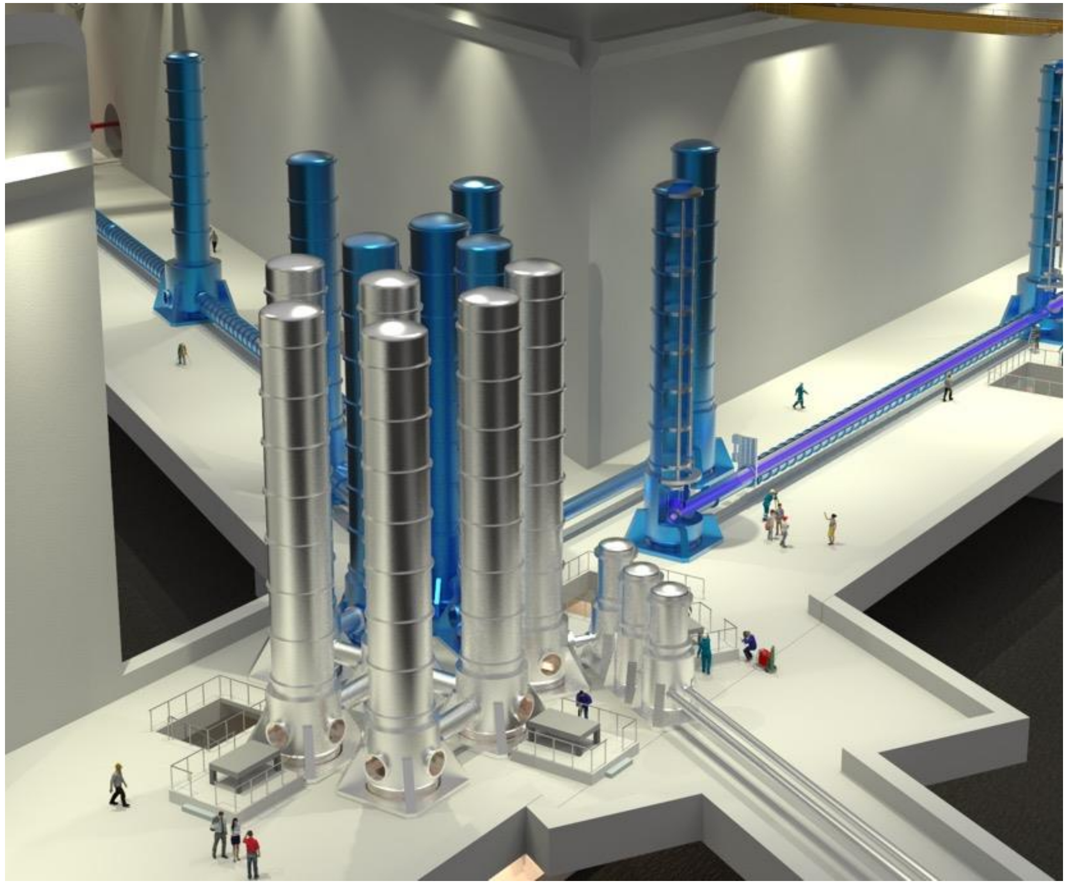
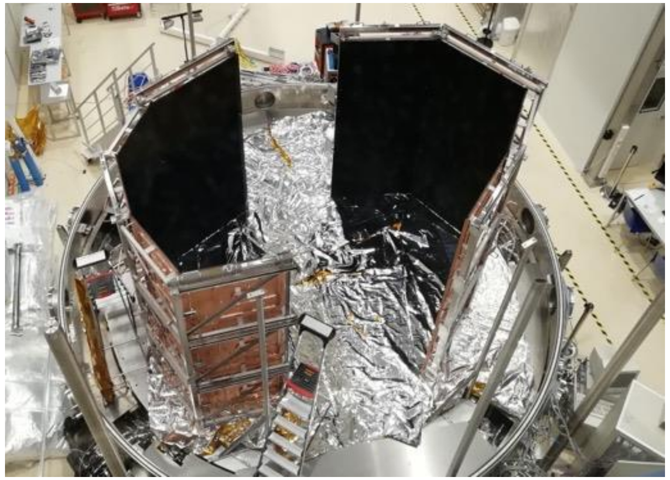
Architecture and performance of the active platform in the E-TEST prototype

Lionel Jacques & Christophe Collette for the E-TEST consortium



Objectives

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



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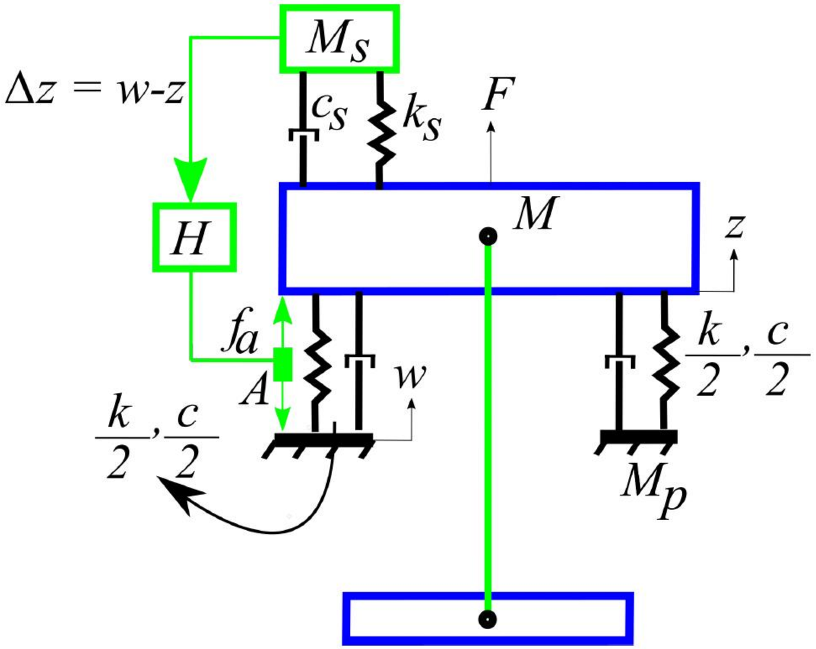
E-TEST Einstein Telescope EMR Site & Technology

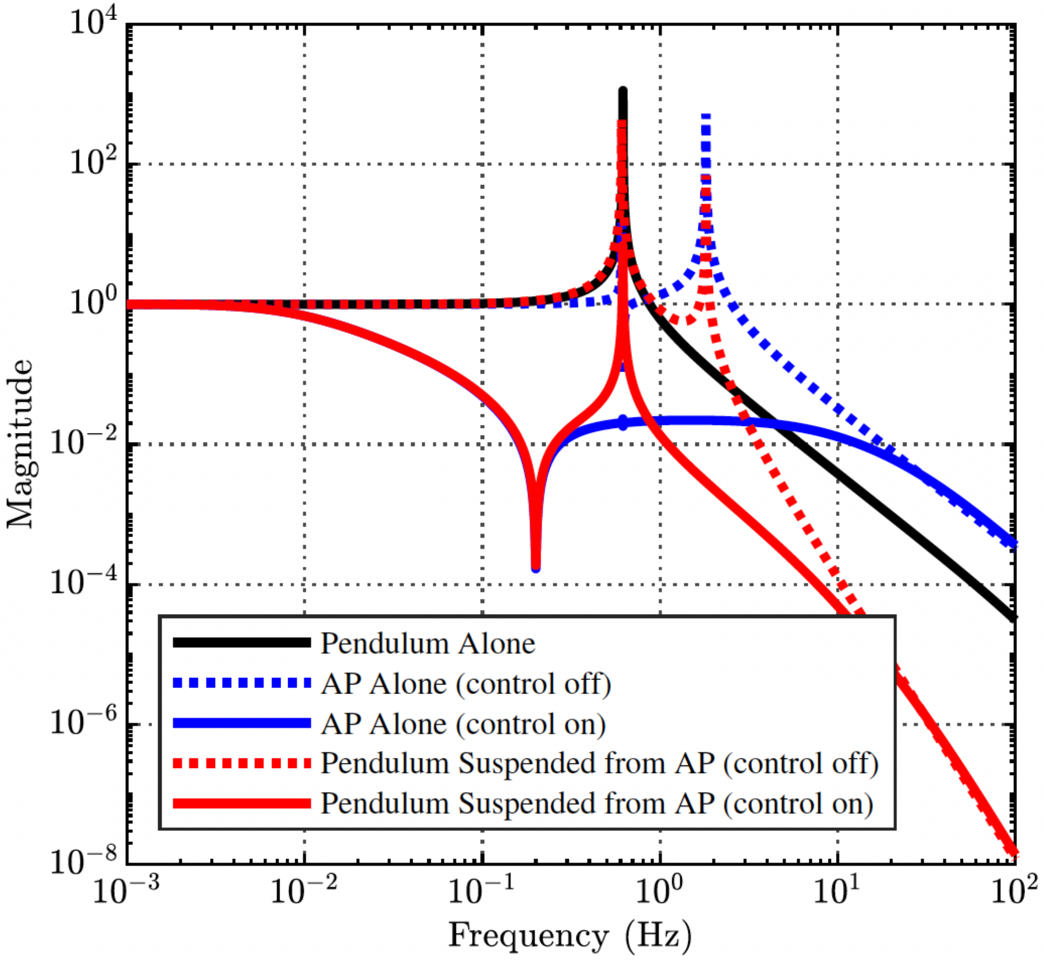
Interreg Euregio Meuse-Rhine European Regional Development Fund

European Union

AP + P

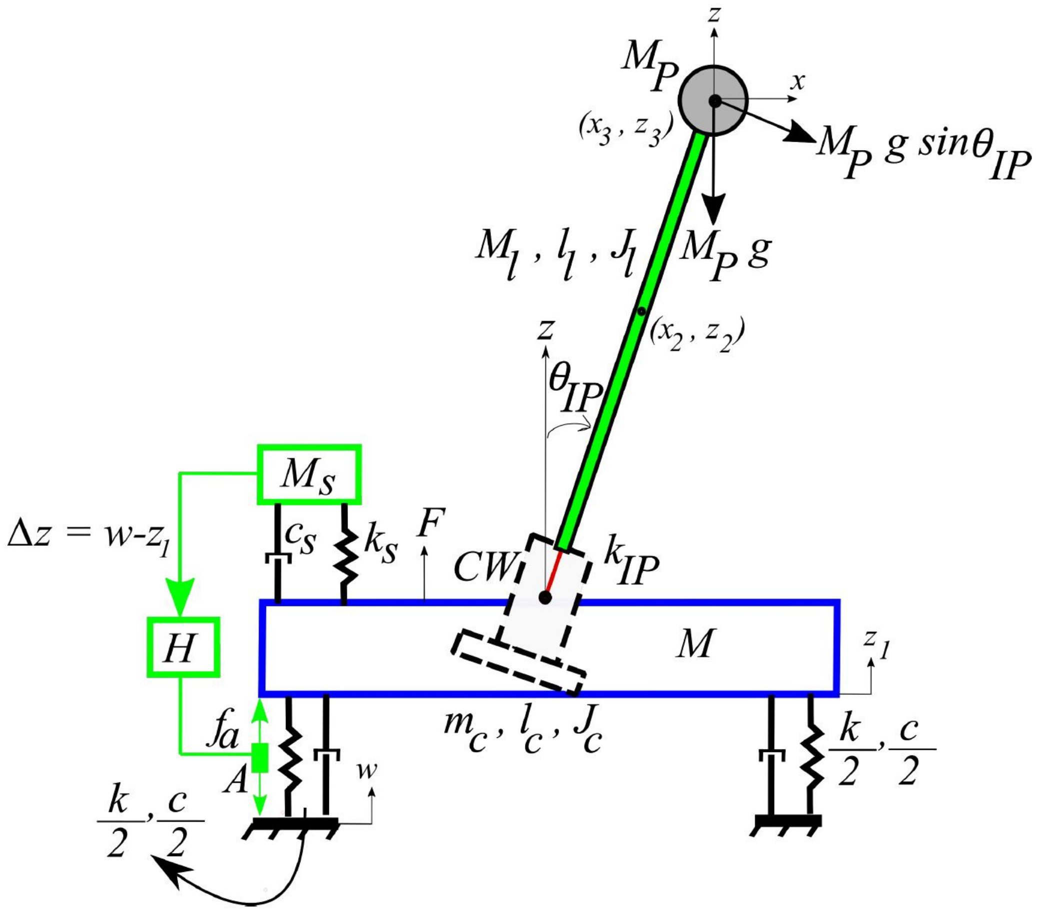


M_s
$\Delta z = w\text{-}z$
c_s
k_s
F
H
M
z
f_a
A
w
$\frac{k}{2}, \frac{c}{2}$
$\frac{k}{2}, \frac{c}{2}$
M_p

