



Research at Precision Mechatronic Lab

An overview

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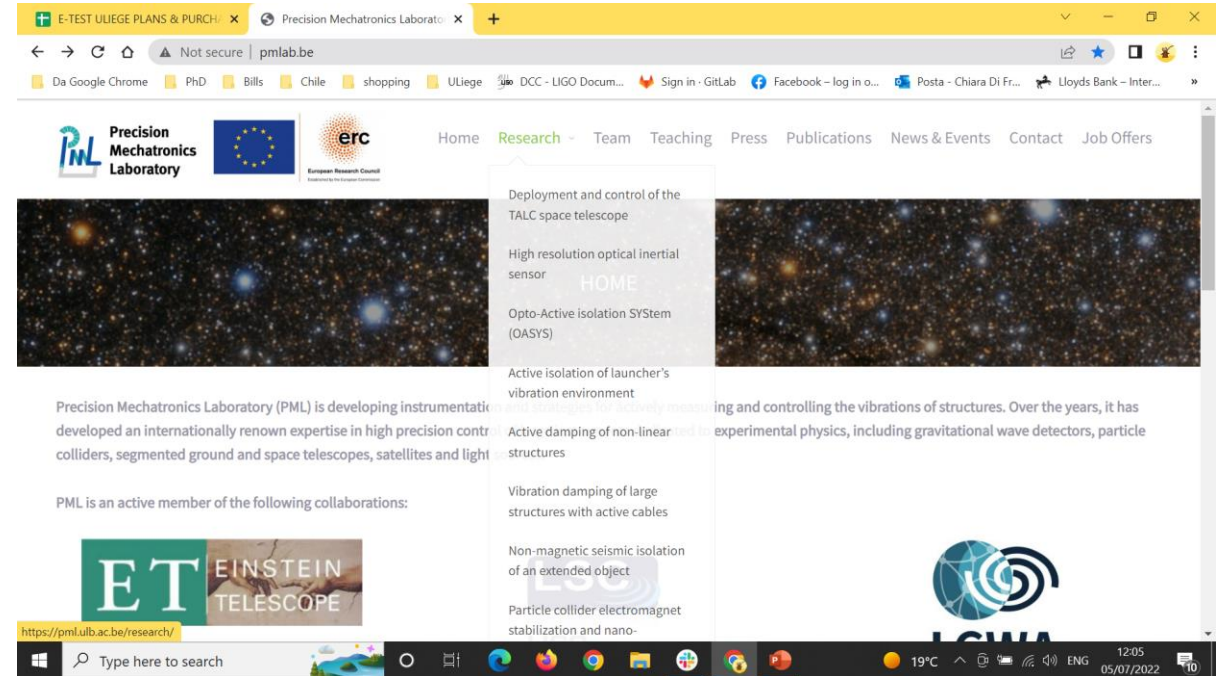
A lab dedicated to seismic science

- There are several topics we cover, split between Université de Liège, Université Libre de Bruxelles and UCLouvain
- Main research is devoted to seismic isolation (for GW science but not only)
- We are a big group including 8 PhD students, 2 postdocs, 1 Msc student and several internships students from abroad, under the supervision of prof. Christophe Collette



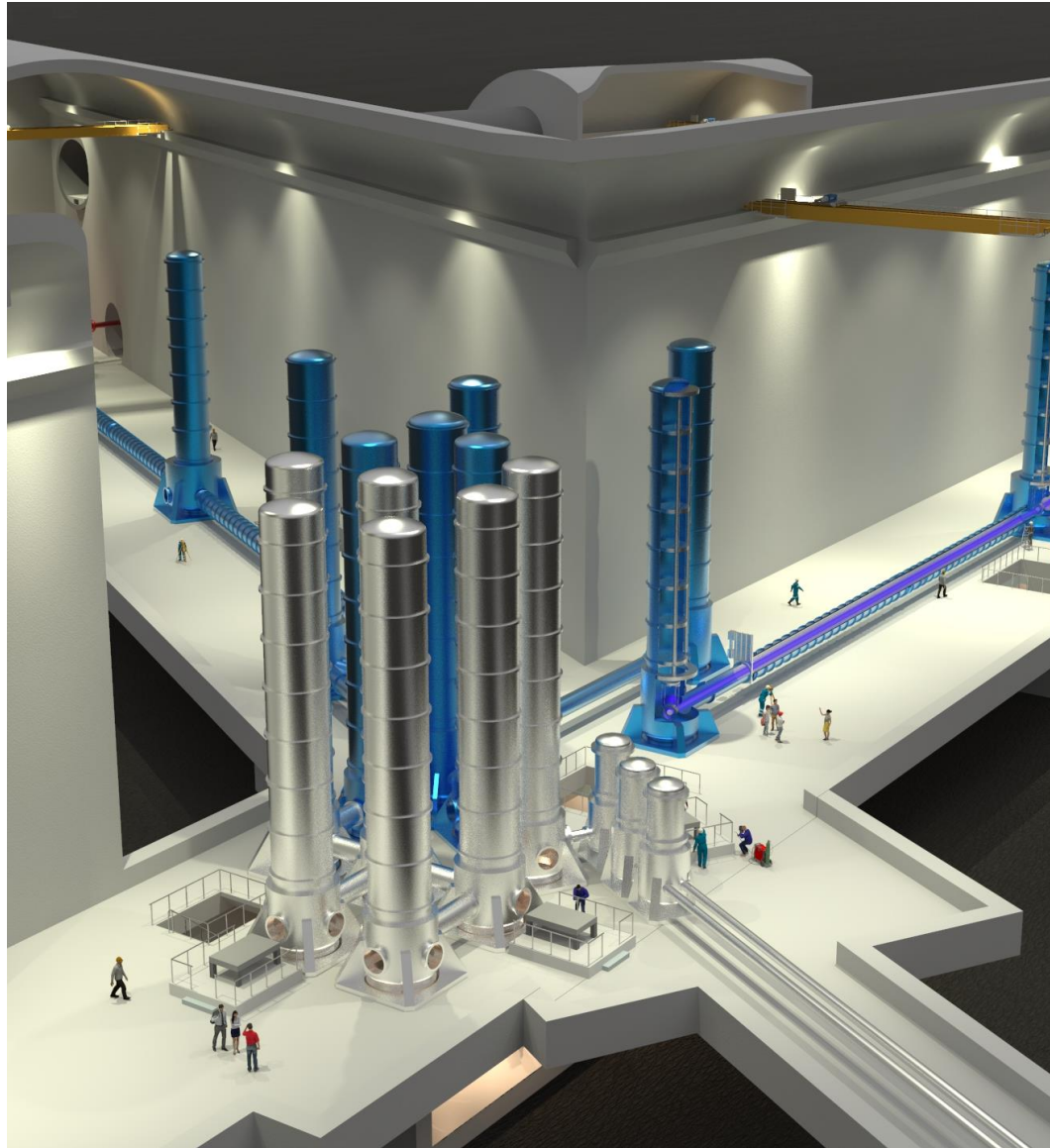
Vibration control for Geo- and Astro- observations

- Developing of new inertial sensors, sensitive at low frequencies
- Improving the sense and control of the gravity acceleration, in order to potentially reduce Newtonian noise
- Research on active control of vibration systems
- Testing the feasibility of the Einstein Telescope mirror isolation: E-TEST project at ULiege



My research, publications and duties

- **PhD** at University of Birmingham (UK) on seismic isolation technologies (<https://etheses.bham.ac.uk//id/eprint/12495/>)
- **Postdoc** at Université de Liège (Belgium), where I'm responsible for the management of the E-TEST ERC project
- In collaboration with Nikhef and UoB, I'm publishing my work on laser stabilization for the 6D isolator
- Mentoring PhD students at ULiège
- Following-up my work on LIGO Hanford site on seismic isolating the ISIs via CPS connections
- Please see DCC for my work with LIGO, and ArXiv for the E-TEST technical design report <https://arxiv.org/abs/2212.10083>
- CQG E-TEST recently published (*Ameer Sider et al 2023 Class. Quantum Grav.*)



E-TEST objectives

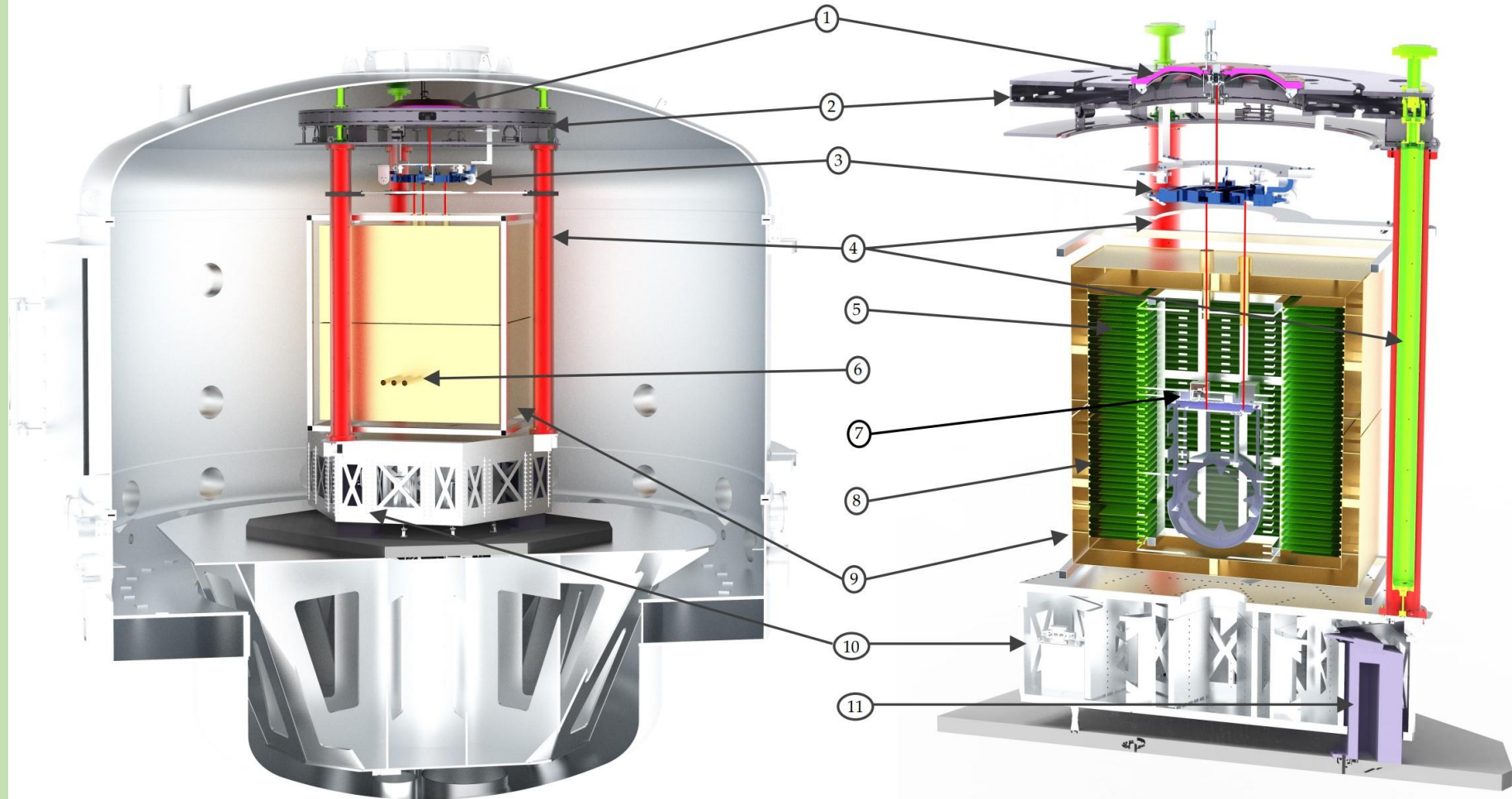
- Large mirror (100 Kg)
- Cryogenic temperature (10-20 K)
- Isolated at low frequency (0.1-10 Hz)
- Compact suspension (4.5 meters)

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.

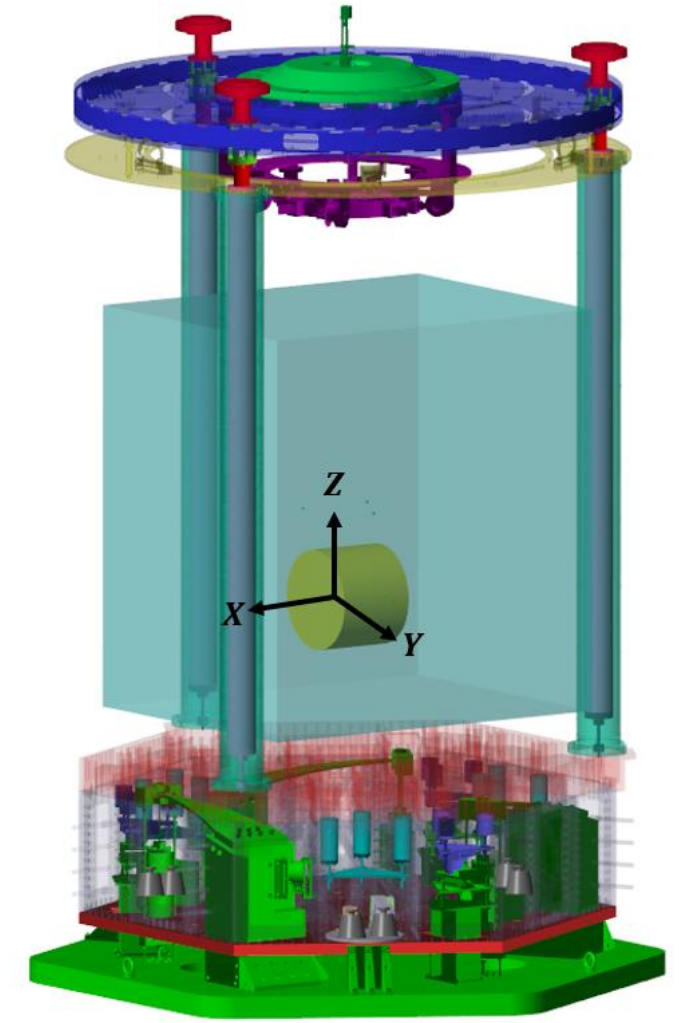


- 1) GAS filter.
- 2) Top stage.
- 3) Marionette.
- 4) Inverted pendulum legs within pipes that support a reference ring below the top stage.
- 5) Inner cryostat which has the interlacing fin type heat exchanger.
- 6) Three access points for outside experiments to interact with the cryogenic mirror.
- 7) The inner cryostat is attached to the cold platform.
- 8) Outer cryostat which provides a cold environment and houses the 100 kg silicon mirror.
- 9) Active platform.
- 10) Three large blades
- 11) Support pillar on the ground.

