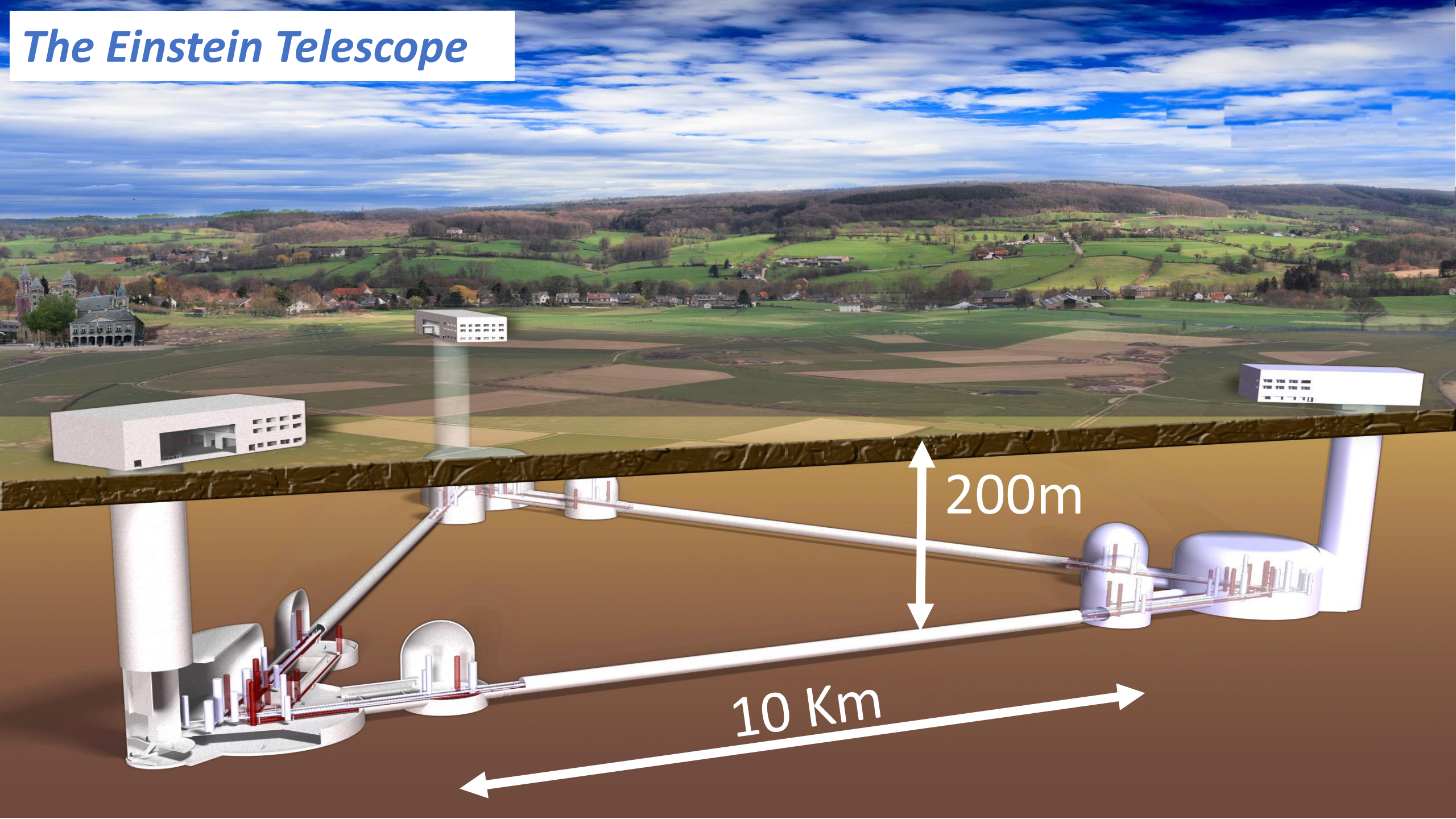
Cryogenic radiative cooling of a large mirror suspended from an inverted pendulum and active platform for gravitational wave detector

Christophe Collette & Lionel Jacques

The Einstein Telescope



Challenges

Instrumental Technologies

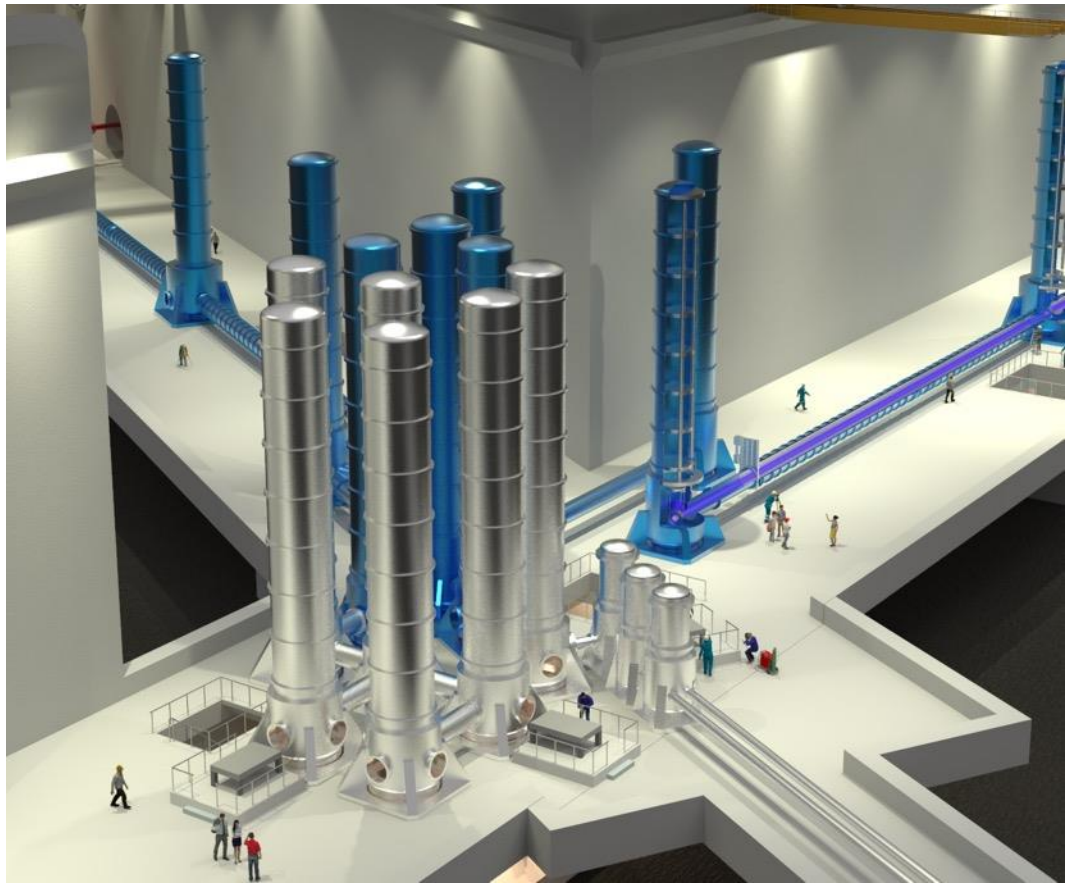
- Cryogenics
- Vacuum
- Precision instruments
- High grade mirrors
- Mirror coatings
- Sensors
- Lasers
- Advanced algorithms

Construction Technologies

- 3D models & Simulations
- Geografic imaging
- Tunneling techniques
- Ground water techniques

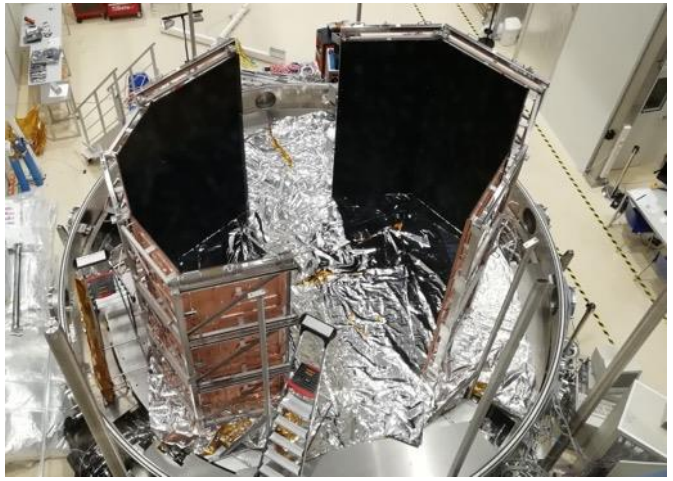
Sustainability

- Sustainable constructions
- Sustainable waste ground removal
- Climate neutral and sustainable energy
- Sustainable logistics
- Sustainable maintenance
- Sustainable decommissioning



Objectives

- Large mirror (100 Kg)
- Cryogenic temperature (20 K)
- Radiative cooling
- Isolated at low frequency (0.1-10 Hz)
- Compact suspension (4.5 meters)



