



# Overview of cryogenics in ET-LF

Steffen Grohmann – On behalf of ET-ISB Division IV: Vacuum and Cryogenics  
XIII ET Symposium, Cagliari, May 8-12, 2023



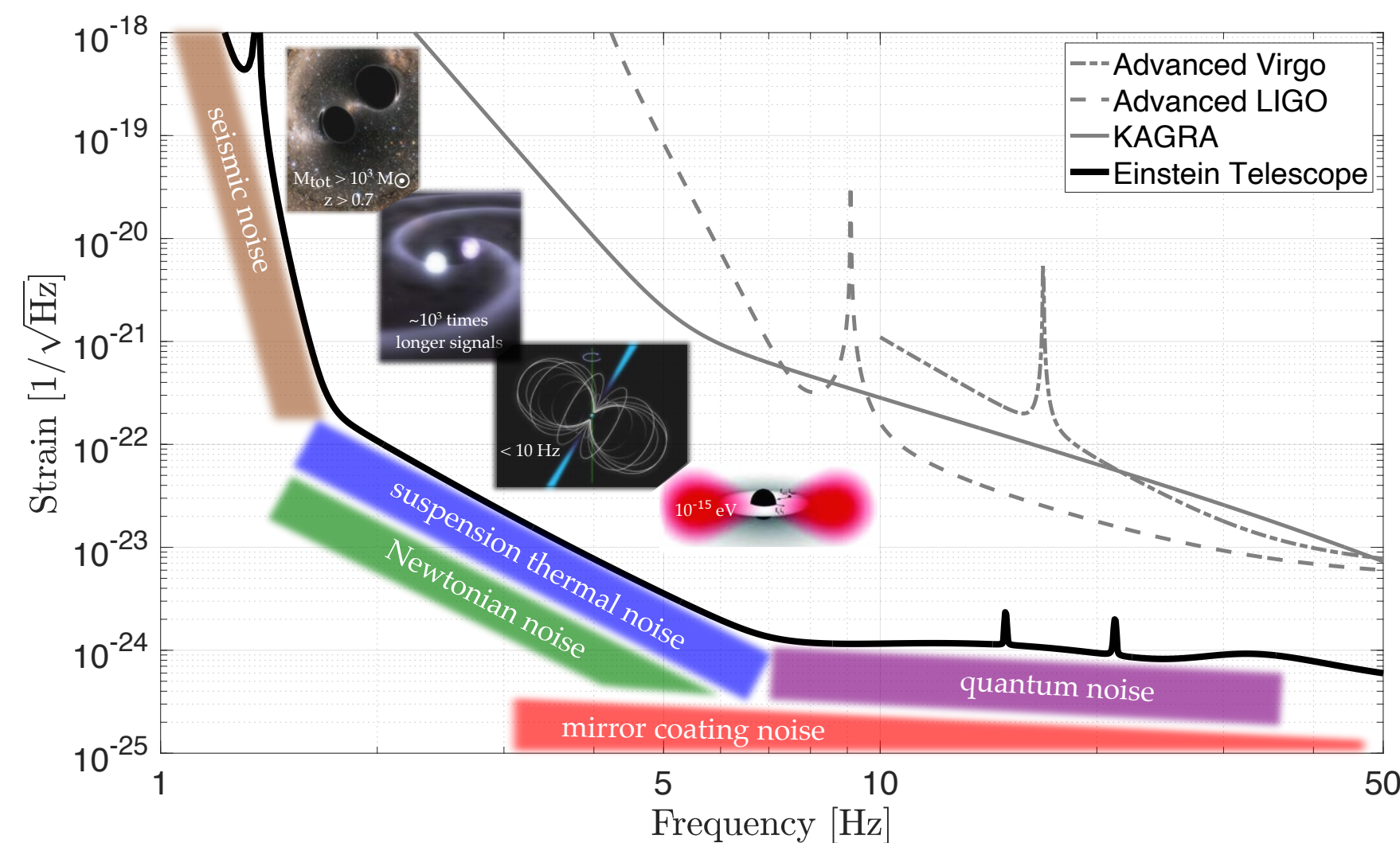
# Outline

- Recap: Necessity of cryogenic ET-LF
- Baseline design of cryogenic payloads for ET-LF
- Conceptual cryostat design
- Mitigation of adsorption on mirrors
- Cryogenic infrastructure concept
- Roadmap to TDR
- R&D facilities

# Necessity of cryogenic ET-LF

## Comparison of low-frequency sensitivities

- Adv. Virgo / Adv. LIGO (2G):  $f_{\min} = 10 \text{ Hz}$
- KAGRA (2.5G):  $f_{\min} = 5 \text{ Hz}$   $\rightarrow$
- ET (3G):  $f_{\min} = 3 \text{ Hz}$   $\rightarrow$  **5 Hz sensitivity  $\times 10^{-3}$ !**



Source: S. D. Pace et al.: Research Facilities for Europe's Next Generation Gravitational-Wave Detector Einstein Telescope. *Galaxies* 10 (3), 65, doi: [10.3390/galaxies10030065](https://doi.org/10.3390/galaxies10030065) (2022)

From: M. Maggiore et al.: Science with the Einstein Telescope: a comparison of different designs. [arXiv:2303.15923](https://arxiv.org/abs/2303.15923) [gr-qc] (2023)

The low-frequency sensitivity is crucial for exploiting the full scientific potential of ET, in particular with regard to:

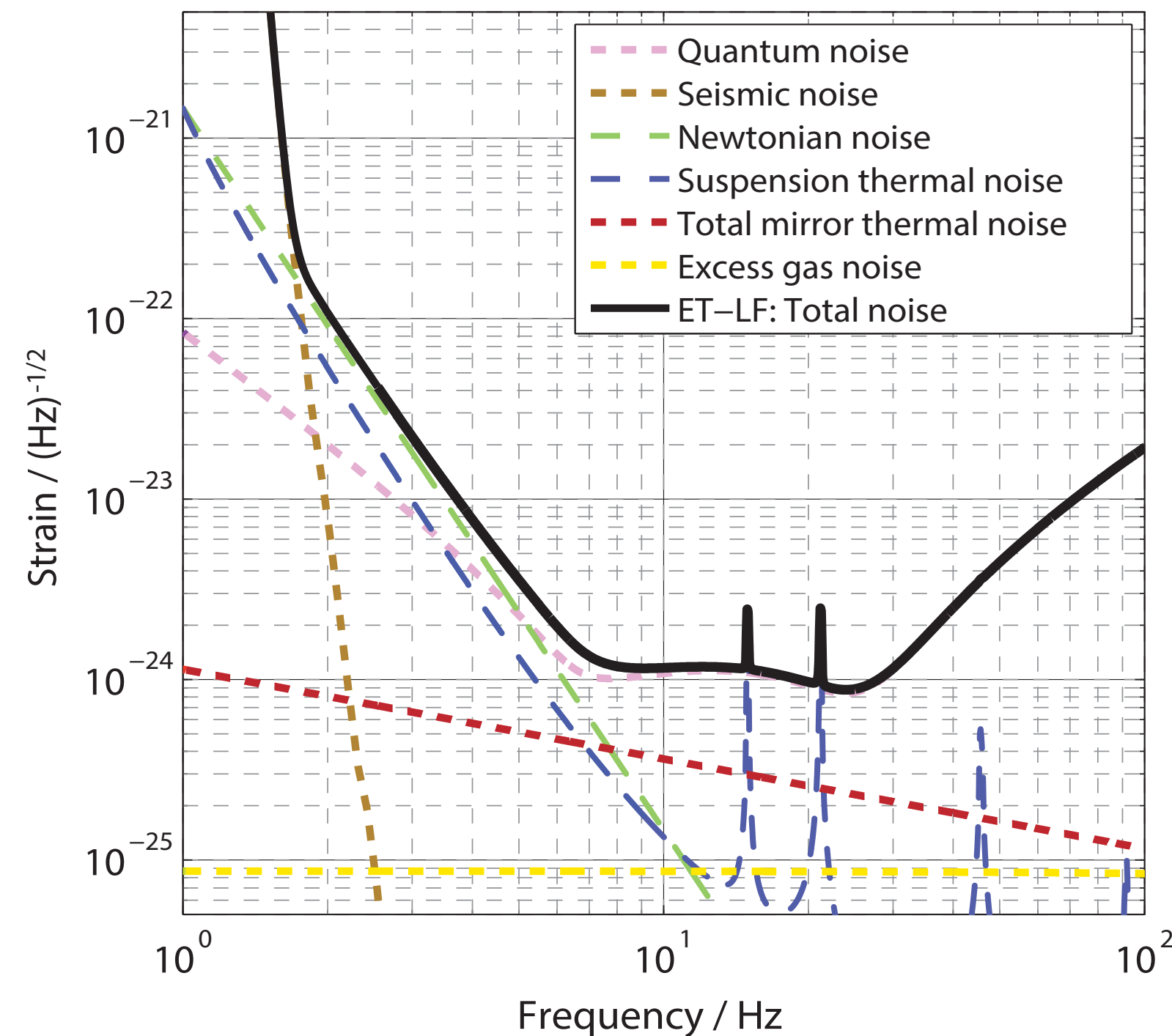
- the observation of binary neutron stars (BNS), staying long time in the bandwidth,
- pre-merger detection to probe the central engine of gamma ray bursts (GRB), particularly to understand the jet composition, the particle acceleration mechanism, the radiation and energy dissipation mechanisms,
- detecting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



