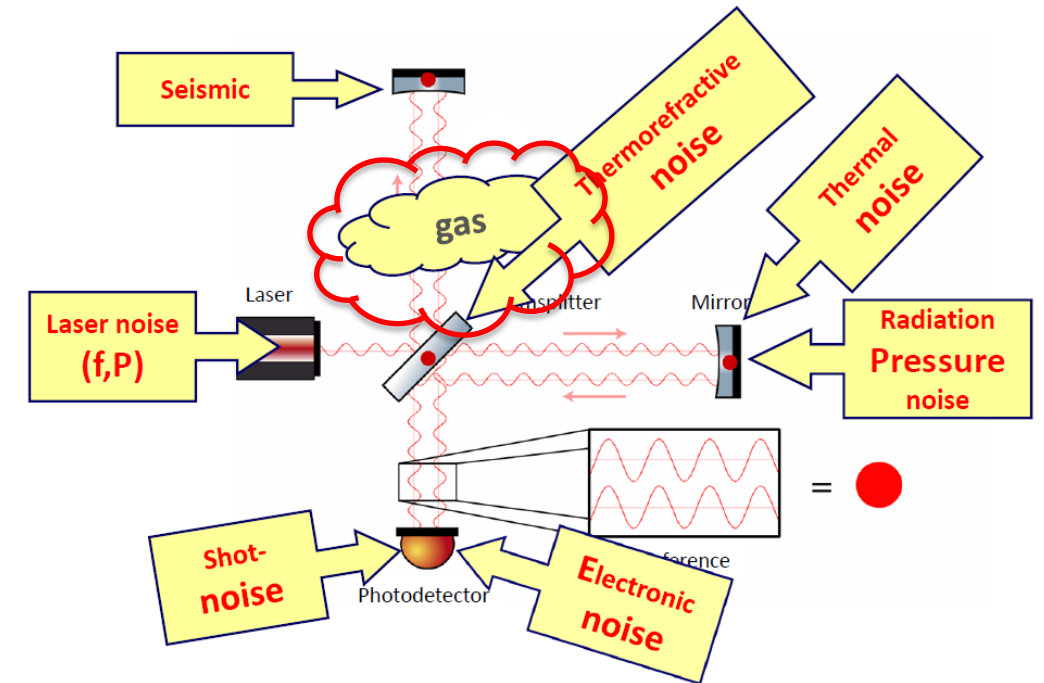
- Shot noise: a light beam consists of a stream of photons and some seconds there arrive more and in other seconds fewer photons at the photodiode
- Radiation pressure noise: photons carry momentum and exert a mechanical pressure on the mirrors
- Seismic noise: earth crust moves relentlessly in a wide frequency range for nHz to hundreds of Hz – tectonic movements, lunar tides, bad weather like wind and sea activity
- Thermal noise: noise which arises from random thermal agitation of the atoms and molecules and the expansion coefficient of the material



Fighting Noise Sources

Fundamental and technical noise sources limit the sensitivity of ET:

- Stray / scattered light noise: laser beam reflects and later recombine with the main beam: residual roughness of the optics, dust, residual gas molecules
- Acoustic noise: pressure fluctuations in air: HVAC
- Newtonian noise: the fluctuating gravitational forces from moving masses in the environment
seismic waves $\rightarrow$ changes rock density $\rightarrow$ gravitational field at the mirror changes
-

