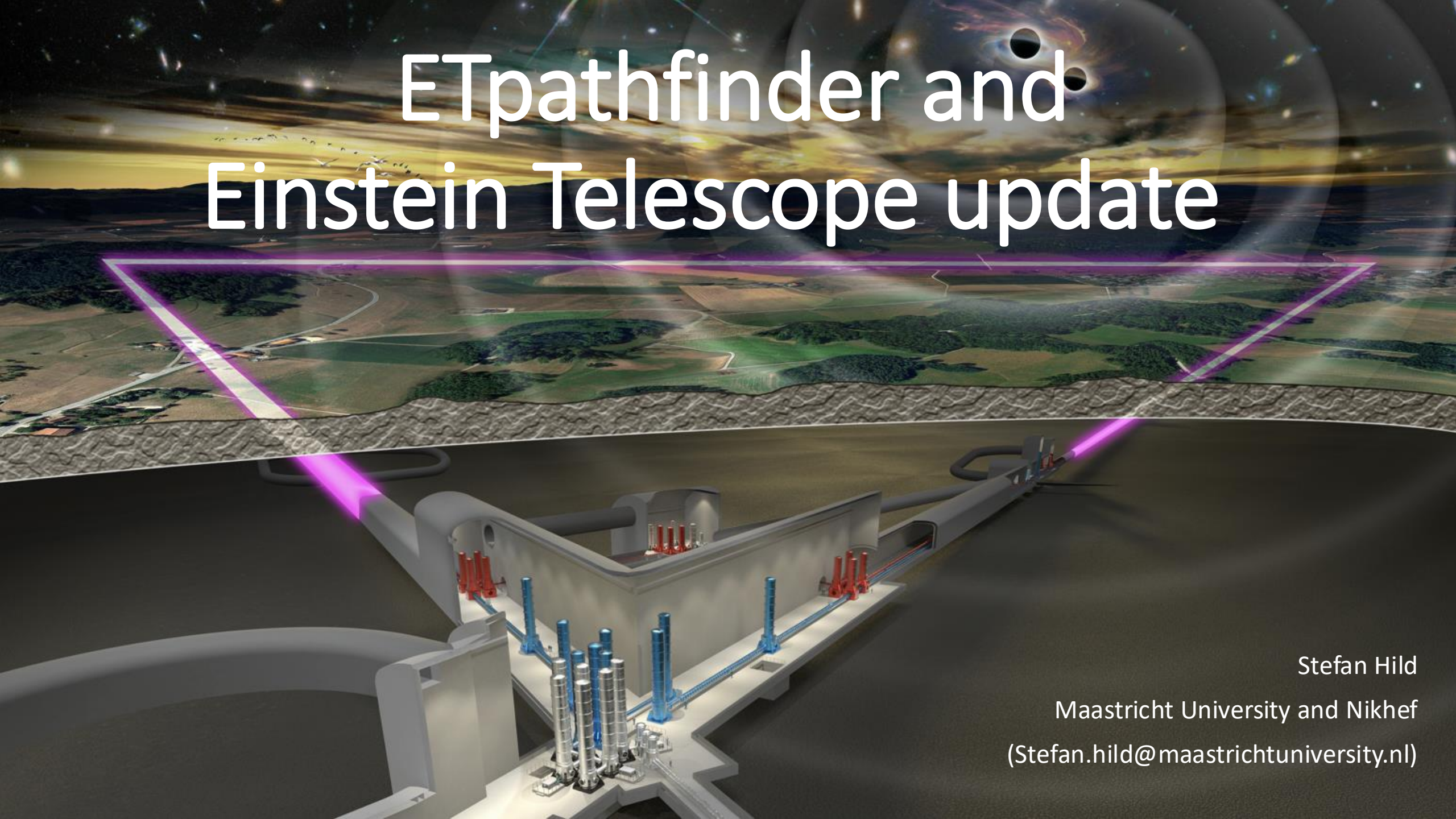
ETpathfinder and Einstein Telescope update



Stefan Hild

Maastricht University and Nikhef

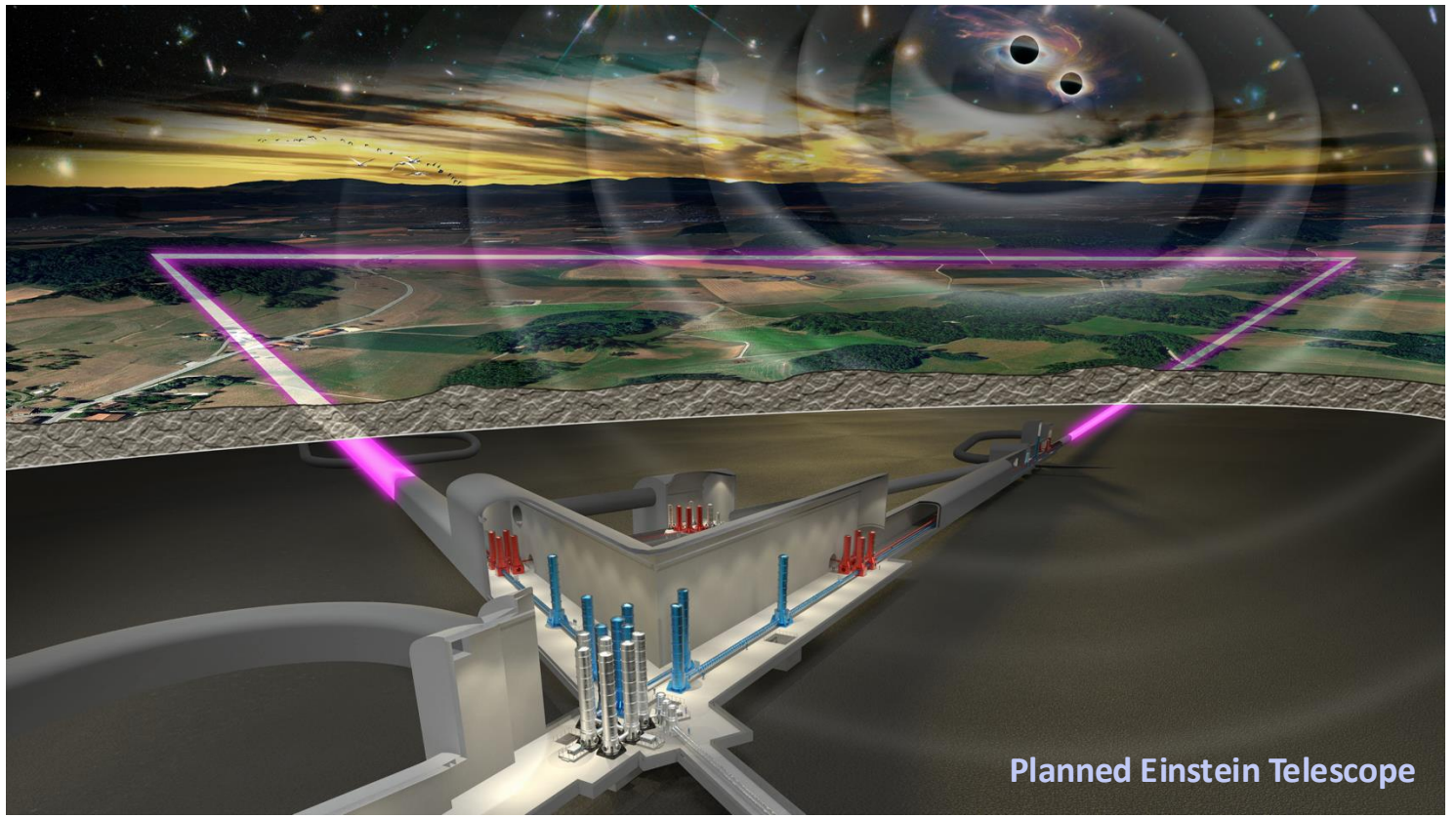
(Stefan.hild@maastrichtuniversity.nl)

Overview

- Reminder of ET corner stones
- Recent developments in ET-land
- Status of ETpathfinder
- Future ambitions of ETpathfinder

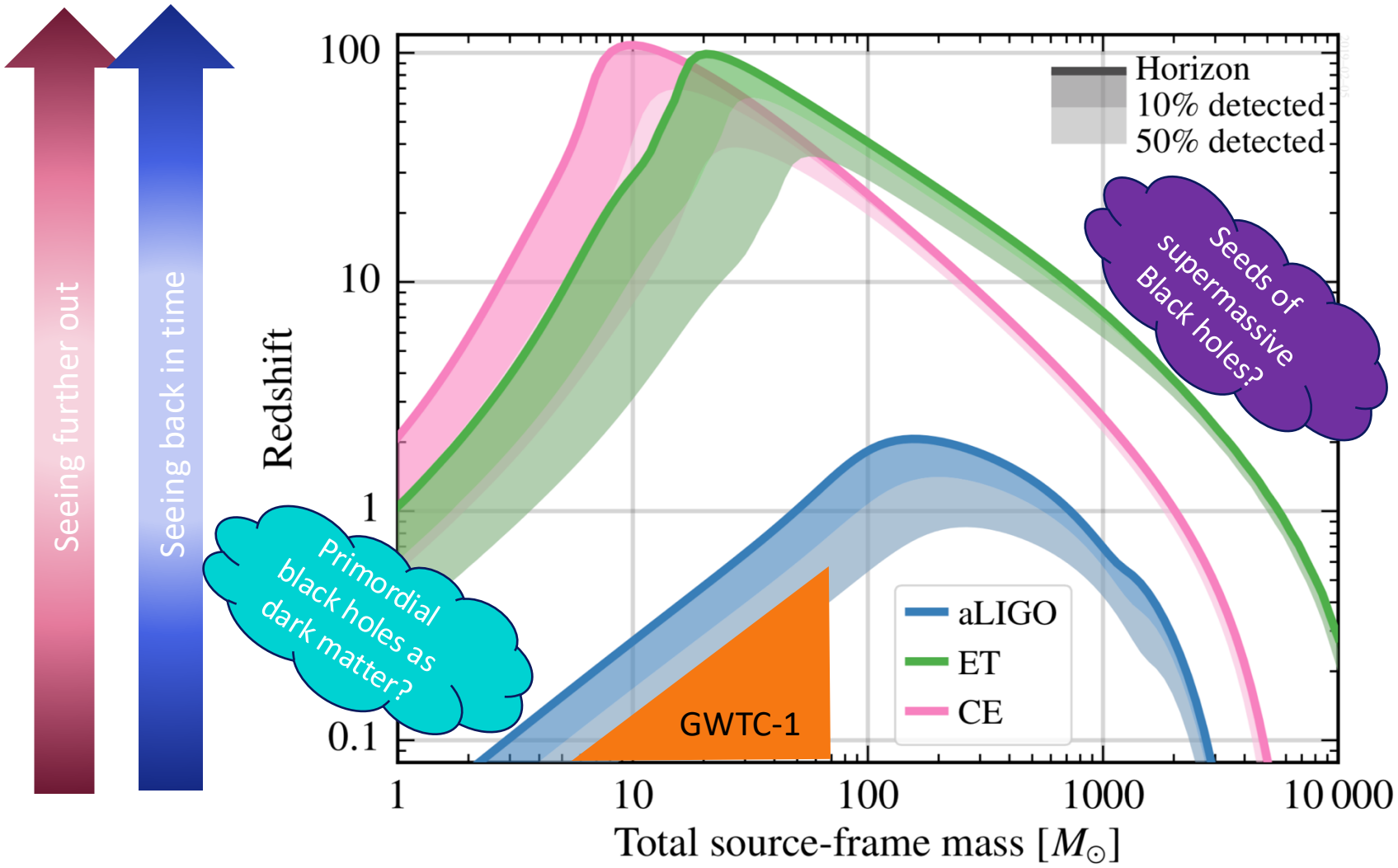
15 minutes too short for either of these (rather complex) topics, so please excuse me going fast and staying very brief

From current detectors to ET



- Current detectors observe about one signal per week.
- ET will observe about 100.000 to 1.000.000 binary black holes mergers per year! And many other new sources => discovery space!

Reaching for the full cosmos!

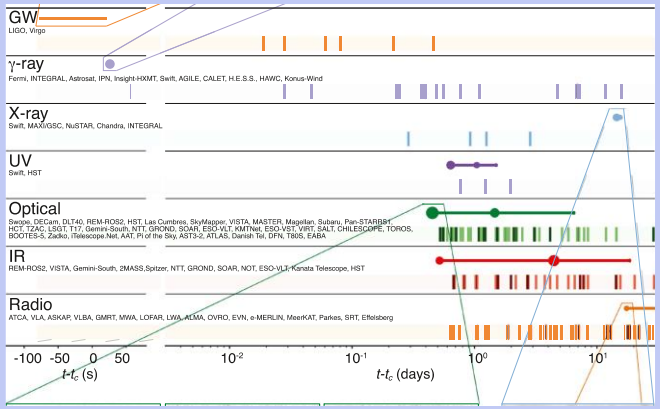


Binary Coalescences Overview:

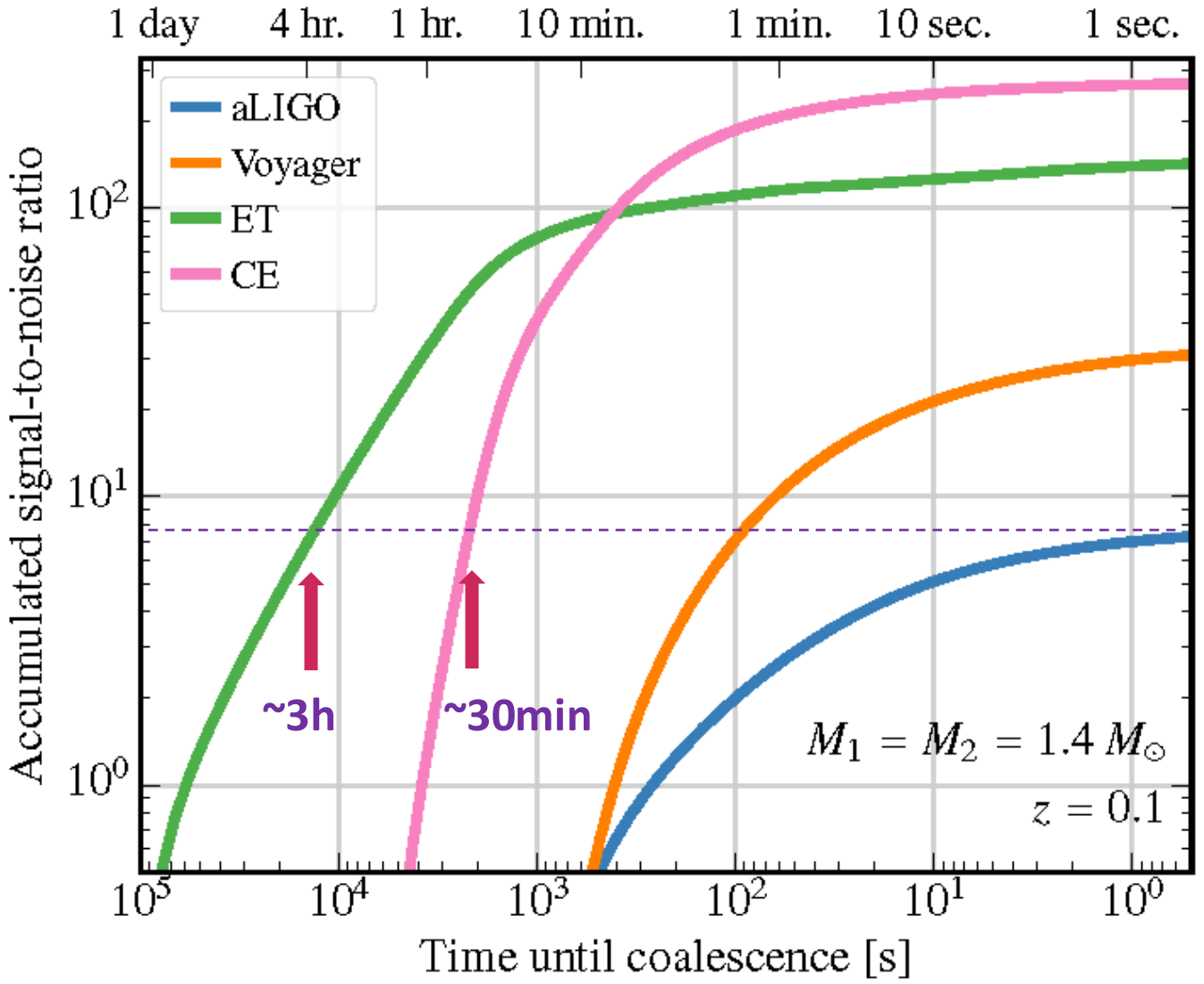
- Census of stellar and intermediate-mass BBH population over full Universe, 10^5-10^6 events per year;
- High SNR events will provide excellent precision to do accurate test of GR, nature of the BH, strong-field dynamics, black hole no-hair theorem etc;
- Extend the range of observed BBH masses towards >1,000M_{sol} and <1$M_{sol;}$
- Observe several 10,000 binary neutron star mergers per year.
- ET will determine NS EOS.

Seeing BNS with GWs before merger!

GW170817: Optical counterpart located ~6 hours after merger.

