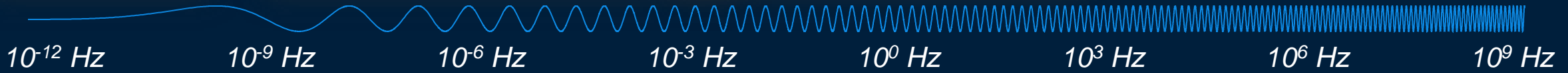
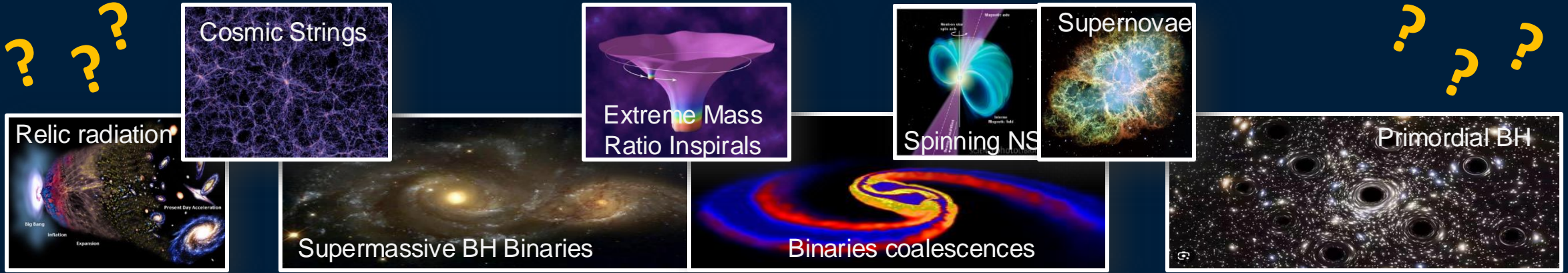


The challenge of interferometry on Earth (Virgo/ET)

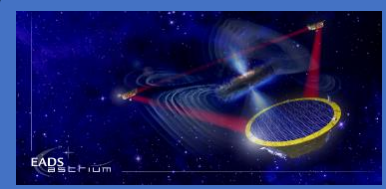
Dott. Davide Rozza

Objective of GRAF: development of new models and analysis techniques for high-precision measurements of gravitational waves

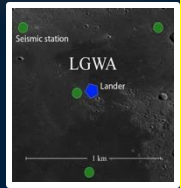
Sources of gravitational waves



Inflation Probe Pulsar timing Space detectors Ground interferometers Resonant detectors



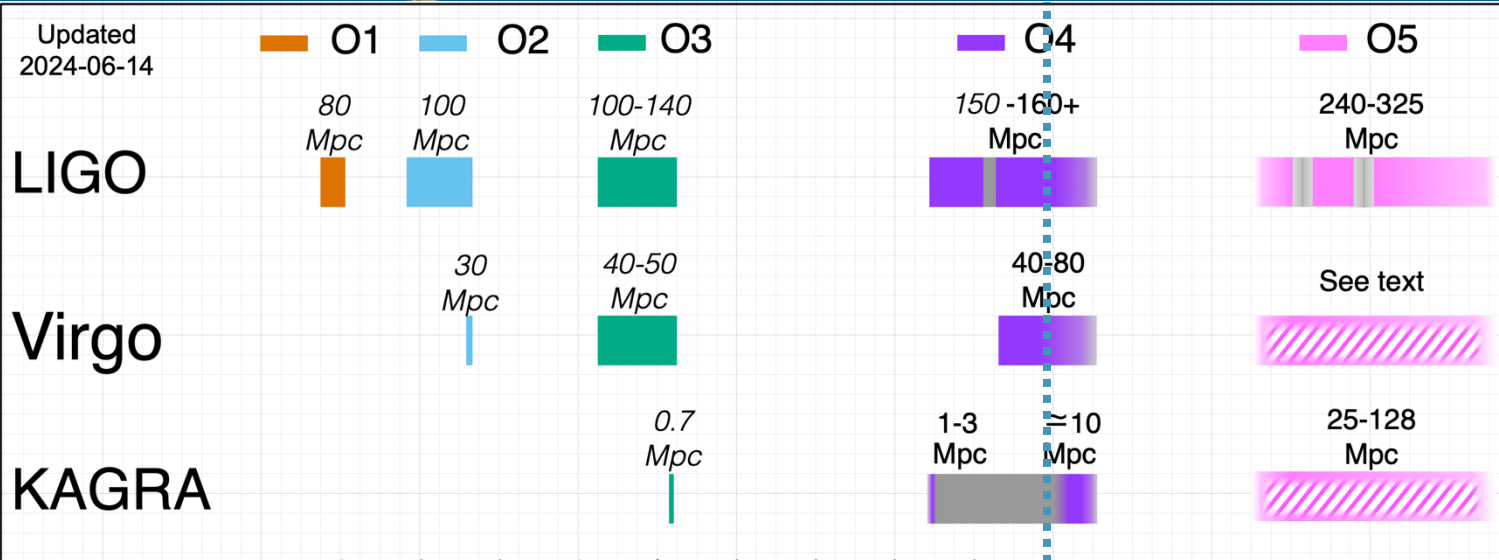
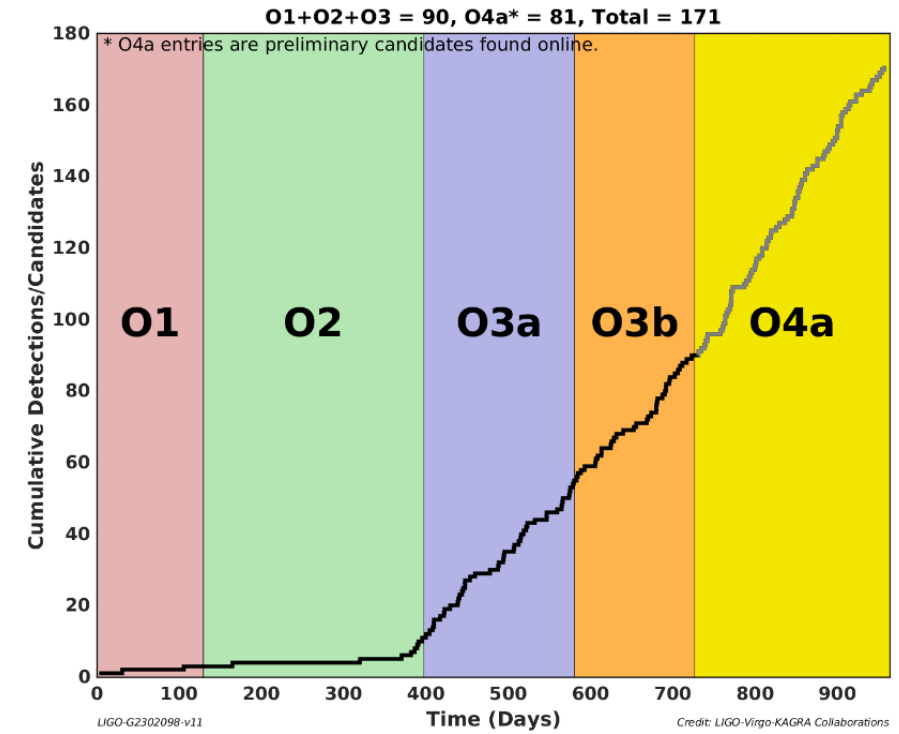
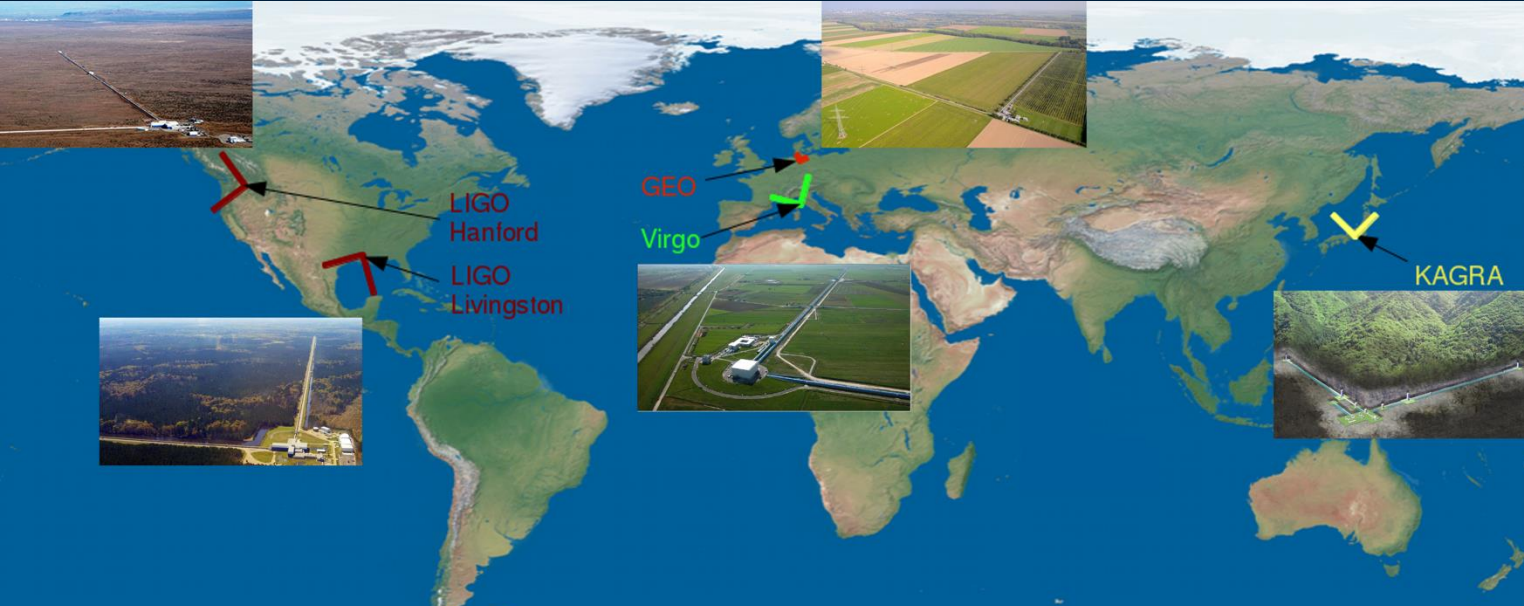
M. Colpi talk



