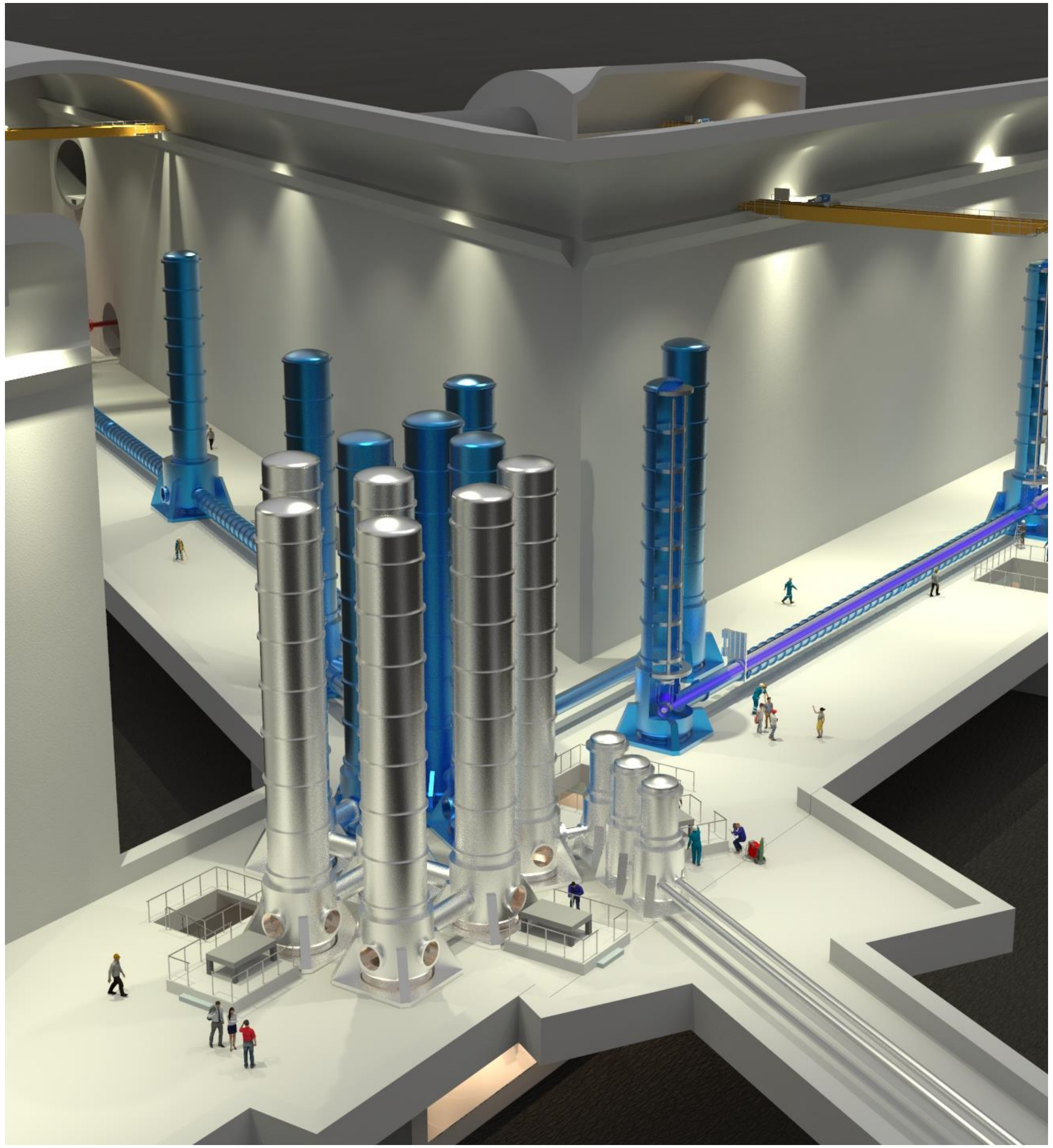
E-TEST : Einstein Telescope EMR Site and Technology

Anthony Amorosi

On behalf of the E-TEST consortium



E-TEST objectives

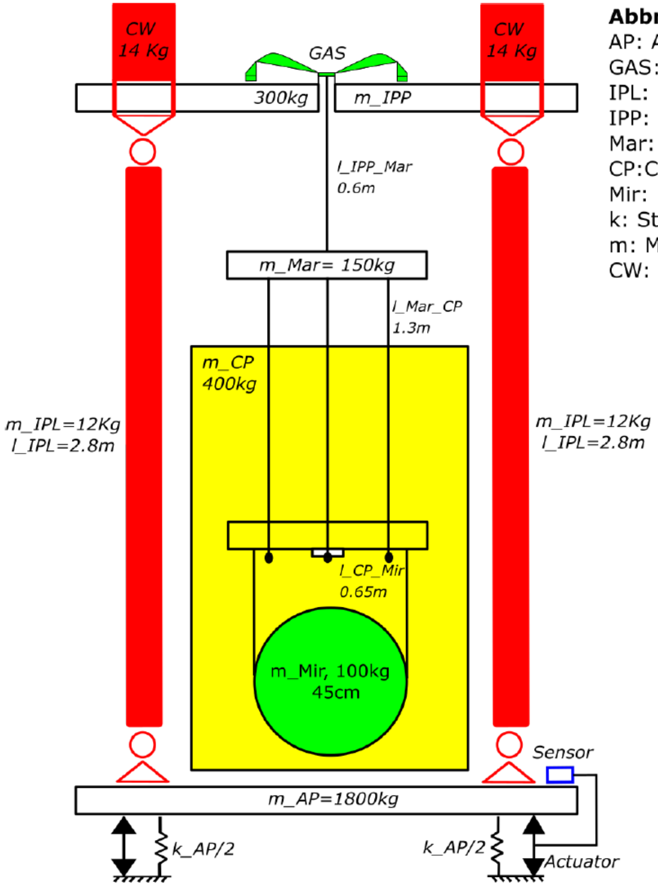
- Large mirror (100 Kg)
- Cryogenic temperature (10-20 K)
- Isolated at low frequency (0.1-10 Hz)
- Compact suspension (4.5 meters)

E-TEST feasibility strategy

E-TEST is a project funded by the Interreg Euregio Meuse-Rhine and ET2SME consortium, which allow us to capitalize on existing infrastructure at Centre Spatial Liège (CSL) for the construction of the facility.

Precision Mechatronics Laboratory · CSL Centre Spatial de Liège · RWTH Aachen University · KU Leuven · Nikhef · UCLouvain · micas KU Leuven · Fraunhofer ILT

E-TEST: how it started



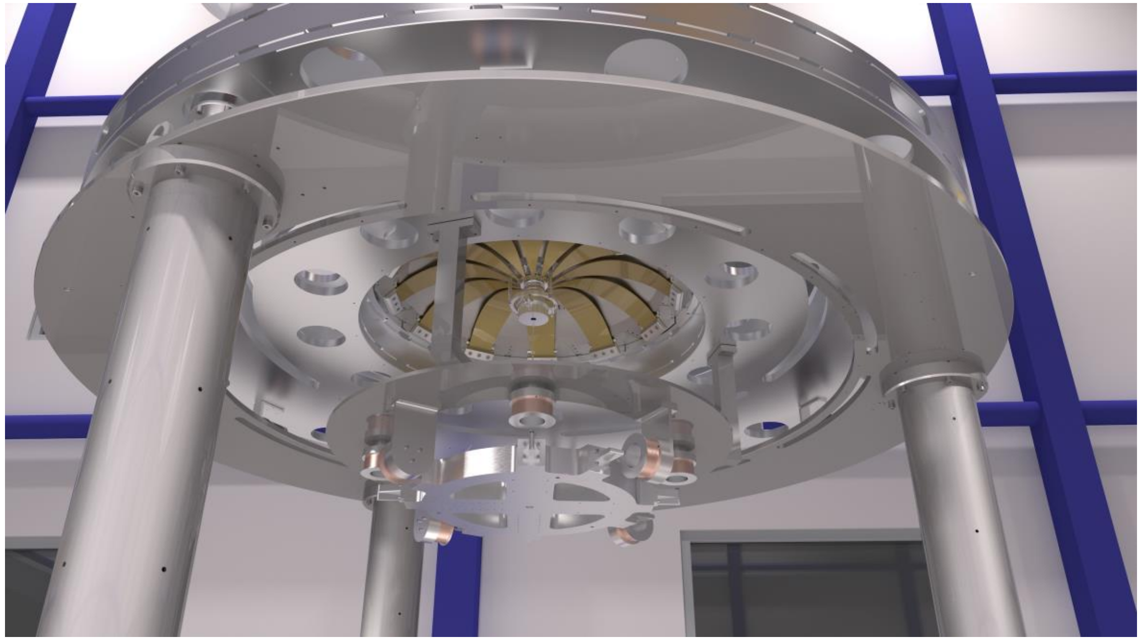
Abbreviation:
AP: Active Inertial Platform
GAS: Geometric Anti-Spring
IPL: Inverted Pendulum Leg
IPP: Inverted Pendulum Platform
Mar: Marionette
CP:Cryostat+Cold Platform
Mir: Mirror
k: Stiffness
m: Mass
CW: Counter Weight

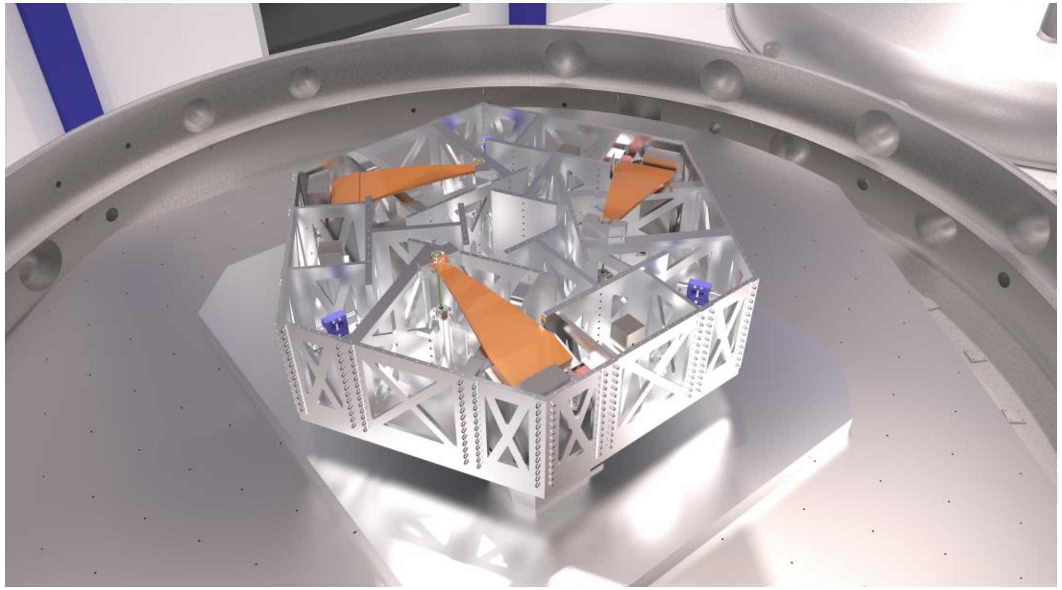
Hybrid (active + passive) isolation
Radiative cooling

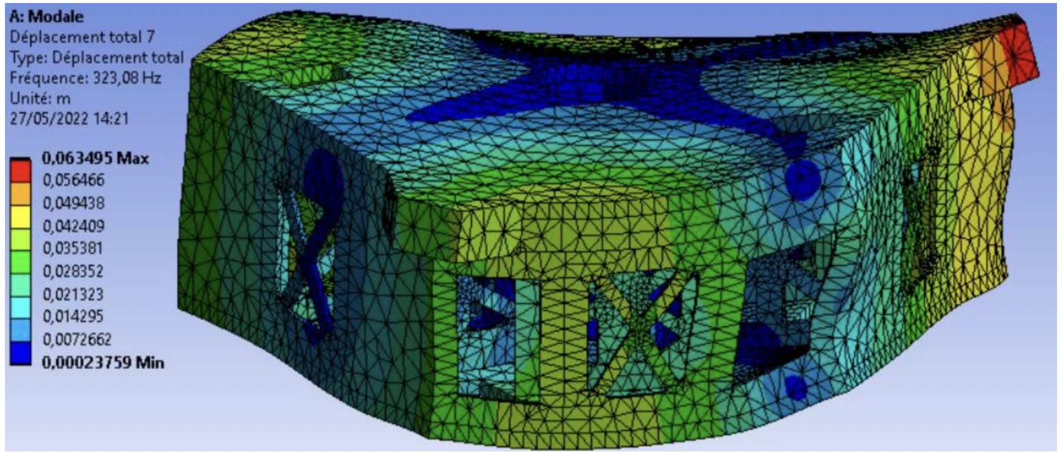
From a design concept to technical drawings

Mechanical isolation system

- Production of the whole prototype finished!
- All mechanical parts in production
- Assembly started in Summer 2023