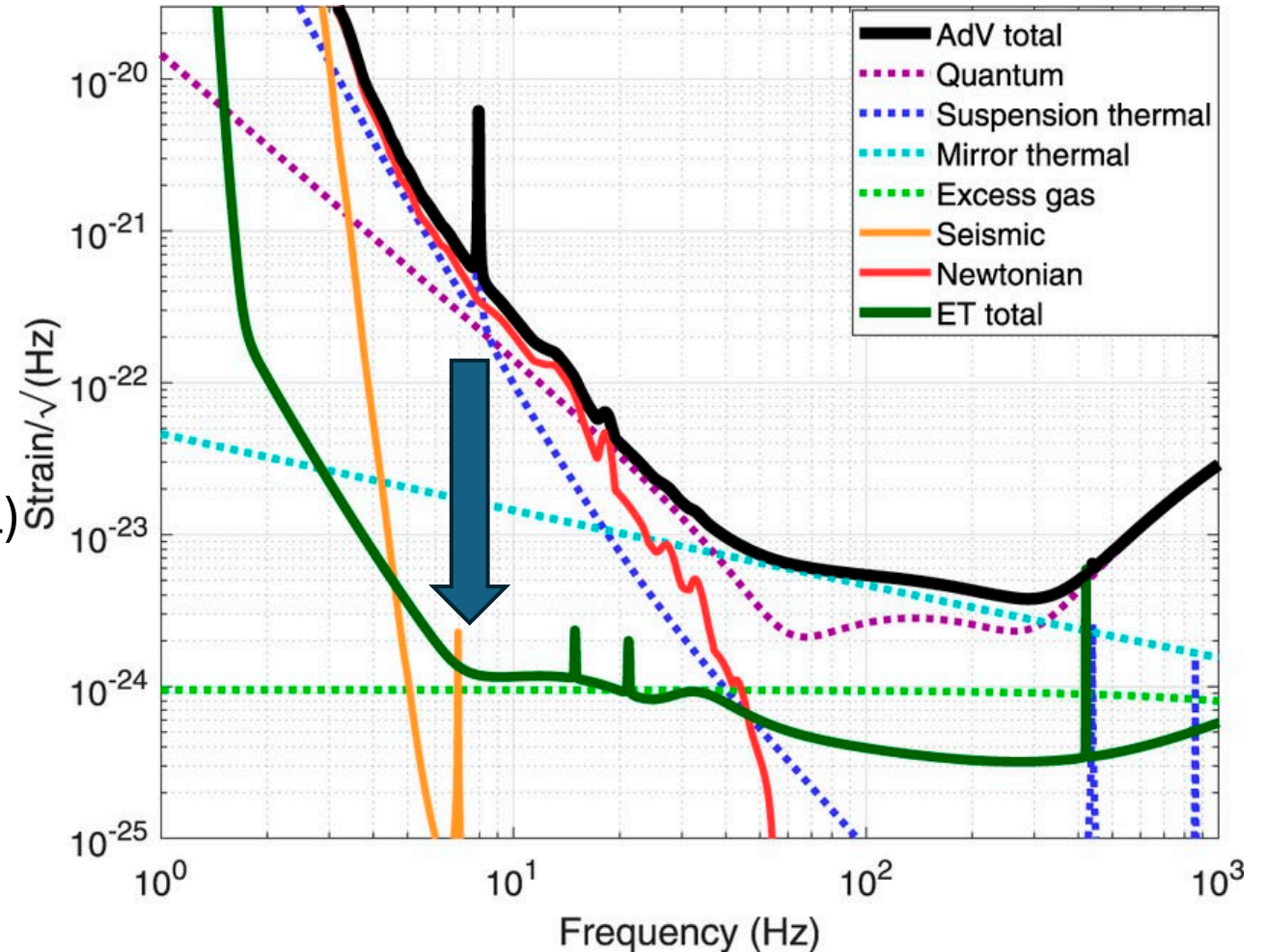


What is limiting ET? – Design Sensitivity Curve

- Increase arm length: $h = \frac{\Delta L_1 - \Delta L_2}{L}$

- High power laser (signal scales with power)