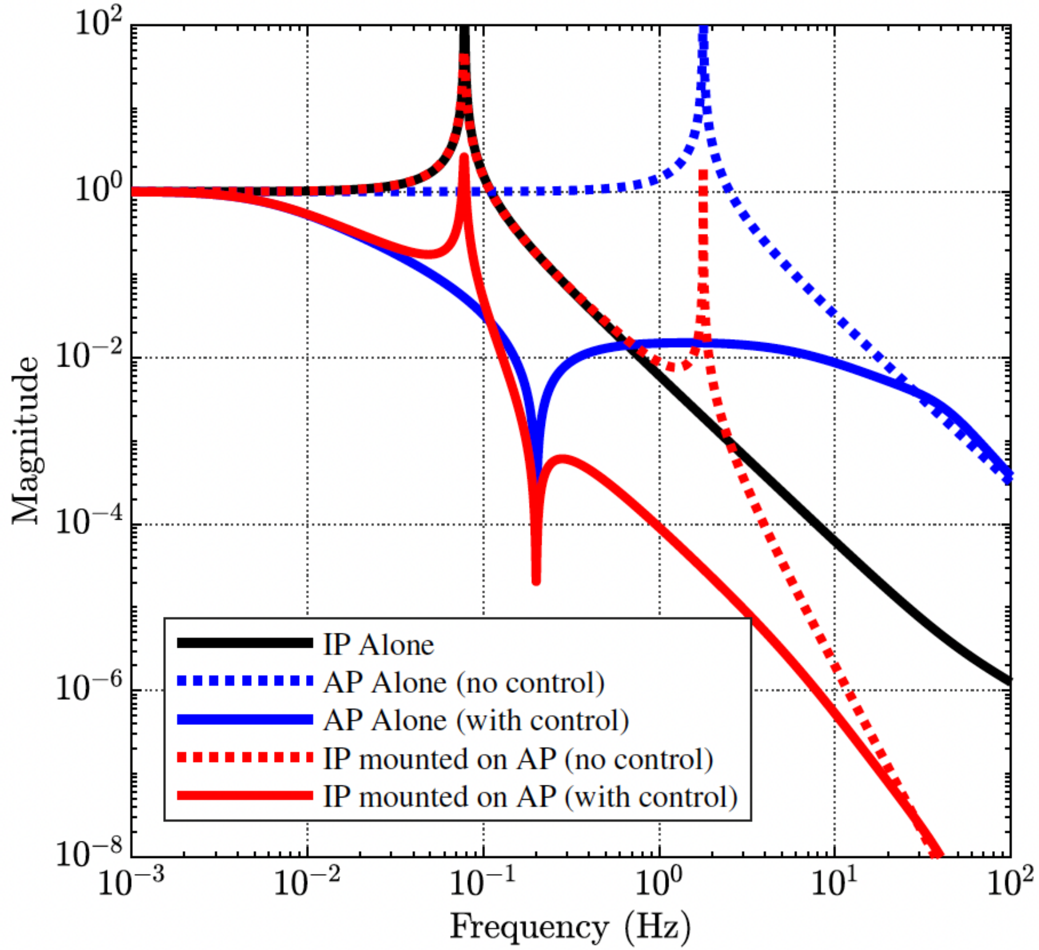


10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
Magnitude
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
Frequency (Hz)
Pendulum Alone
AP Alone (control off)
AP Alone (control on)
Pendulum Suspended from AP (control off)
Pendulum Suspended from AP (control on)

AP +IP

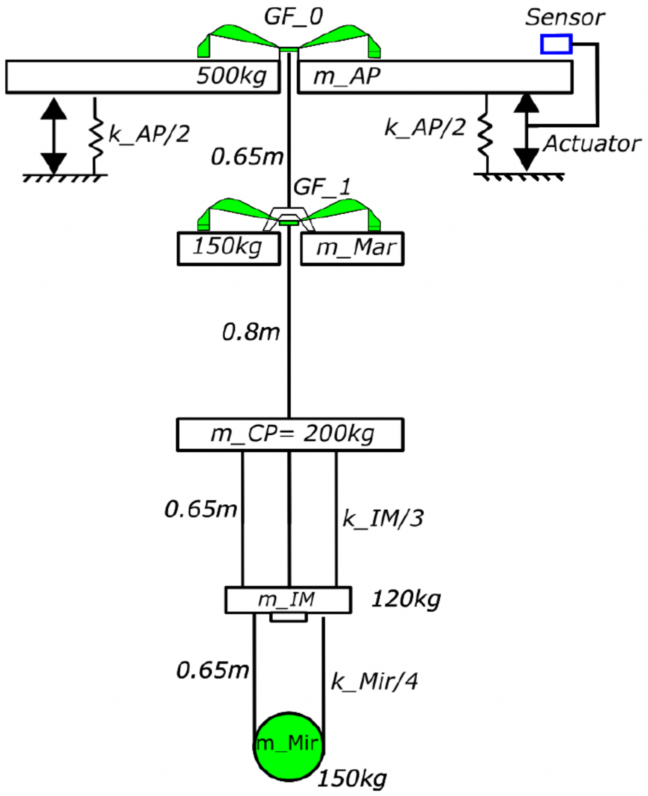


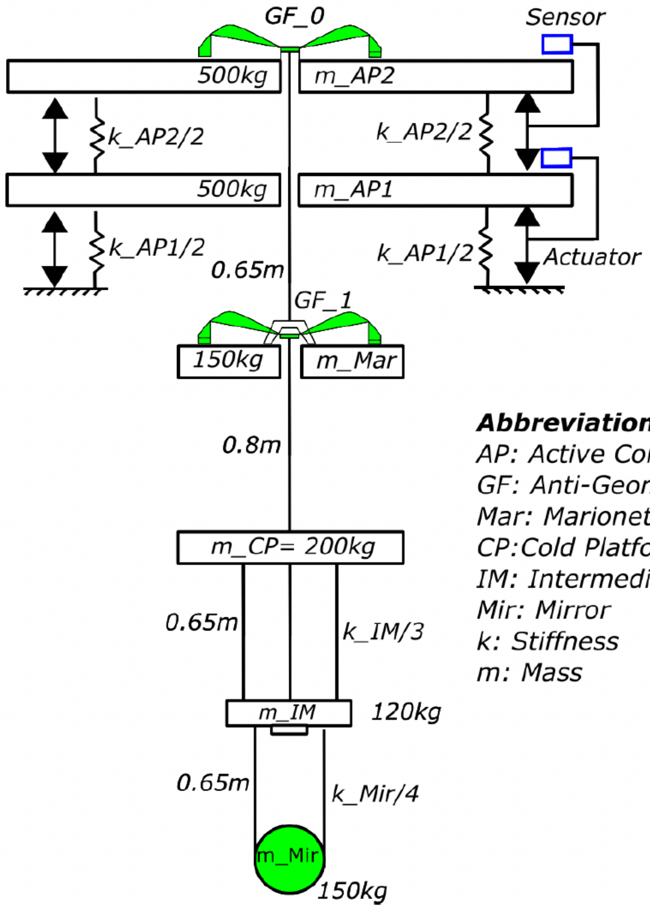
M_P
(x_3, z_3)
$M_P\ g\ sin\theta_{IP}$
M_l, l_l, J_l
$M_P\ g$
(x_2, z_2)
θ_{IP}
M_S
$\Delta z = w\text{-}z_1$
c_S
k_S
F
CW
k_{IP}
H
M
z_1
f_a
A
w
m_c, l_c, J_c
$\frac{k}{2}, \frac{c}{2}$



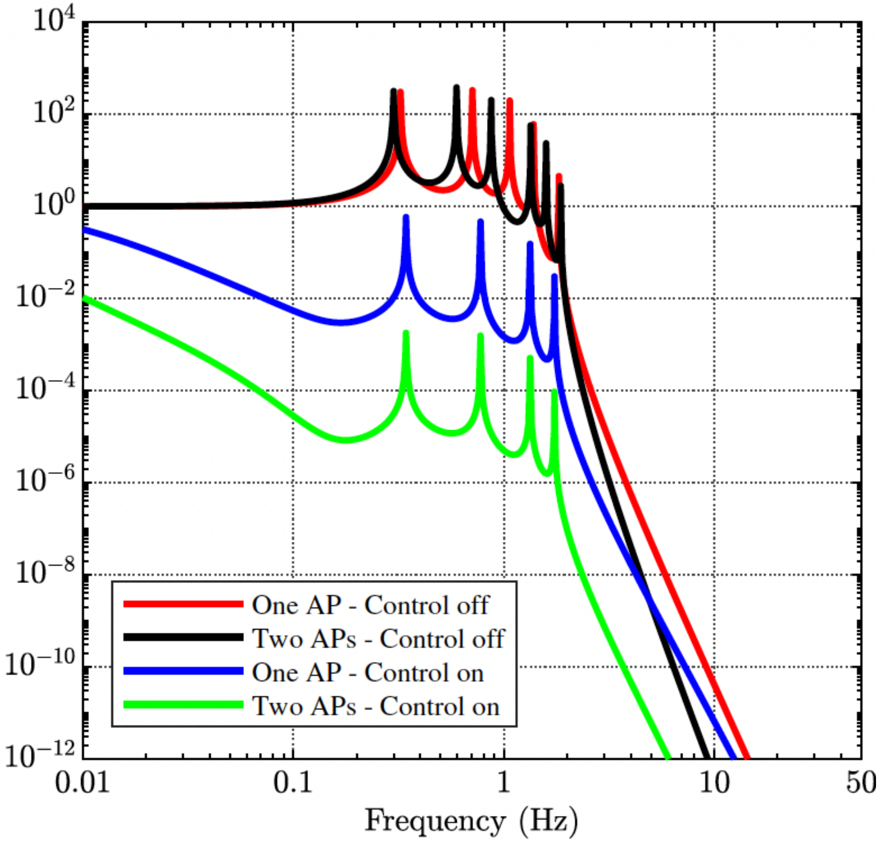
Magnitude
Frequency (Hz)
IP Alone
AP Alone (no control)
AP Alone (with control)
IP mounted on AP (no control)
IP mounted on AP (with control)