L. Canonica talk

Detectors

Ground interferometers



* O4 entries are preliminary candidates found online

O4a: 2023-05-24 to 2024-01-16

O4b: 2024-04-10 to 2025-01-23

O4c: 2025-01-24 to 2025-06-09

930 members

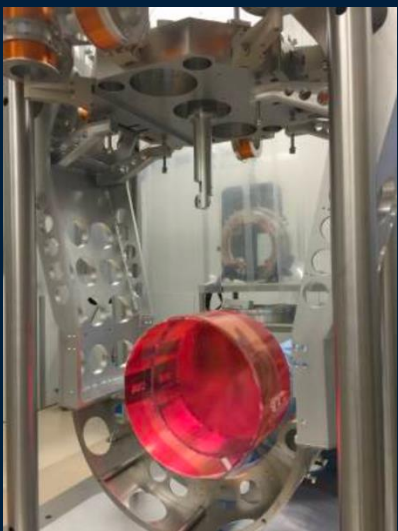
165 institutions

20 Countries



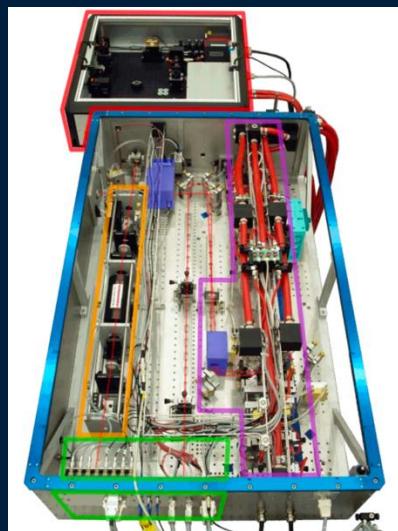
Basic of GW detections

Two test masses

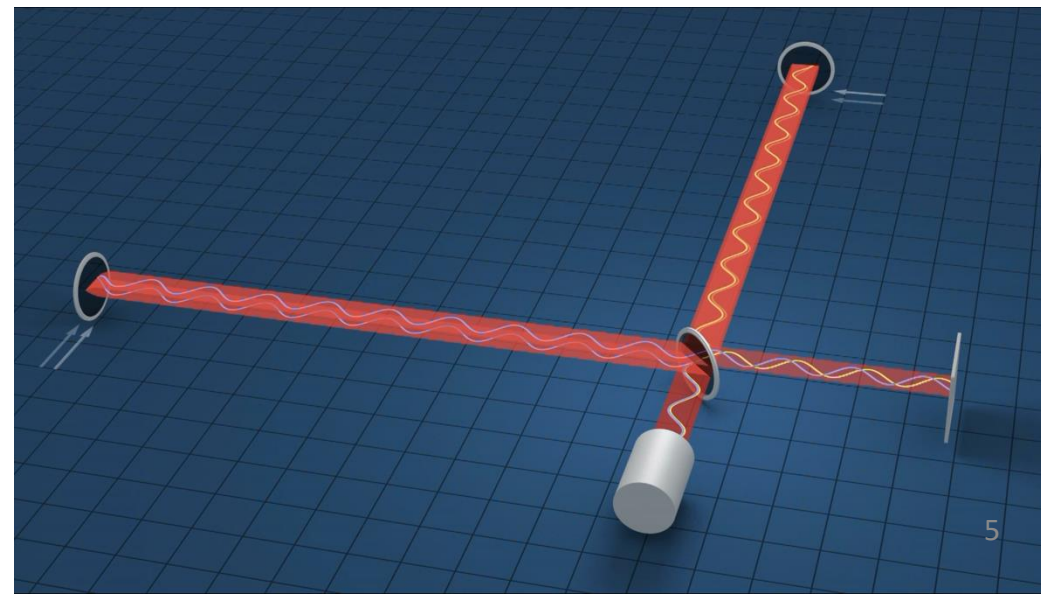
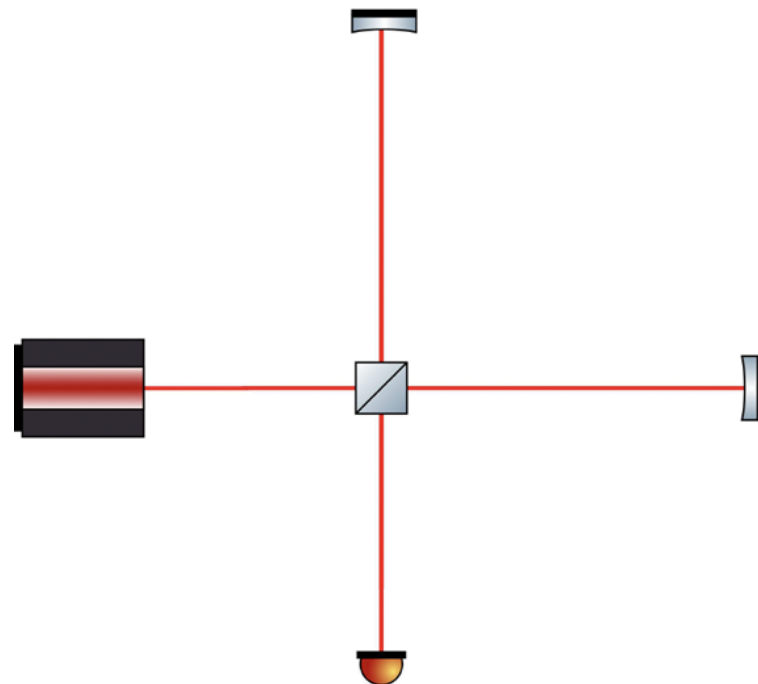


Free falling objects that sense the GW

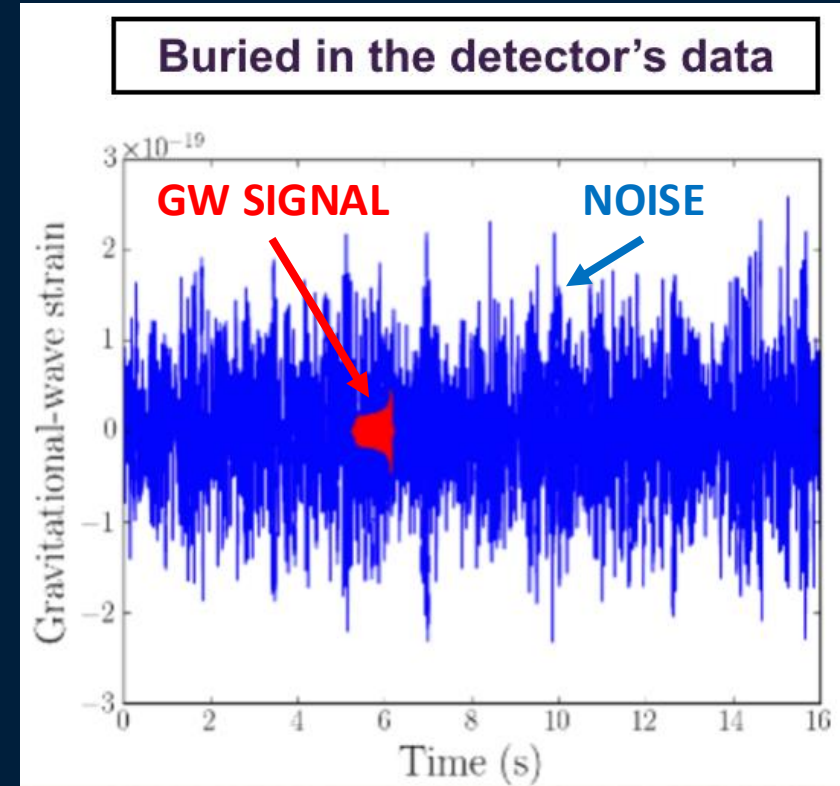
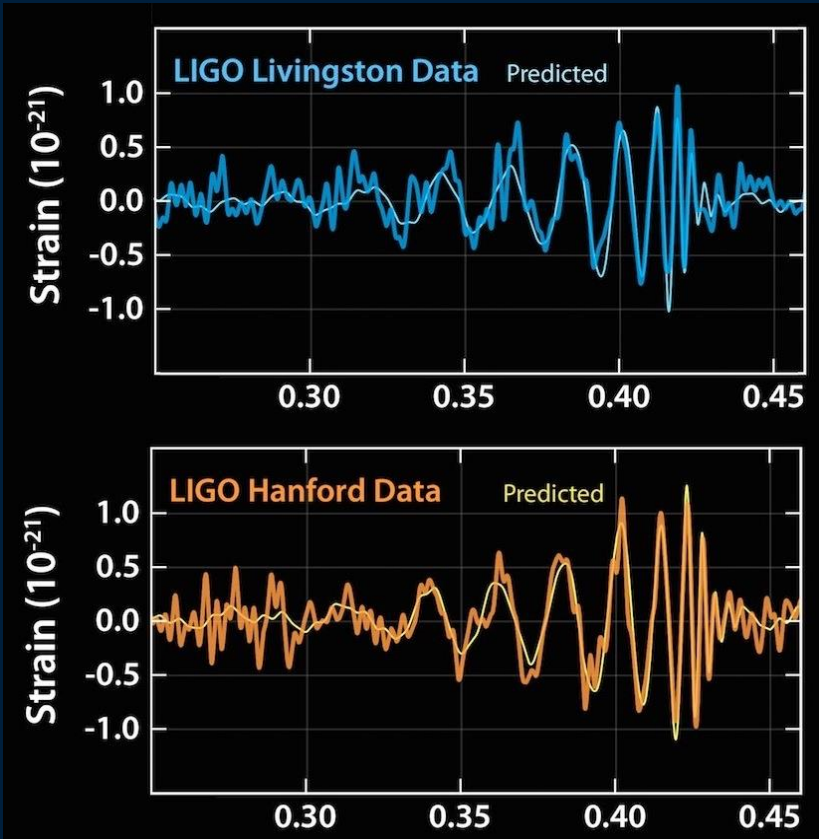
A ruler