Contact: Ameer Sider (PML)
asider@uliege.be

From a design concept to technical drawings

Contact: Cedric Lenaerts (CSL)
Cedric.Lenaerts@uliege.be

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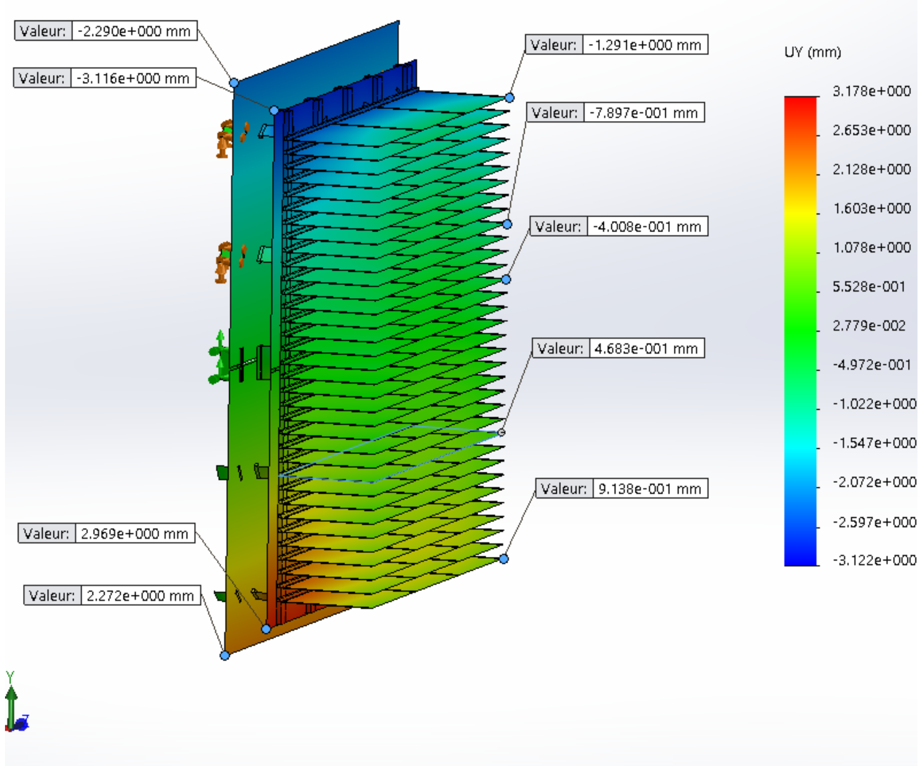
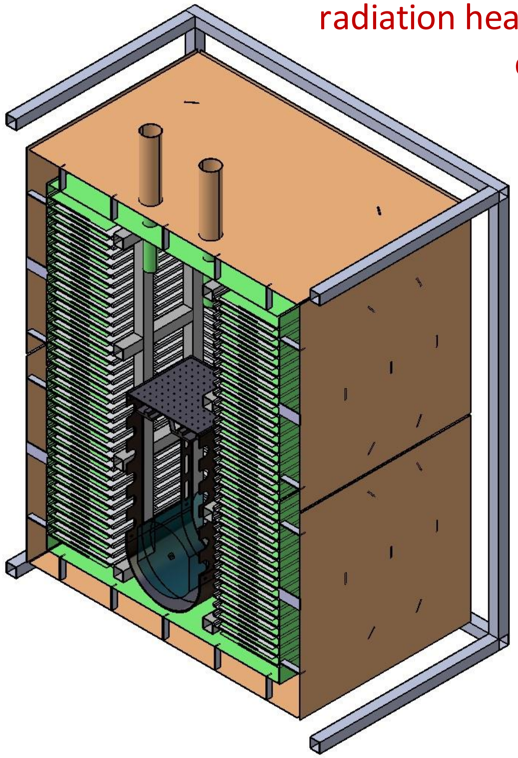
Radiative cooling design

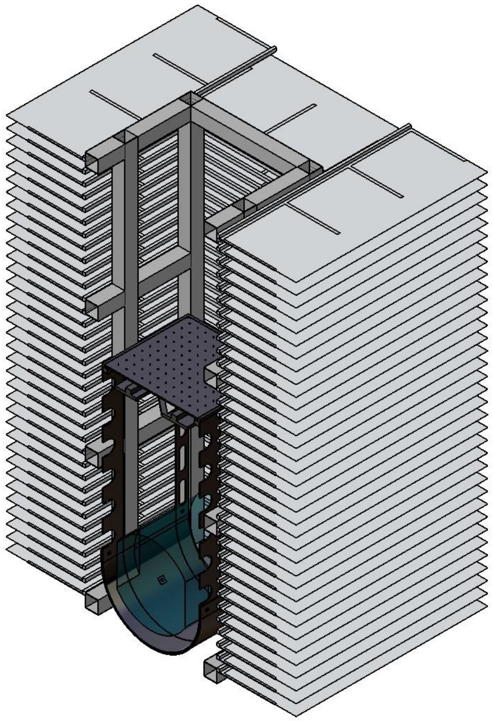
- Overall dimensions: 1.8 x 1.6 x 2 m^3
- Conventional radiator design with horizontal fins (25K)
- Three 30-mm diameter optical feedthroughs towards the mirror



radiation heat transfer for mirror cooling



Outer cryostat
(connected to the vacuum chamber):
- 80K LN2 shield (brown)
- 25K GHe panels (green)

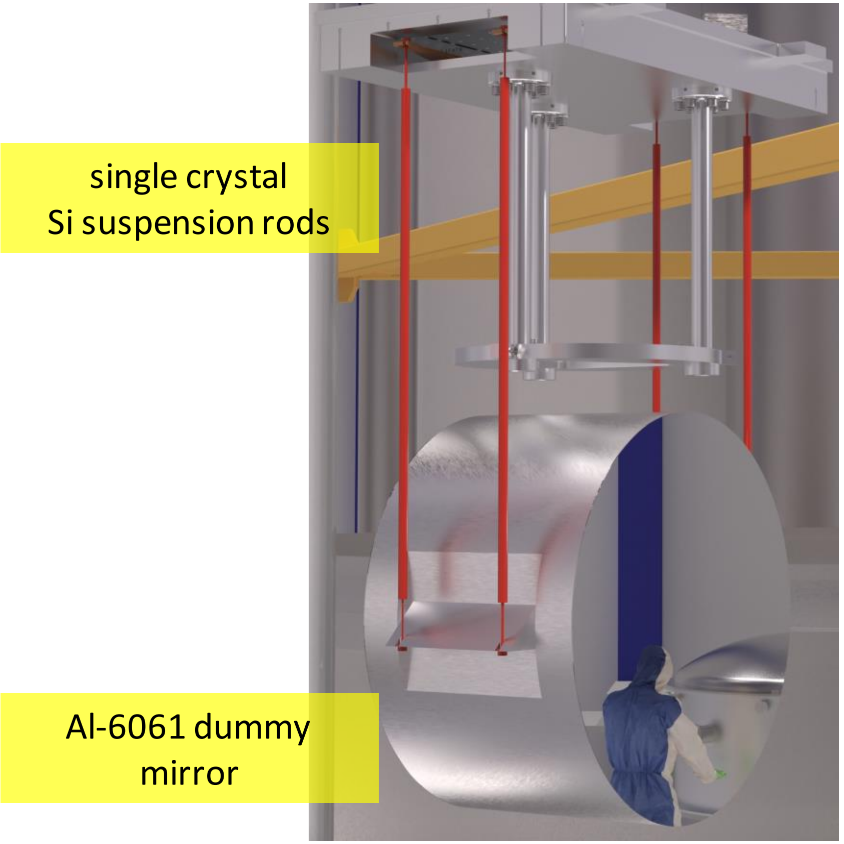


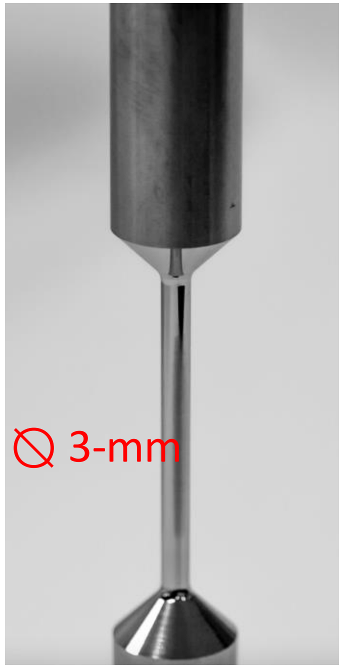
Inner cryostat
suspended and conductively linked to the silicon mirror

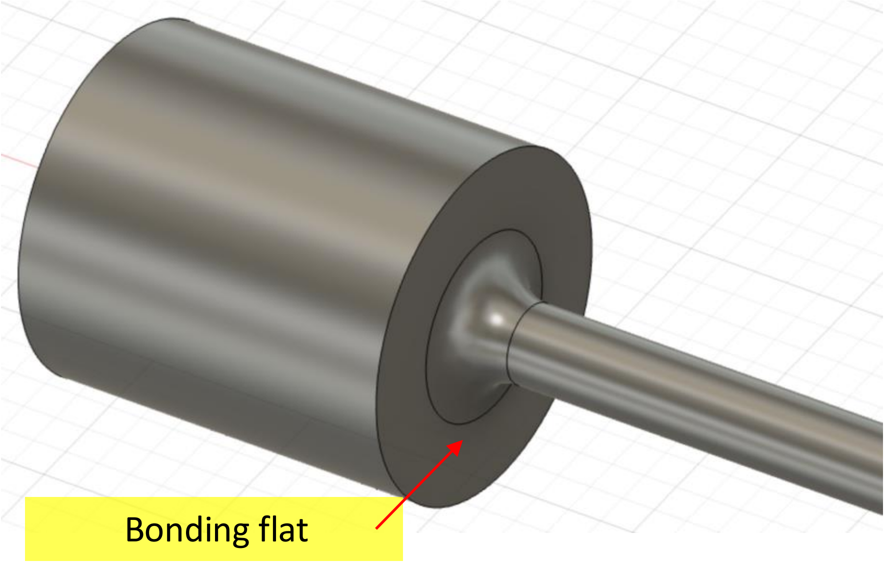
Ultra-cold vibration control

Crystalline silicon mirror suspension

- Crucial technology aspect for ET: no proven solution exists
- Four machined samples delivered



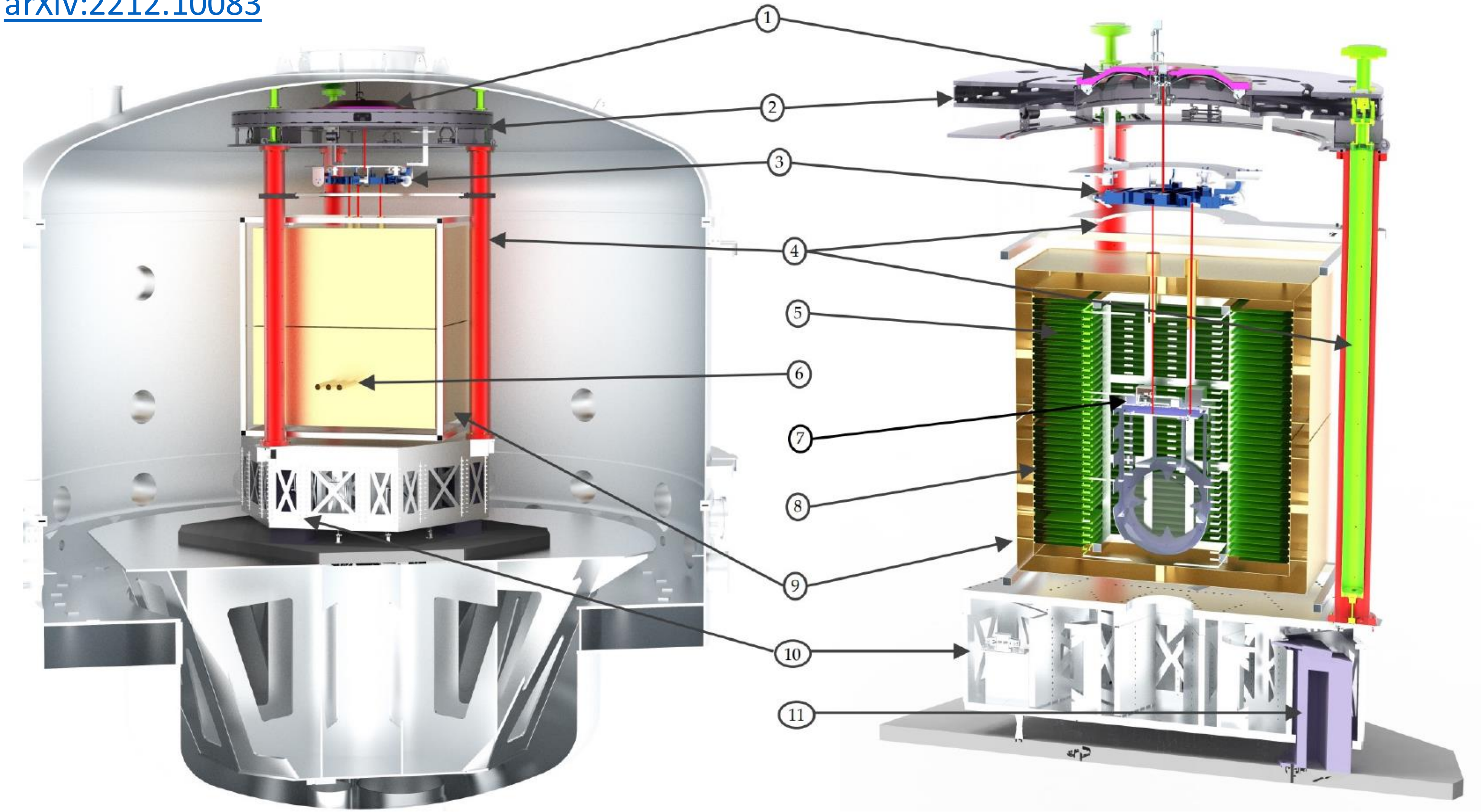




- All samples, including the new ones with bonding flats, sent to Università di Perugia for mechanical loss vs T and tensile strength measurements
- ET2SME partners Mat-Tech (NL) and MaTecK (D) will do R&D on Si-metal interfaces