# Feasibility of cryogenic payloads for ET-LF



## ET-D sensitivity curve



## Assumptions

- ET Conceptual Design Study (2011)
- Design Report Update (2020)

	Marionette	Recoil mass	Mirror
Mass (kg)	422	211	211
Suspension length (m)	2	2	2
Suspension diameter (mm)	3	3	3
Suspension material (-)	Ti6Al4V	Silicon	Silicon
Loss angle (-)	$1 \times 10^{-5}$	$1 \times 10^{-8}$	$1 \times 10^{-8}$
Temperature (K)	2	10	10

- Technical implementation not straightforward
- ▶ **Baseline design study** carried out by ET-ISB Divisions I and IV

# Baseline design of ET-LF cryogenic payloads



## New reference paper

Link: <https://arxiv.org/abs/2305.01419>

## Objectives

Consistent design study in terms of

- Mechanical design
- Thermal design
- STN modelling

Compete description of the **STN model**, including collection of available material data

Stepping stone for future design optimisation(s)

Reference for **cryostat design** (dimensions)

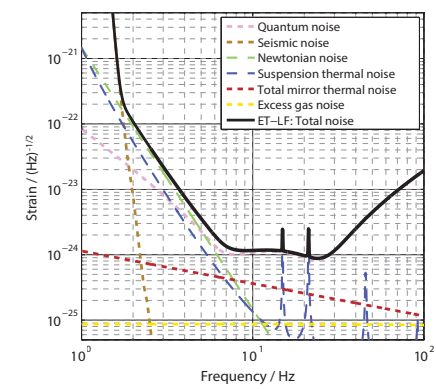
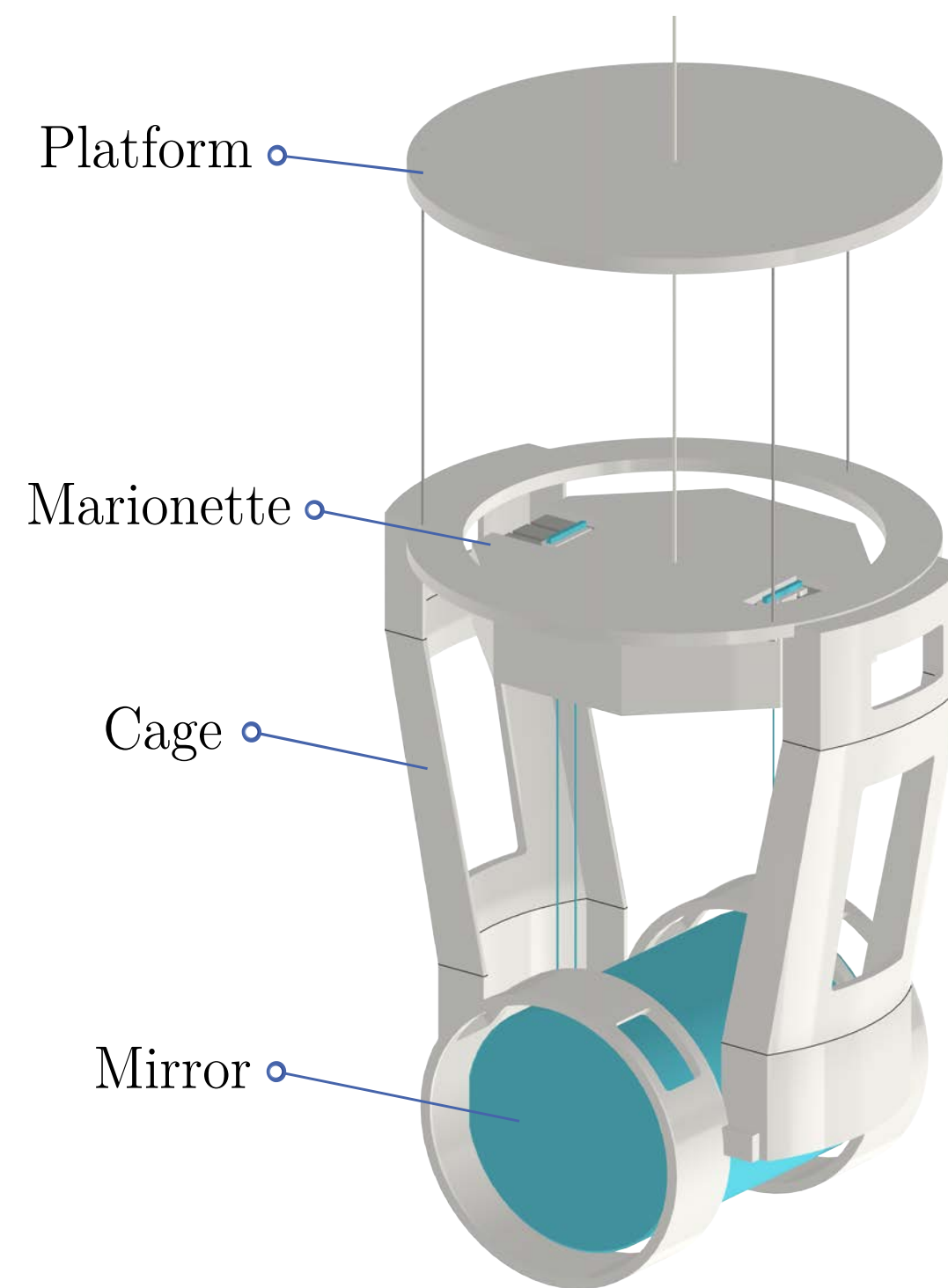
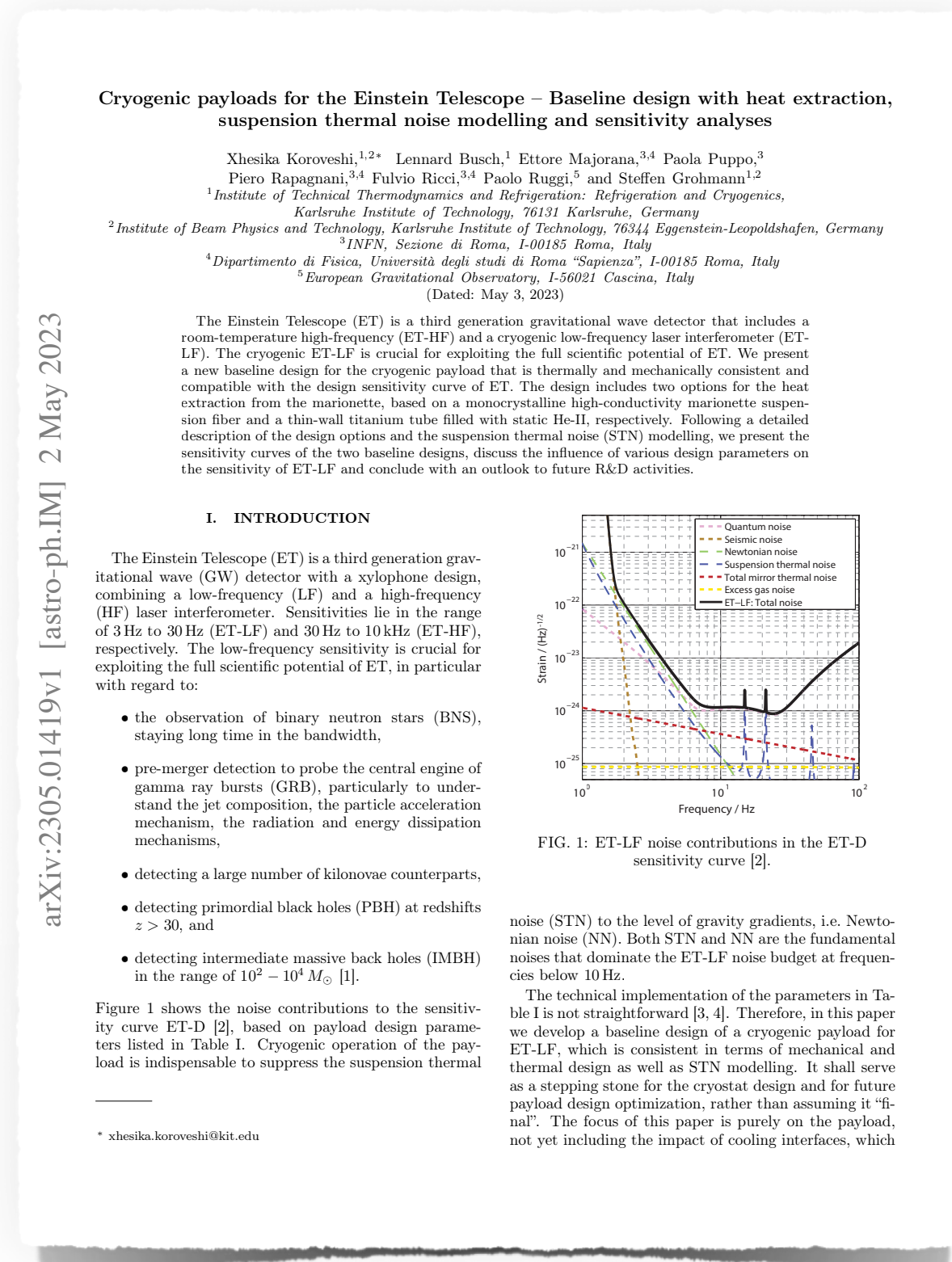