A laser light, λ is the ruler tick mark



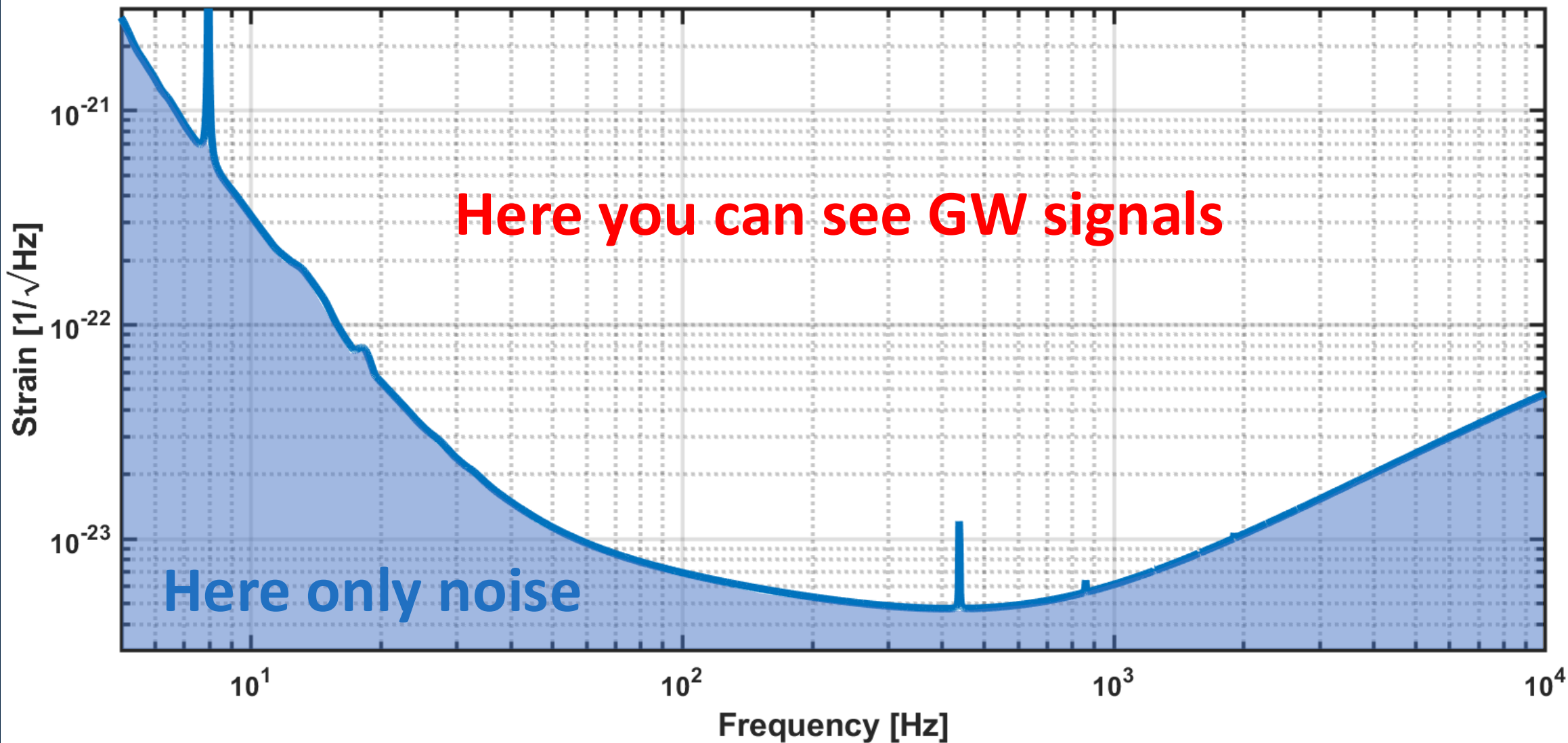
GW signals and... noise

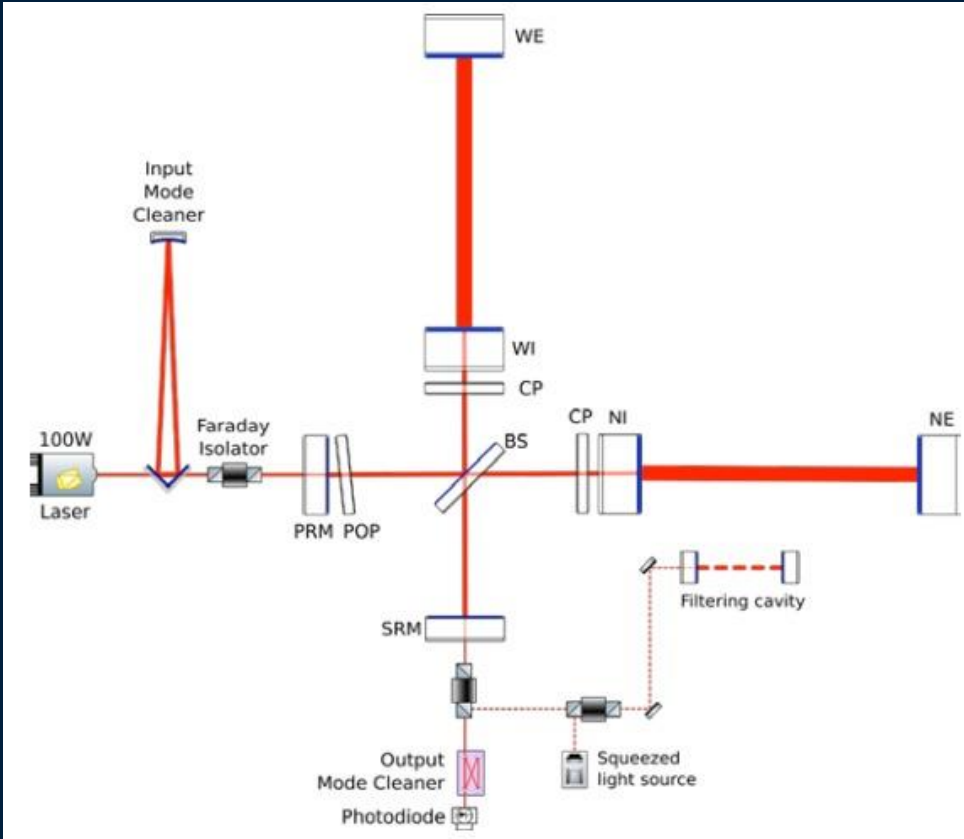


We need to **enhance the signal** and **reduce the noise**

Sensitivity curve

Advanced Virgo Noise Curve: $P_{in} = 125.0 \text{ W}$



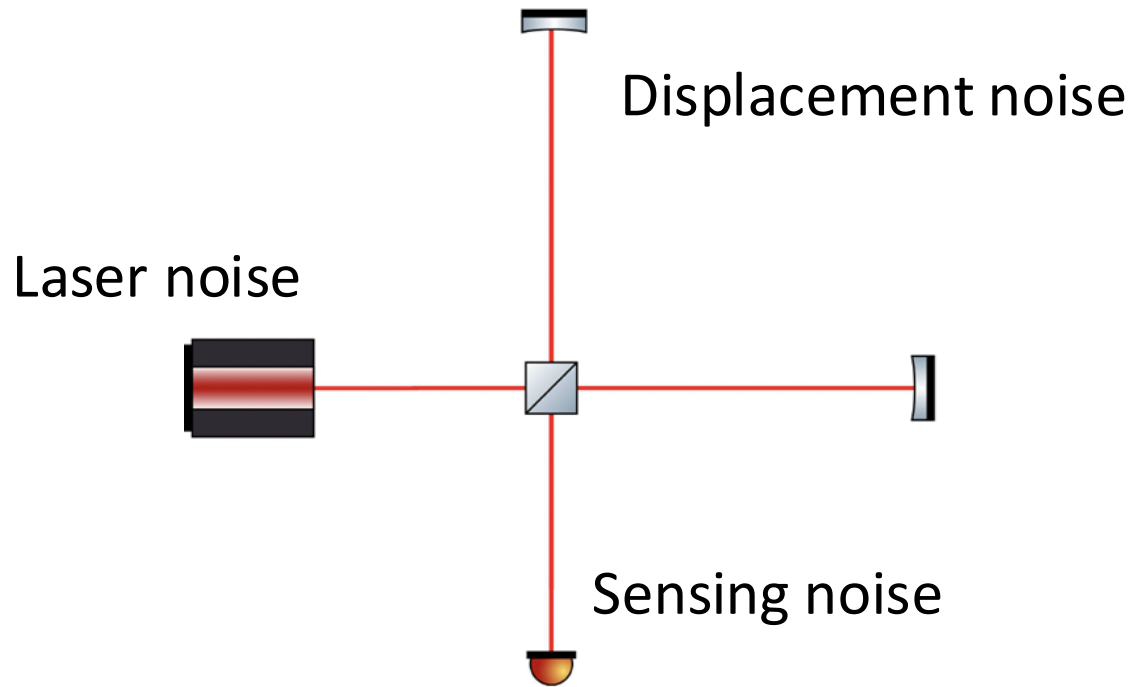


Fabry-Perot cavity for “longer arms”: the presence of the optical cavities increases the number of round trip of the light, therefore enhancing the gain of the instrument

Input and output mode cleaner to reject the laser high-order modes

Power Recycling mirror to recover the power reflected from the arms and increase the optical power (*PRM*)

Signal Recycling mirror (SRM) to reshape the detector frequency response



Displacement noise

Other forces acting on the mirror moving it



Sensing noise

Other signals added to what is read-out from the photodiode

Quantum noise

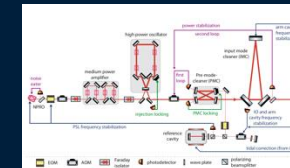
Electronic noise

Optical cavities

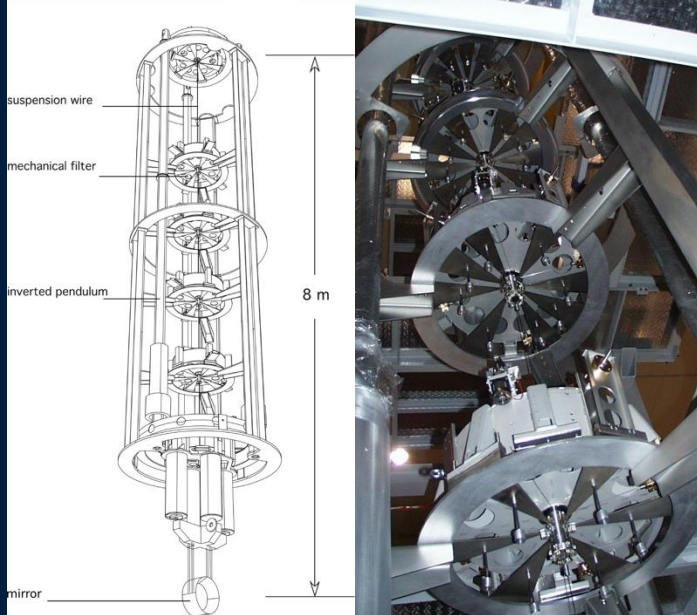
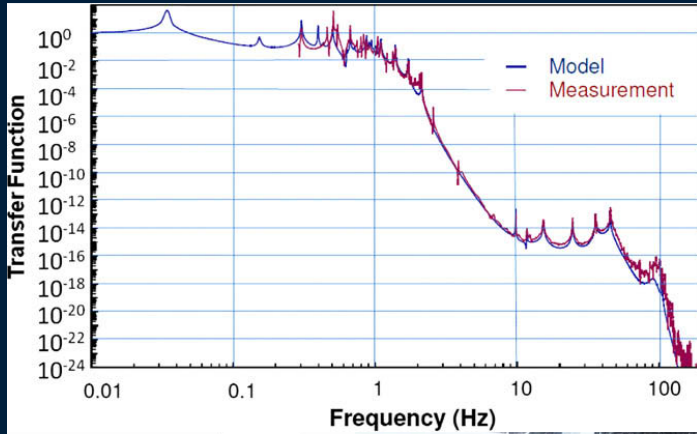
Scattered light

Laser noise

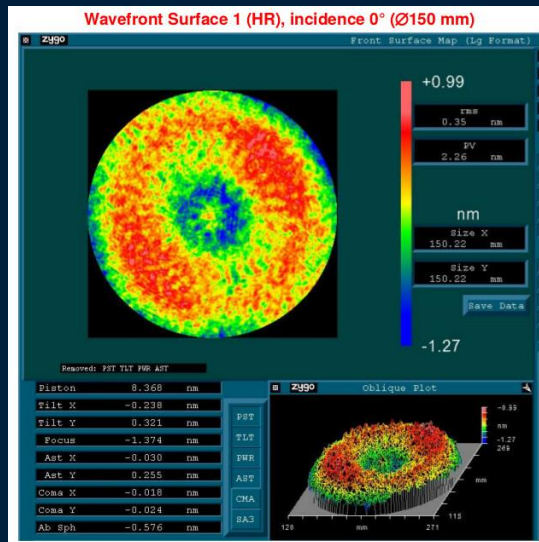
Noise in the light used for the measurement



Superattenuators: reduces mirrors seismic vibration by a factor 10^{15}



Thermal fluctuation of the mirror surface.
40 kg mirrors fused silica



Ultra high vacuum
It has a total volume of 7000 m³ and is kept at a pressure of 10^{-9} mbar

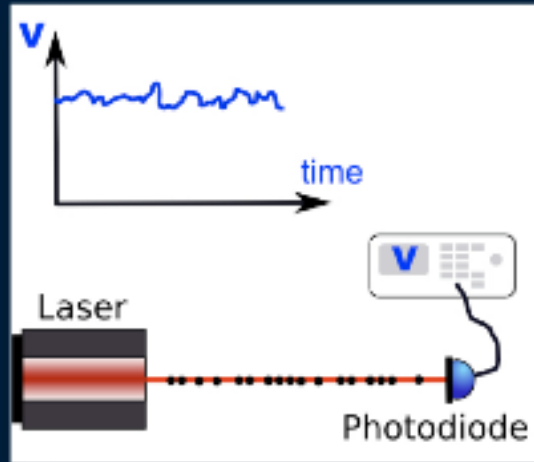


Magnetic noise sources
Magnets are attached to mirrors to allow position control (electronics at least 10 m from the mirrors, lightning...)

Local gravity (NN)
(ground moves due to seismic earthquakes, sea waves...)

