The Science of the Einstein Telescope

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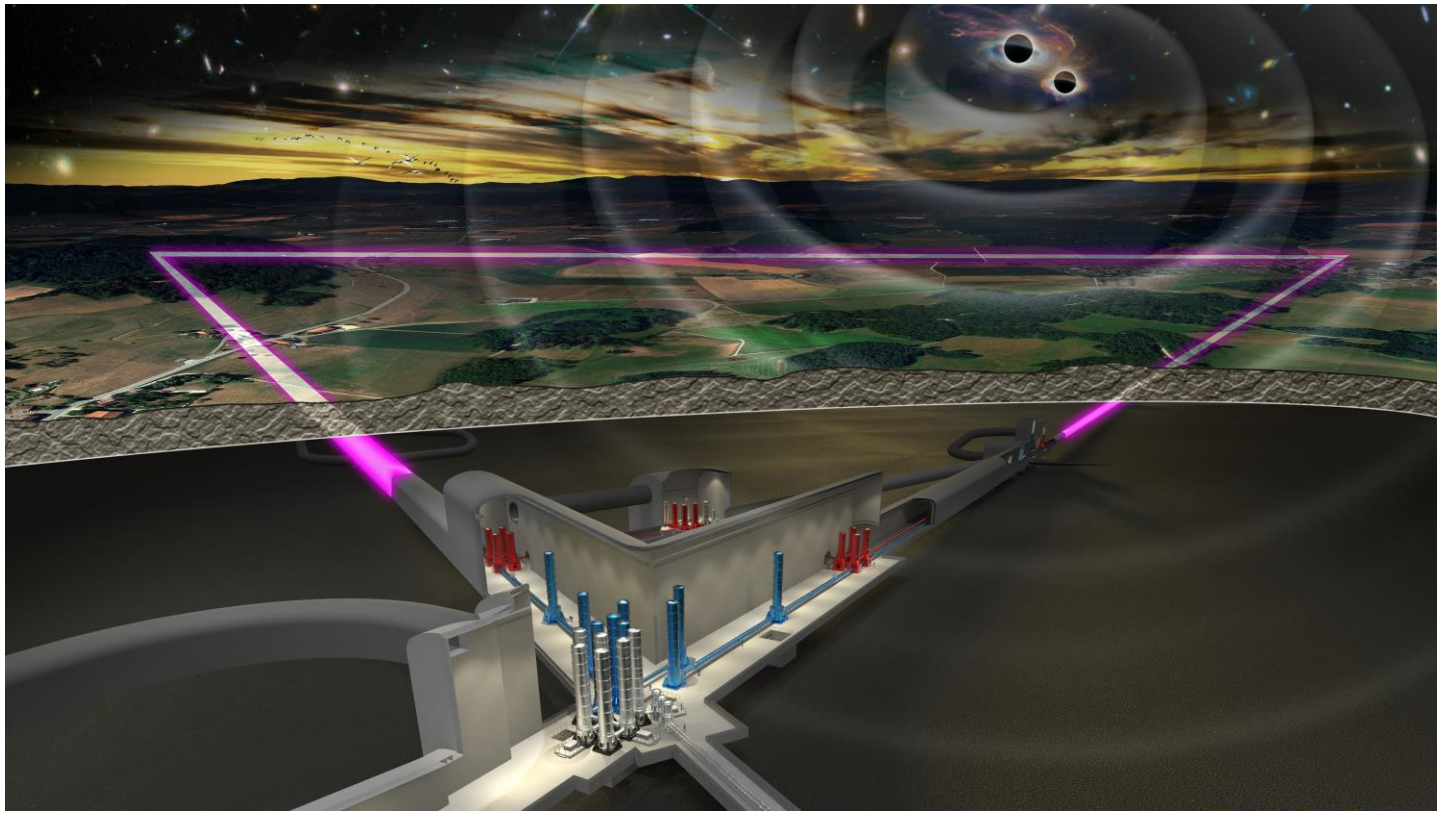
The Einstein Telescope is a future observatory of gravitational waves

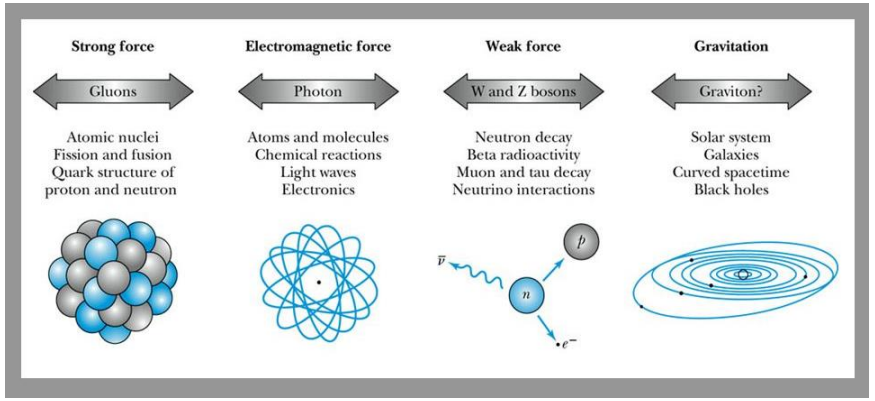
→Gravity

→Universe

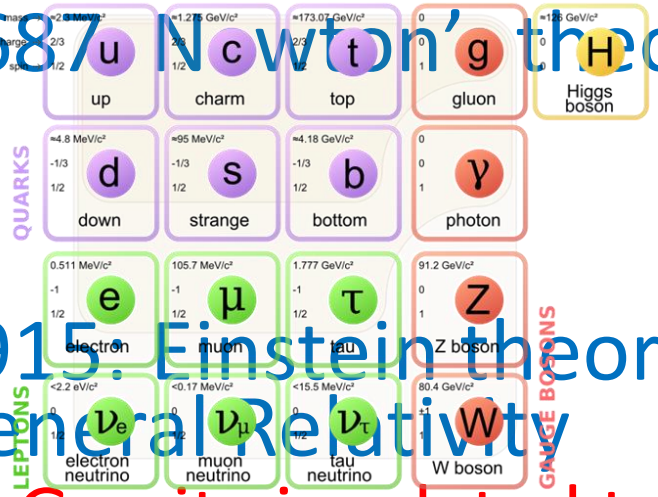


Gravity

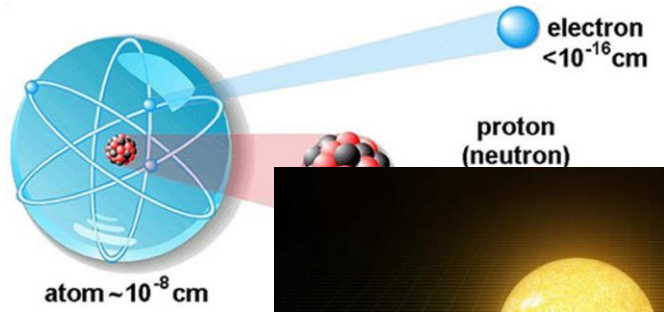
- One of the four fundamental interactions
  - The only one not yet described by a **quantum** relativistic theory