Partners

Precision Mechatronics Laboratory

CSL Centre Spatial de Liège

RWTH Aachen University

KU Leuven

Nikhef

UCLouvain

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Fraunhofer ILT

E-TEST Einstein Telescope EMR Site & Technology

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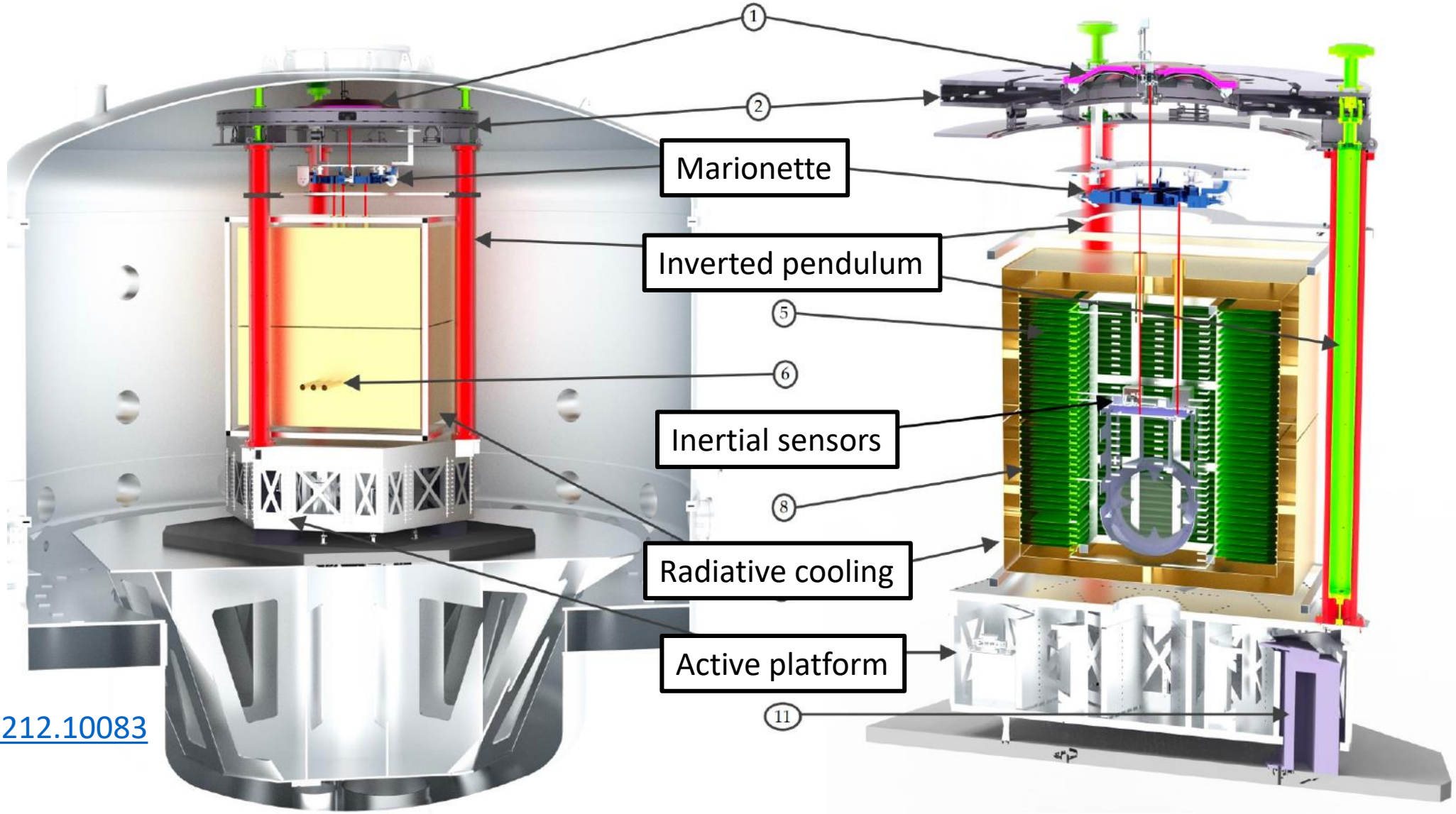
European Union

Conceptual design

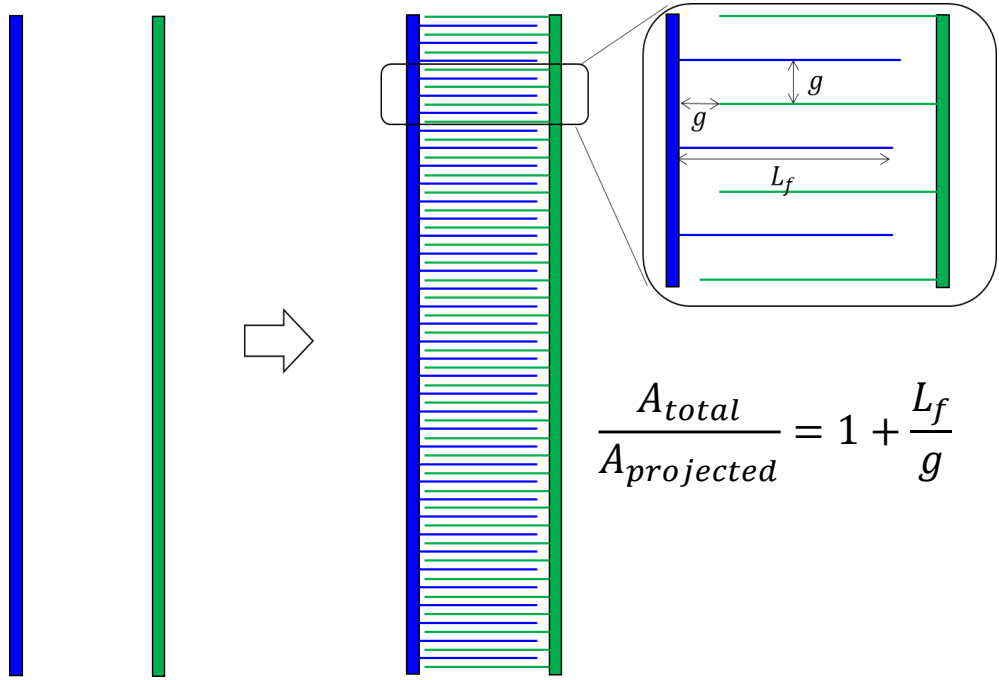
Submitted: 12/2021
Revised: 03/2022

https://arxiv.org/abs/2212.10083



How to fit ~100m² around the payload?

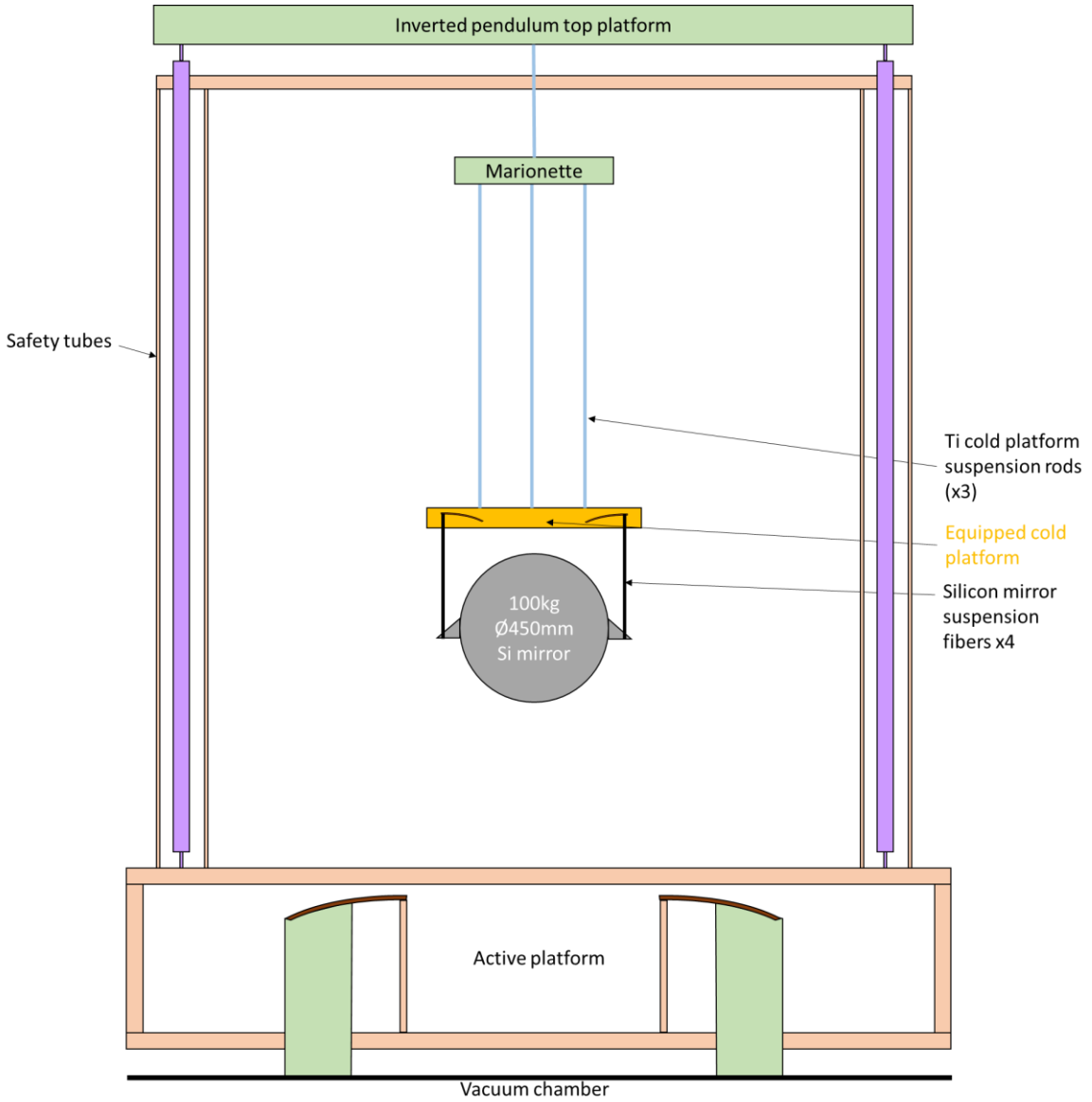
- Compress the radiative heat exchanger area: interleaved fins!
- Trade-offs:
  - Fin length & thickness ↔ stiffness
    mass (cooling time)
  - Gap ↔ no-contact
    deformation
    relative motion