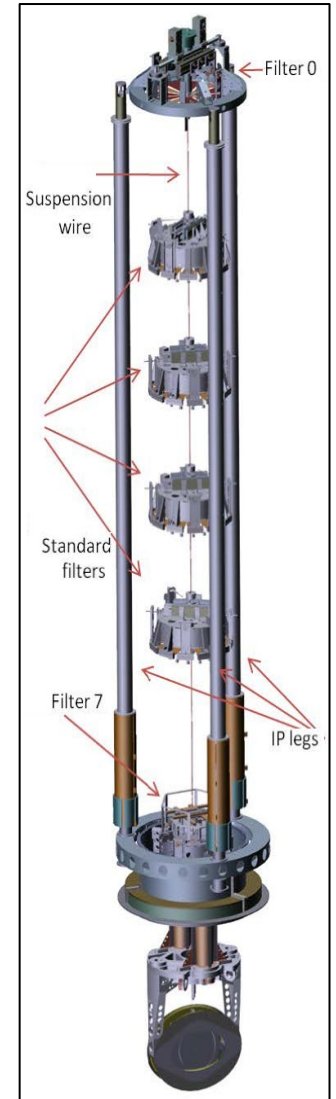
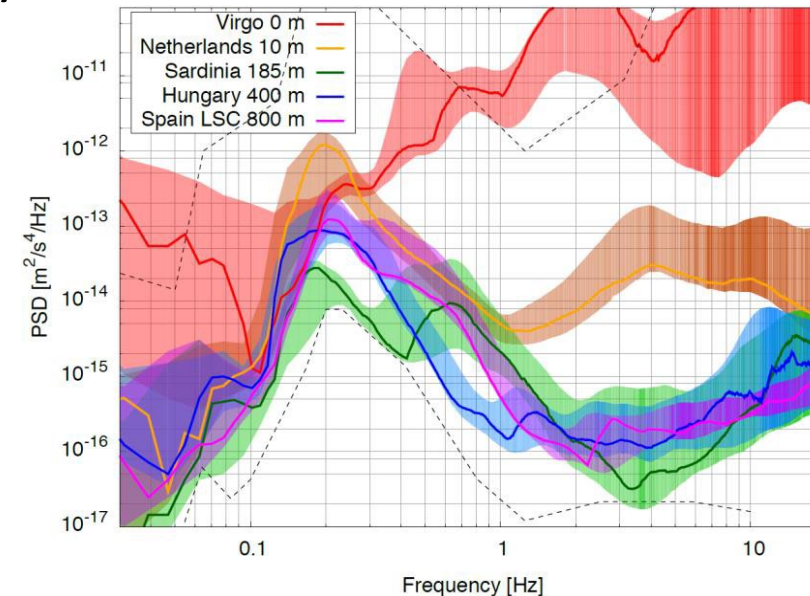
- Going underground (Newtonian)
- Cryogenics for Low Frequency (Thermal)
- Increase the mirror mass (Quantum)
- Stop everything from shaking (Seismic)
- Better vacuum (Excess gas)
-



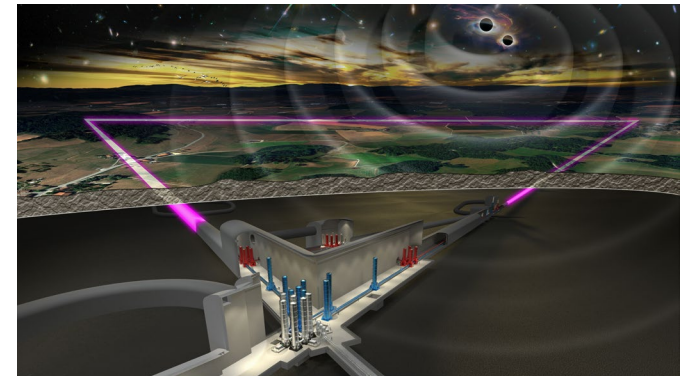
Interferometer noise sources

Underground infrastructure:

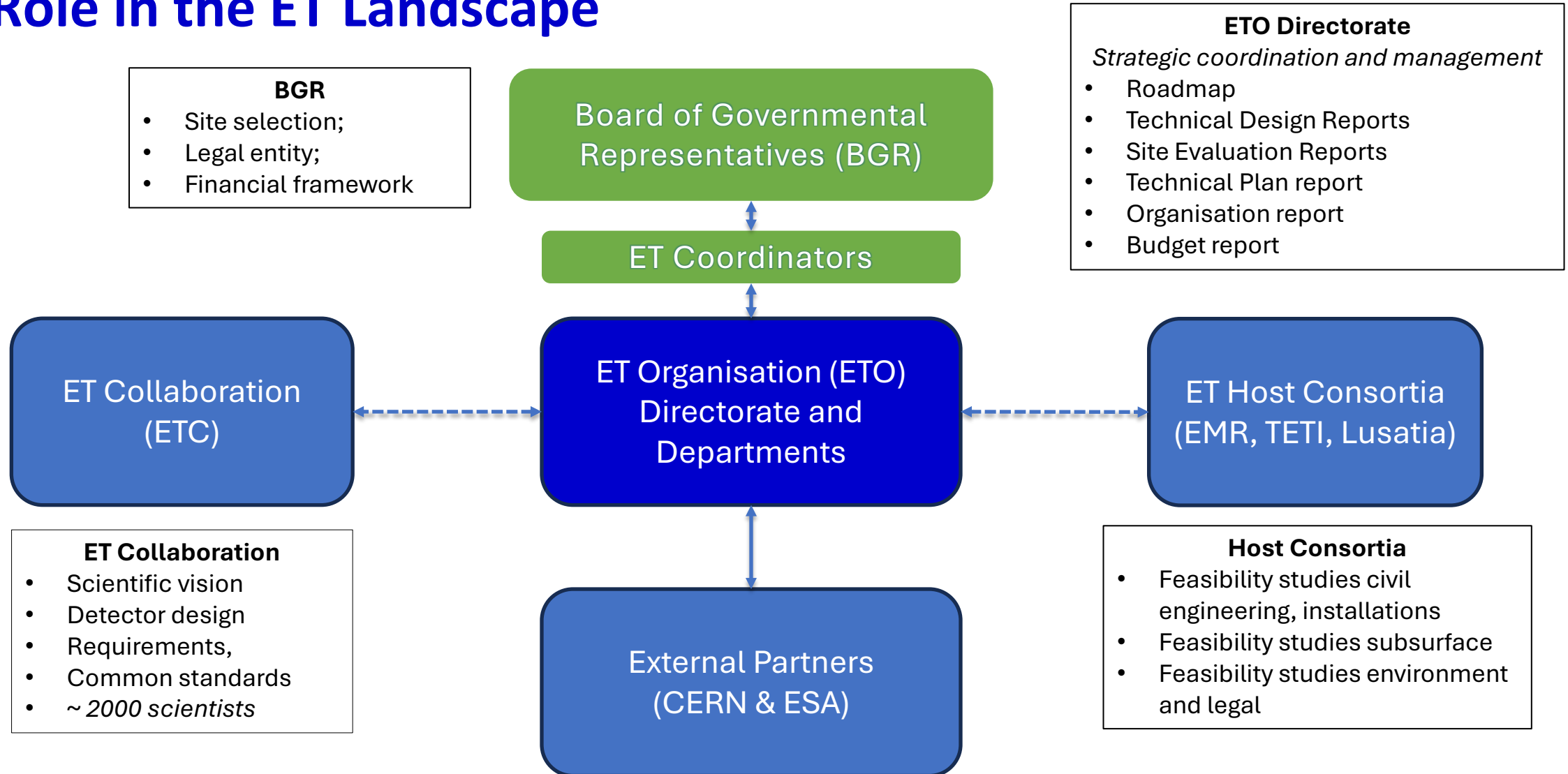
- Active and passive vibration isolation systems are used to suppress seismic noise.
- Newtonian noise (gravity gradients) acts directly on test masses (main mirrors)
- Newtonian noise limits sensitivity at low frequency
- We need a site with low ambient seismic noise: **at ~ 250 m depth we can reach our sensitivity**



Development of the Einstein Telescope



ETO Role in the ET Landscape



Current ET BGR Composition



The ET Scientific Collaboration includes many more countries from across Europe and globally.

- University of Geneva is member of ETC
- Consortium led by PSI (Paul Scherrer Institute) with VAT and Kompaflex to support development for the vacuum beampipe @CERN

Possible ET Sites

Currently there are three official candidate sites to host the Einstein Telescope:

1. The Sardinia site, close to the Sos Enattos mine
2. The Euroregion Meuse-Rhine site close to the NL-B-D border
3. Lusatia site in Saxony, east Germany