Contact: Alessandro Bertolini (Nikhef)
alberto@nikhef.nl

Submitted: 12/2021
Revised: 03/2022
arXiv:2212.10083



Vibration isolator
1) GAS filter
2) Inverted Pendulum (IP) platform
3) Marionette
4) IP legs
10) Active platform

Cryogenic payload
5) Heat exchanger and cold platform
7) 25K inner thermal shield
8) 80K outer thermal shield

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Outline

ETEST in a nutshell

Mechanics and instrumentation

Cryogenic cooling

Optics and laser development

Continuation of work

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ETEST in a nutshell

Mechanics and instrumentation

Cryogenic cooling

Optics and laser development

Continuation of work

Assembly the prototype at CSL

Teamwork makes dreams work!!!

Contact: Ameer Sider (PML)
asider@uliege.be
Christophe Collette (PML)
Christophe.Collette@uliege.be
Cédric Lenaerts (CLS)
cedric.lenaerts@uliege.be

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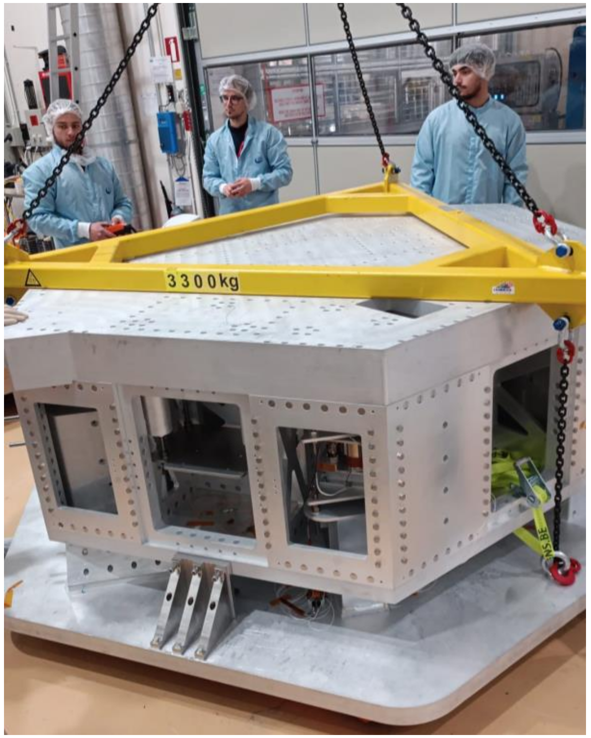

