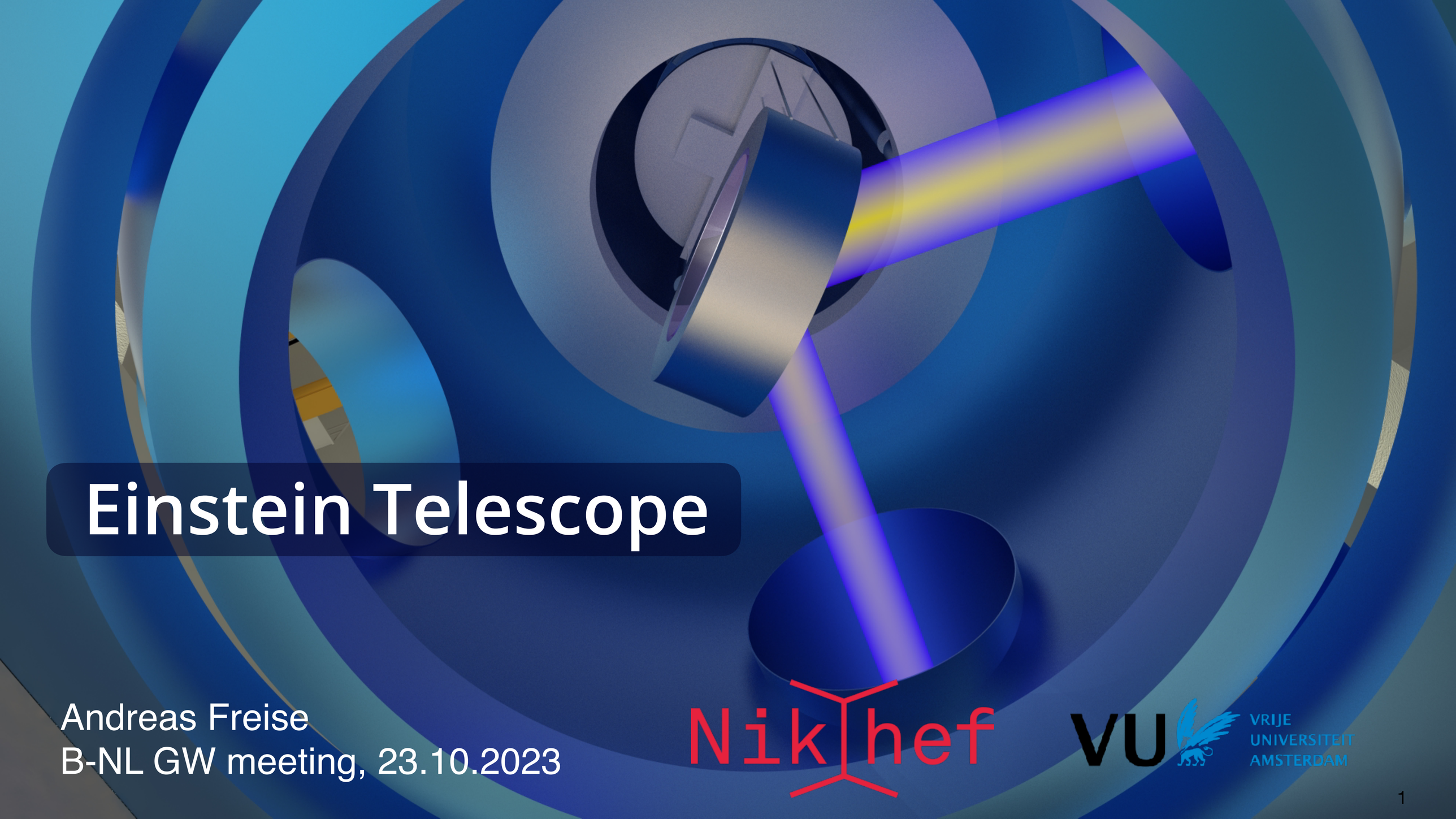
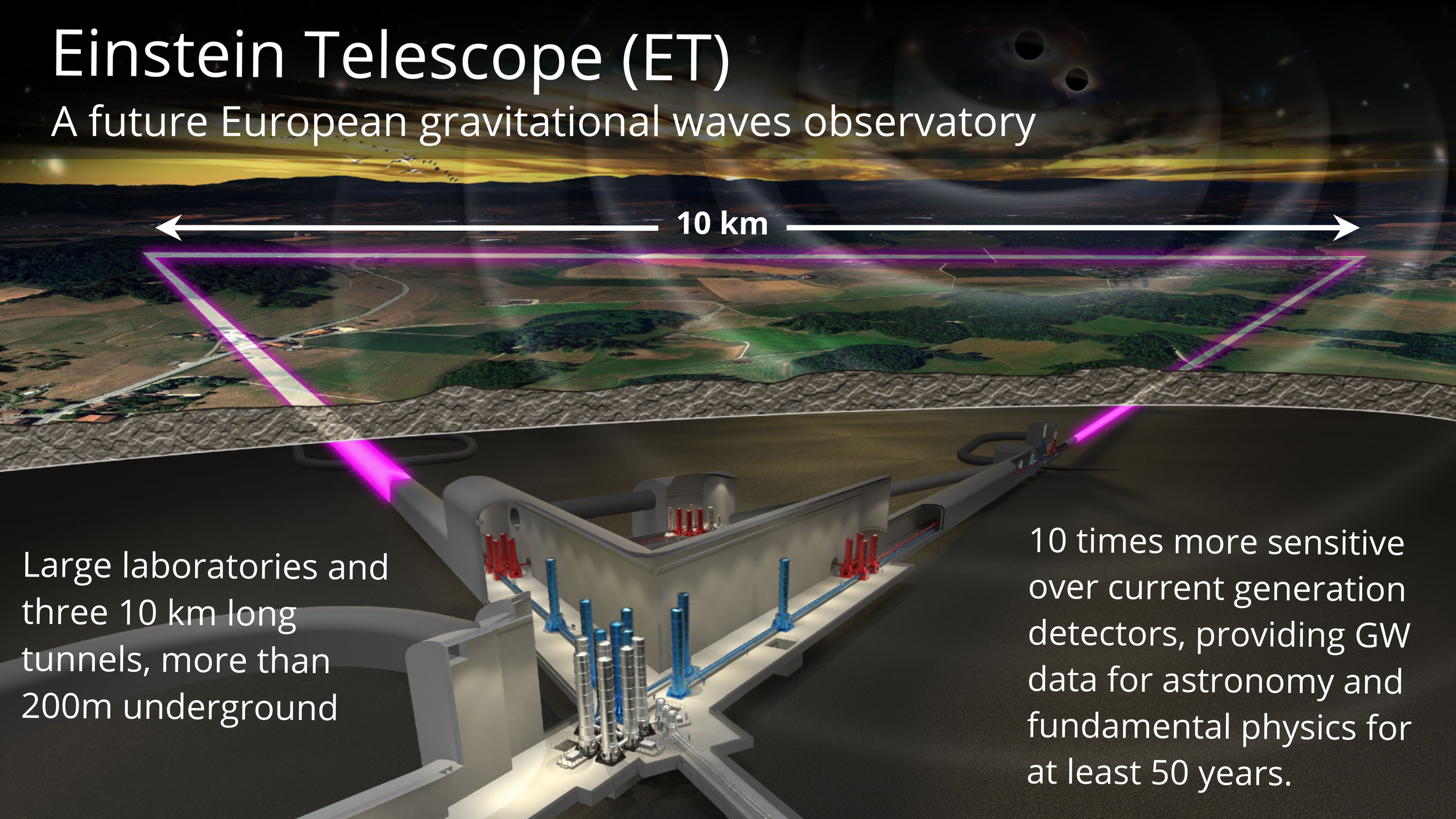


Einstein Telescope

Andreas Freise
B-NL GW meeting, 23.10.2023

Einstein Telescope (ET)

A future European gravitational waves observatory



Large laboratories and three 10 km long tunnels, more than 200m underground

10 times more sensitive over current generation detectors, providing GW data for astronomy and fundamental physics for at least 50 years.