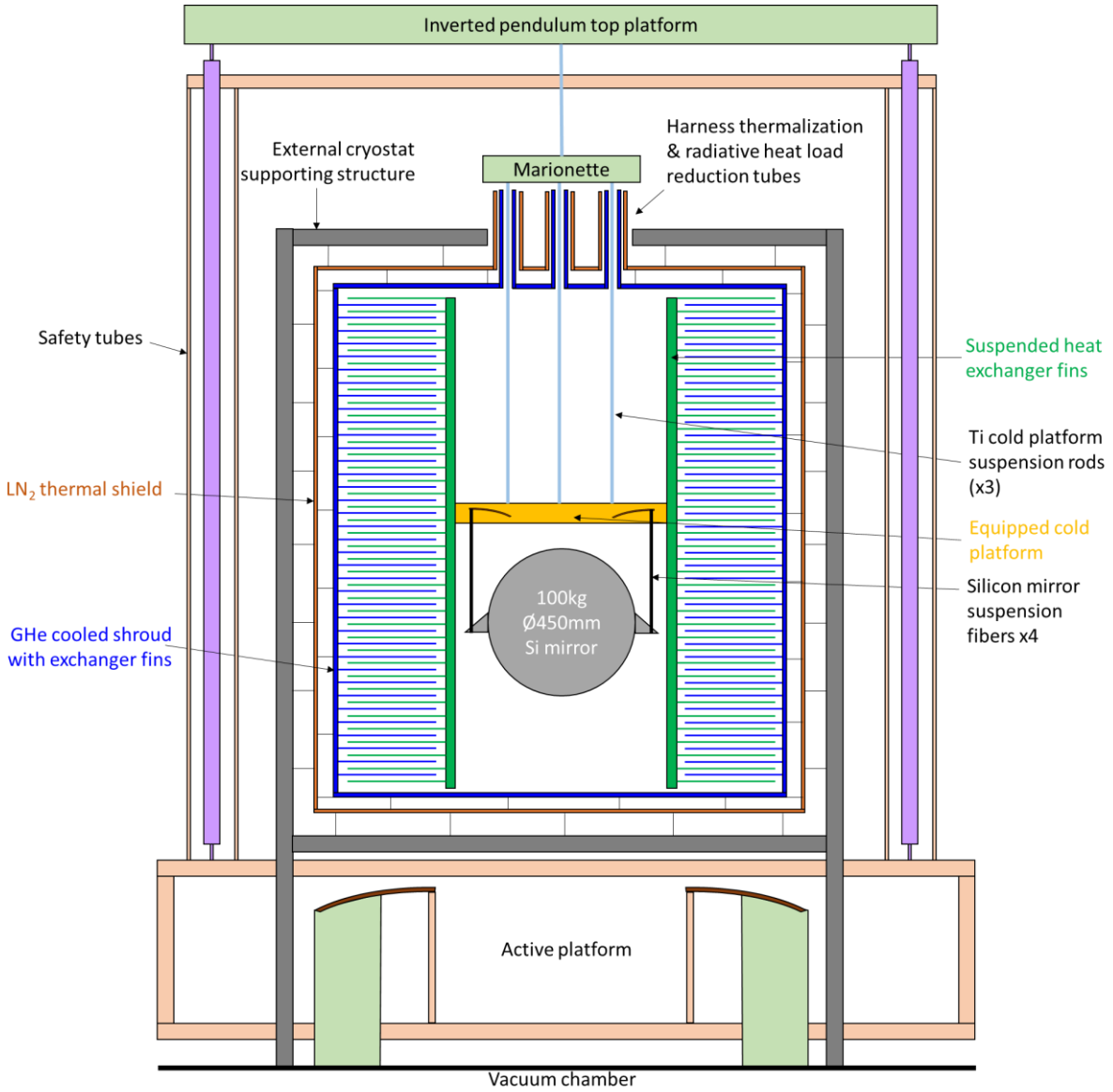


$$\frac{A_{total}}{A_{projected}} = 1 + \frac{L_f}{g}$$

- 300mm long fins, 20mm gap
- Amplification factor = 16
- 75m² → 5m² around the cold platform, 1m² footprint

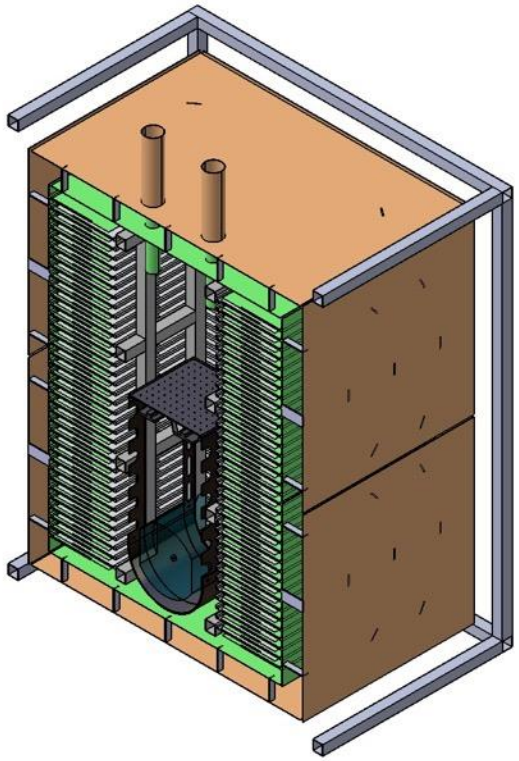
Fitting the heat exchanger around the payload



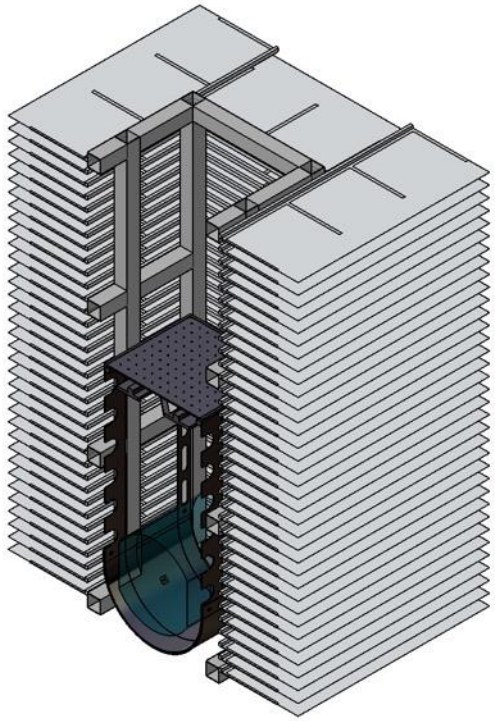


Cryostat development

- ✓ overall dimensions: 1.8 x 1.6 x 2 m^3
- ✓ conventional radiator design with horizontal fins (25K)
- ✓ three 30-mm diameter optical feedthroughs towards the mirror



Outer cryostat:
80K LN2 shield (brown)
25K GHe panels (green)