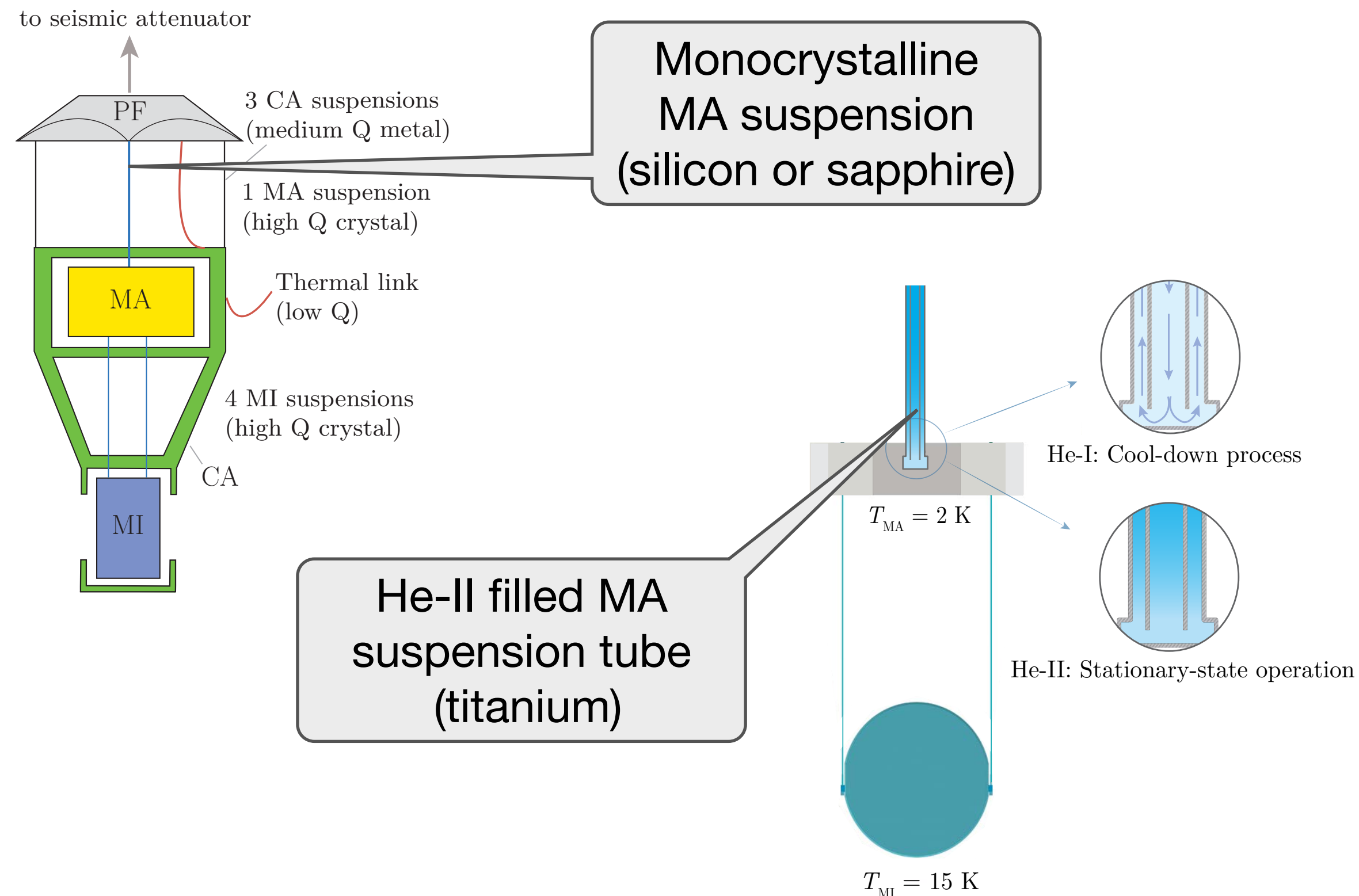
FIG. 1: ET-LF noise contributions in the ET-D sensitivity curve [2].

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.

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

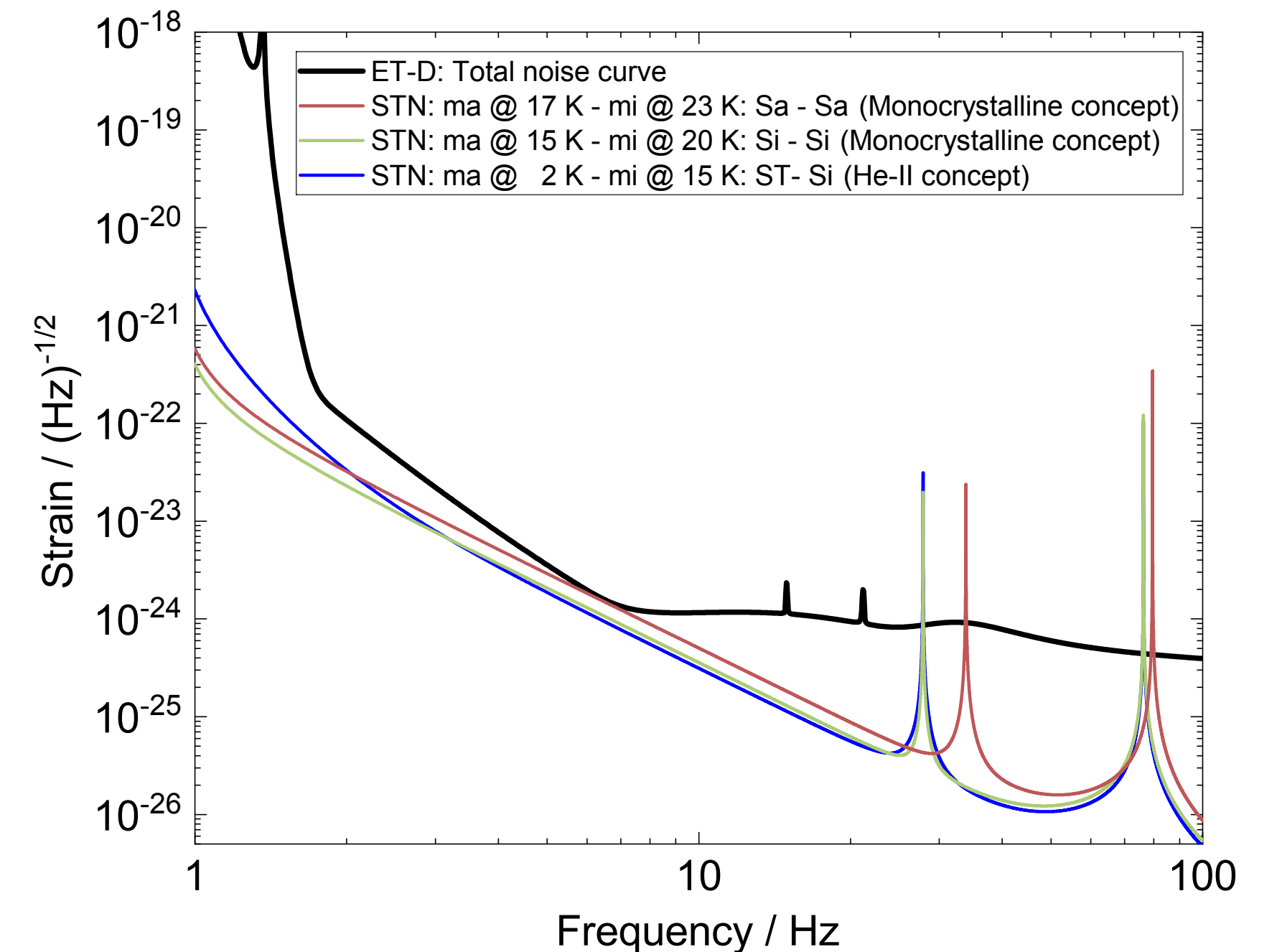
# Baseline design of ET-LF cryogenic payloads