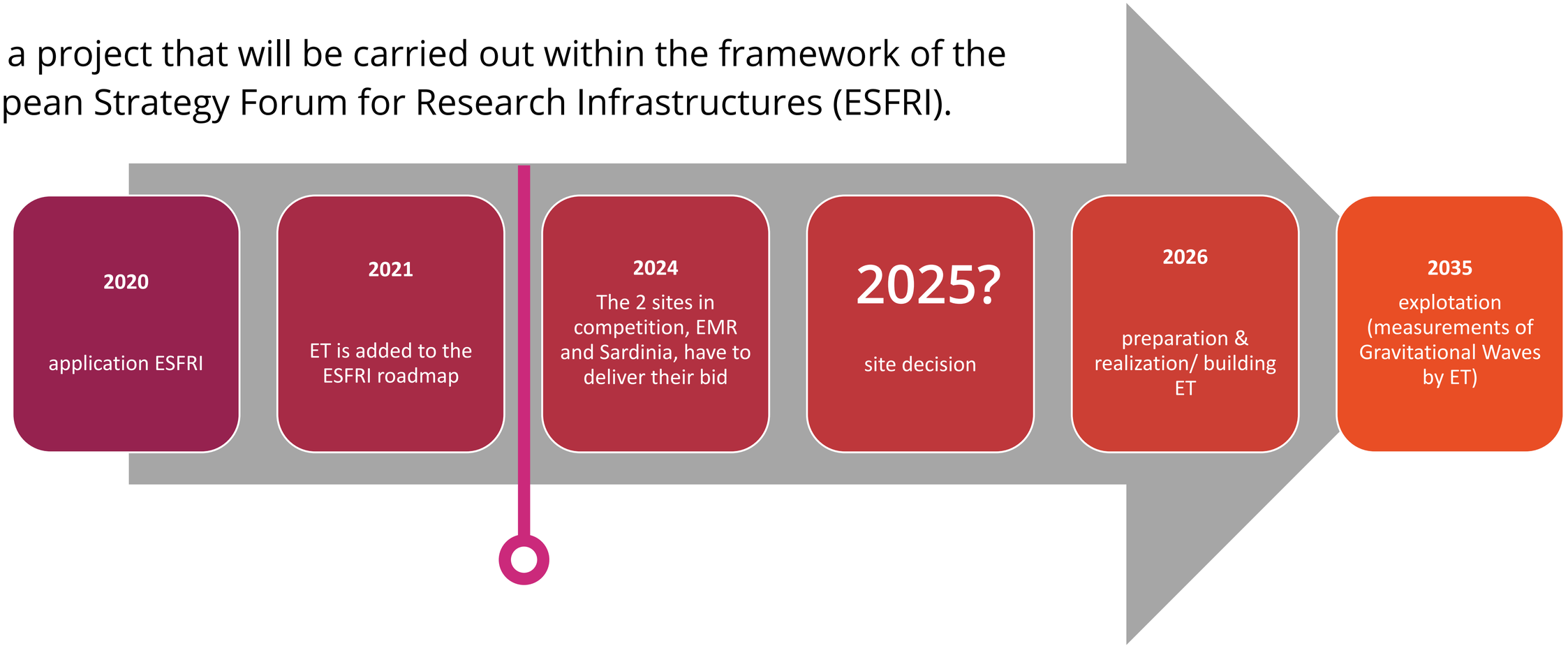
Possible ET sites

[https://www.interregemr.eu/]

- Currently there are **two candidate sites** in Europe to host ET:
  - The Sardinia site, close to the Sos Enattos mine
  - The Euregio Meuse-Rhine (**EMR**) site, close to the NL-B-D border
- A third option in Saxony (Germany) is under discussion, but not yet a candidate.

Upcoming: approval to build ET (somewhere)

ET is a project that will be carried out within the framework of the European Strategy Forum for Research Infrastructures (ESFRI).

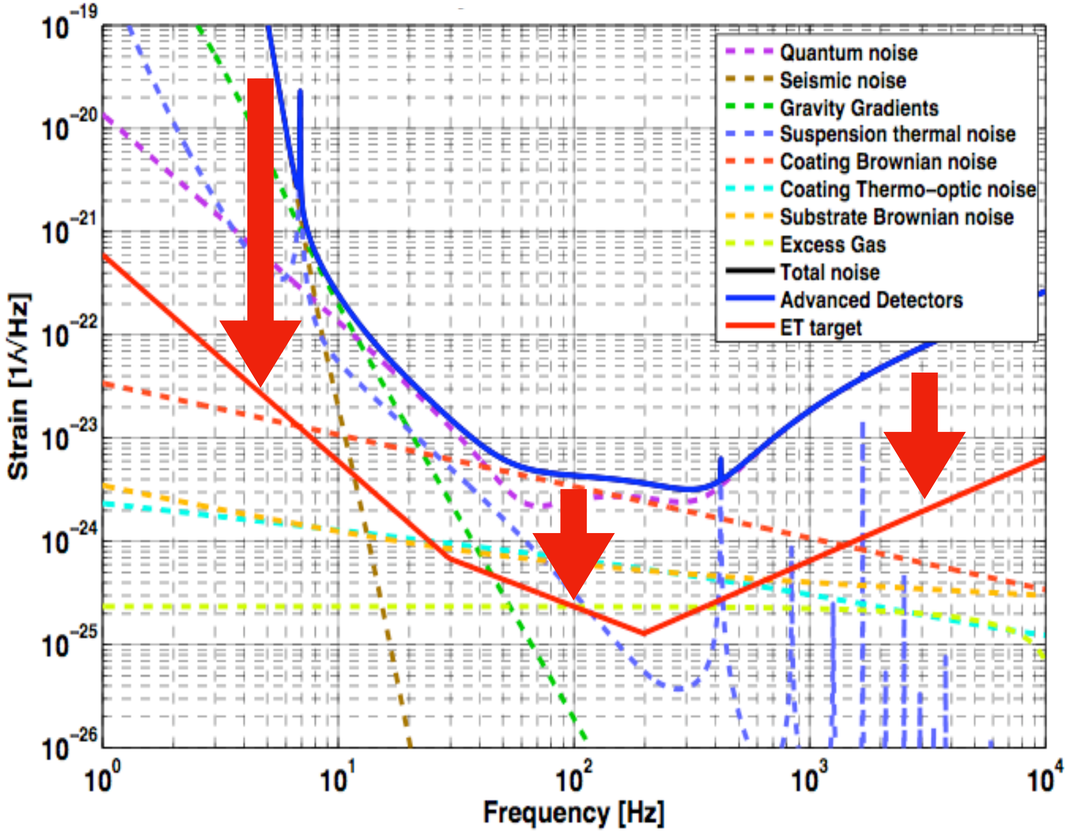


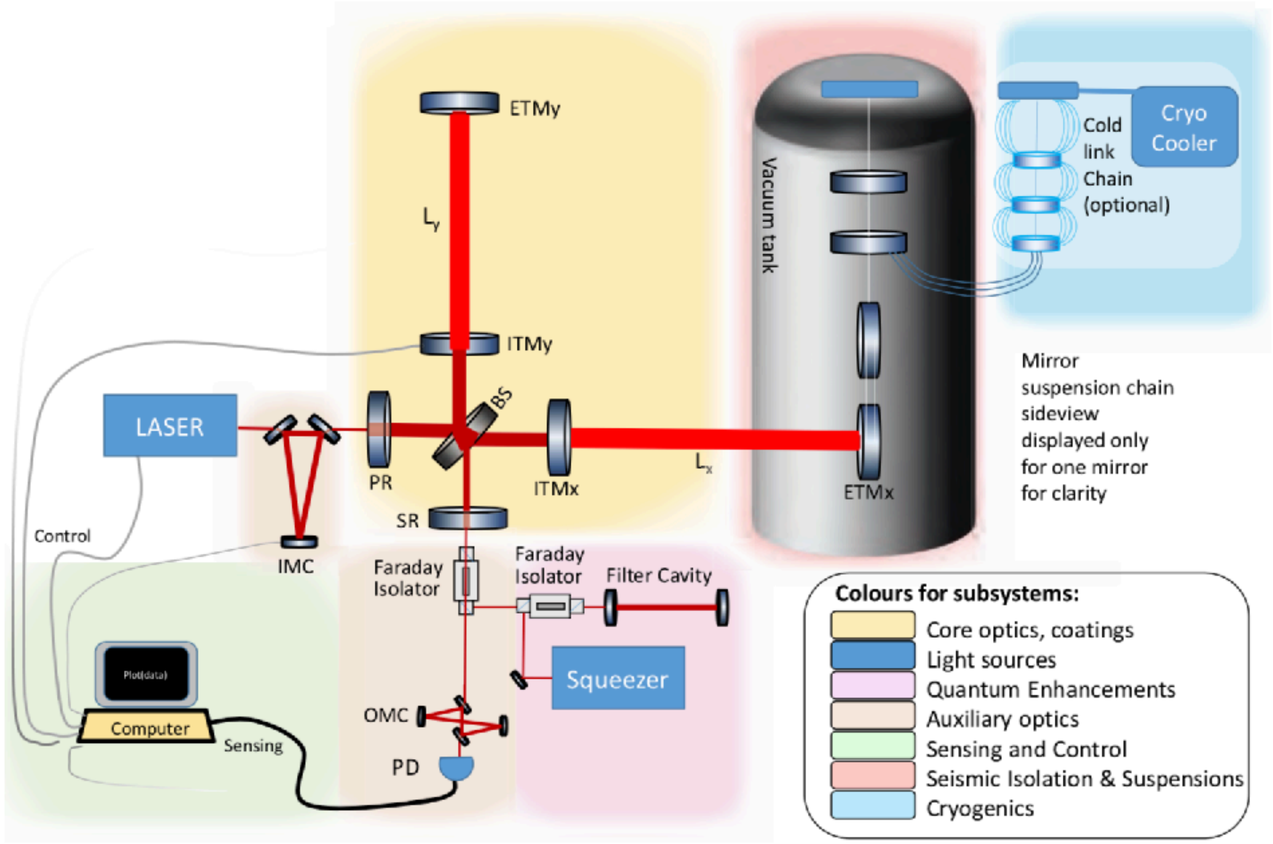
Note: this schedule from the ESFRI proposal is out of date. New schedule will be based on a detailed work plan and engineering studies.