...

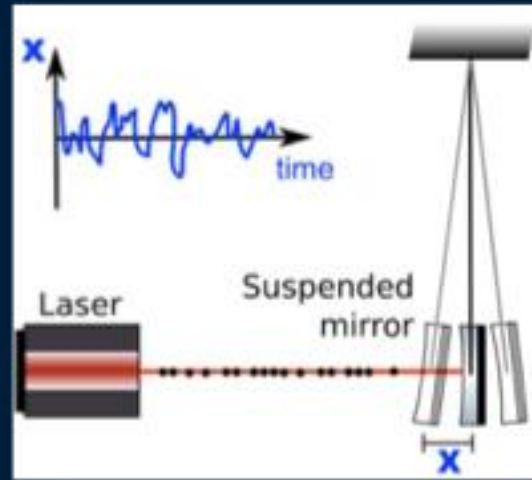
Shot noise: photon counting noise



$$h_{shot} \propto \frac{1}{L} \sqrt{\frac{1}{P}}$$

P = Power

Radiation pressure noise: Photons fluctuations translate in radiation pressure fluctuations, giving rise to random motion of the mirrors



$$h_{rad} \propto \frac{1}{f^2 L} \frac{\sqrt{P}}{m}$$

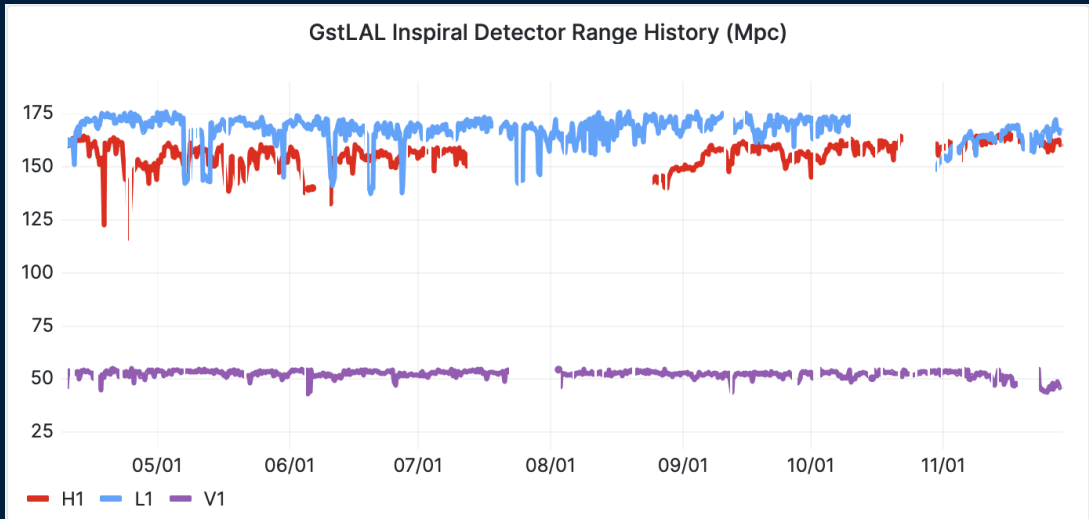
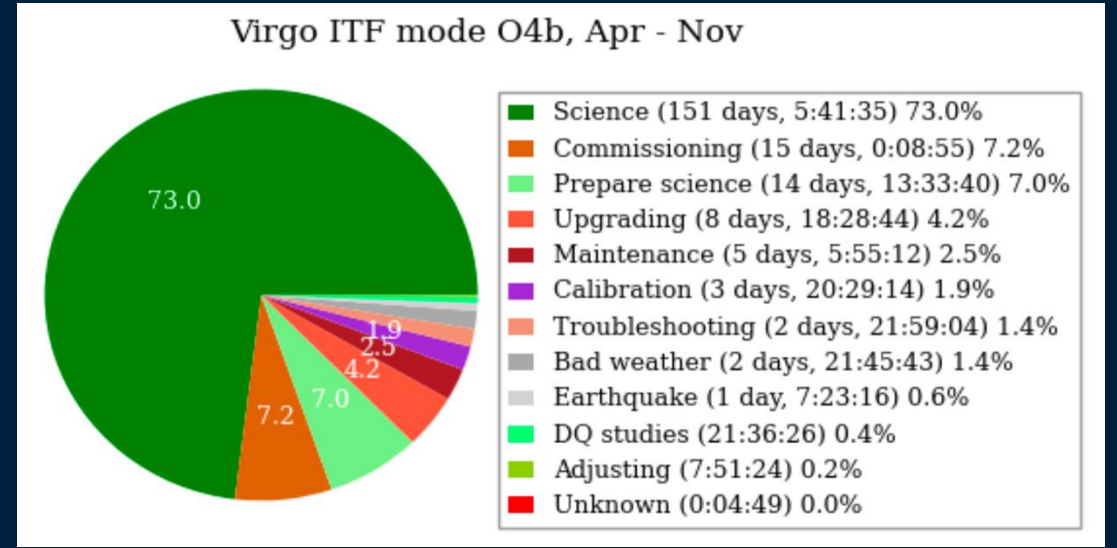
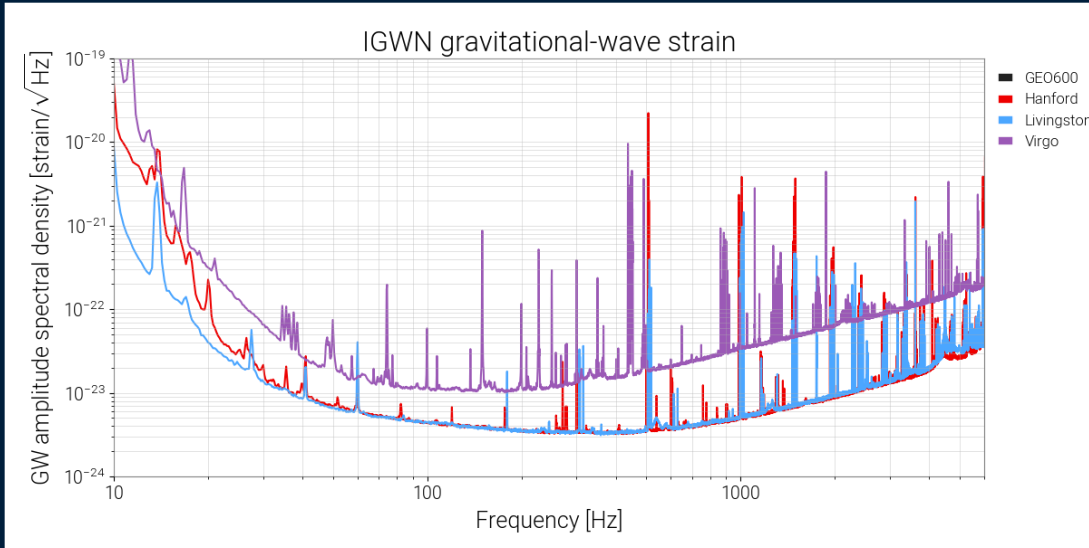
Dark noise

Electronic noise

Scattered light

(add absorbing glass everywhere, suspend optical elements, ...)

...



BNS range holes due to:

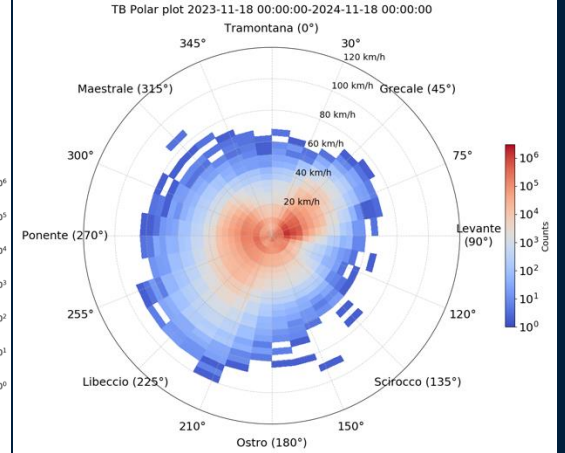
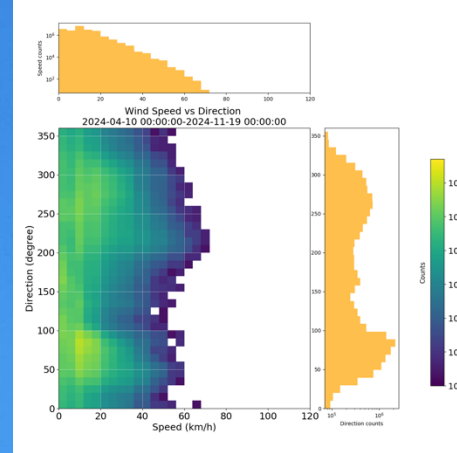
exceptional intervention, strong wind...

BNS range performance reduction:

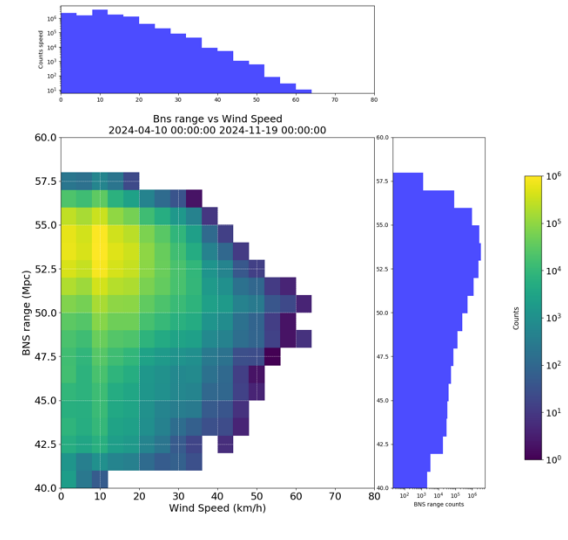
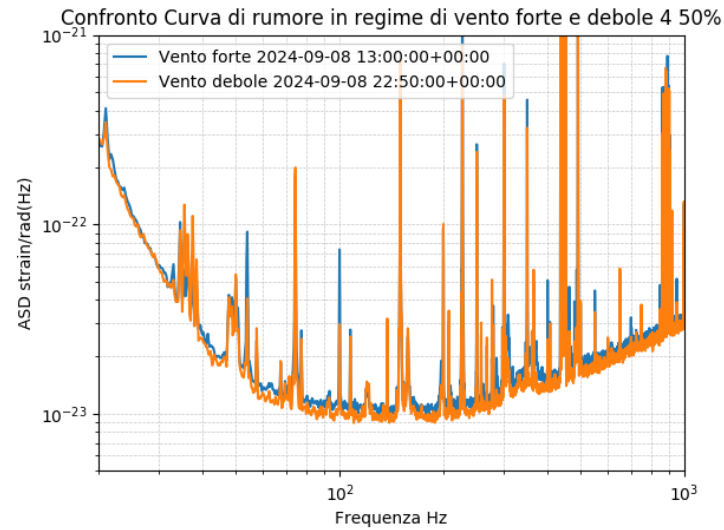
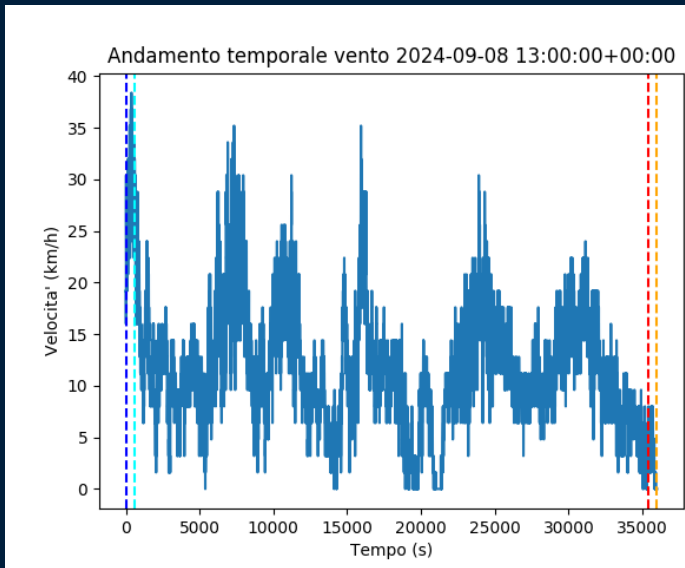
bad weather, glitches, issues, photodiode saturation...