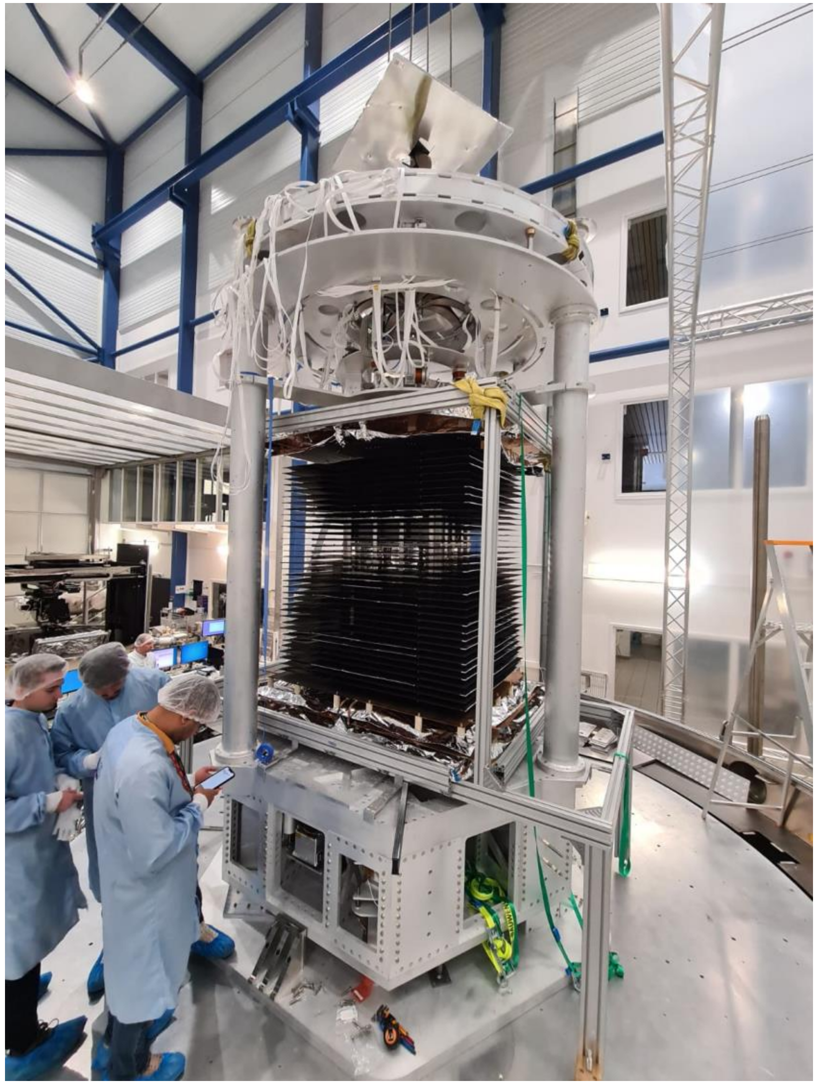

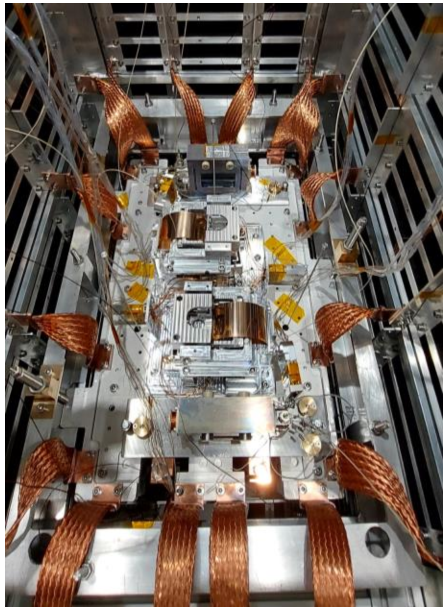

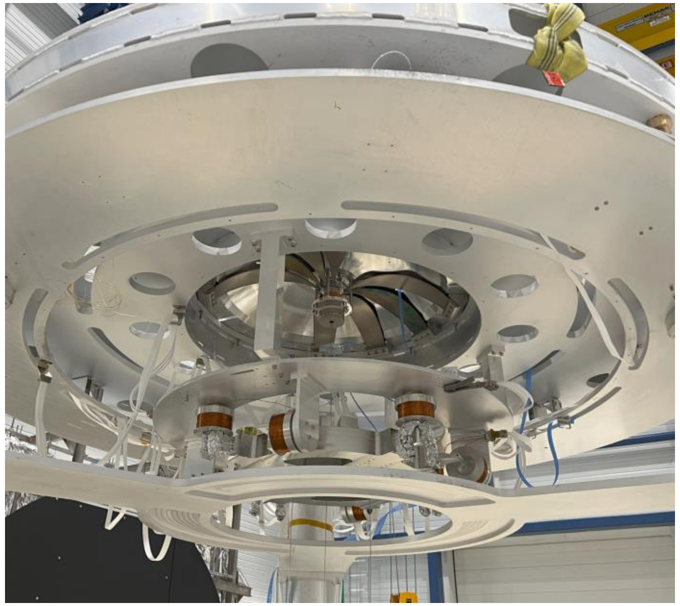

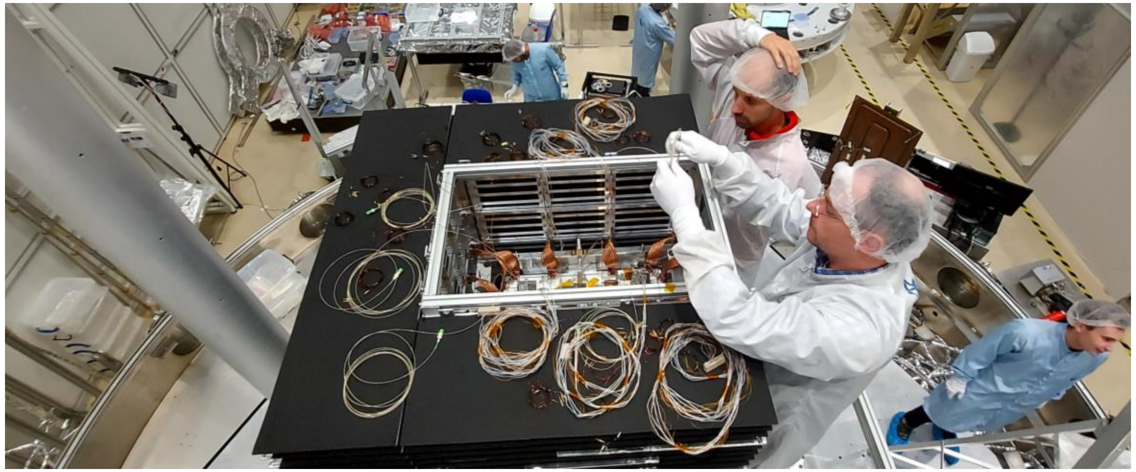

Inverted pendulum displacement sensing

Contact: Anthony Amorosi (PML)
Anthony.amorosi@uliege.be

Loïc Amez-Droz (PML)
lamezdroz@uliege.be

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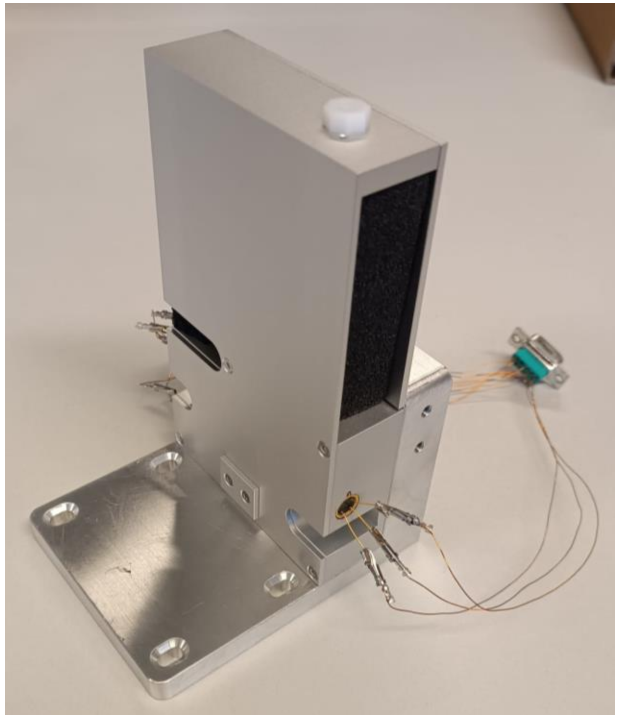
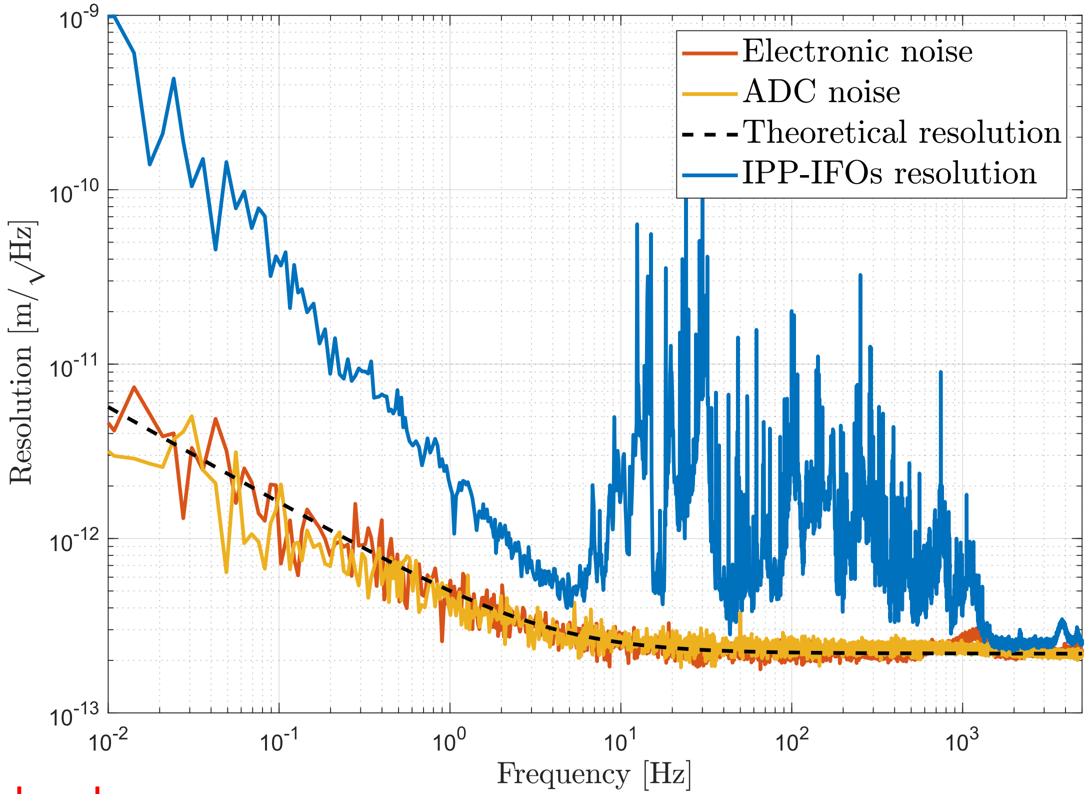
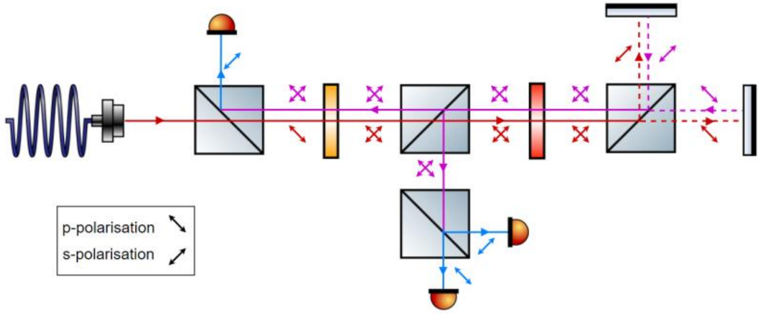
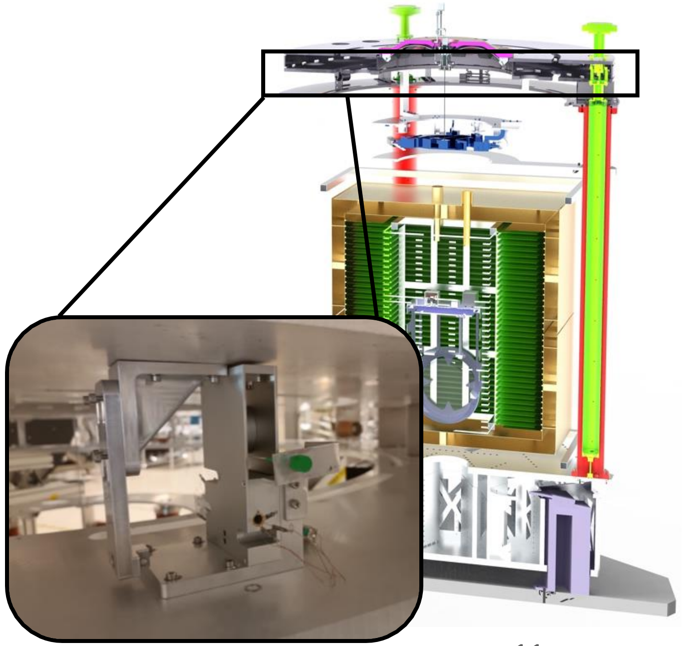
Homodyne quadrature Michelson interferometers

- Custom homodyne quadrature Michelson readout device.
- Sub-pm resolution.
- Long dynamic range (multi-fringe reading).









+ Additional LVDT reading for redundancy

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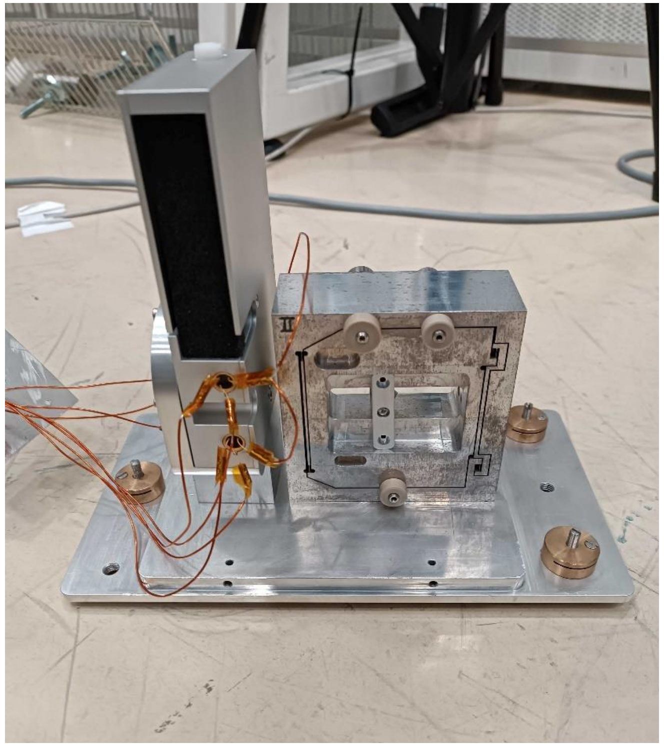
Inertial sensing of the Active Platform

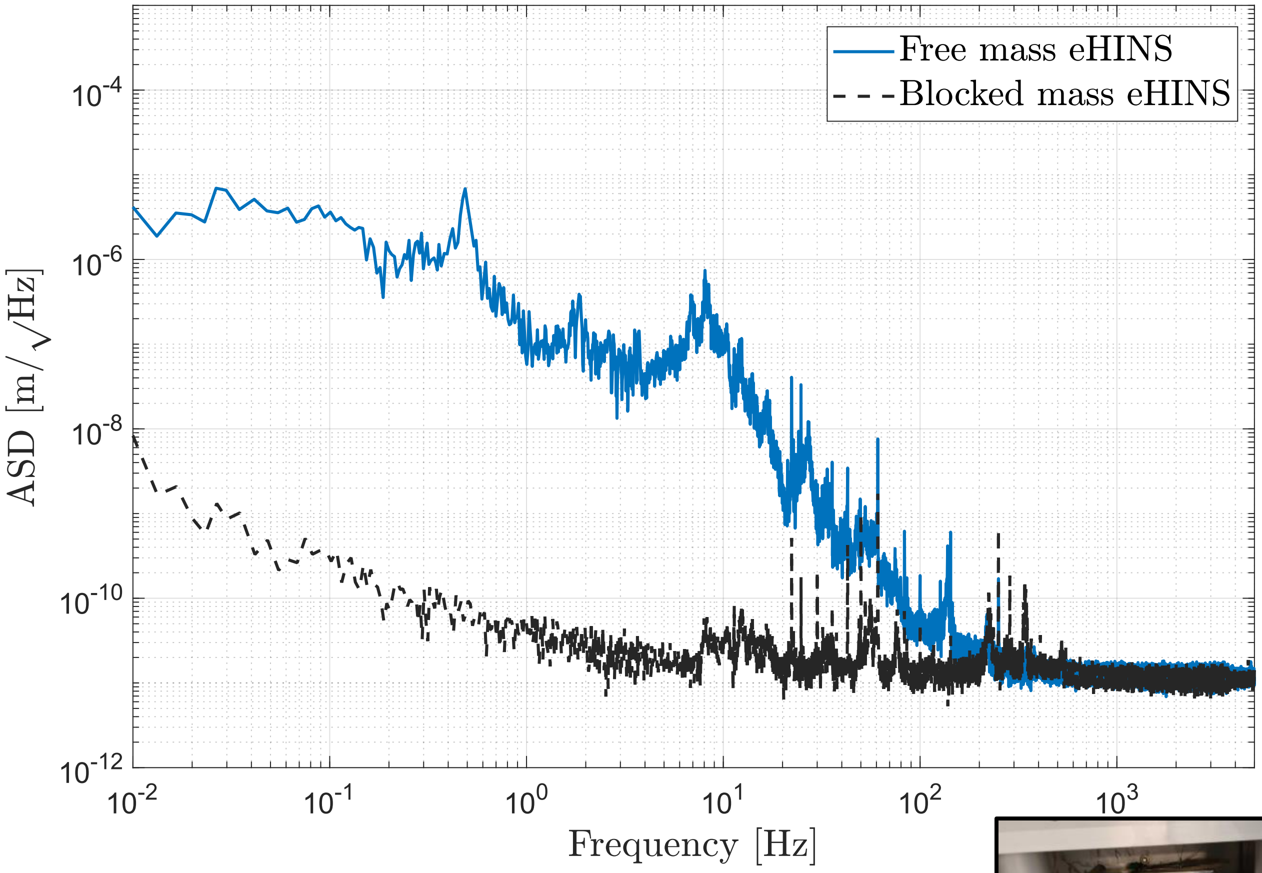
High resolution, low-frequency, optical horizontal seismometer

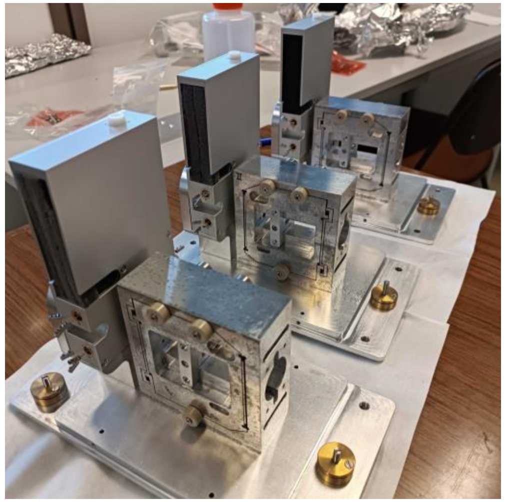
Contact: Anthony Amorosi (PML)
Anthony.amorosi@uliege.be

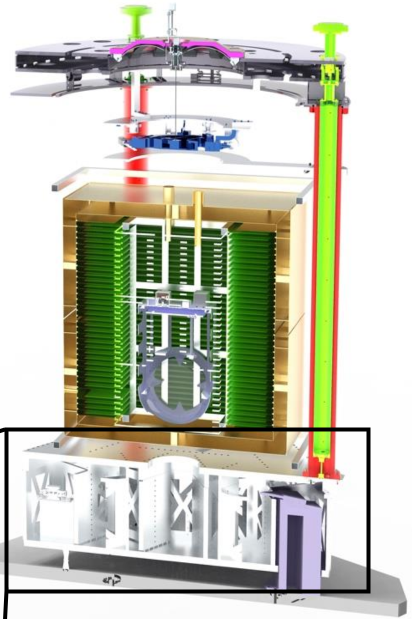
Loïc Amez-Droz (PML)
lamezdroz@uliege.be

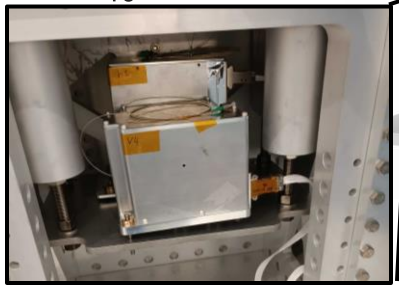
Precision Mechatronics Laboratory











- Sub-Hz resonance frequency.
- pm-Michelson optical readout.

+ BOSEMs for DC and relative motion reading.