How to build the Einstein Telescope?

- Research and Technology
- Organisation and Politics
- Infrastructure and Engineering

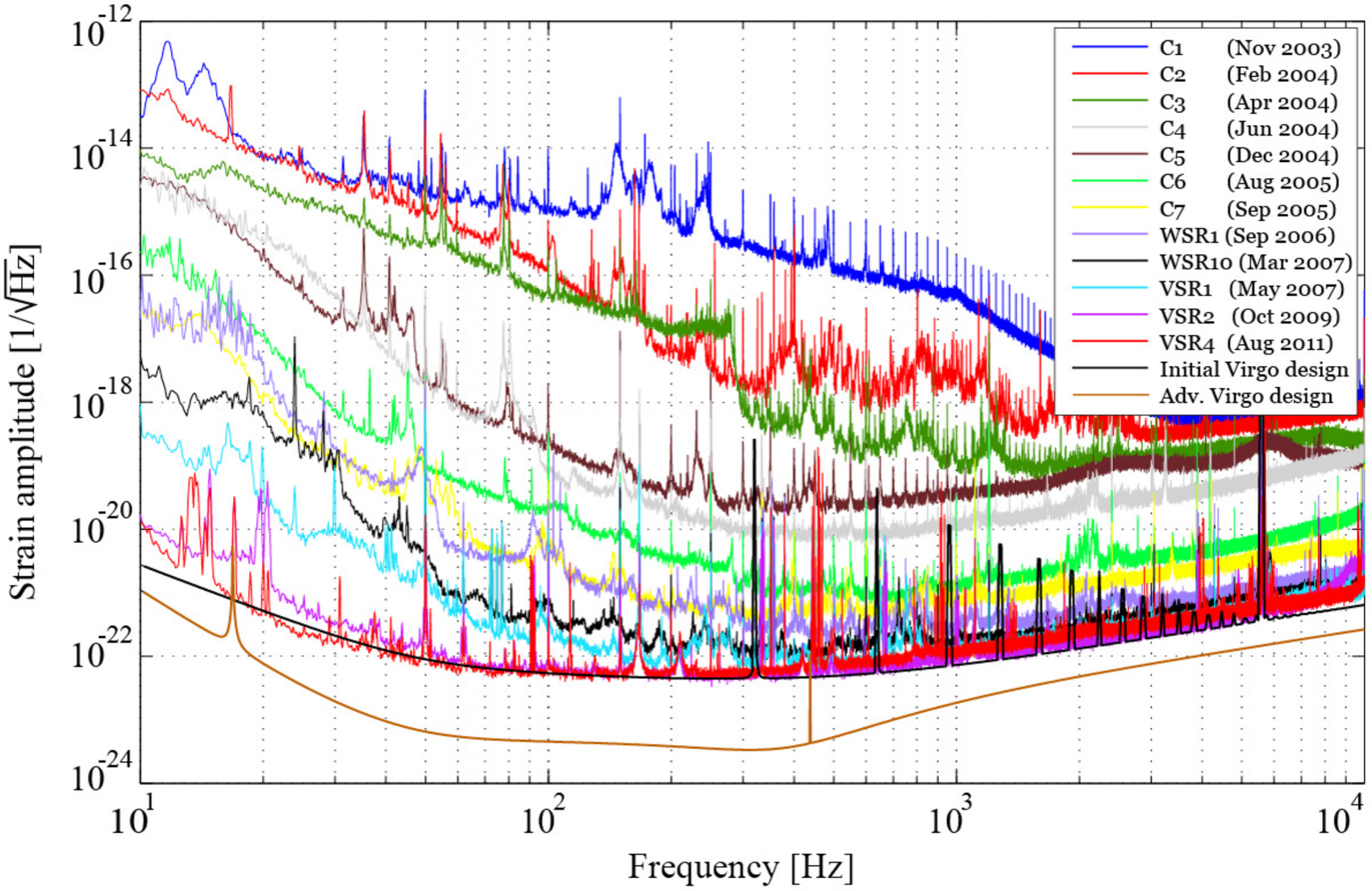
Updating detector technology piece by piece…





https://gwic.ligo.org/3Gsubcomm/documents/GWIC_3G_R_D_Subcommittee_report_July_2019.pdf

… is not enough. We need better designs too!

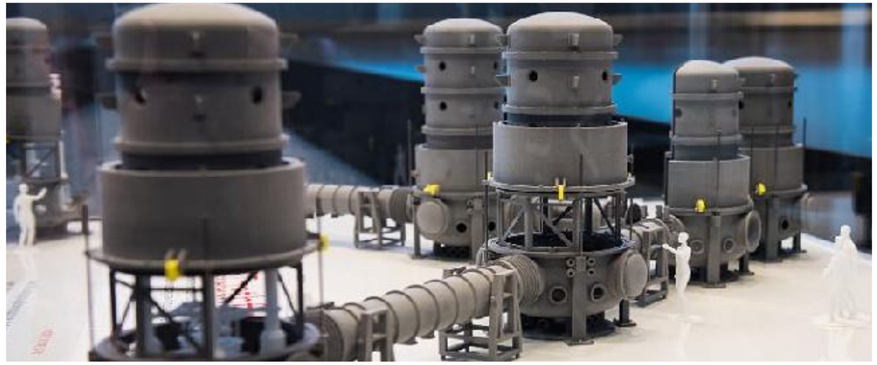


Virgo detector

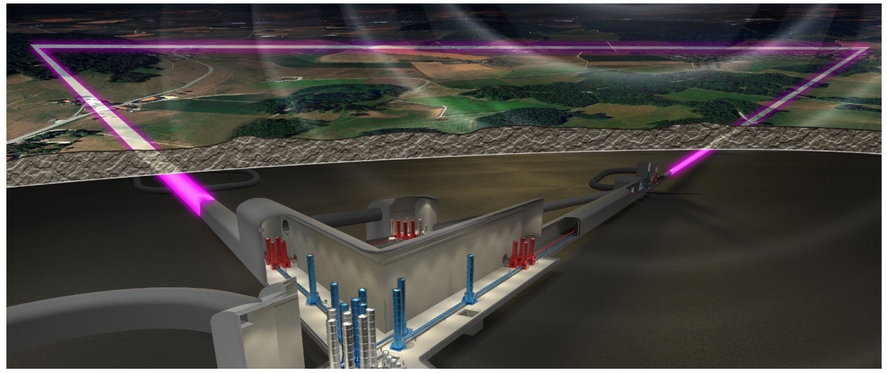
8 years from first full operation of the detector to (almost) design sensitivity.

