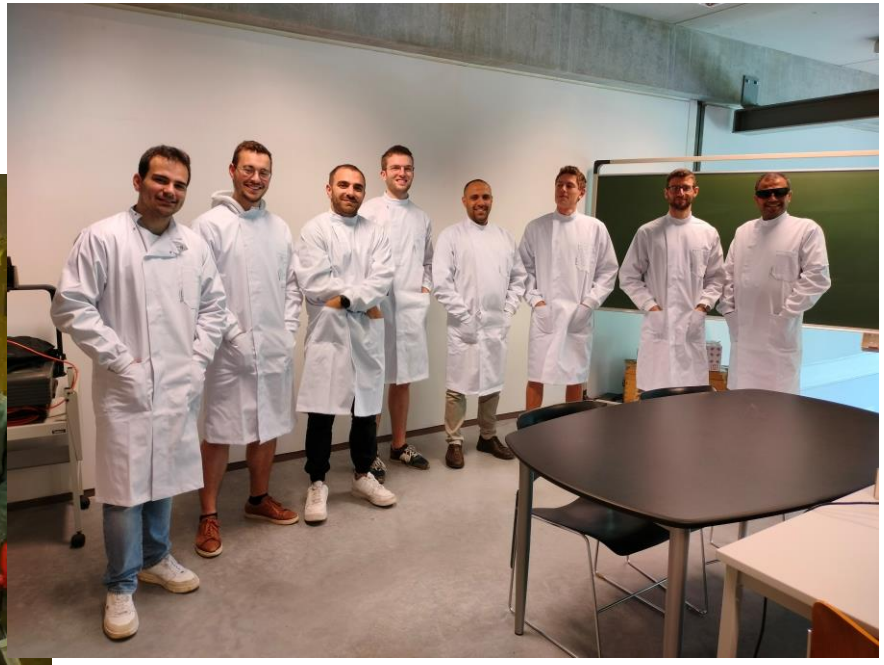
E-TEST prototype and advanced GW technologies

Chiara Di Fronzo
Postdoctoral researcher at PML
Université de Liège
Belgium

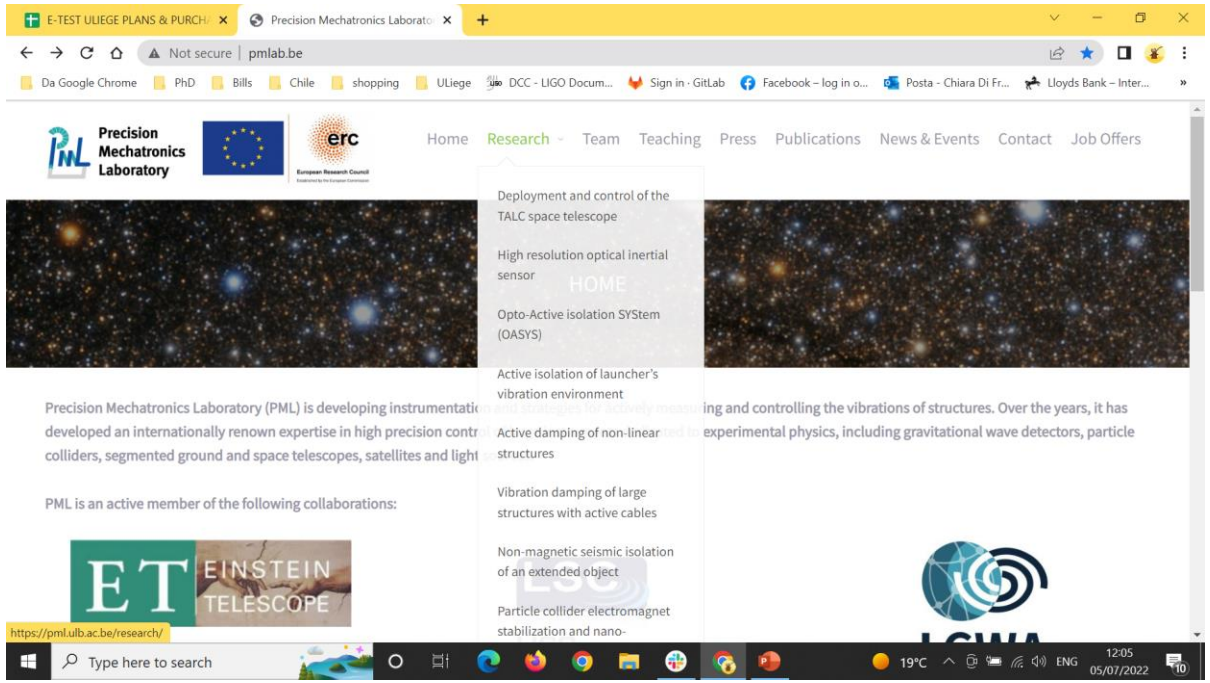
A lab dedicated to seismic science

- 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 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