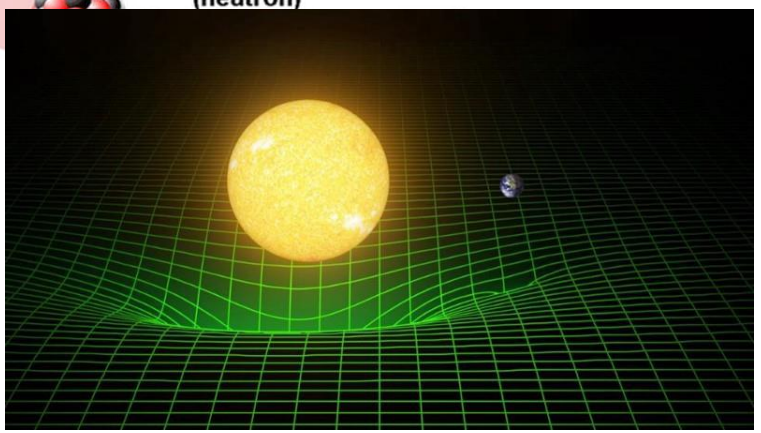


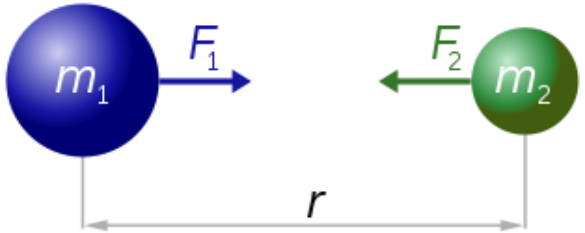
- 1687: Newton's theory



- 1915: Einstein theory of General Relativity
  - Gravity is related to space, time and matter





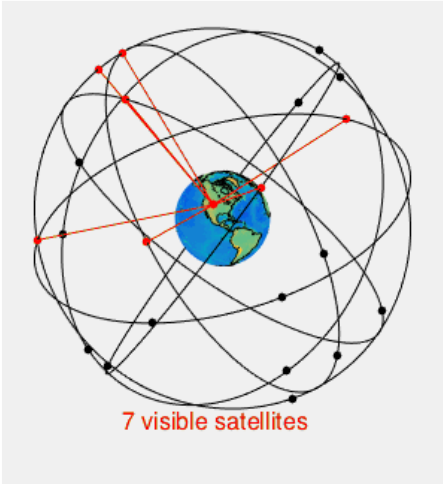


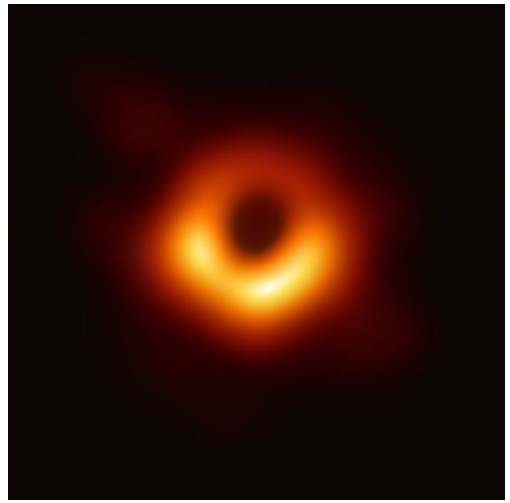
$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

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

Some predictions of General Relativity

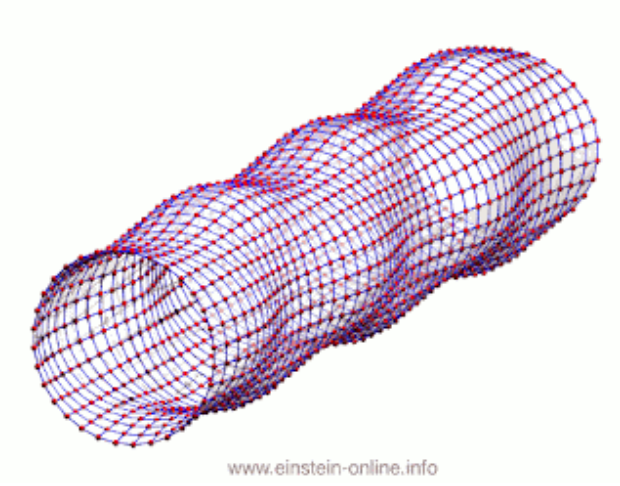
- Space and time are « curved » by matter
  - e.g. atomic clocks on GPS satellites run as fast as ~40 µs per day w.r.t. those on earth





- Black holes

- Gravitational waves
  - Space-time deformations travelling at the speed of light
  - Observed for the first time in 2015



The universe

- Universe observations so far via:
  - photons (e.m. waves, x-rays, γ-rays)
  - cosmic rays (p, e, nuclei)
  - neutrinos

- GW revolution: unperturbed, rich, far-reaching information
  - Astrophysics
  - fundamental interactions (gravity, strong interaction)
  - Cosmology (dark matter, accelerating universe expansion, universe evolution)