Scheme 1

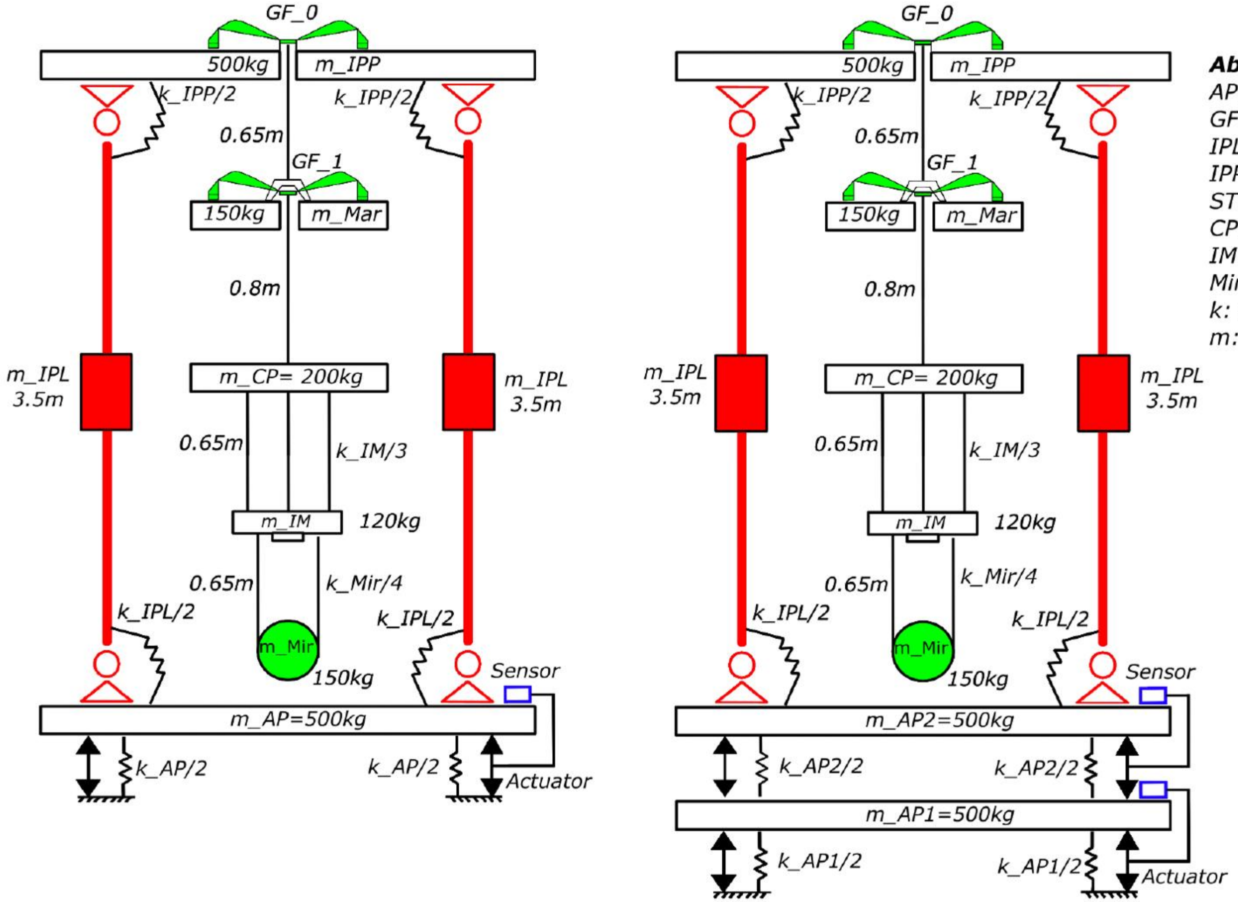




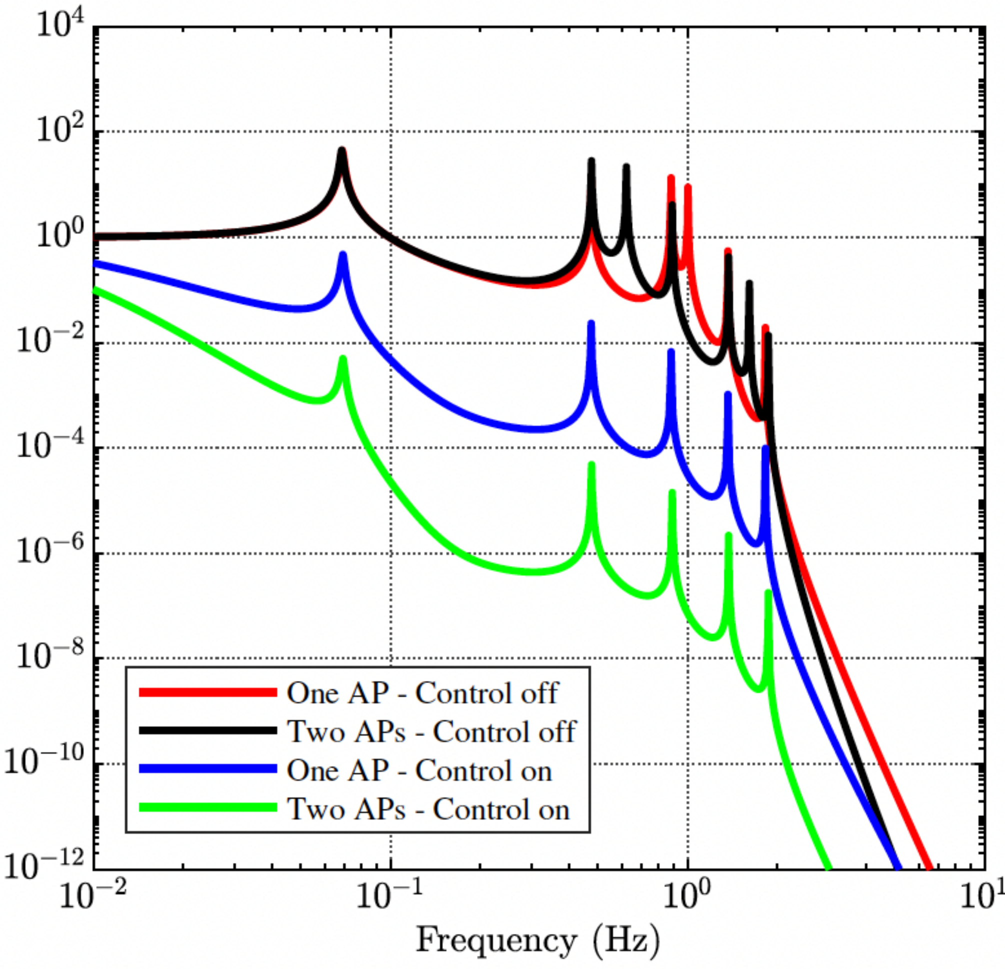
Abbreviation:
AP: Active Control Platform
GF: Anti-Geometric Spring Filter
Mar: Marionette
CP:Cold Platform
IM: Intermediate Mass
Mir: Mirror
k: Stiffness
m: Mass



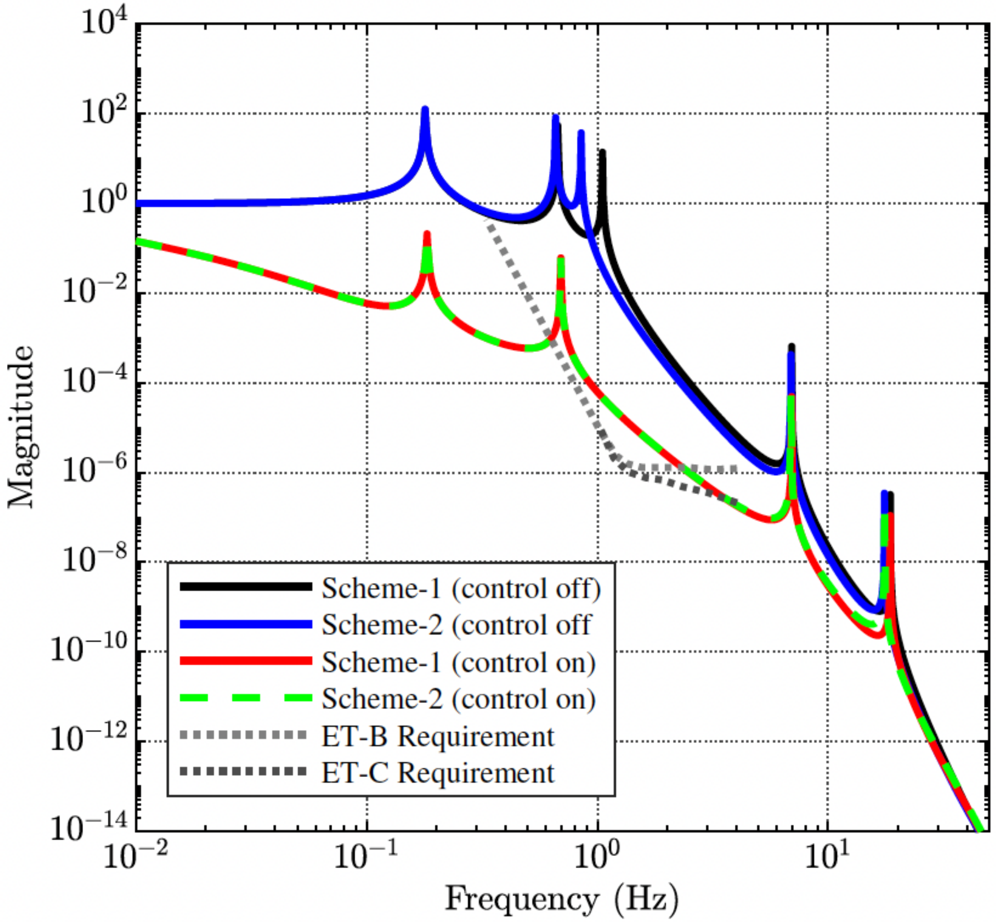
Scheme 2

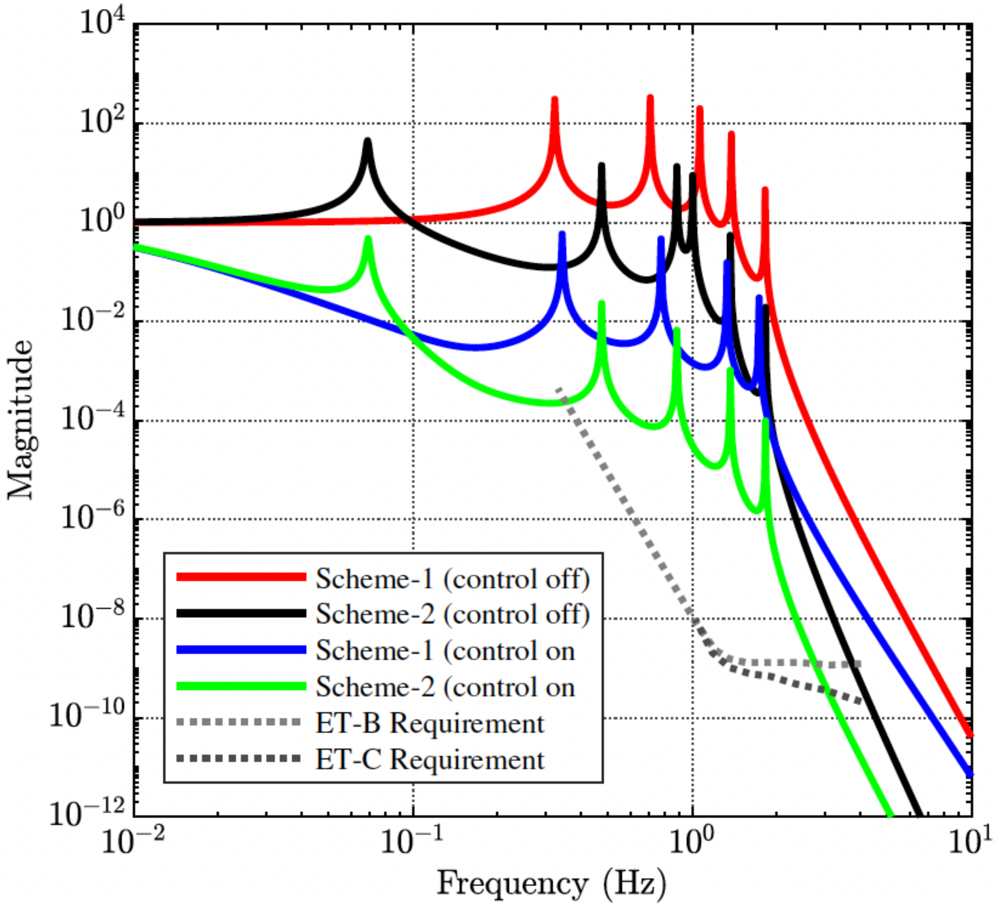


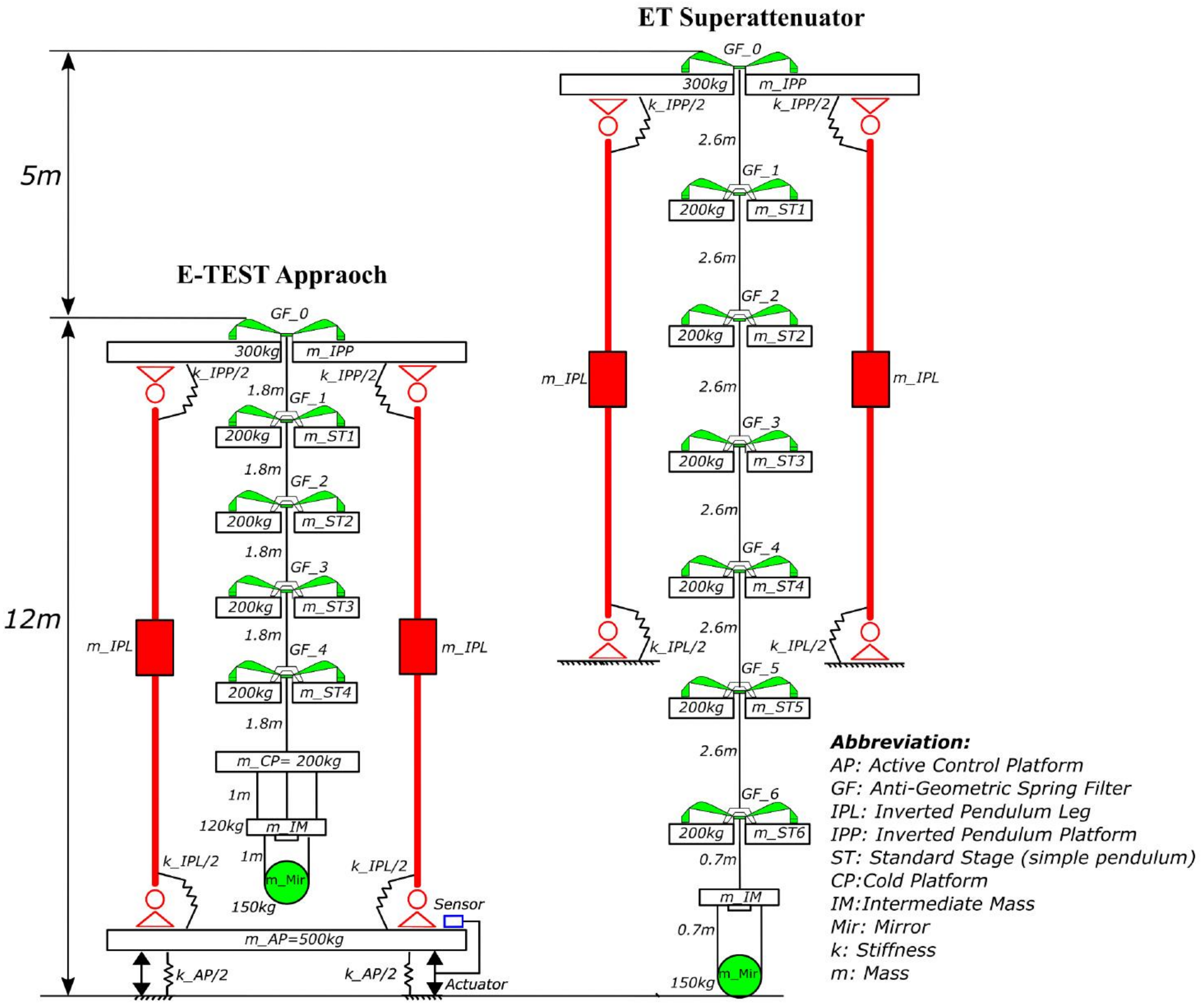
Abbreviation:
AP: Active Control Platform
GF: Anti-Geometric Spring Filt
IPL: Inverted Pendulum Leg
IPP: Inverted Pendulum Platfo
ST: Standard Stage
CP:Cold Platform
IM:Intermediate Mass
Mir: Mirror
k: Stiffness
m: Mass