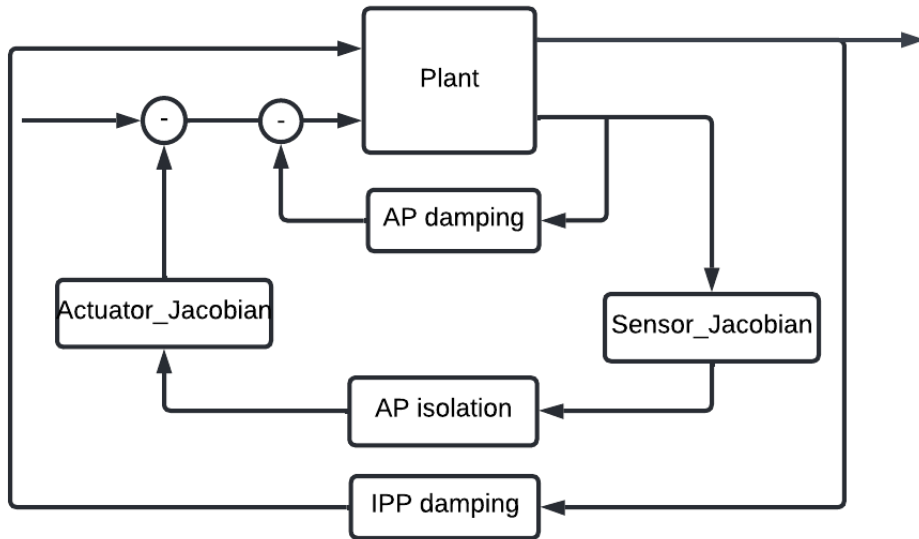


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E-TEST Simscape model

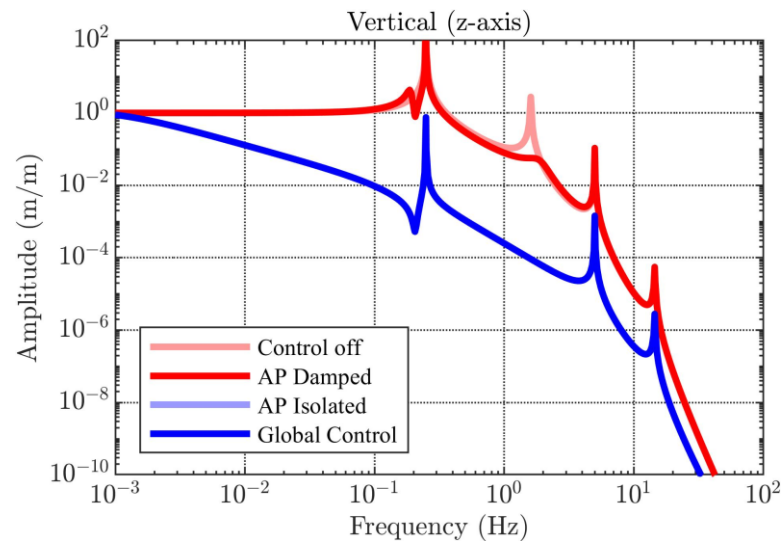
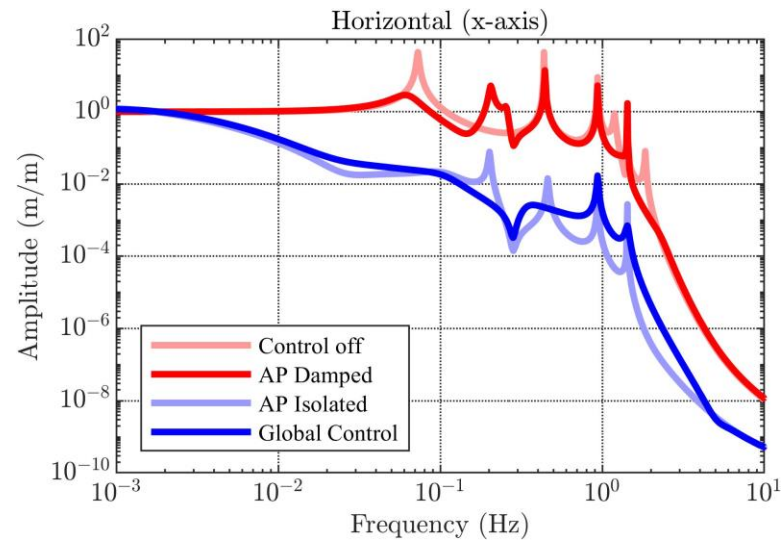


Schematic Control of E-TEST

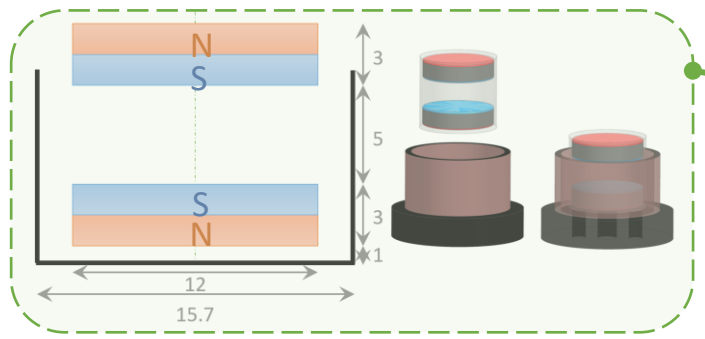


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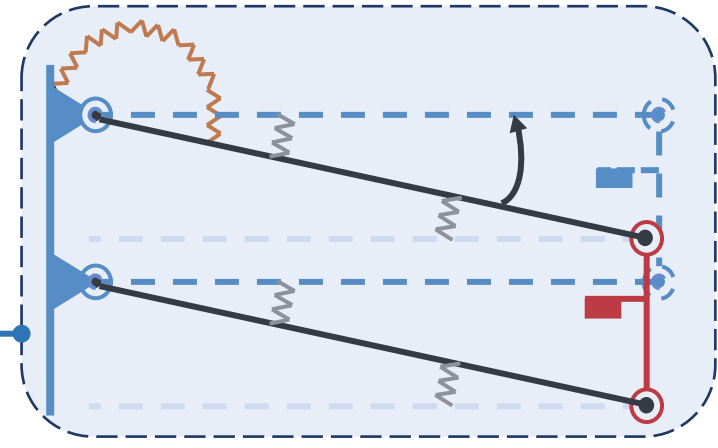
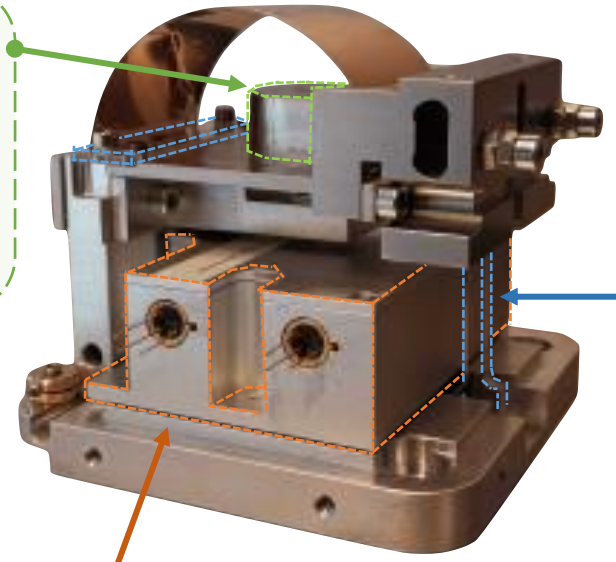
Transmissibility (Mirror/ground)



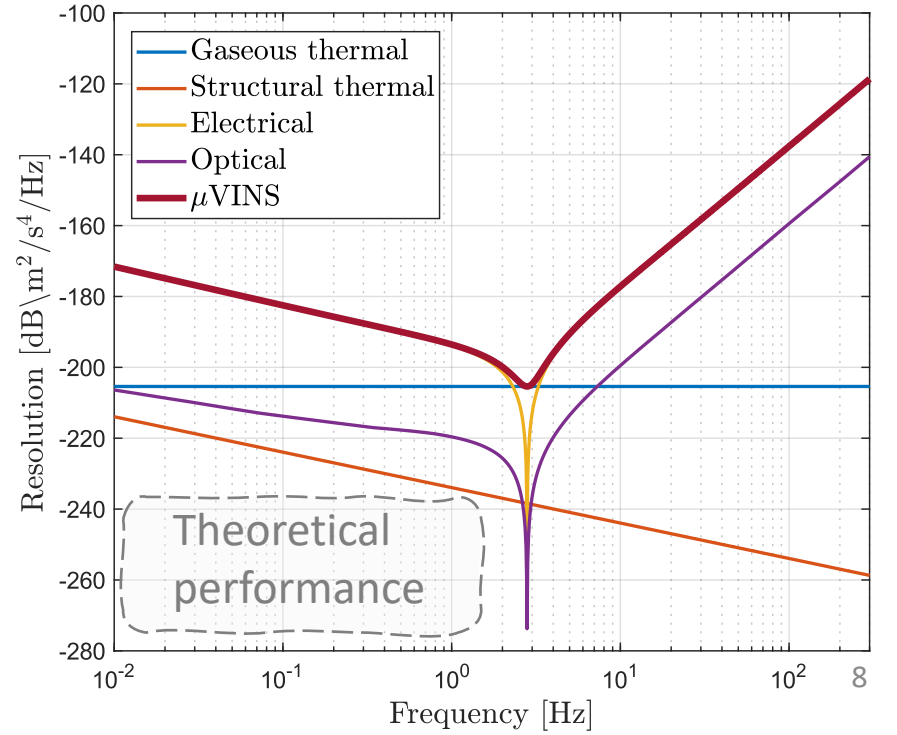
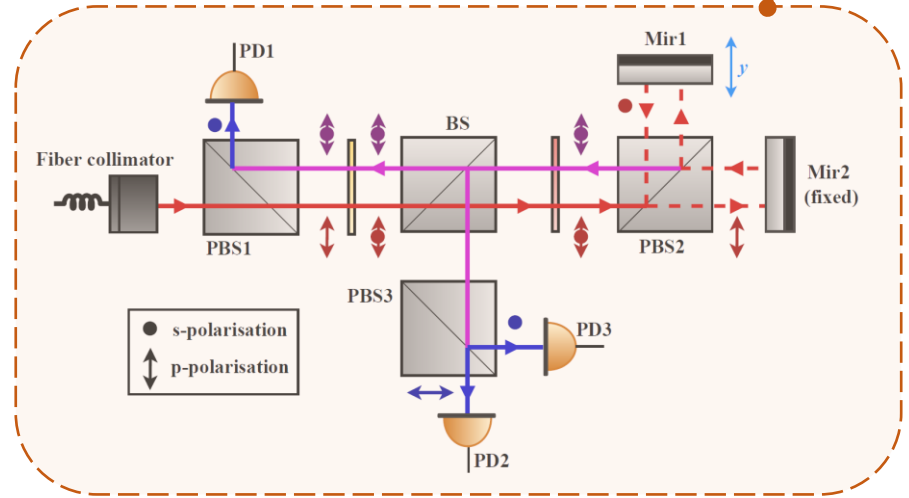
High resolution long-period accelerometer