Inner cryostat suspended and conductively linked to the silicon mirror

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Active platform

Contact : Haidar Lakkis (ULiege)
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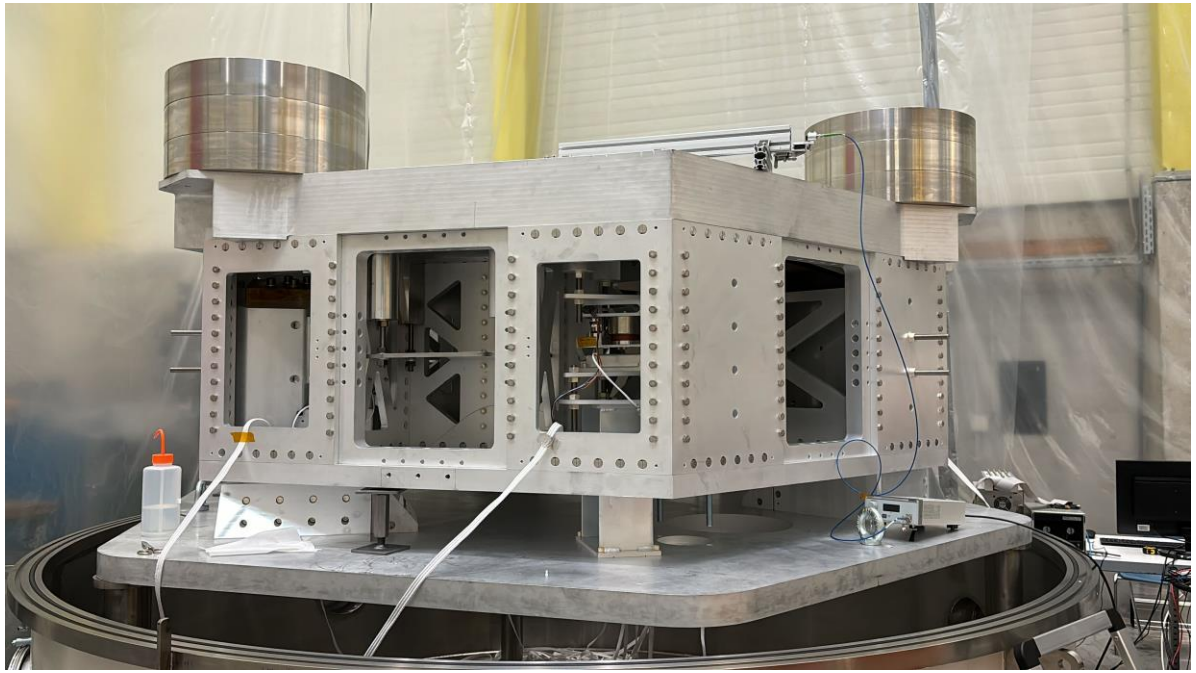
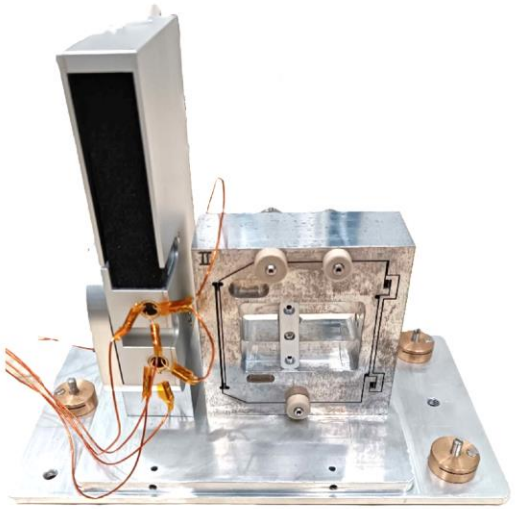
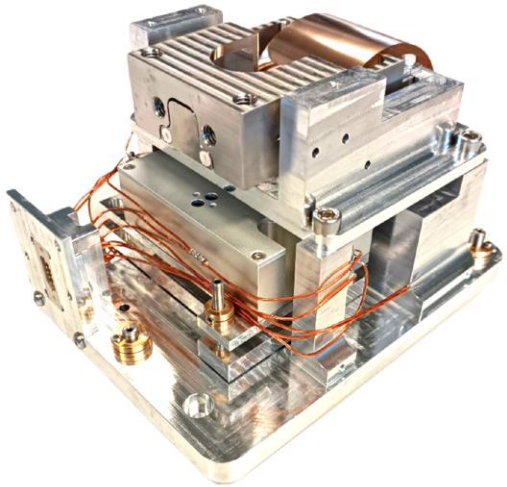
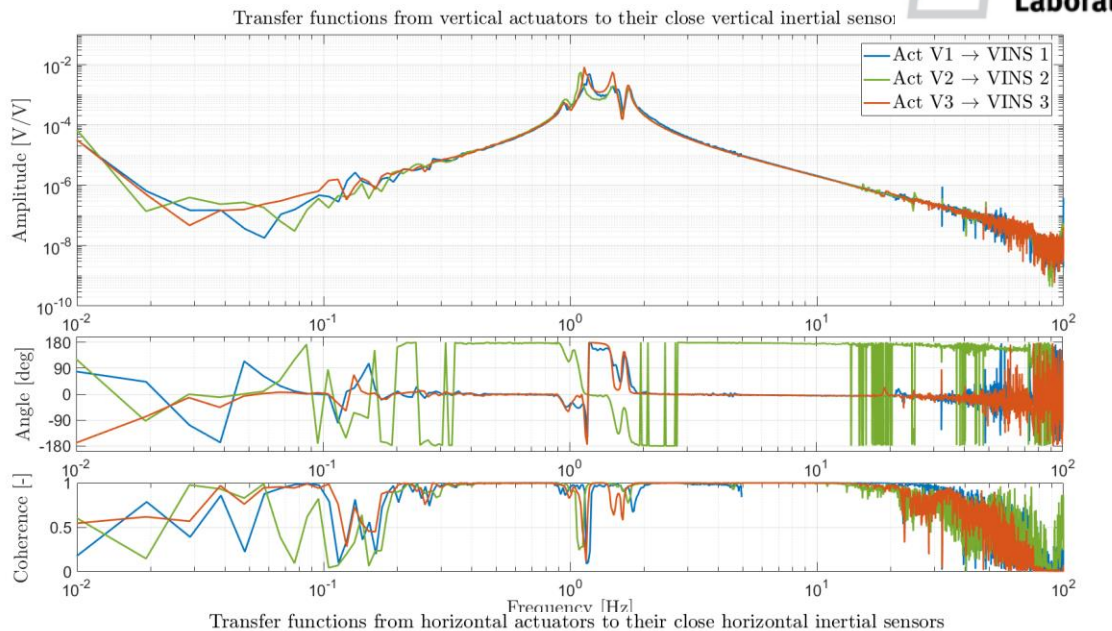
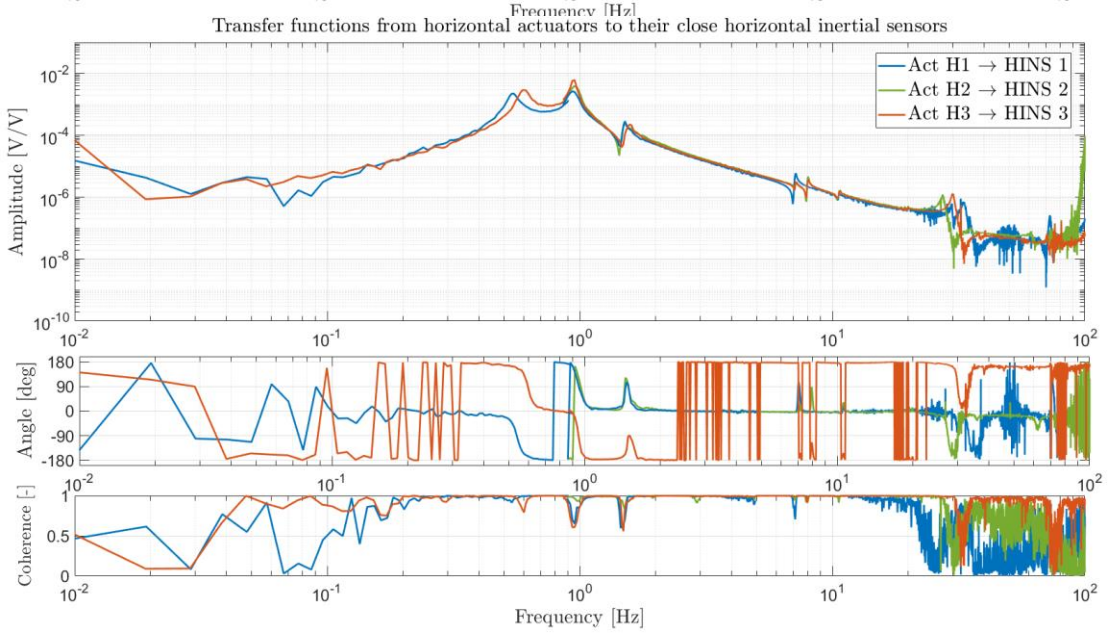
Precision Mechatronics Laboratory











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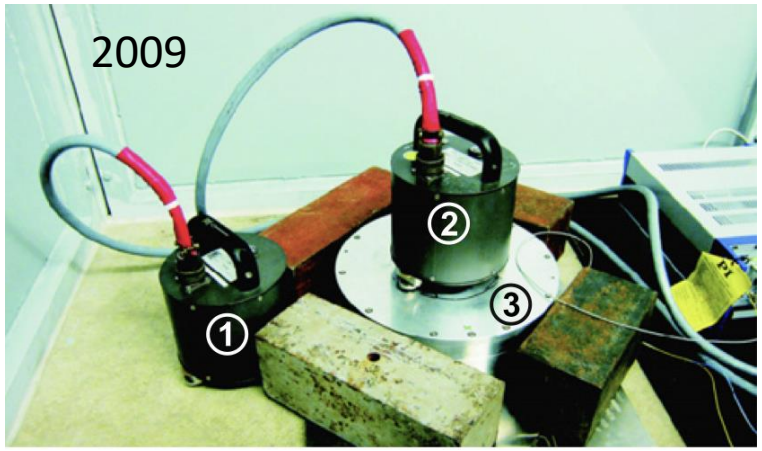
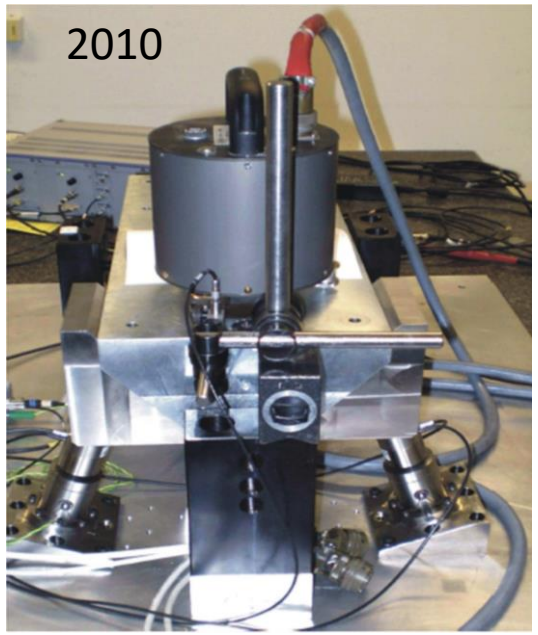
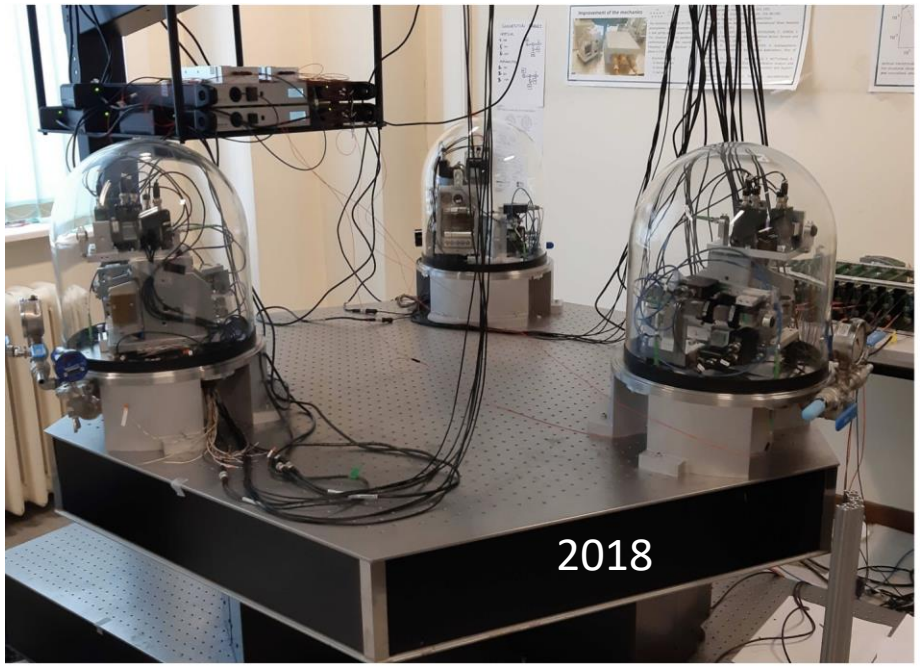
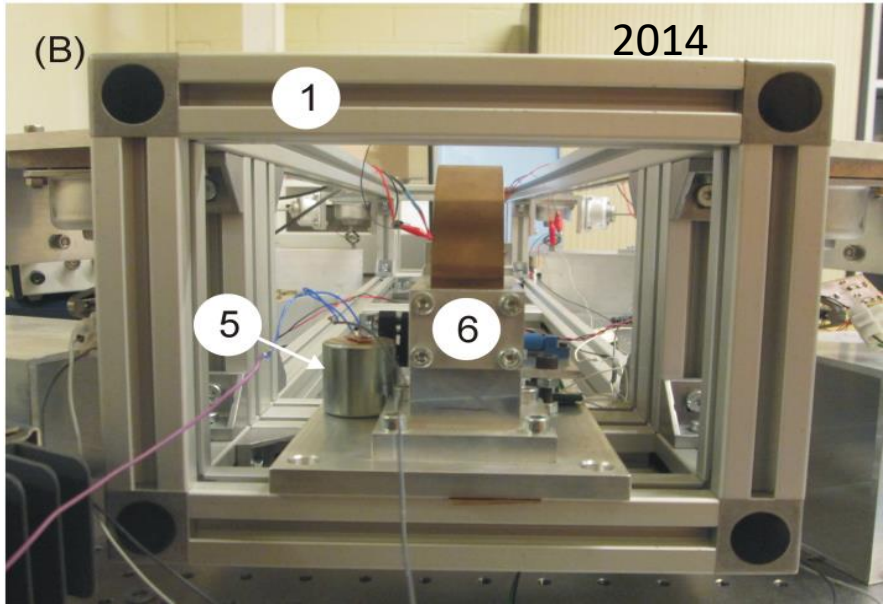
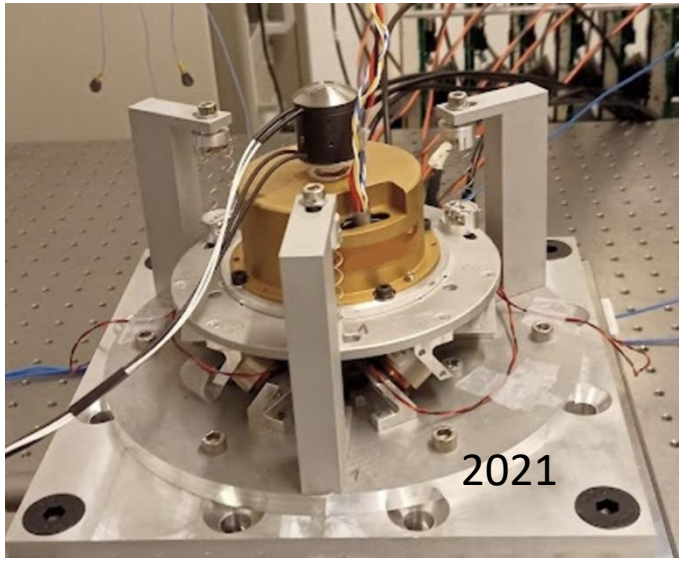
Active vibration isolation

