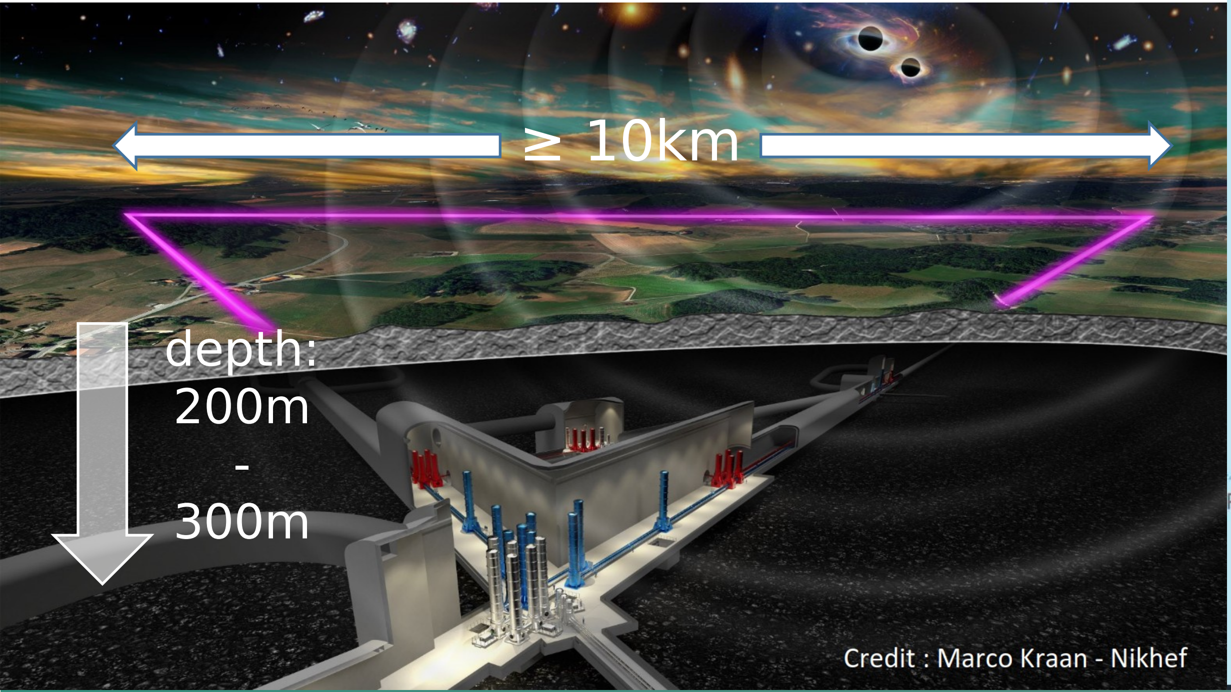
3rd generation detector: Einstein Telescope

Angélique Lartaux - IJCLab

Next generation gravitational wave detector

New infrastructure capable of hosting future upgrades for decades without limiting observing capabilities

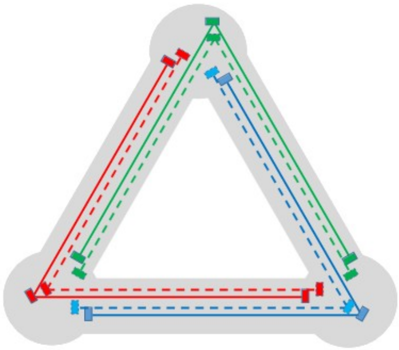
To start observing in the late 2030's

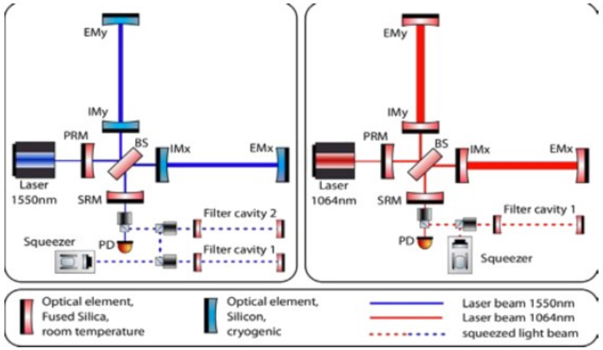


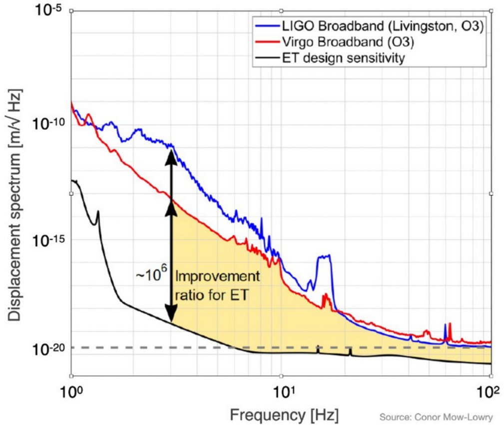
To improve the sensitivity wrt 2nd generation

Goal:

- 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
- Large science case both on astrophysics, fundamental physics and cosmology





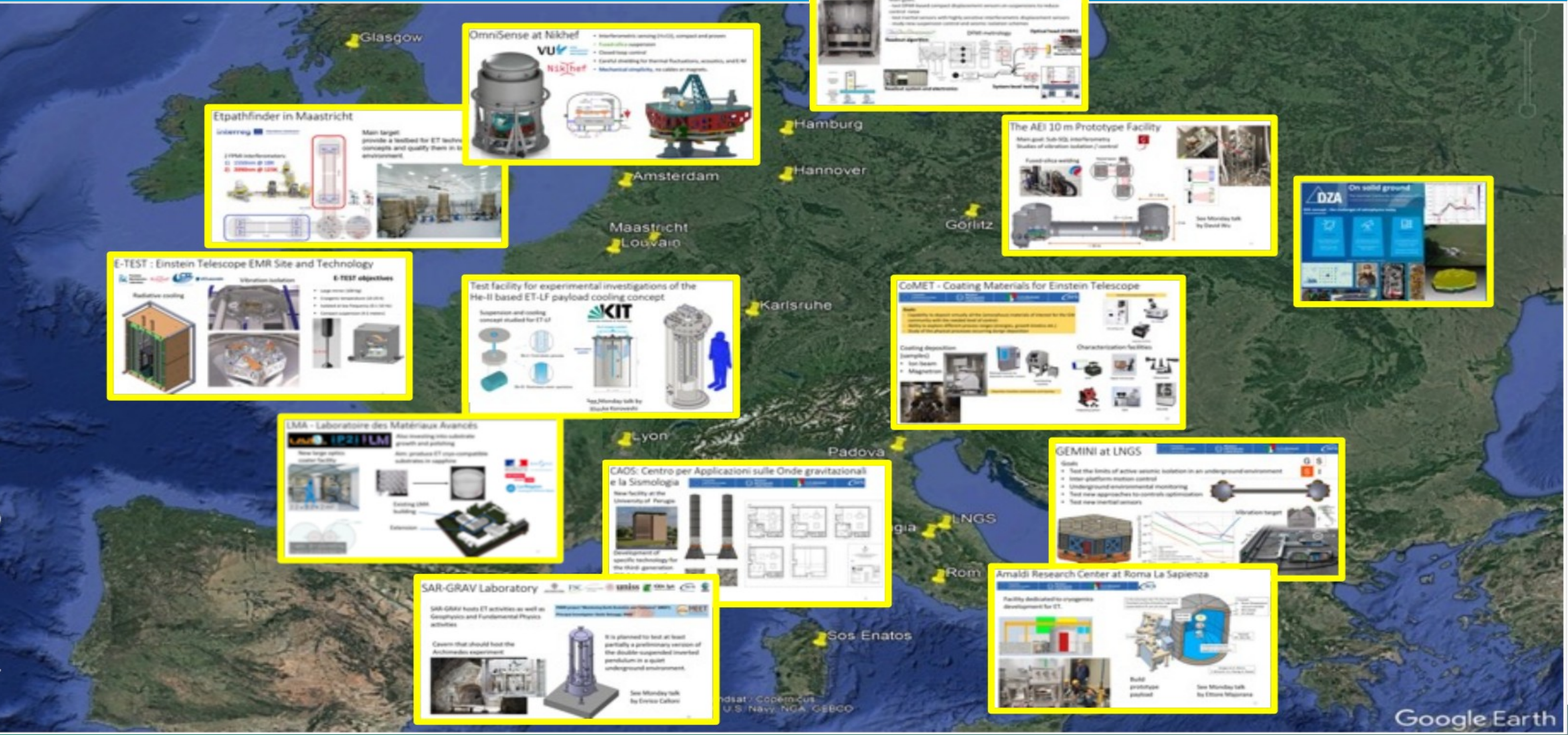


Parameter	ET-HF	ET-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10-20 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	45 cm/ 57 cm
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase (rad)	tuned (0.0)	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)	$5 \cdot 10^{-10}$ m/f^2	$5 \cdot 10^{-10}$ m/f^2
Gravity gradient subtraction	none	factor of a few