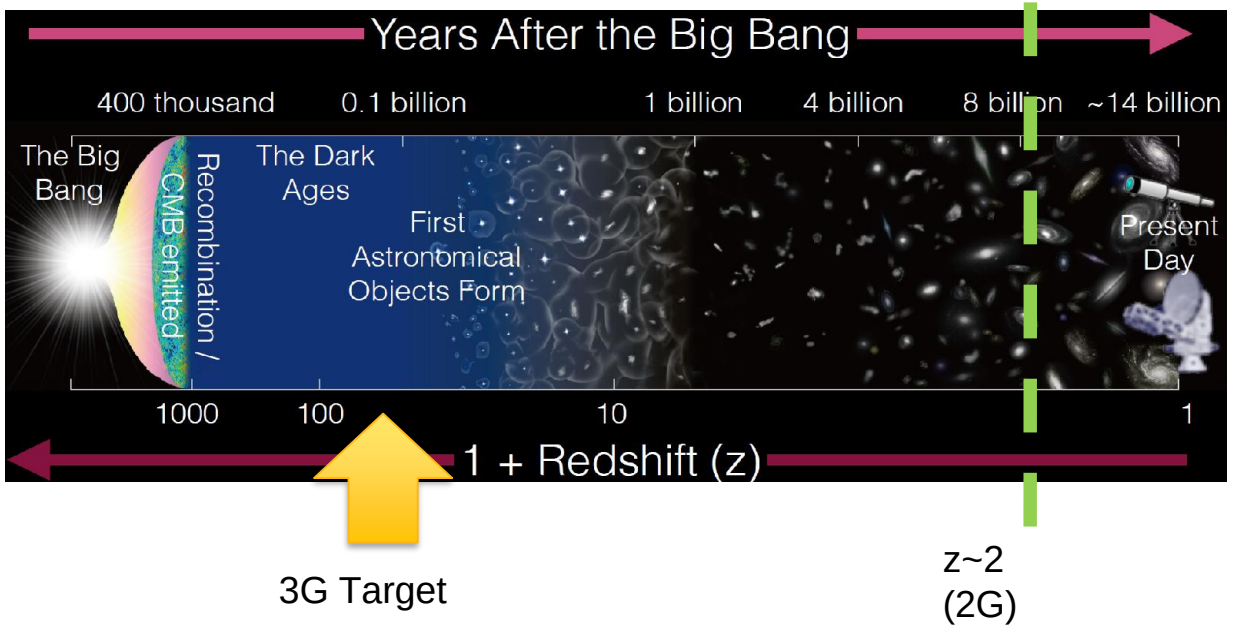
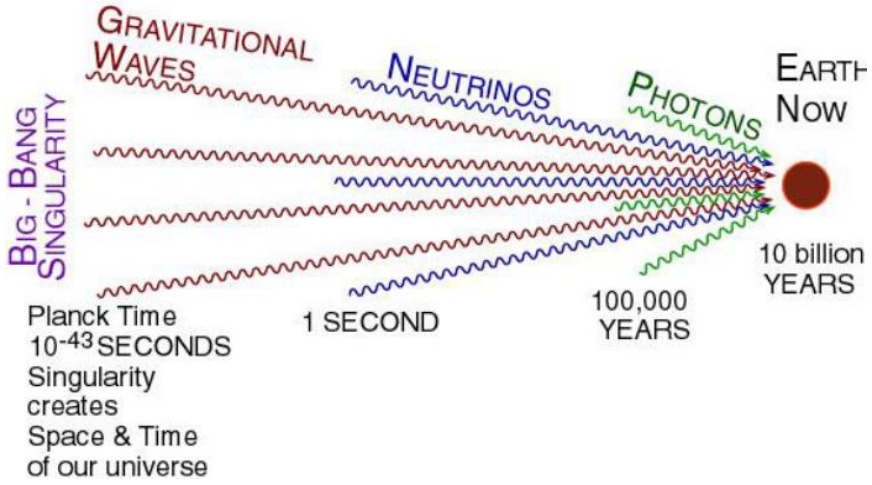
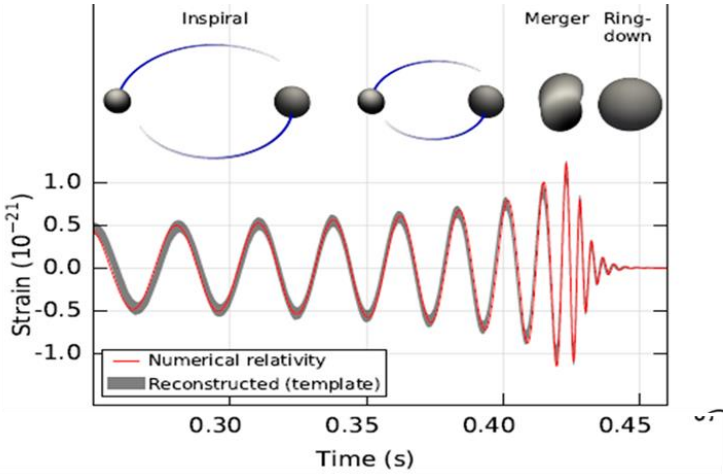


Image credit: NAOJ/ALMA
http://alma.mtk.nao.ac.jp/

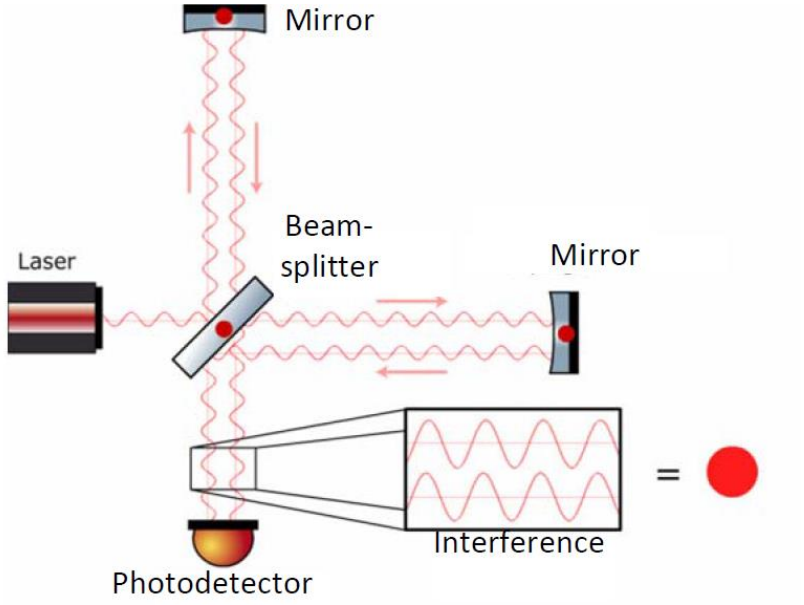


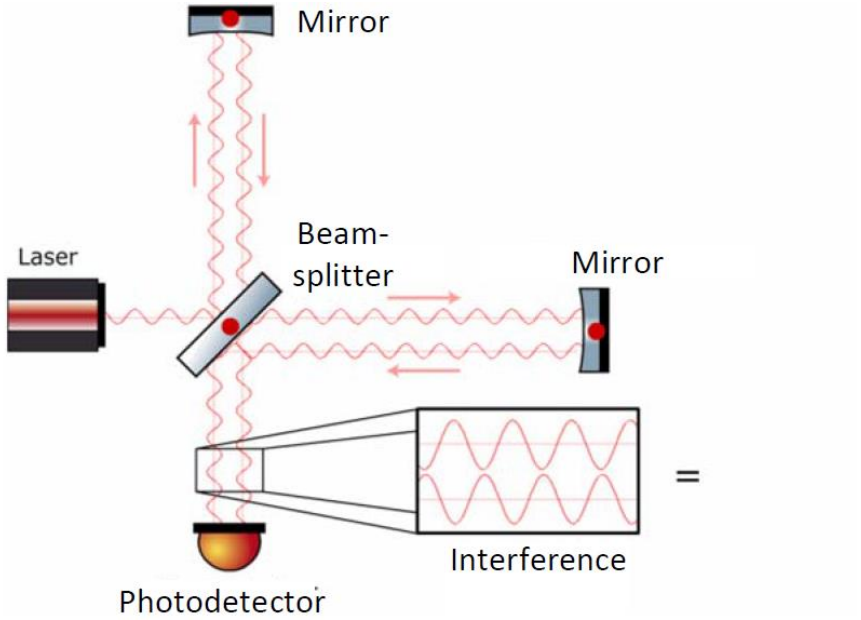
Direct observation of gravitational waves