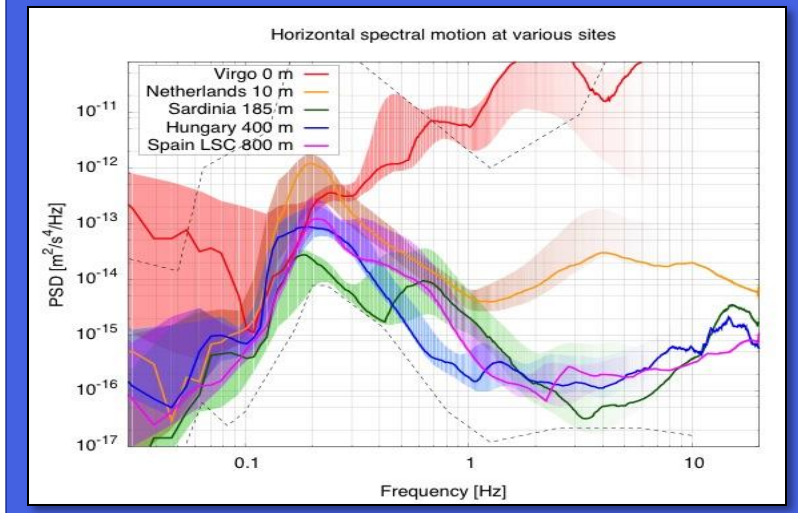


With ET we have a chance to observe the kilonova right from the beginning, observe fast radio emission and pin down the engine of short GRBs.



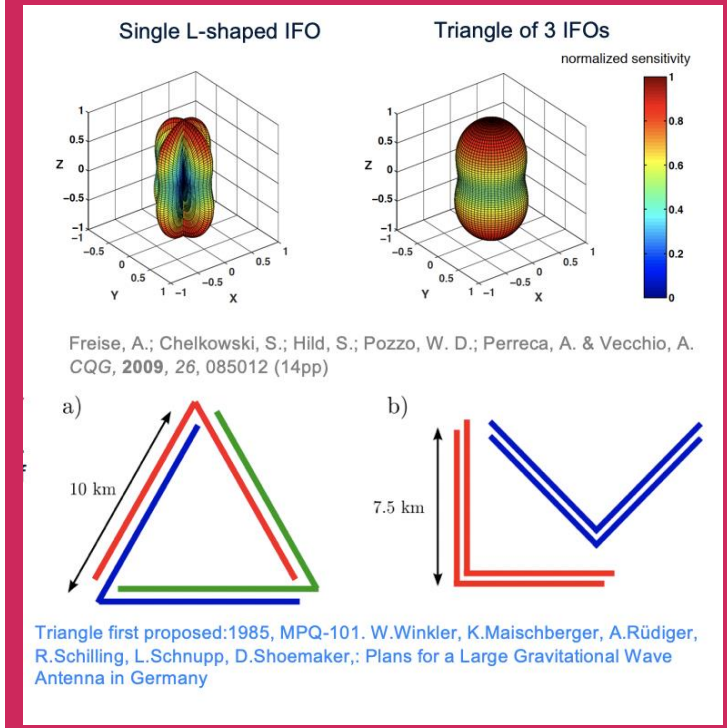
Credit: Evan Hall

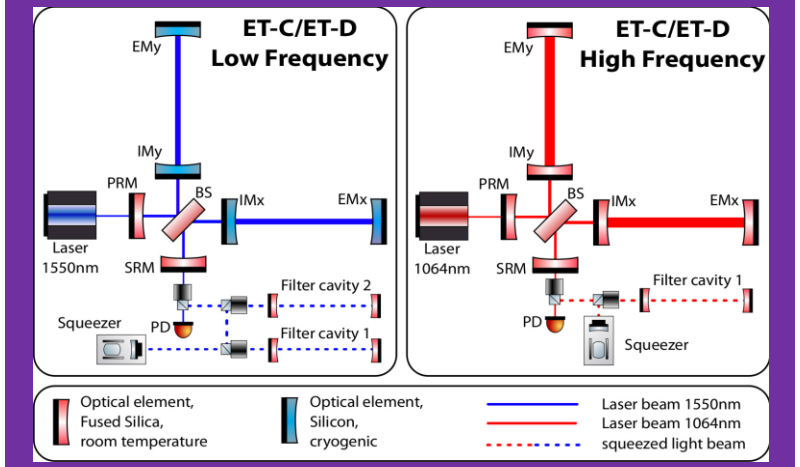
Key concepts of ET in a single slide



Underground location for Reduction of seismic and atmospheric GGN
+ long baseline

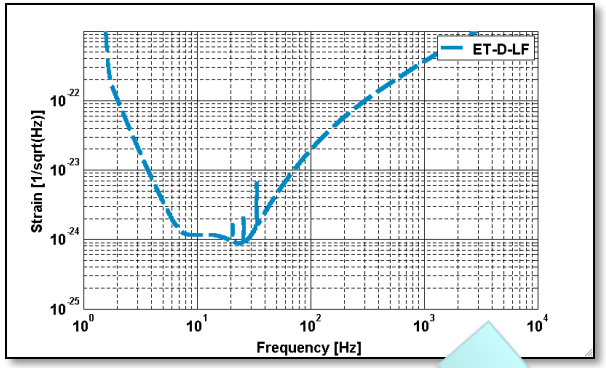
Triangular for full sky coverage and redundancy

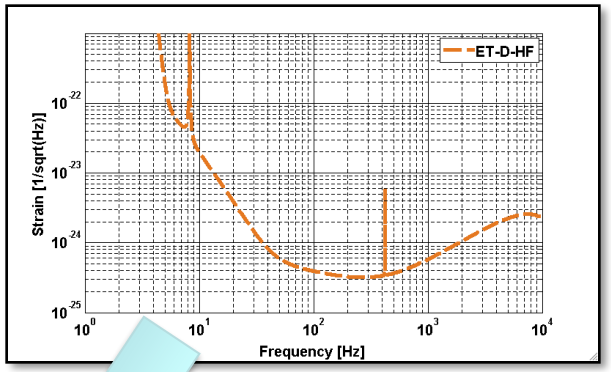




Xylophone concept

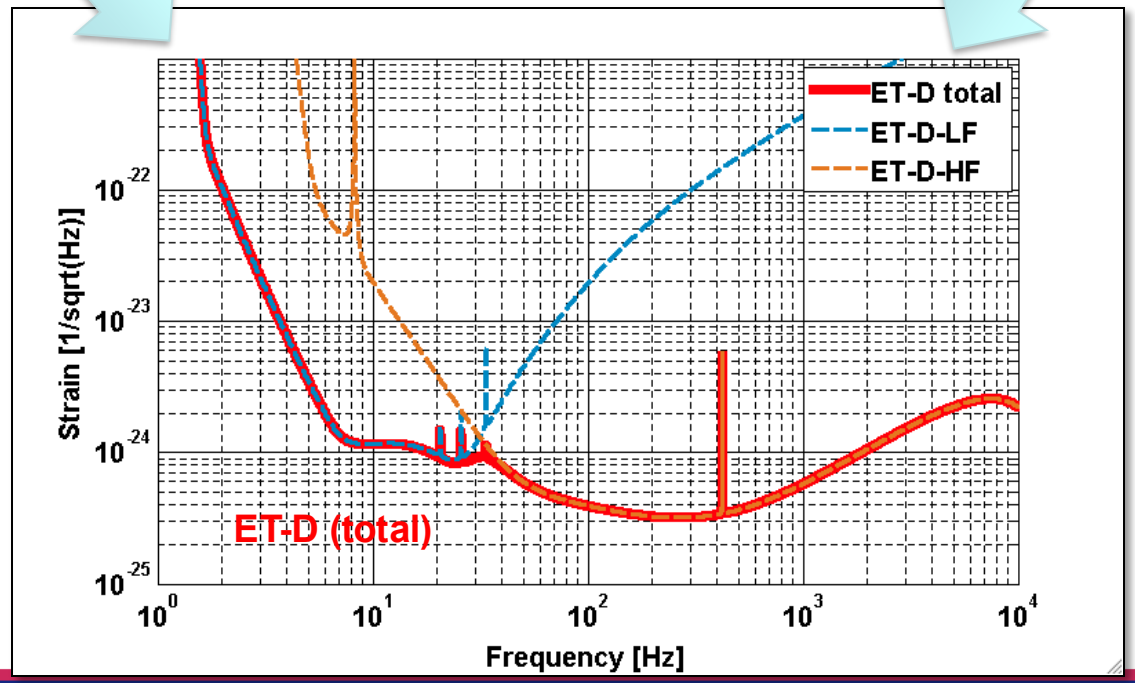
Combining 2 IFOs





ET-D-LF

ET-D-HF



Overview

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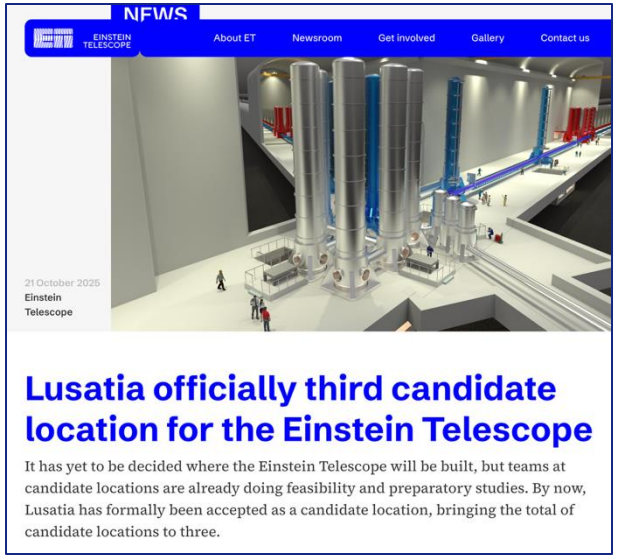
Many challenges still ahead

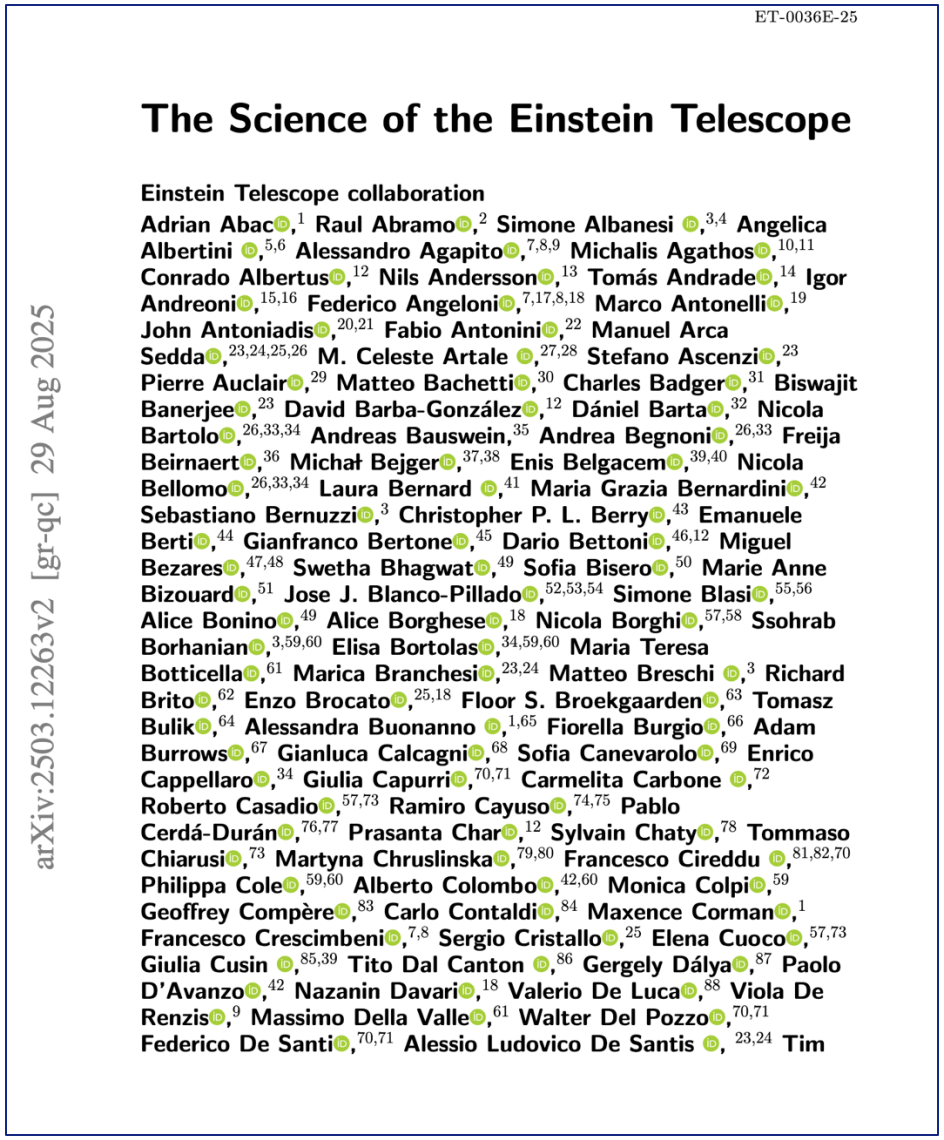
- **ET very attractive!** (3 official site candidates being pushed)
- **ET very flexible!** (Different geometries available to do marvelous science.)

- Still many technologies challenges that need development!
- Still many challenges to converge on functioning governance.



Science Blue Book

- Amazing work (especiallu inside the observational science board!) to bring this together.
- **899 pages showing what ET will be able to do …**
- https://arxiv.org/pdf/2503.12263



ET-0036E-25

The Science of the Einstein Telescope

Einstein Telescope collaboration

Adrian Abac[1] Raul Abramo[2] Simone Albanesi[3,4] Angelica Albertini[5,6] Alessandro Agapito[7,8,9] Michalis Agathos[10,11] Conrado Albertus[12] Nils Andersson[13] Tomás Andrade[14] Igor Andreoni[15,16] Federico Angeloni[7,17,8,18] Marco Antonelli[19] John Antoniadis[20,21] Fabio Antonini[22] Manuel Arca Sedda[23,24,25,26] M. Celeste Artale[27,28] Stefano Ascenzi[23] Pierre Auclair[29] Matteo Bachetti[30] Charles Badger[31] Biswajit Banerjee[23] David Barba-González[12] Dániel Barta[32] Nicola Bartolo[26,33,34] Andreas Bauswein,[35] Andrea Begnoni[26,33] Freija Beirnaert[36] Michał Bejger[37,38] Enis Belgacem[39,40] Nicola Bellomo[26,33,34] Laura Bernard[41] Maria Grazia Bernardini[42] Sebastiano Bernuzzi[3] Christopher P. L. Berry[43] Emanuele Berti[44] Gianfranco Bertone[45] Dario Bettoni[46,12] Miguel Bezares[47,48] Swetha Bhagwat[49] Sofia Bisero[50] Marie Anne Bizouard[51] Jose J. Blanco-Pillado[52,53,54] Simone Blasi[55,56] Alice Bonino[49] Alice Borghese[18] Nicola Borghi[57,58] Ssohrab Borhanian[3,59,60] Elisa Bortolas[34,59,60] Maria Teresa Botticella[61] Marica Branchesi[23,24] Matteo Breschi[3] Richard Brito[62] Enzo Brocato[25,18] Floor S. Broekgaarden[63] Tomasz Bulik[64] Alessandra Buonanno[1,65] Fiorella Burgio[66] Adam Burrows[67] Gianluca Calcagni[68] Sofia Canevarolo[69] Enrico Cappellaro[34] Giulia Capurri[70,71] Carmelita Carbone[72] Roberto Casadio[57,73] Ramiro Cayuso[74,75] Pablo Cerdá-Durán[76,77] Prasanta Char[12] Sylvain Chaty[78] Tommaso Chiarusi[73] Martyna Chruslinska[79,80] Francesco Cireddu[81,82,70] Philippa Cole[59,60] Alberto Colombo[42,60] Monica Colpi[59] Geoffrey Compère[83] Carlo Contaldi[84] Maxence Corman[1] Francesco Crescimbeni[7,8] Sergio Cristallo[25] Elena Cuoco[57,73] Giulia Cusin[85,39] Tito Dal Canton[86] Gergely Dálya[87] Paolo D'Avanzo[42] Nazanin Davari[18] Valerio De Luca[88] Viola De Renzis[9] Massimo Della Valle[61] Walter Del Pozzo[70,71] Federico De Santi[70,71] Alessio Ludovico De Santis[23,24] Tim