VIRGO data used in low latency for sky localization

Still working to identify noise sources and reduce them

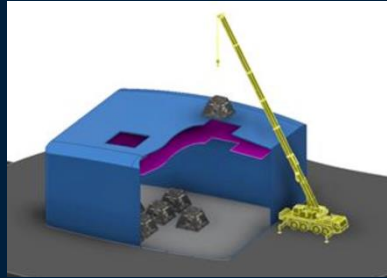


Impact of the wind on the Virgo sensitivity and BNS range

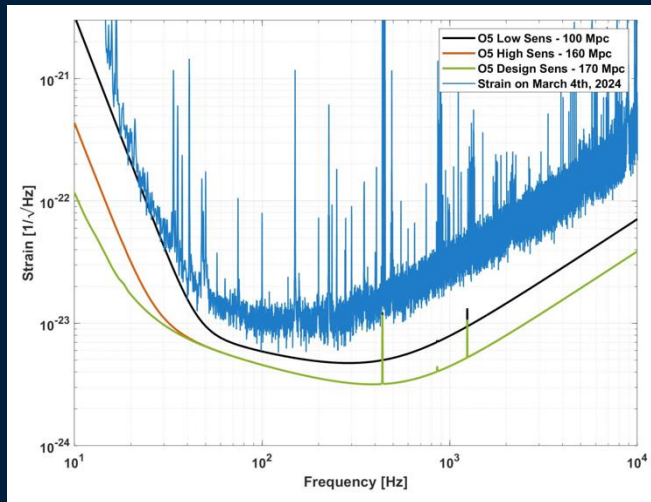


O5 (AdV+)

Improve detector robustness, with the installation of stable recycling cavities
 Improve sensitivity, avoiding that gap with LIGO becomes too deep



Current plan: short (internal) stable cavities at the cost of a later start of O5



BNS range = 100 Mpc (Low), 160 Mpc (High)
 BBH range = 1 Gpc (Low), 1.42 Gpc (High)

Post O5 (Virgo nEXT)

Same infrastructure
 Same laser wavelength
 Room temperature mirrors

Upgrades:

0 (MW) intracavity power
 Larger test masses, better coatings
 NN subtraction
 Improved LF sensitivity

Virgo_nEXT will be a “pathfinder” for ET(HF)

	AdV+ best	V_next best	ET HF
Power inj.	125 W	277 W	500 W
Arm power	390 kW	1.5 MW	3 MW
FDS detected	6 dB	10 dB	10 dB
Mirror mass	42/105 kg	105 kg	200 kg
beam radius	49/91 mm	91 mm	120 mm

3rd GW detectors



3rd generation GW observatory. Sensitivity aims at least one order of magnitude better with respect to the nominal sensitivity of advanced detectors in all the detection frequency band

Precision measurement and a new discovery project.
A wide frequency band observatory



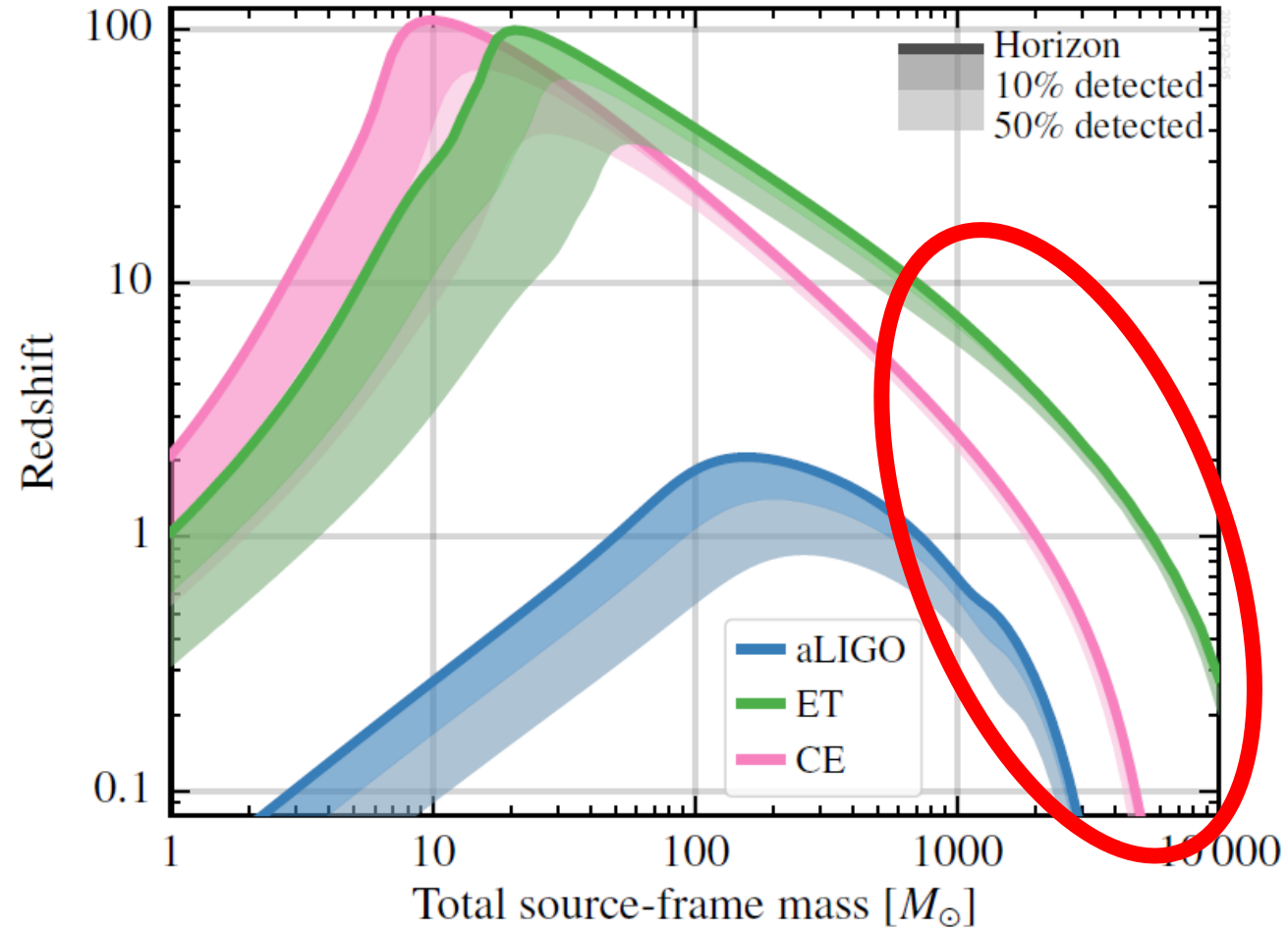
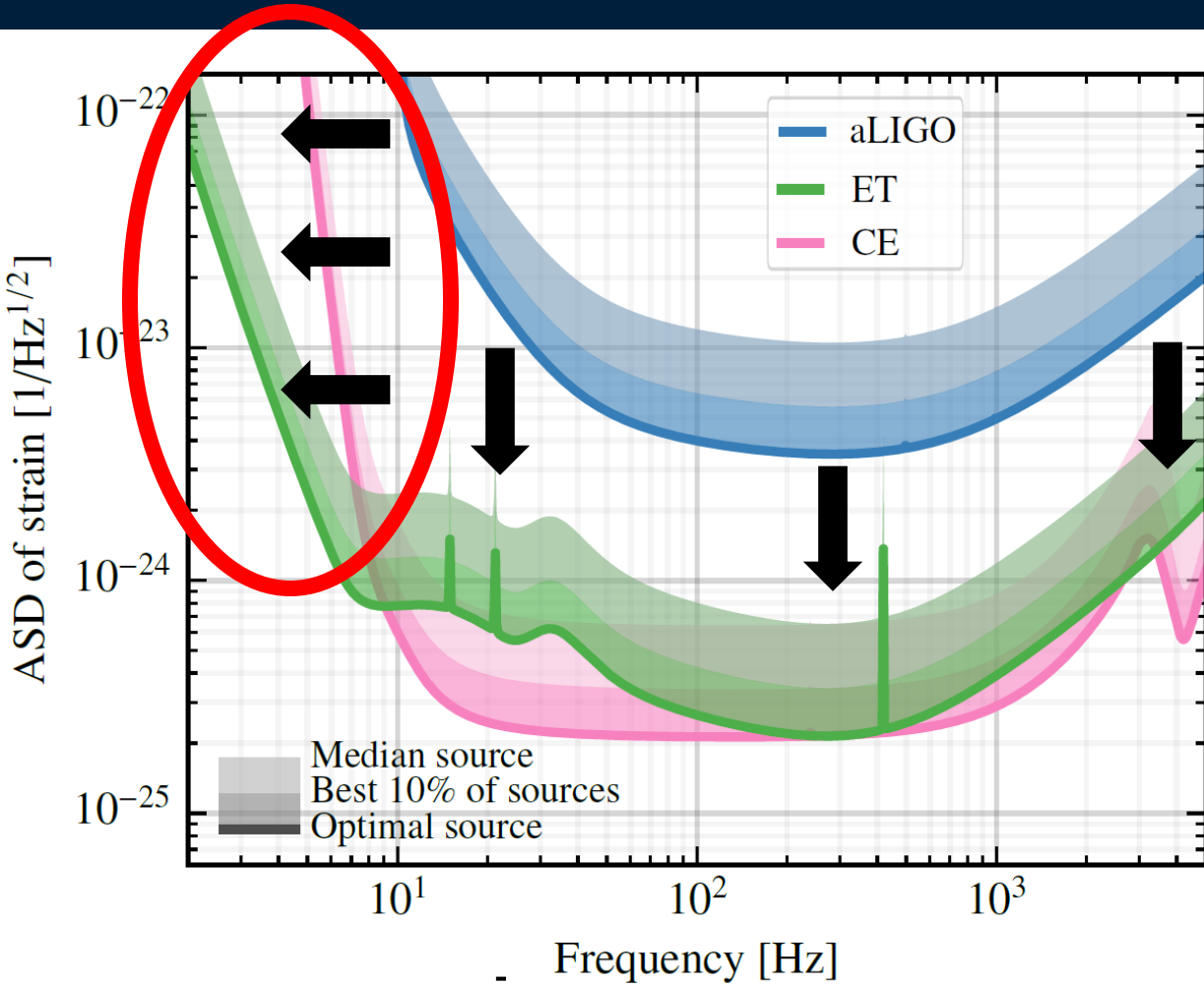
Special focus on massive (or intermediate mass) black holes. Extraordinary sensitivity at low frequency (few Hz)

High reliability. High observation duty cycle



Lifetime of several decades. Capable to host the evolution of the detectors, without limiting their sensitivity