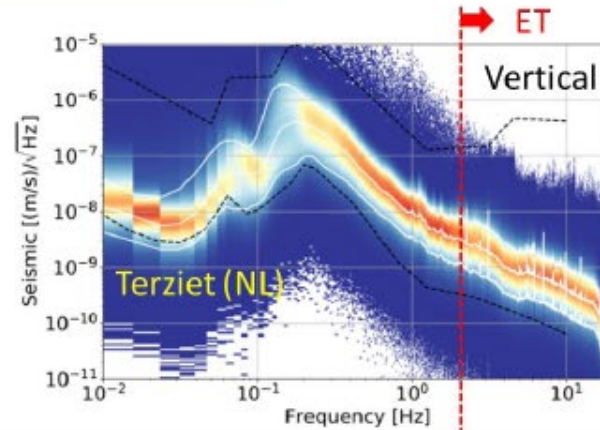
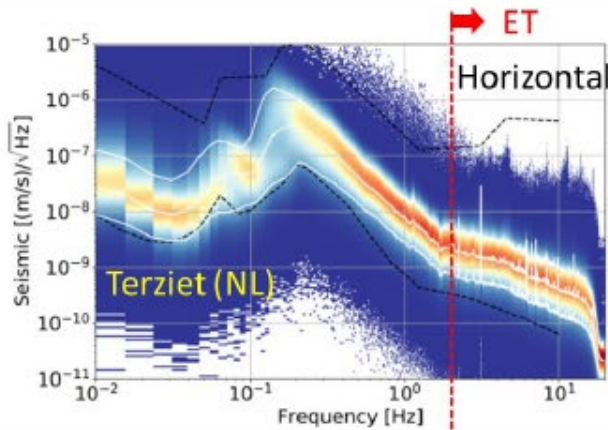
Site characterisation is underway in all three locations.



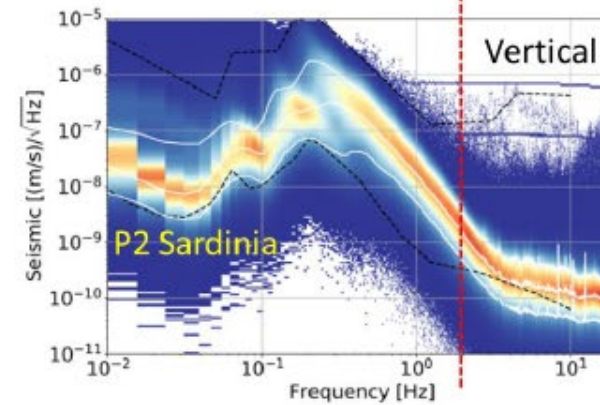
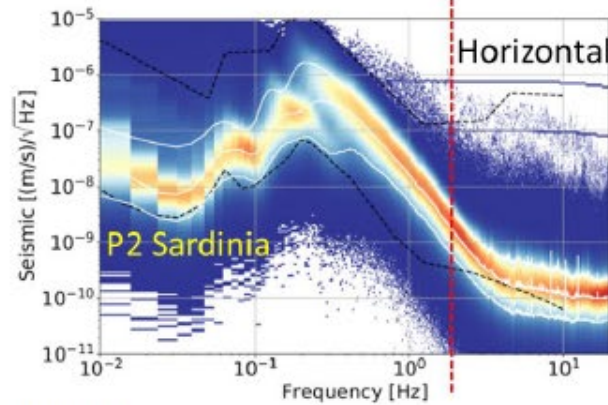
Possible ET Sites