- First direct detection by LIGO/Virgo collaborations in 2015
  - Nobel prize 2017 for R. Weiss, K. Thorne and B. Barish
  - 2016 G. Lemaitre prize from UCLouvain to K. Thorne

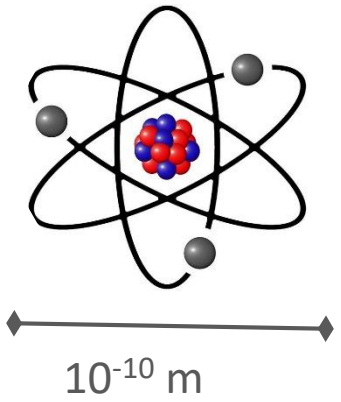


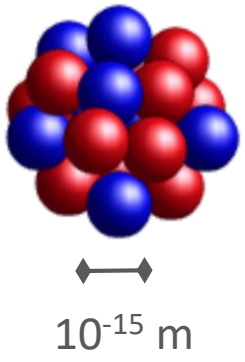
GW detection principle



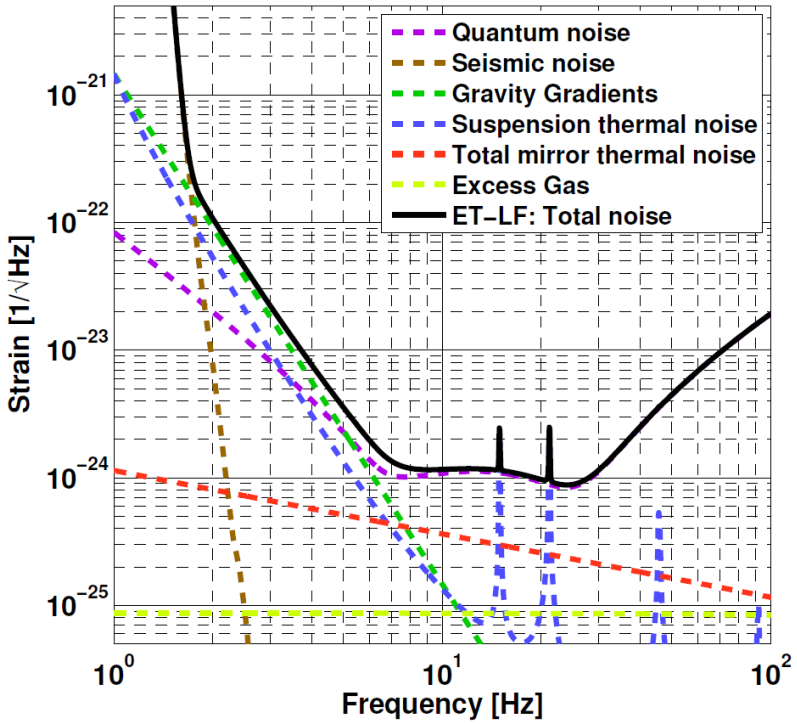


- Laser interferometers measure changes in arm length difference
- Effect of merger of two BHs (30 solar masses each) at 10^9 light years ~ 10^{-18} m
- Laser wavelength ~ 10^{-6} m