Synergies in instrument development

Virgo: large-scale detector in Italy, able to detect GWs, **currently being upgraded.**

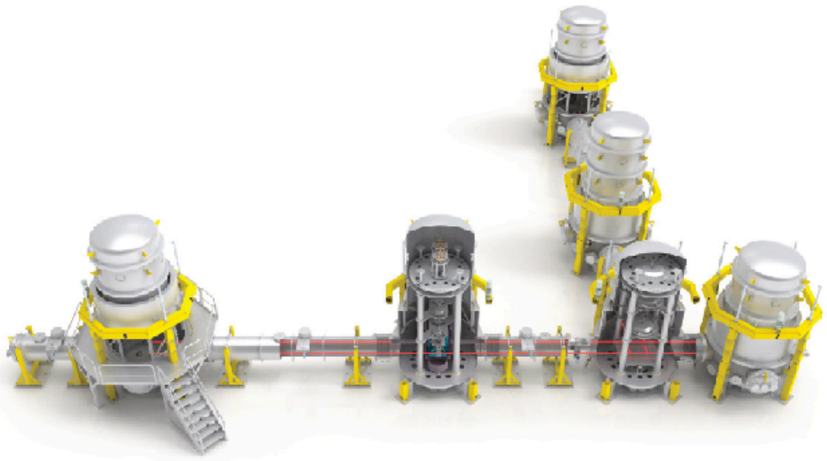


ETpathfinder: 10m scale prototype interferometer, a testbed for future GW technologies, **currently under construction.**



Einstein Telescope: plan for future observatory in Europe, currently design, site selection, **research and technology development.**

ETpathfinder



Silicon mirrors

Pre-stabilised lasers
- 1550 and 2090 nm
- About 1W

Fabry-Perot resonators

Arm length 9.23 m

Input mode cleaners

Two Michelson interferometers: Each arm allows operating at a different cryogenic temperature (123K and 18K).

See also: arXiv: 2206.04905v1 10 June 2022

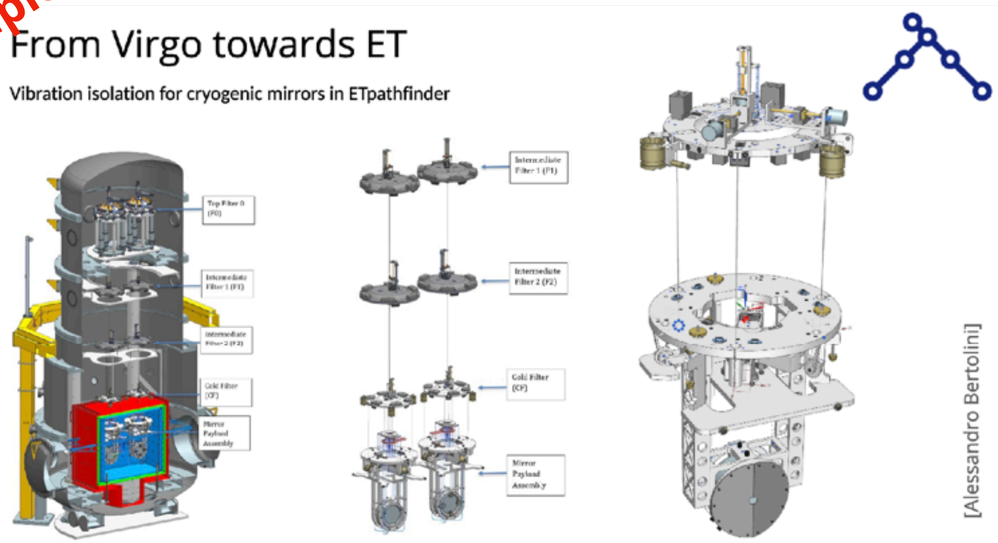
[Paul Kuijer]

Broad R+D Programme for essential technologies

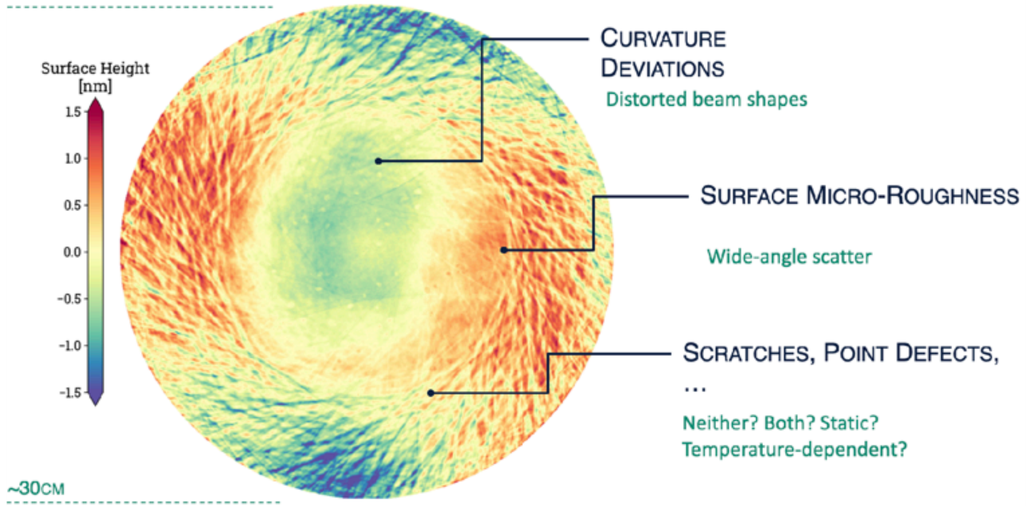
Examples

From Virgo towards ET

Vibration isolation for cryogenic mirrors in ETpathfinder

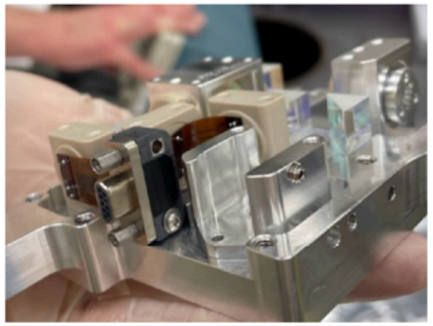


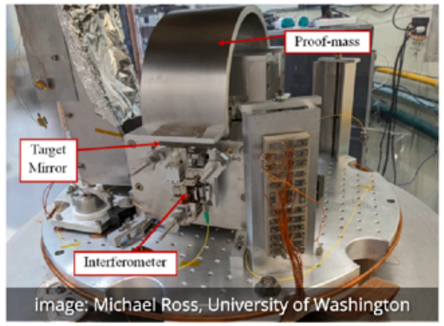
[Alessandro Bertolini]



Interferometric sensors for Virgo and ET

HoQI and the Cylindrical Rotation Sensor





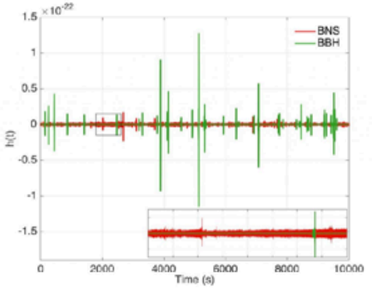
[Conor Mow-Lowry]

'HoQI' interferometric sensors have been deployed at facilities in the US, Germany, UK, and Netherlands.

The cylindrical rotation sensor will improve Virgo's stability in windy conditions.

Data analysis challenges in the ET era

- **Long signals:** $\tau \simeq 4.5 \times 10^5 \,\mathrm{sec} \left(\frac{1.22\,M_\odot}{\mathcal{M}_c}\right)^{5/3} \left(\frac{1\,\mathrm{Hz}}{f_{\mathrm{low}}}\right)^{8/3}$
  - GW170817 only a few minutes long as seen in LIGO-Virgo, but took months to analyze!
  - Same signal in ET would be in-band for hours
- **Loud signals**
  - Computing requirements increase with signal-to-noise ratio
- **Large number of signals lead to overlapping signals**
  - Can we still get precision science out of them?
- **How to characterize noise properties if signals are present all the time?**
  - Triangular shape: sum of detector outputs contains no GW signals ("null stream")
    (Still doesn't yield individual noise spectra in the 3 detectors separately, only average)