A bit about myself

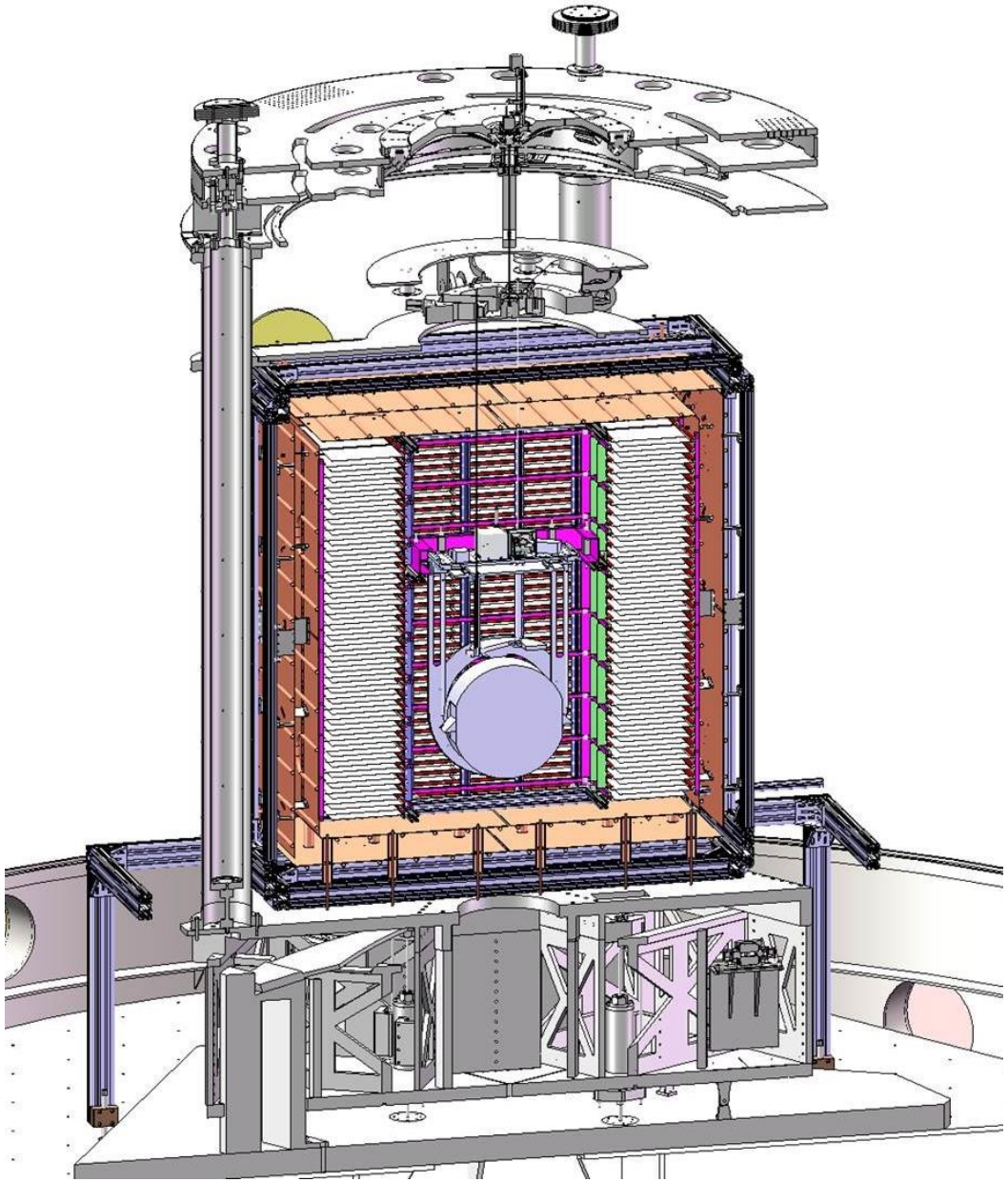
- **PhD** at University of Birmingham (UK) on seismic isolation technologies (https://etheses.bham.ac.uk//id/eprint/12495/)
- **Postdoc** at Université de Liège (Belgium), where I'm responsible for the management of the E-TEST ERC project
- In collaboration with Nikhef and UoB, I'm publishing my work on laser stabilization for the 6D isolator ERC project
- Mentoring PhD students at ULiège
- Following-up my work on LIGO Hanford site on seismic isolating the active platforms via positions sensors connections
- I am an editor of the LIGO magazine, my last two articles are online
- CQG E-TEST recently published *(Ameer Sider et al 2023 Class. Quantum Grav.)*