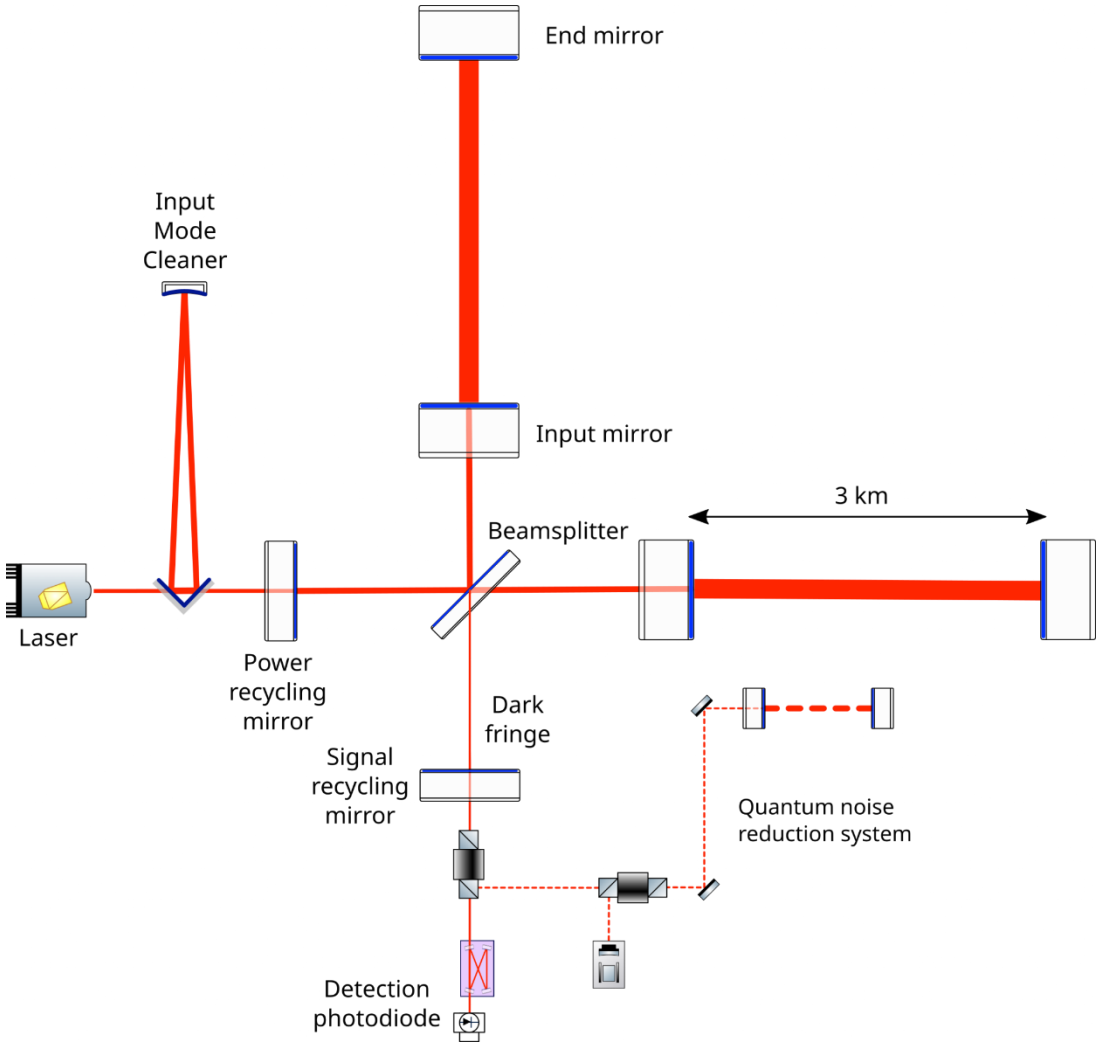
Detector sensitivity



- Seismic noise
- Gravity gradient noise
- Thermal noise
- Quantum noise
- Excess gas

.. and myriad of technical noise sources

A GW observatory in operation (Virgo)

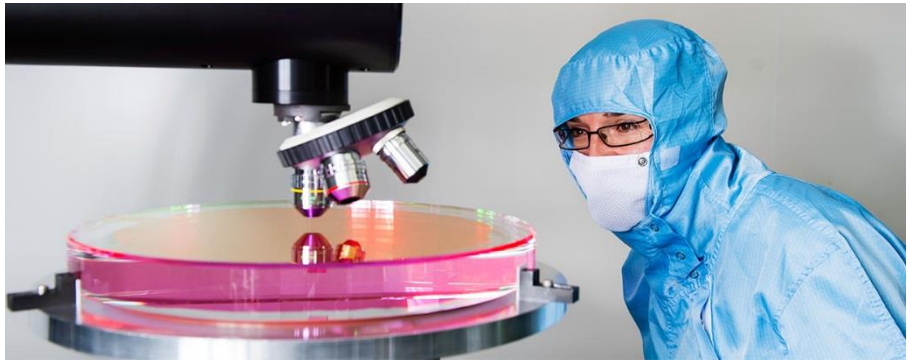


GW Technology

Pushing frontiers in mechatronics, lasers and optics, material sciences, vacuum and cryogeny, controls, …