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Inertial sensing of the Active Platform

High resolution, low-frequency, optical vertical seismometer

Contact: Anthony Amorosi (PML)
Anthony.amorosi@uliege.be

Loïc Amez-Droz (PML)
lamezdroz@uliege.be

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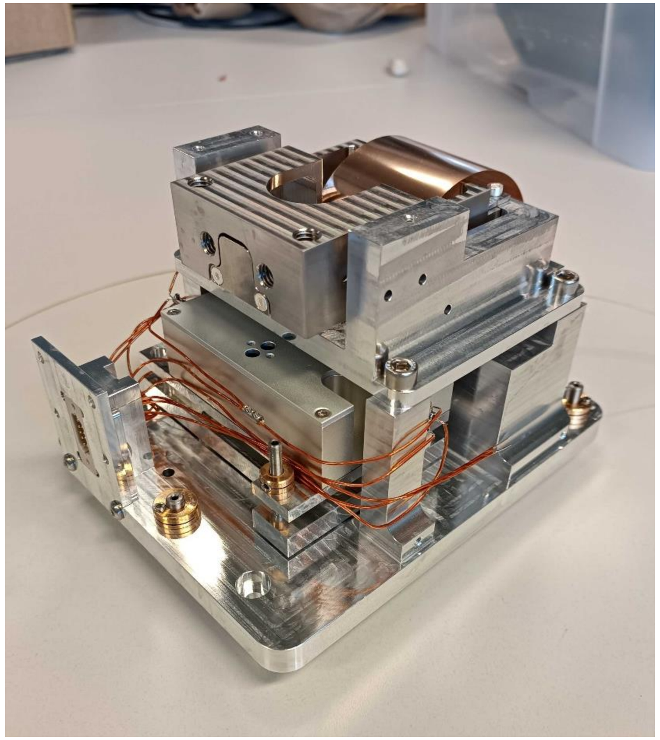

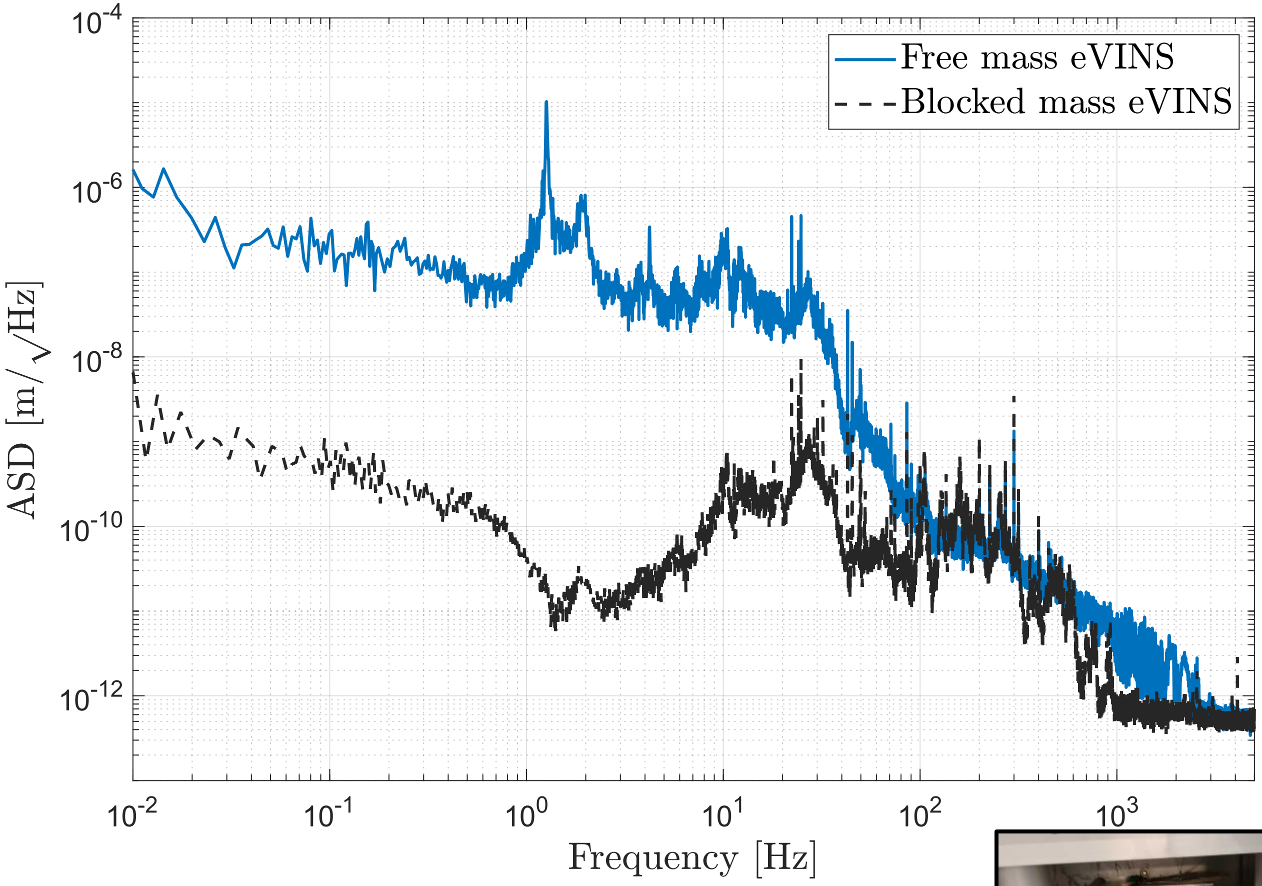

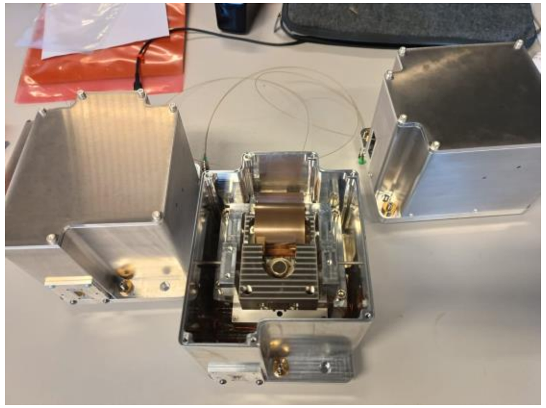

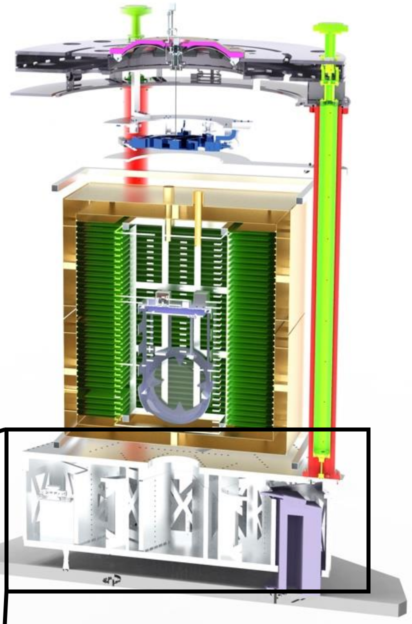

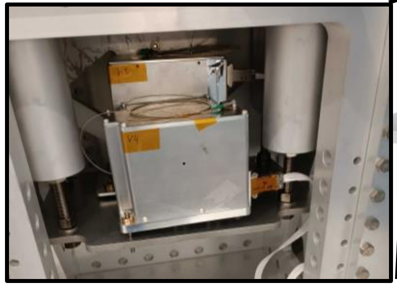

- Approx 1 Hz resonance frequency.
- pm-Michelson optical readout.

+ BOSEMs for DC and relative motion reading.

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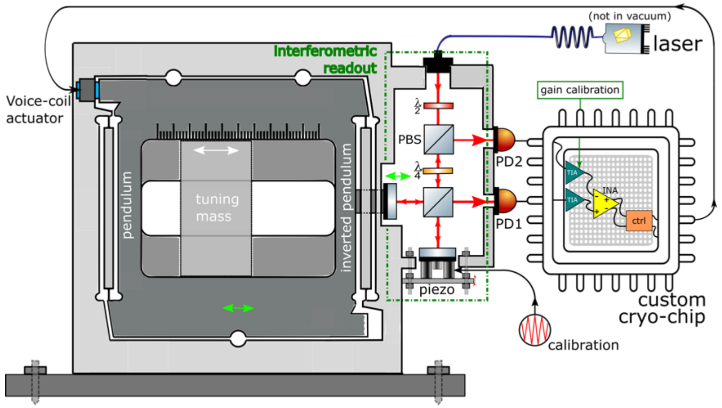
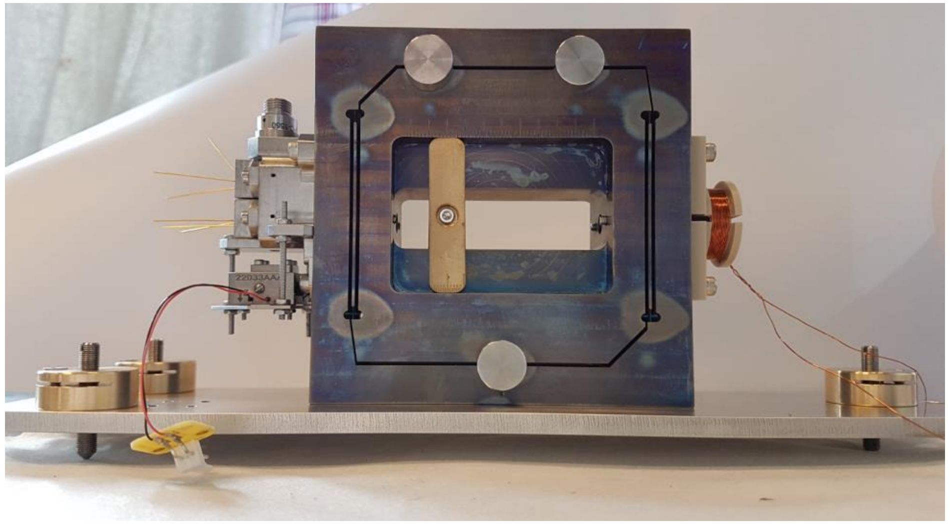
Ultra-cold vibration control

Morgane Zeoli (PML)
morgane.zeoli@uliege.be
RWTH AACHEN UNIVERSITY
UCLouvain

Cryogenic inertial sensors

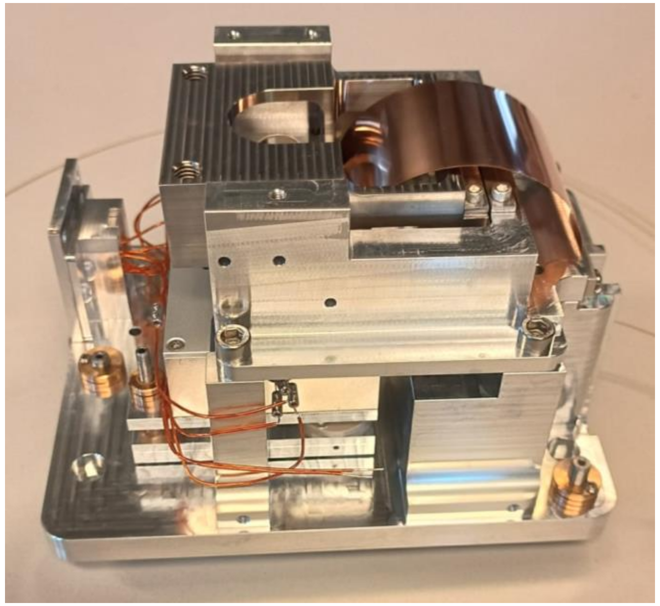
CSIS-H

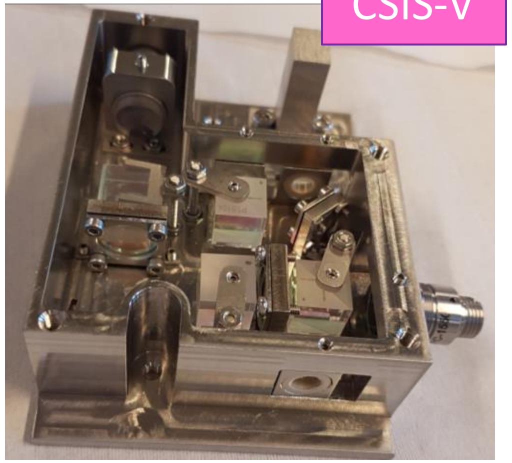




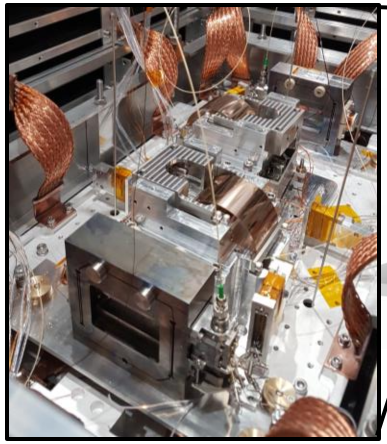
- Sub-Hz resonance frequency.
- fm differential optical readout

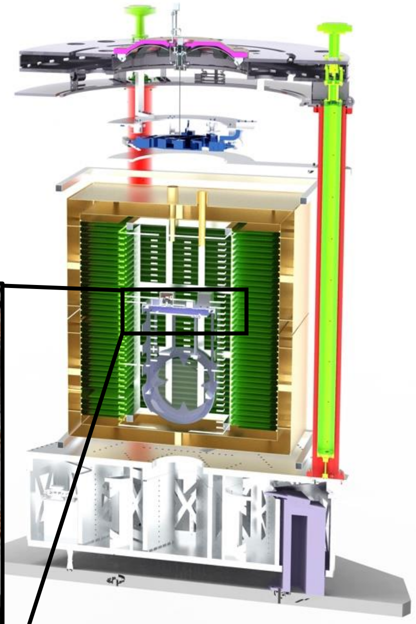
CSIS-V



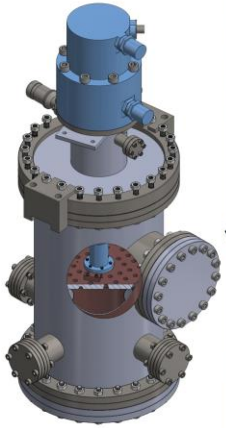


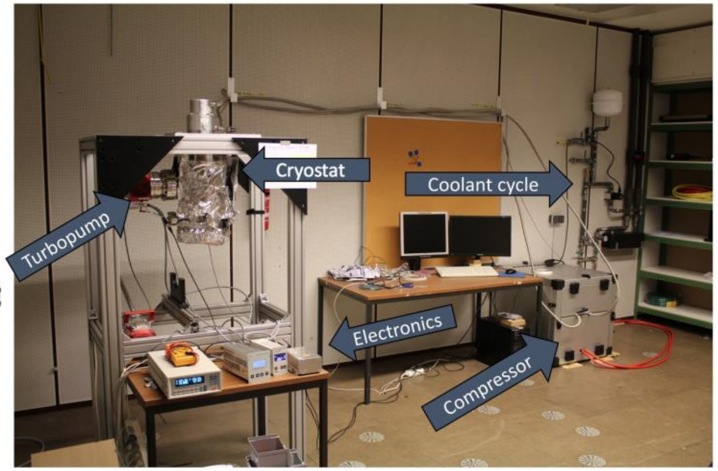
- Approx. 1 Hz leaf-spring resonance frequency.
- Homodyne, fringe-counting, optical readout.