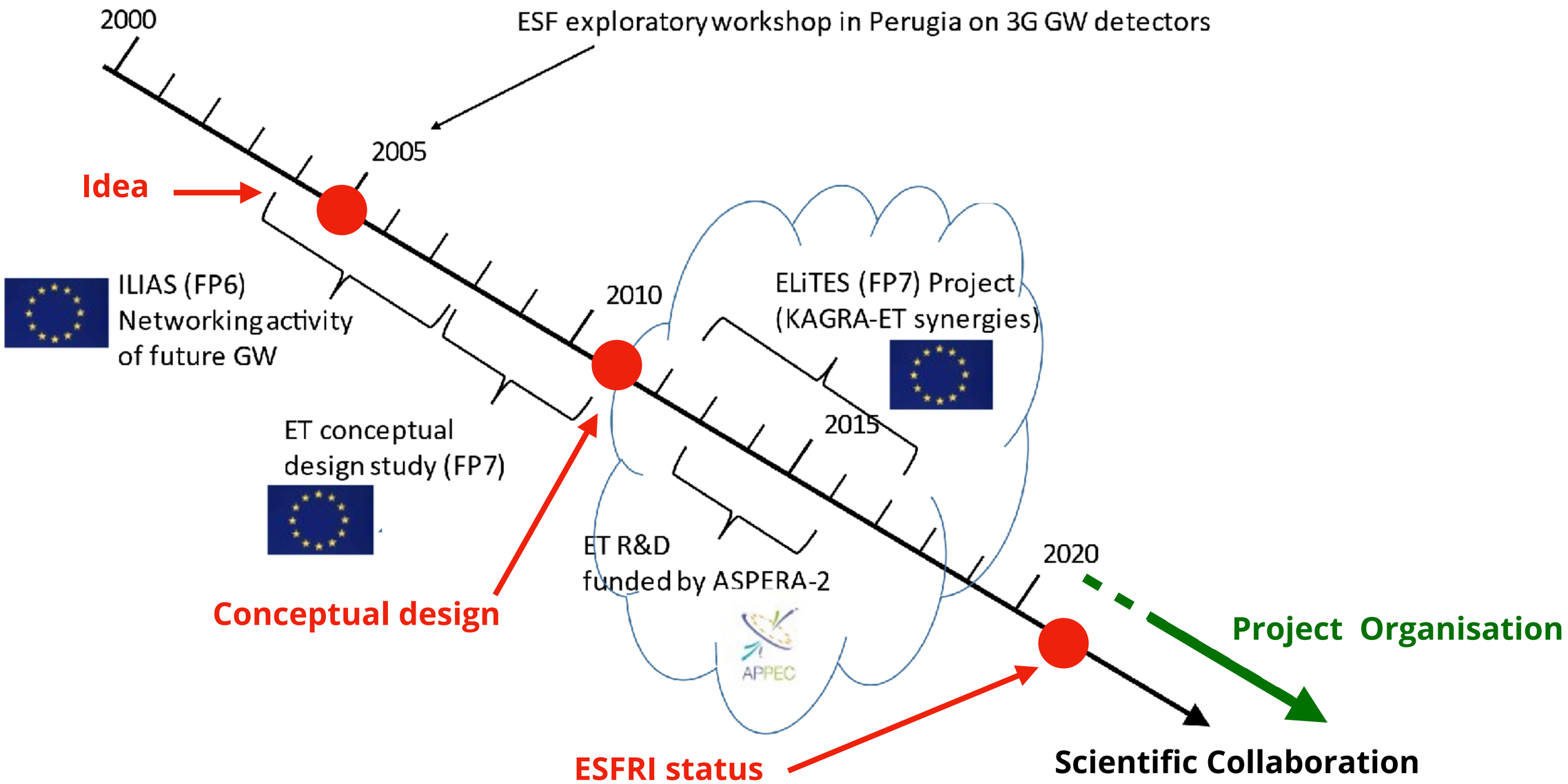


Current analysis techniques qualitatively inadequate, novel methodologies needed

How to build the Einstein Telescope?

- Research and Technology
- Organisation and Politics
- Infrastructure and Engineering

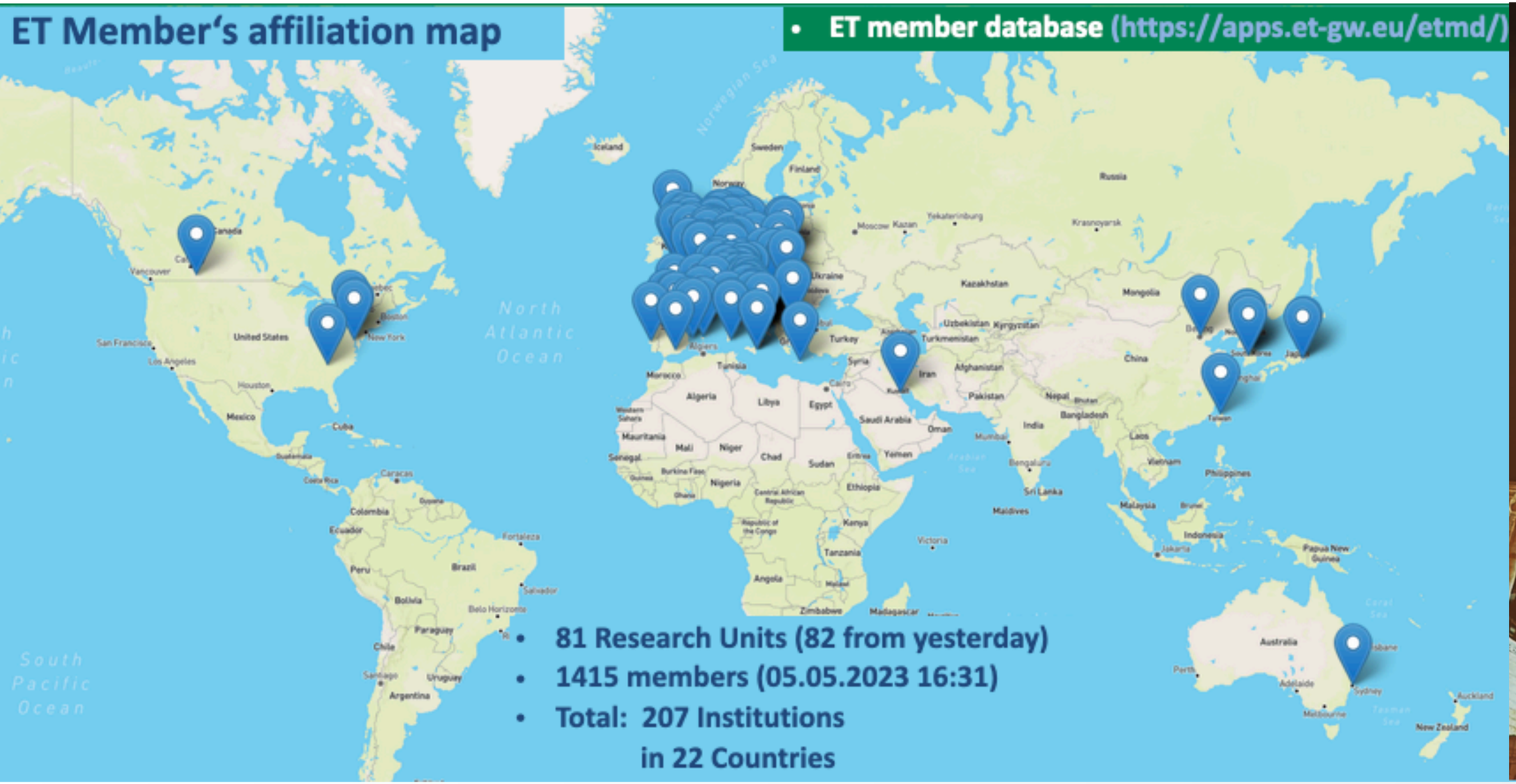
Einstein Telescope: from idea to project