## Two options for the heat extraction



## Sensitivity (STN)

Both concepts fulfil the requirements of the ET-D curve



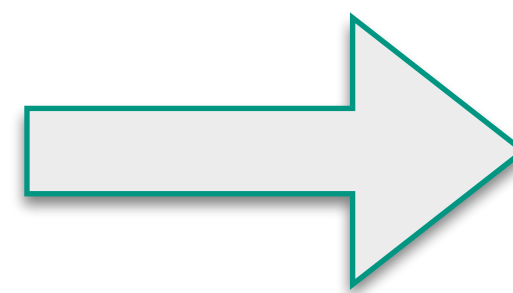
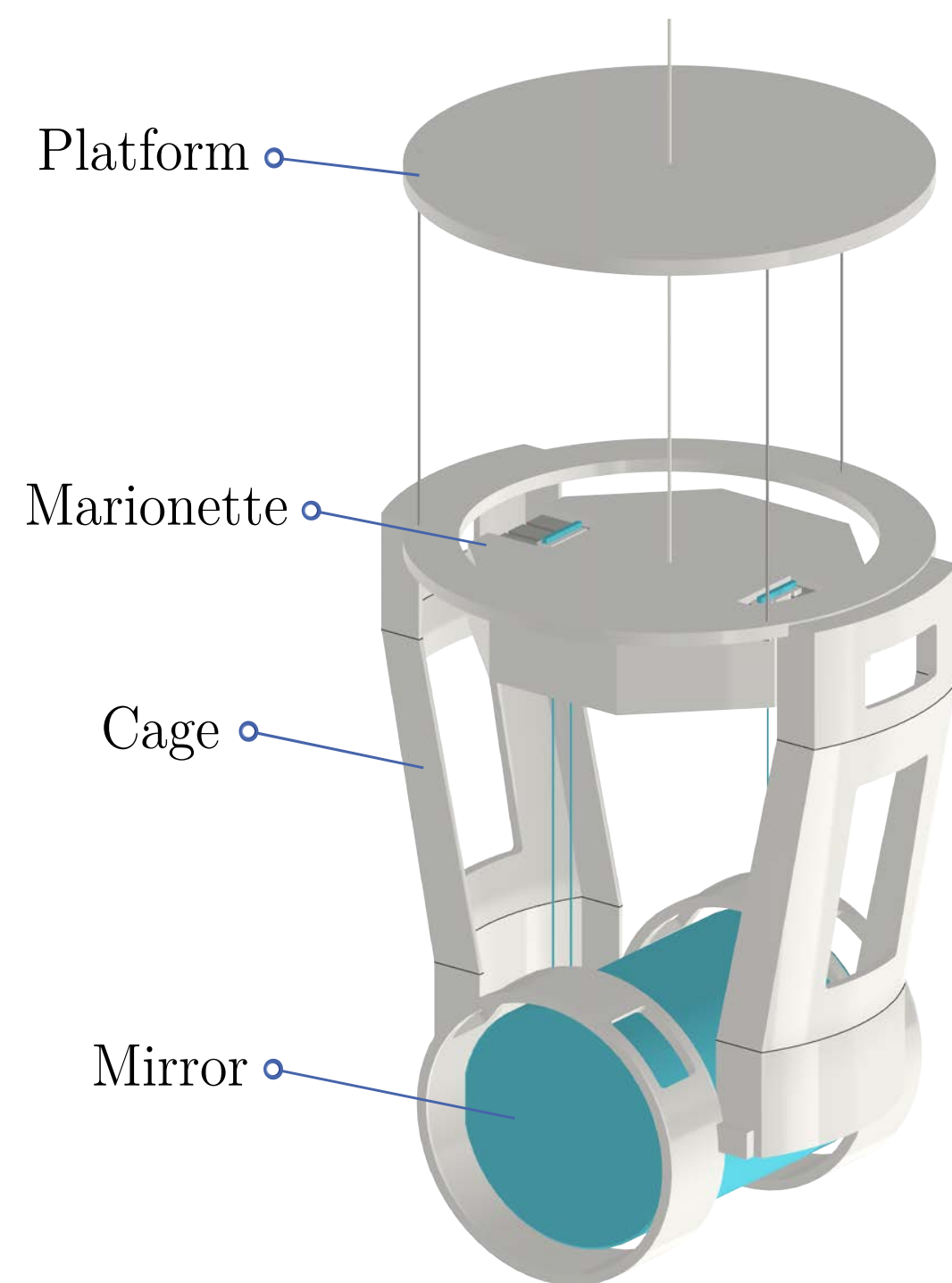
► Cooling interfaces **not yet** part of the study!



# Conceptual design of ET-LF cryostat

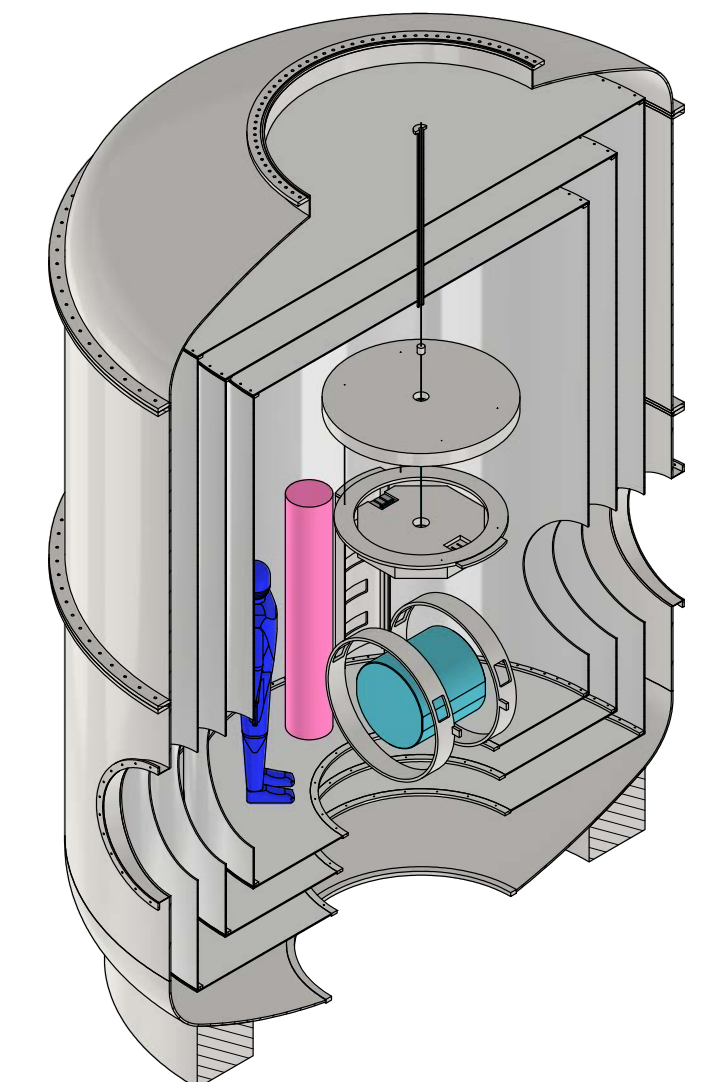
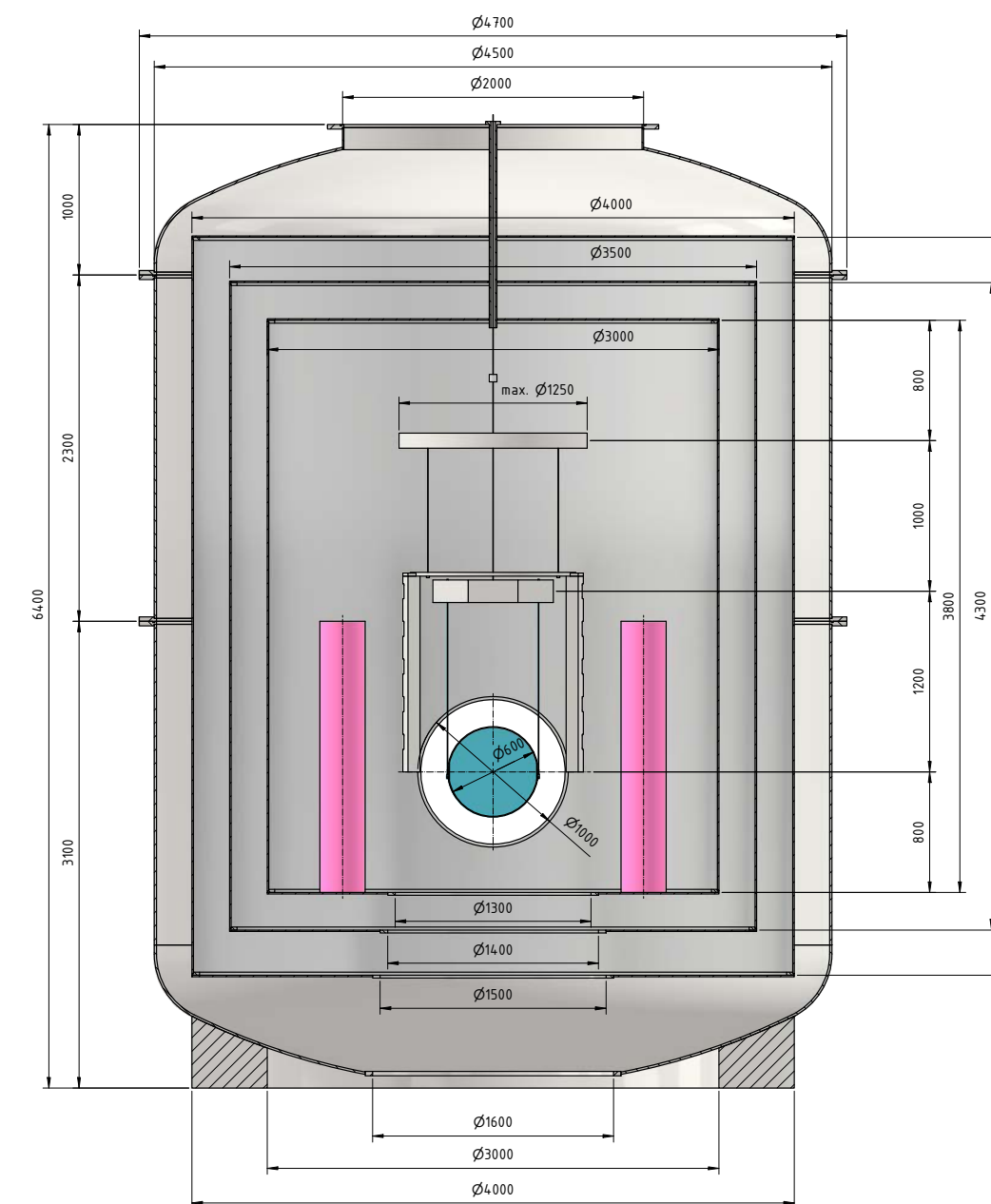
## ■ Baseline payload design

- Details: <https://arxiv.org/abs/2305.01419>



## ■ Conceptual cryostat design

- Details: ET-0272A-22  
<https://apps.et-gw.eu/tds/ql/?c=16460>



# Mitigation of adsorption on mirrors



## Cryogenic operation in KAGRA

### 3.2.3. Recent Results on Cryogenics

Cooling mirrors for reducing thermal noise are a unique feature of KAGRA, adding certain difficulties related to cryogenics. One of them is molecular adsorption on the cryogenic mirror surface, which causes variations in the reflectivity of the mirrors and laser absorption in the molecular layers [41]. Because molecular layers of a few micrometers cause significant changes in the sensitivity of KAGRA, the mirrors need to be frequently warmed to desorb the molecules from the mirror surface. For this purpose, new heaters for the desorption of molecules were newly installed on the IM stage of the cryogenic payload to mitigate the downtime of observation. Owing to these new heaters, the downtime of the desorption process is expected to reduce from several weeks to a few days.