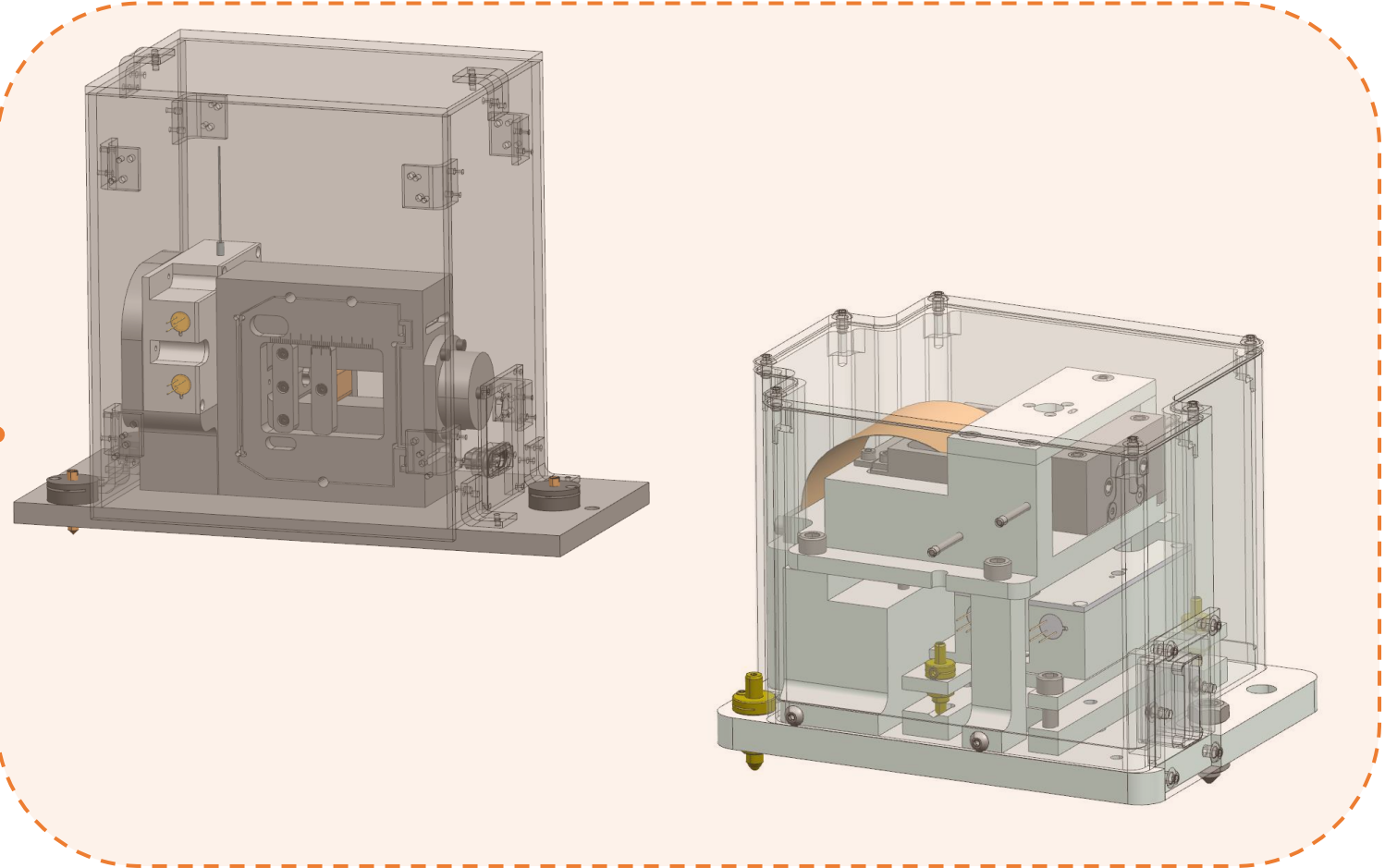
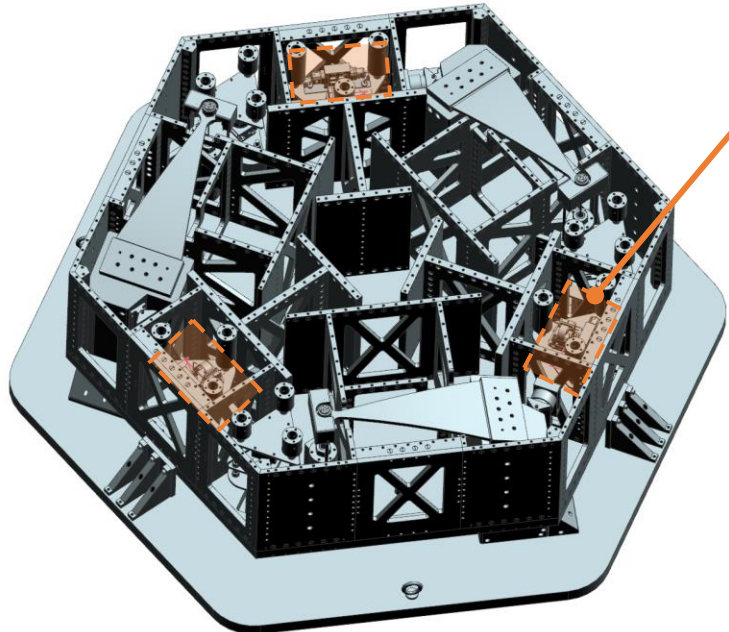
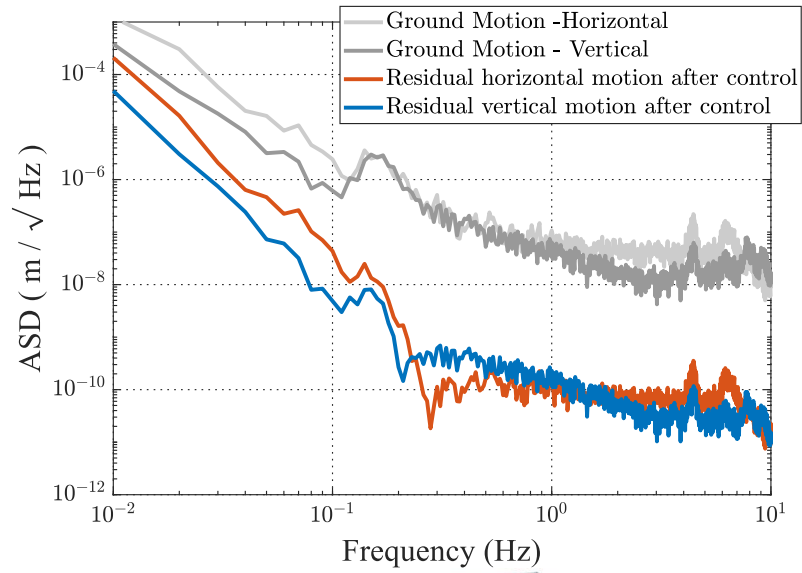
- Feedback actuator:**
- Moving magnet VCA.
 - Self-shielded quadrupole magnet.



- Mechanics**
- Long period: $f_0 = 2$ Hz
 - Low loss fused-silica flexures.
 - Linear mechanical guide for the optical readout.



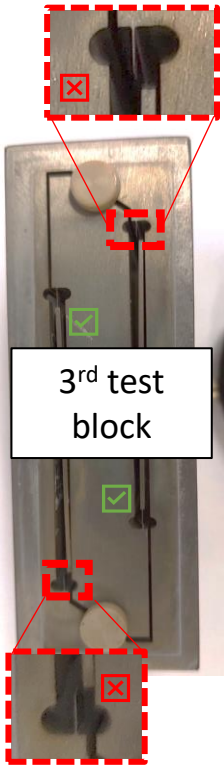
Inertial sensor development for the E-TEST project



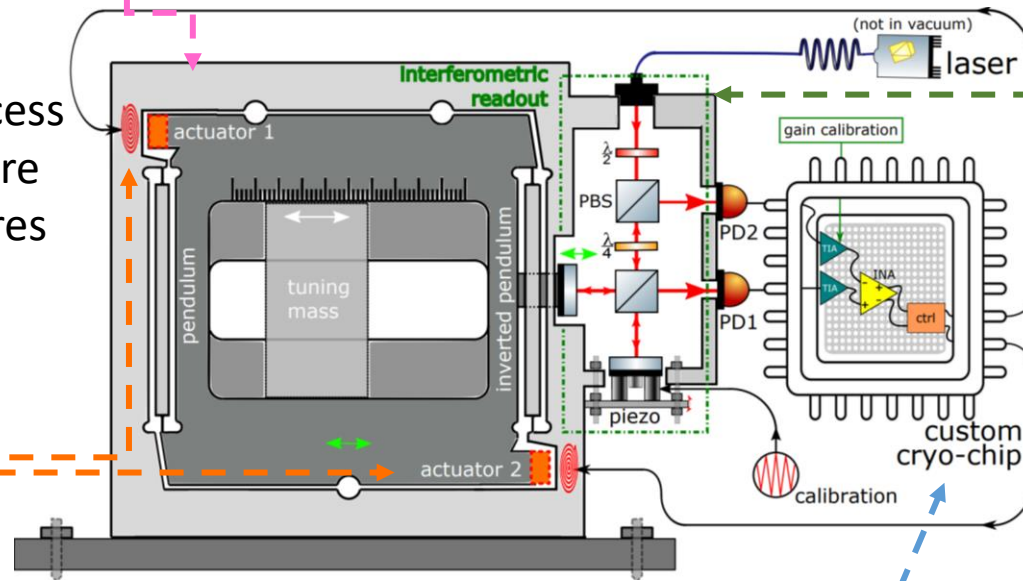
Development of cryogenic interferometric (superconductive) inertial sensors - CSIS

Niobium proof-mass in a Watt's linkage configuration

Trying to find the right process to manufacture Nb thin flexures



3rd test block

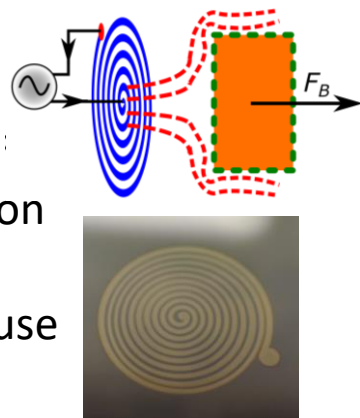


Interferometric read-out

Homodyne interferometry using the differential signal as a feedback signal to lock the mass.

Superconductive actuator

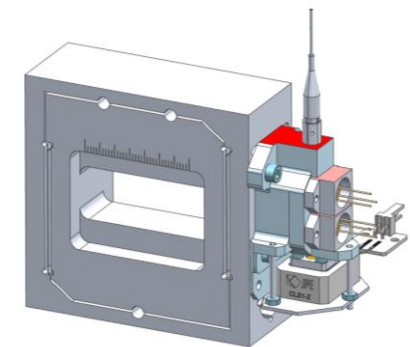
Actuation force applied on the proof-mass by magnetic pressure because of the **Meissner effect**.



Custom cryo-chip

Custom 65nm-CMOS cryo-chip developed at KULeuven to post-process the differential signal and control the actuators

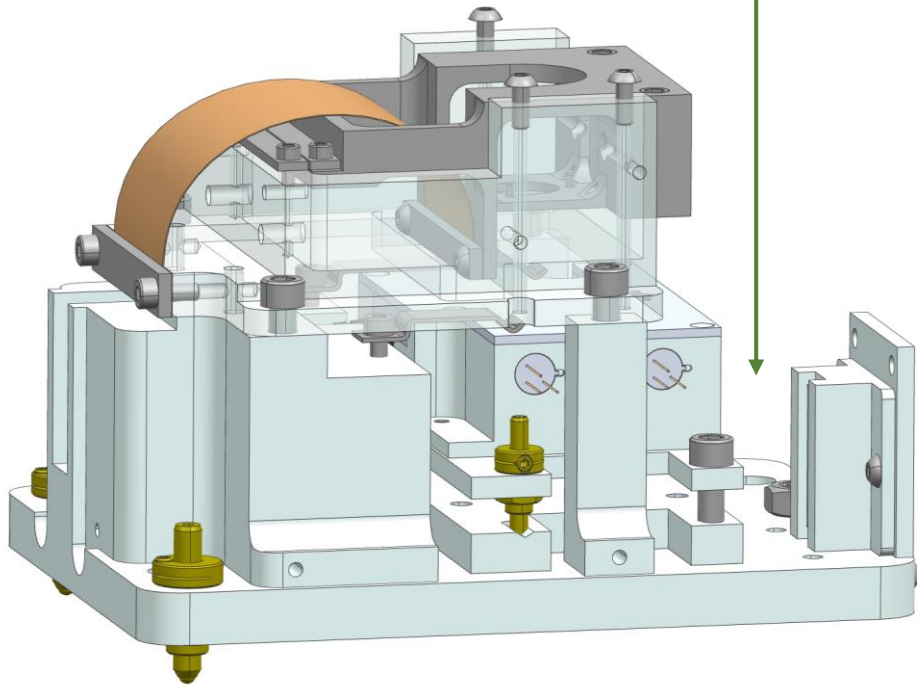
Horizontal



Development of cryogenic interferometric (superconductive) inertial sensors - CSIS

E-VINS design adapted for cryogenic working conditions

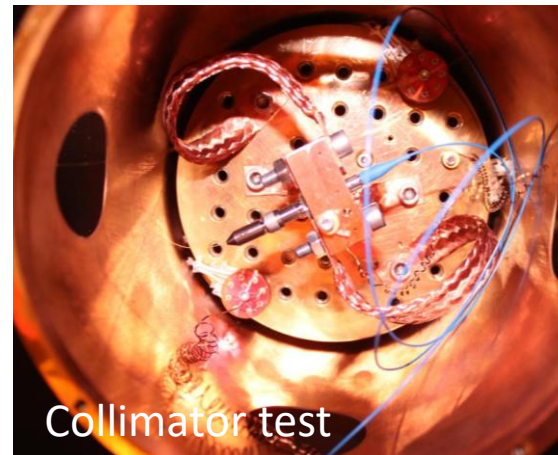
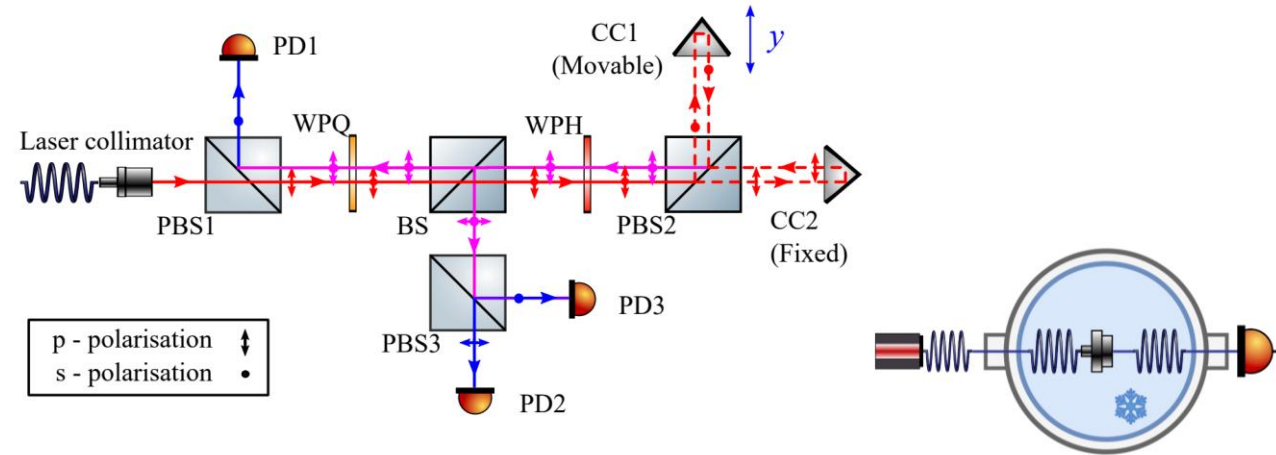
Stainless steel proof-mass suspended with a BeCu2 leaf spring. The sensor works in open-loop.