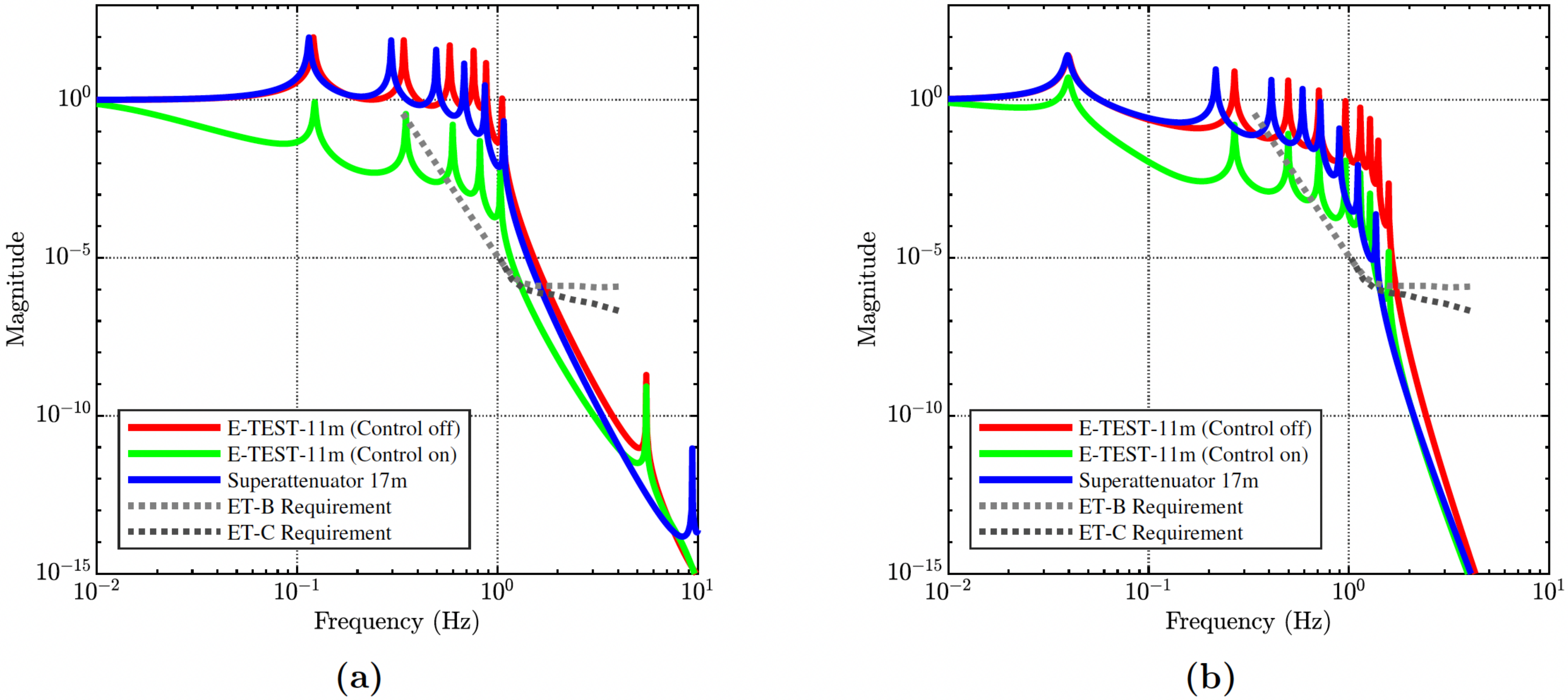


Comparison


Magnitude
Frequency (Hz)
Scheme-1 (control off)
Scheme-2 (control off
Scheme-1 (control on)
Scheme-2 (control on)
ET-B Requirement
ET-C Requirement


Magnitude
Frequency (Hz)
Scheme-1 (control off)
Scheme-2 (control off)
Scheme-1 (control on
Scheme-2 (control on
ET-B Requirement
ET-C Requirement


ET Superattenuator
E-TEST Appraoch
5m
12m
GF_0
300kg
m_IPP
k_IPP/2
1.8m
GF_1
200kg
m_ST1
GF_2
m_ST2
GF_3
m_ST3
GF_4
m_ST4
GF_5
m_ST5
GF_6
m_ST6
2.6m
0.7m
m_IPL
k_IPL/2
m_CP= 200kg
1m
120kg
m_IM
m_Mir
150kg
Sensor
m_AP=500kg
k_AP/2
Actuator
Abbreviation:
AP: Active Control Platform
GF: Anti-Geometric Spring Filter
IPL: Inverted Pendulum Leg
IPP: Inverted Pendulum Platform
ST: Standard Stage (simple pendulum)
CP:Cold Platform
IM:Intermediate Mass
Mir: Mirror
k: Stiffness
m: Mass



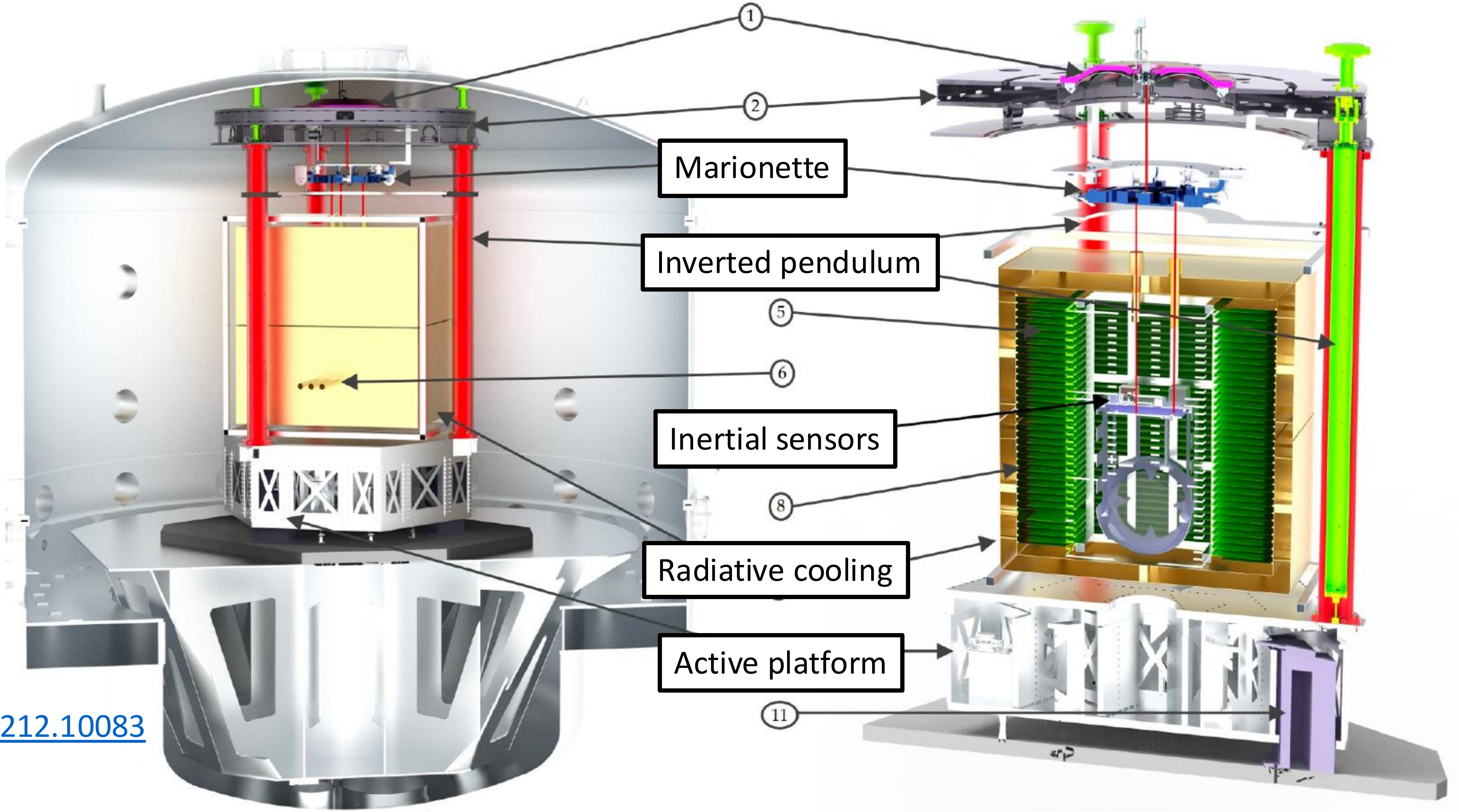
E-TEST-11m (Control off)
E-TEST-11m (Control on)
Superattenuator 17m
ET-B Requirement
ET-C Requirement
Magnitude
Frequency (Hz)
(a)
(b)

Conceptual design


E–TEST prototype
Design Report
The E–TEST Prototype Team*
*Nikhef, Maastricht University, Katholieke Universiteit Leuven, Université Catholique de Louvain, Hasselt University, Vrije Universiteit Brussel, Fraunhofer Institute for Laser Technology, RWTH Aachen, Liege Université.