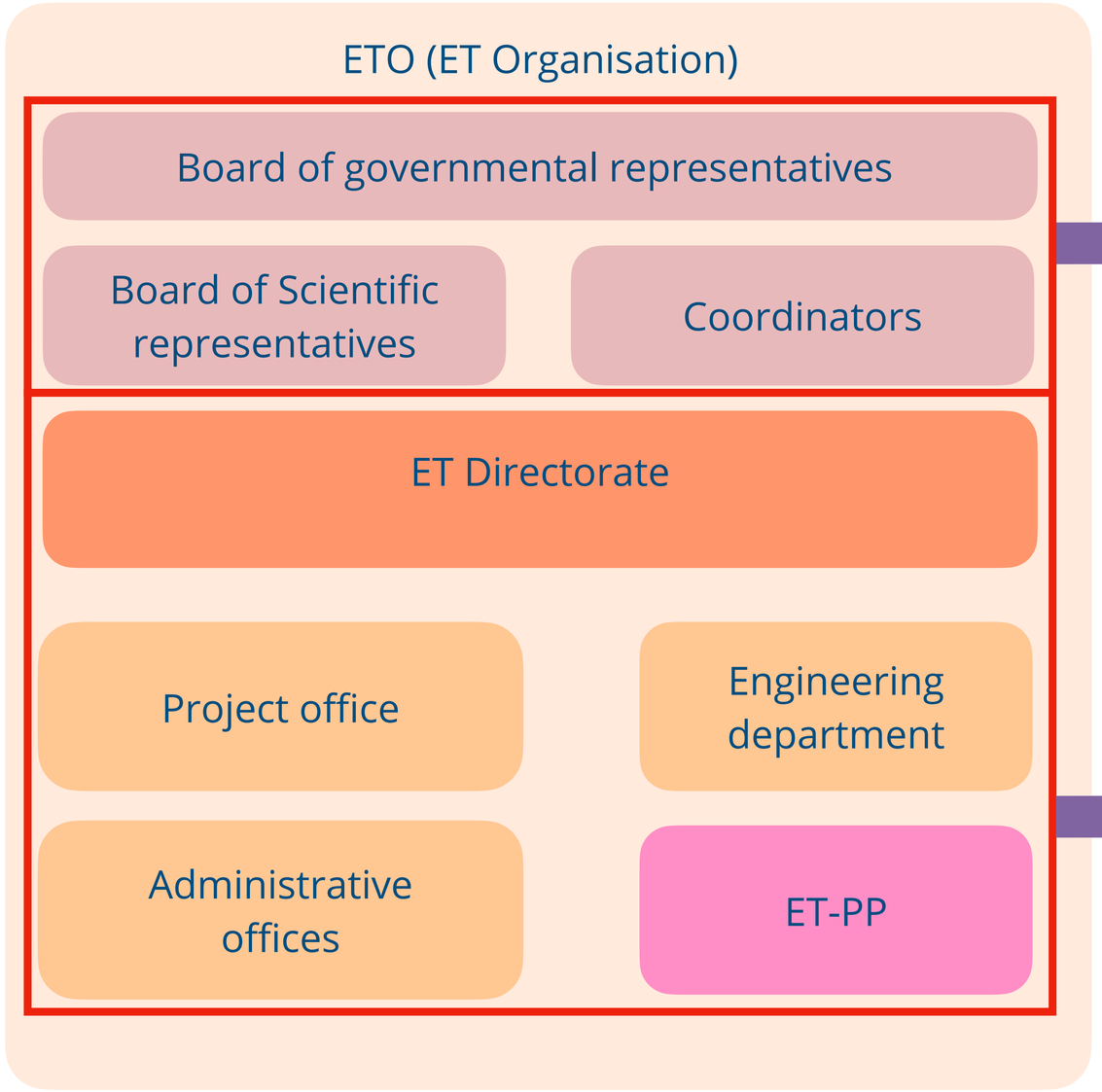
[Timeline: Michele Punturo]

Scientific Collaboration

The collaboration is the **heart and soul** of ET, organically grown since 2005, formalised in 2022.



ETO: an organisation for realising ET



Temporary groups, working towards becoming the ET governing body, such as a Council. **Our most important link to governments and funding agencies** (Austria, Belgium, France, Italy, Netherlands, Poland, Spain, UK are members with Germany as observer).

An small but active organisation with the formal responsibility to realise of ET. **A future legal entity for ET would be based on this structure.**

ETO: an organisation to provide project management and engineering support

ETO (ET Organisation)

Board of governmental representatives

Board of Scientific representatives

Coordinators

ET Directorate

Communication office

Engineering department

Head of communication: Martine Oudenhoven

Head of engineering : Patrick Werneke

Fernando Ferroni (INFN, Italy)

Andreas Freise (Nikhef, NL)

Mario Martinez (IFAE, Spain)

Currently **bootstrapping** the organisation:

- **team building**, recruiting
- clarifying roles and responsibilities
- **negotiating** with partner states
- organising a **new funding** line (several million per year)

EMR Organisation

An **EMR projectbureau** has been established in Maastricht, in order to prepare:

- feasibility studies for civil engineering and geology;
- feasibility studies for planning and regulations;
- stakeholder communications;

The **EMR Task Force** engages **governments in the region**, with tasks to decide upon:

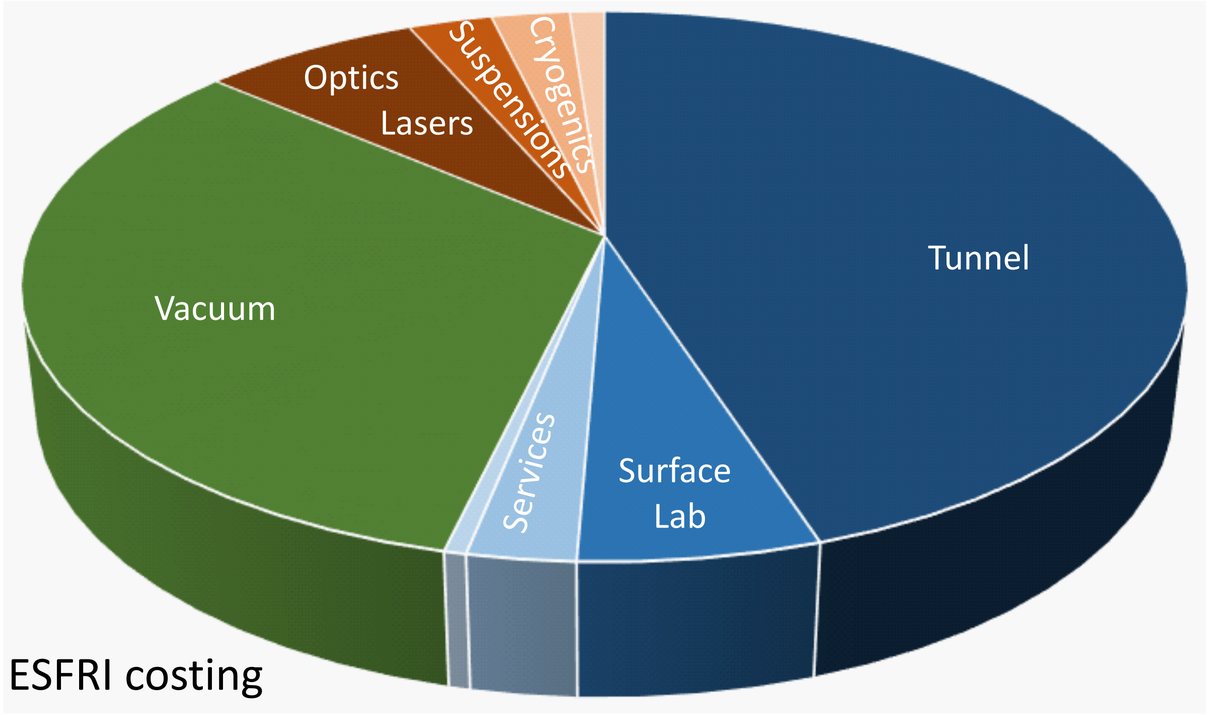
- Collection and dissemination of relevant information;
- coordination with scientific experts and committees;
- preparation of bid book;
- preparation of host consortium of governments.

- Members of the task force:
  - Netherlands and Province of Limburg;
  - North Rhine-Westphalia;
  - Belgian federal entity;
  - Flanders (Belgium);
  - Wallonia (Belgium);
  - German speaking community (Belgium)
- Observers of the Task Force:
  - Federal Republic of Germany;
  - Benelux-Union;
  - Euregion Meuse-Rhine

How to build the Einstein Telescope?