**Source:** H. Abe et al.: The Current Status and Future Prospects of KAGRA, the Large-Scale Cryogenic Gravitational Wave Telescope Built in the Kamioka Underground. *Galaxies* 10, 63, doi: [10.3390/galaxies10030063](https://doi.org/10.3390/galaxies10030063) (2022)

## Paper of frost mitigation strategies

**Source:** L. Spallino et al.: Cryogenic vacuum considerations for future gravitational wave detectors. *Phys. Rev. D* 104, p. 062001, doi: [10.1103/PhysRevD.104.062001](https://doi.org/10.1103/PhysRevD.104.062001) (2021)

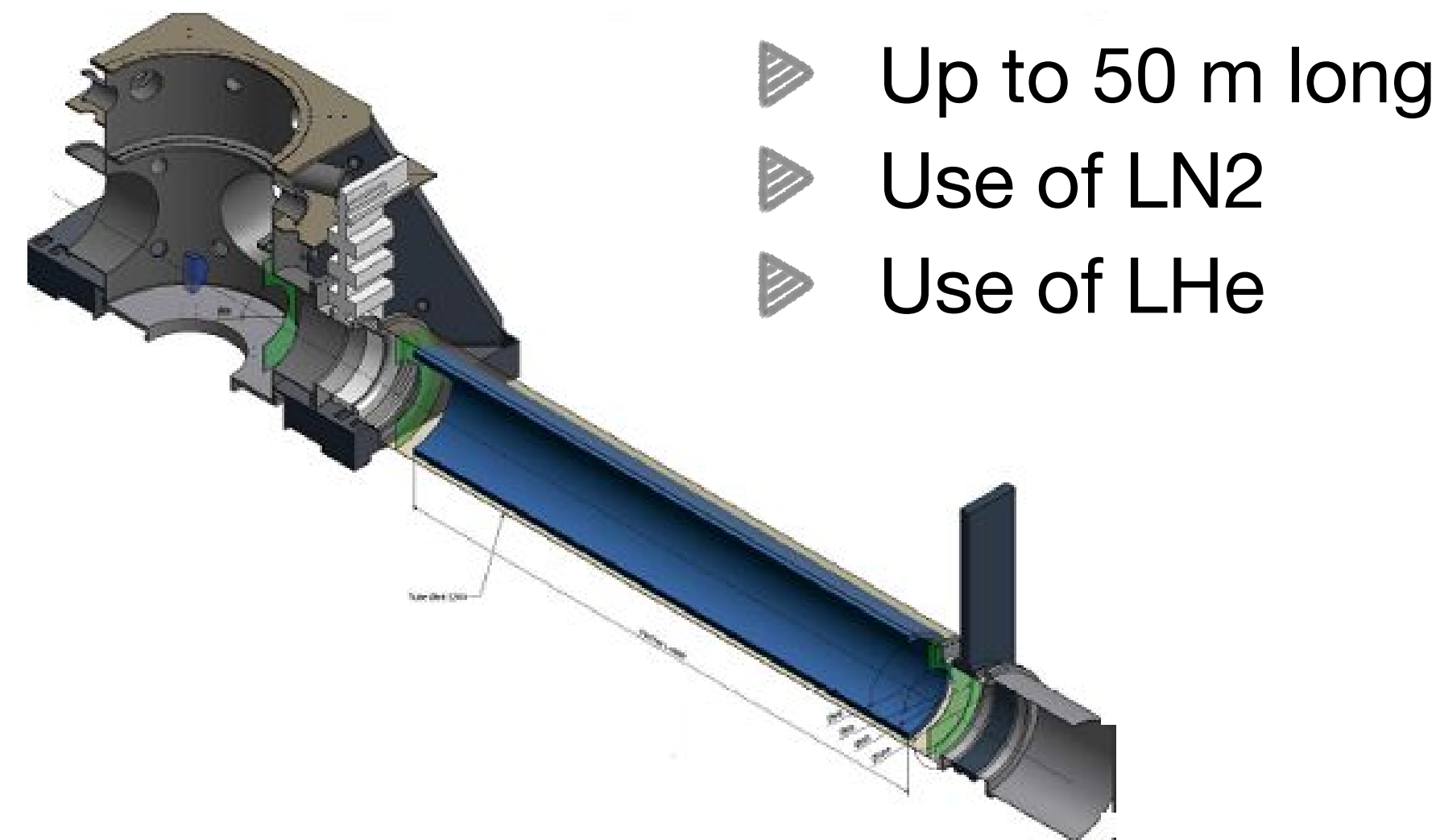




# Cryopump development for ET-LF

## Original concept

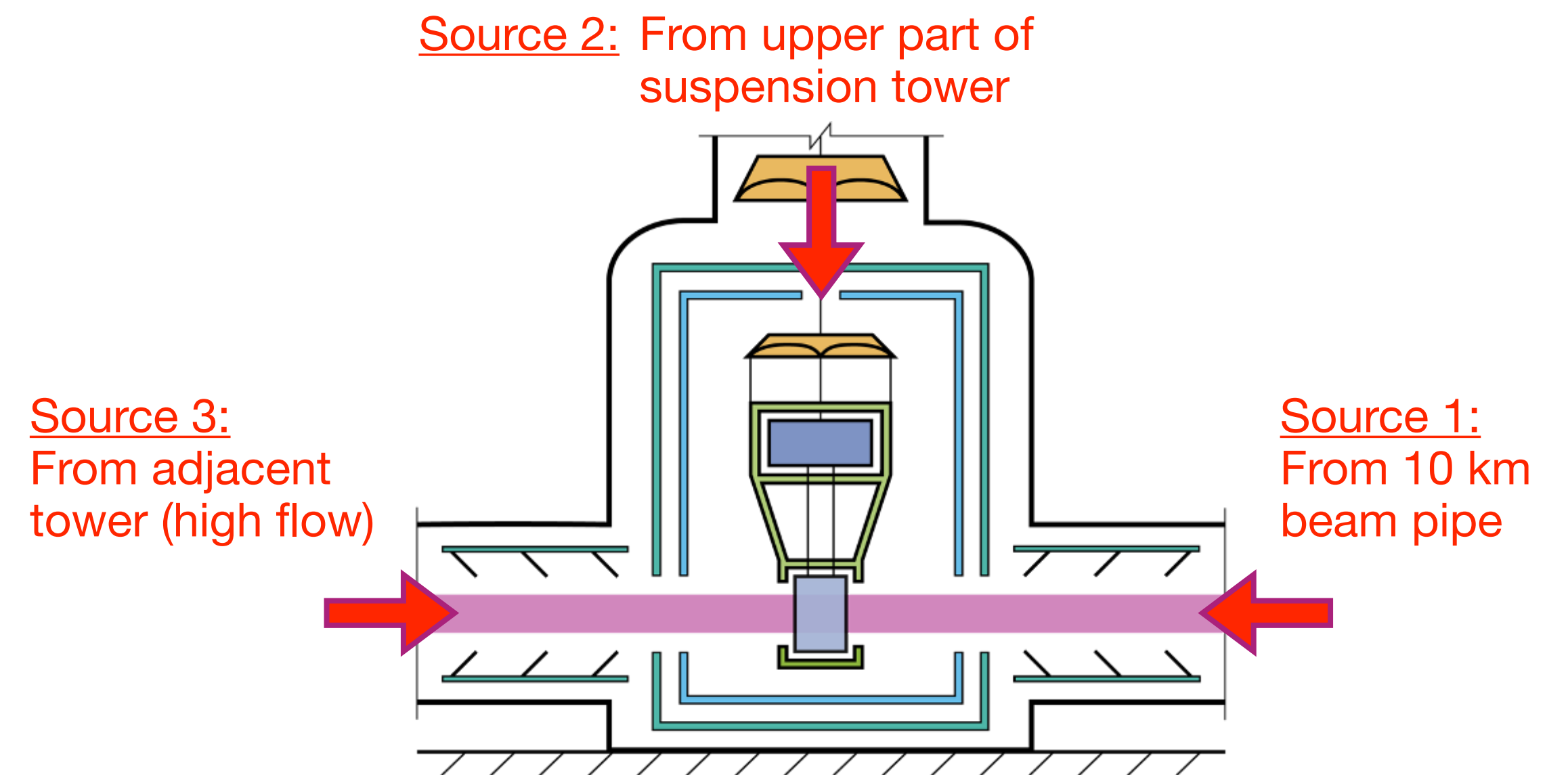
- ET Conceptual Design Study (2011)
- Design Report Update (2020)