Submitted: 12/2021
Revised: 03/2022

https://arxiv.org/abs/2212.10083



Active platform

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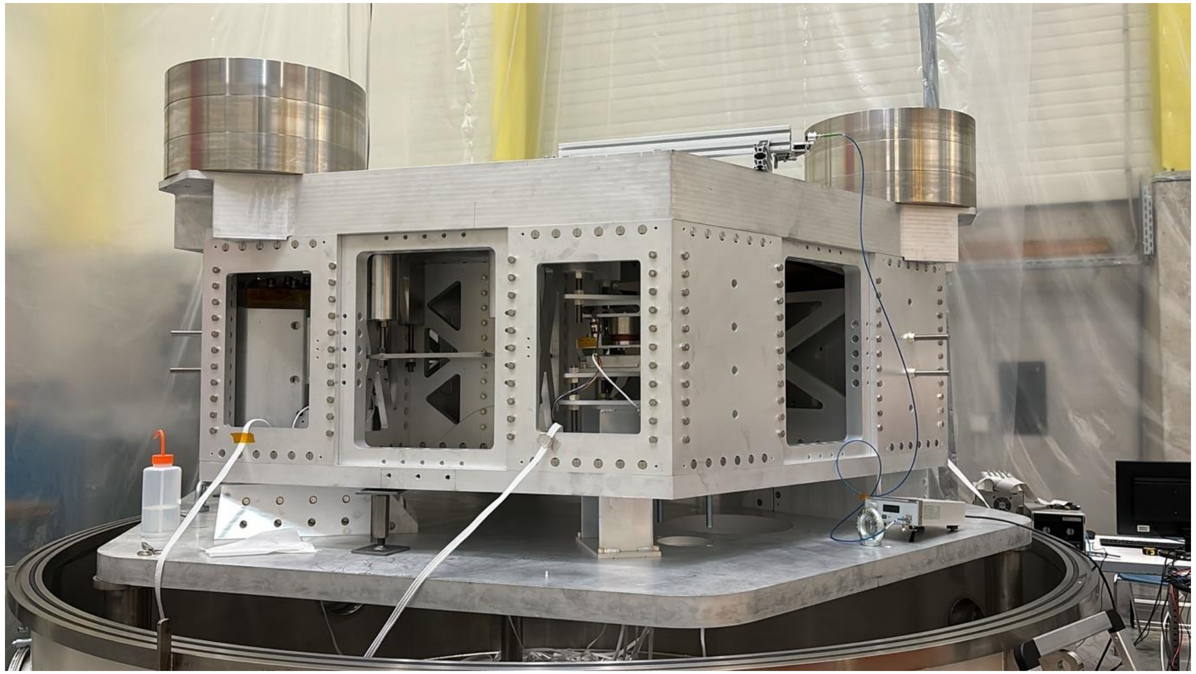

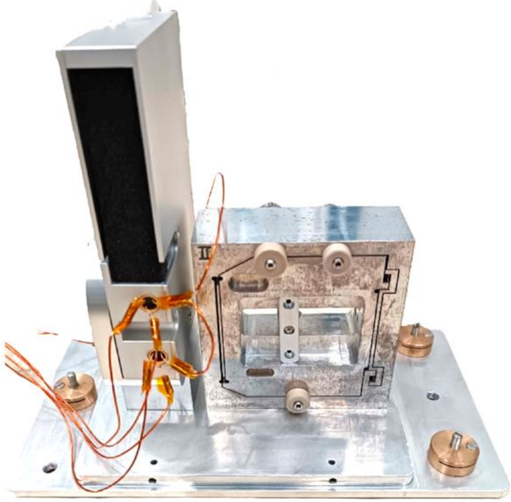

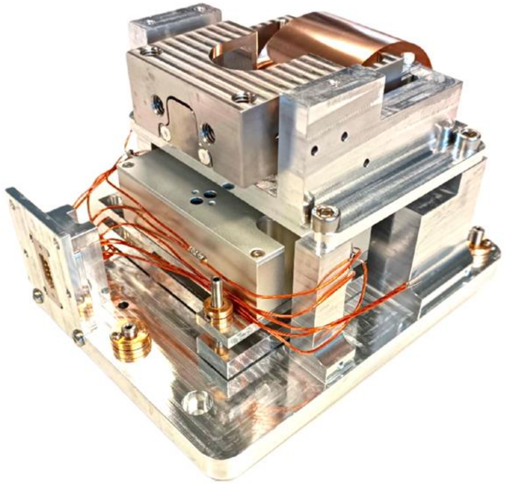

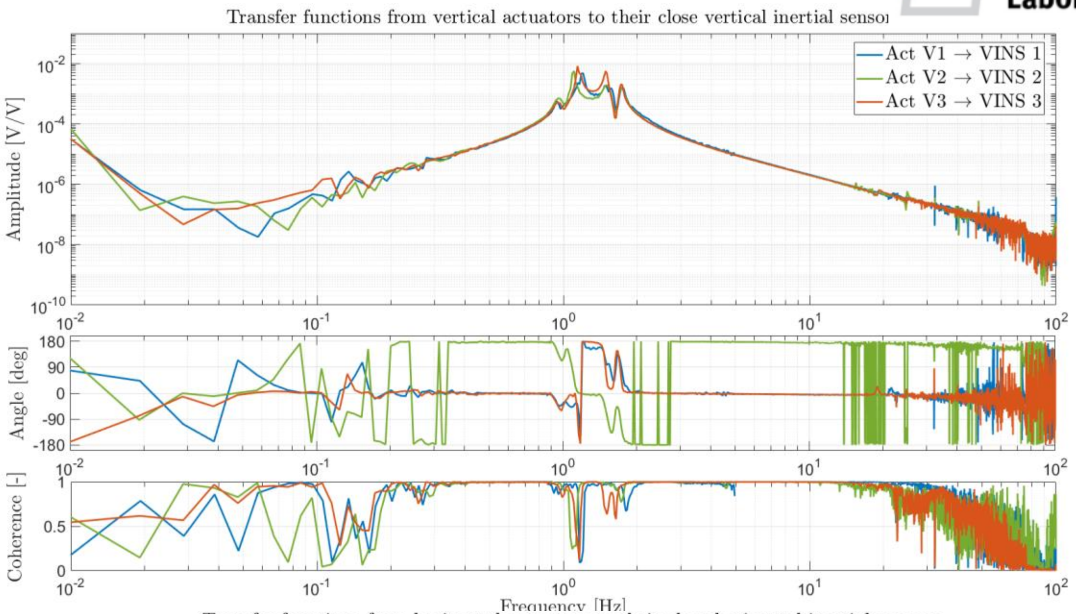

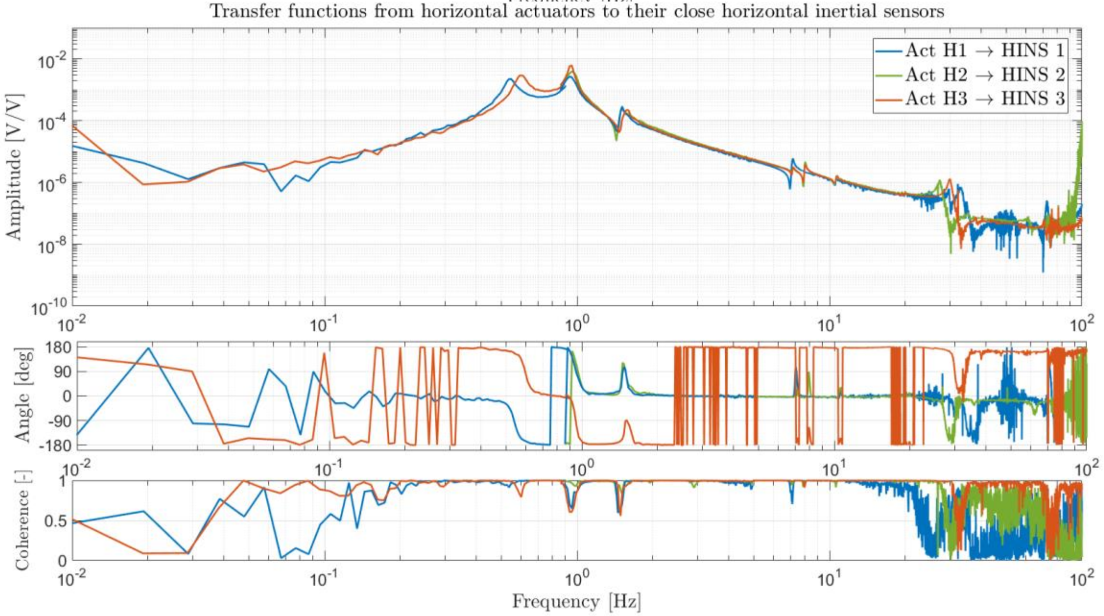

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Low-frequency active Isolation

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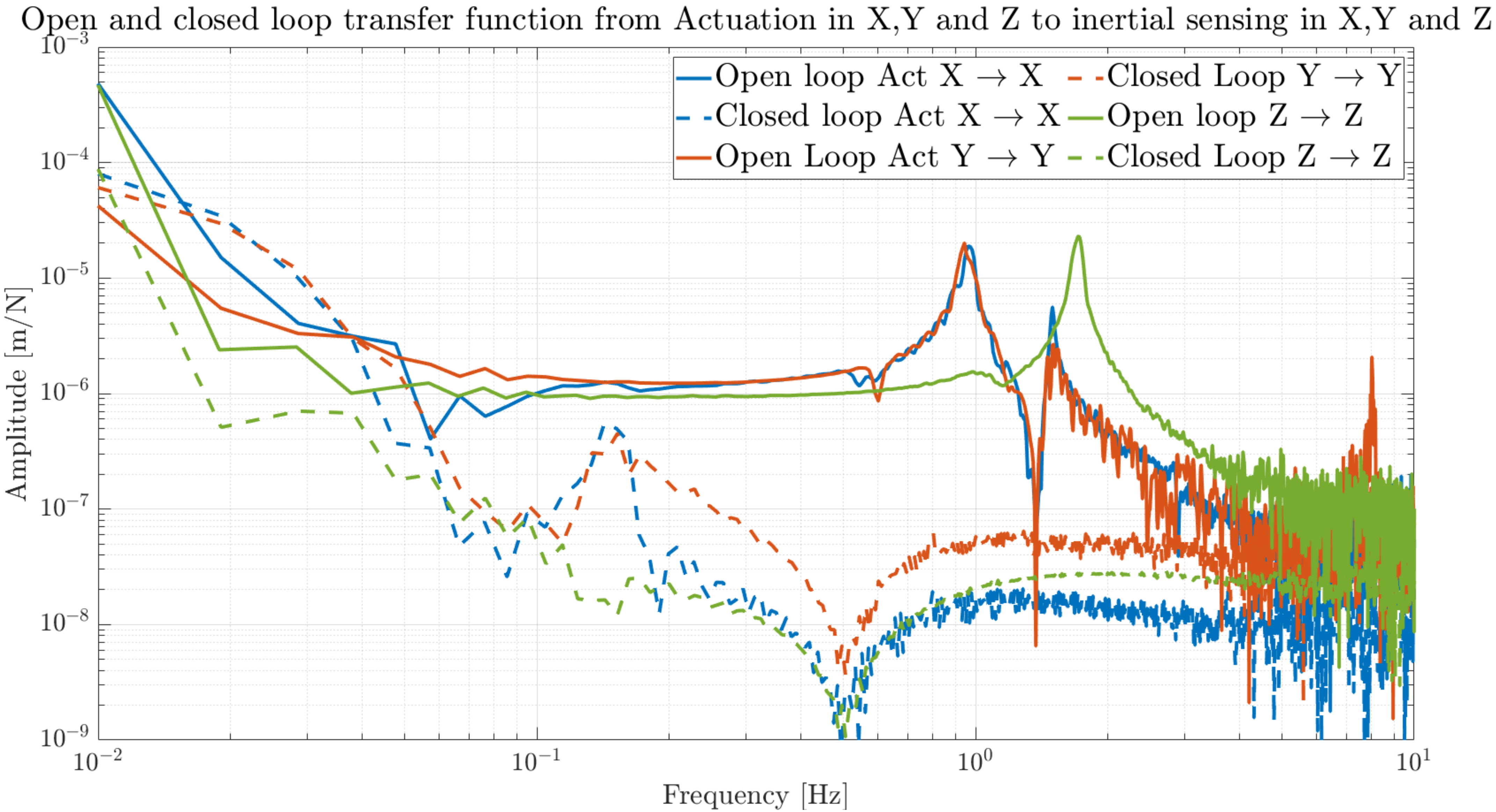