The E-TEST project at ULiège

- Research at ULiege is ongoing to *improve inertial sensors* and to validate the advanced technology for new GW detectors, as Einstein Telescope (ET)
- At ULiege, the prototype E-TEST is under construction to *test the hybrid technology* mentioned before
- For more info about E-TEST in general, please visit:

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

Work in progress.
Credit: Haidar Lakkis



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)

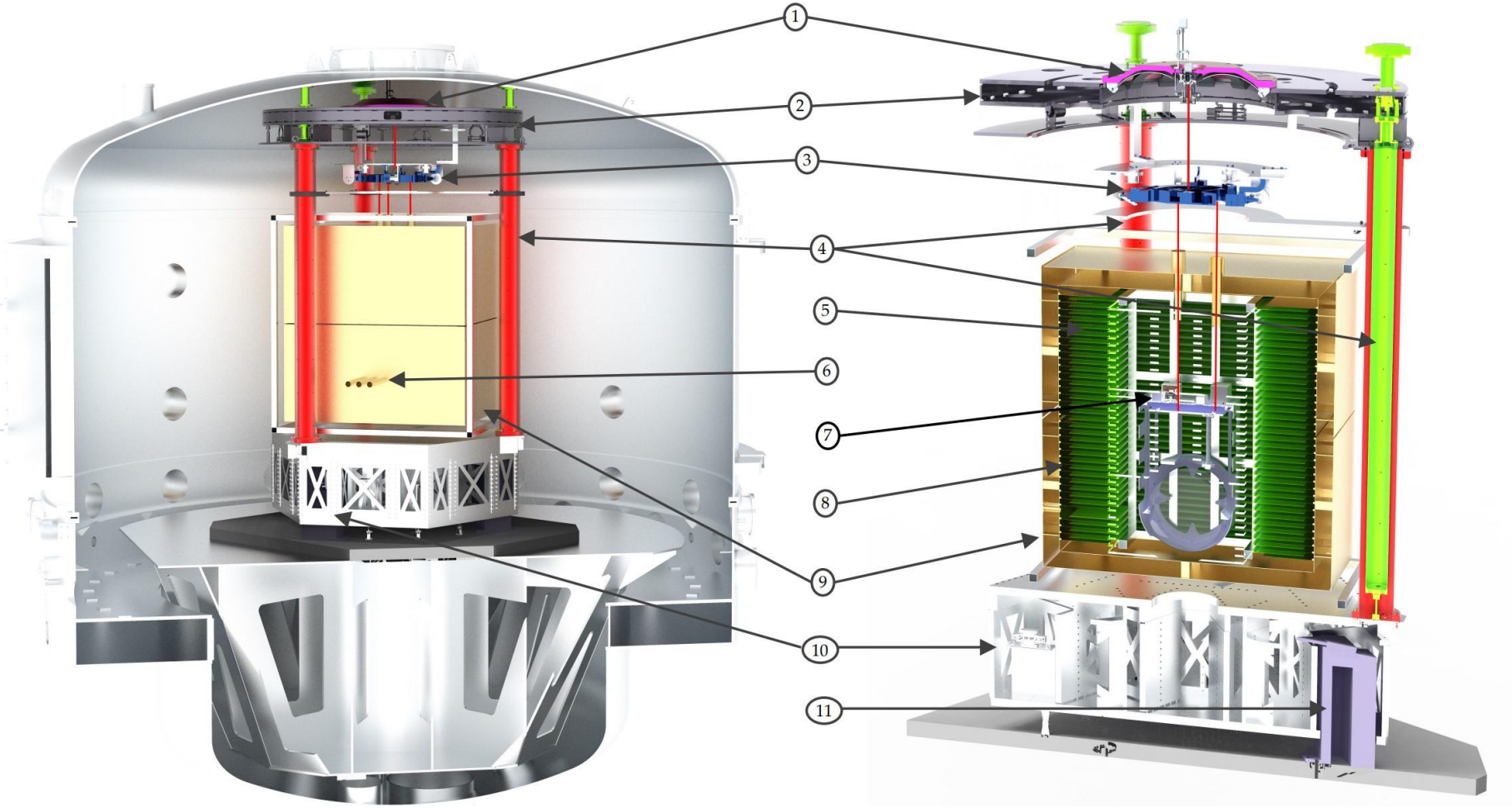
E-TEST feasibility strategy

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 Isolation System - Conceptual Design

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.