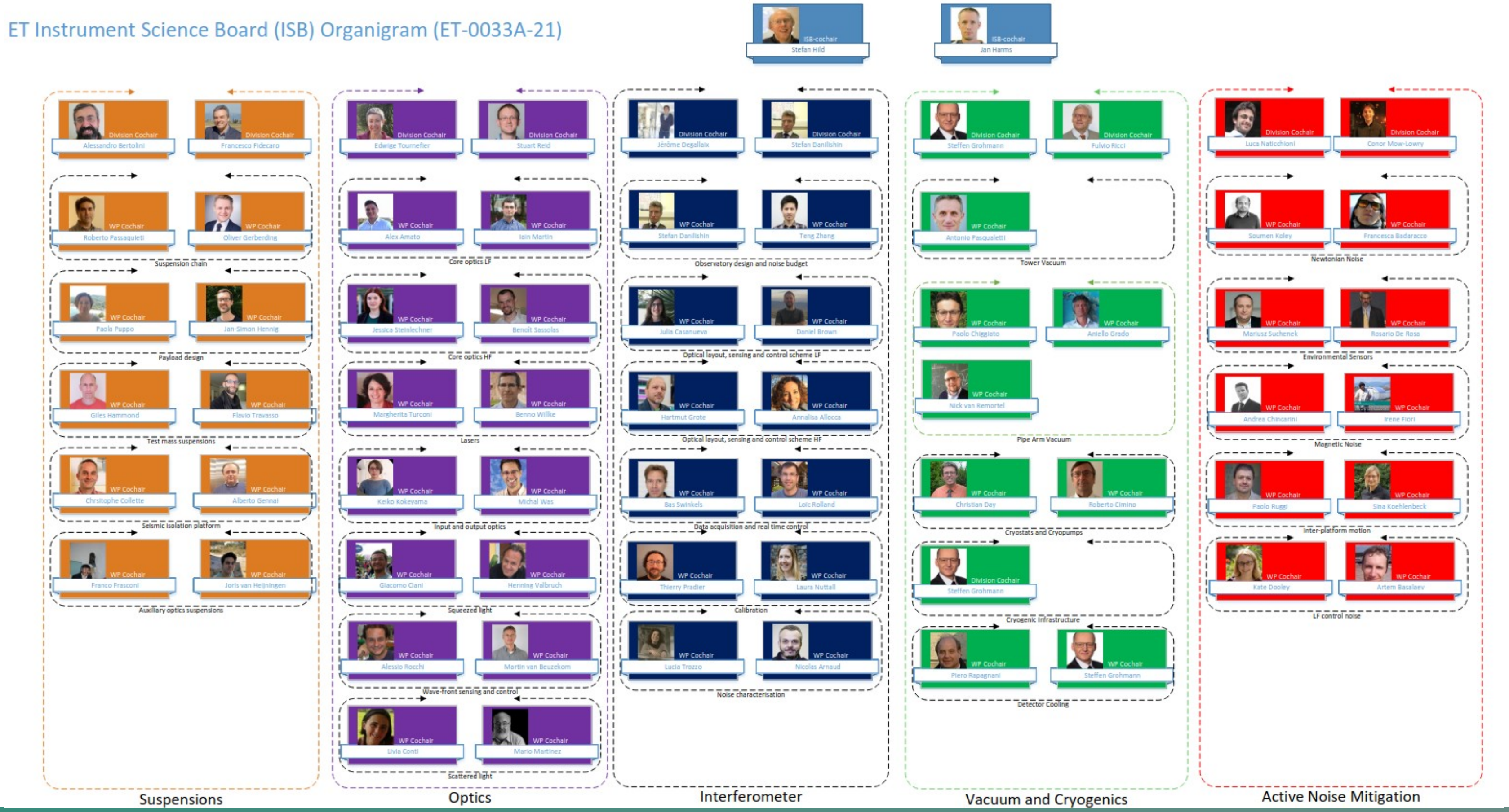
ET EINSTEIN TELESCOPE

Lots of R&D studies in Europe

From the XIII ET symposium, an incomplete selection of thepresented large facilities



Organization of the Instrument Science

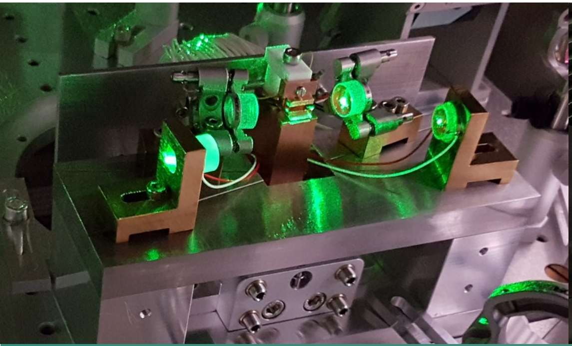


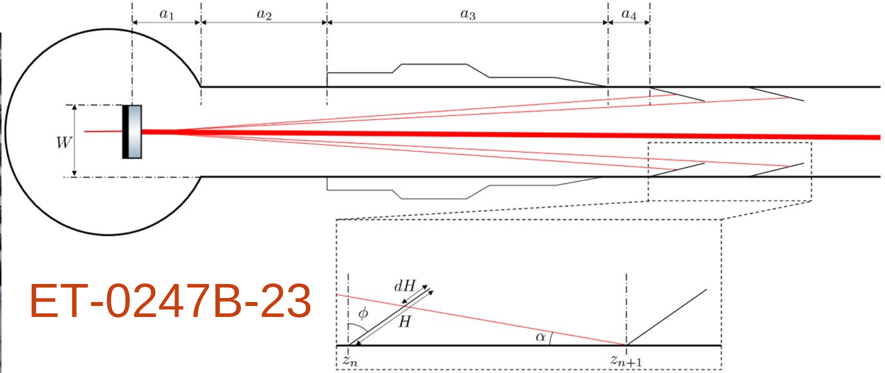
Optics

Squeezing
- Same target as Virgo_nEXT: 10dB
- For ET-HF @1064nm:
  - Reduction of loss sources
  - Study of in-vacuum squeezing source
  - 1 filter cavity (1 km ?)
- For ET-LF @1550nm or 2µm:
  - Development of squeezing source
  - 2 filter cavities (1 km ?)
  - Study of coupled filter cavities