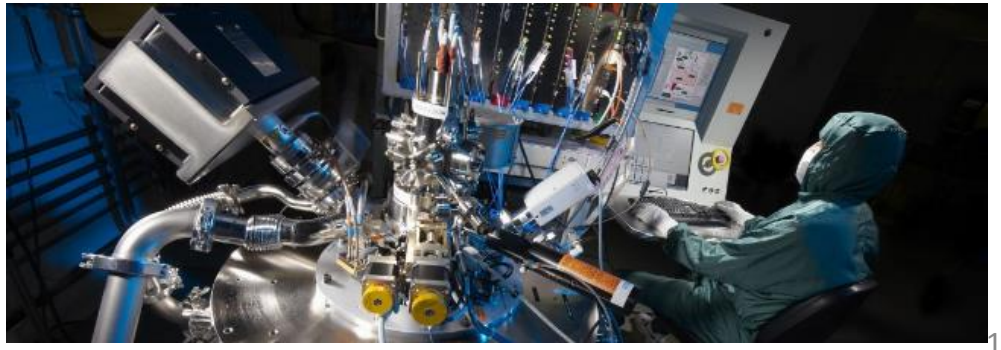
Measuring and attenuating vibrations

Optics, coatings, special materials, laser technology, semiconductor technology



Vacuum technology

Cryogenic systems

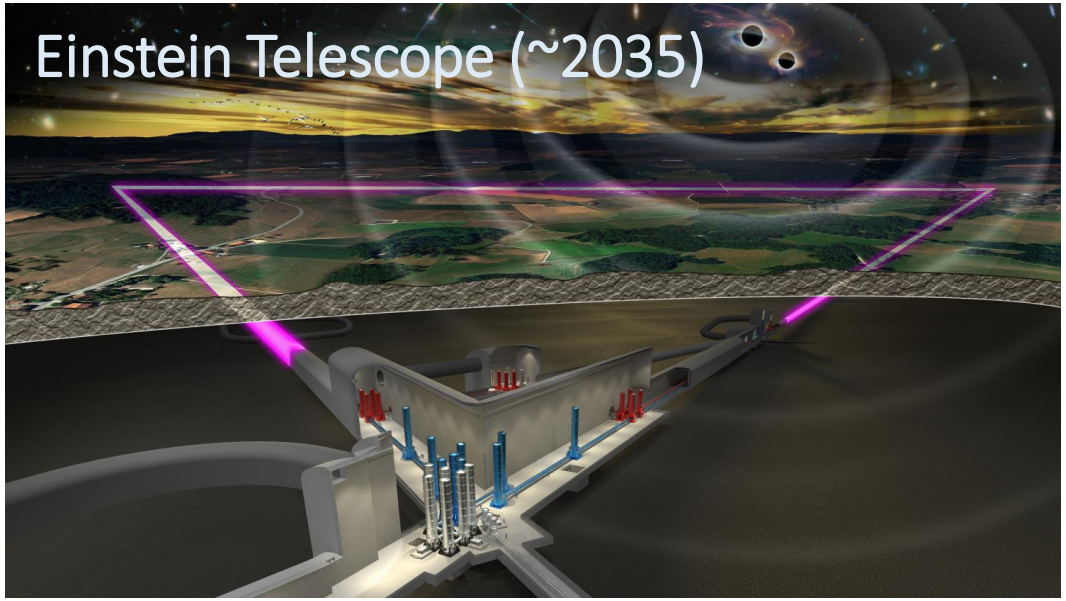


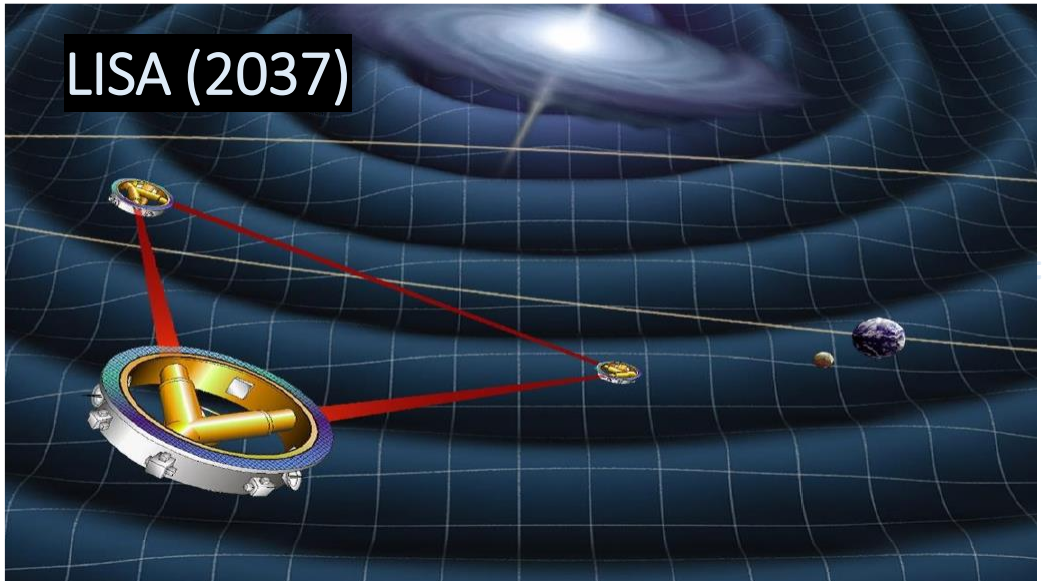
Virgo collaboration

- ~800 members, ~450 authors, 136 institutions from 15 countries
- 36 Groups:
  - 32 full members
  - 4 in the first year
- 9 countries

- Belgium: 7 universities, 50 members
- Contributions: instrumentation, computing and data analysis

From current detectors to the next generation





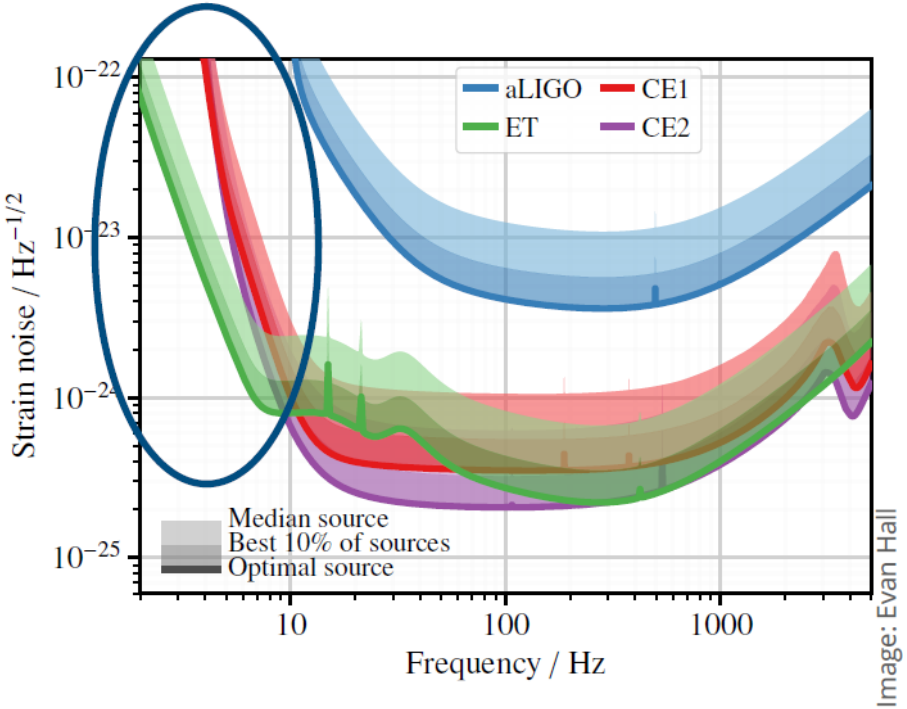
Einstein Telescope design

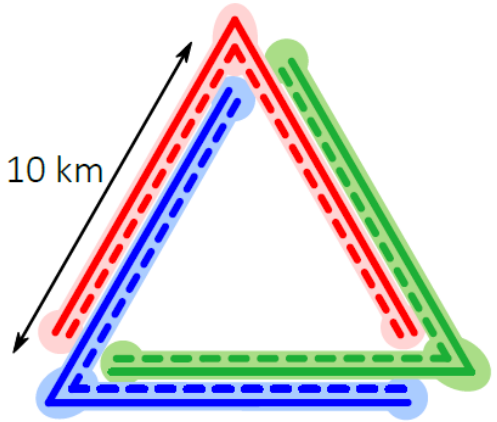
- Longer arms (10 km)
  - Effect of GW is equivalent to a relative change in the arm lengths (ΔL/L)

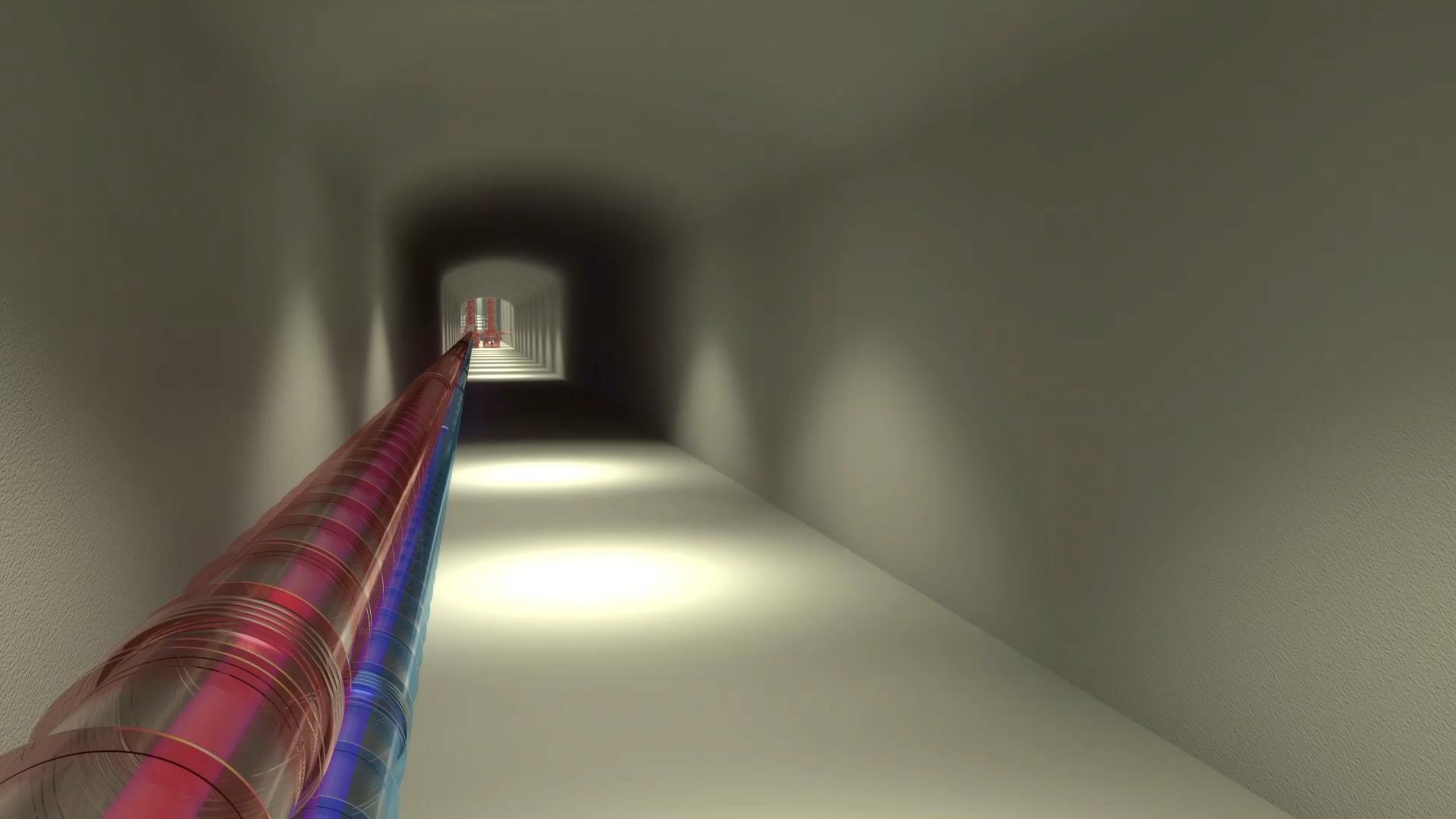
  →All mirror displacement noise sources reduced by making L larger