Source: ET science team: Einstein gravitational wave Telescope conceptual design study. <https://apps.et-gw.eu/tds/ql/?c=7954> (2011)

## Vacuum modelling and cryopump development at KIT

- TPMC modelling with all gas sources and simplified geometry
- KIT in-house code ProVac3D

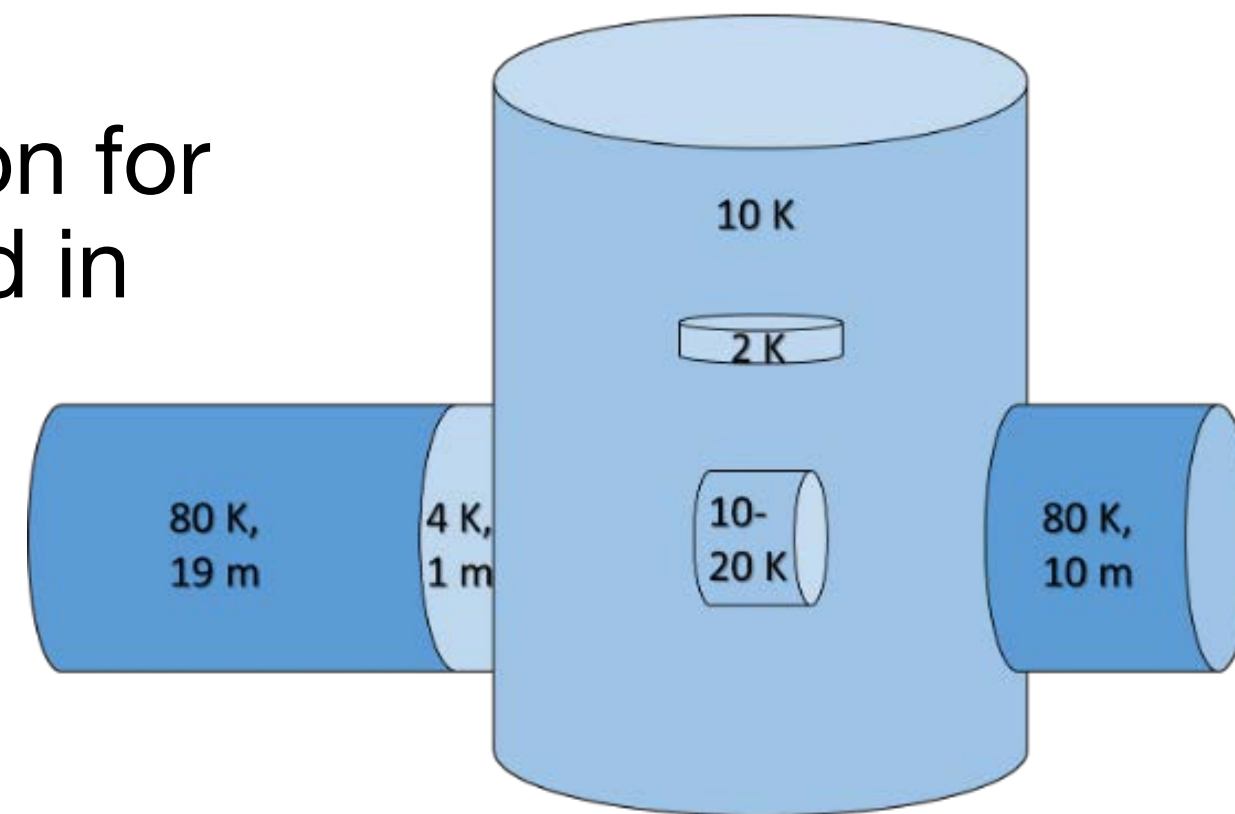


# Preliminary results of tower vacuum modelling



## Modelling results

- **Source 1:**  
Cryopump at 80 K for water trapping sufficient
- **Source 2:**  
Conductance minimisation plus (cryo)pumping in upper tower needed to reduce flow
- **Source 3:**  
Cryopump section for hydrogen needed in addition to main water pumping section



**Source:** S. Hanke, K. Battes, X. Luo and C. Day: Cryopumps at the extremities of the beampipes: design and performance. Beampipes for Gravitational Wave Telescopes 2023, CERN, March 2023, <https://indico.cern.ch/event/1208957/>

## Main conclusions

- **Pressures** around mirror
  - ▶ Hydrogen:  $p_{\text{H}_2} \approx 3 \times 10^{-13}$  mbar
  - ▶ Water:  $p_{\text{H}_2\text{O}} \approx 1 \times 10^{-14}$  mbar
- **Water ice** build-up ~2 years for 1 ML
- Pumping of **water** at 80 K
- Pumping of **hydrogen**
  - ▶ 10 K with adsorbent
  - ▶ 3.8 K with metallic surface
  - ▶ **Helium cooling** needed for H2 cryopumps

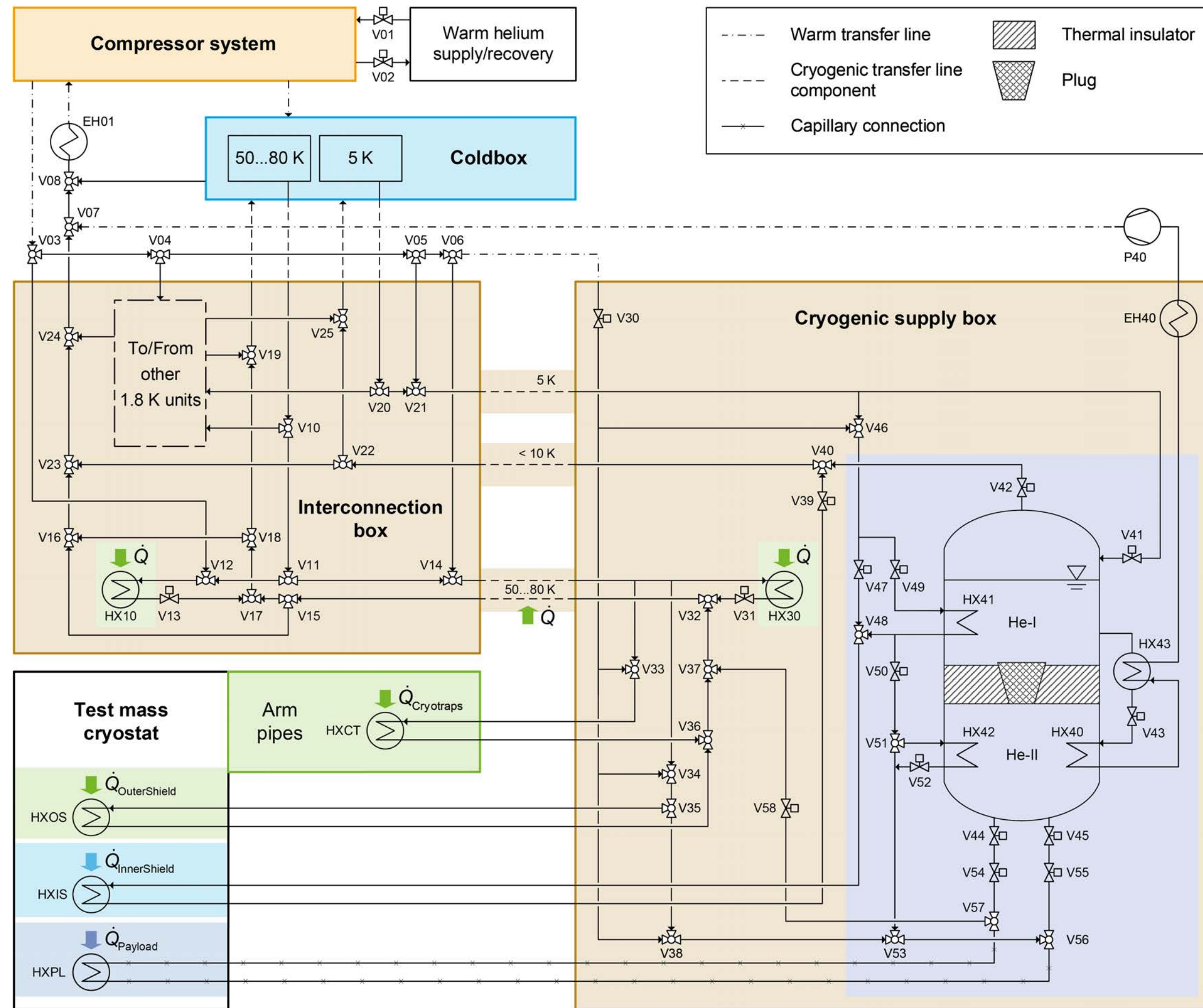
▶ Adsorption can be mitigated by appropriate cryopump R&D

# Intermediate conclusions

- 1) **Cryogenic payloads** compatible with ET-D are **technically feasible** ✓
- 2) **Particle adsorption** on cryogenic mirrors **can be mitigated** ✓
- 3) Work on **technical solutions** for
  - Cryopump design
  - Cryostat design
  - Cryogenic infrastructure design
  - Cooling integration in the payloads
  - ...