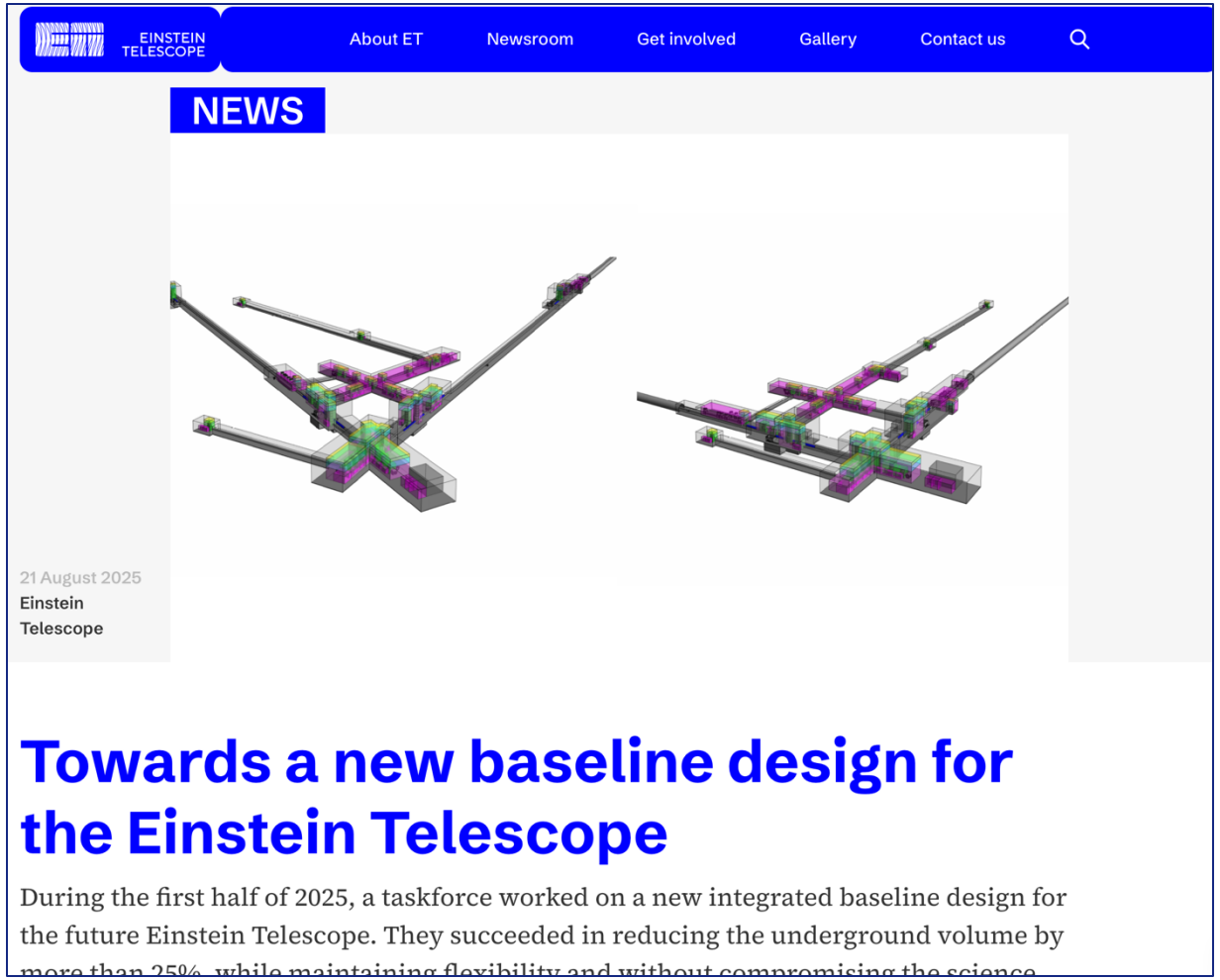
arXiv:2503.12263v2 [gr-qc] 29 Aug 2025

Design Task Force output

- During first half of 2025, ETO organised a task force on updaing the infrastructure design.

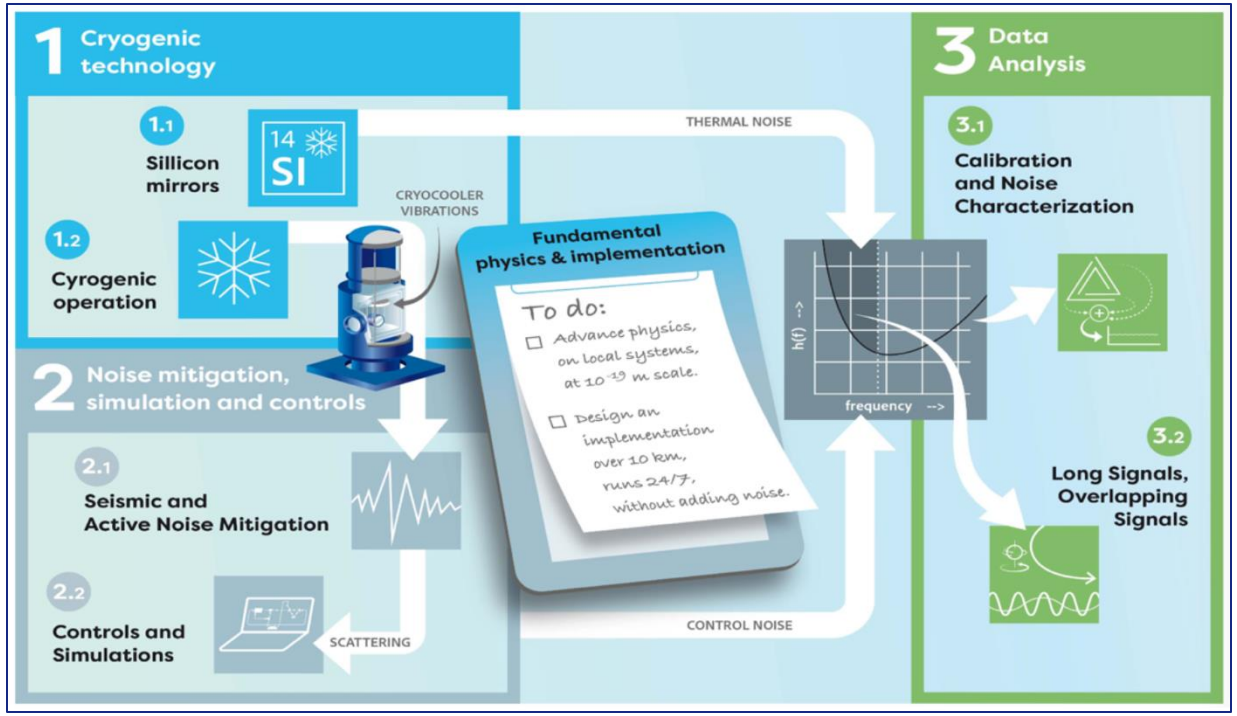
- Nice, joint effort of many people from ET collaboration working in project mode under ETO organisational methods.

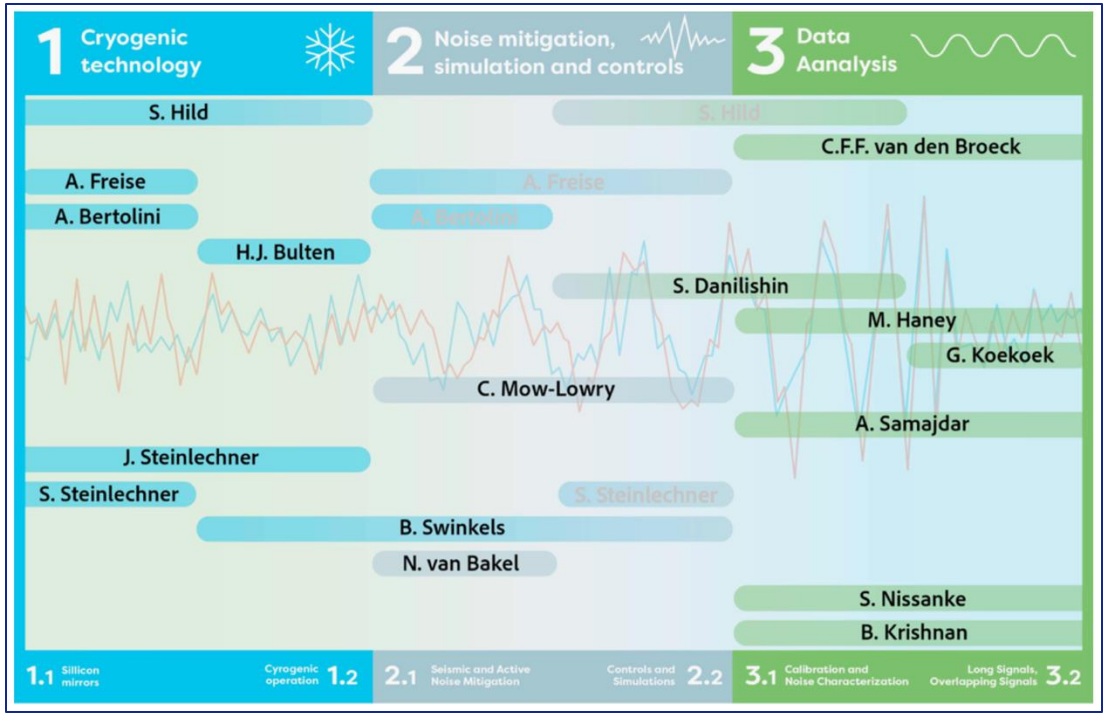
- https://gitlab.et-gw.eu/et/eto/eto-task-force-detector-layout-2025-comments-from-etc



Dutch ENW XL grant: Enabling ET

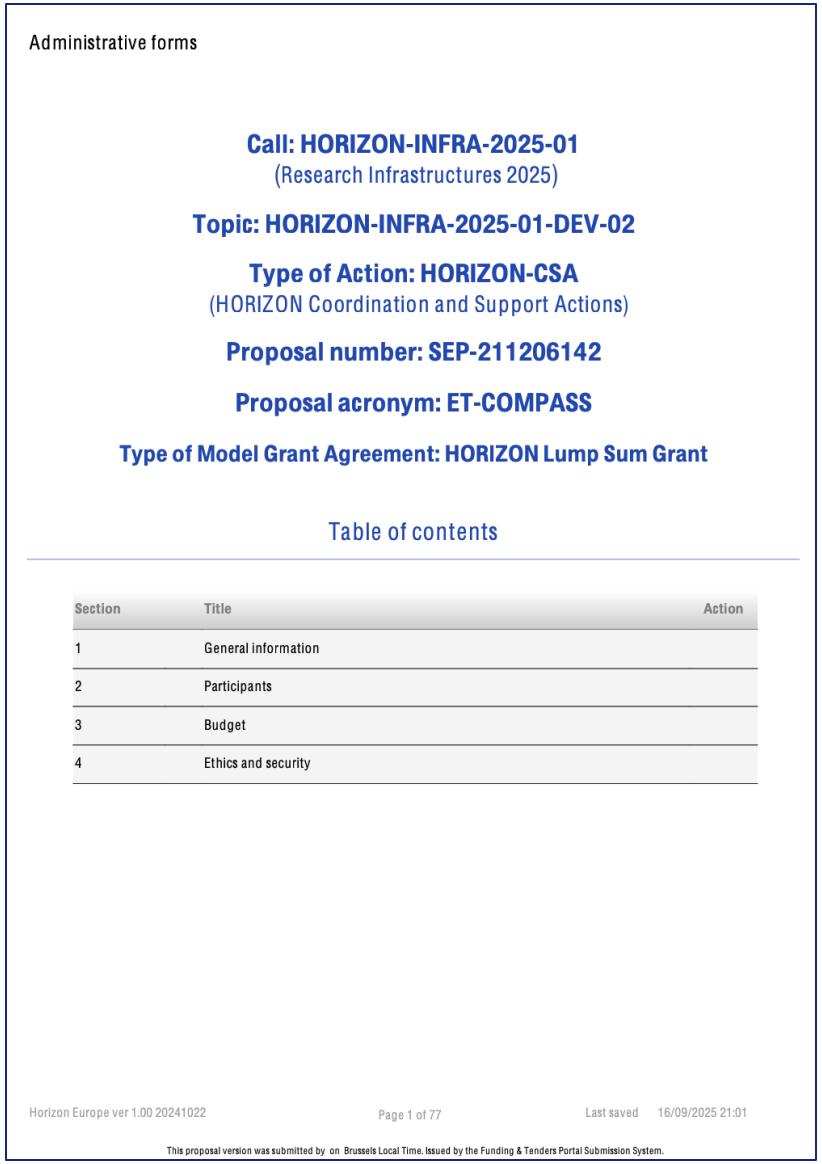
6 PhD stduents (4 years each) and 6 postdoc (each 2 years). Many of them having recently started or starting soon.





Many ongoing activities (selection)

- Started writing of preliminary detector TDR
  - Writing team forum, every Friday 11am-12noon
- CERN working on beam pipe TDR
- CERN contracts for civil infrastrutcure design starting up
- ET program about to being definded
- New EU grant: INFRA-DEV (successor of ET-PP submitted)



Administrative forms

Call: HORIZON-INFRA-2025-01
(Research Infrastructures 2025)

Topic: HORIZON-INFRA-2025-01-DEV-02

Type of Action: HORIZON-CSA
(HORIZON Coordination and Support Actions)

Proposal number: SEP-211206142

Proposal acronym: ET-COMPASS

Type of Model Grant Agreement: HORIZON Lump Sum Grant

Table of contents

Section	Title	Action
1	General information	
2	Participants	
3	Budget	
4	Ethics and security	

Horizon Europe ver 1.00 20241022 Page 1 of 77 Last saved 16/09/2025 21:01

This proposal version was submitted by on Brussels Local Time. Issued by the Funding & Tenders Portal Submission System.

Overview

- Reminder of ET corner stones
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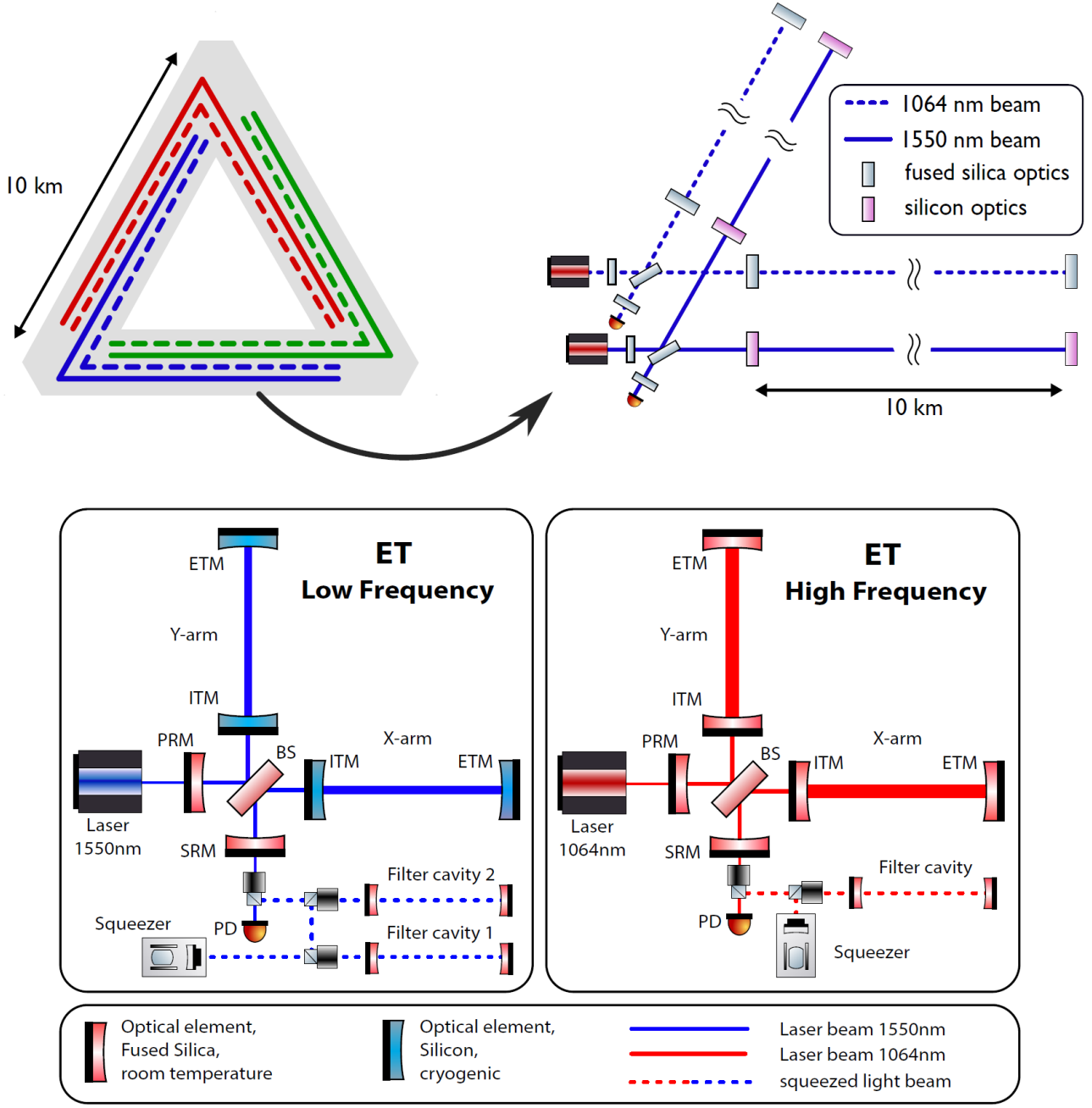
While we preparing for Einstein Telescope ….
ETpathfinder (and ET-Cristal etc) is already reality!