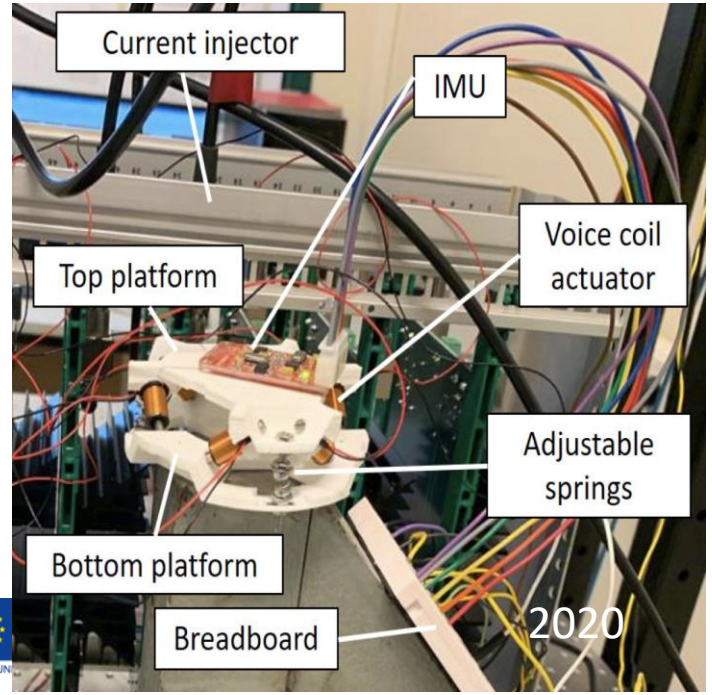




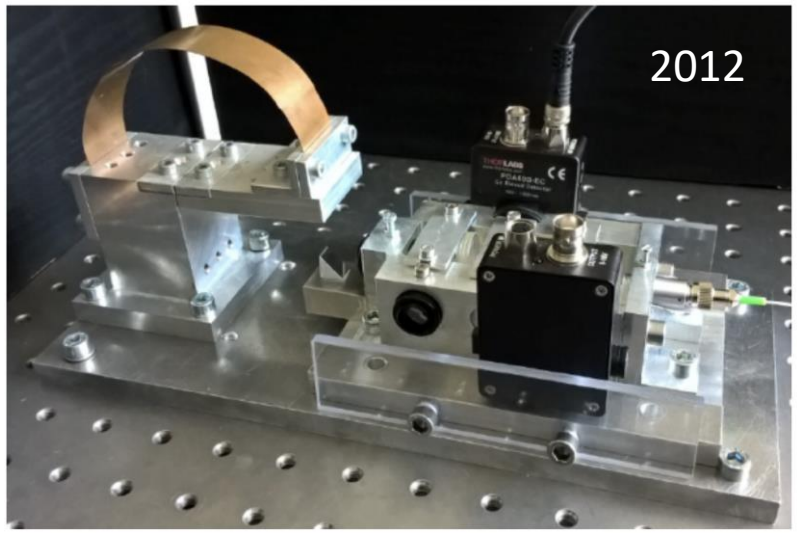


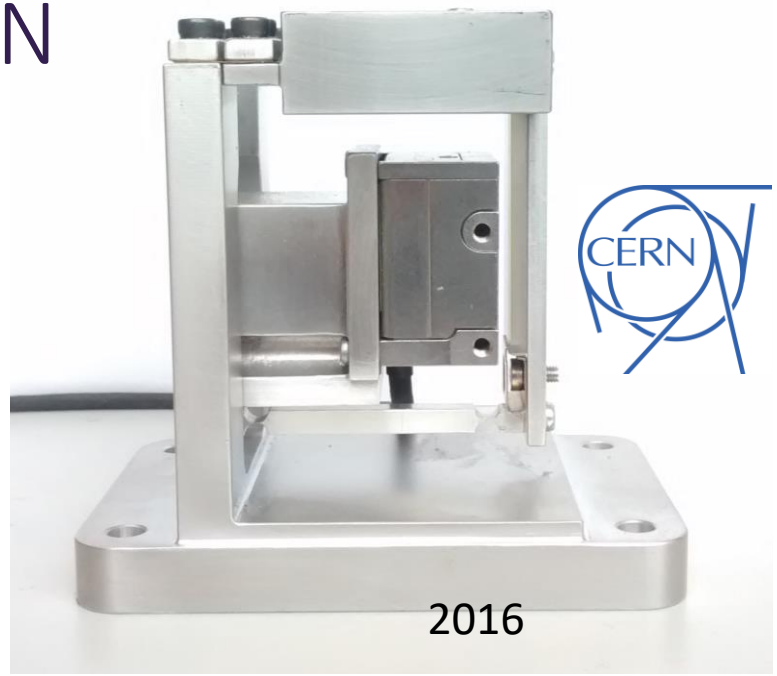


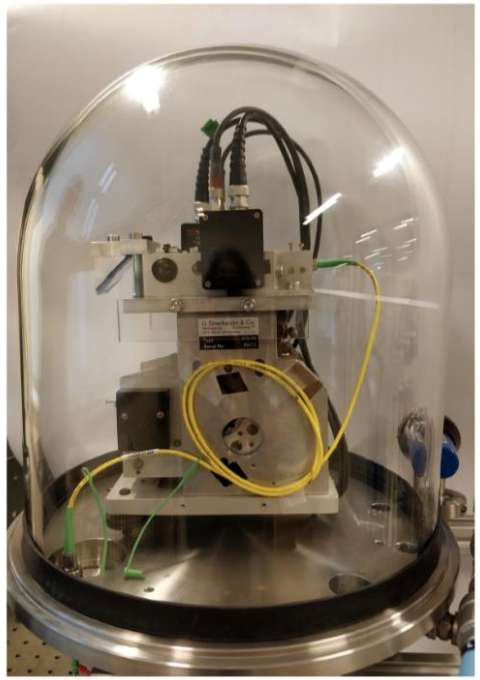


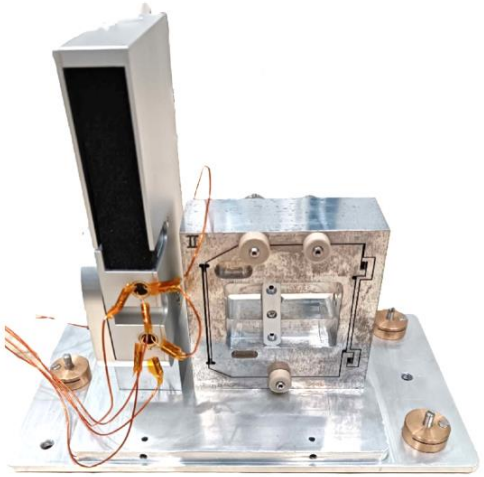


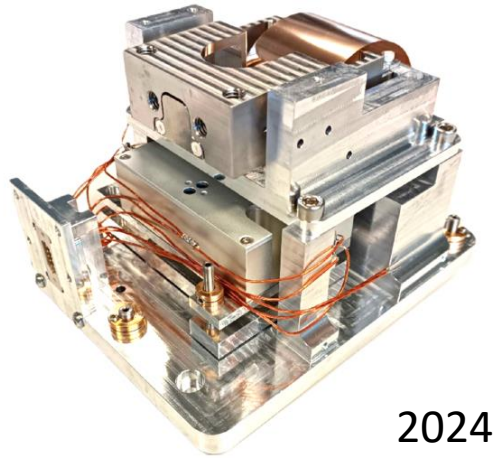
Optical inertial sensors at PML started at CERN