- Research and Technology
- Organisation and Politics
- Infrastructure and Engineering

Einstein Telescope: initial cost estimates



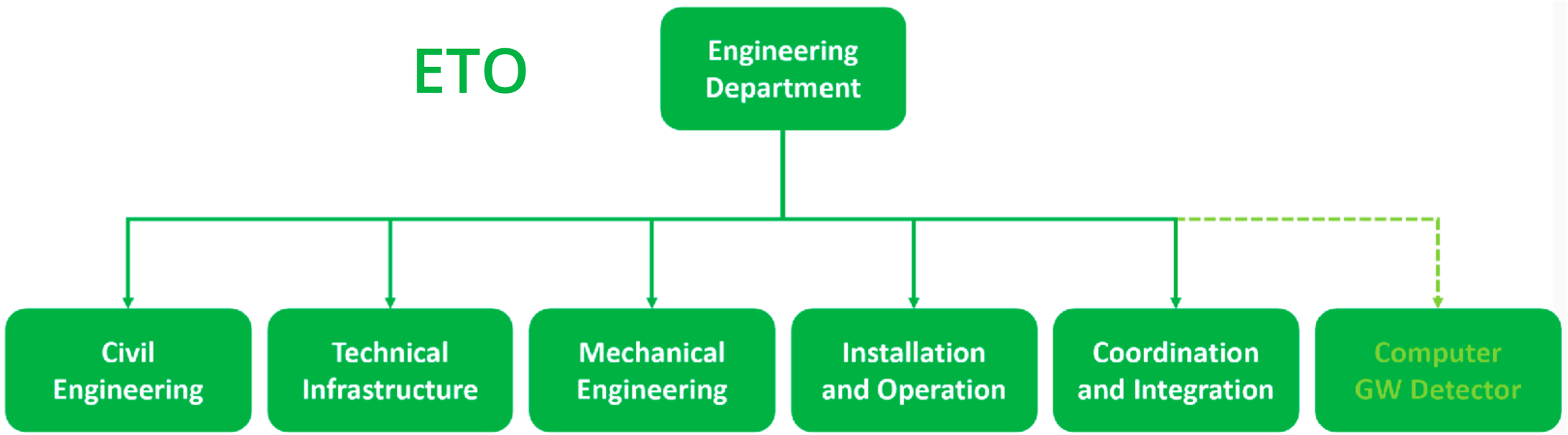
Tunnel	781 M€
Surface Lab	98 M€
Underground Services	44 M€
Direction	9 M€
	932 M€
Vacuum Systems	566 M€
	566 M€
Optics & Lasers	125 M€
Suspensions	48 M€
Cryogenics	45 M€
Installation	20 M€
	238 M€

Underground infrastructure for
more than 50 years of operation

Plus design and development cost: ~200 M€
Total cost (excluding personnel): ~1.900 M€

(Costing is based on conceptual design, requires updates based on technical designs.)

ETO in charge of civil engineering and technical infrastructure



- **We are working with CERN** to get support from their team for these topics.
- Major parts of the design require the involvement of companies. We need to have in-house expertise in order to define the required work and to write correct tenders.
- This also requires coordination of the ET Collaboration and the national teams doing technical work towards the bidbooks for the candidate sites.

Gravitational Waves at CERN

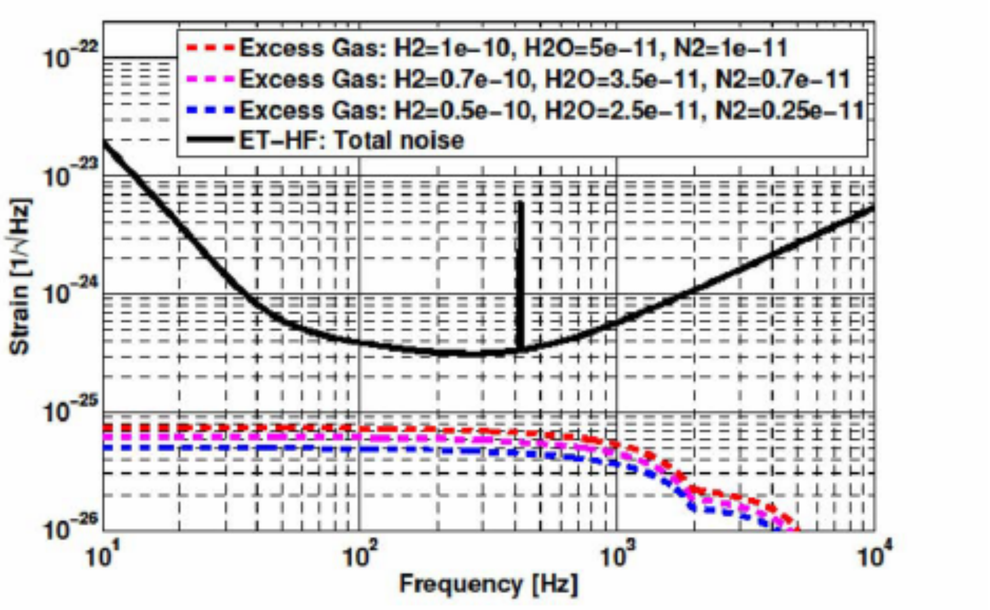
- **We actively seek collaborations with technical teams at CERN**. Those teams can provide extremely valuable expertise for urgent topics, such as vacuum pipe systems and the construction of underground infrastructures.

- By working with CERN we are established links and building ET-related knowledge within the technical teams at CERN and we are establishing ET as a active topic within the CERN systems, **opening the doors for future opportunities** (management, coordination, …).

- The Einstein Telescope is now a '**recognised experiment**' at CERN. This will allow easier access to CERN itself and to CERN tools.

- However, so far CERN does not (and cannot) use its resources to support ET. We have to pay (extra) for any ET work done at CERN.

First project: ET vacuum pipe technical design



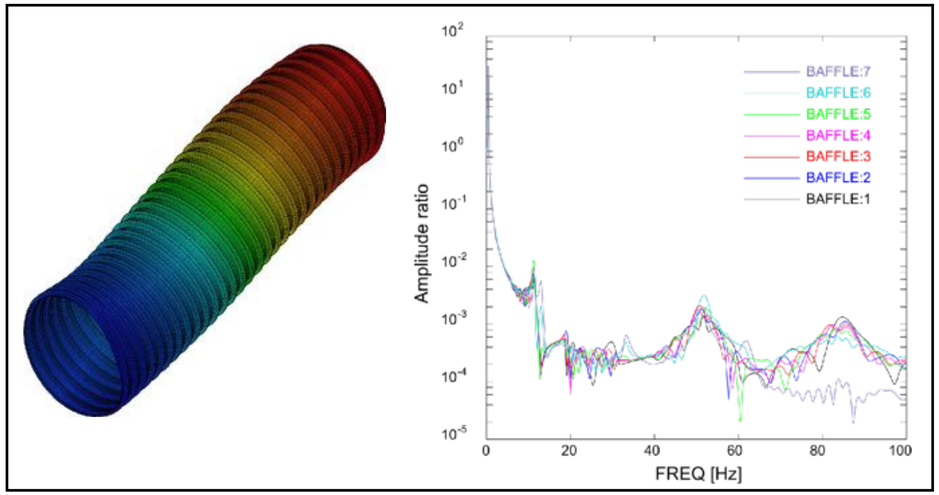
Noise level below 10^{-25} $Hz^{-1/2}$

Main specifications (ET-HF most critical):

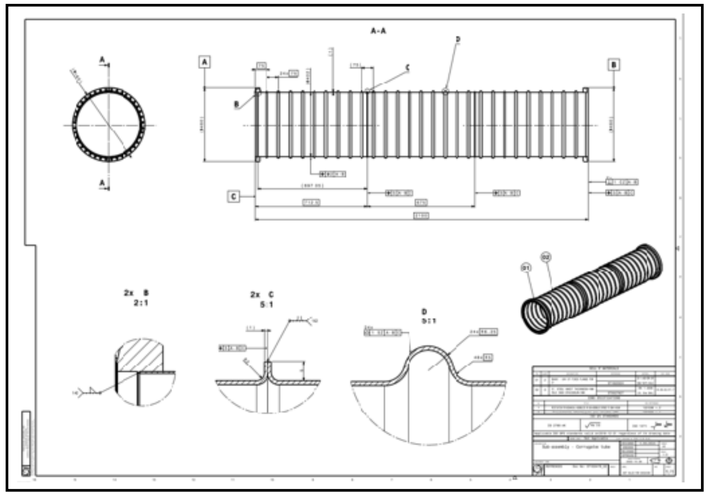
- 1 meter inner diameter
- $P_{H2} \approx 10^{-10}$ mbar
- $P_{H2O} < 5*10^{-11}$ mbar
- $P_{CxHy} < 10^{-14}$ mbar (M>100 amu)

[Patrick Werneke]