Einstein Telescope design

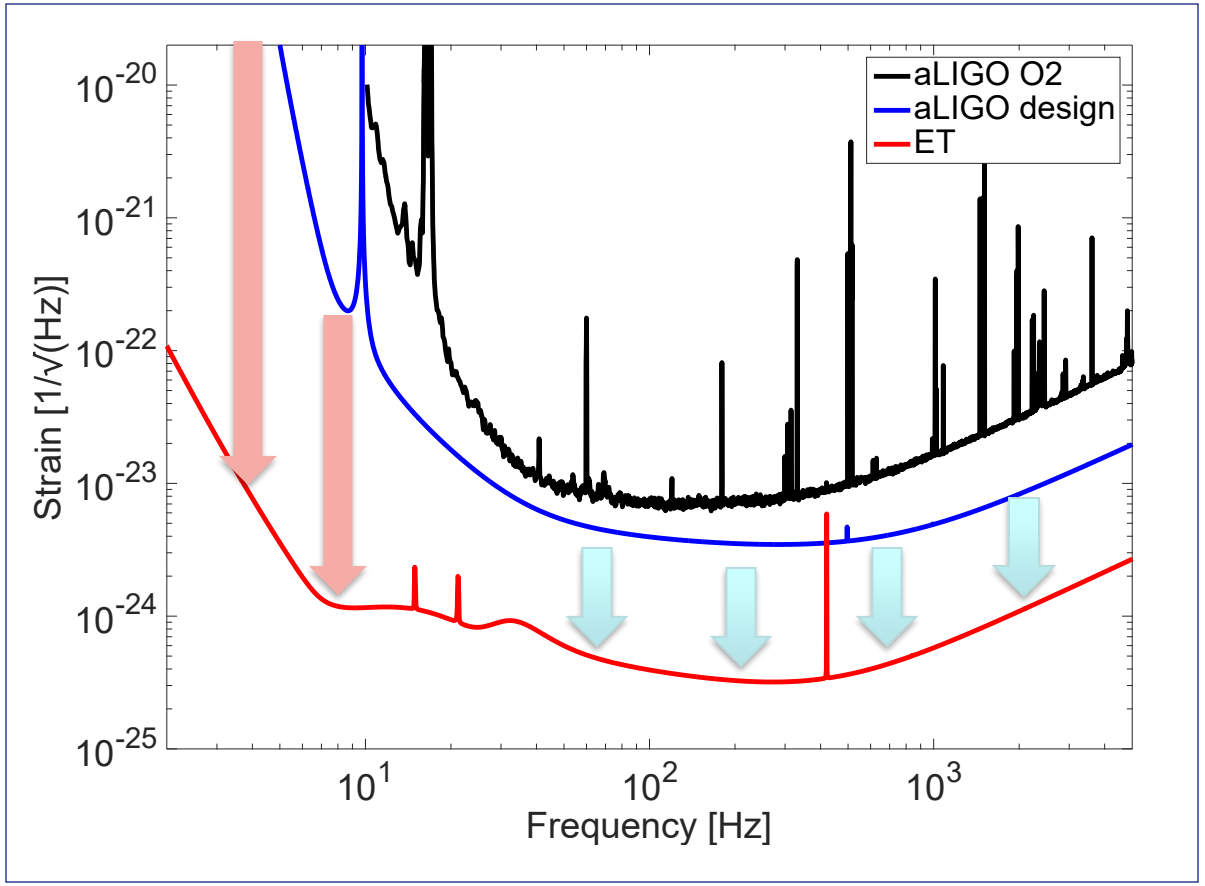
Parameter	ET-HF	ET-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10-20 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	45 cm/ 57 cm
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase (rad)	tuned (0.0)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



LF part of ET is where the challenges are!

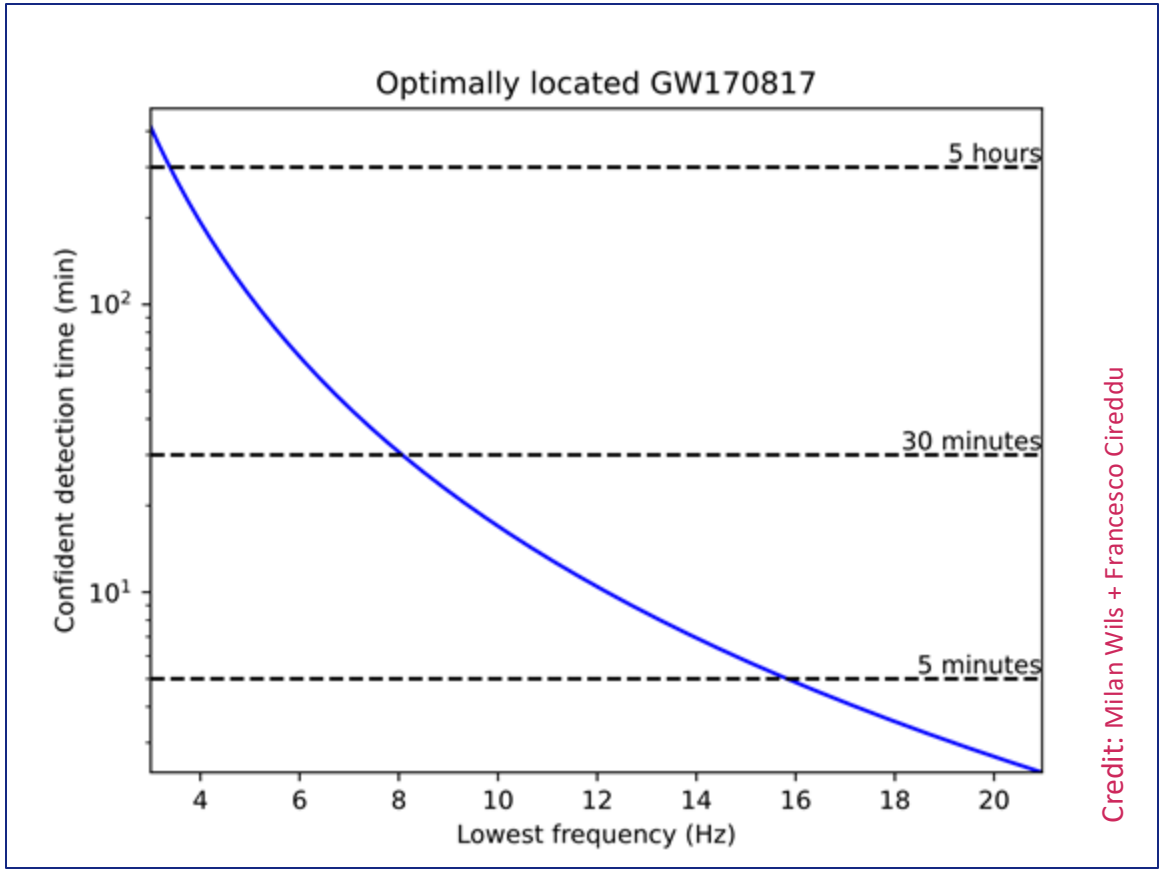
The Low-Frequency Challenge:

- At mid and high frequency we aim for factor ~10 improvement.
- At low frequency we are aiming for factors 100, 1000 and more improvement.
- **Needs fundamental changes in technology and concepts, that need testing and prototyping.**



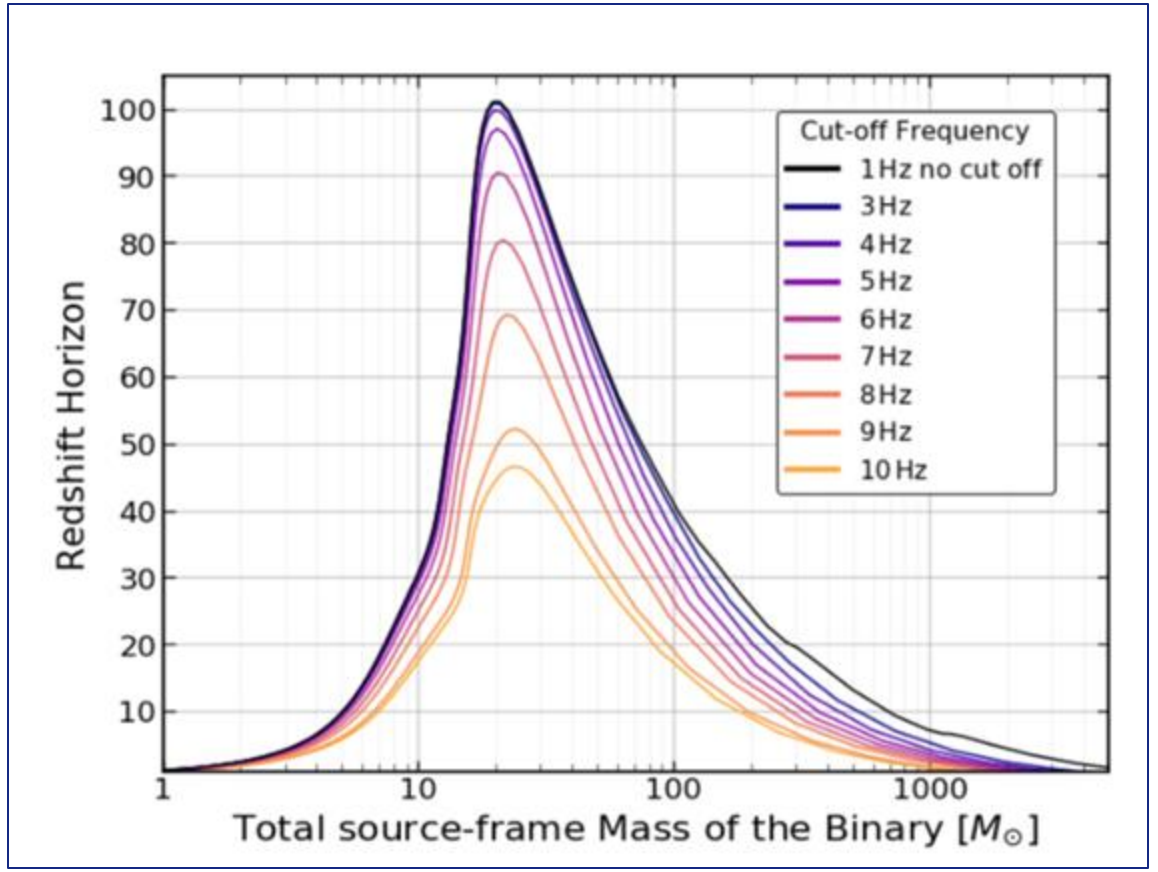
Low frequencies “making the difference”

Pre-warning time for BNS



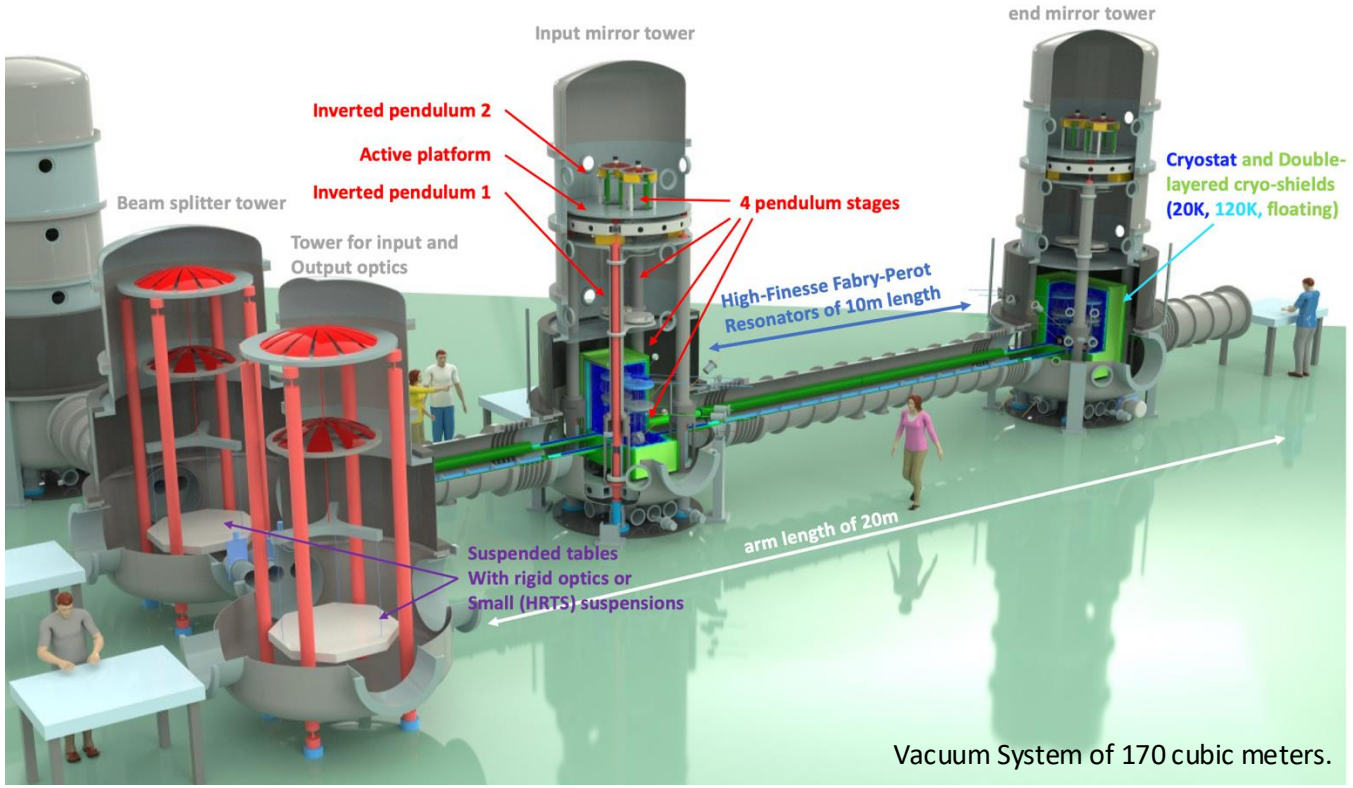
Credit: Milan Wils + Francesco Cireddu

Heavy & red shifted binaries



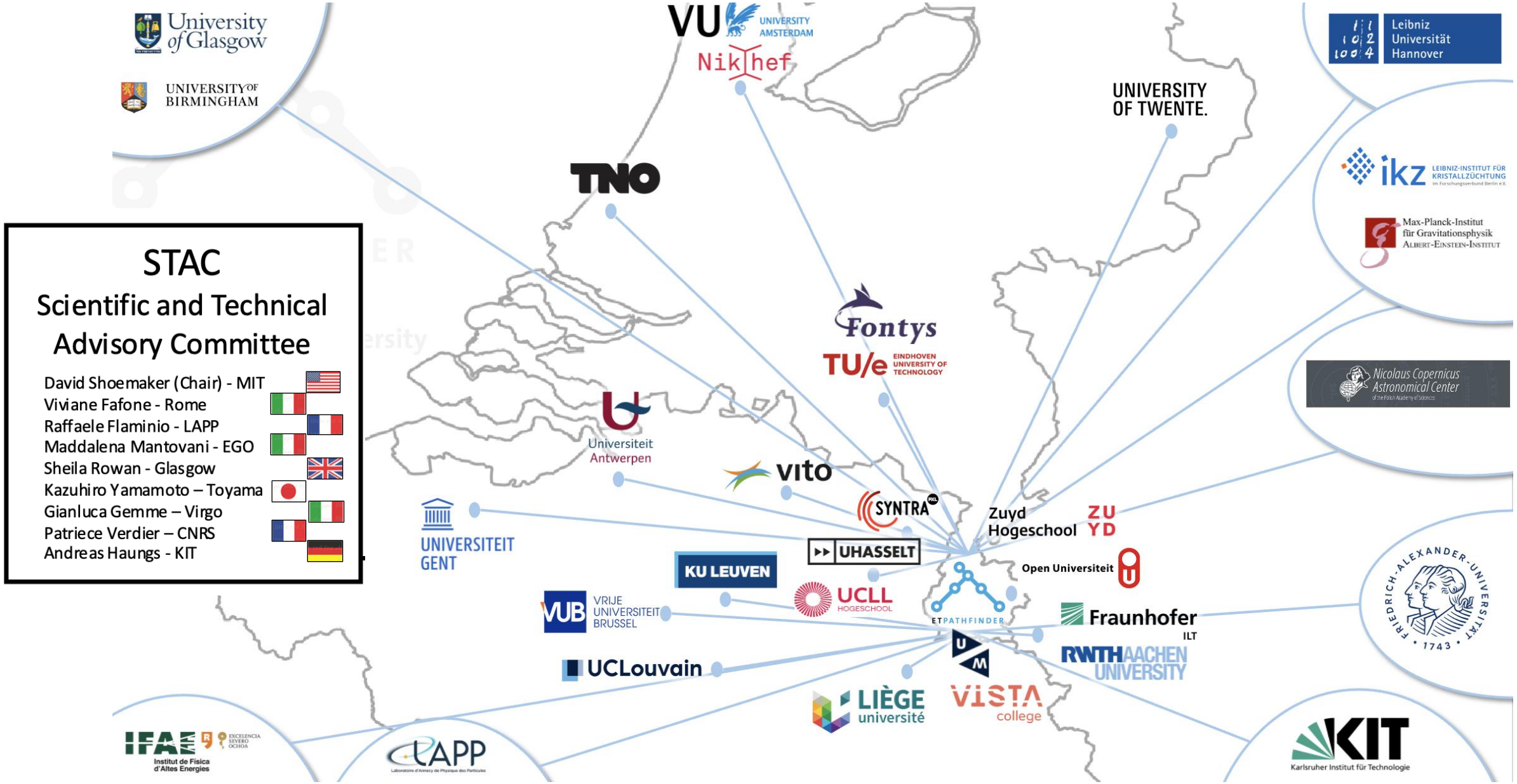
ETpathfinder Overview

- Facility for testing and validating new ET technology in a low-noise, full-interferometer setup at 10^{-18}m level.
- Key aspects: Silicon mirrors (3 to 100+kg), cryogenics (cryogenic liquids and sorption coolers, water/ice management), “new” wavelengths (1550 and 2090nm), coatings … which cannot be tested by Virgo/LIGO
- 20+ research partners from NL/B/G/FR/SP/UK/PL
- Initial capital funding of 14.5 MEuro.
- Everyone (researcher/industry) welcome to Join (contact: S.hild@nikhef.nl).
- www.etpathfinder.eu