  but this increases laser beam size (need for large mirrors)
- Underground operation (~250 m)
  - Reduction of seismic and gravity gradient noise

  →key for sensitivity at low frequency
- Triangular shape
  - Wave polarizations
  - Null streams
  - Redundancy
  - Sky coverage
  - Single compact infrastructure
- "Xylophone design"







ET site

- Science
  - Seismic, Newtonian, anthropogenic noise
- Cost and feasibility
  - Geology, topography, climate, access, services, local regulations
- Socio-political factors
  - Availability of funds

Preparing the ground for ET

Research and development facilities for ET technology in the Euregio Meuse-Rhine

ETpathfinder

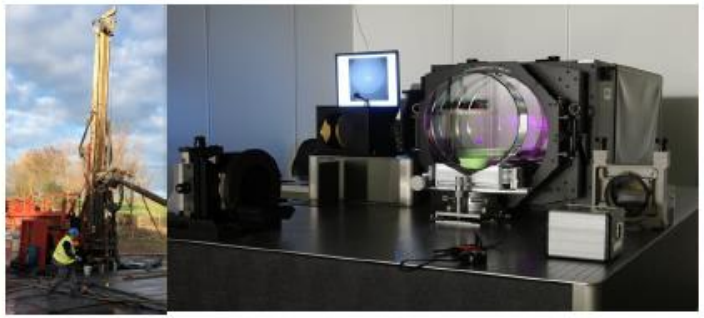
Objective: Development of a model infrastructure for testing new gravitational wave detector technologies and concepts in a complete interferometer in an ET-like environment

Location: UMaastricht-NL

Budget: € 14,8 million

Duration : 2019 – 2022

E-TEST



Objective: Development of ET-technology

- Geological exploration of the EMR and determination of the optimal ET location.
- Developement of advanced prototypes for cryogenics, optics and seismic isolation.

Location: CSL ULiège - BE

Budget: € 15,0 million

Duration : 2020 – 2023

ET2SMEs

Objective: Promotion of cooperation between SMEs, large companies and R&D institutions that deal with ET-relevant key technologies in a broad understanding and towards multiple application fields by initiating SME-driven cross-border R&D projects.