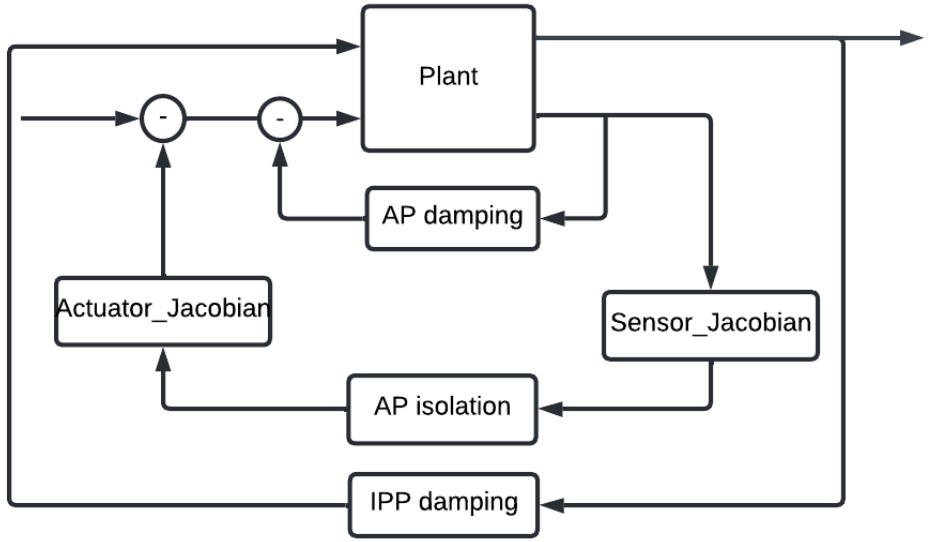


Di Pace, S., Mangano, V., Pierini, L., Rezaei, A., Hennig, J. S., Hennig, M., ... & Van Heijningen, J. (2022). Research Facilities for Europe's Next Generation Gravitational-Wave Detector Einstein Telescope. *Galaxies*, *10*(3), 65.