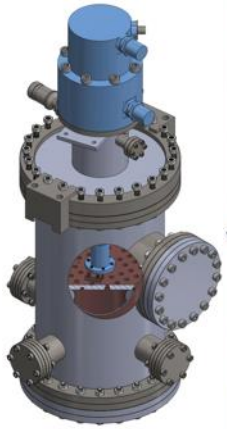


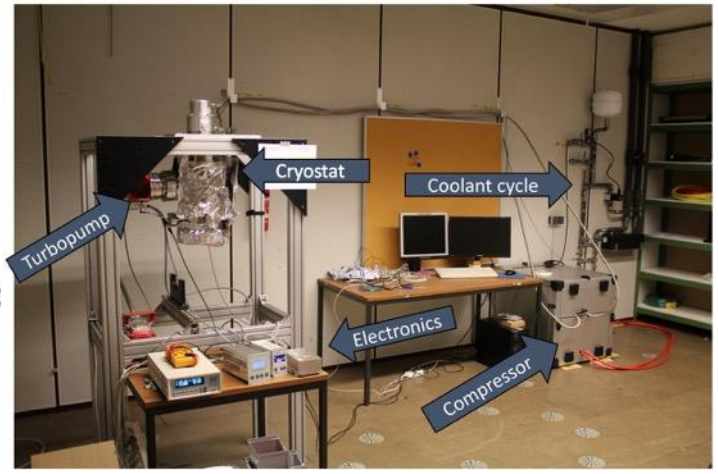






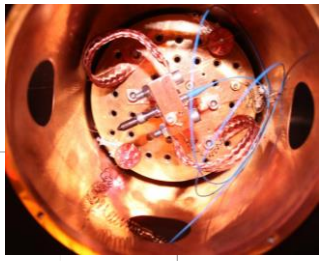
Cryogenic test bench

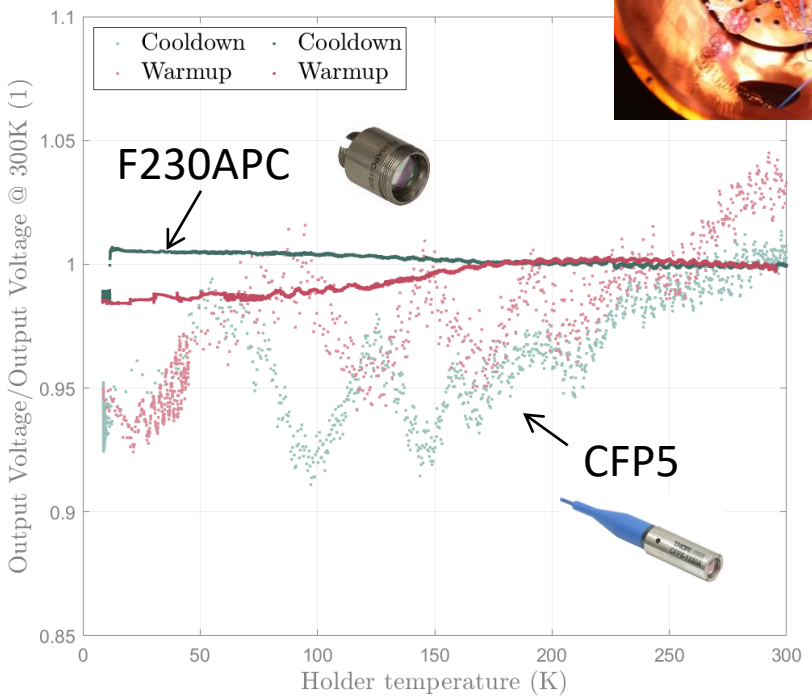




- Closed-cycle cryostat with up to 1W cooling power at 10K
- Vacuum level: better than 10^{-9} mbar
- Usable volume: cylindrical 15x15cm
- Fast turnaround and low running costs
- Useful for testing materials, components and assemblies

Collimators





More sensitive to temperature fluctuations

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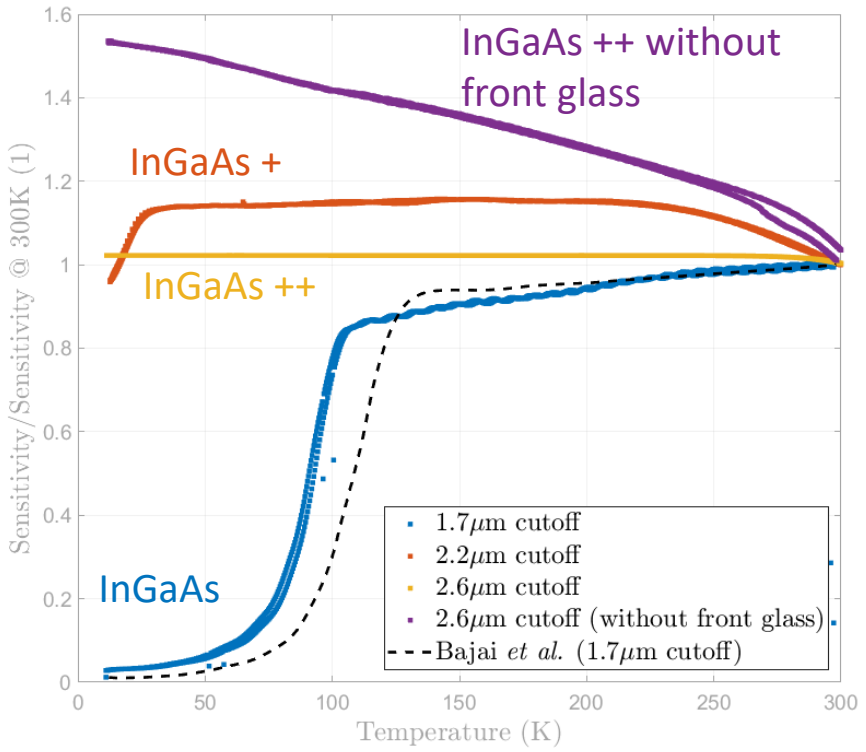
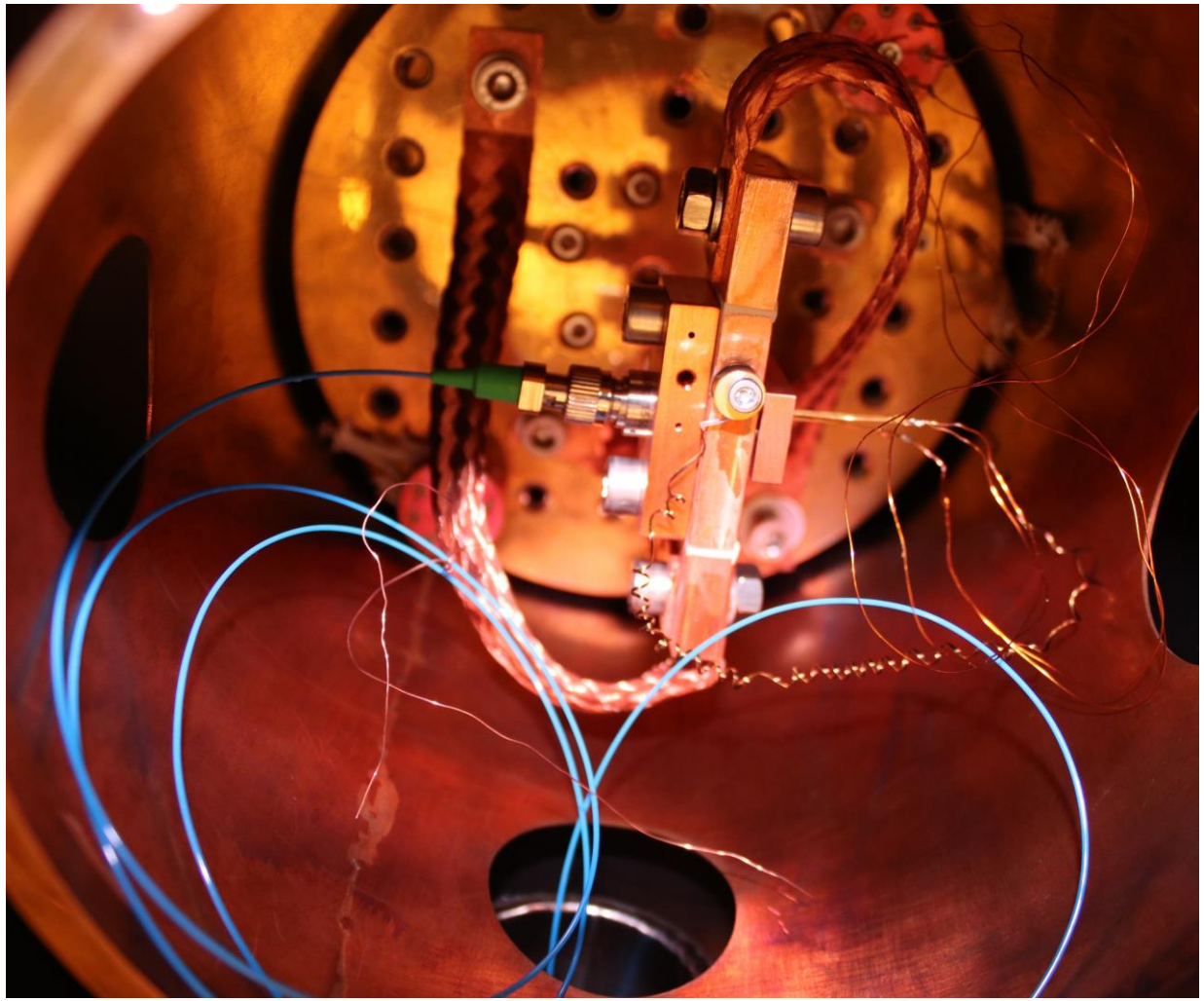
Validation of 1550 nm optical elements in cryogenic conditions