Cryogenic test bench

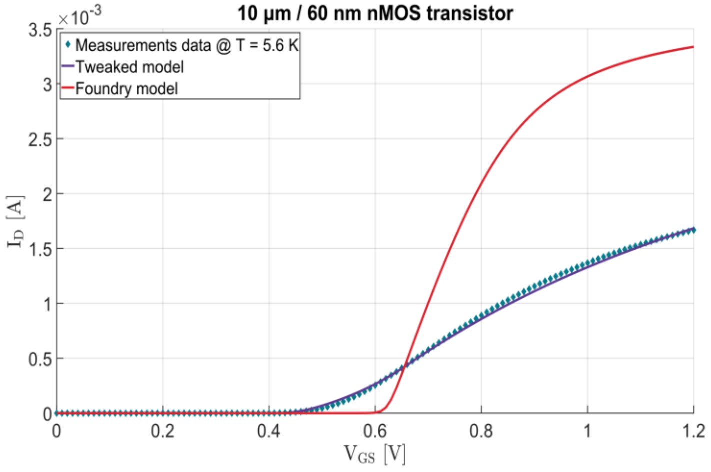




- Closed-cycle cryostat providing up to 1W cooling power at 10K
- Vacuum level: better than 10^{-9} mbar
- Usable volume: cylindrical 15x15cm
- Fast turnaround and low running costs
- Useful for testing materials, components and assemblies

Contacts: Robert Joppe
joppe@physik.rwth-aachen.de
Tim Kuhlbusch
tim.kuhlbusch@rwth-aachen.de

Custom CMOS chips for sensor signal conditioning at low temperature



- Major achievement in cryogenic CMOS structures modeling: faithful representation over the full range of gate-channel geometries
- Custom Au-plated parts for photodiode test setup received

FOUNDRY MODEL	OUR CRYO-MODEL (SO FAR)
Error* up to 65 %	Error* < 5.7 %

*Maximum current error in saturation and linear region of operation

Contact: Alberto Gatti
Alberto.Gatti@esat.kuleuven.be

Outline

ETEST in a nutshell

Mechanics and instrumentation

Cryogenic cooling

Optics and laser development

Continuation of work

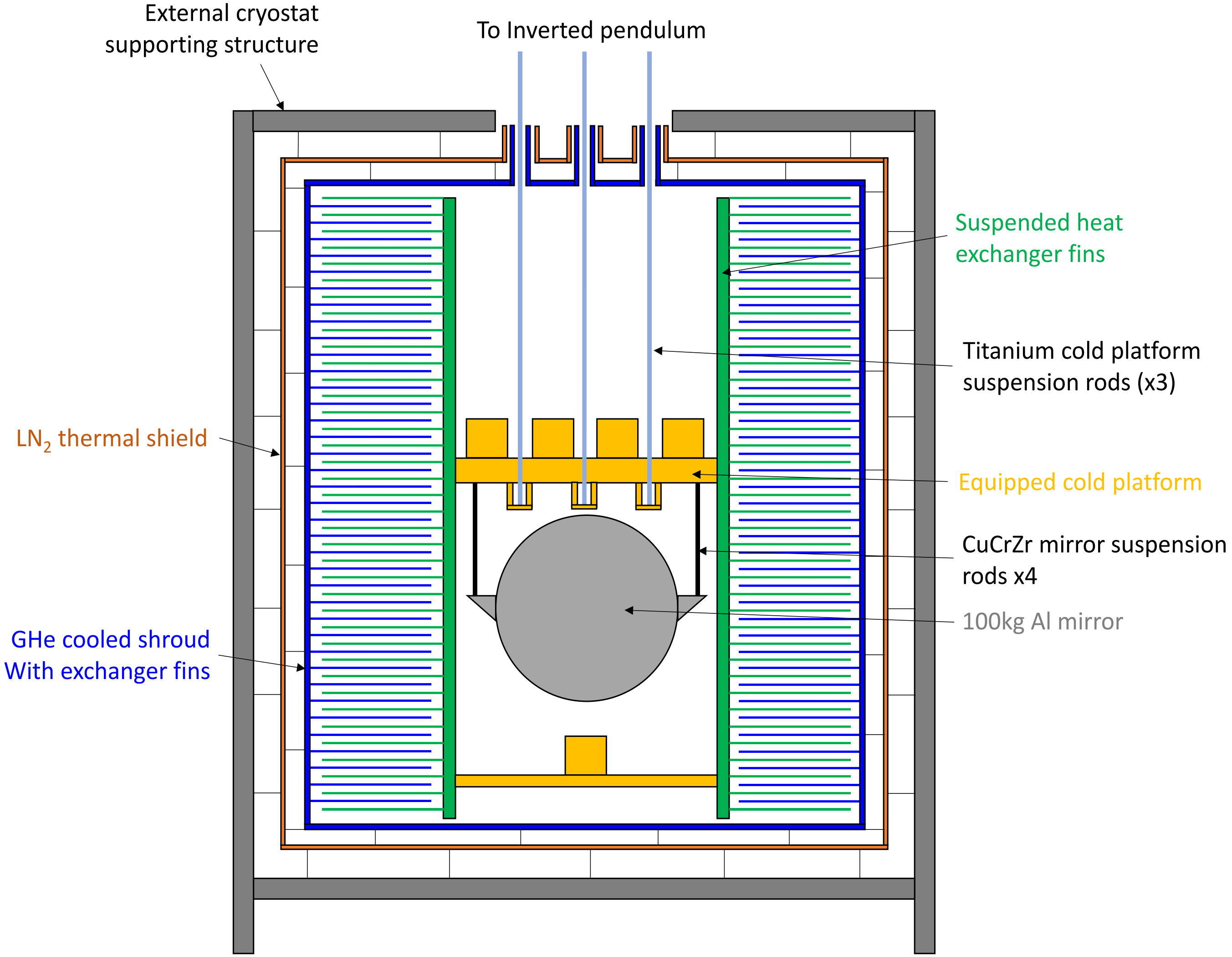
Contactless Radiative cooling strategy

Contact :Cédric Lenaerts (CLS)
cedric.lenaerts@uliege.be

Lionel Jacques (CSL)
ljacques@uliege.be

CENTRE SPATIAL DE LIÈGE

- Compact heat exchanger:
  - $80m^2$ for ~$5m^2$ flat surface (x16)
  - 0.2mm thick black-painted Aluminium fins
  - Lightweight to minimize cooling time
- Sized for
  - 250mW heat load
  - 25K with a sink at 20K

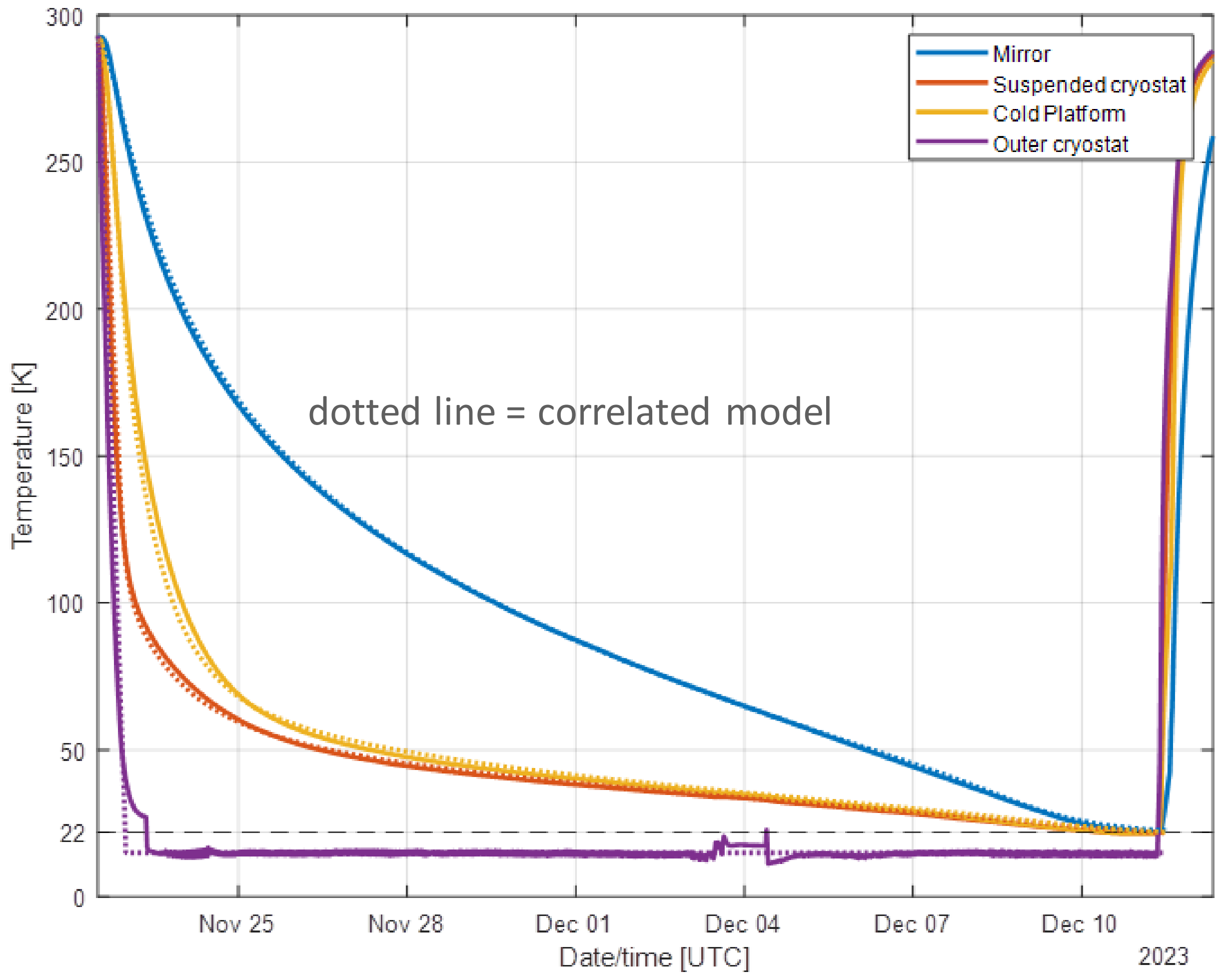


22K achieved in 18days

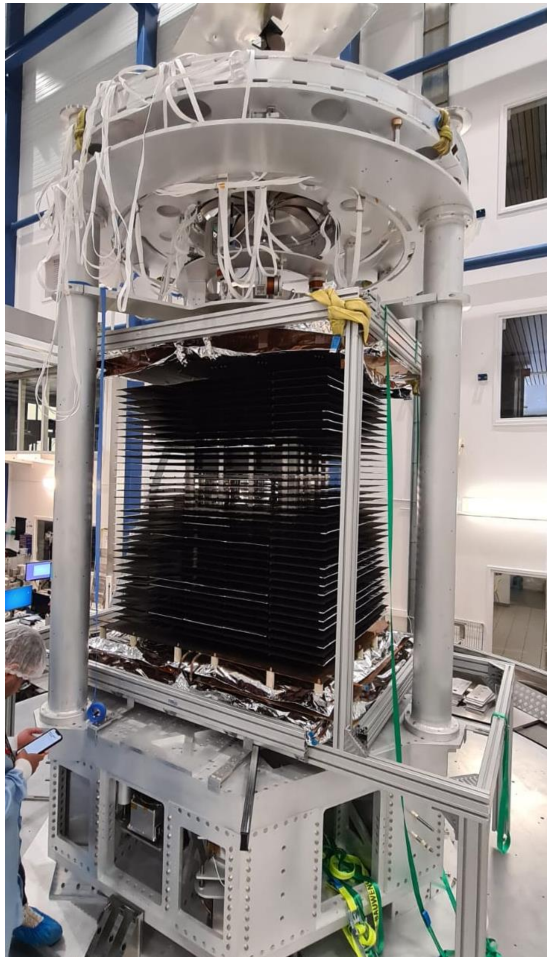
Contact :Cédric Lenaerts (CLS)
cedric.lenaerts@uliege.be