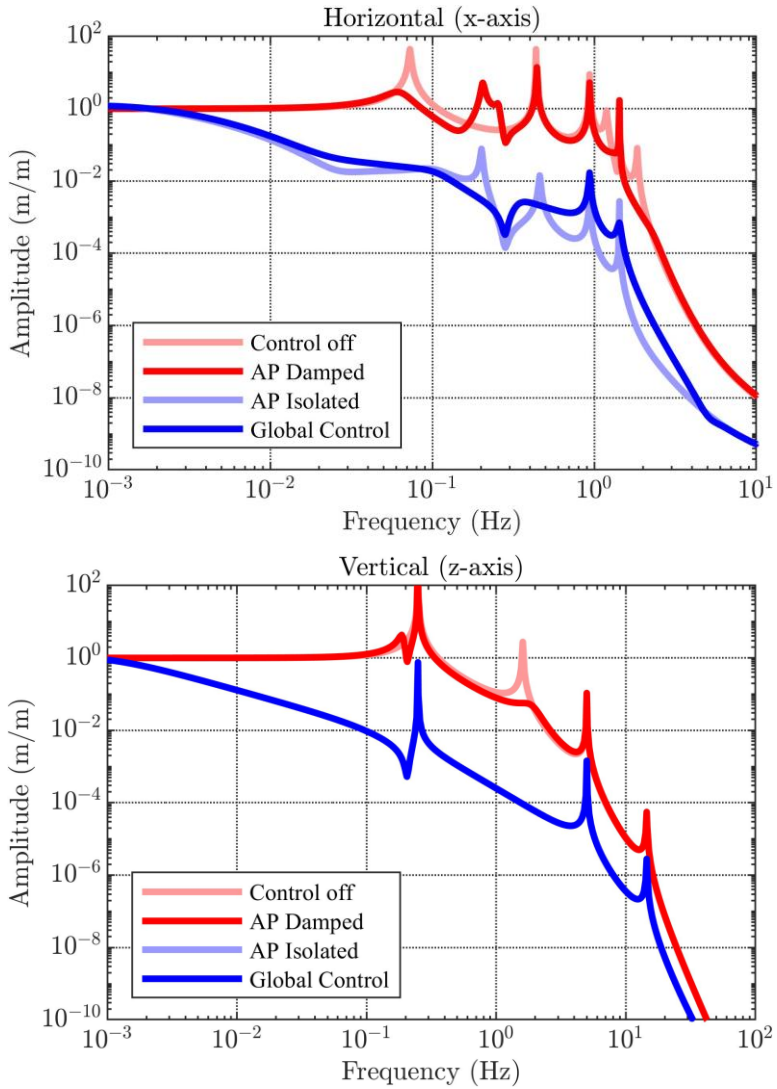
Ameer Sider
asider@uliege.be

Multi-body model and control strategy

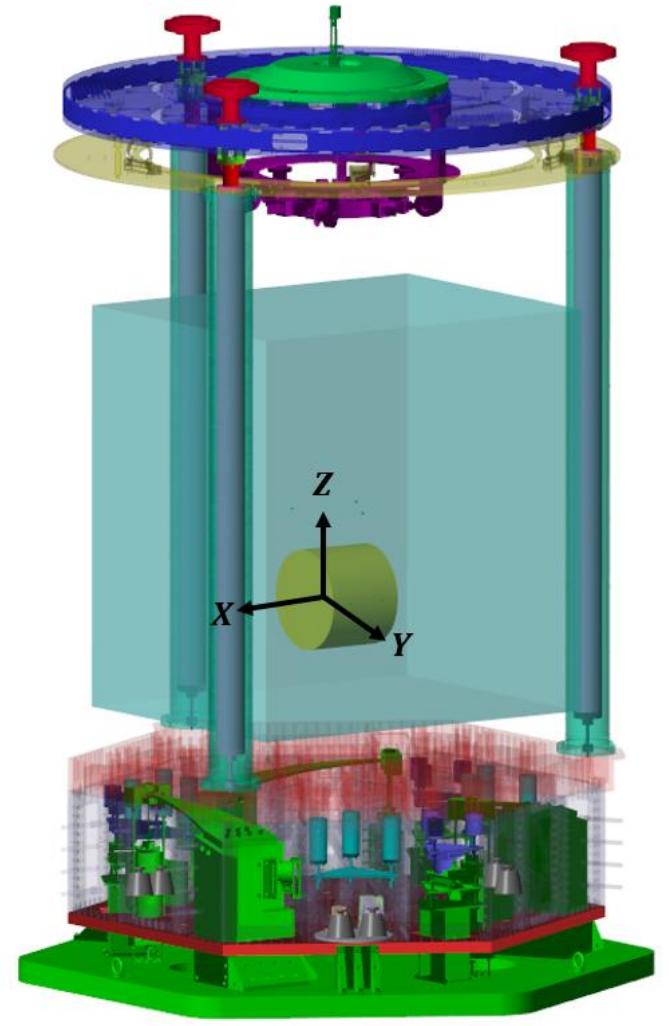
Schematic Control of E-TEST



Transmissibility (Mirror/ground)

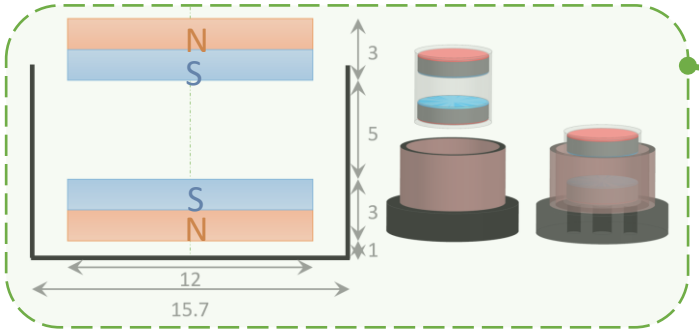


E-TEST Simscape model



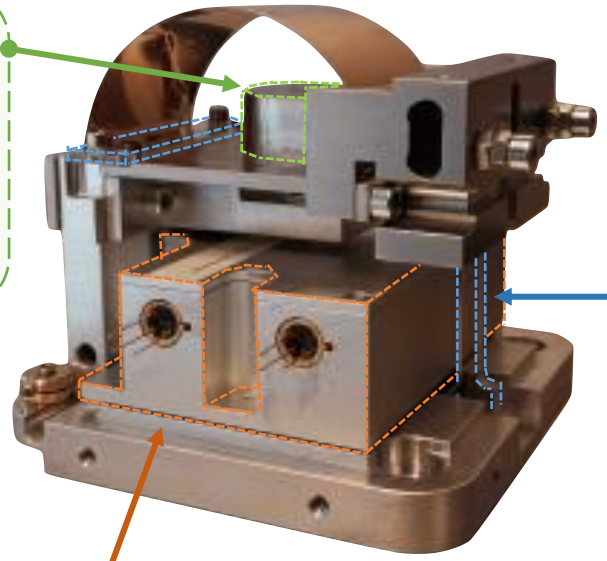
Ameer Sider (PML)
asider@uliege.be

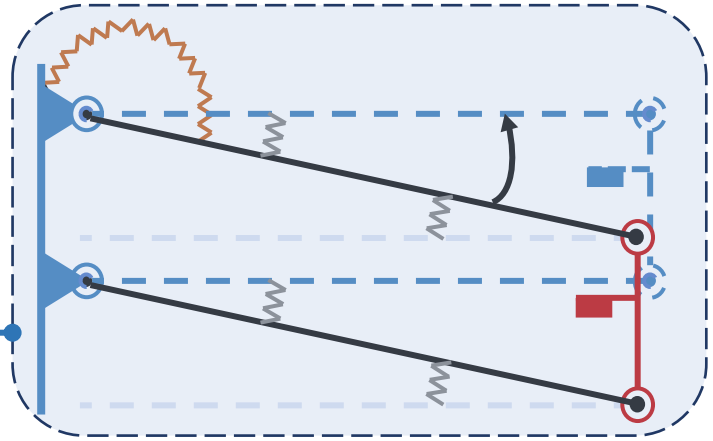
Room T inertial sensor for the E-TEST project