https://doi.org/10.1016/j.cryogenics.2024.103895

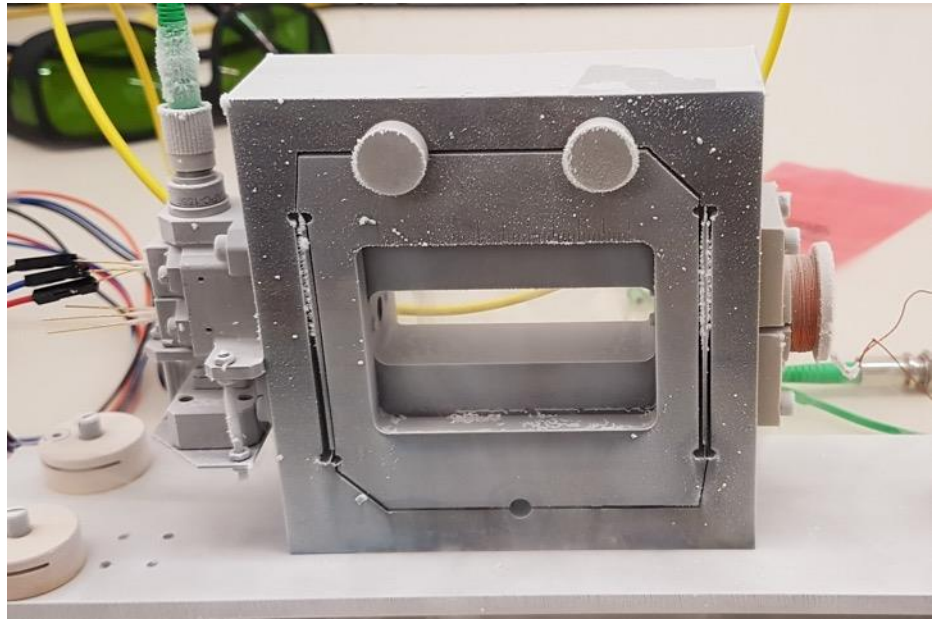
Photodiodes

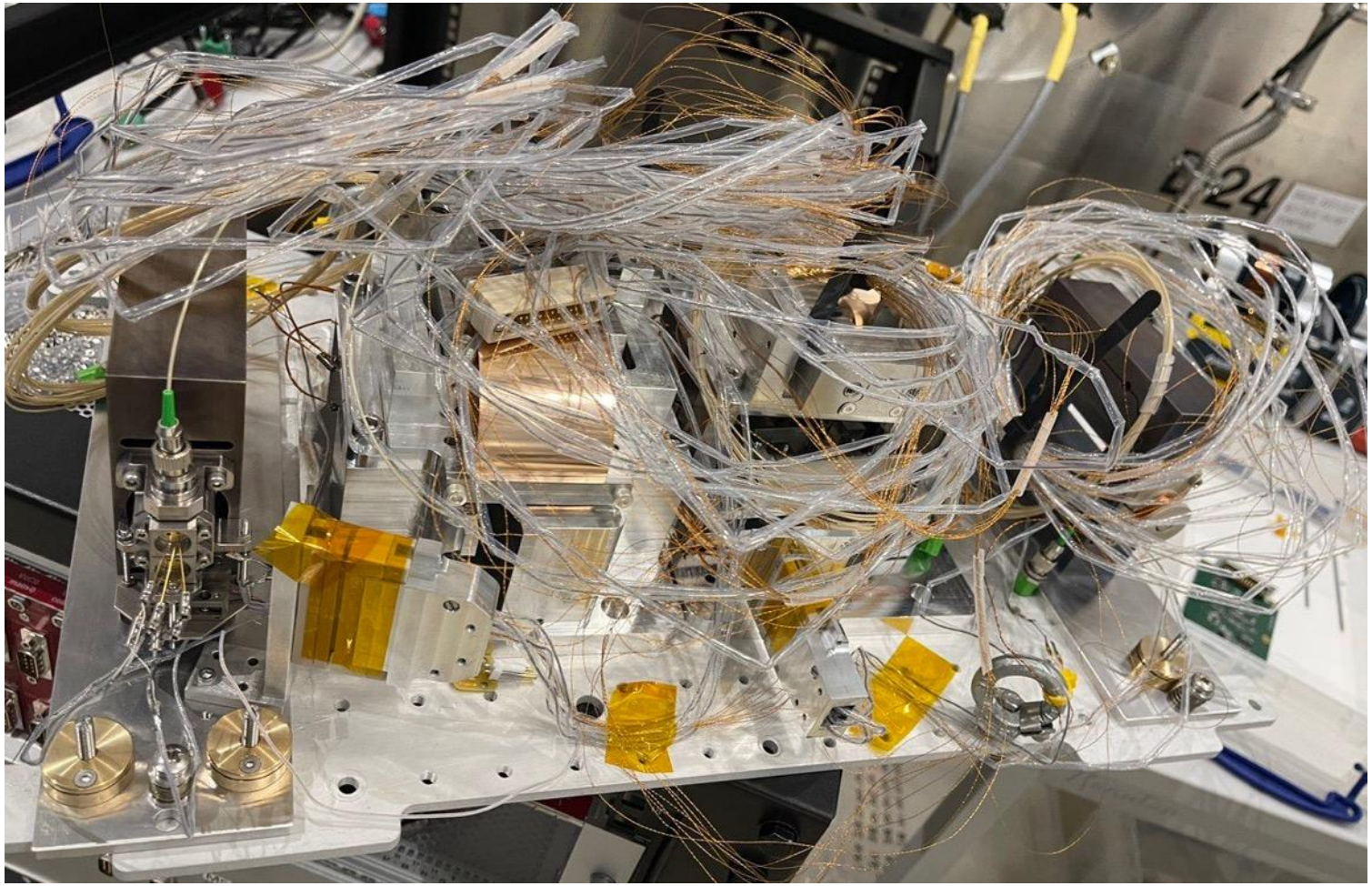
Constant improvement of the responsivity