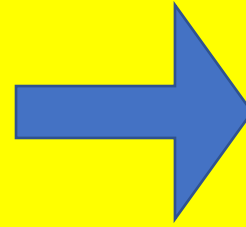
Einstein Telescope physics



ET challenges

Requirements

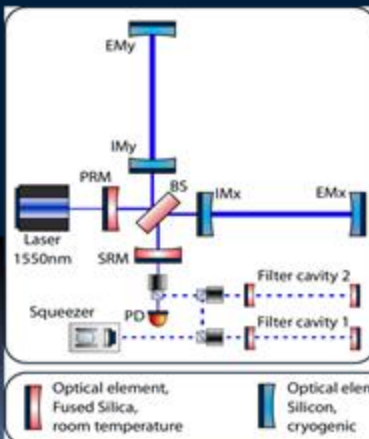
- Wide frequency range
- Massive black holes (LF focus)
- Localisation capability
- (more) Uniform sky coverage
- Polarisation disentanglement
- High Reliability (high duty cycle)
- High SNR



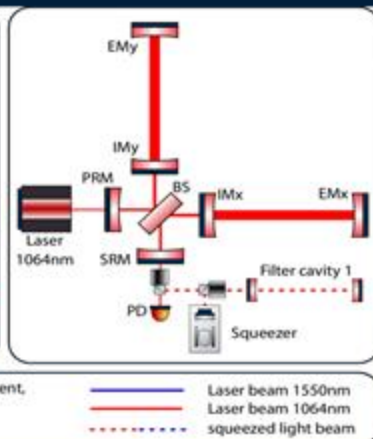
Design Specifications

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

ET - LF
 low-power, cryogenic
 low-frequency detector



ET - HF
 high-power, room-temperature
 high-frequency detector



ET-HF:

300 K

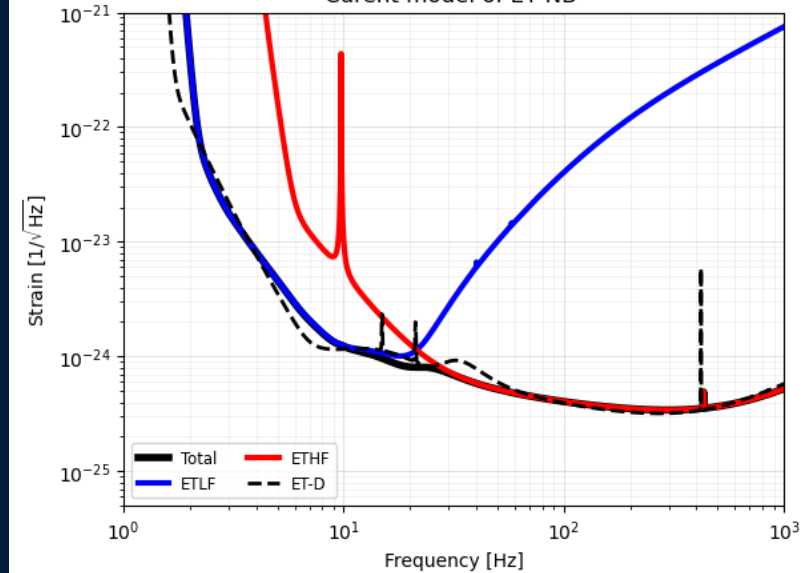
- High power laser
- High circulating light power
- Thermal compensation
- Large test masses
- New coatings
- Frequency dependent squeezing

ET-LF:

10 - 20 K

- Cryogenics
- Seismic suspensions
- Silicon (Sapphire) test masses
- Large test masses
- New coatings
- New laser wavelength
- Frequency dependent squeezing, Filter cavities

Current model of ET NB



ET candidate sites

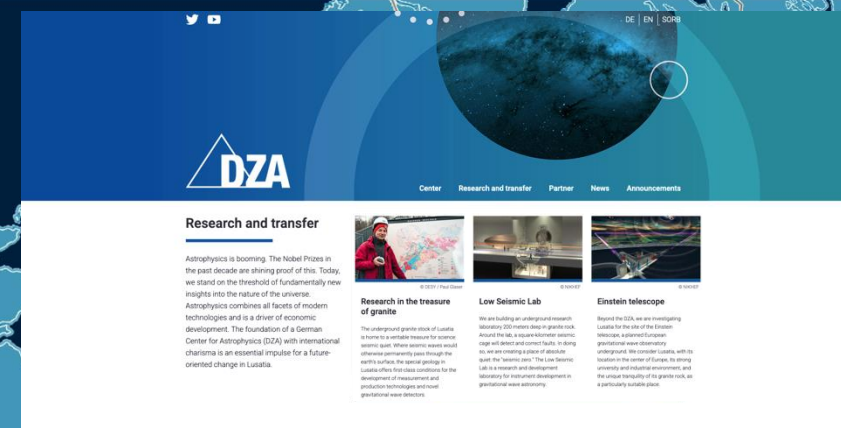


Einstein Telescope

Einstein Telescope ▾ News Projects Join us! Contact ▾

EN / FR / DE / NL

Einstein Telescope and the Euregio Meuse-Rhine



DZA

Center Research and transfer Partner News Announcements

Research and transfer

Astrophysics is booming. The Nobel Prize in the past decade is a shining proof of this. Today, we stand on the threshold of fundamentally new insights into the nature of the universe. Astrophysics combines all facets of modern technologies and is a driver of economic development. The foundation of a German Center for Astrophysics (DZA) with international character is an essential impulse for a future-oriented change in Lusatia.

Research in the treasure of granite

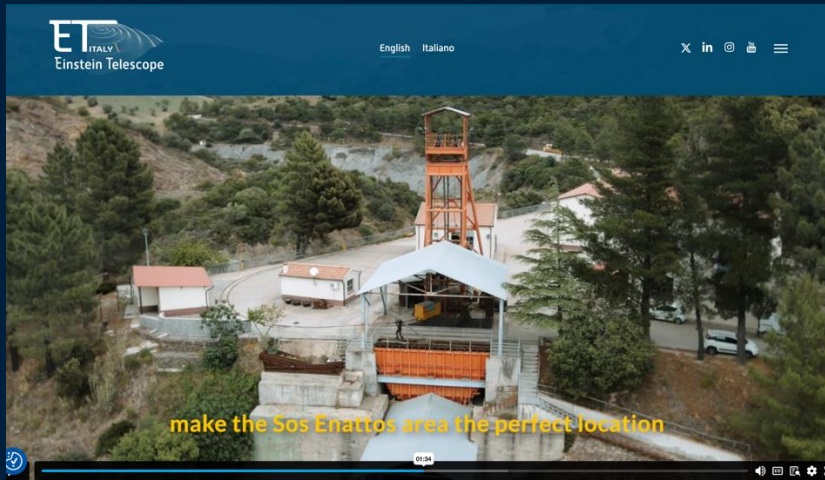
The underground granite stock of Lusatia is a treasure for scientific research for various scientific goals. When seismic events occur, they release energy that can be detected through the earth's surface, the special geology in Lusatia offers ideal conditions for the development of measurement and production technologies and for gravitational wave detectors.

Low Seismic Lab

We are building an underground research laboratory 200 meters deep in granite rock. Above the lab, a superconducting magnetic cage will shield and correct fields. In doing so, we are creating a shield of absolute quiet: the "seismic cave". The Low Seismic Lab is a research and development laboratory for instrument development in gravitational wave astronomy.

Einstein telescope

Beyond the DZA, we are investigating Lusatia for the site of the Einstein Telescope, a proposed large-scale gravitational wave observatory underground in the Lusatian granite, with its location in the center of Europe, its strong seismic and tectonic environment, and the unique transparency of its granite rock, as a particularly suitable place.