Lionel Jacques (CSL)
ljacques@uliege.be

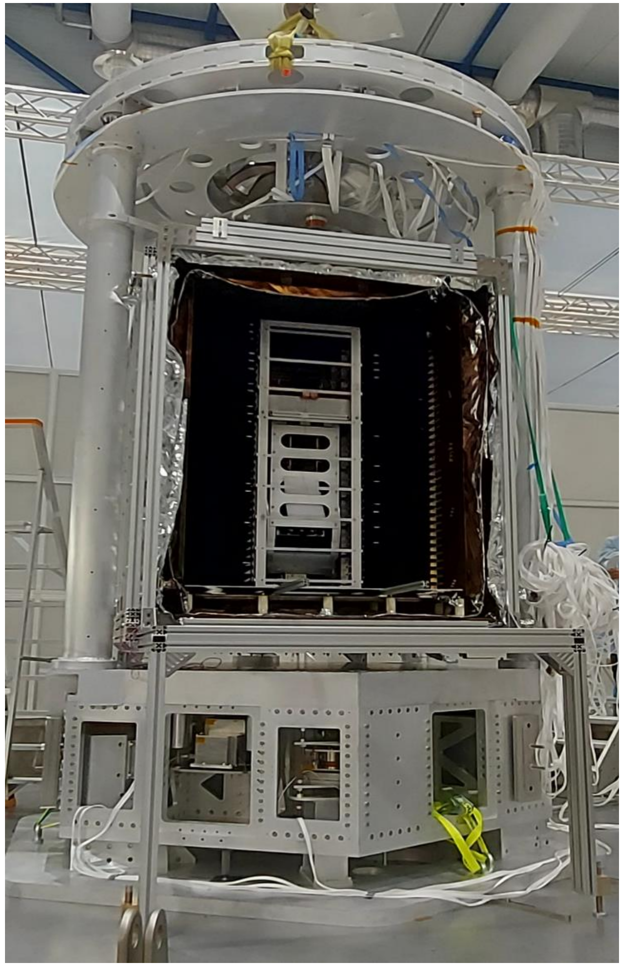
- Sink @16K (recirculating GHe)
- Black-paint emissivity >60% @ 22K



Suspended inner cryostat



After integration of outer cryostat including LN_2 shield and GHe panels



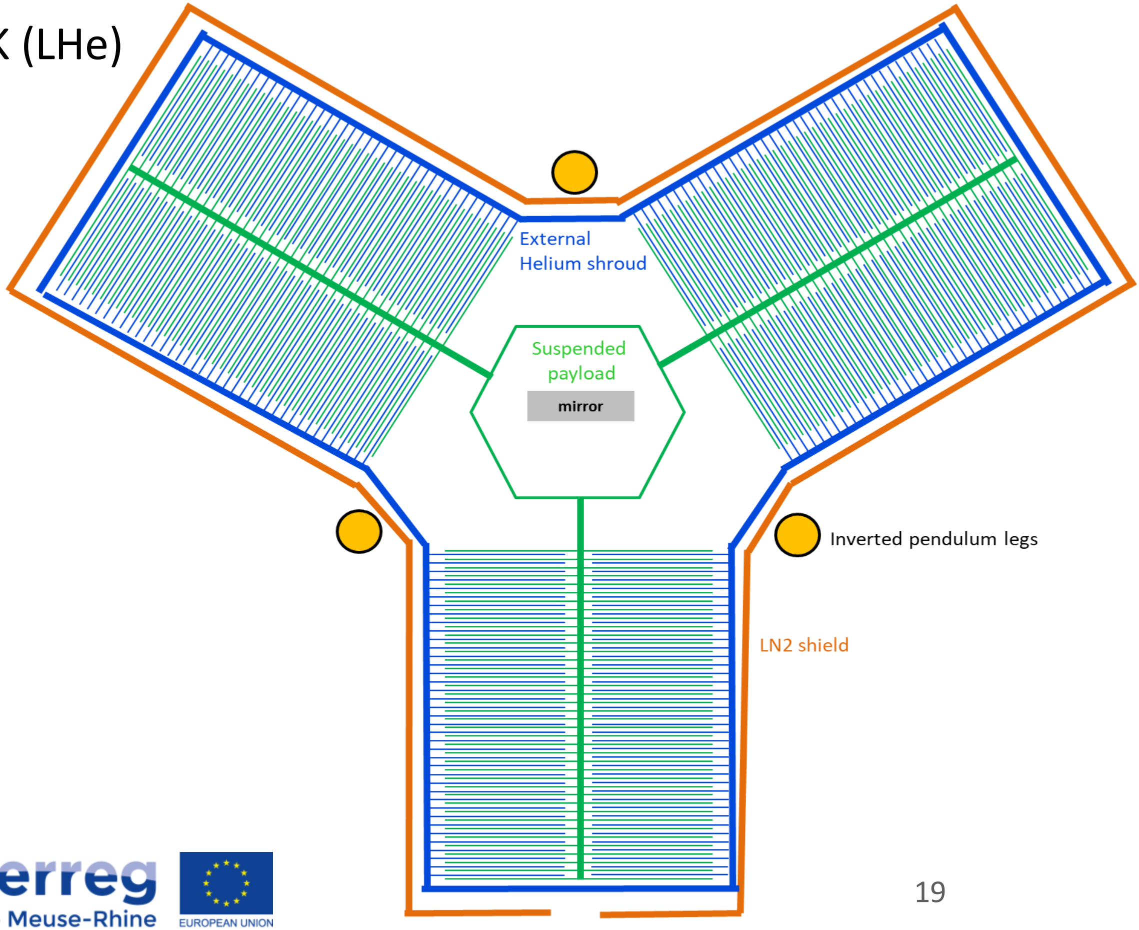
Lessons Learned & Perspectives

Contact :Cédric Lenaerts (CLS)
cedric.lenaerts@uliege.be

Lionel Jacques (CSL)
ljacques@uliege.be

CENTRE SPATIAL DE LIÈGE

- Cold-platform to mirror suspension = bottleneck → easier with Silicon mirror and Sapphire or Silicon suspension
- Heat exchanger modal/dynamic behavior to be investigated
- Several ways to further improve low-T emissivity
- Alternative heat exchanger geometry enabling T<15K with sink at 4K (LHe) and 250mW heat load



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Mechanics and instrumentation

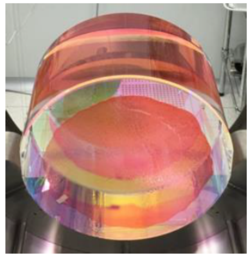
Cryogenic cooling

Optics and laser development

Continuation of work

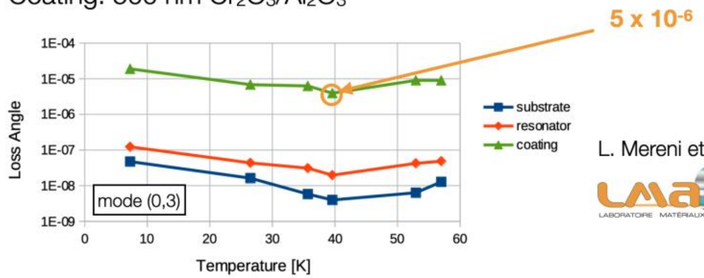
Silicon Mirror Coating

- State of the art:
  Noise of amorphous coatings are the main performance limitation for GW telescopes, especially the thermal noise
- ETEST approach: single-crystal oxide mirror coatings
- Current activities
  - Setup of Cr_2O_3 thin film thickness set
  - More data expected next time



Mechanical losses

- Coating: 500 nm Cr_2O_3/Al_2O_3



L. Mereni et al.

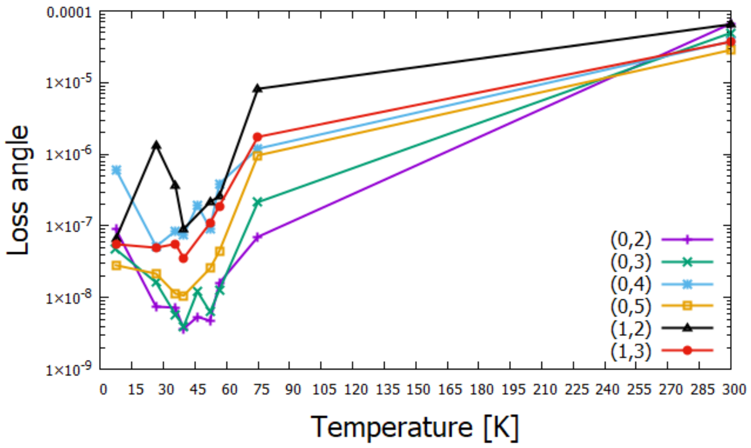
- Dilution factor= 0.0034

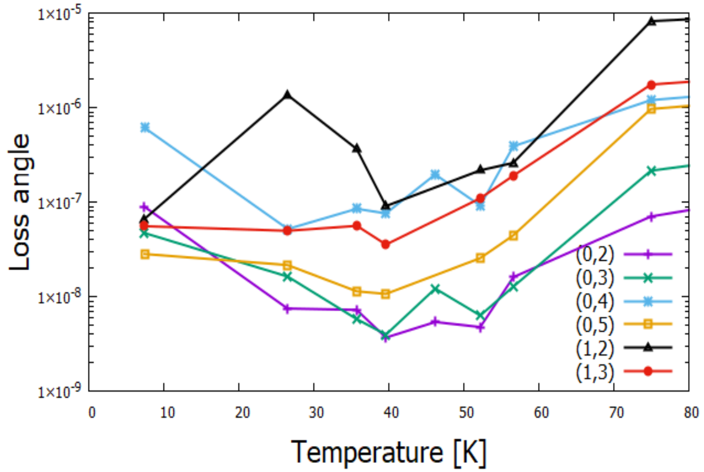
Assumptions:

$d_{coating}$ = 500 nm
$d_{substrate}$ = 0.3 mm
$Y_{coating}$ = 260 GPa
$Y_{substrate}$ = 385 GPa

First tests:

- Cryogenic measurements of crystalline substrates
  - Analysis of mechanical loss with respect to the temperature
    - Different lines correspond to different wave modes
- Preliminary result: Minimum of the loss angle at 40 K
  - Origin yet unknown, further analysis will follow
- Next step
  - Deposit Cr2O3 thin film on the characterized substrates and measure new combination

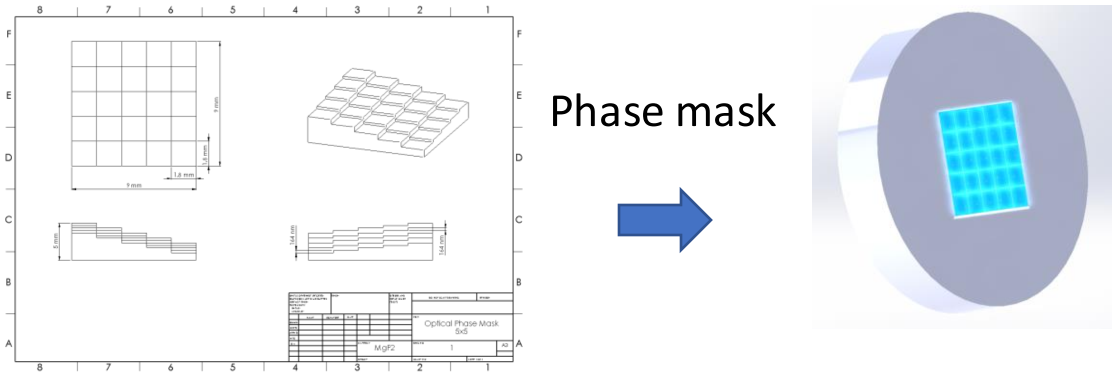


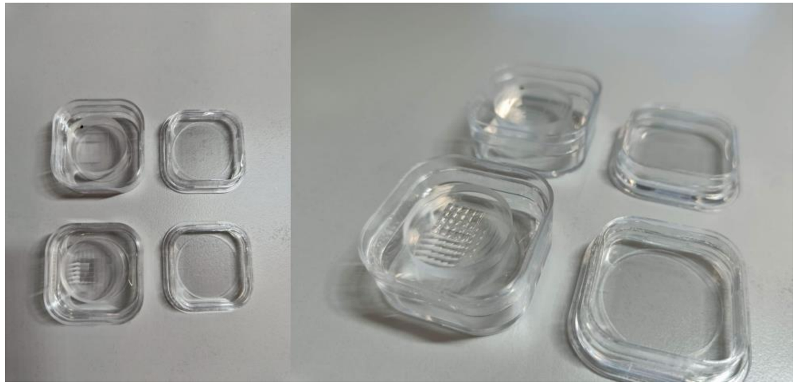


Contact: Jean-Pierre Locquet
jeanpierre.locquet@kuleuven.be

Silicon Mirror Manufacturing & Test

- Experiment purpose
  - Characterization of the cryogenic mirrors for GW detectors on operation
- Added value
  - Measurement of local values of vibration and topology change instead of a single absolute value of the full mirror
- Current tasks
  - Optical design development
  - Custom optical phase mask arrived and experiments on proof of concept are being performed