Borehole measurements comparison

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



EMR Terziet (NL) borehole



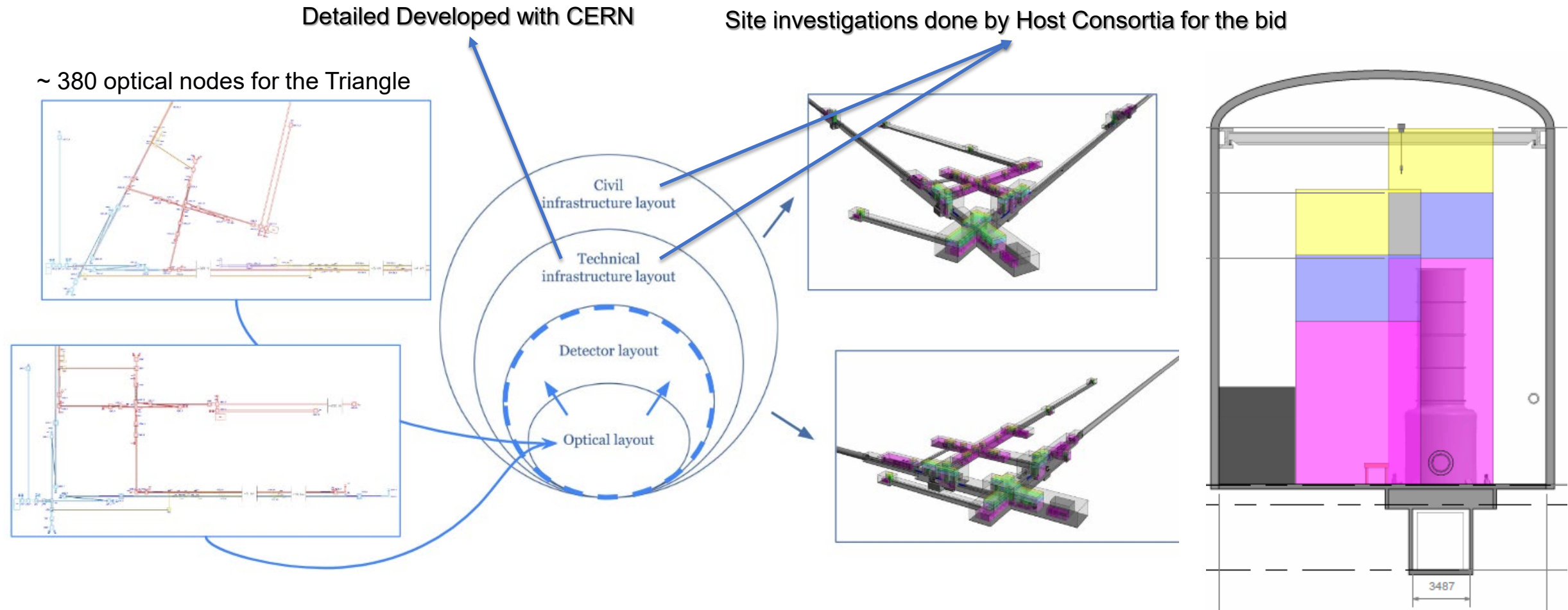
Sardinia P2 borehole



Credit L. Naticchioni

52

From Optical Layout to Detector Layout



Next steps for ET:

- **Design and Preparation Phase 1:**

Preparing preliminary design documents for the detector and the infrastructure. Providing all the necessary documents for a decision of the site(s).

- December 2026: open of call for tenders (Bidbook by the Host Consortia)
- June 2027: closing of call for tenders
- Q3 2027: Site selection

Q3 2027

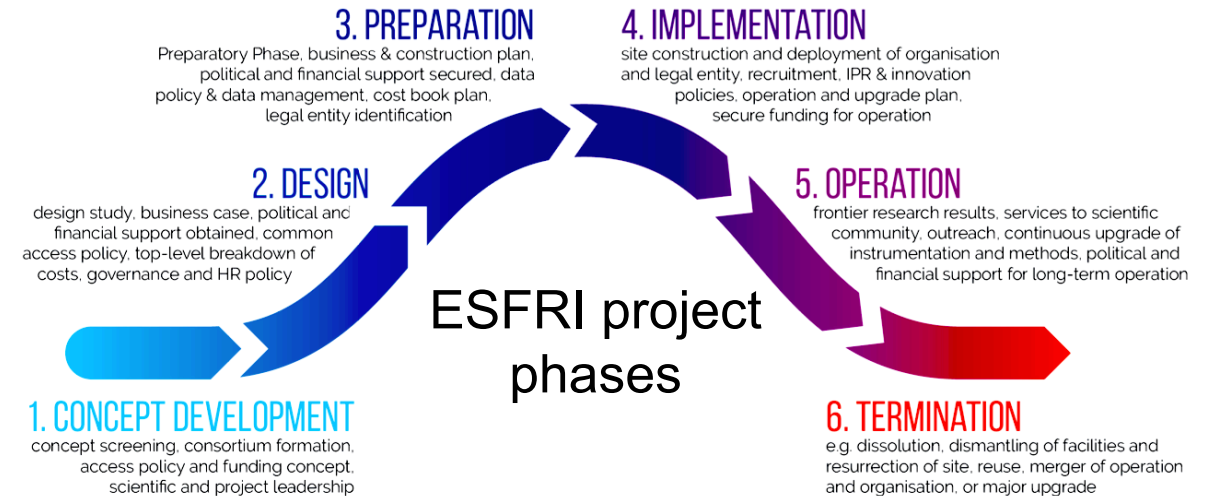
- **Design and Preparation Phase 2:**

Adapt the preliminary designs to the chosen site(s) and complete the site preparation work for project approval. Create legal entity to oversee construction and operation.