ETpathfinder Milestones

- Construction start in Jan 2020.
- Officially opened by Science Minister van Engelshoven in Nov 2021
- Focus point for ET ambitions in EMR.
- Will act as R&D center for ET for decades to come independent of site decision.
- Since 2024 strong industry consortia around ETapthfinder via NGF.
- 2025: SMART Skills Lab will start. (provinding skills training to SMEs also targetting MBO and HBO)
- Longterm ambition: Integration center for low frequency ET technologies



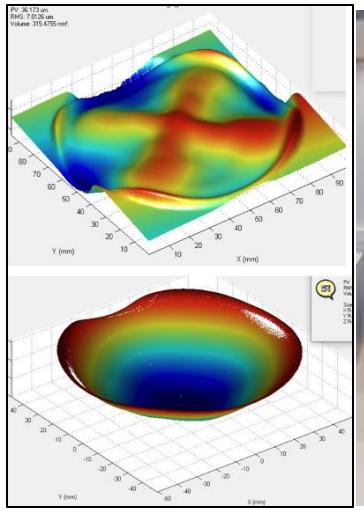
STAC

Scientific and Technical Advisory Committee

David Shoemaker (Chair) - MIT
Viviane Fafone - Rome
Raffaele Flaminio - LAPP
Maddalena Mantovani - EGO
Sheila Rowan - Glasgow
Kazuhiro Yamamoto – Toyama
Gianluca Gemme – Virgo
Patriece Verdier – CNRS
Andreas Haungs - KIT

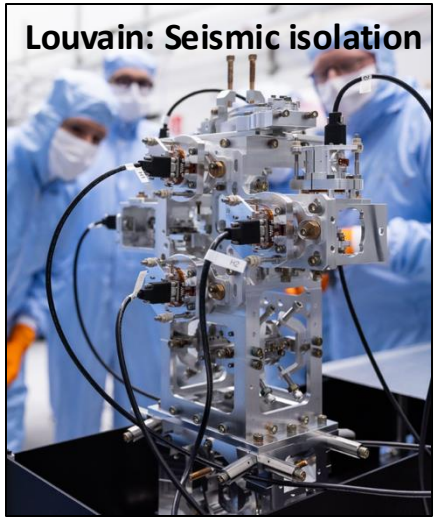
Belgium partners in ETpathfinder (some highlighst)

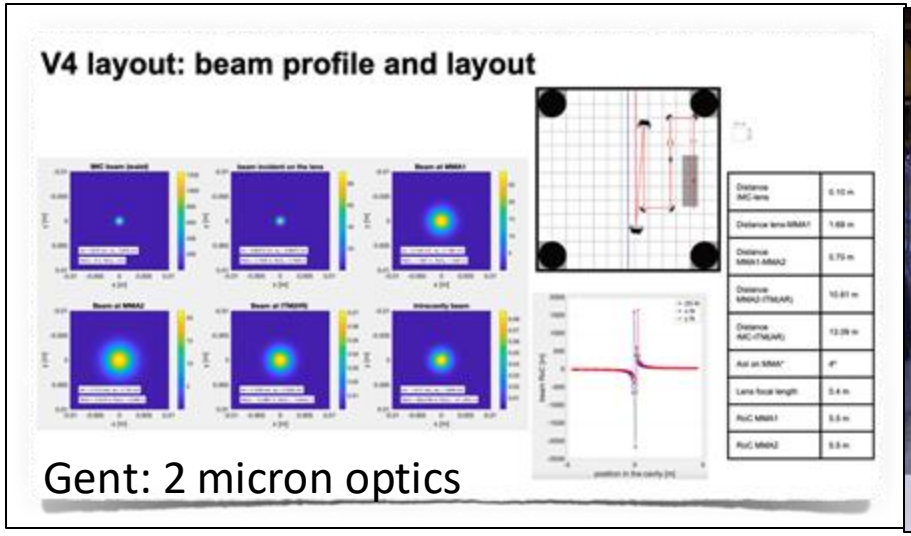
Antwerpen: Actuators, controls, electronics



Brussels/B-phot: mirror polishing + Photonics

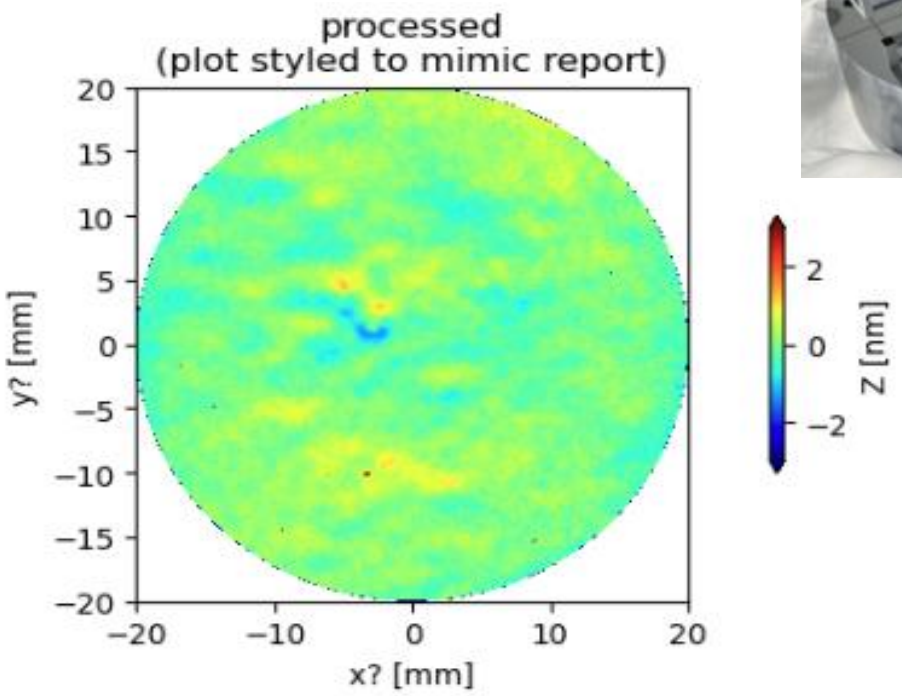
Leuven: Cystalline coatings

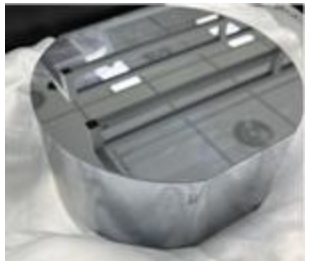




Gent: 2 micron optics

Silicon Results



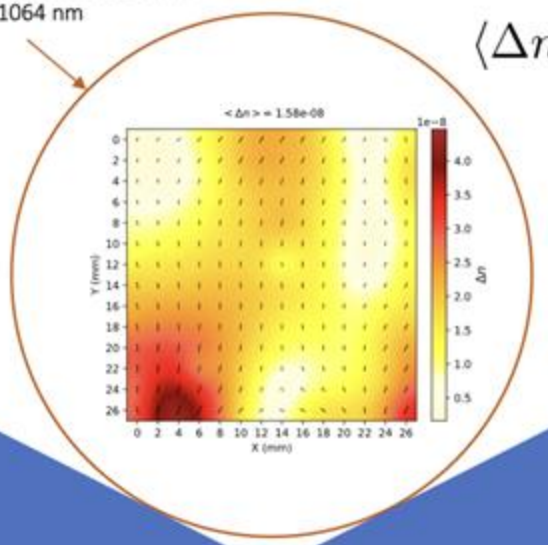


ET Pathfinder Silicon samples WW03-02*

Sample grown by IKZ, Berlin
Diameter: 5 cm; thickness: 5 mm
Measured at 1064 nm

The average birefringence is

$$\langle \Delta n \rangle = 1.58 \times 10^{-8}$$



Considering that, at the center, gravity contributes for

$$1.3 \times 10^{-8} < \Delta n_{\text{gravity}} < 2.2 \times 10^{-8}$$

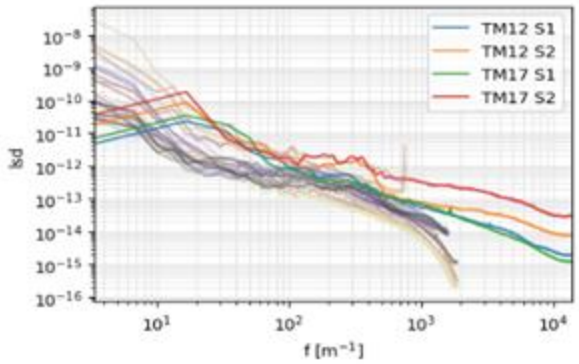
$$\Delta n_{\text{sample}} \lesssim 10^{-8}$$

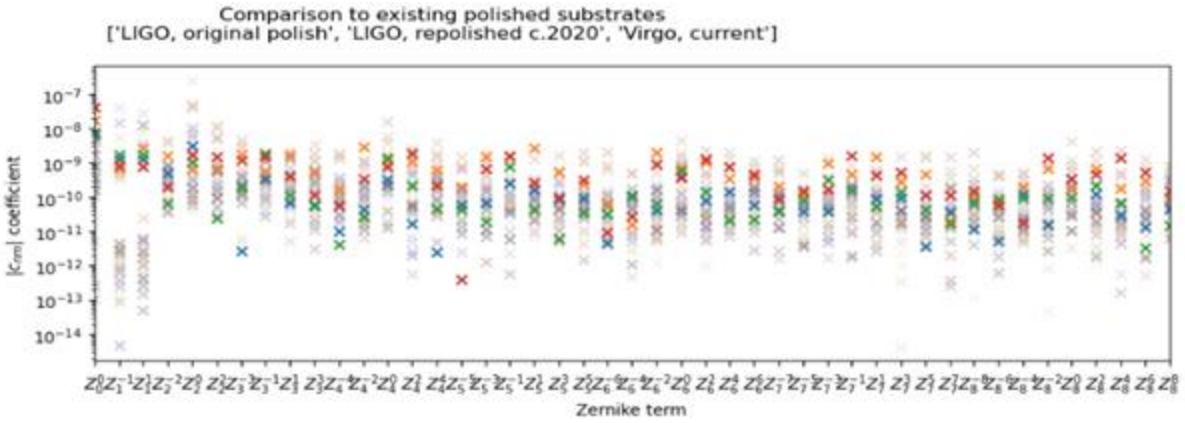
Finite element simulations are underway

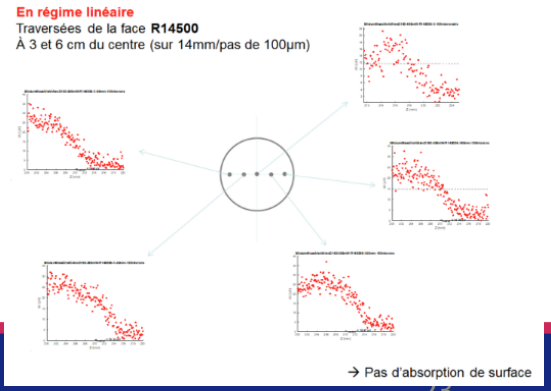
G. Zavattini, ET Symposium: Bologna, 28th May, 2025. 15

* Kindly lent to us by the ET-Maastricht group

- Measured two Si samples from the ET Maastricht group grown by IKZ – Berlin. These samples are extremely good with very low birefringence seemingly compatible with a requirement of Δn < 10^{-8}



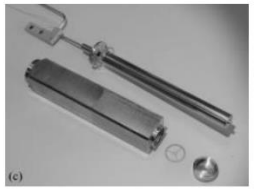




Roadmap sorption cryocooling for Einstein Telescope

1995
TRL 1
University of Twente sorption cryocooler R&D start

2001
TRL 2/3
Proof-of-concept Sorption cryocooler



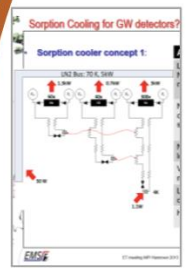
2007
TRL 4
ESA Darwin mission 10 mW @ 4.5 K demonstrator

2008
Kryoz founded by Pieter Lerou

2009
Cooll founded by Johannes Burger

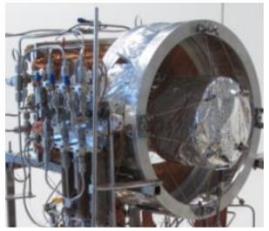
Industrialization

Academic



2013
TRL 4
ESA Darwin mission 25 mW @ 14.5 K

2013
Marcel ter Brake presents at 5th ET symposium



Industrialization

2014
TRL 6
Sorption cryocooler for Telecom

2014
TRL 4
METIS on E-ELT 0.4 W @ 8 K

2016
Kryoz joins Demcon Group

2017
TRL 5
ESA Darwin mission shaker testing

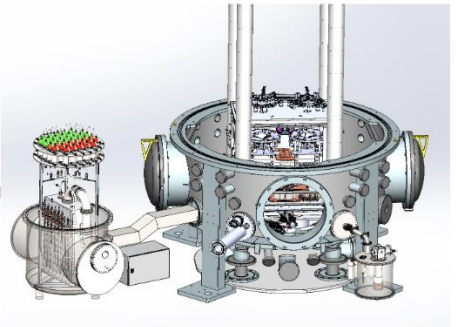
2018
TRL 6
Sorption system prototype

2021
TRL 9
JT crycooler

2024
TRL 9
Sorption domestic system

2024
Cryo consortium is formed

2026
TRL 6/7
Technology fully proven in ETpathfinder



2035
TRL 9
Technology implementation in ET

Sorption technology & Industrial supply chain qualified for ET

Academic to Industrialization

Example: Cryocooling for ET/ETpathfinder

Test facilities

Maastricht University

Cryogenic precooler

STIRLING CRYOGENICS

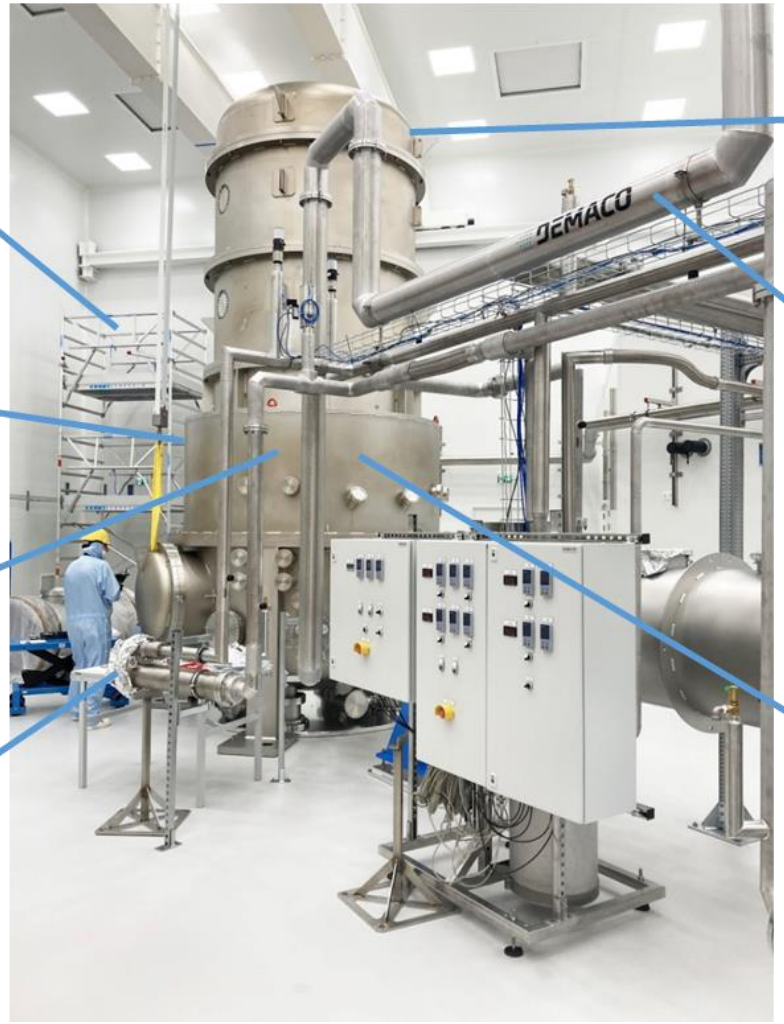
Cryogenic vibration suppression

JPE Driven by innovation

Universiteit Leiden

Cryogenic transfer lines

cryoworld advanced cryogenics



System Architect

Nikhef

LN_2 infrastructure

DEMACO

Zero-vibration Sorption Cryocooler

DEMCON

KRYOZ

UNIVERSITY OF TWENTE.