Laser
- ET-HF => Input: 500-700 W @ 1064nm needs coherent beam combination
- ET-LF => Input: 3-5 W @ 1550nm or 2µm with low noise, different technologies explored like fiber laser

Scattered light
- Baffles study: number, position, size, etc.





ET-0247B-23

Interferometer (1)

Sensitivity curves ET-0007B-23

- Update wrt 2011 Conceptual Design Report and 2020 Design Report Update
- Started for COBA
- More realistic technologies and noise sources

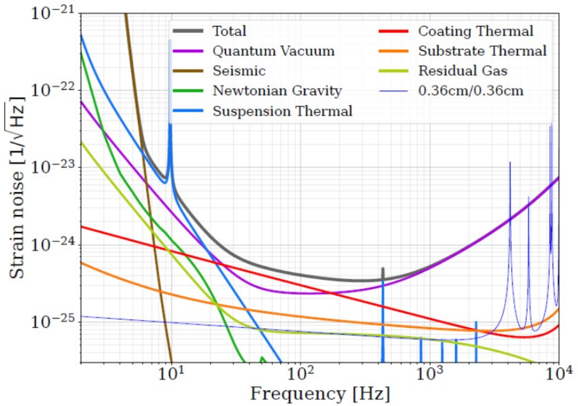


Figure 1: Strain noise budget of the HF detector. Noise traces shown in this figure correspond to a single interferometer with an intersection angle of 90 degrees ("L" shape).

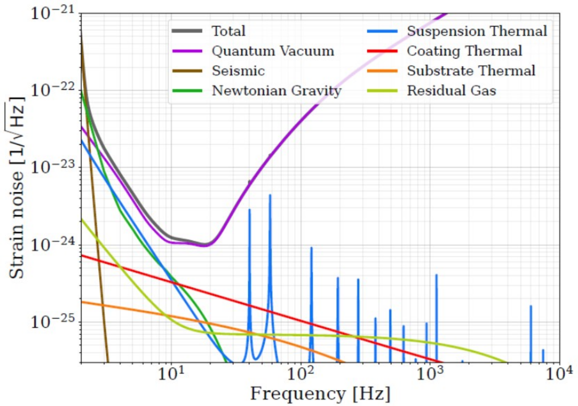
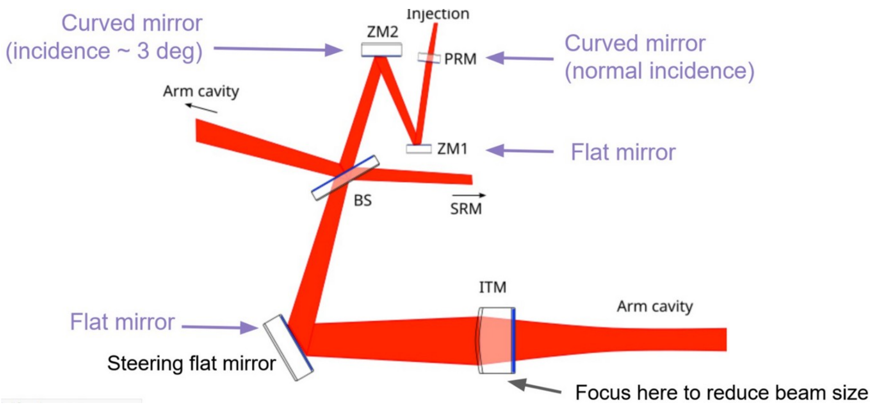


Figure 2: Strain noise budget of the LF detector. Noise traces shown in this figure correspond to a single interferometer with an intersection angle of 90 degrees ("L" shape).

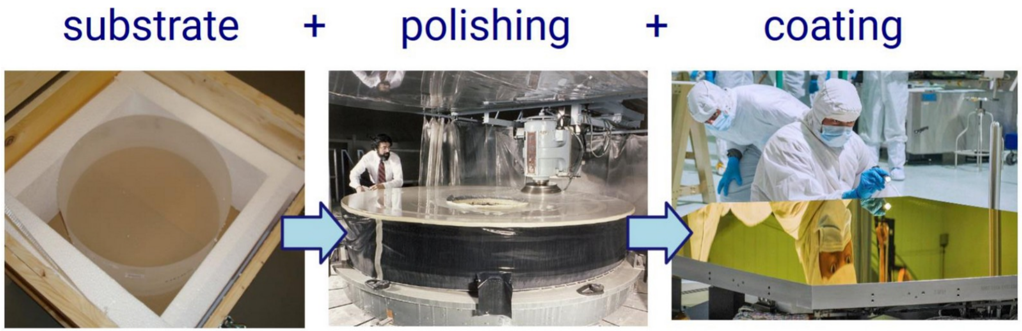
Optical design

- Work on central ET-HF parts
- Stable recycling cavities
- Symmetrical cavities for Power Recycling and Signal Recycling ?
- Common work with Virgo and Cosmic Explorer