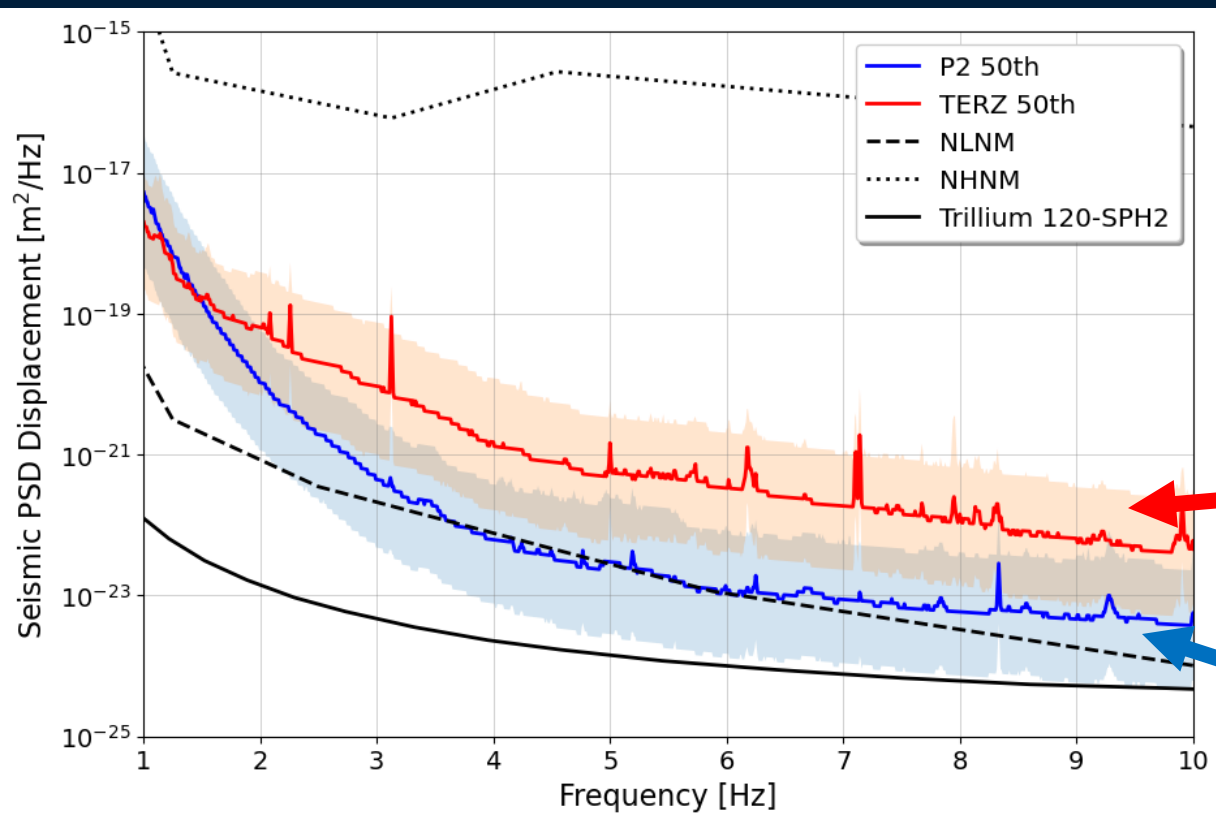
ET ITALY Einstein Telescope

English Italiano

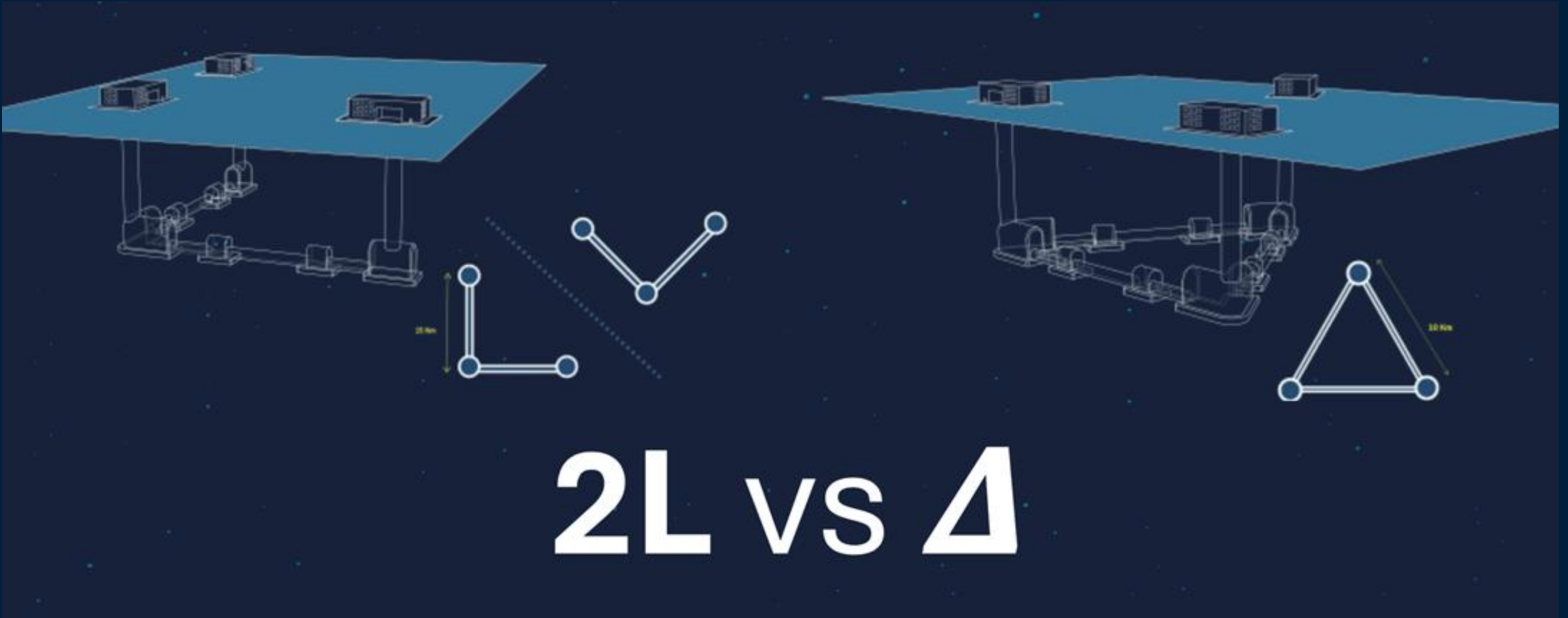
make the Sos Enattos area the perfect location



Site characterization



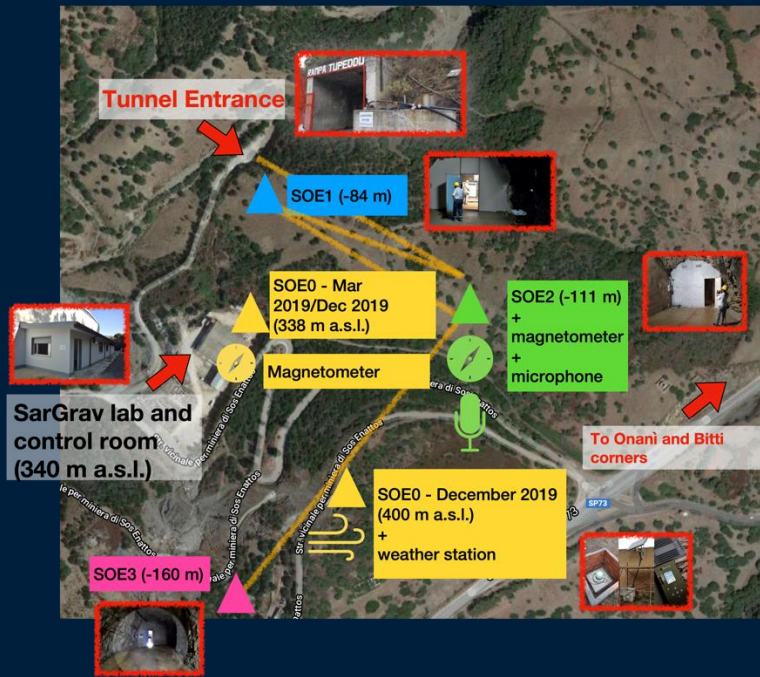
ET layout



2L vs Δ

Since **COBA** and **ETRAC** analysis are in agreements that 2L are favoured wrt Δ , and thanks to the **geology**, in Sardinia it is possible to host both Δ and L configurations

Site characterization



Permanent and temporary ARRAY for characterization and Newtonian noise purposes

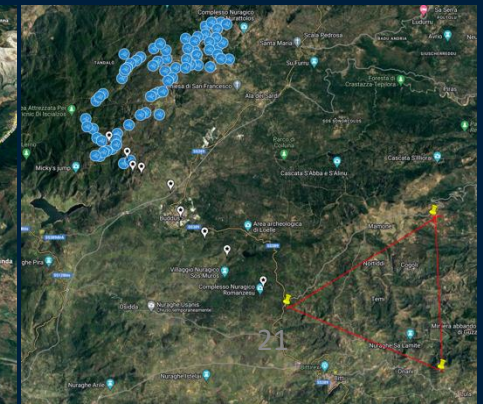
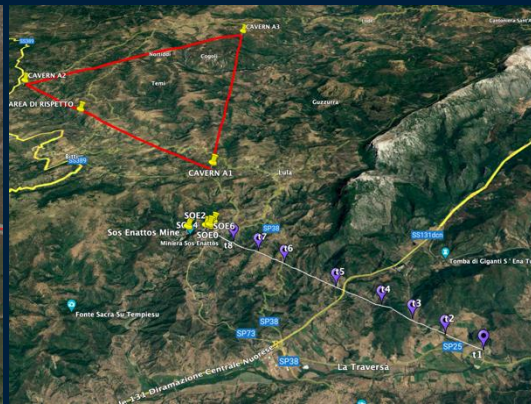
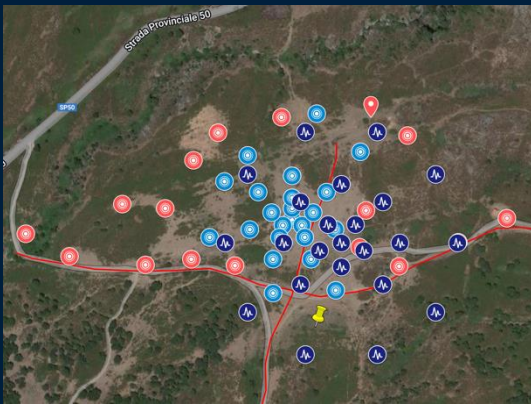
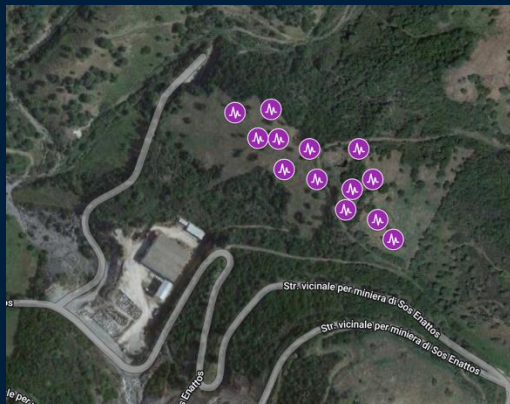
Sos Enattos broadband array
 (January 2021)

P2 broadband array +
 geophones (September 2021)

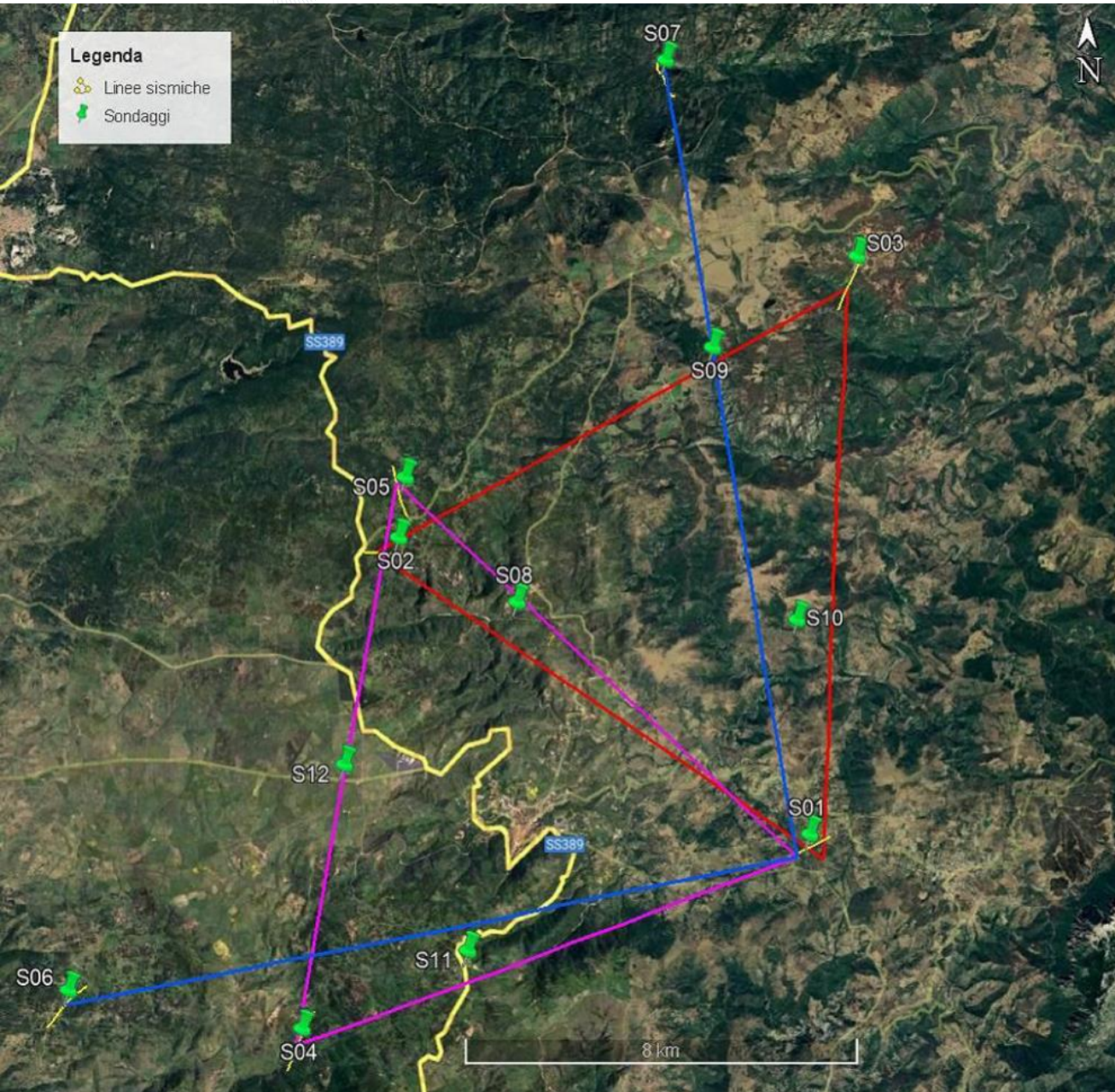
P3 broadband array +
 geophones (July & Oct 2021)

Explosion broadband array
 (early 2022)

Wind Park broadband array
 (early 2023)



Site characterization



Sensors installed or to be installed:

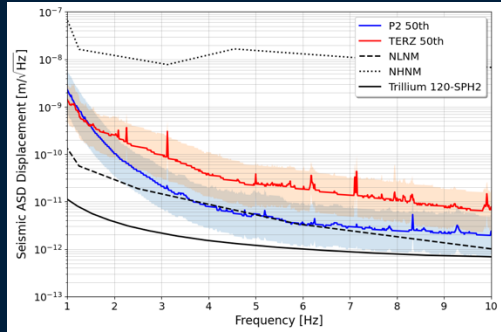
- Seismometers
- Magnetometers
- Micro-barometers
- Acoustic sensors
- Weather stations
- Gravimeters
- ...