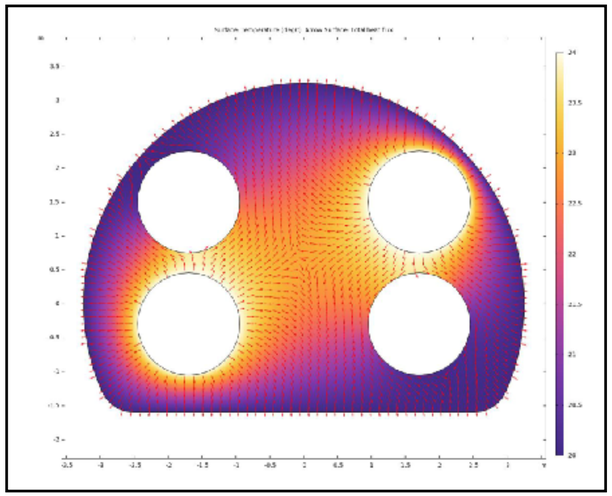
CERN vacuum project: output



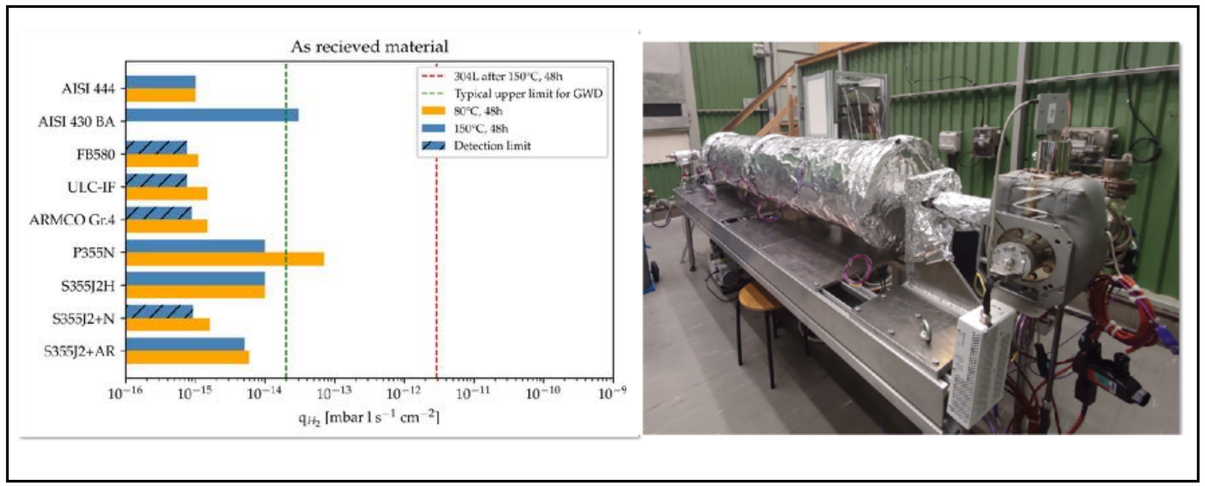
Modelling



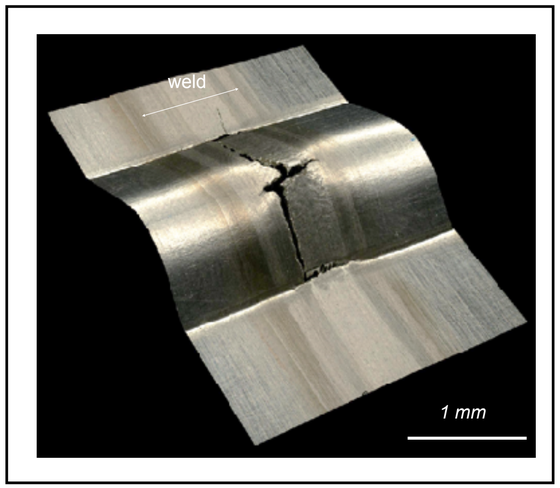
Design



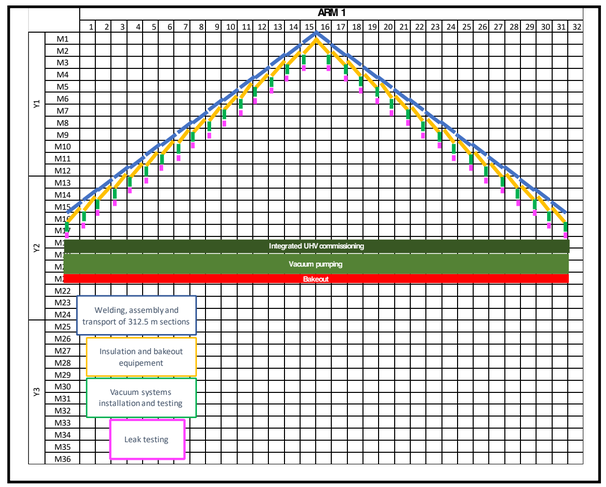
Simulation



Material test



Welding test



Planning

GWs in the CERN Courier

12.05.2023

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

C Hervé

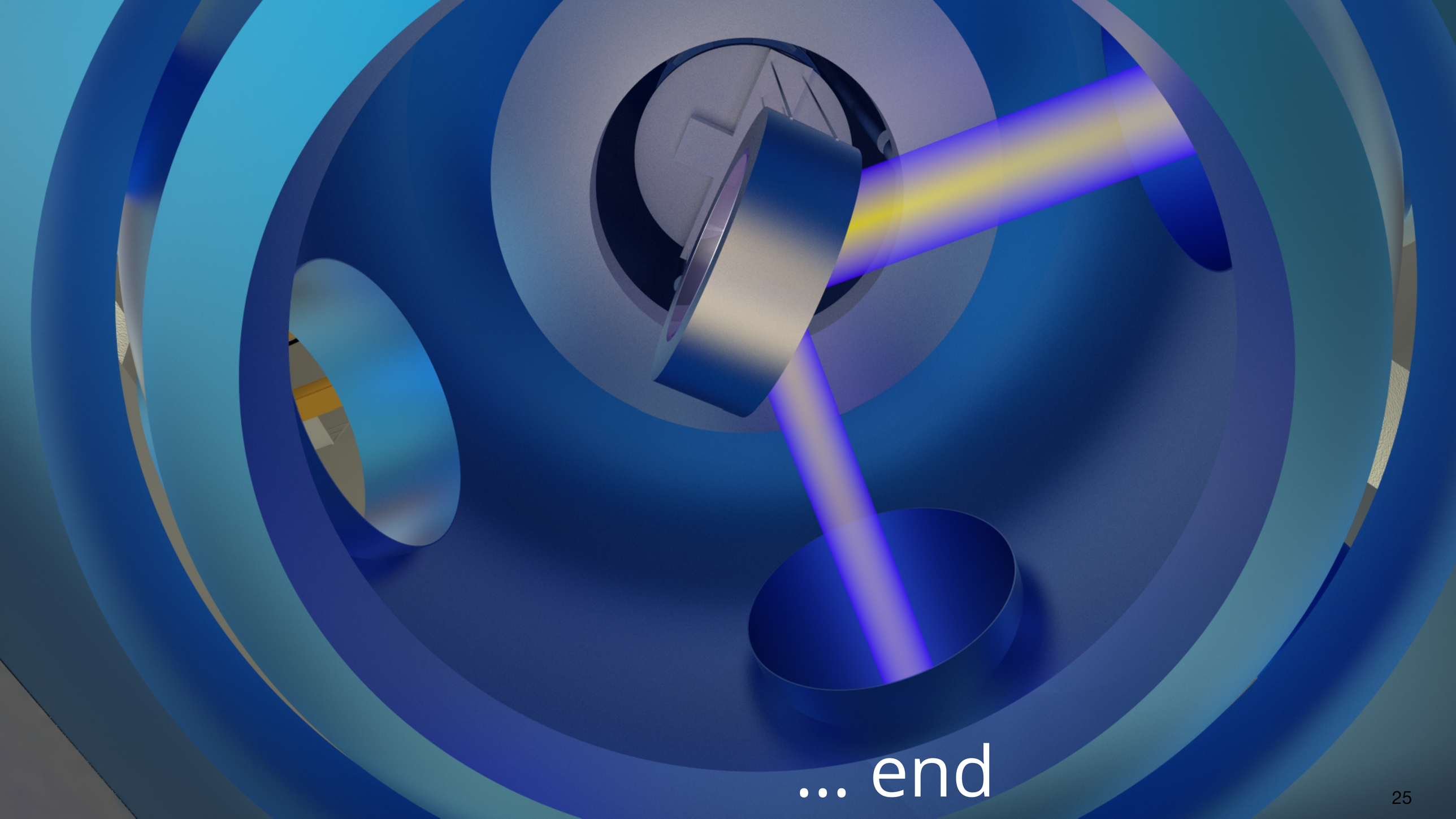
Beam me up
The participants of the March workshop that was dedicated to vacuum technologies for beampipes of

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

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, logis-

https://cerncourier.com/a/cern-shares-beampipe-know-how-for-gravitational-wave-observatories/

Next ET-NL meeting 25.10 here in Maastricht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