Vertical

Interferometric read-out

Homodyne quadrature interferometry

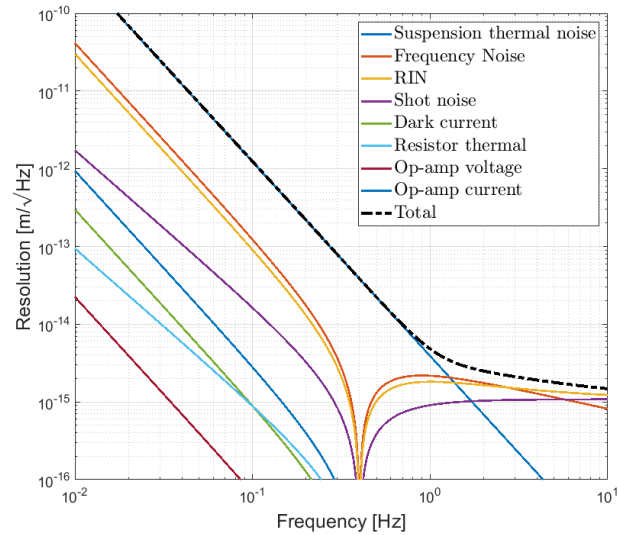


A test campaign is currently happening in collaboration with RWTH Aachen to select the optical elements that works the best in cryogenic conditions (collimators, photodiodes, polarization, alignment, etc). The results will be used for both CSIS-V and H.

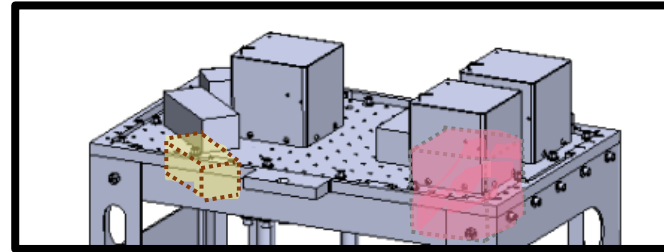
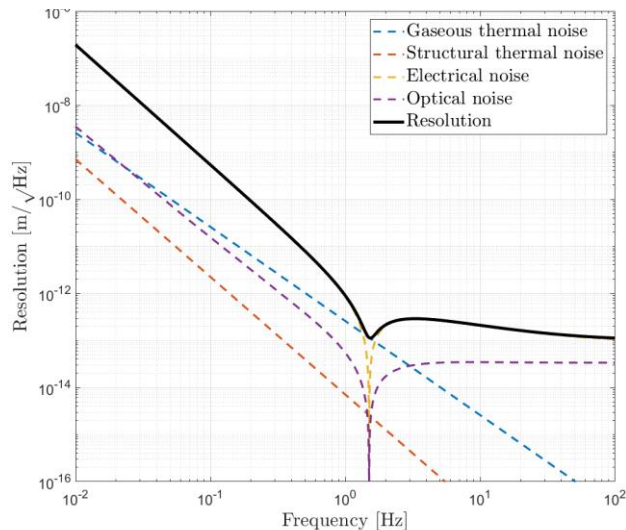
Final use and test bench

- Monitor residual motion with fm/ $\sqrt{\text{Hz}}$ sensitivity down to 1 Hz
- Exploit E-TEST cold platform low-vibration cryogenic environment to perform a self-noise measurement

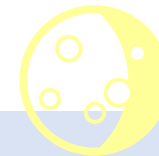
Horizontal



Vertical



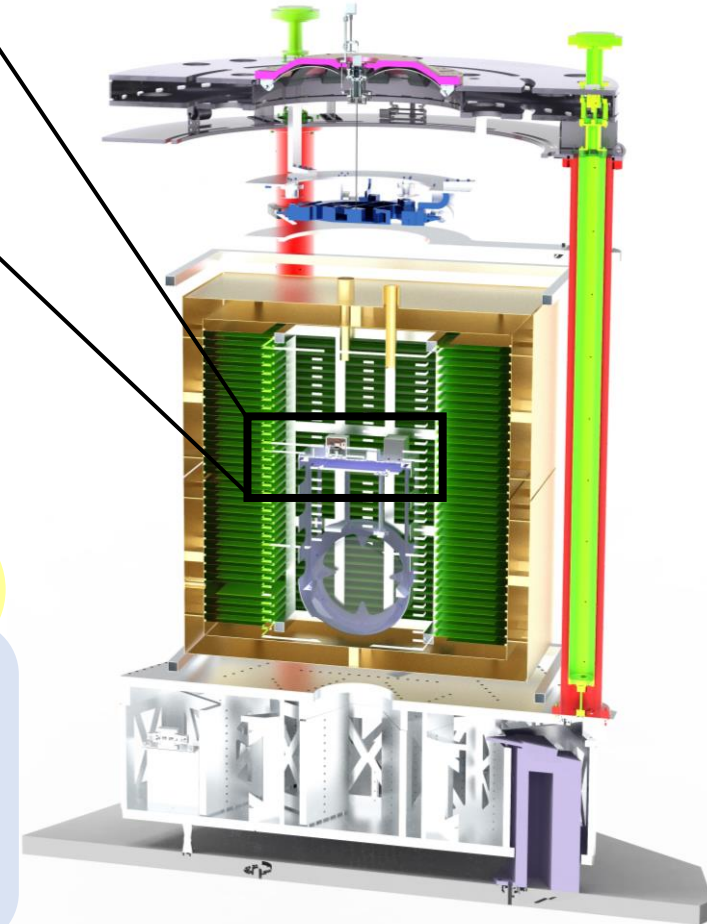
After the CSIS validation with E-TEST, an adaptation of this sensor will be embedded in the **LGWA (Lunar Gravitational Wave Antenna)**



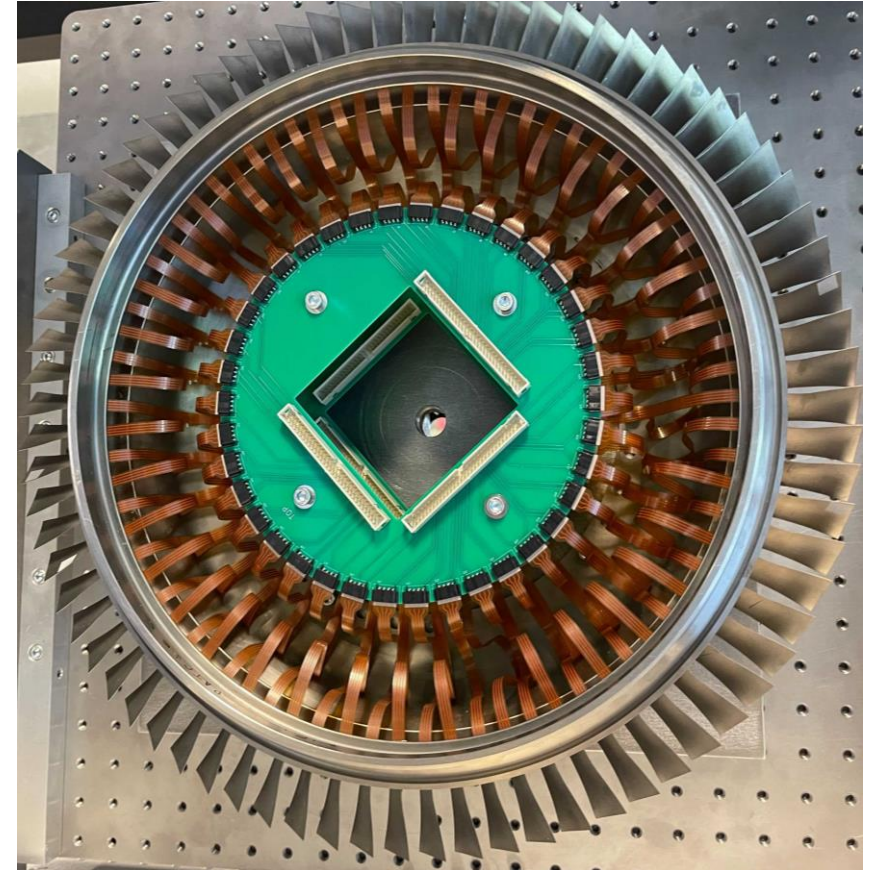
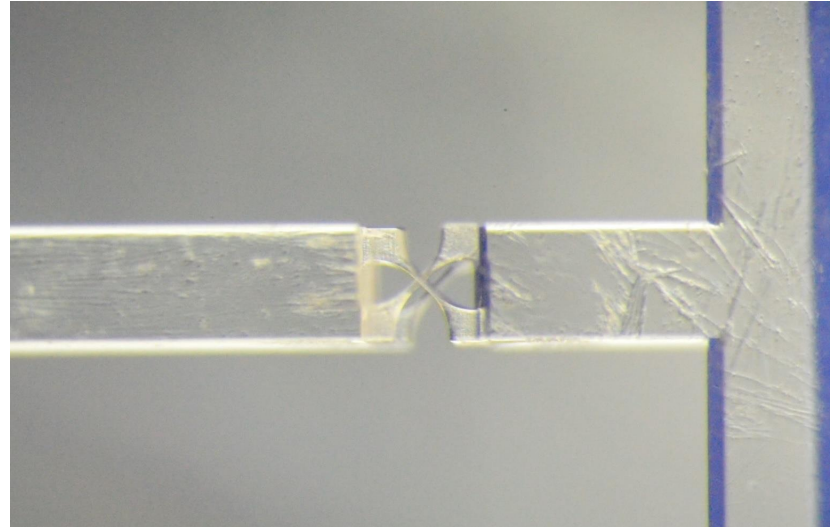
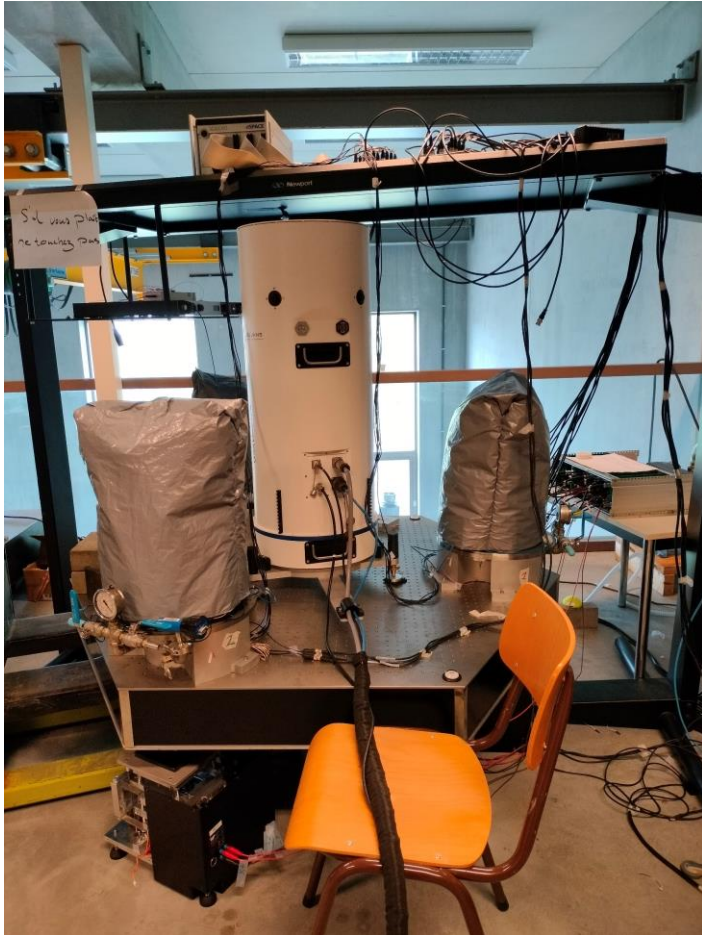
GOAL:

Measure the GW passing by the Moon

- New GW spectrum
- Selene physics



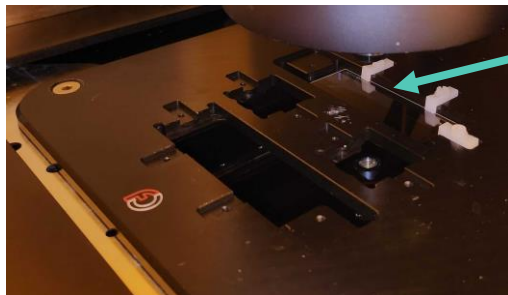
Other than E-TEST



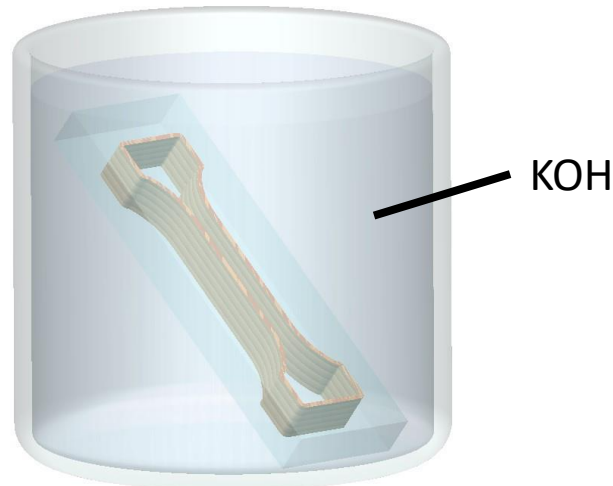
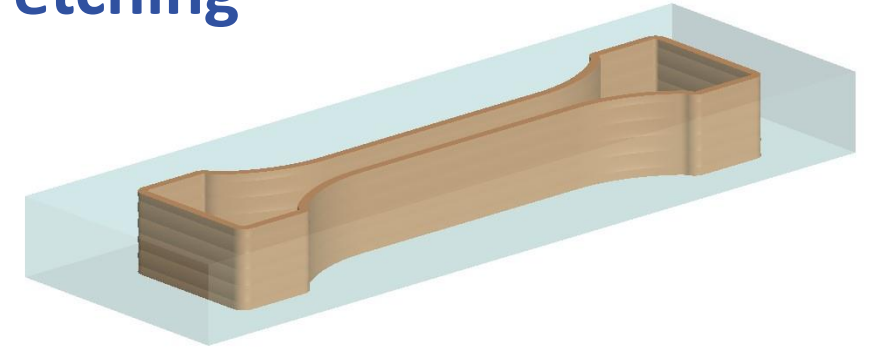
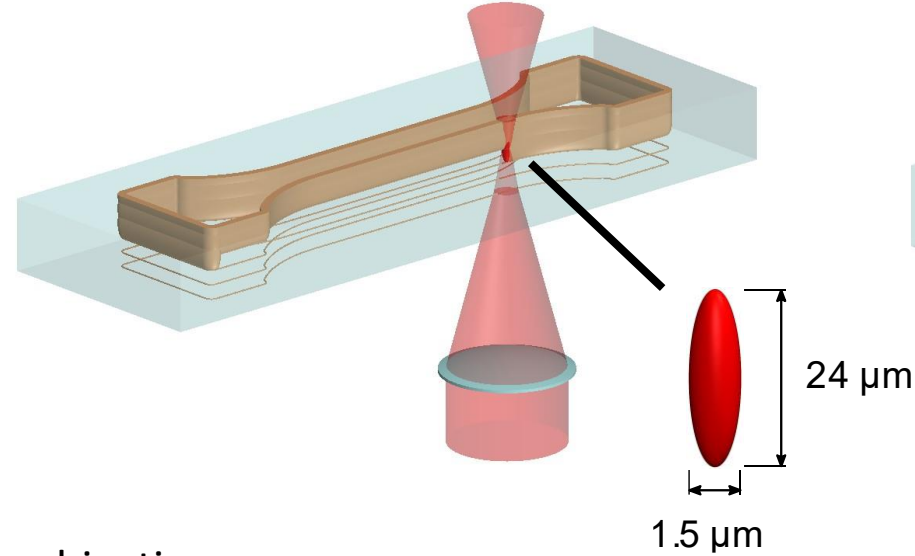
Glass structure manufacturing: laser assisted etching