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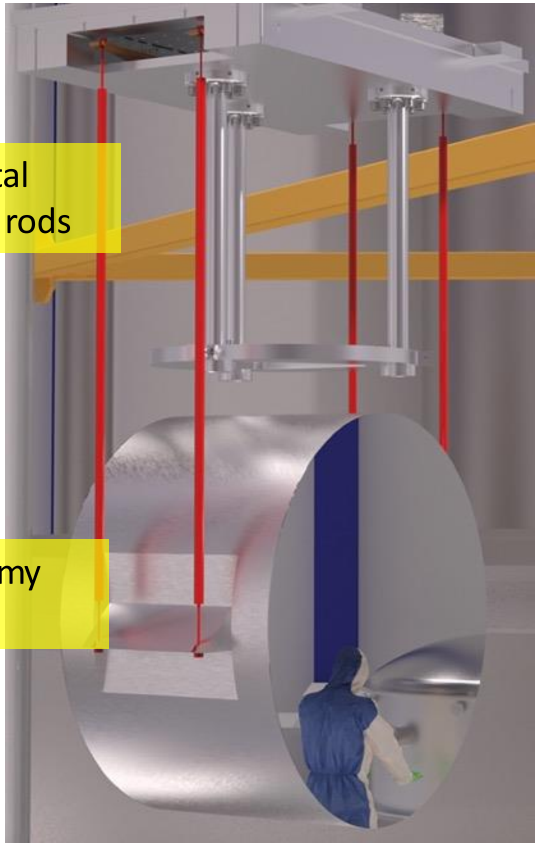
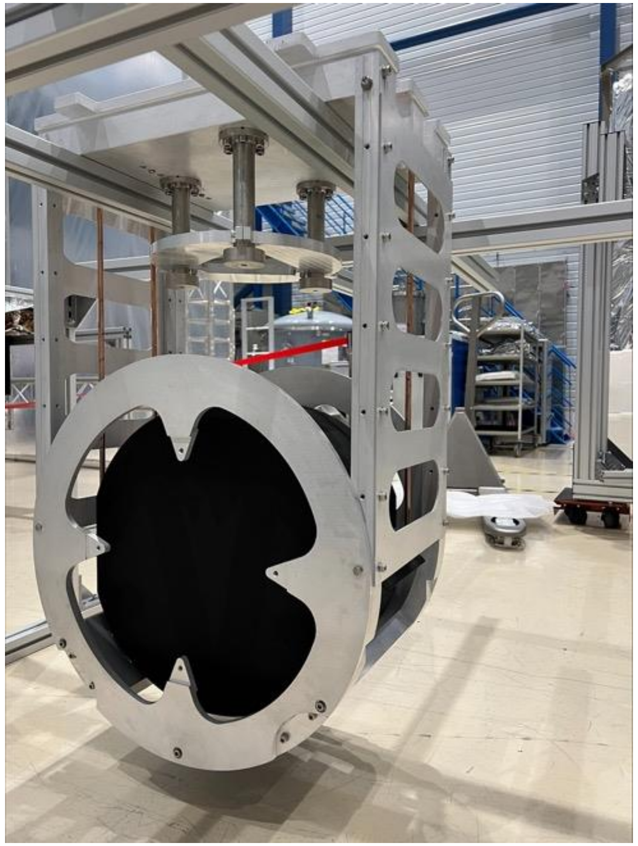
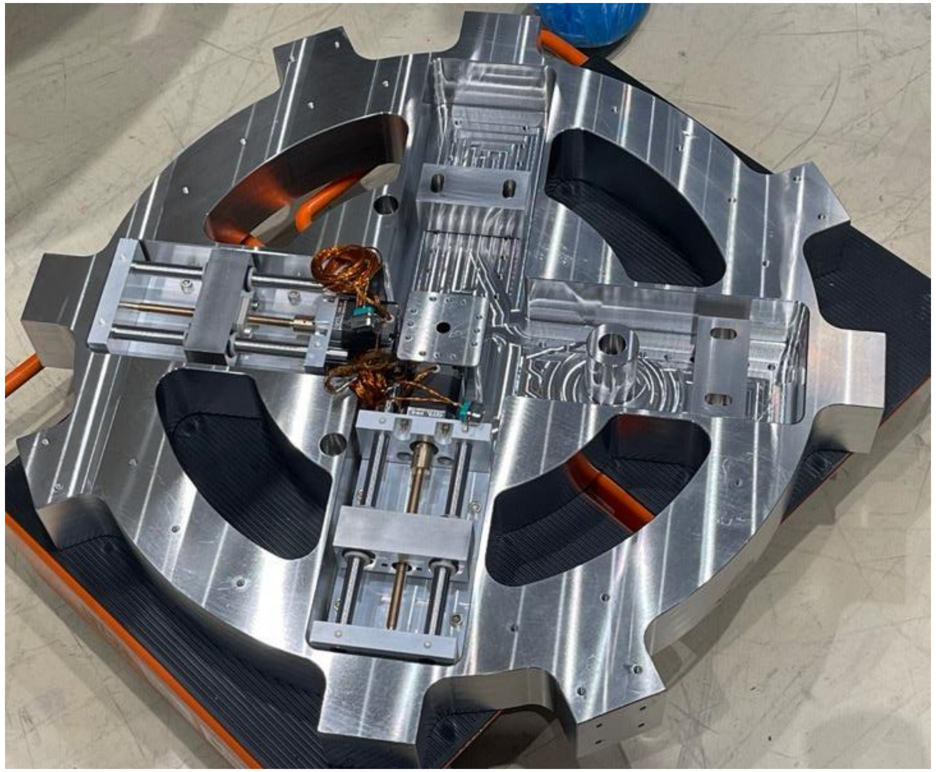
100 kg test mass & suspension

- Crucial technology aspect for ET: no proven solution exists
- Four machined samples delivered
- Silicon mirror ordered (delivery end of 2024)





Marionette



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Nikhef
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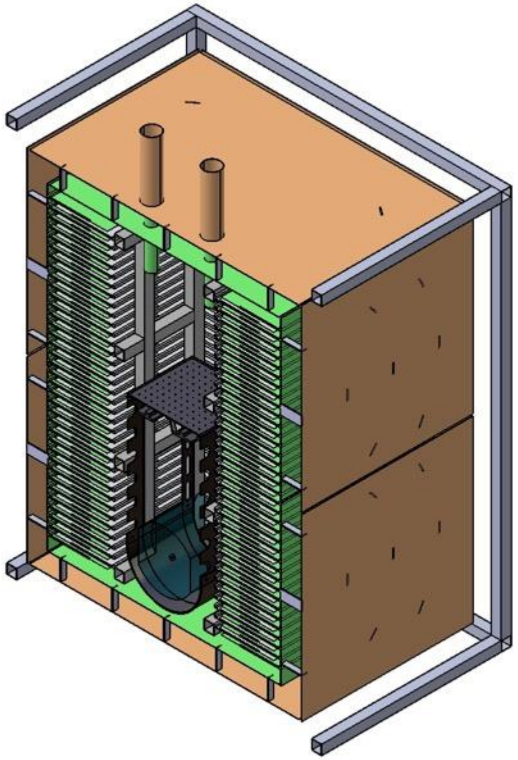
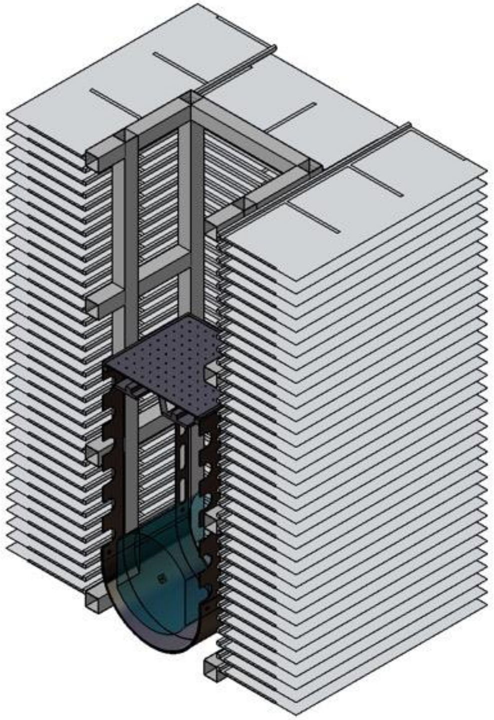
CSL CENTRE SPATIAL DE LIÈGE
UCLouvain

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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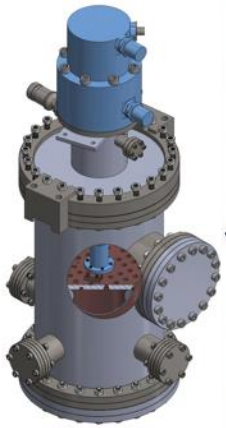
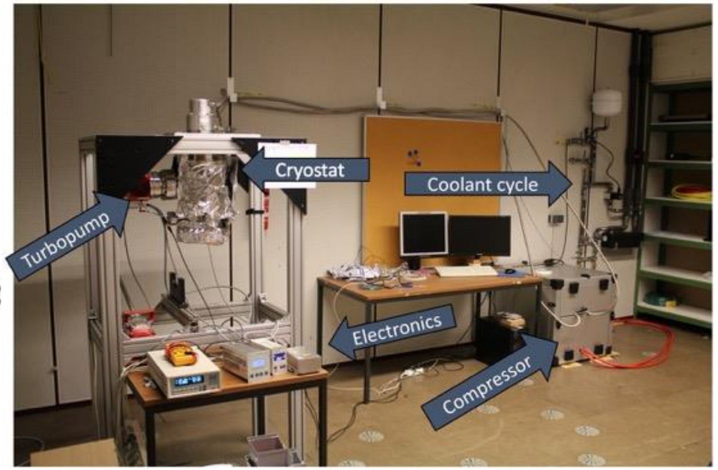
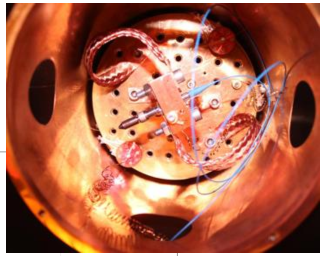
Cryogenic test bench

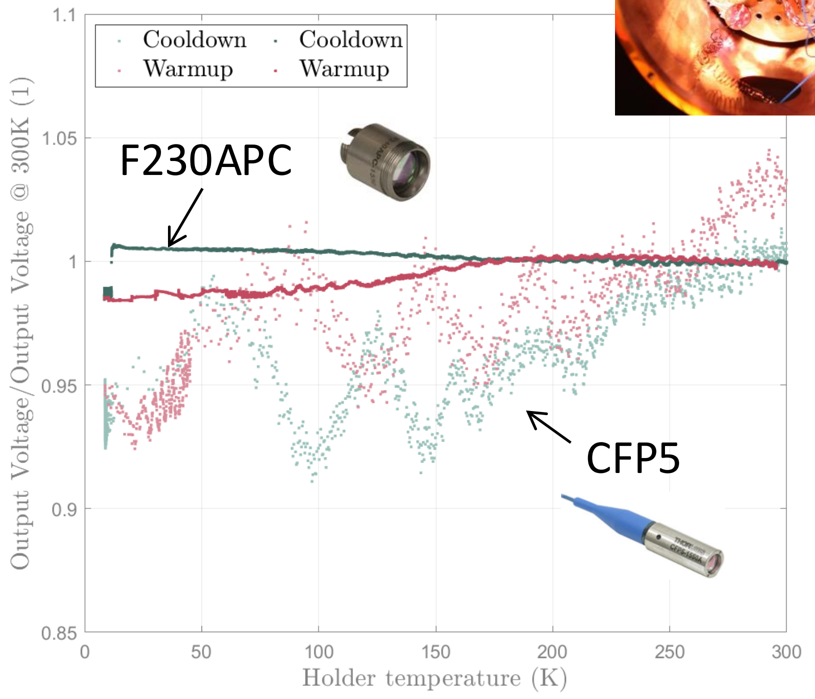




- Closed-cycle cryostat with up to 1W cooling power at 10K
- Vacuum level: better than 10^{-9} mbar
- Usable volume: cylindrical 15x15cm
- Fast turnaround and low running costs
- Useful for testing materials, components and assemblies

Collimators





More sensitive to temperature fluctuations

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Validation of 1550 nm optical elements in cryogenic conditions

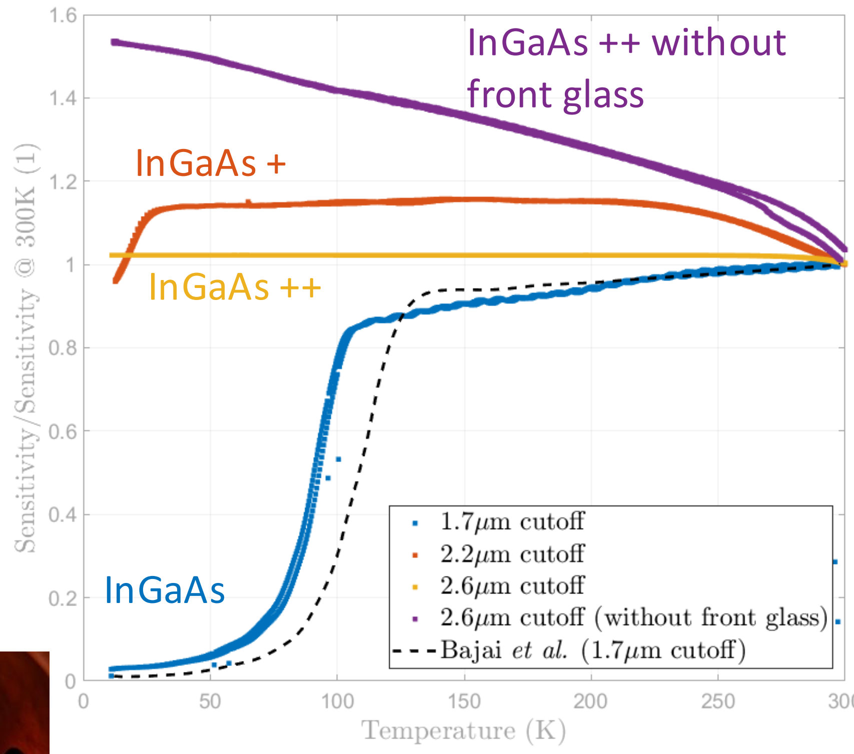
https://doi.org/10.1016/j.cryogenics.2024.103895