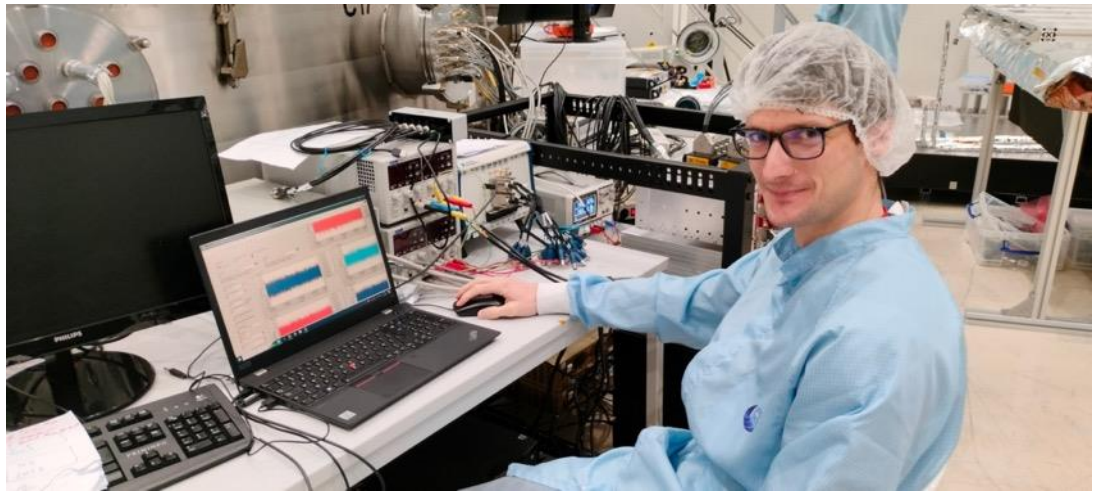


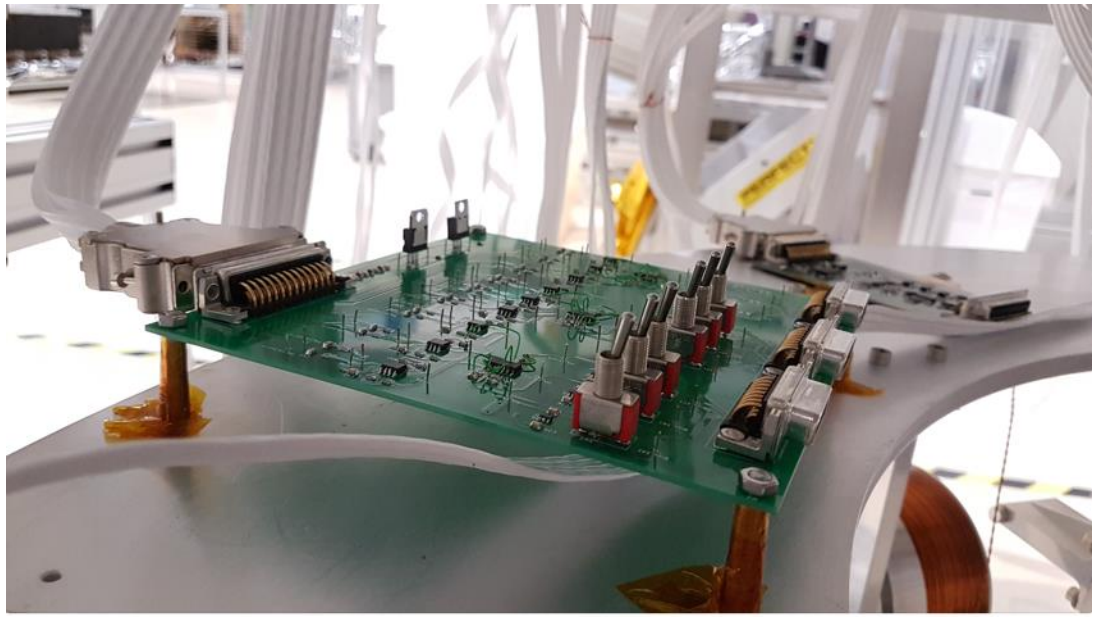
Cryogenic inertial sensors





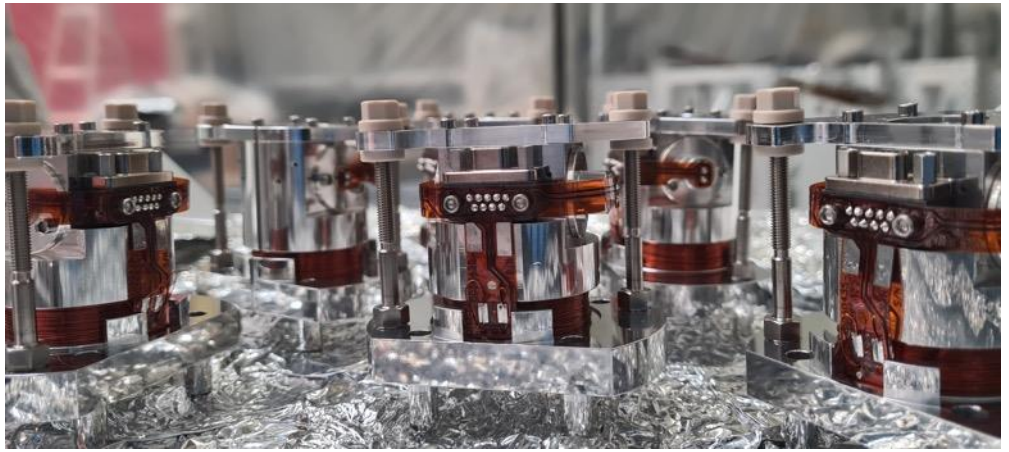
Electronics and control





Assembly of the prototype

AMOS
ADVANCED MECHANICAL & OPTICAL SYSTEMS



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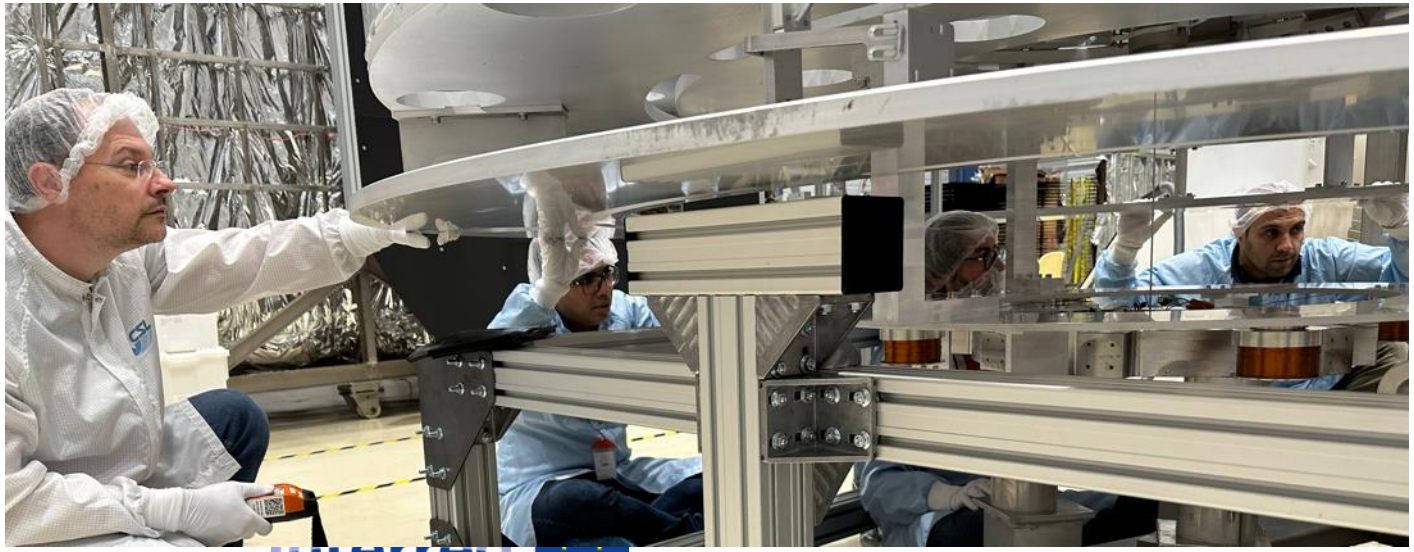
UCLouvain

Final installation at CSL



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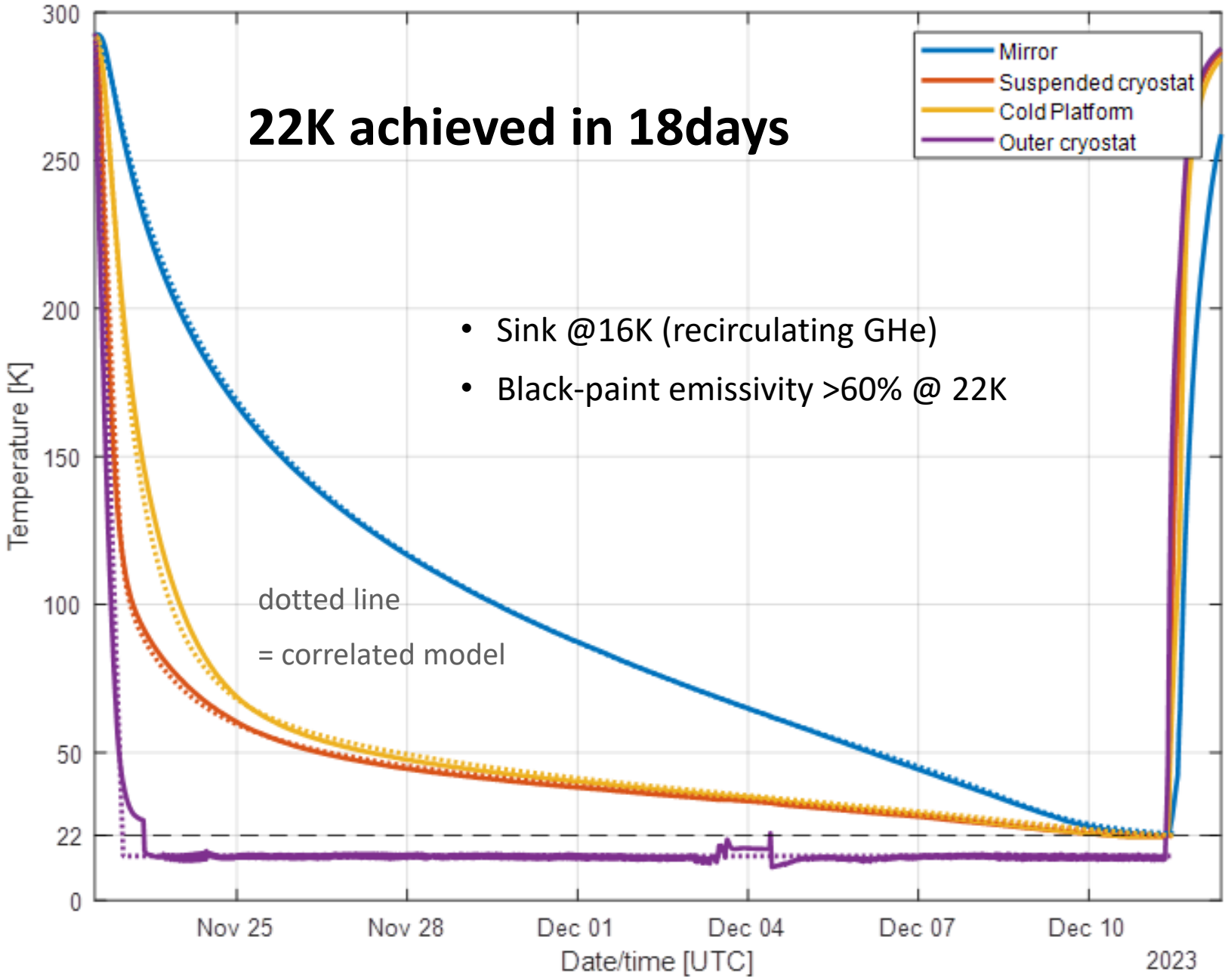
CENTRE SPATIAL DE LIÈGE

22K achieved in 18days



- Sink @16K (recirculating GHe)
- Black-paint emissivity >60% @ 22K

dotted line

= correlated model

After integration of outer cryostat including LN_2 shield and GHe panels

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Summary @ plan

- 2023: 1st run: Fully assembled prototype
  - 100 kg test mass
  - Low frequency seismic isolation
  - Radiative cooling strategy
- 2024:
  - 100kg Si mirror being polished
  - Improvement of sensor
  - Control strategies

E-TEST becomes CRISTAL

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2025-

- High-emissivity @ cryogenic T° → coating + surface structuring
- Thermal noise of suspended heat exchanger structure
- Silicon mirror suspension
- Improved architecture → integration sequence & scale-up to ET
- Electronics:
  - Current injector noise < 1 µA/rt(Hz)
  - Amplifier noise < 10 µV/rt(Hz)
  - Cryogenic electronics