Drilling campaign

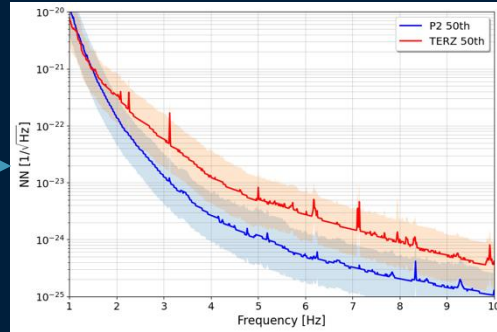


Study the impact of site noise on the ET sensitivity curve and its impact on the detectability of the aforementioned GW sources for early warning purposes.

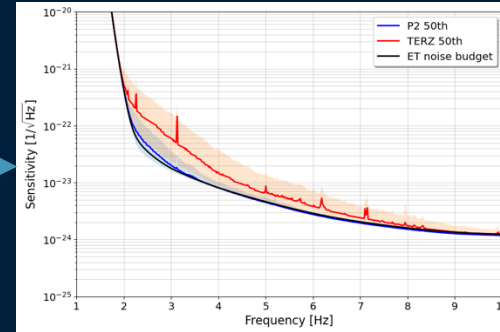
Seismic ASD Displ.



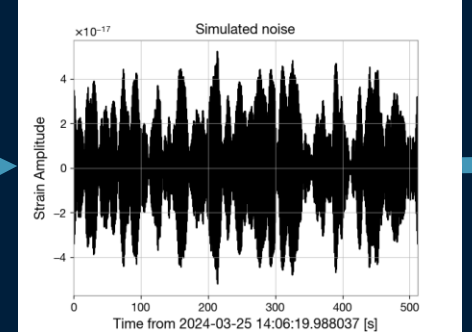
Newtonian Noise ASD



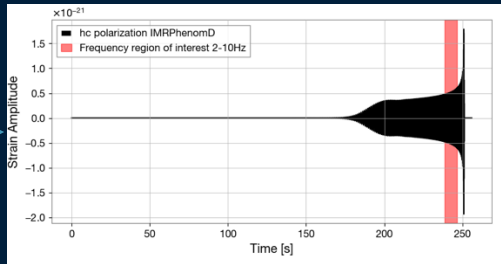
ET sensitivity



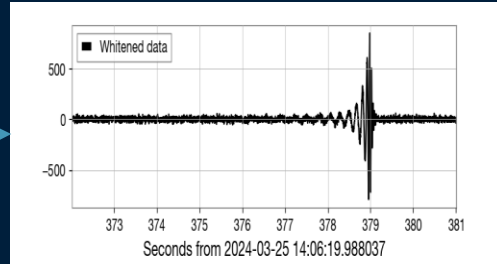
ET noise



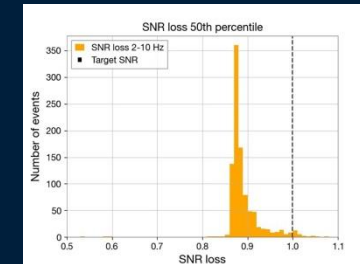
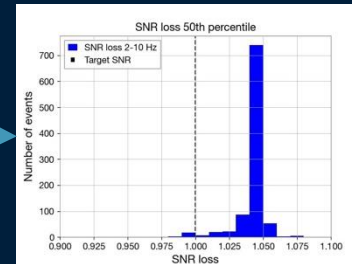
Generate waveforms



Inject signal into noise

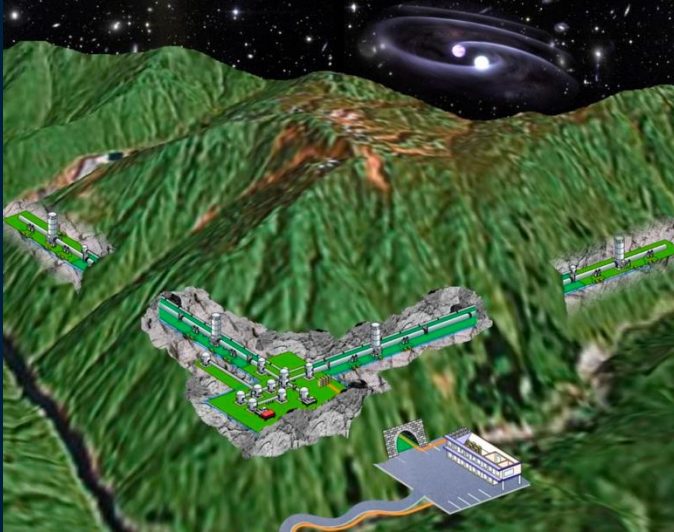


Compare the SNRs with the design case



SNR/SNR_design

GW global network: Kagra



KAGRA (かぐら)

Large-scale Cryogenic Gravitational-wave Telescope
2nd generation GW detector in Japan

Large-scale Detector

Baseline length: 3km

High-power Interferometer

Cryogenic interferometer

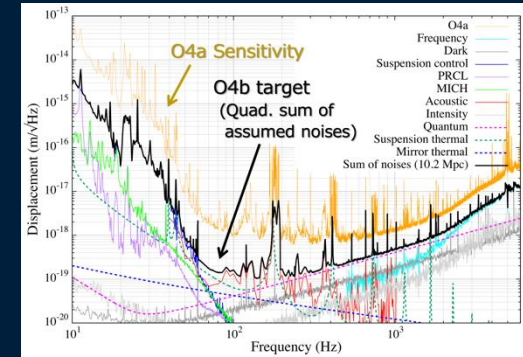
Mirror temperature: 20K

Underground site

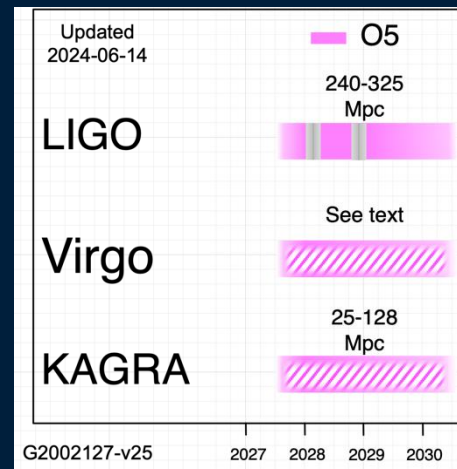
Kamioka site dedicated

L-shaped tunnel

O4a (may-June) 2023: ~1.3 Mpc
All the noise source are identified
~10 Mpc for the end of O4b



Kagra will join O5 with > 25 Mpc



- New ITMs for O5 (better symmetry and birefringence)
- Mirror/Suspension Q-factor improvement
- New SRM/ITM
- High Power Laser
- Squeezer
- Possibly a Filter Cavity
-
- O5 is expected to run for 3 years from 2027 (TBC)
- Make a detailed plan for post-O5 upgrade in 2025
- Start the preparation for the post-O5 upgrade from 2026
- O6 plan is too ambiguous at this moment ?

GW global network: LIGO-India



Planned for 2030

GW global network: LIGO → CE



LIGO Hanford, Washington



LIGO Livingston, Louisiana

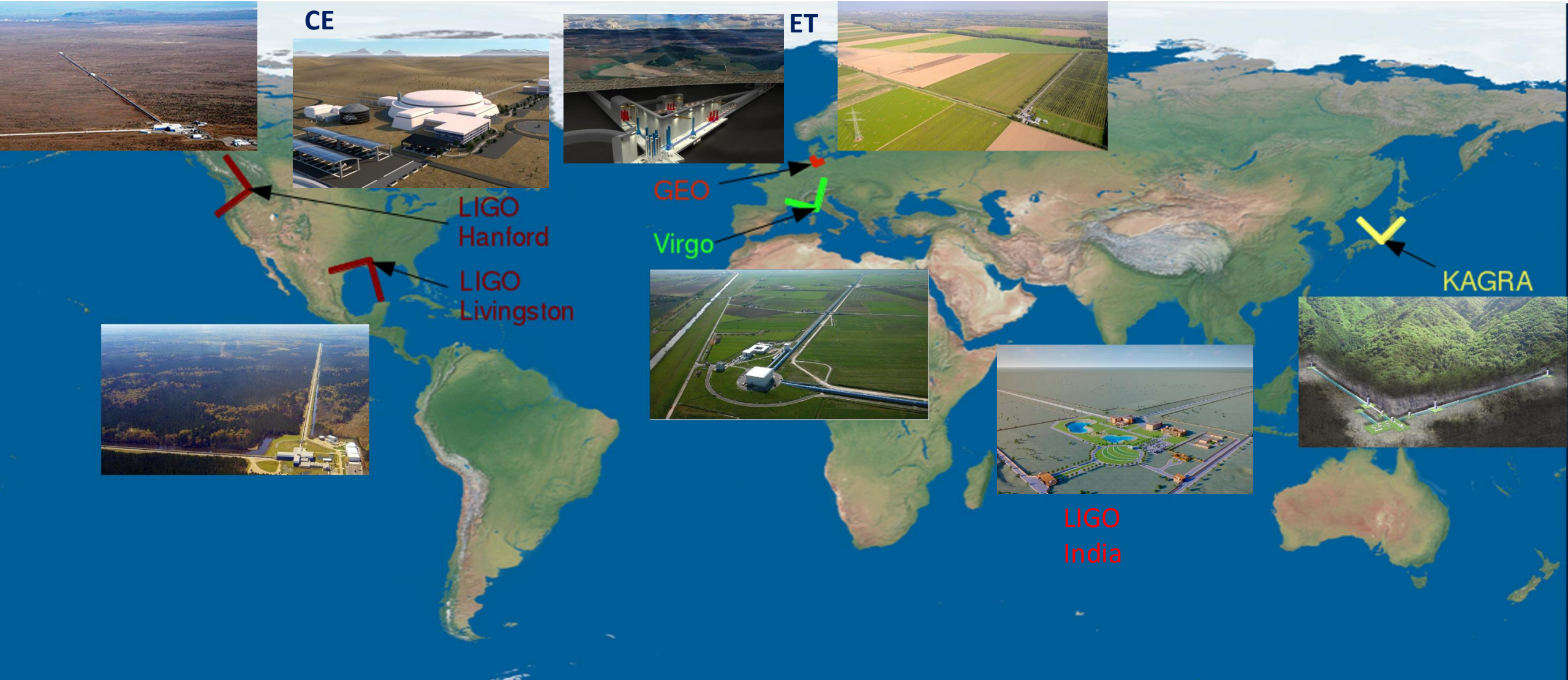
Quantity	A+ (O5)	A# (O6)	CE
Arm length (km)	4	4	40
Wavelength (nm)	1064	1064	1064
Mirror mass (kg)	40	100	320
Mirror diameter (cm)	34	46	70
Arm power (MW)	0.8	1.5	1.5
Squeezing (dB)	6	10	10



Credit: Angela Nguyen, Virginia Kitchen, Eddie Anaya, California State University Fullerton

Cosmic Explorer

Future GW global network



To obtain meaningful astronomical results, we need a network of gravitational wave detectors.