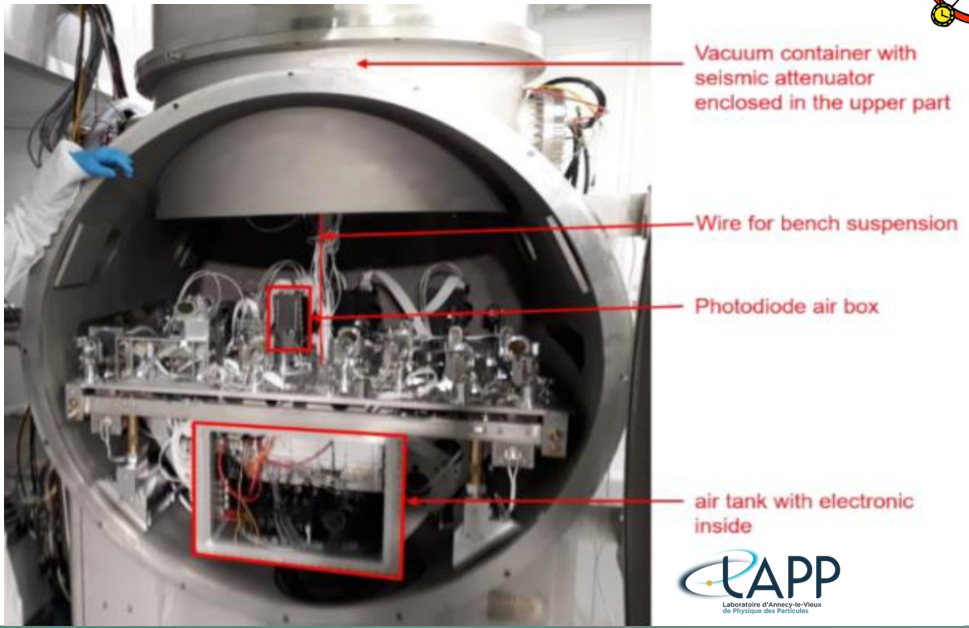
Interferometer (2)

Mirrors
- ET-HF: 62cm diameter and 200 kg
  => fused silica almost on the shelf
- ET-LF: 45cm diameter and ~200 kg
  => 2 options not on shelf:
  - sapphire used in KAGRA
  - silicon



Piece of glass for Virgo — *Polishing of the mirror for the Hubble space telescope* — *Inspection of the mirrors of the James Webb telescope*

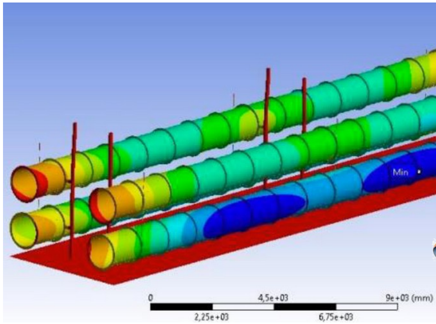
Data acquisition
- Plan to move digital demodulation out of the air tank
- Synchronization using White Rabbit

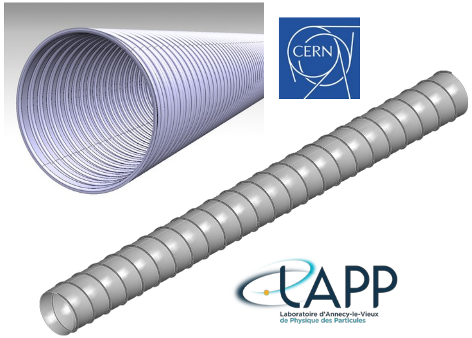


Vacuum and Cryogenics (1)

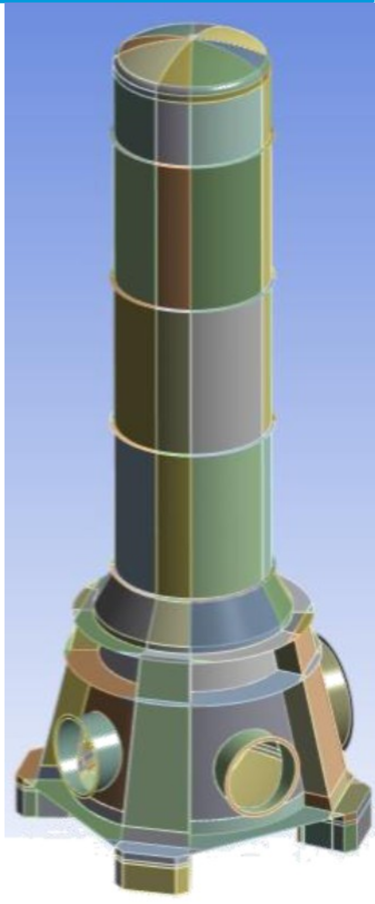
Selected topics

Beam pipes
- Agreement with CERN to design the vacuum pipes (TDR + prototype)
- 4 vacuum tubes of 1m diameter per tunnel
- ~50 years lifespan expected
- Virgo as a baseline: 3 designs under consideration
- Undergoing discussions with industry