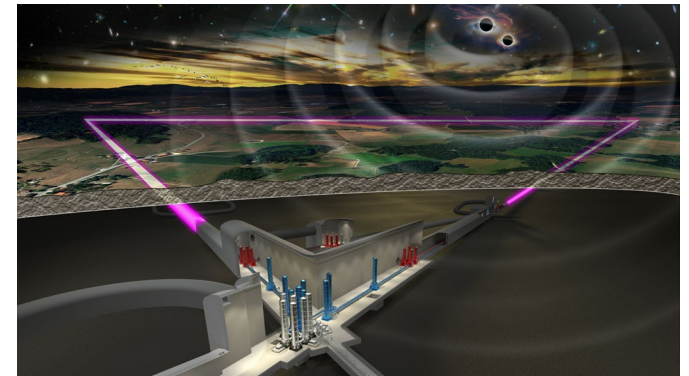
- **Implementation Phase:**

Construction of the infrastructure and installation of the detectors

- **Operation Phase**



Einstein Telescope & CERN



Collaboration Agreement with CERN

ETO has a Collaboration Agreement with CERN for their support in technical topics.

- Several similarities between ET and CERN projects

Signed agreements:

- Civil Engineering → Tamara's talk
- On Vacuum System for the Arm Vacuum Pipe
- Engineering Department and Safety Unit

CERN expands its collaboration on the Einstein Telescope

CERN and the Einstein Telescope collaboration have signed a new collaboration agreement in the field of engineering and safety to advance Europe's next-generation gravitational-wave observatory

20 MAY, 2025 | By Chetna Krishna & Anaïs Schaeffer



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 week of measurement by studying and minimising all possible noise sources, including seismic vibration and residual gas scattering. The latter is reduced



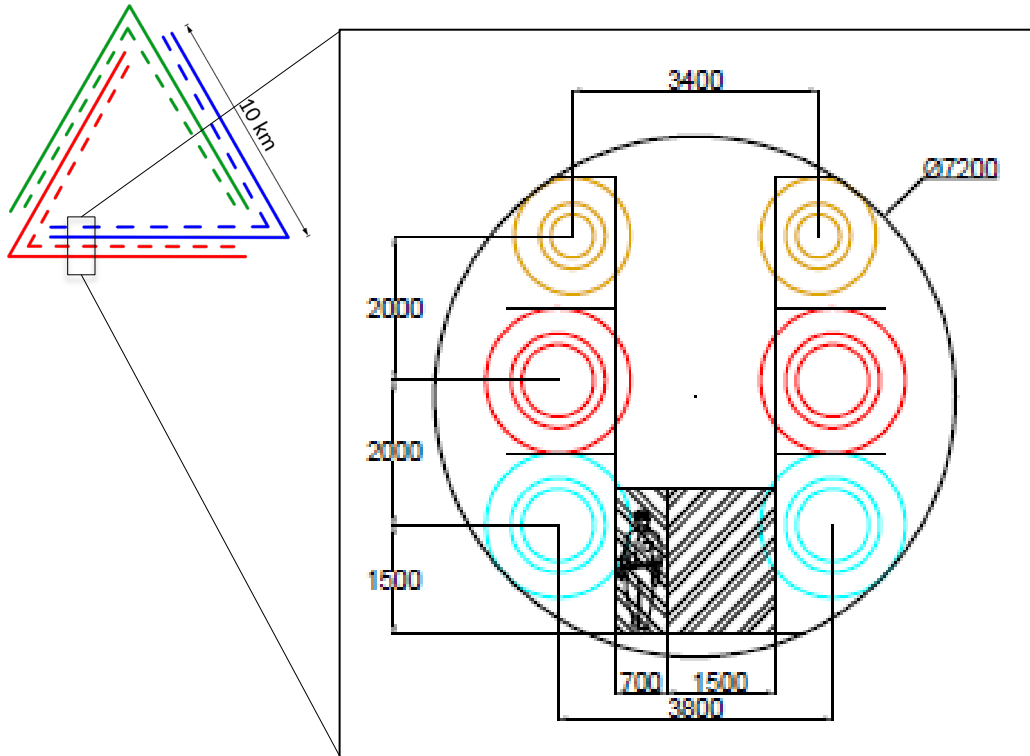
Beam me up
The participants of the March workshop that was dedicated to vacuum technologies for beampipes of next-generation gravitational-wave telescopes.