Budget: € 2,23 million

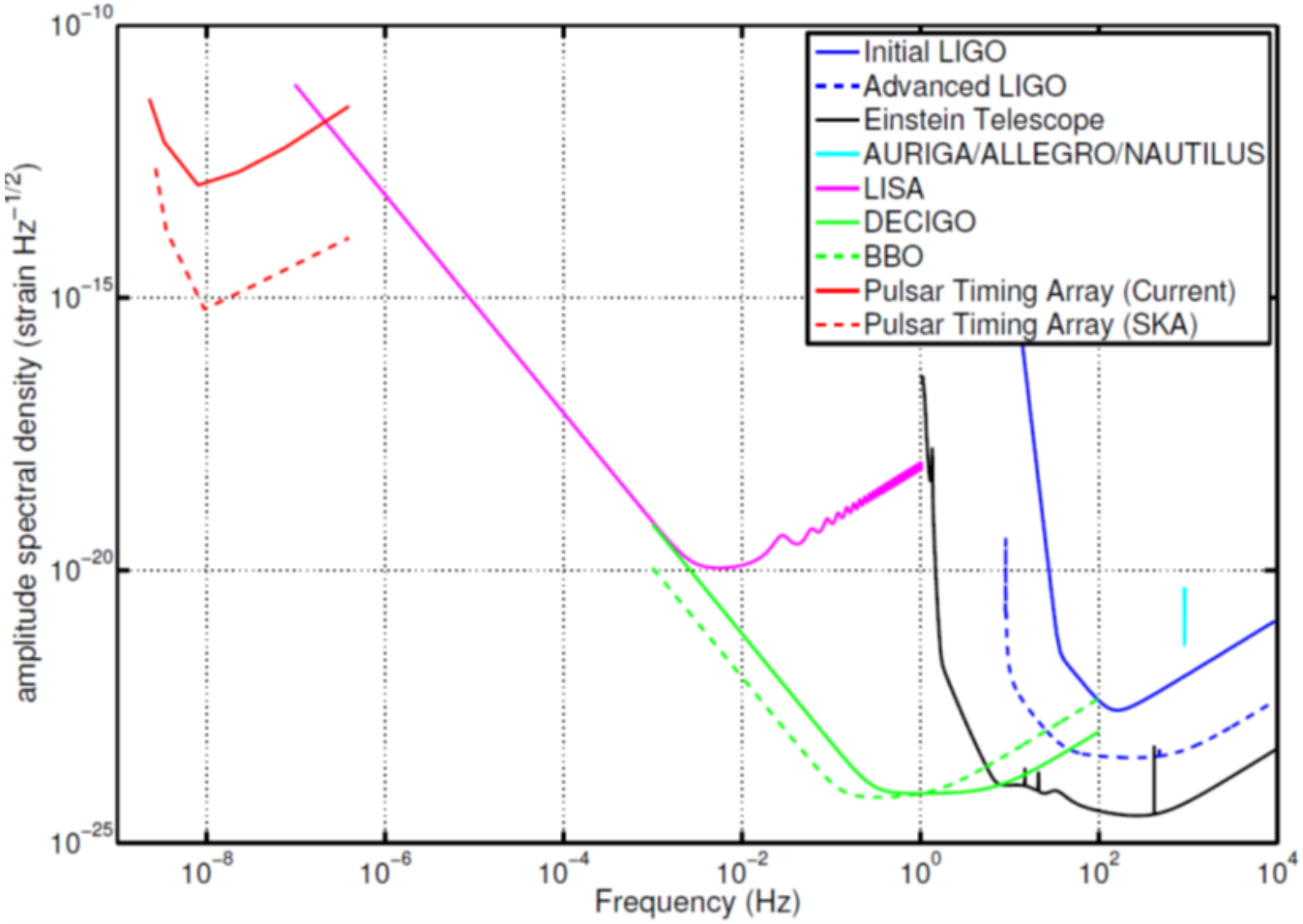
Duration : 2021 – 2023

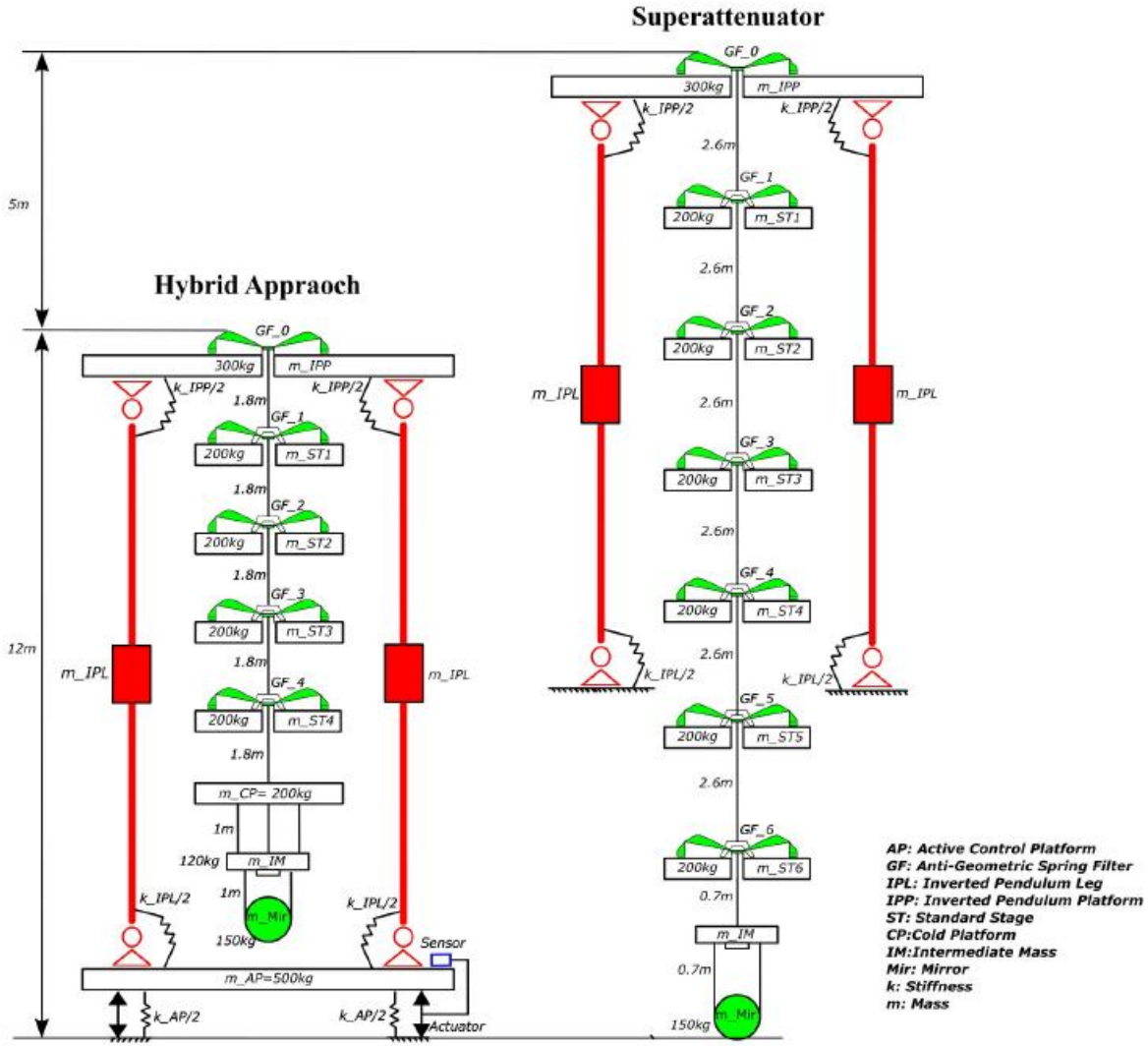
BACK-UP

System	GW amplitude
Tennis ball rotating around a post attached to a 1 m string and at 10 m distance	$h \sim 1.\ 10^{-54}$
Hulse and Taylor pulsar	$h \sim 1.\ 10^{-26}$
Io around Jupiter	$h \sim 2.\ 10^{-25}$
Binary neutron star merger at the Milky Way center	$h \sim 2.\ 10^{-19}$
BH (30 Msun) binary merger at 10^9 parsecs	$h \sim 1.\ 10^{-21}$

GW detectors

Living Rev. Relativity, 14, (2011), 5




Superattenuator
Hybrid Appraoch
5m
12m
GF_0
300kg
m_IPP
k_IPP/2
2.6m
GF_1
200kg
m_ST1
GF_2
m_ST2
GF_3
m_ST3
GF_4
m_ST4
GF_5
m_ST5
GF_6
m_ST6
1.8m
m_IPL
m_CP= 200kg
1m
120kg
m_IM
0.7m
150kg
m_Mir
k_IPL/2
Sensor
m_AP=500kg
k_AP/2
Actuator
AP: Active Control Platform
GF: Anti-Geometric Spring Filter
IPL: Inverted Pendulum Leg
IPP: Inverted Pendulum Platform
ST: Standard Stage
CP:Cold Platform
IM:Intermediate Mass
Mir: Mirror
k: Stiffness
m: Mass