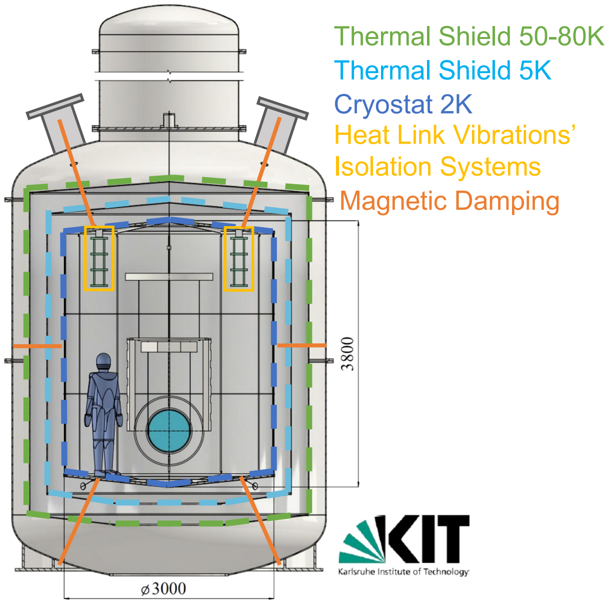
Towers
- Design of ET-HF towers adapted from the Virgo towers
- Modal analysis undergoing
- Optimization of the weight and resonance frequency
- Design of ET-LF towers still need to be discussed depending on suspension chain and cryostat design

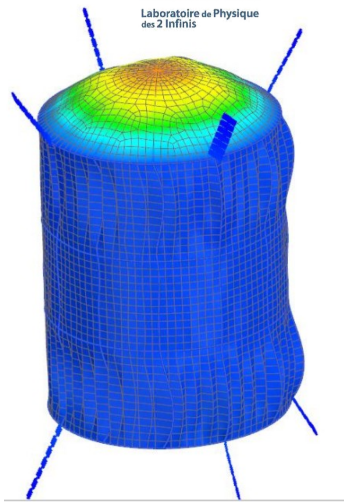


Vacuum and Cryogenics (2)

Cryostat ET-0272A-22

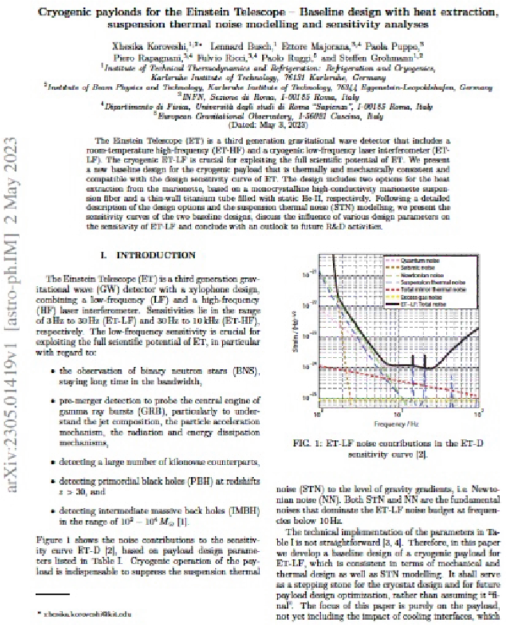
- Active cooling of the 2 external thermal shields
- Superfluid Helium-II cooling of inner shield





ET-LF Payload

- Design for heat extraction with low suspension thermal noise
- Allow for large mirrors



Cryogenic payloads for the Einstein Telescope – Baseline design with heat extraction, suspension thermal noise modelling and sensitivity analyses

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The Einstein Telescope (ET) is a third generation gravitational wave detector that includes a room-temperature high-frequency (ET-HF) and a cryogenic low-frequency laser interferometer (ET-LF). The cryogenic ET-LF is crucial for exploiting the full scientific potential of ET. We present a new baseline design for the cryogenic payload that is thermally and mechanically consistent and compatible with the design sensitivity curve of ET. The design includes two options for the heat extraction from the marionette, based on a monocrystalline high-conductivity marionette suspension fiber and a thin-wall titanium tube filled with static He-II, respectively. Following a detailed description of the design options and the suspension thermal noise (STN) modelling, we present the sensitivity curves of the two baseline designs, discuss the influence of various design parameters on the sensitivity of ET-LF and conclude with an outlook to future R&D activities.