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 requires the development of different technical approaches with respect to previous-generation facilities. Developing cheaper technologies is also a key subject

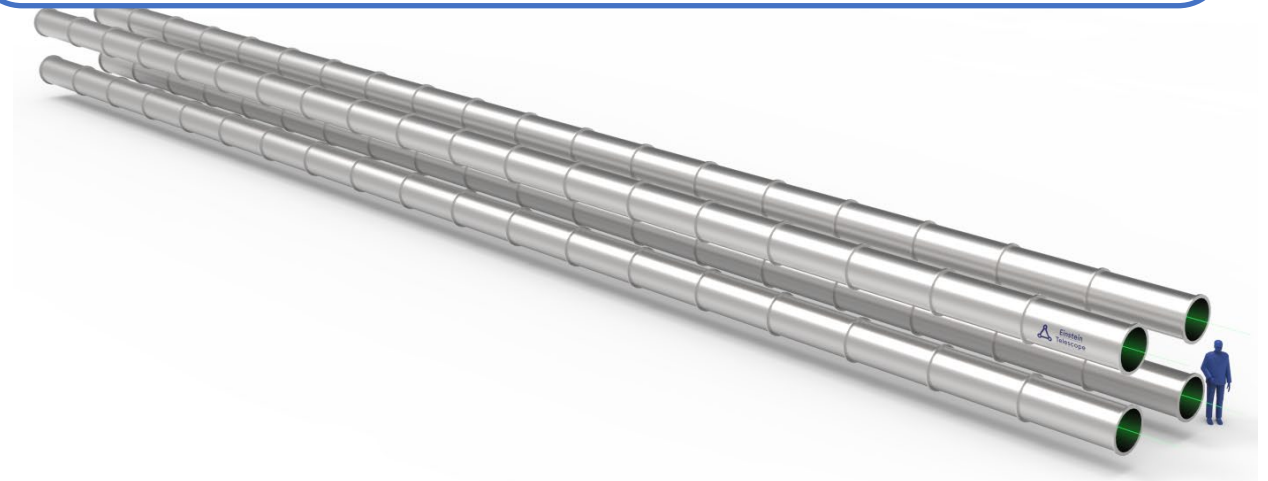
vacuum systems provided a starting point for the presentations of ongoing developments. To conduct an effective cost analysis and reduction, the entire process must be taken into account – including raw-material production and treatment, manufacturing, surface treatment, logistics, installation and commissioning in the tunnel. Additionally, the interfaces with the experimental areas and other services

Einstein Telescope Beampipe Vacuum System

The 10 km long optical cavities require ultrahigh vacuum to reduce the noise due to gas pressure fluctuations along the laser trajectory.



- Beampipe diameter: 1 meter
- Total Beam Pipe length: 120 km
- Pressure requirements $< 10^{-10}$ mbar



Developments of the Technical Infrastructure and Safety

Signed an agreement with CERN Engineering Department (EN) and Occupational Health and Safety Department (HSE - OHS):

- Cooling & Ventilation (CV)
- Electrical Engineering (EL)
- Access & Alarms (AA)
- Accelerator Coordination and Engineering (ACE)
- Information Management (IM)
- Safety (OHS)



Spacetime big winner at the Cannes World Film Festival

- De 3D-film 'Spacetime, the era of gravitational waves' has won the 'Best Scientific Film' award at the Cannes World Film Festival.
- https://www.youtube.com/watch?v=rV_3Ger1CGU



EINSTEIN
TELESCOPE
ORGANISATION

Thank you

einsteintelelescope.eu