Feedback actuator:

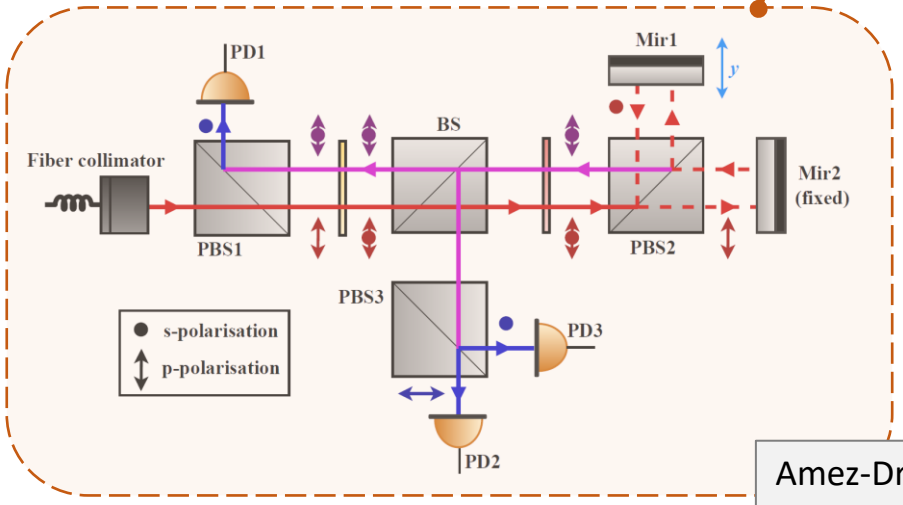
- Moving magnet VCA.
- Self-shielded quadrupole magnet.