I. INTRODUCTION

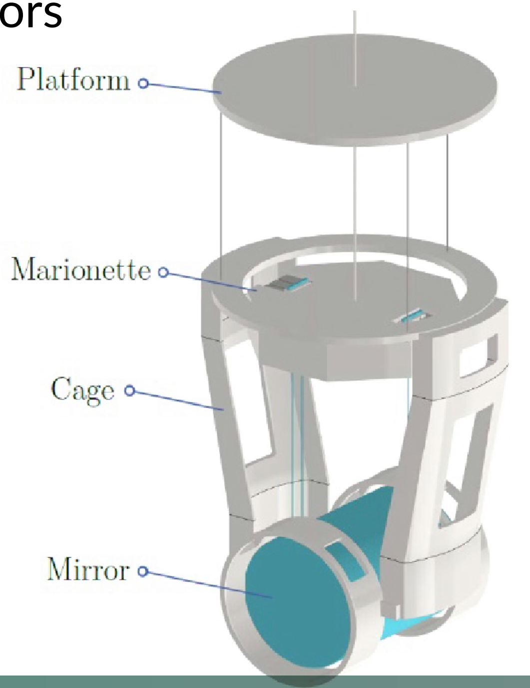
The Einstein Telescope (ET) is a third generation gravitational wave (GW) detector with a xylophone design, combining a low-frequency (LF) and a high-frequency (HF) laser interferometer. Sensitivities lie in the range of 3 Hz to 30 Hz (ET-LF) and 30 Hz to 10 kHz (ET-HF), respectively. The low-frequency sensitivity is crucial for exploiting the full scientific potential of ET, in particular with regard to:

- the observation of binary neutron stars (BNS), staying long time in the bandwidth,
- pre-merger detection to probe the central engine of gamma ray bursts (GRB), particularly to understand the jet composition, the particle acceleration mechanism, the radiation and energy dissipation mechanisms,
- detecting a large number of kilonovae counterparts,
- detecting primordial black holes (PBH) at redshifts $z > 30$, and
- detecting intermediate massive back holes (IMBH) in the range of $10^2 - 10^4\,M_\odot$ [1].

Figure 1 shows the noise contributions to the sensitivity curve ET-D [2], based on payload design parameters listed in Table I. Cryogenic operation of the payload is indispensable to suppress the suspension thermal noise (STN) to the level of gravity gradients, i.e. Newtonian noise (NN). Both STN and NN are the fundamental noises that dominate the ET-LF noise budget at frequencies below 10 Hz.

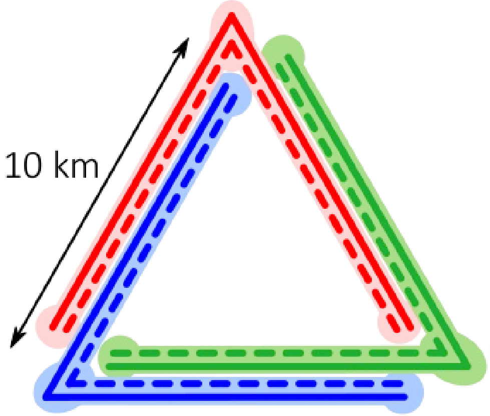
FIG. 1: ET-LF noise contributions in the ET-D sensitivity curve [2].

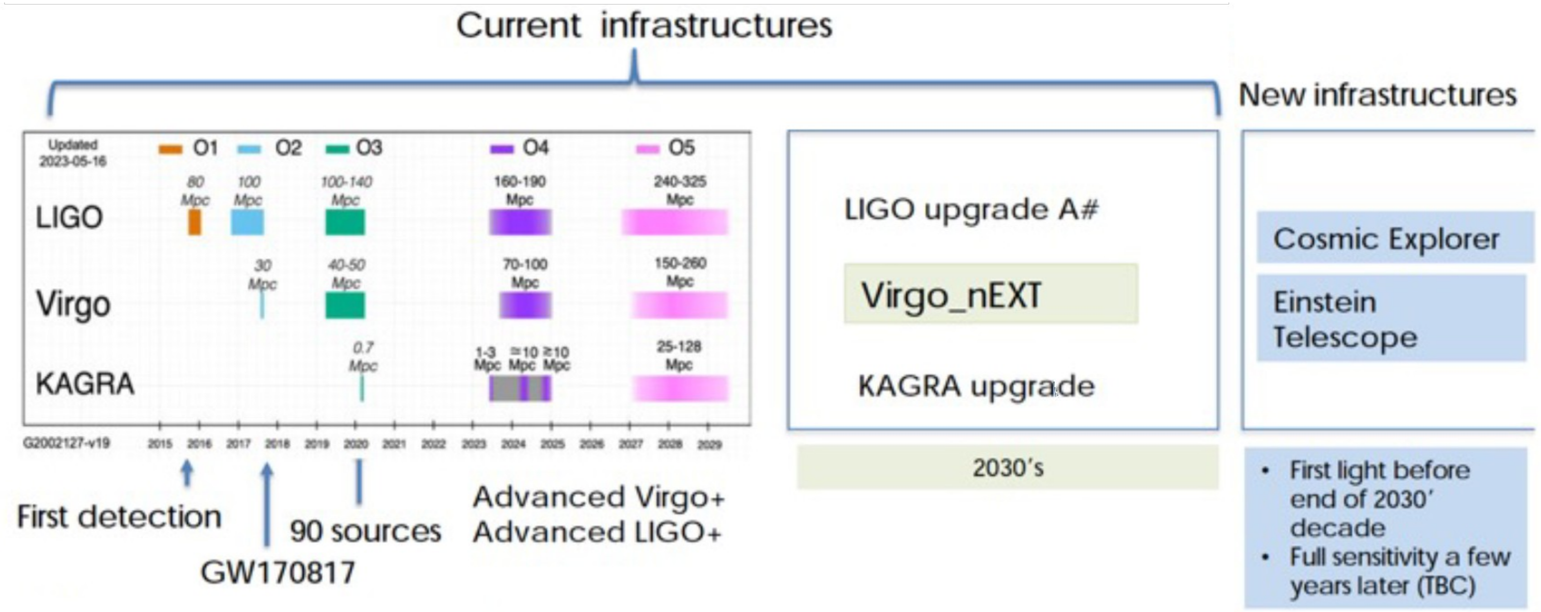
The technical implementation of the parameters in Table I is not straightforward [3, 4]. Therefore, in this paper we develop a baseline design of a cryogenic payload for ET-LF, which is consistent in terms of mechanical and thermal design as well as STN modelling. It shall serve as a stepping stone for the cryostat design and for future payload design optimization, rather than assuming it "final". The focus of this paper is purely on the payload, not yet including the impact of cooling interfaces, which