Laser objective



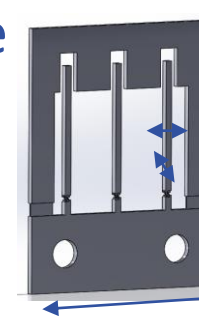
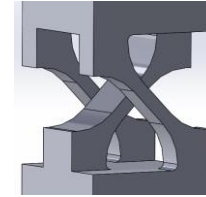
Substrate



- The laser path is defined to expose the shape of the desired part in a glass substrate
- Then, the substrate is placed in a KOH bath. Laser-exposed glass is etched 100x faster than non-exposed glass

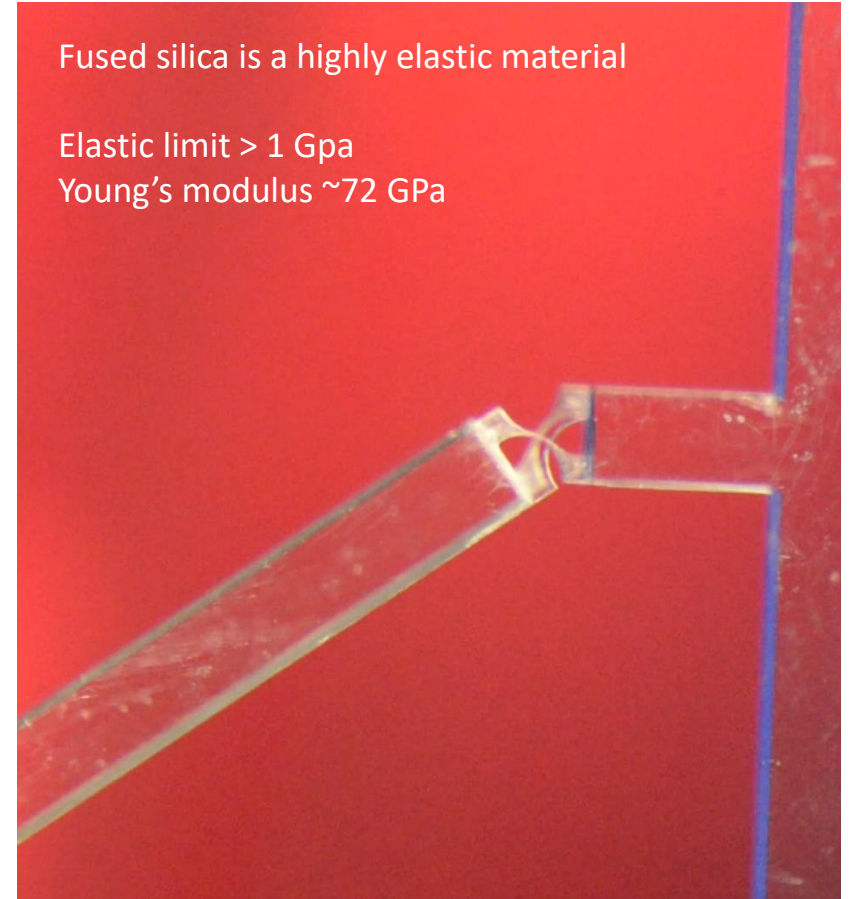
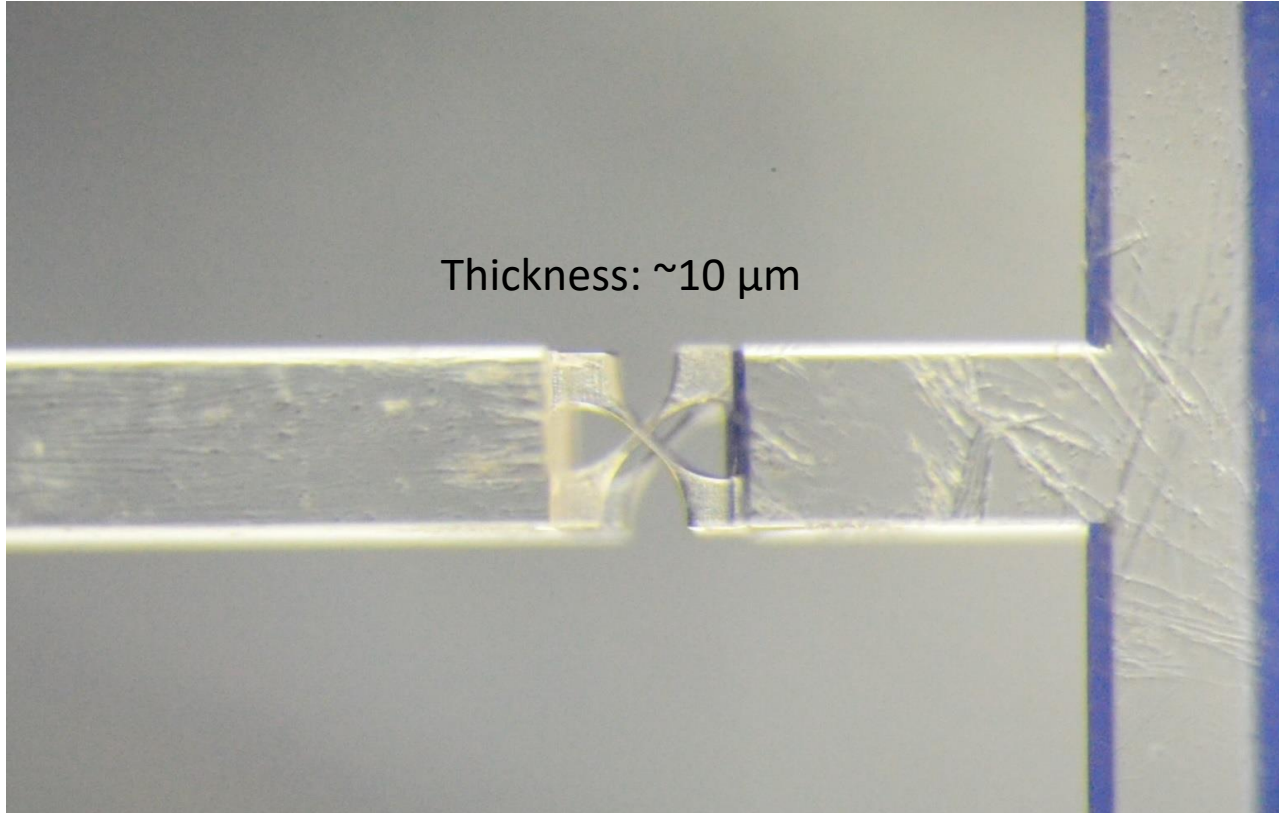


Cross-spring pivot hinge



0.5 mm

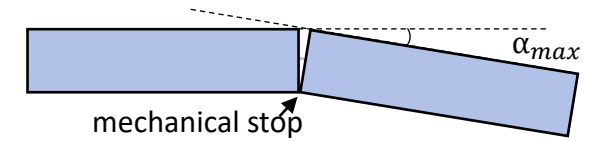
10 mm



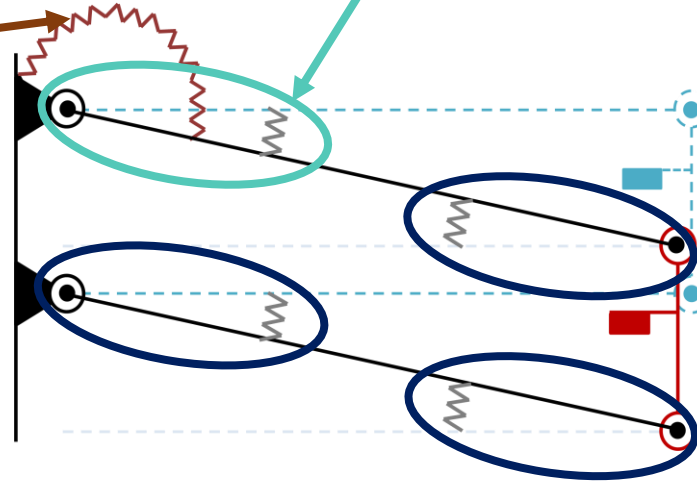
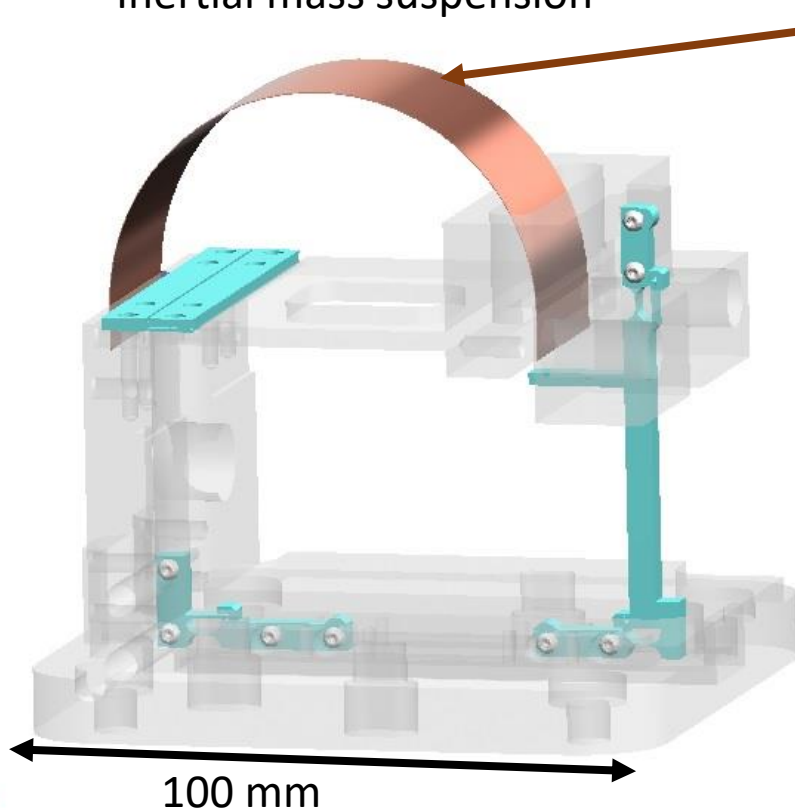
Thanks to the high aspect ratio of the manufacturing process, we are able to produce monolithic compliant mechanisms