COOLL

Example:Cryocooling for ET/ETpathfinder

Einstein Telescoop - 10 Kelvin trillingsvrije cryokoeling

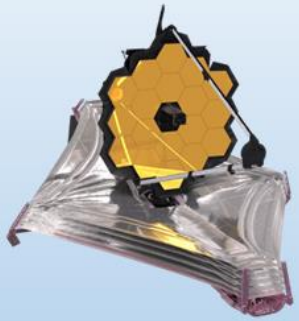
Life-sciences & materiaal onderzoek

(bio)sample onderzoek bij extreem lage temperaturen

Halfgeleider industrie

supergeleidende lineaire motoren voor wafer steppers

Ruimtevaart



cryogeen gekoelde optische sensoren in ruimtevaart satellieten

Quantum computing

(kosten) efficiënte Qubit cryokoeling voor quantum computers

Industry consortia working on ET technologies

Six new consortia funded in NL …

… activities started for similar schemes in Belgium

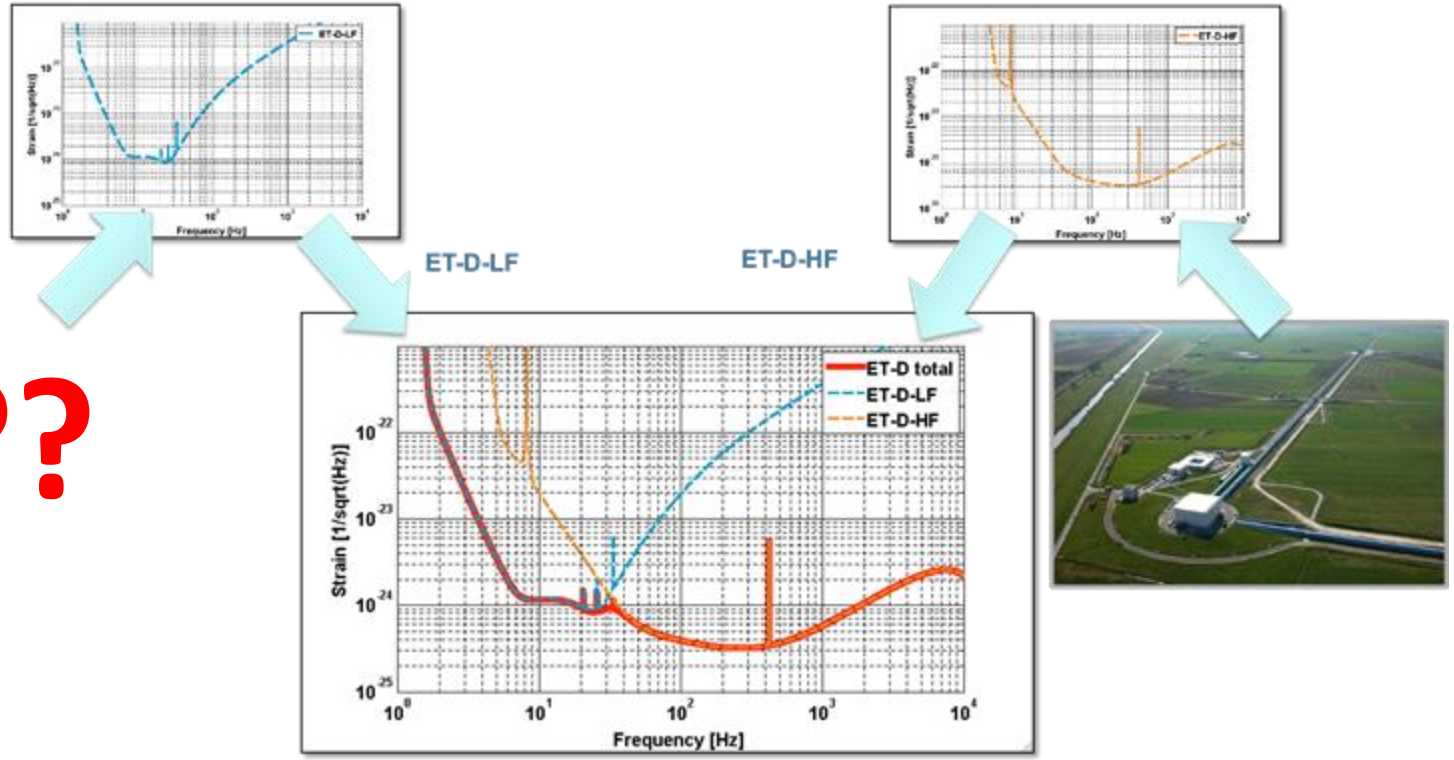
Overview

- Reminder of ET corner stones
- Recent developments in ET-land
- Status of ETpathfinder
- Future ambitions of ETpathfinder

15 minutes too short for either of these (rather complex) topics, so please excuse me going fast and staying very brief

Let’s look at what we learned from ETpathfinder installation

Key Question: Where and When do we want to do this essential work for ET-LF?



???

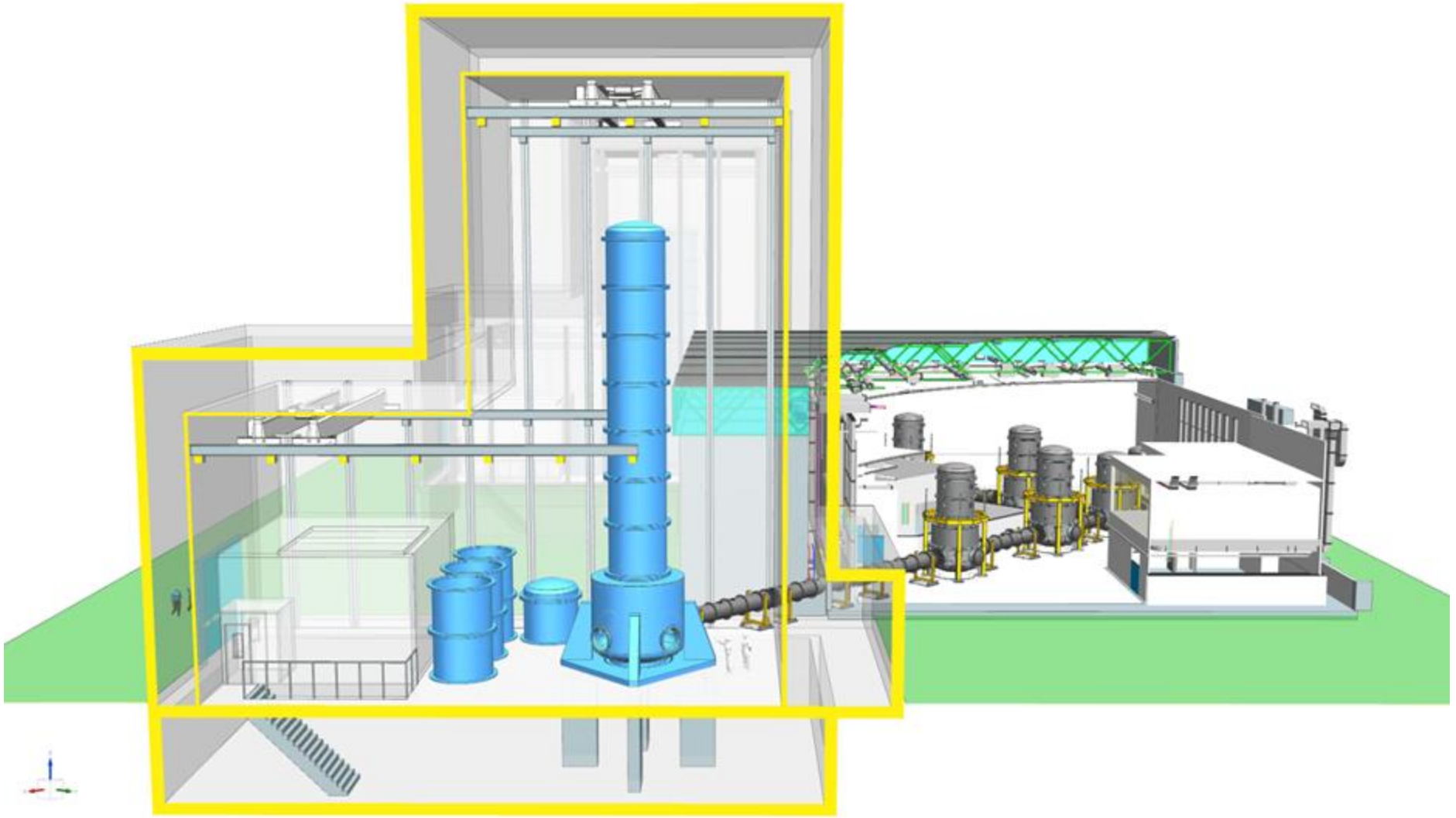
- **In 2035 standing for the first time 250m underground in front of an LF-tower ???**
- **Or can we do some of this over the next 10 years already?**
  - **Derisk ET-LF, …, faster commissioning later on etc**

ET LF integration facility

- It will be essential to have an ET-LF integration facility somewhere.
  - Would need allow to test mots critical procedures and develop installation guides and quality aspects mainly of the LF towers.
  - Allows also to train people and test procedures upfront or during operation of ET.
- Note: Not necessarily an ESTEC or similar in the sense that all hardware needs to go through this facility. BUT one real unit (not a variant or something slightly similar, but exactly the LF-tower) needs to go through such a facility.
- Wouldn't it be nice if that LF integration facility would also have the capability to demonstrate sensitivity of such LF towers of 10^{-18}m level?
  - If yes: why not add something like this to ETpathfinder?

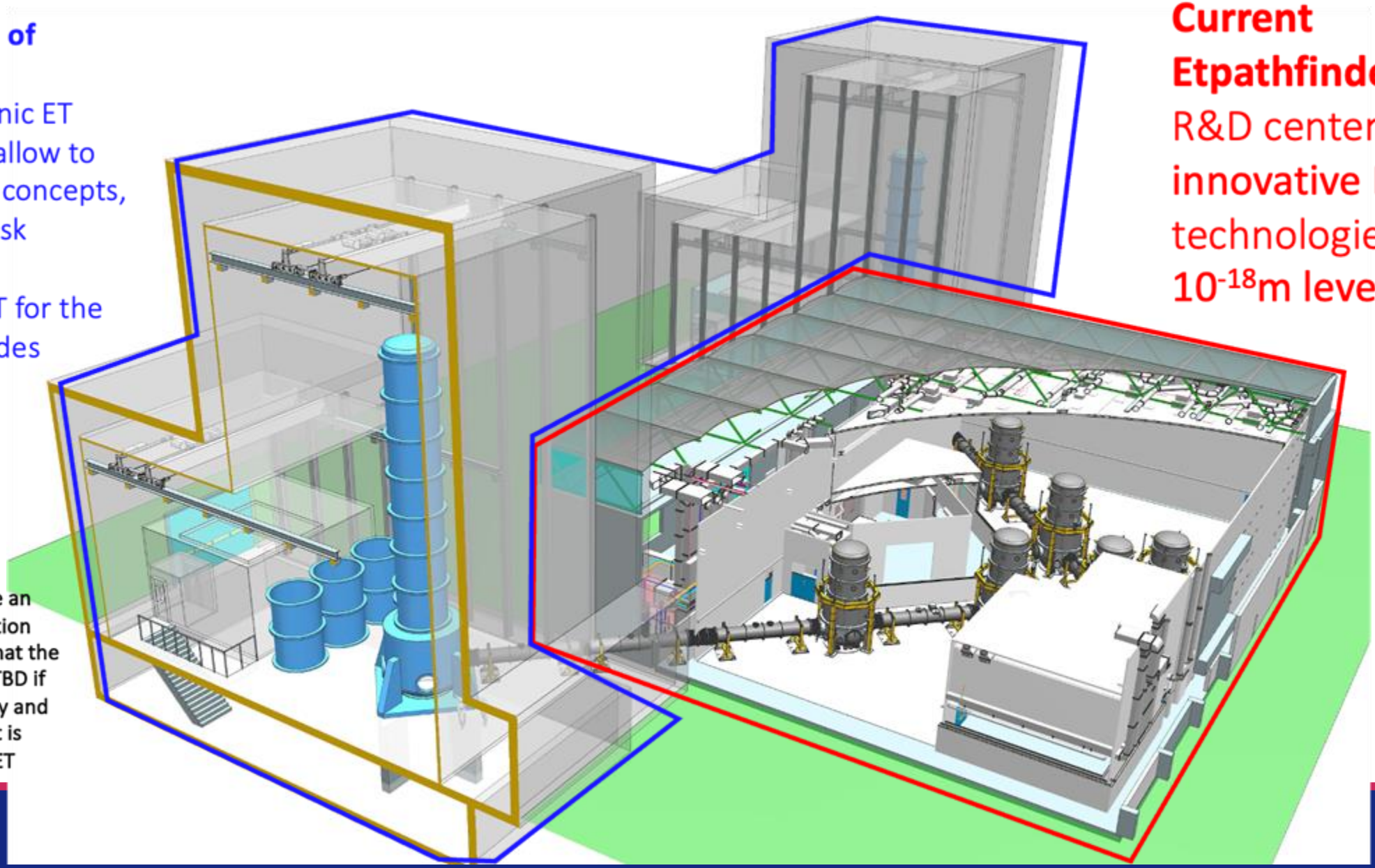
Attach the ET-LF tower to ETpathfinder

Note: The ET-LF tower design is not frozen. So this is a Gedanken-Experiment to give an idea of what such an ET-LF integration center could look like.



ETpathfinder R&D testbed & ET-LF facility

Potential Extension of Etpathfinder:
2x Full Scale Cryogenic ET mirror towers. Will allow to develop integration concepts, quality assurance, risk reduction, faster commissioning of ET for the next couple of decades



Current Etpathfinder:
R&D center **for innovative** ET technologies at 10^{-18}m level

Note: Artistic concept to give an idea of how an ET LF integration center could look like and what the scale would be. Exact plans TBD if dream comes closer to reality and need all of ET to decide what is wanted/needed/helpful for ET

2-pager: ETpathfinder future ambitions

Einstein Telescope Low-Frequency Development, Training and Integration Center (ET-LFC)

Context: The Einstein Telescope features a double detector design, with the high-frequency signal being covered by ET-HF, and the low frequencies being covered by ET-LF. While the ET-HF interferometers will broadly employ current LIGO/Virgo technologies and hence can be tested best in Virgo, the ET-LF interferometers feature many new technologies (e.g. 'Cryogenic silicon testmasses') which cannot be tested in current GW detectors. While in recent years a variety of R&D initiatives have been initiated in Europe, such as ETpathfinder (Maastricht), CAOS (Perugia) ET-CRISTAL (Liege), Amaldi Center (Rome), to do the required R&D on ET-LF technologies, none of these facilities features a final ET-LF interferometer cryogenic mirror towers.

Figure 1: ETpathfinder Facility

Need: In order to transition ET-LF interferometers as quickly and as low risk as possible from construction to scientific observation it is urgently necessary to use the time window until installation of ET will start to construct the **first full-scale ET-LF cryogenic integrated towers** in order to:

- Integrate and validate and the performance of ET-LF technology at a **system close to the real ET and a displacement sensitivity close to the targeted ET-level;**
- Develop and validate **installation and maintenance procedures** for ET-LF towers;
- Develop and validate **quality assurance procedures;**
- Critical training **of staff** and **development of skills;**

From 2025 ETpathfinder STAC report:*
"The value of an infrastructure that can serve for developing and practicing installation and initial stand-alone commissioning of all in-vacuum components was recognized by all. Past experience at e.g., the MIT LASTI facility to exercise seismic isolation installation and stand-alone commissioning has shown the great value of such a facility; the cost of the facility is rapidly recovered in time saved at the final site. This time saving has several dimensions: the development of procedures and tools in advance of the final installation, and the critical training of staff."

Opportunity: The ETpathfinder offers a **fast-track, low-risk and good-value-for-money** opportunity to realise an ET-LFC via an expansion of the current ETpathfinder facility:

- ETpathfinder was setup as a facility in which **full interferometer configurations** (Fabry Perot-Michelson interferometers) can be tested at a **sensitivity level of 10^{-19}m** at signal frequencies of 10Hz.
- There is an **existing international collaboration** of about 25 universities and research institutes from 7 countries which can act as turbo-nucleus for an growing ET-LFC.

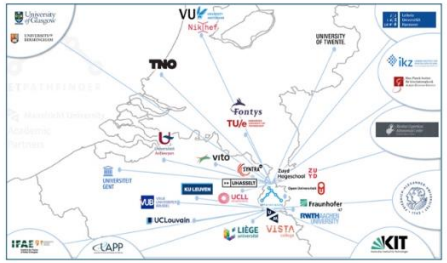


Figure 2: ETpathfinder collaboration

- The current ETpathfinder team of scientists and engineers has laid a solid foundation and built up **organisational structures and culture for robust procedures** for installations, integration and QA procedures.

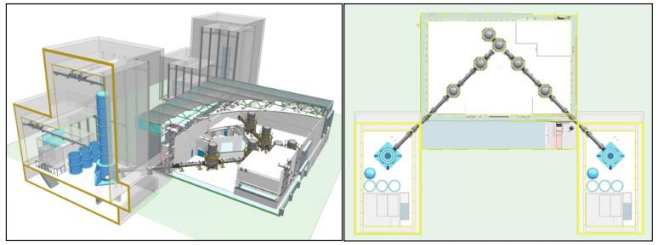


Figure 3: Artistic Illustration of a potential realisation of the ET-LFC. Left: Attached to the current ETpathfinder R&D fieldlab are two full scale ET-LF towers. Right: Top view showing the position of the two full scale towers in extension of the current ETpathfinder arms, allowing to make use of the full sensitivity of ETpathfinder.