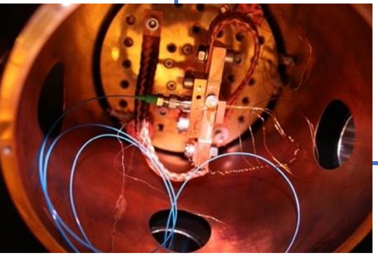
[1] Zhang *et al*, 1997 https://ui.adsabs.harvard

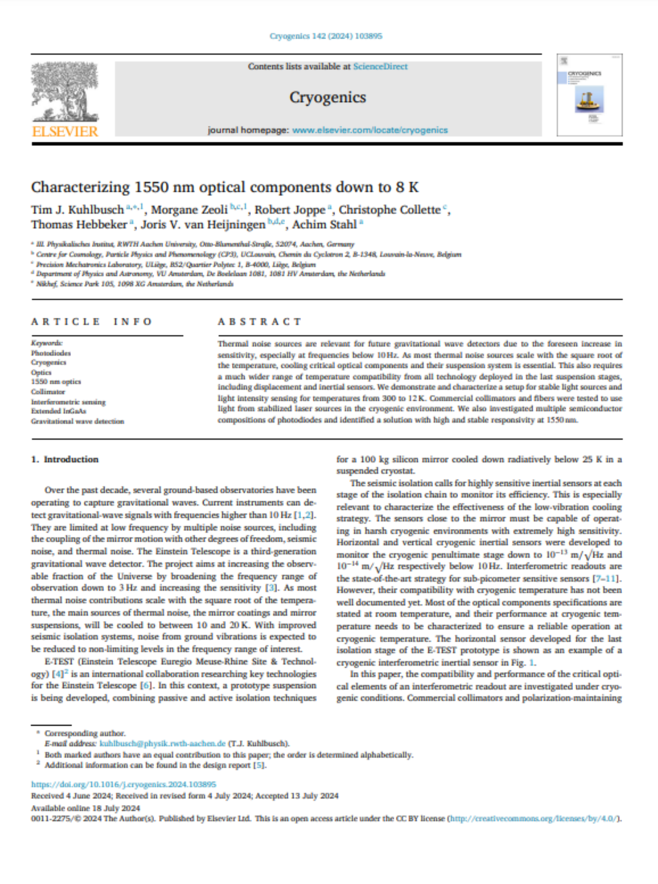
[2] Bajpai *et al*, 2022 arxiv 2203.10427v1]

Photodiodes

Constant improvement of the responsivity







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ELSEVIER

Characterizing 1550 nm optical components down to 8 K

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Interferometric sensing
Extended InGaAs
Gravitational wave detection

ABSTRACT

Thermal noise sources are relevant for future gravitational wave detectors due to the foreseen increase in sensitivity, especially at frequencies below 10 Hz. As most thermal noise sources scale with the square root of the temperature, cooling critical optical components and their suspension system is essential. This also requires a much wider range of temperature compatibility from all technology deployed in the last suspension stages, including displacement and inertial sensors. We demonstrate and characterize a setup for stable light sources and light intensity sensing for temperatures from 300 to 12 K. Commercial collimators and fibers were tested to use light from stabilized laser sources in the cryogenic environment. We also investigated multiple semiconductor compositions of photodiodes and identified a solution with high and stable responsivity at 1550 nm.

1. Introduction

Over the past decade, several ground-based observatories have been operating to capture gravitational waves. Current instruments can detect gravitational-wave signals with frequencies higher than 10 Hz [1,2]. They are limited at low frequency by multiple noise sources, including the coupling of the mirror motion with other degrees of freedom, seismic noise, and thermal noise. The Einstein Telescope is a third-generation gravitational wave detector. The project aims at increasing the observable fraction of the Universe by broadening the frequency range of observation down to 3 Hz and increasing the sensitivity [3]. As most thermal noise contributions scale with the square root of the temperature, the main sources of thermal noise, the mirror coatings and mirror suspensions, will be cooled to between 10 and 20 K. With improved seismic isolation systems, noise from ground vibrations is expected to be reduced to non-limiting levels in the frequency range of interest.

E-TEST (Einstein Telescope Euregio Meuse-Rhine Site & Technology) [4][2] is an international collaboration researching key technologies for the Einstein Telescope [6]. In this context, a prototype suspension is being developed, combining passive and active isolation techniques for a 100 kg silicon mirror cooled down radiatively below 25 K in a suspended cryostat.

The seismic isolation calls for highly sensitive inertial sensors at each stage of the isolation chain to monitor its efficiency. This is especially relevant to characterize the effectiveness of the low-vibration cooling strategy. The sensors close to the mirror must be capable of operating in harsh cryogenic environments with extremely high sensitivity. Horizontal and vertical cryogenic inertial sensors were developed to monitor the cryogenic penultimate stage down to 10^{-13} m/$\sqrt{\text{Hz}}$ and 10^{-14} m/$\sqrt{\text{Hz}}$ respectively below 10 Hz. Interferometric readouts are the state-of-the-art strategy for sub-picometer sensitive sensors [7–11]. However, their compatibility with cryogenic temperature has not been well documented yet. Most of the optical components specifications are stated at room temperature, and their performance at cryogenic temperature needs to be characterized to ensure a reliable operation at cryogenic temperature. The horizontal sensor developed for the last isolation stage of the E-TEST prototype is shown as an example of a cryogenic interferometric inertial sensor in Fig. 1.

In this paper, the compatibility and performance of the critical optical elements of an interferometric readout are investigated under cryogenic conditions. Commercial collimators and polarization-maintaining

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1 Both marked authors have an equal contribution to this paper; the order is determined alphabetically.
2 Additional information can be found in the design report [5].

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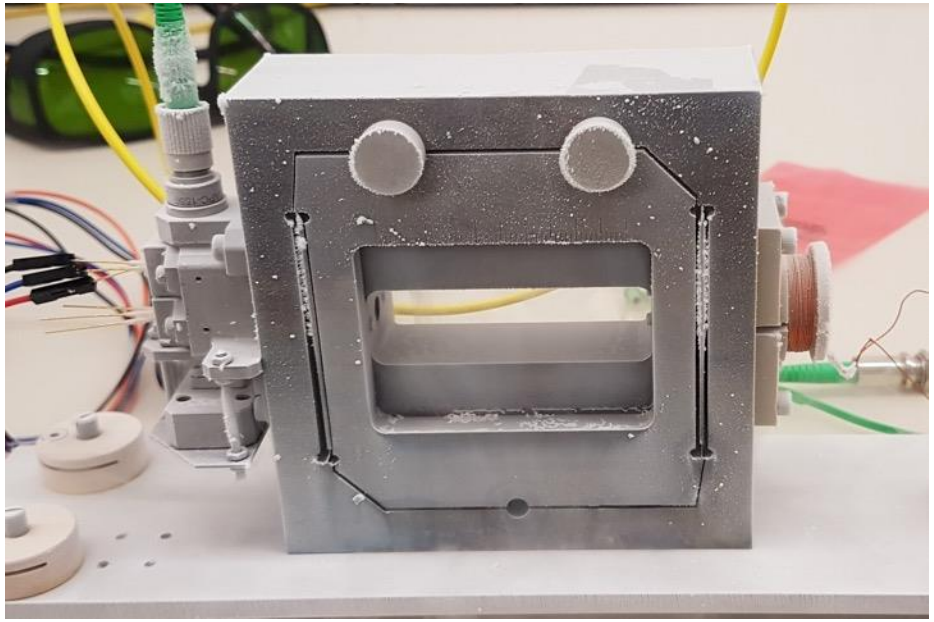
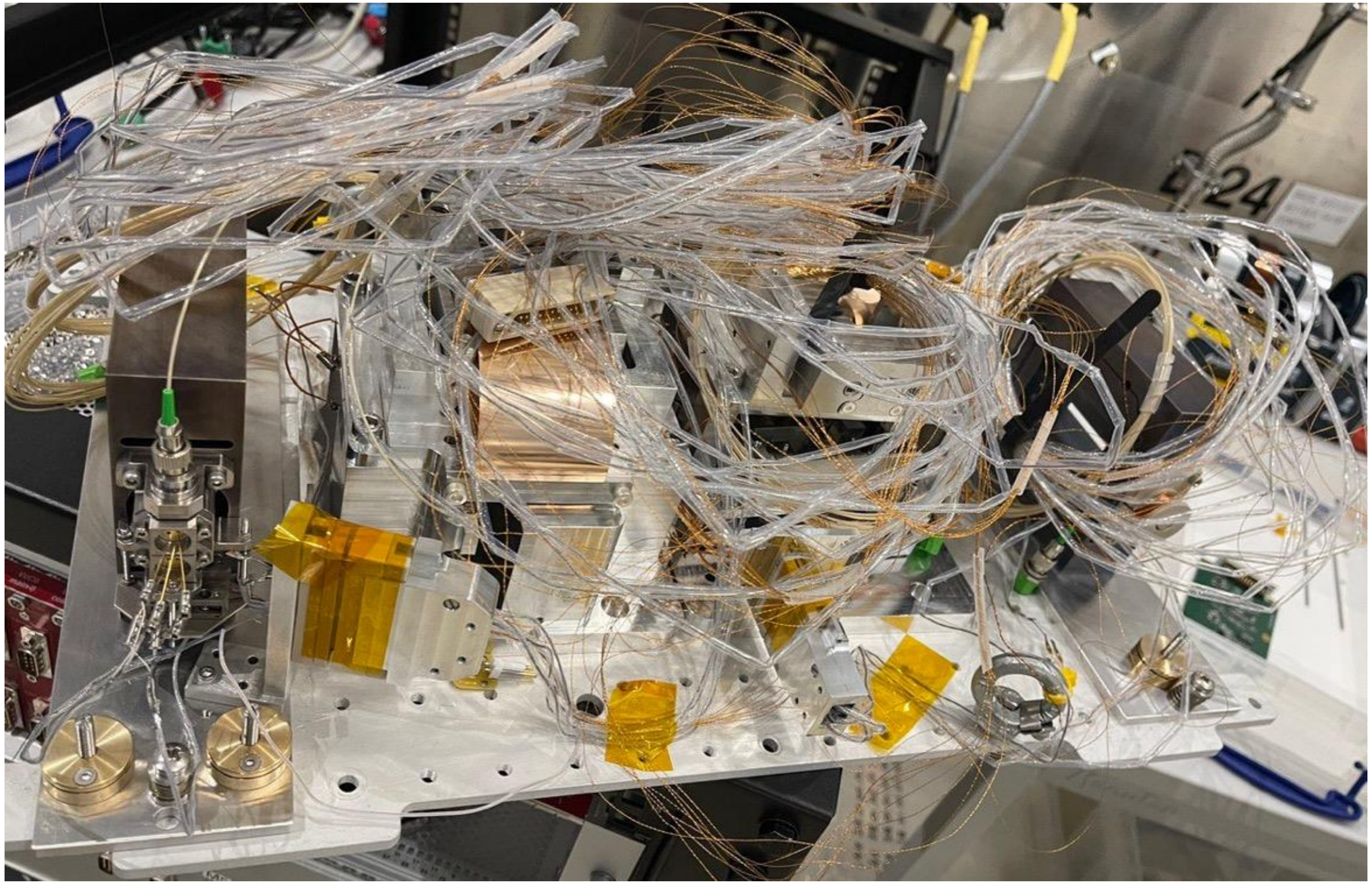
Available online 18 July 2024