Inertial sensor μ VINS

Inertial mass leaf-spring hinge

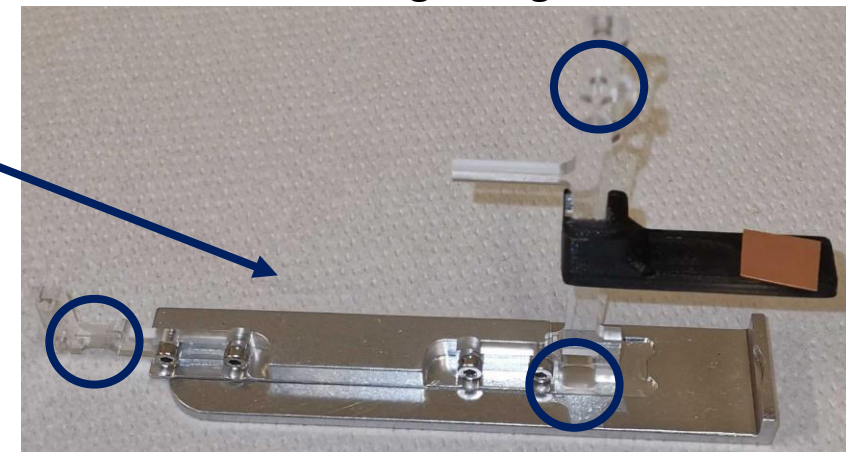


Inertial mass suspension

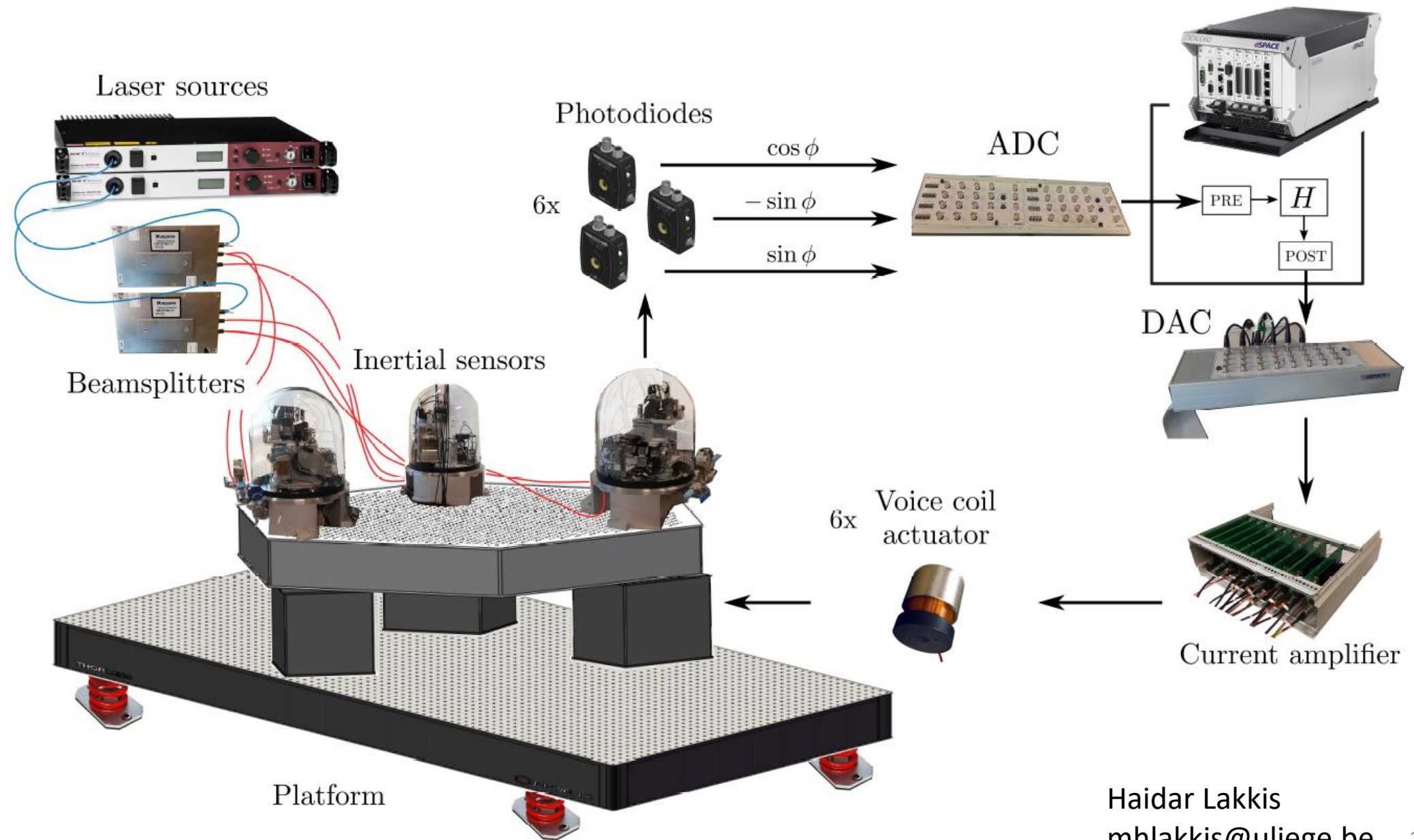


- Glass can be used for compliant joints to reduce drift and thermal noise (depending on the stress ratio between the joint and the suspension)

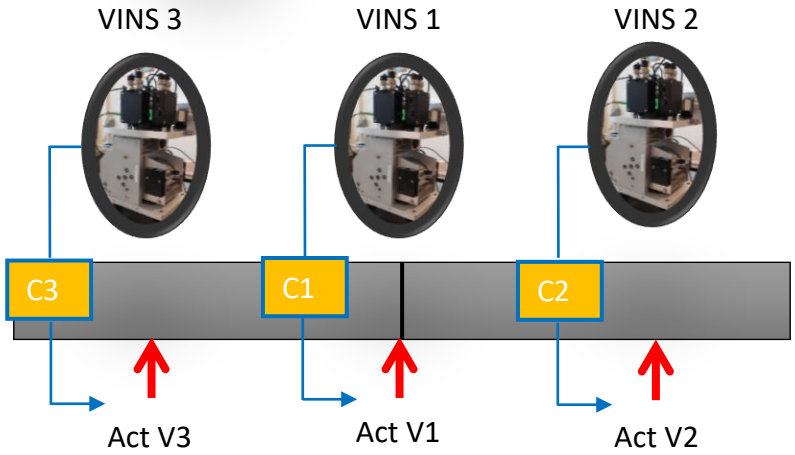
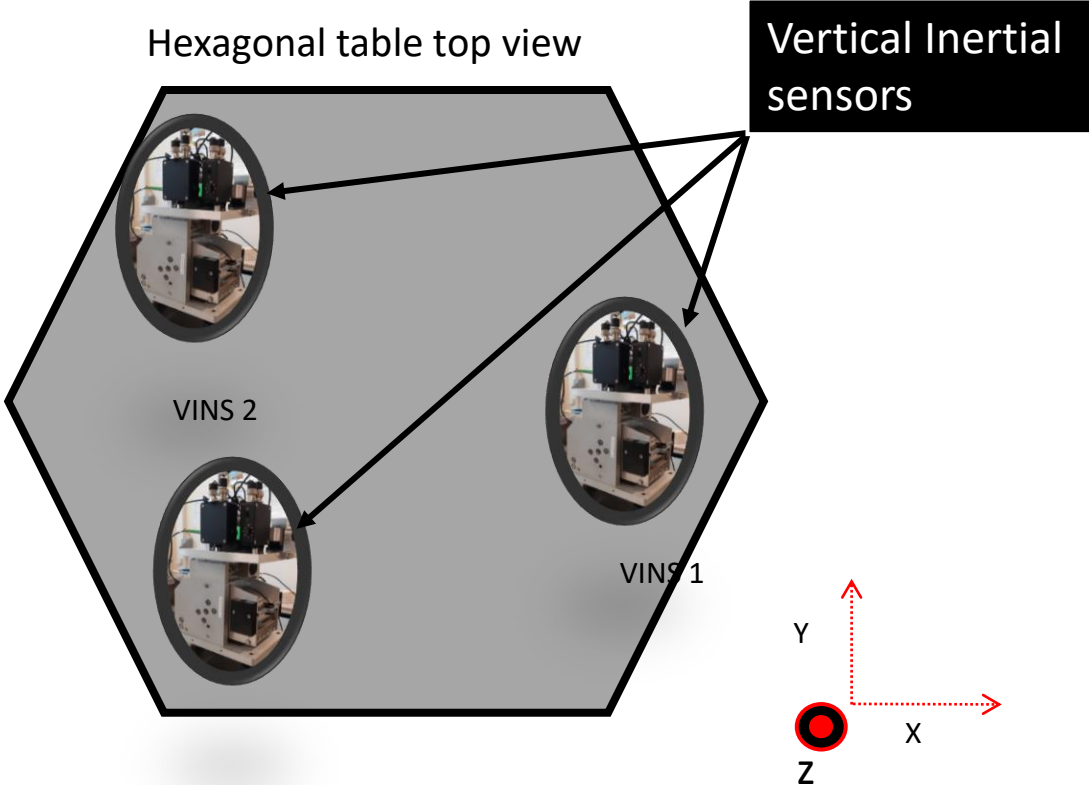
Mirror guiding



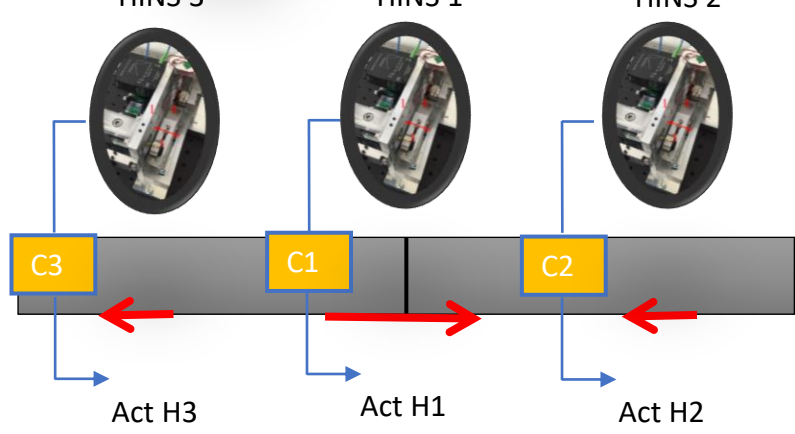
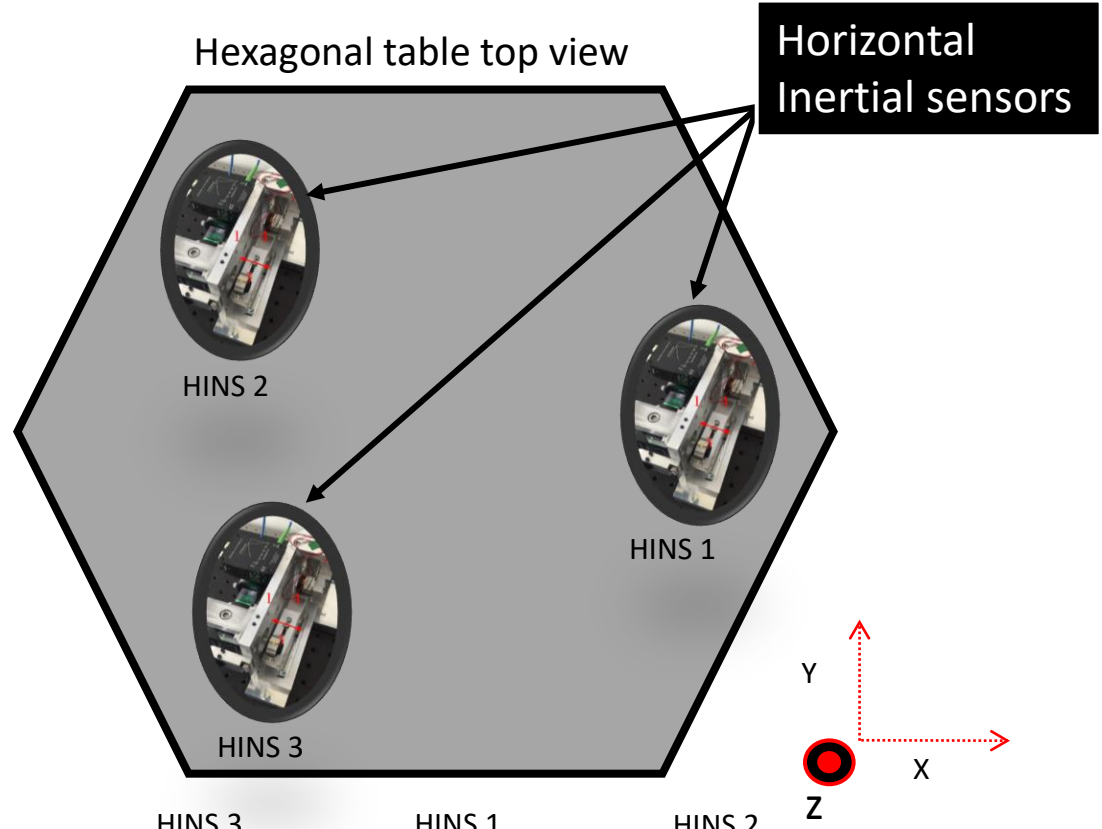
Low-frequency isolation of six degree of freedom systems using inertial sensors



Decentralized Control :



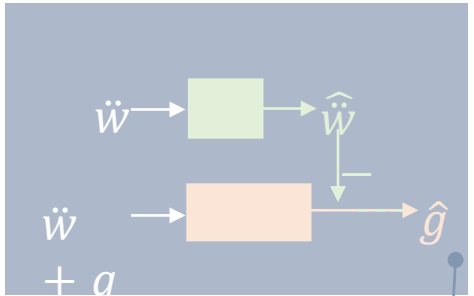
Vertical loops closed in a decentralized way



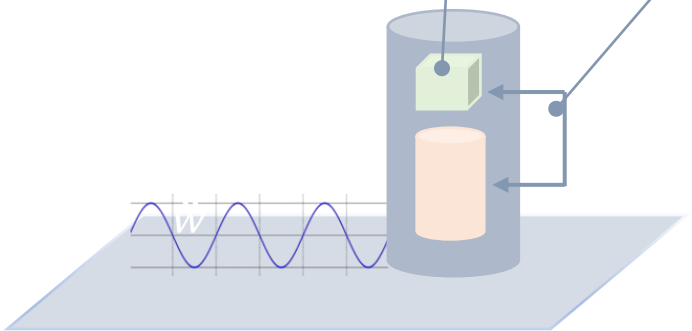
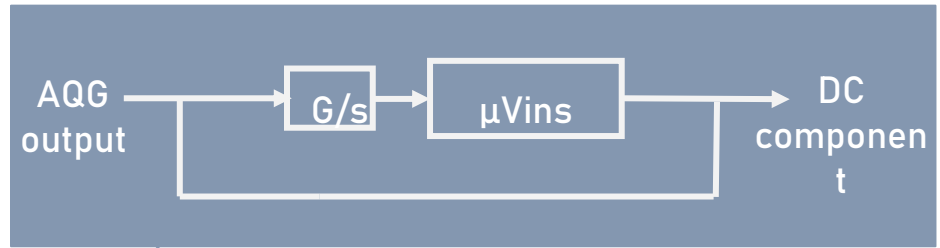
Horizontal loops closed in a decentralized way