Benefits of an ET-LFC coupled to ETpathfinder: We have the opportunity to co-locate the ET-LFC (focussing on integration and training) with the ETpfinder project (focussing on R&D). This provides several significant additional benefits to the ET project, such as: i) **reduced time** between completion of the construction of the civil infrastructure and the first operation of an ET-LF interferometer in observation mode and therefore **savings** in terms of operational costs during the period ET has not reached science mode yet (note: ET operation costs are estimated to be 50M€ per year); ii) **reduced risk of overlooking unknown unknows** in the ET-LF technologies and designs; iii) **training of researchers and technical personnel.**

A key prerequisite for realising the ET-LFC is a clear and strong mandate from the whole ET, including ETO, the ET Collaboration and other key stakeholders.

Cost estimate: Initial checks (local zoning exercise, cost studies by architecture office and cleanroom builder) have been done to estimate the budget required for adding an ET-LFC next to ETpathfinder. The total cost has been estimated to be **52M€ of capital investment over the period 2026-2029** (19M€ for the 2 new tower buildings, 12M€ for the cleanrooms, HVAC and cranes, 10M€ for the vacuum systems and 11M€ for the inner mechanics and optics) and **an annual operation and maintenance budget of 2M€** (running costs of 600k€, 100k€ maintenance contracts, 200k€ consumables + a strong central systems, integration and QA engineering team for 1.1M€) **from 2026 onwards.**

Figure 4: Installation works at ETpathfinder

From 2025 ETpathfinder STAC* report:

"many of the activities are simply going amazingly well"

"In conclusion: The STAC was very impressed with the progress made and the bright future for the coming year."

* ETpathfinder STAC composition: V. Fafone (Rome), Raffaele Flaminio (Annecy), Gianluca Gemme (INFN Genova), Andreas Haungs (KIT), Maddalena Mantovani (EGO), Sheila Rowan (University of Glasgow), David Shoemaker (MIT) (Chair), Patrice Verdier (IN2P3), Kazuhiro Yamamoto (University of Toyama)

Contact person: Stefan Hild (Maastricht University & Nikhef)
23rd of September 2025

Thanks for your attention! Questions?

ETpf design report

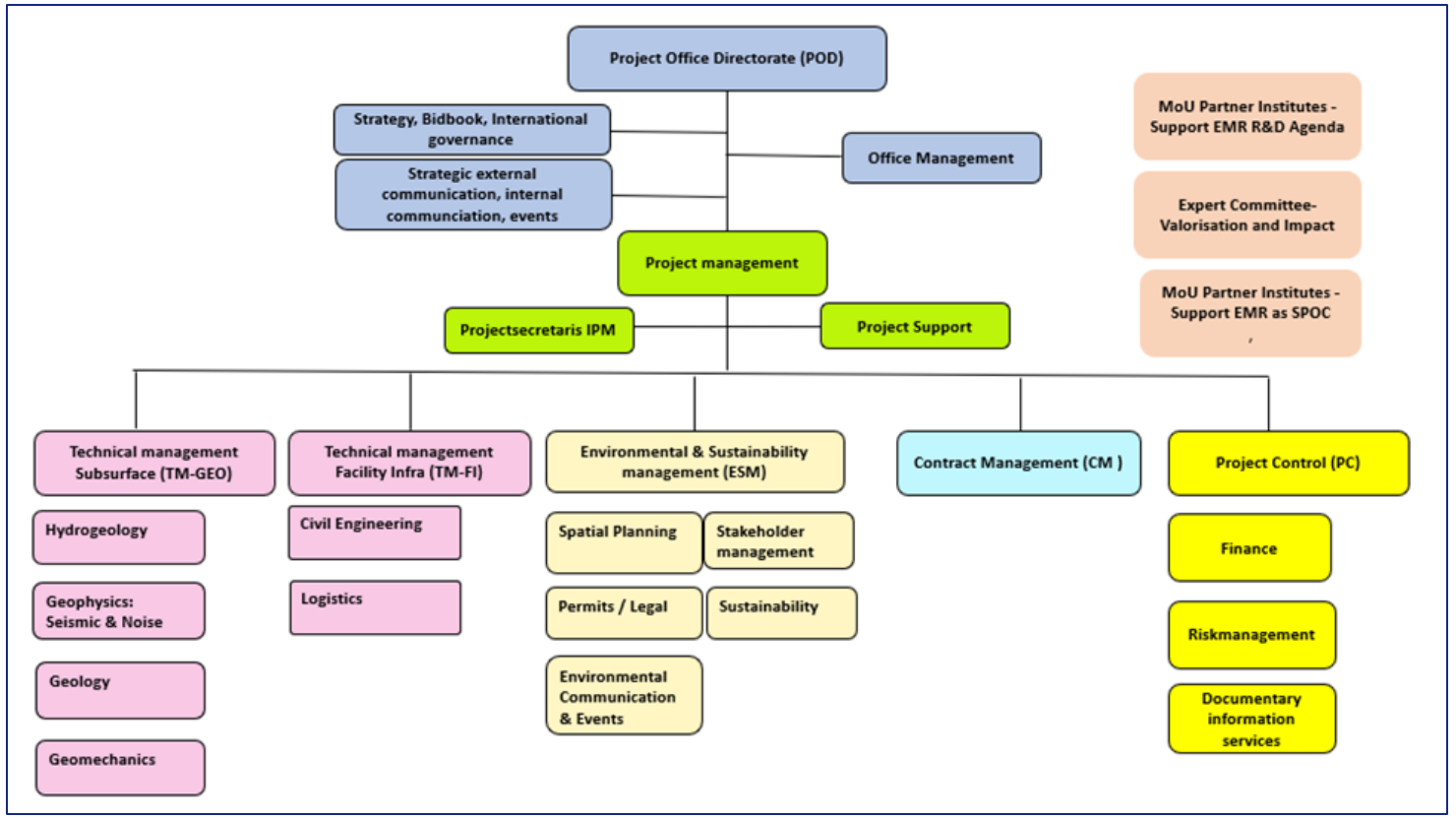
ETpf sensitivity paper

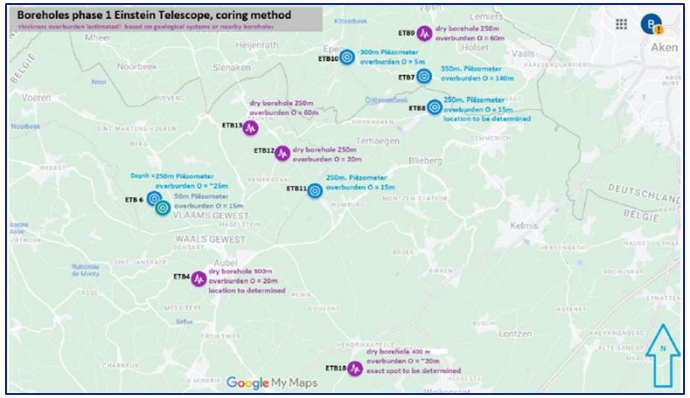
Research – ETpathfinder

ETpathfinder: a cryogenic testbed for interferometric gravitational-wave detectors - IOPscience

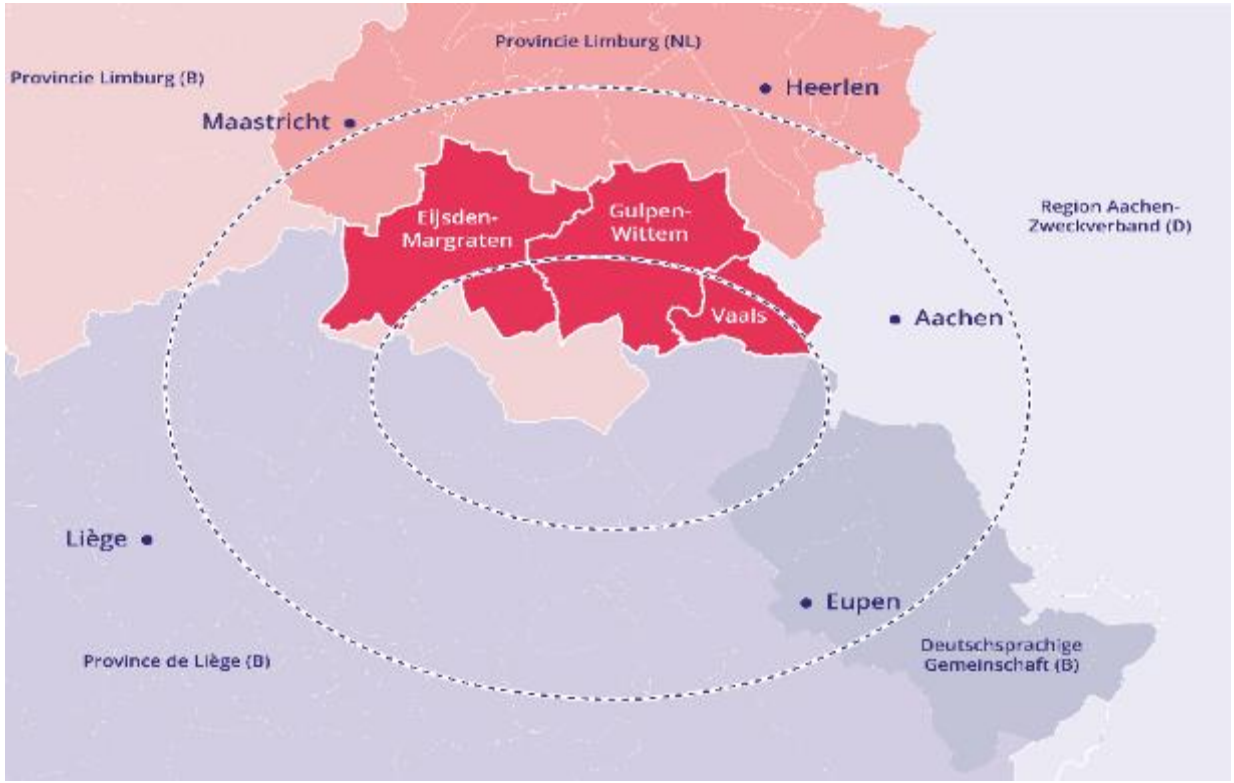
ET at EMR:

- Favourable noise characteristics identified in 2016.
- Many studies over past 10 years.
- Full project office started operation in Jan 2024.
- Sub-surface studies (geology, noise, stability civil infrastructure, sustainability).
- Many town hall meetings with local population.
- Education, Outreach





ET at EMR



The Netherlands

- **Feasibility studies**: 25 M€
- **Construction**: reservation of 870 M€

Germany / NRW

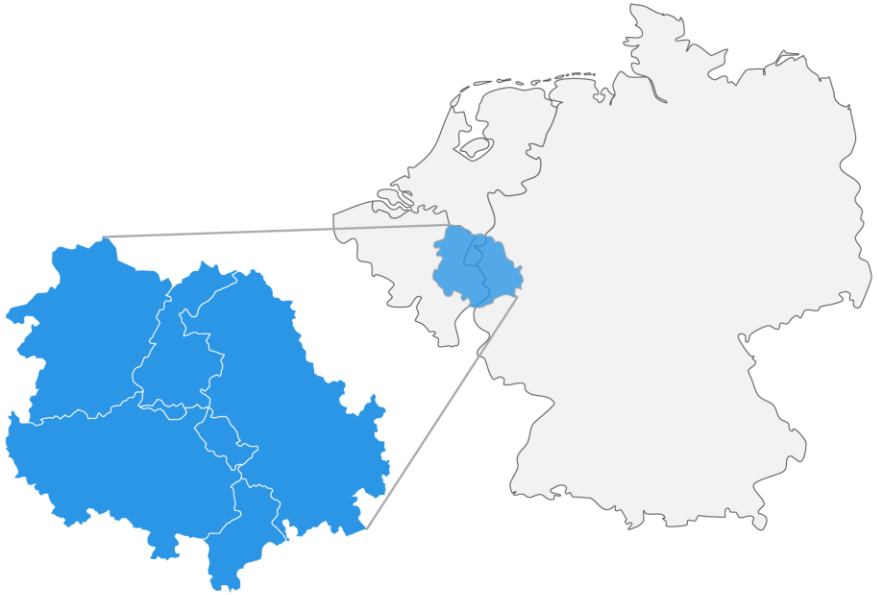
- **Feasibility studies**: 12 M€
- **Construction**: *Priorisierungsverfahren* on-going

Belgium

- **Feasibility studies**: 12 M€
- **Construction**: Flanders: reservation of 200 M€

ET at EMR:

- High dynamics: External review gave ‘ok’ for geology (Oct 2024), noise studies in progress (right now), company in standby to start civil engieering designs (Starting June 2025).
- Vibrant ecosystem of top research institutes and a cluster of high-tech industry.
- Sharing opportunities as well as risks between involved countries.
- Many pilot projects (Science, innovation, education, valorisation etc) to showcase ET-ecosystem in ‘live’.



Organisation on the European Level

BGR
Site selection;
Legal entity;
Financial framework

Board of Governmental Representatives (BGR)

ET coordinators
Coordinate the EU project - ESFRI

ET Coordinators

ETO Directorate
Strategic coordination and management

- ET Roadmap
- Technical Design Reports
- Site Evaluation Reports
- Technical Plan report
- Organisation report
- Budget report

ETO
Directorate and Depts

Host Consortia

- Feasibility studies civil engineering, installations
- Feasibility studies subsurface
- Feasibility studies environment and legal

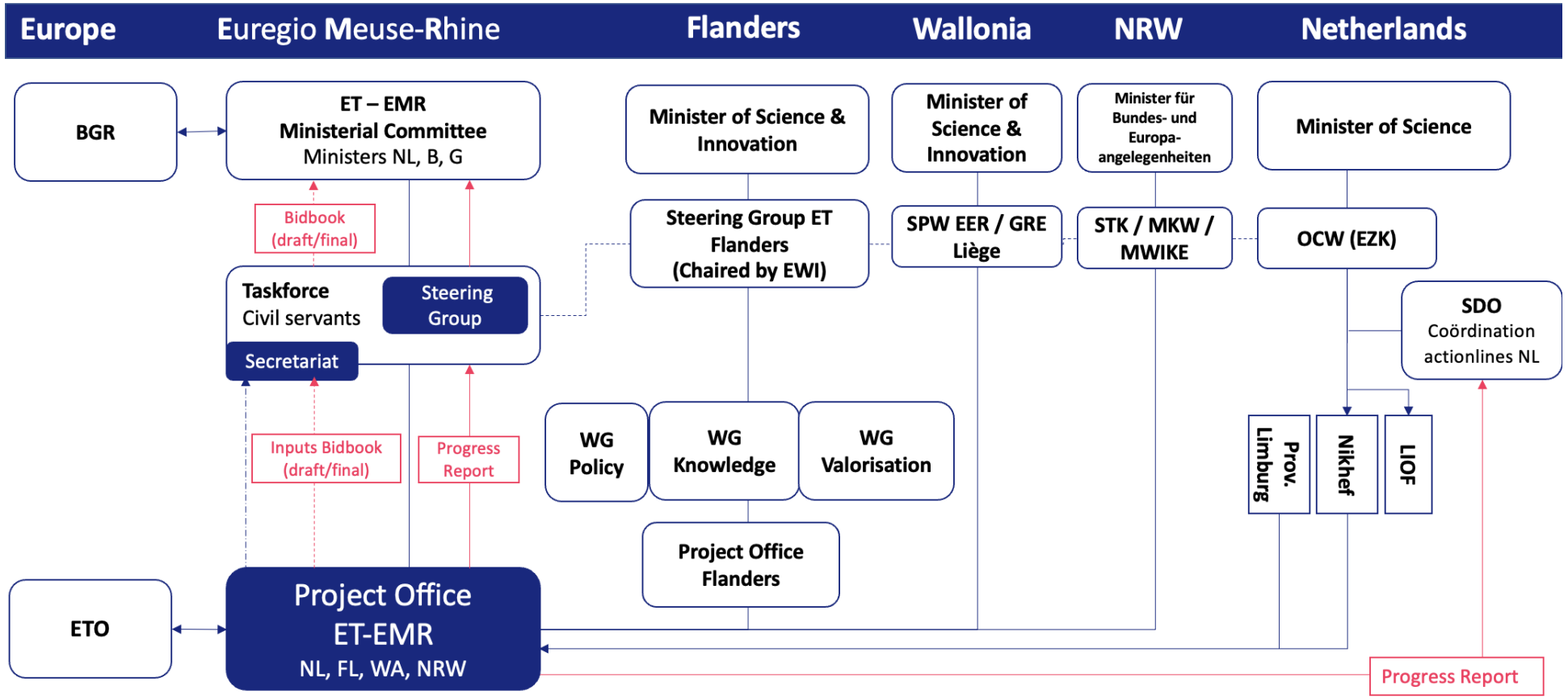
ET Collaboration

- Scientific vision
- Detector design
- Requirements,
- Common standards

ET Host Consortia (EMR and TETI)

ET Collaboration (ETC)