Cryogenic inertial sensors





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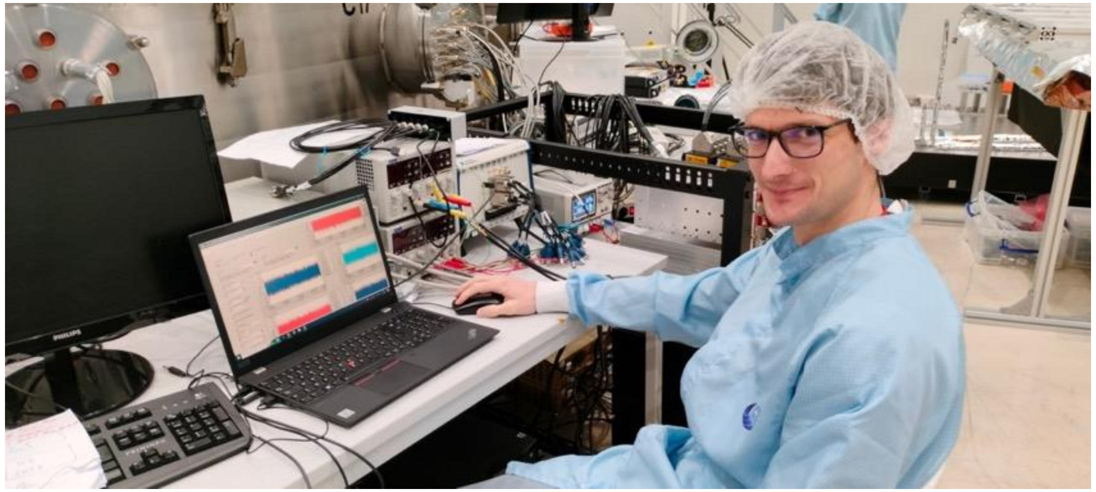
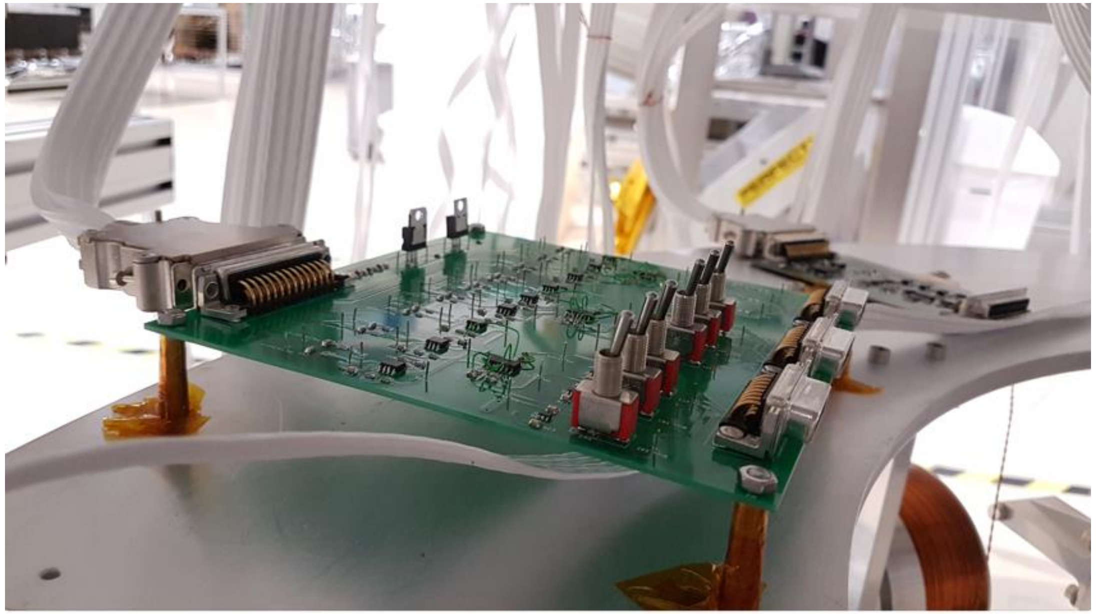
Electronics and control





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Assembly of the prototype

AMOS
ADVANCED MECHANICAL & OPTICAL SYSTEMS

Nikhef
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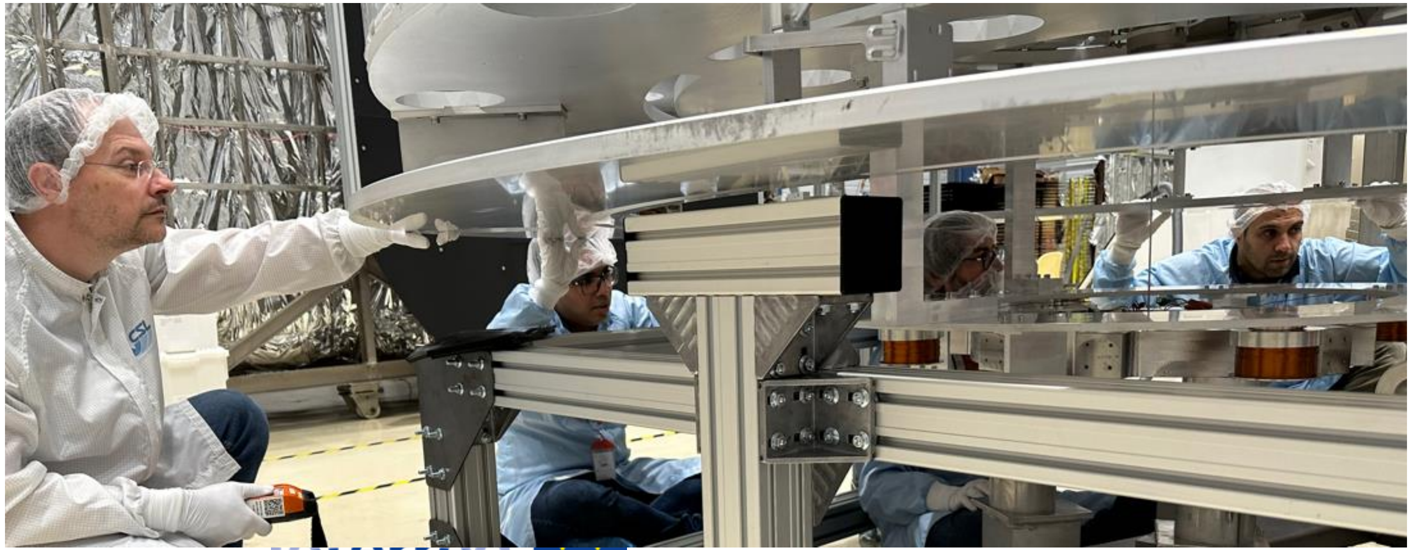
Final installation at CSL



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Lionel Jacques (CSL)
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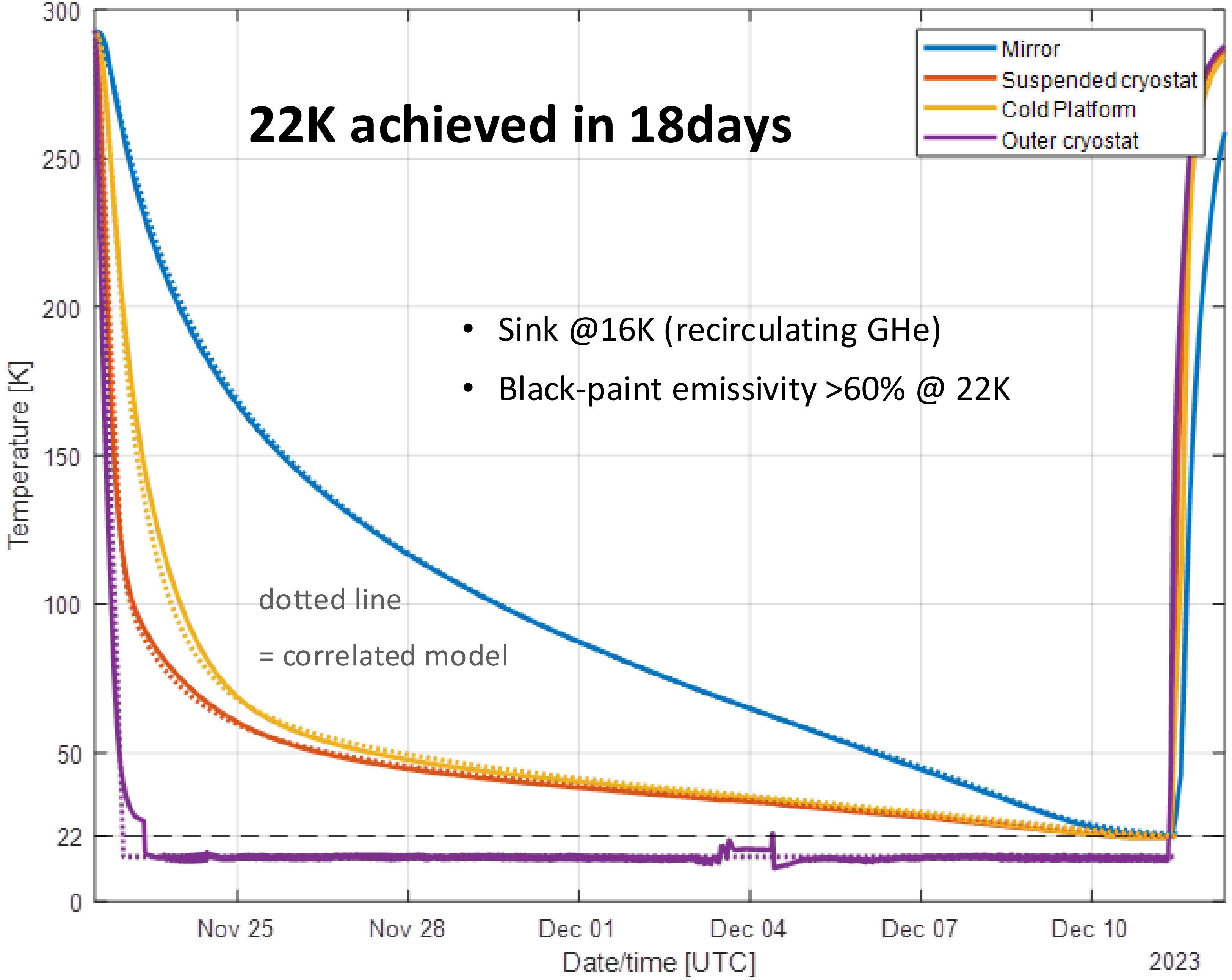
22K achieved in 18days

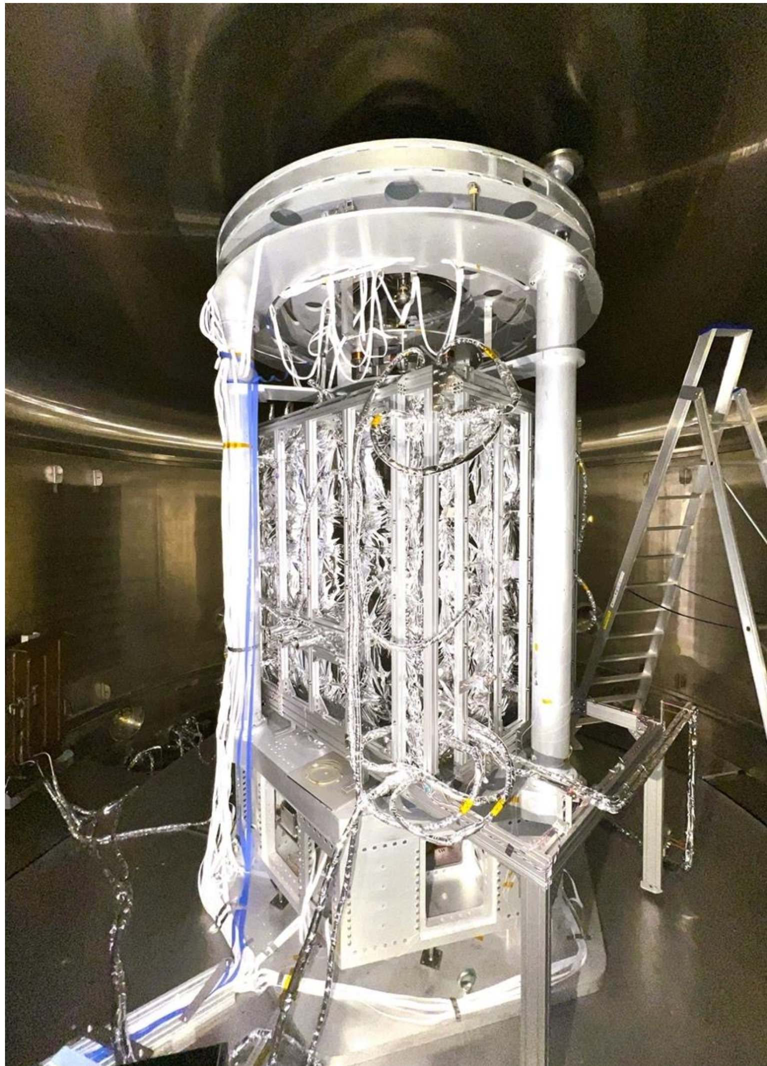
- Sink @16K (recirculating GHe)
- Black-paint emissivity >60% @ 22K

dotted line

= correlated model



After integration of outer cryostat including LN_2 shield and GHe panels



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E-TEST becomes CRISTAL

Summary @ plan

- 1st run: Fully assembled prototype combining
  - 100 kg test mass
  - Low frequency seismic isolation
  - Radiative cooling strategy
- Currently:
  - 100kg Si mirror being polished
  - Improvement of sensor, control strategies
  - Si suspension design
  - Preparation of Q & T experiments
- 2nd run in the new chamber in 2025

Two post-doc positions open at ULiege on Newtonian Noise !

https://www.etest-emr.eu/
http://www.pmlab.be/

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