Atomic Quantum Gravimeter ibridization

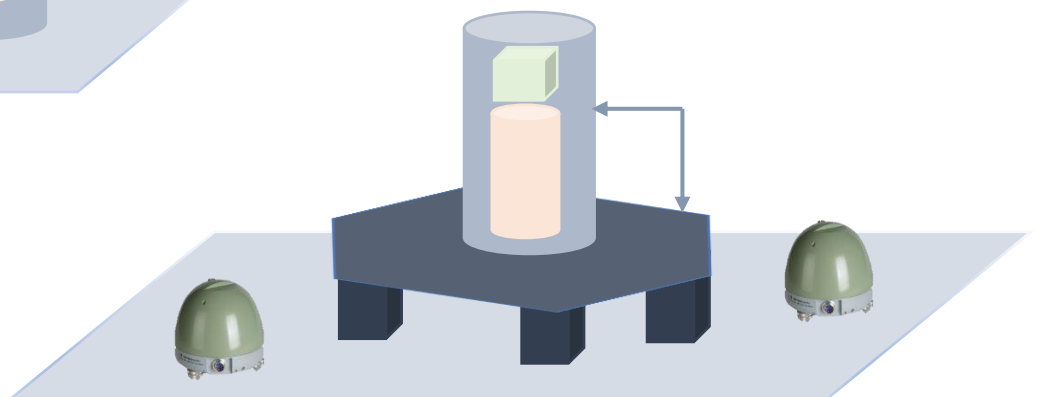
1. Improve the gravimeter



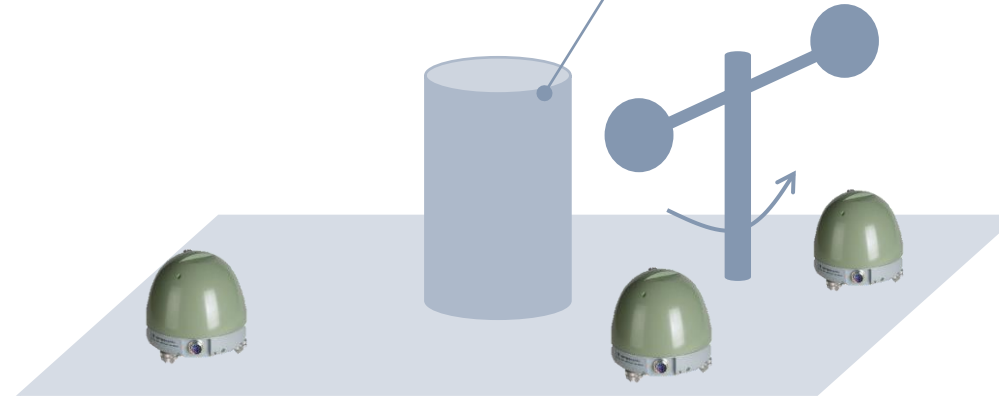
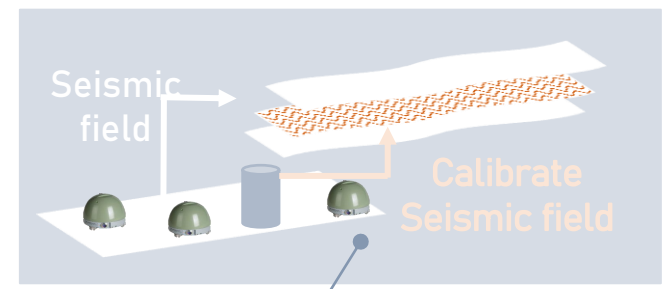
2. Double hybridization



3. Active Isolation



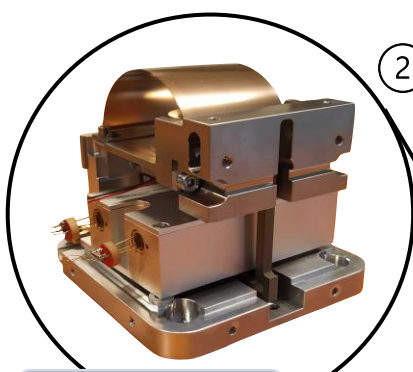
4. Seismic Newtonian Noise Calibration



Overview

② Hybrid sensor: AQG + classical accelerometer

Broad bandwidth
Continuous
Long-term stability



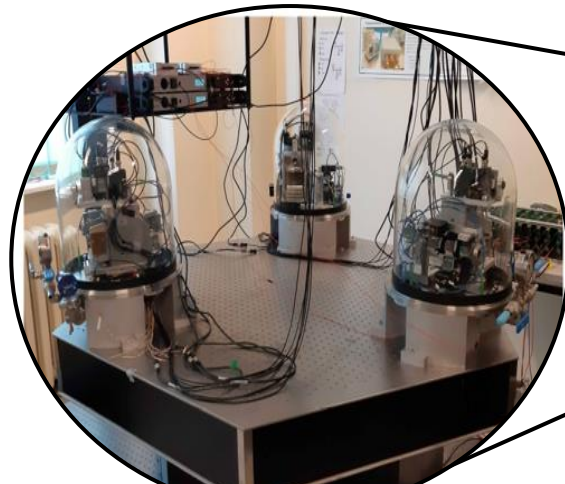
① μ Vins



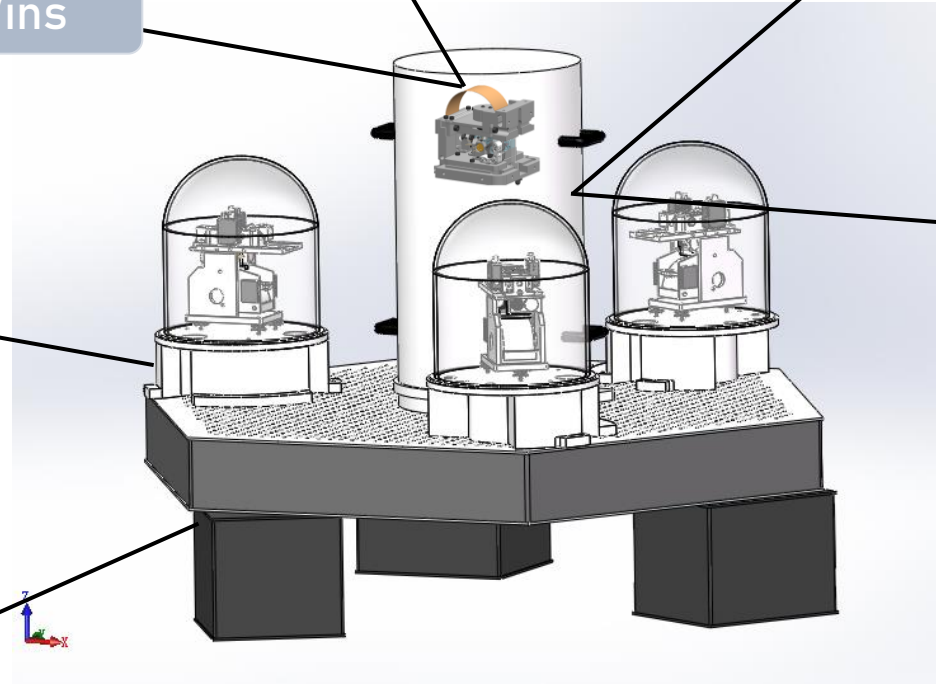
exail

Atomic
Quantum
Gravimeter

④ Newtonian
Noise



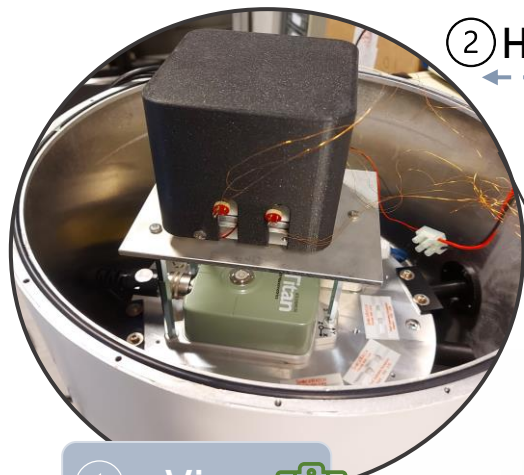
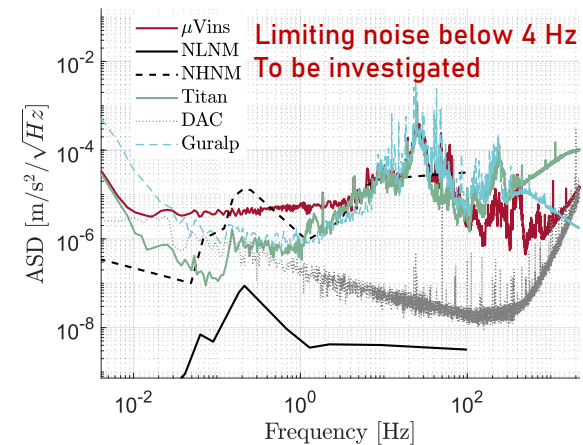
③ Active
platform



Active isolation

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Preliminary result



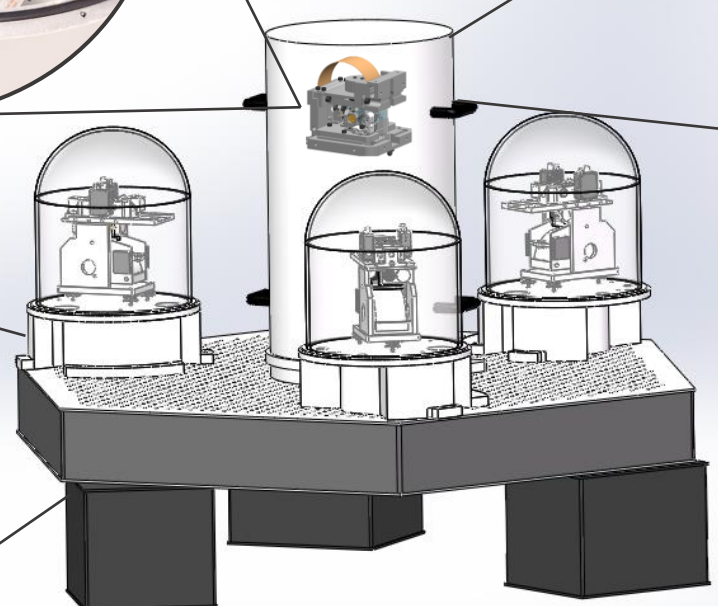
① μ Vins

② Hybrid sensor: AQG + classical accelerometer

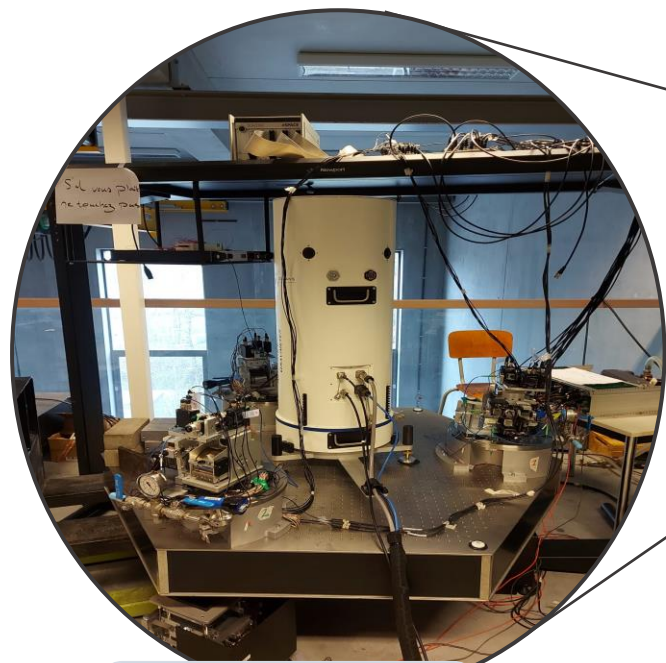


Atomic Quantum Gravimeter

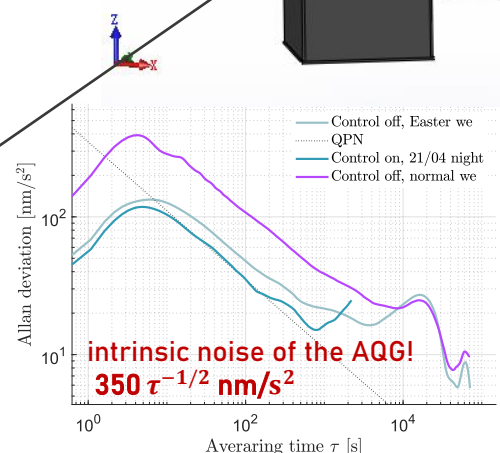
Performance limited by ground vibrations in noisy environment



④ Newtonian Noise



③ Active platform

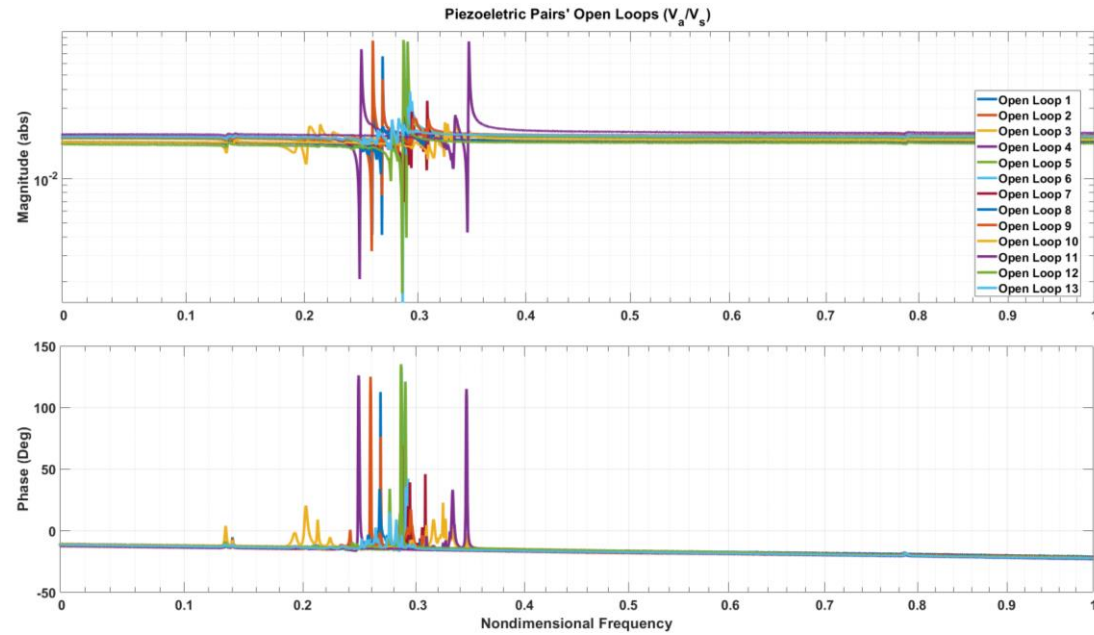
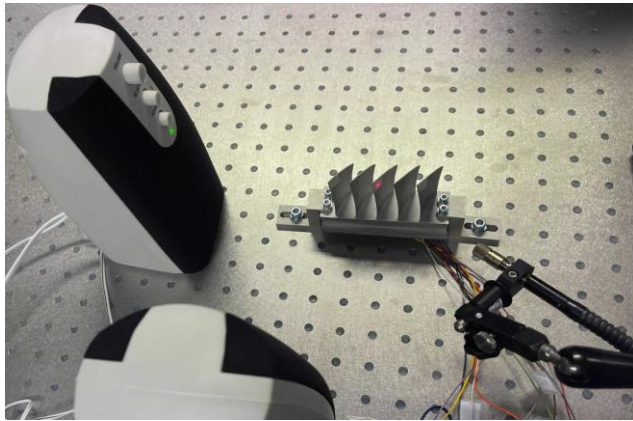


With the active isolation, we are reaching the intrinsic noise of the gravimeter which is set by the laser. So ground noise is now completely removed from gravity measurement.