Conclusion

- ET-HF can be build on the experience acquired on LIGO/Virgo detectors and on-going R&D
- Some experience of KAGRA is useful for ET-LF but there are still many studies needed
- Lots of R&D in Europe and well organized collaboration work
- The path is long towards the first observation



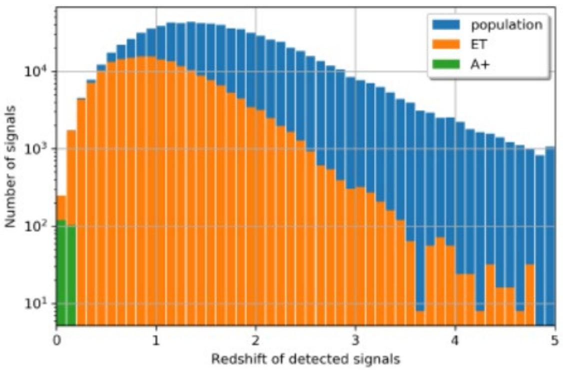


Thank you

ET EINSTEIN TELESCOPE

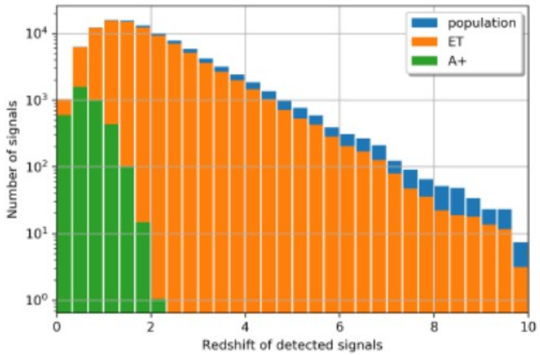
ET Sensitivity

BINARY NEUTRON-STAR MERGERS



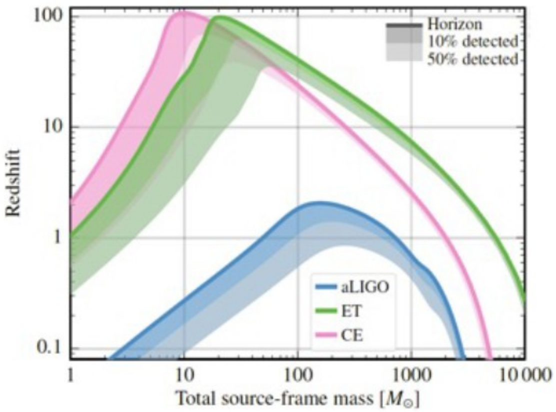
~1 detection every 30s

BINARY BLACK-HOLE MERGERS



- 10^5-10^6 BBH detections per year
- 10^4-10^5 BNS detections per year among which ~10-100 with EM counterparts
- High SNR events
- Overlapping events

- ET 1st Mock Data challenge in progress
- 40 papers since 2022 summer on ET science



Suspensions

Goal:

- reduce seismic and vibration noise in the detection band;
- reduce the broadband RMS motion of the suspension systems
- provide slow large-scale position and angle control of each suspended optical element.

Design starting from Virgo Super Attenuators

- ET-LF would require 17m height (instead of 8m)
- Undergoing studies to reduce this height to 10m (with some active control)

Monolithic suspension

- ET-HF => fused silica well known
- ET-LF => silicon or sapphire under study

Cryogenic payload => see Vacuum and Cryogenic