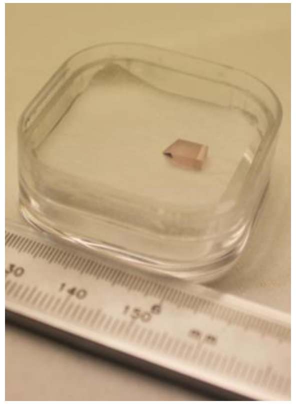


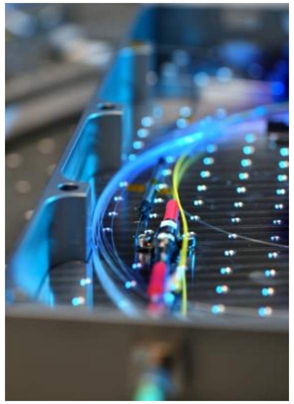


Contact: Jesus Vilaboa Perez (CSL)
jvilaboaperez@uliege.be

Laser Development

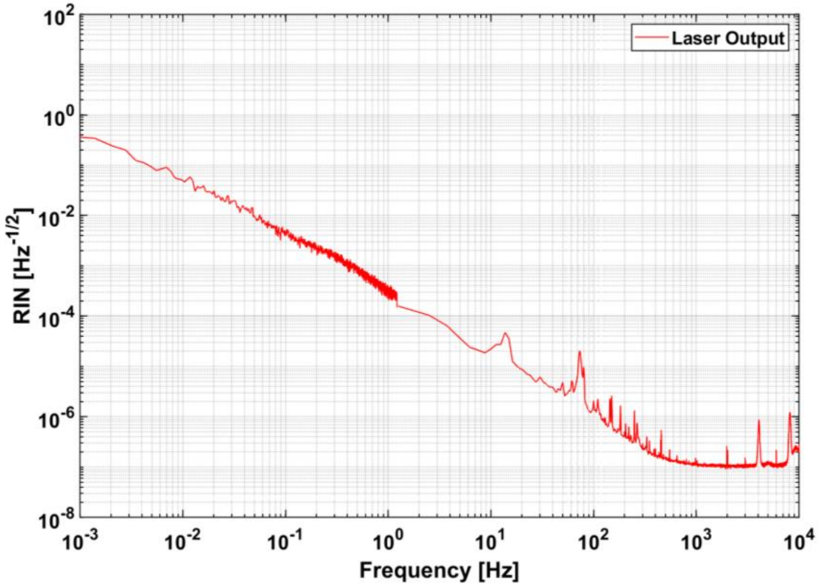
- Requirements:
  - High stability, Narrow linewidth
  - Wavelength: 2090 nm, Power: 5-10 W
- Approach:
  - Solid state laser seed source (Ring-Oscillator / Non-Planar Ring-Oscillator)
  - Two-stage holmium-doped fiber amplifier
  - Internal stabilization mechanisms
- Current activities
  - Setup of final stages and power stabilization





Contact: Patrick Baer (ILT)
patrick.baer@ilt.fraunhofer.de

- Status: Most fiber laser requirements successfully demonstrated
  - Output power, spectrum, polarization, …
  - Current analysis: Relative Intensity Noise (RIN)
- Holmium-amplifier (Ho1) preliminary results without stabilization
  - Low frequencies: High RIN expected
    → No thermal stabilization
  - Mid frequencies: Good results without stabilization
    → **RIN @ 100 Hz is app. 10^{-6} 1/√Hz**
    → **Already very close to the project goals**
- Next steps: Active power stabilization and further improvement of setup



Outline

ETEST in a nutshell

Mechanics and instrumentation

Cryogenic cooling

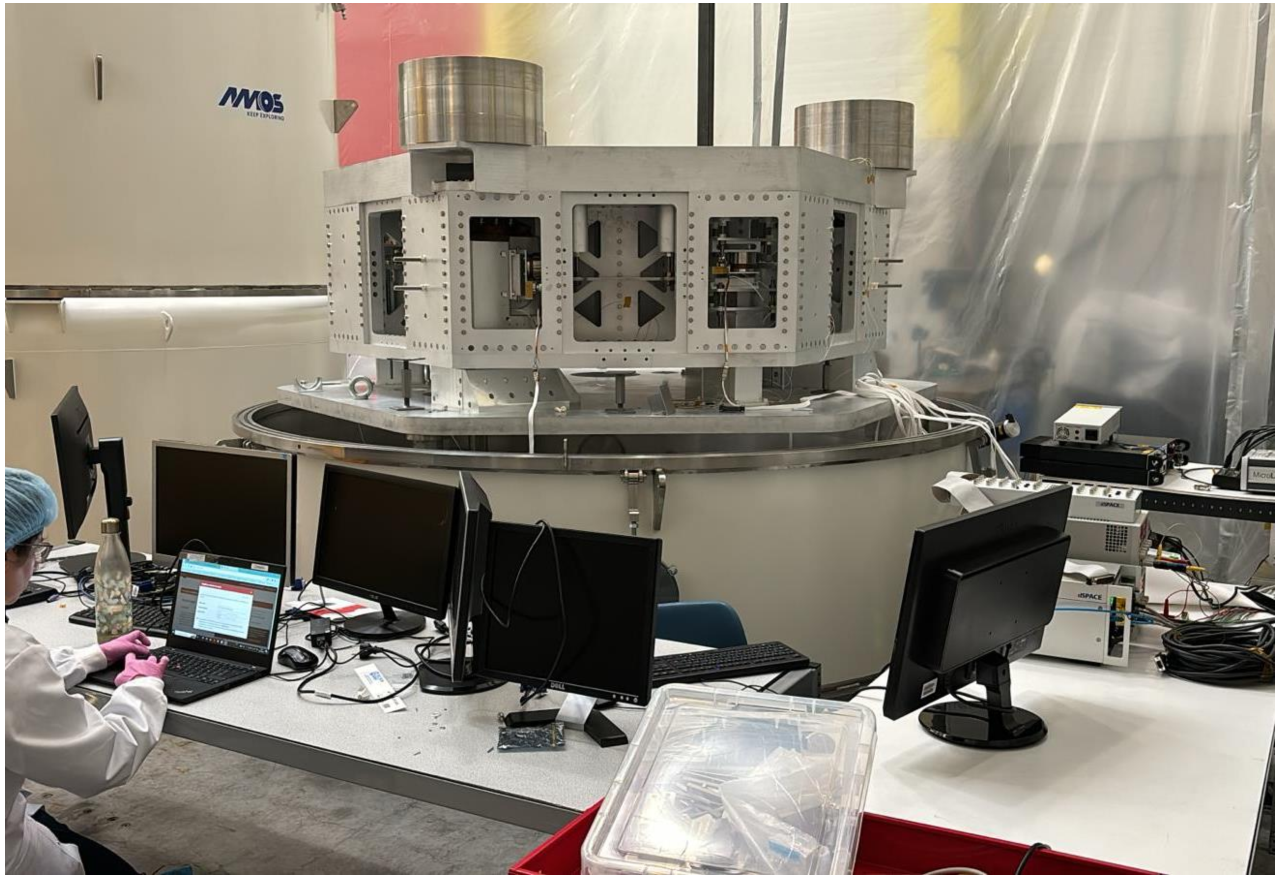
Optics and laser development

Continuation of work

Preparing the next run at Amos

- Revise the prototype based on the experience at CSL.
  - ➢ Sensor robustness.
  - ➢ Mechanical friction.

- Prepare for the optical test with the Si mass coming this year.
  - ➢ Residual stress measurement.
  - ➢ Temperature measurement.
  - ➢ Quality factor measurement.



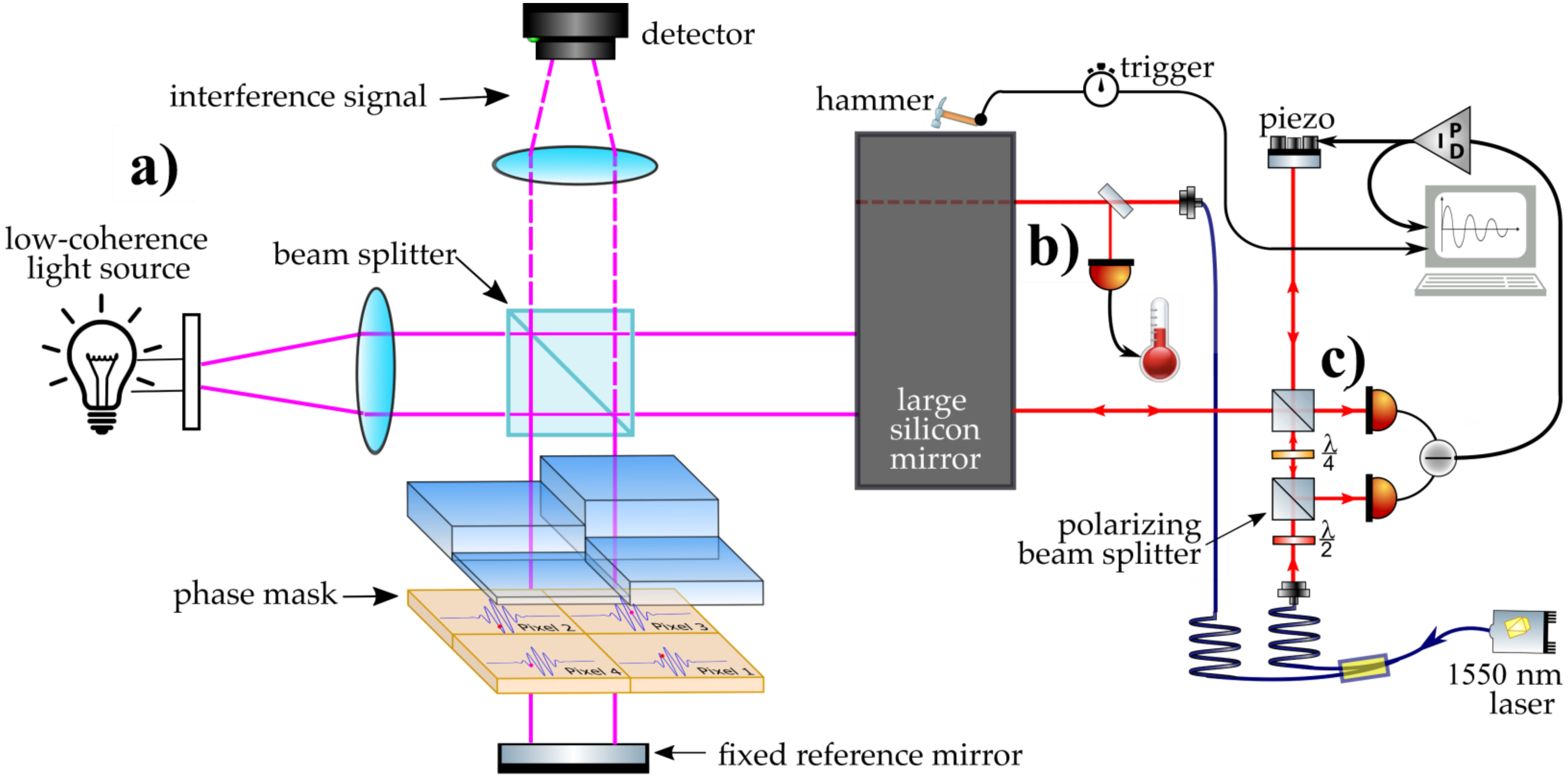
Final validation of the prototype

a) White light interferometry (residual stress)
b) Temperature measurement
c) Quality factor

Tests at CSL timeline:

2023: with dummy Al mirror

End 2024: with 100kg Si mirror



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Contacts:

Prof. Christophe Collette
Christophe.Collette@uliege.be
Anthony Amorosi
anthony.amorosi@doct.uliege.be

Useful links:

TDR
https://arxiv.org/abs/2212.10083
E-TEST Project website
https://www.etest-emr.eu/
PML website
http://www.pmlab.be/