# Cryogenic infrastructure concept



- No underground LN<sub>2</sub> (safety)
- One He refrigerator at each vertex
  - (Remote) surface compressors
  - Underground coldbox
  - Interconnection box to several cryogenic supply boxes (1 for each tower/cryostat)
    - ▶ Up to c. 500 m long transfer lines
  - 1-phase cooling H<sub>2</sub>O cryopumps/outer shields
  - 1-phase cooling H<sub>2</sub> cryopumps/inner shields
  - Optional He-II payload cooling/inner shield

**Reference:**  
 L. Busch, S. Grohmann: Conceptual Layout of a Helium Cooling System for the Einstein Telescope. Procs. CEC/ICMC 2021, doi: [10.1088/1757-899x/1240/1/012095](https://doi.org/10.1088/1757-899x/1240/1/012095).

# Required cooling capacities

## Consumers at 80 K

- Cryopumps for water (10...20 m)
- Other thermal shields (use of **MLI open...**)
- Shielding of transfer lines and cryostats

## Consumers at 5 K

- Cryopumps for hydrogen
- Cryogenic supply boxes
- Inner thermal shields

Poster  
Lennard Busch

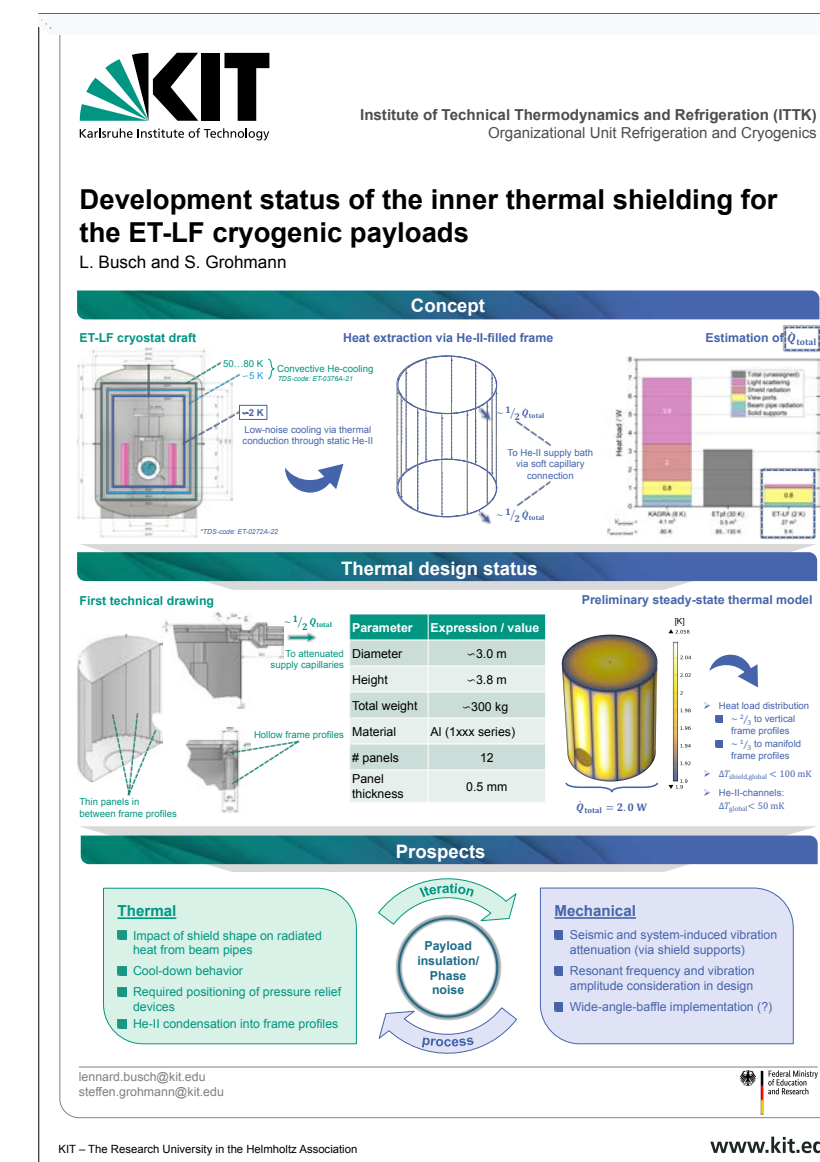
## Consumers at 2 K

- Cryogenic payloads (0.5 W each) ✓
- Inner thermal shields (2 W each) ✓



## Present status

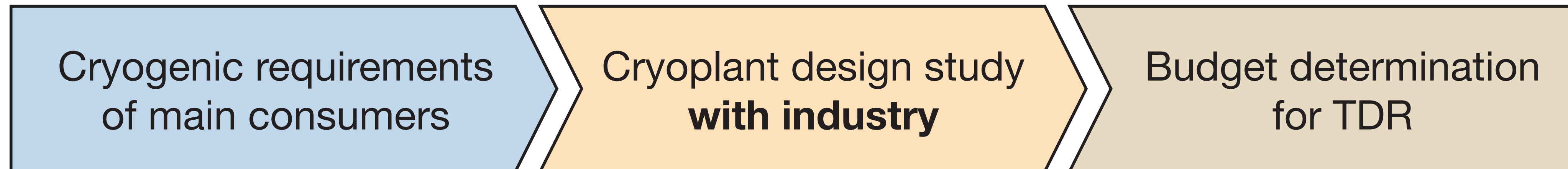
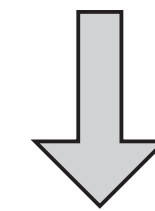
We need **results** from tower vacuum simulations and cryopump design (i.e. the **main consumers**) to determine **the size** of the cryogenic infrastructure



# Roadmap to TDR



Budget required for this study



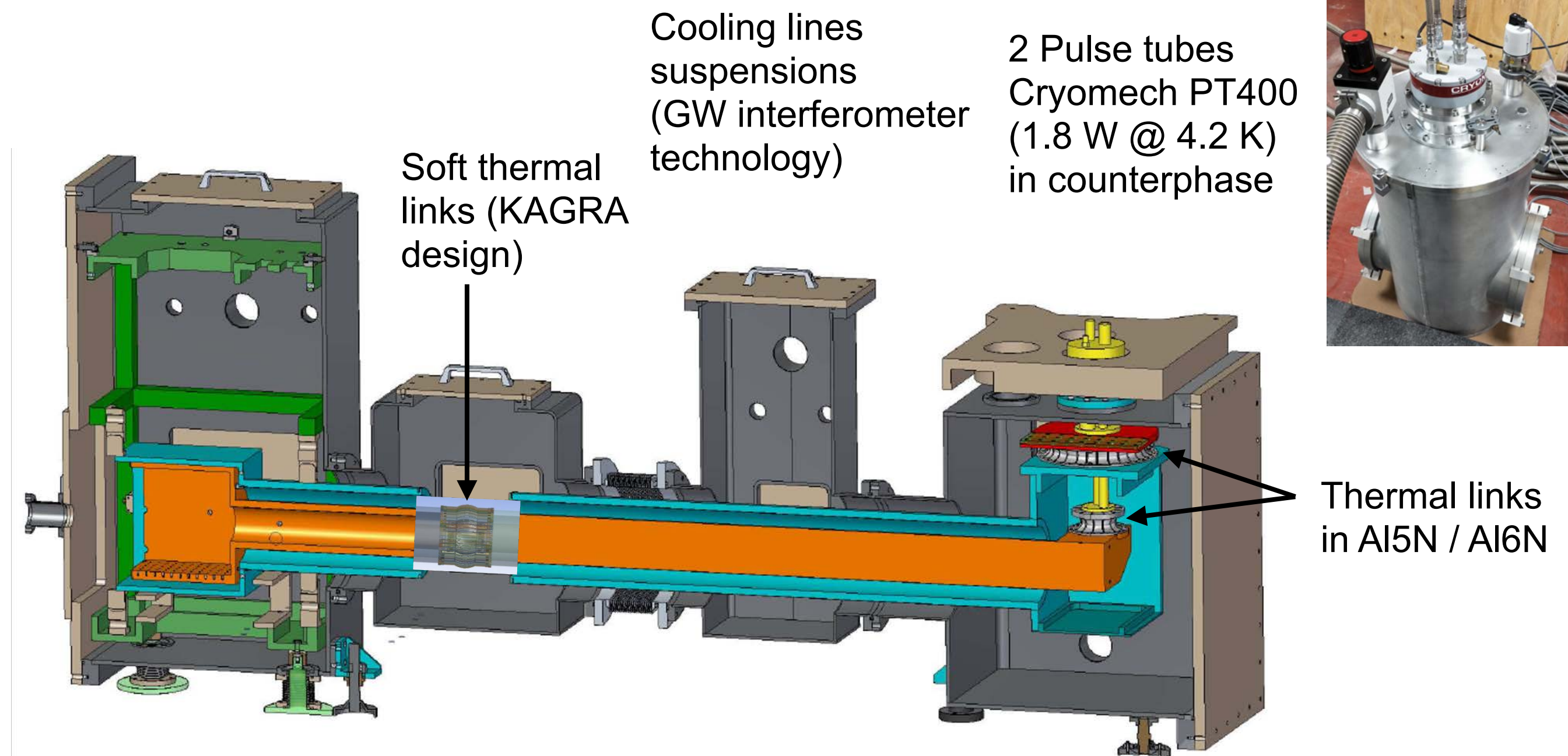


# R&D FACILITIES (OVERVIEW)

# R&D facilities – ARC (Rome)

■ Objective: Development of complete ET-LF payloads

Contact: [https://www.phys.uniroma1.it/fisica/en/arc\\_amaldi\\_research\\_center](https://www.phys.uniroma1.it/fisica/en/arc_amaldi_research_center)