The gravimeter performance are limited by the ground cancellation strategy.

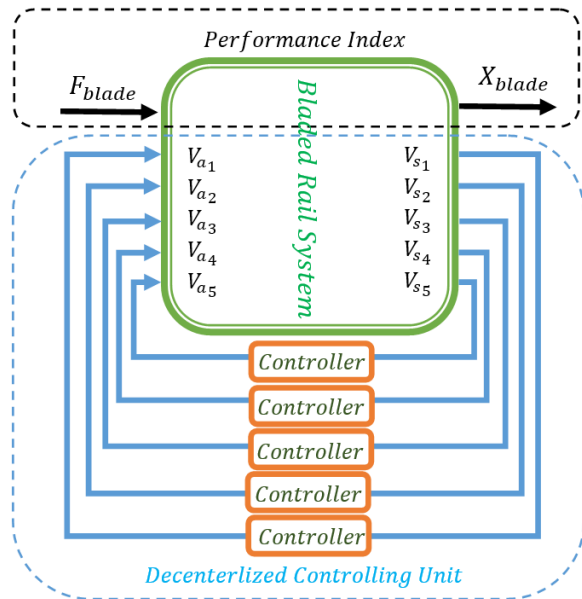
Maverick experiment

Bladed Rail

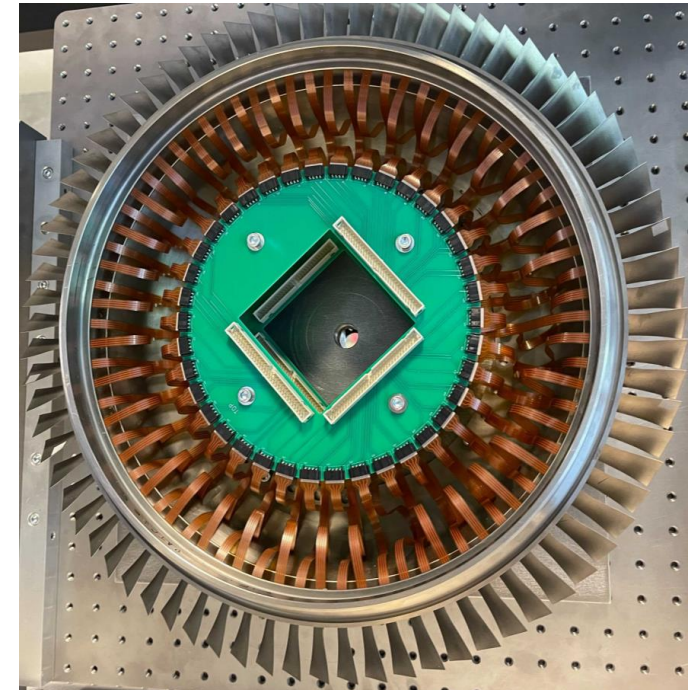
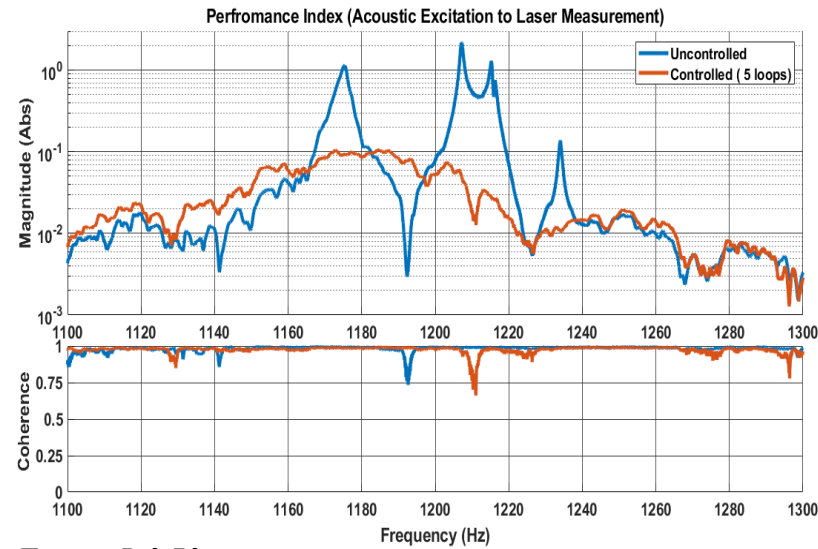


Open Loops of BLUM

Open Loops of Bladed Rail



Performance Index of Bladed Rail



BLUM

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Useful links:

TDR

<https://arxiv.org/abs/2212.10083>

E-TEST Project website

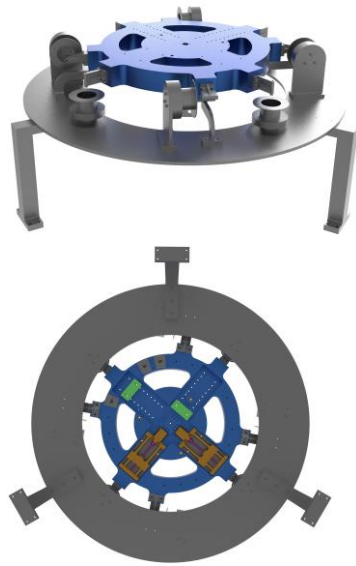
<https://www.etest-emr.eu/>

PML website

<http://www.pmlab.be/>



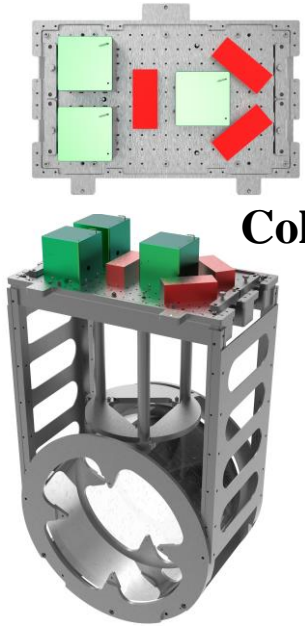
Marionette



Cryostat



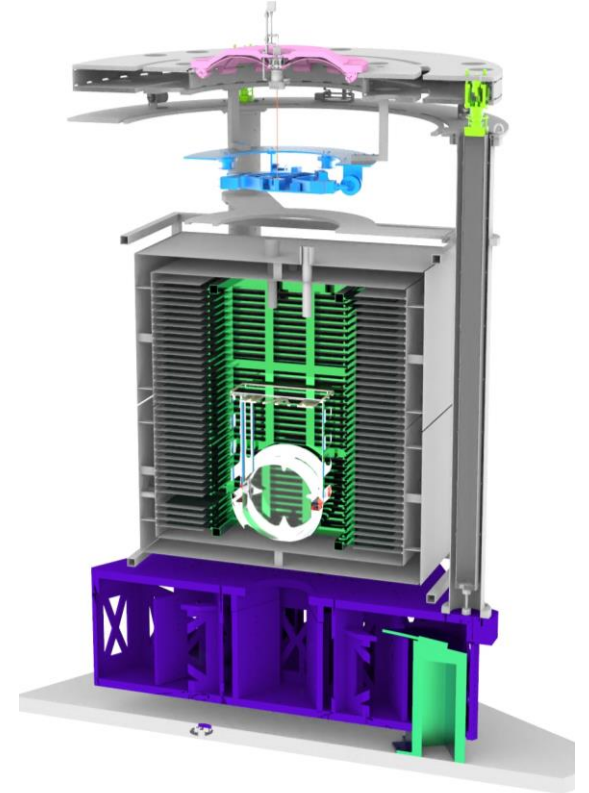
**Cold platform
&
Mirror**



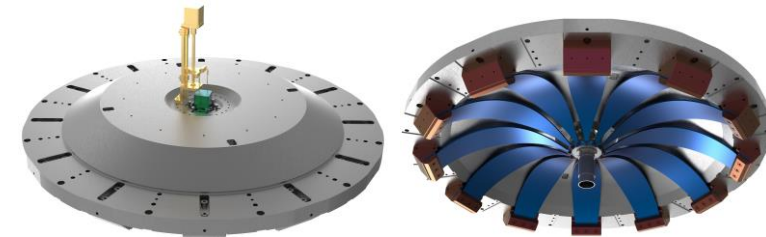
Inverted Pendulum



Active platform

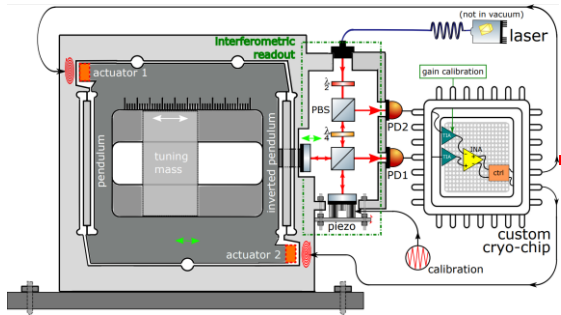


GAS filter



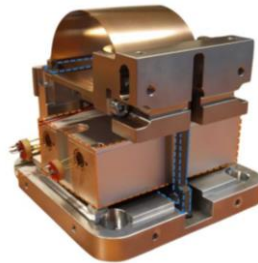
Sensors & Actuators (vacuum compatible)

6 Cryogenic inertial sensors



Temperature sensors

6 Inertial sensors

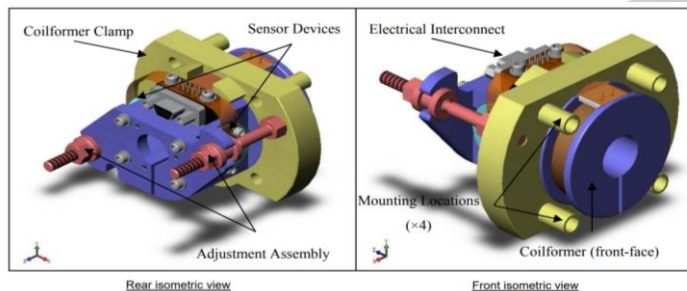


6 voice coil Actuators

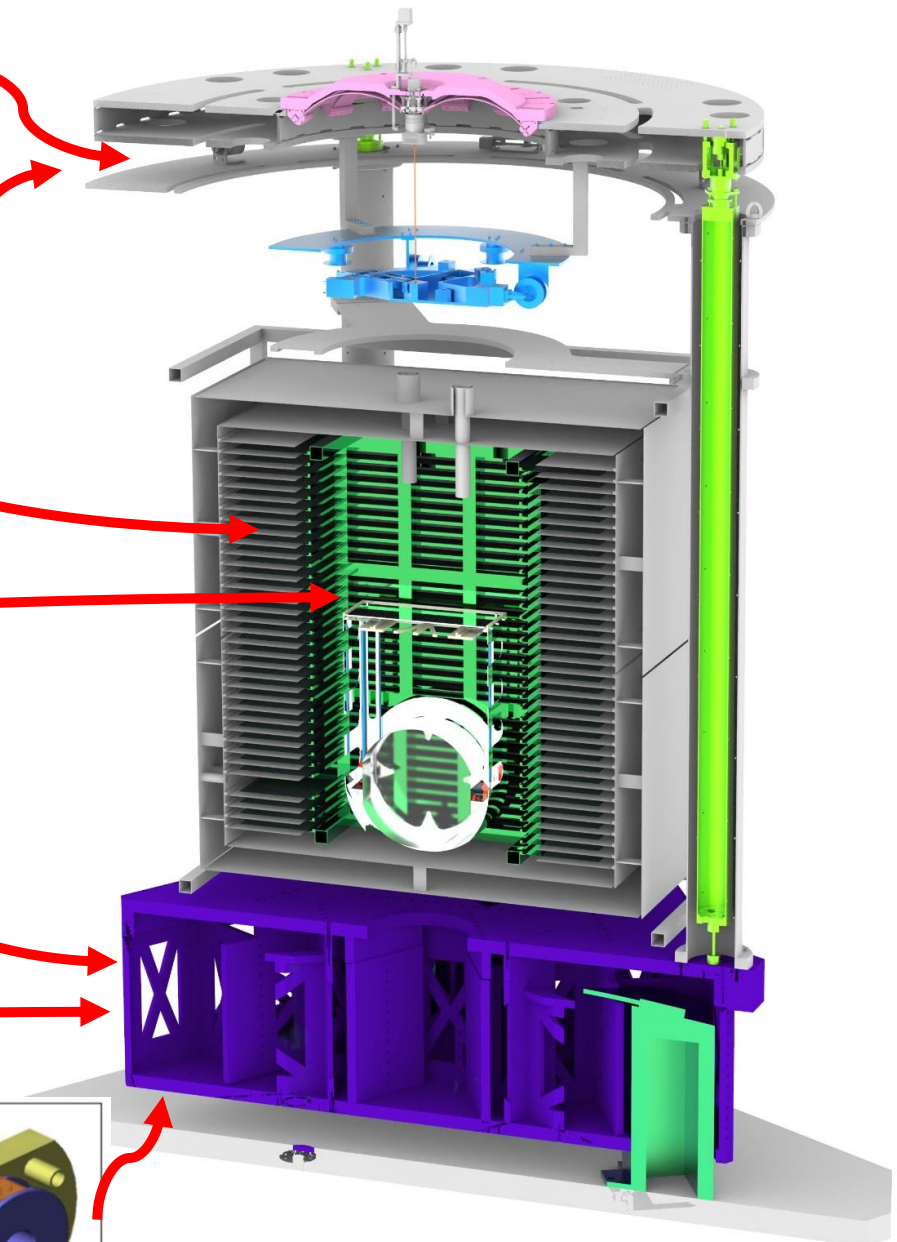


4 Optical Sensors

4 Voice coil actuators



6 BOSEMs



Cross-spring pivot hinge