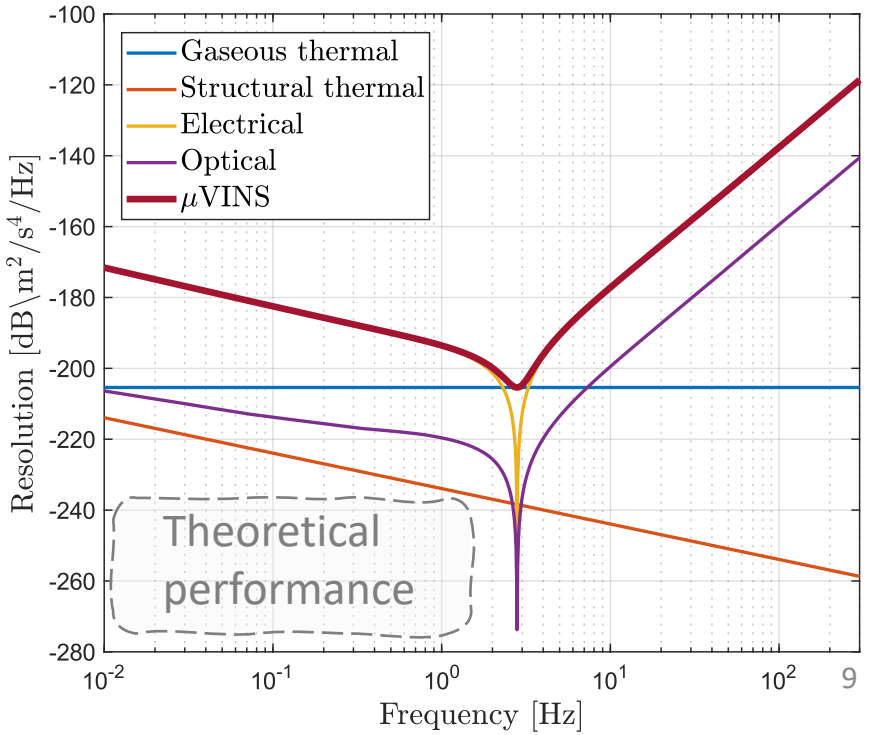
Mechanics

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

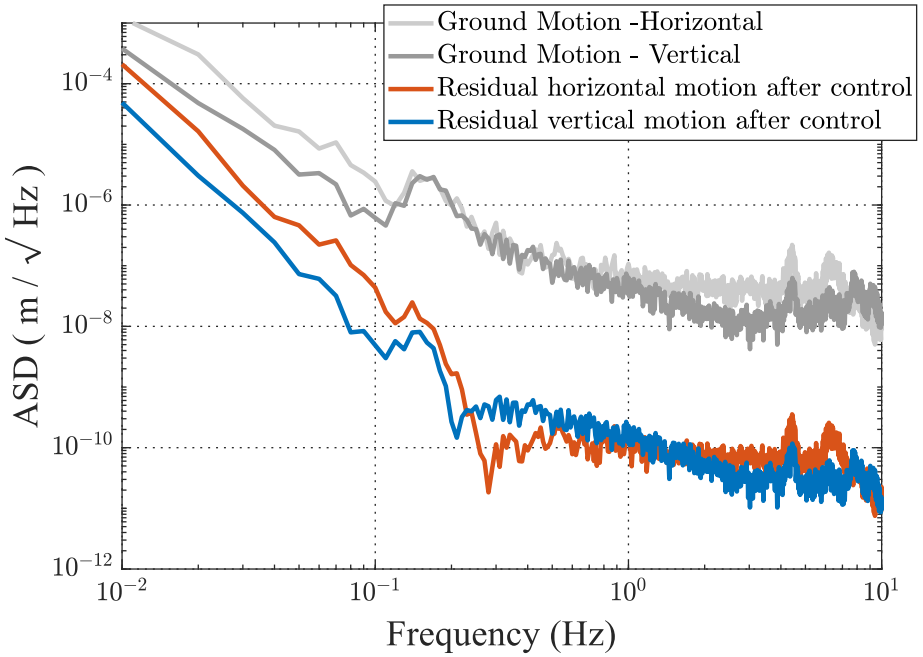


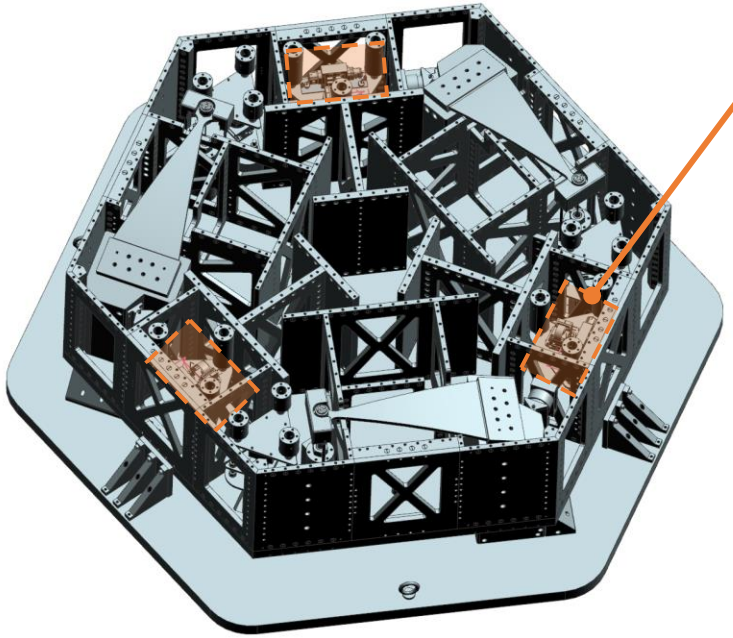
Quadrature Michelson interferometer

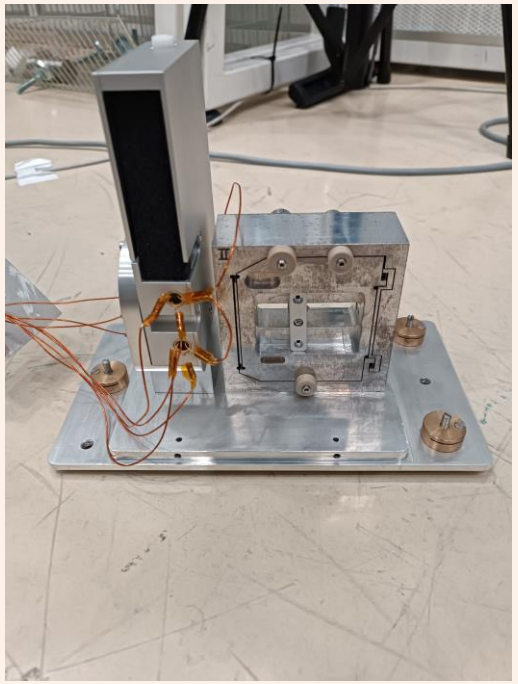
- High dynamic range.
- High resolution: 2×10^{-13} m/√Hz.