More details: See presentation by Ettore Majorana

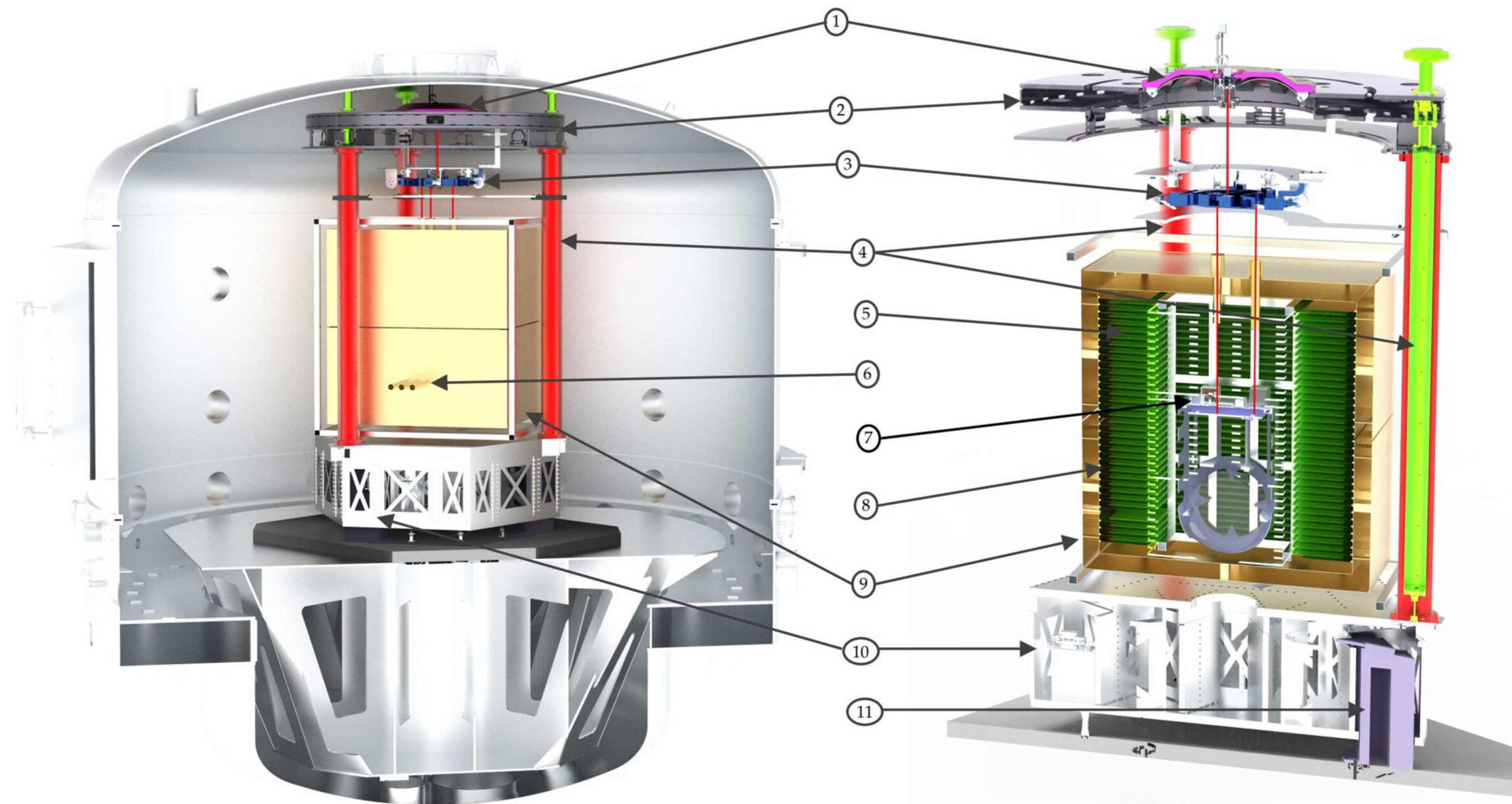




# R&D facilities – E-Test (Liège)

■ Objective: R&D on optics, cryogenics and seismic isolation

Contact: <https://www.etest-emr.eu/activities/prototype-2/>



Communication:  
**No interaction with  
ISB Div. IV!**



# R&D facilities – ETpathfinder (Maastricht)

■ Objective: Testing of full ET-LF interferometer configurations

Contact: <https://www.maastrichtuniversity.nl/etpathfinder>



Communication:  
**Interaction with ISB  
Div. IV could be  
improved**



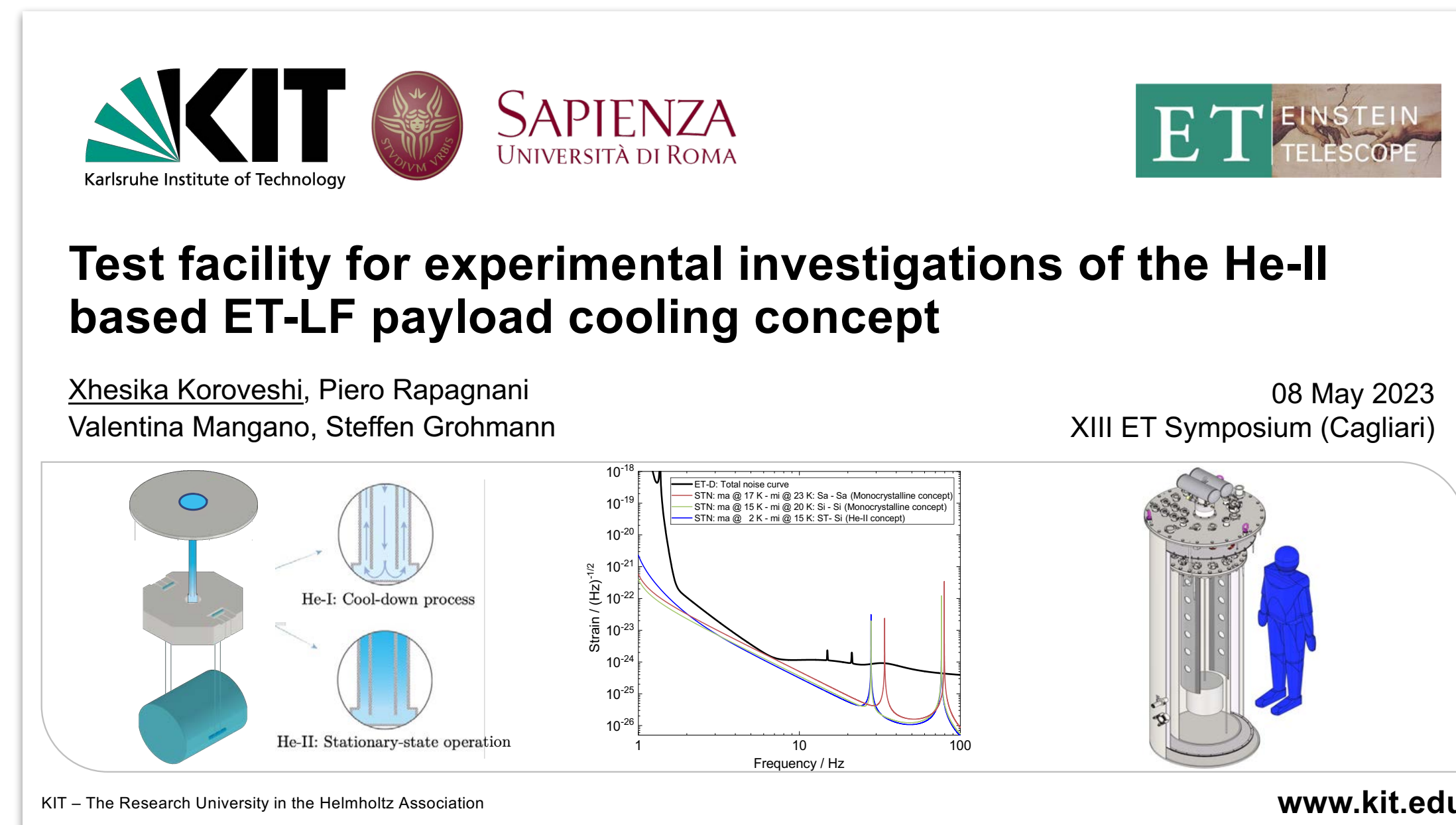
# R&D facilities – KIT (Karlsruhe)



Objective of **new proposal**: Development of He-II technology to **TRL4**

Contact: <https://kkt.ttk.kit.edu/>

Presentation  
Xhesika Koroveshi



The slide features logos for KIT (Karlsruhe Institute of Technology), Sapienza Università di Roma, and the Einstein Telescope (ET). The main title is "Test facility for experimental investigations of the He-II based ET-LF payload cooling concept". The presenters are Xhesika Koroveshi, Piero Rapagnani, Valentina Mangano, and Steffen Grohmann. The date and location are 08 May 2023, XIII ET Symposium (Cagliari). The slide contains three main visual elements: a schematic of the He-I cool-down process and He-II stationary-state operation; a log-log plot of Strain / (Hz)<sup>1/2</sup> vs Frequency / Hz showing noise curves for ET-D and various STN concepts; and a photograph of the test facility with a person for scale. The website www.kit.edu is listed at the bottom right.





Thank you for your attention!

Source: ET Design Report Update (2020)