EMR project office

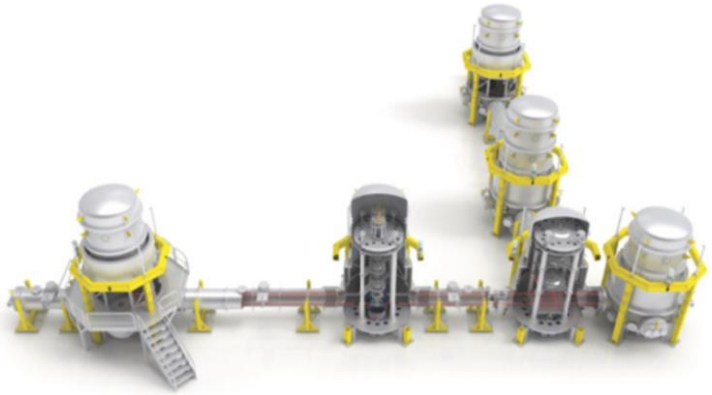


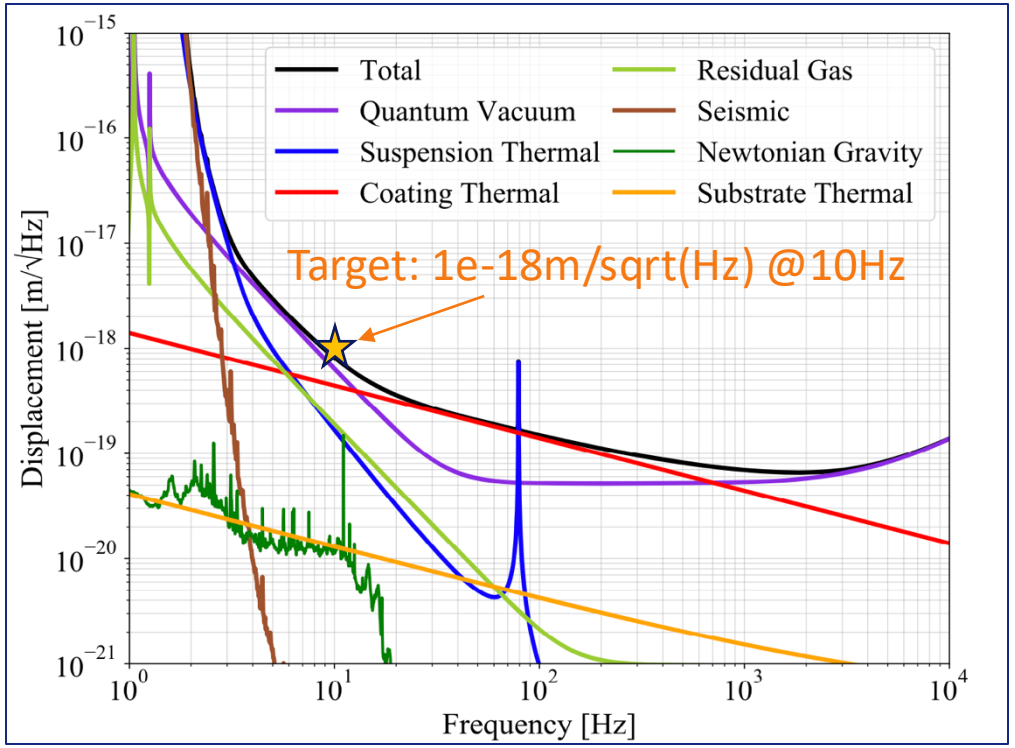
P1.1_014_Governance ET-EMR_V2.0

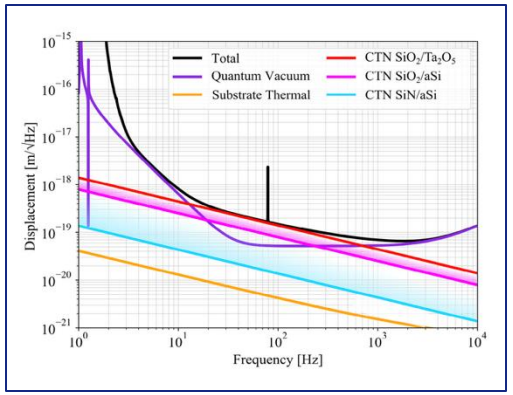
Top-Level layout

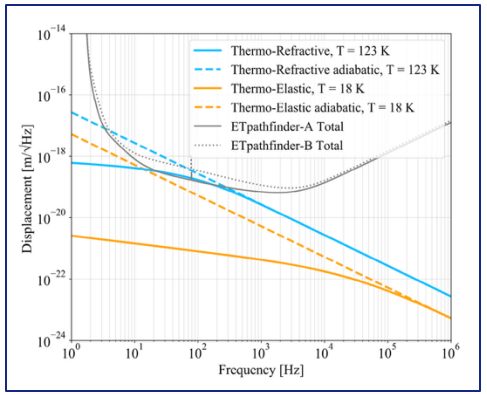
2 FPMI interferometers:

1) **1550nm @ 18K**
2) **2090nm @ 123K**










January 2020

April 2020

Summer 2020

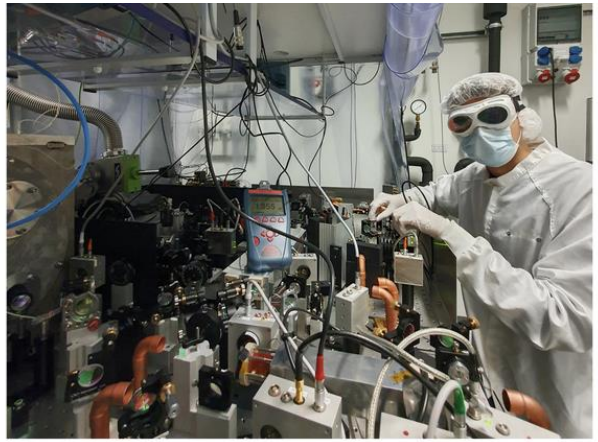
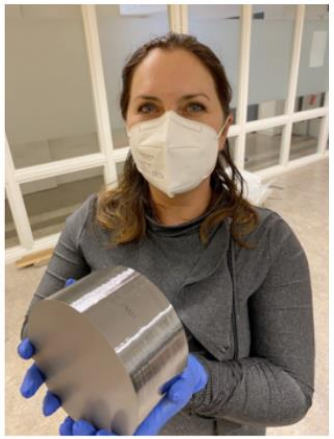
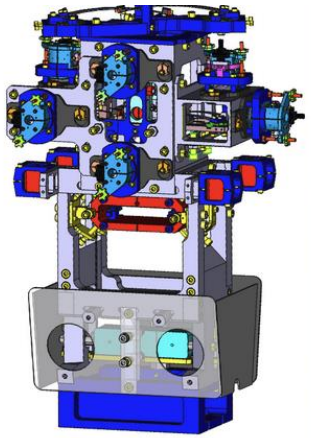
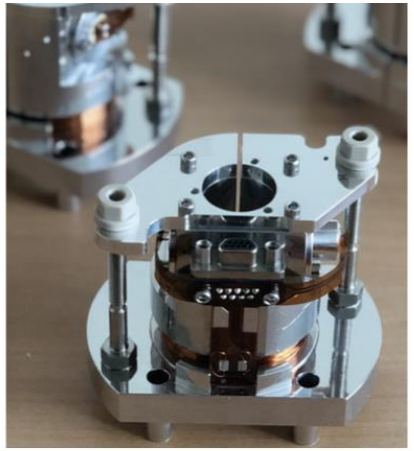
Autumn 2020

Summer 2021

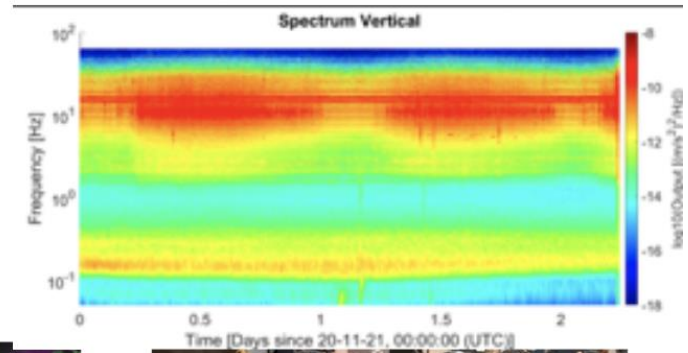

Autumn 2021

Summer 2022

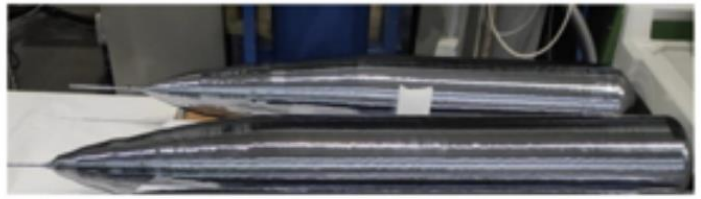
Some Impressions ETpathfinder Activities

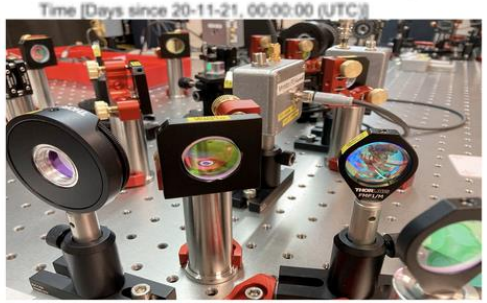










- Need high-purity (high resistivity) silicon to keep optical absorption as low as possible
- Obtained Silicon ingots of moderate resistivity (> 1kOhm cm)
- Currently being cut into more manageable pieces before shipping to Maastricht





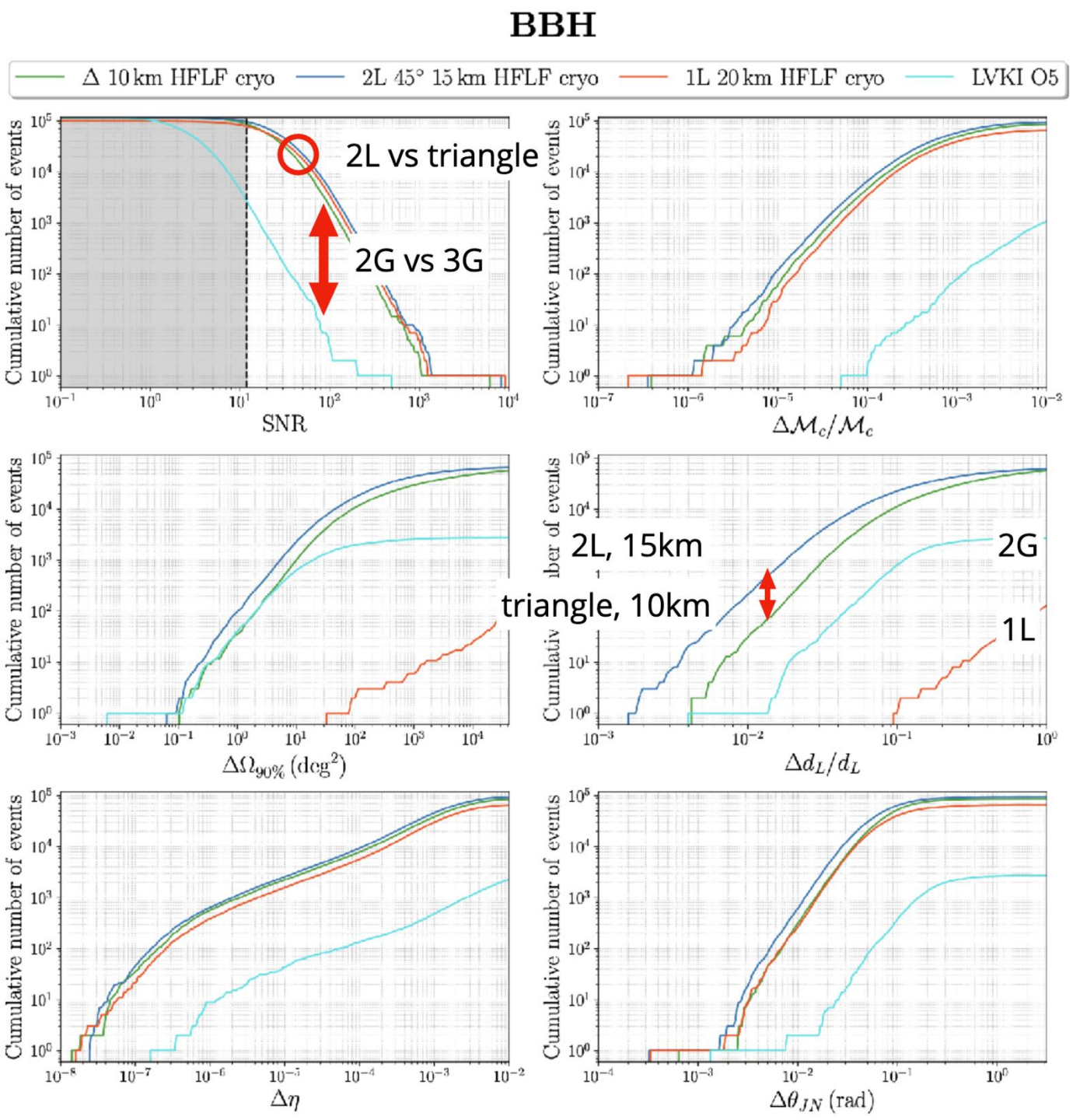
ETpathfinder SMART Skills Lab

- Expanding “ET eco-system” regarding human capital agenda
- **Target: Provide skills trainings to SMEs on Key Enabling Technologies** (e.g. photonics, optics, robotics, vacuum and cryogenics, seismic vibration damping and precision mechatronic)
- Interreg application: 4.4 million Euro => project expected to start in April 2025
- New element: also targetting **HBO/MBO**
- Partners: UMaastricht, Nikhef, Tue, KULeuven, UAntwerp, VUBrussels, UGent, RWTH, Open University, Fontys, UCLL, Vista College, Syntra PXL, POM, LIOF

ETpathfinder core partners

Link to SMEs

New partners: Technical universities, MBO, HBO, training centers

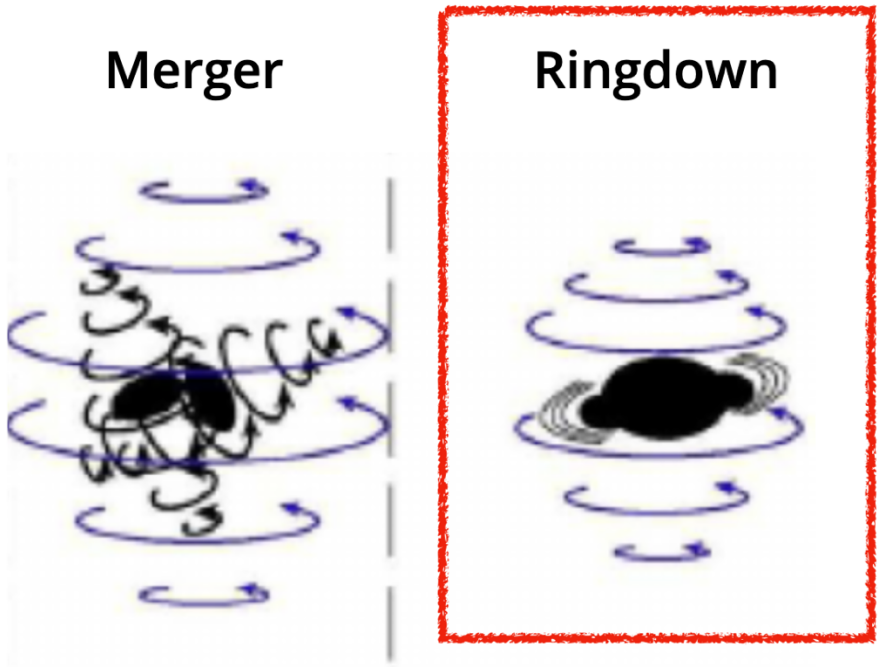


Example graph showing some of many specific results

- 2G = 'second generation', refers to future performance of current detectors (LIGO, Virgo, KAGRA)
- 3G = 'third generation' refers to ET
- y-axis: higher is better, note the logarithmic scale
- x-axes: different parameters of the source signal

The difference can be significant

Two black holes, after a collision:



	$N_{\rm det}(\mathrm{SNR} \geq 12)$	$N_{\rm det}(\mathrm{SNR} \geq 50)$	$N_{\rm det}(\mathrm{SNR} \geq 100)$	max(SNR)
LVKI-O5	15	0	0	38
ET				
Δ-10 km	4665	34	3	262
Δ-15 km	11692	117	13	317
2L-15 km-0°	11627	110	11	281
2L-15 km-45°	10175	97	9	330
2L-20 km-0°	18972	255	21	327
2L-20 km-45°	17185	228	18	384

Table 14. Number of ringdown events per year above the detection threshold (SNR $\geq$ 12), with high signal-to-noise ratio (SNR $\geq$ 50), and golden events (SNR $\geq$ 100) for different proposed detector designs (all taken in the HFLF-cryo configuration) and compared to the most optmistic prospect for LVKI in O5. The last column displays the SNR of the loudest event in the catalogue. Here SNR refers to the ringdown part of the signal only.

- The “small” differences in the logarithmic plot can be significant.
- The 15km Ls (or an 15 km triangle) could make a big difference for some key events.