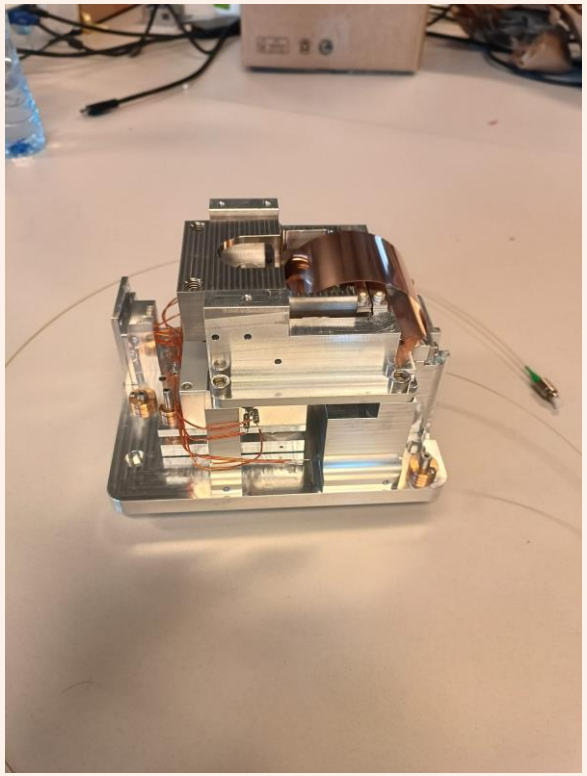


Amez-Droz L. (Loic.Amez-Droz@ulb.be)
Amorosi A. (anthony.amorosi@uliege.be)



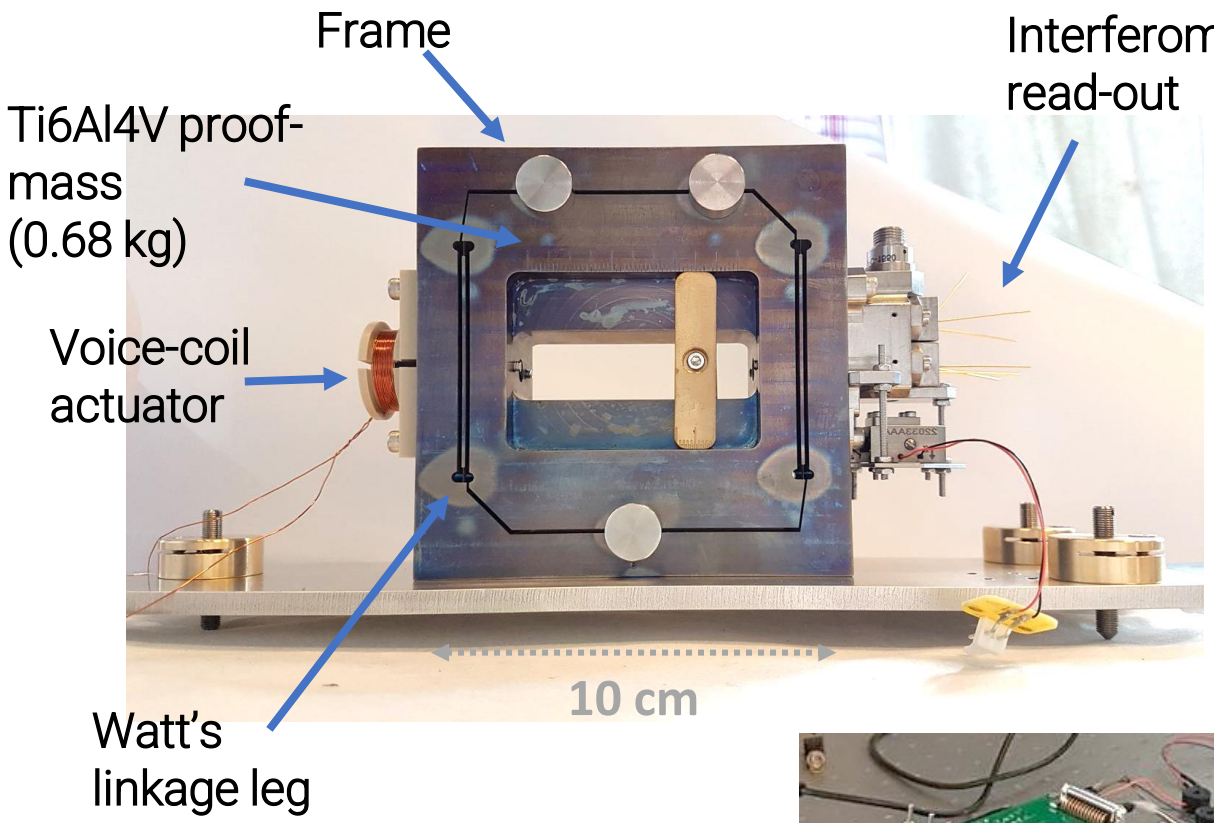


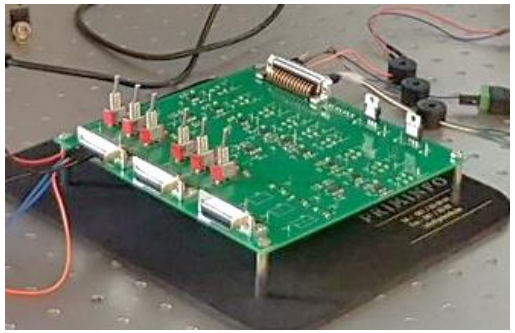




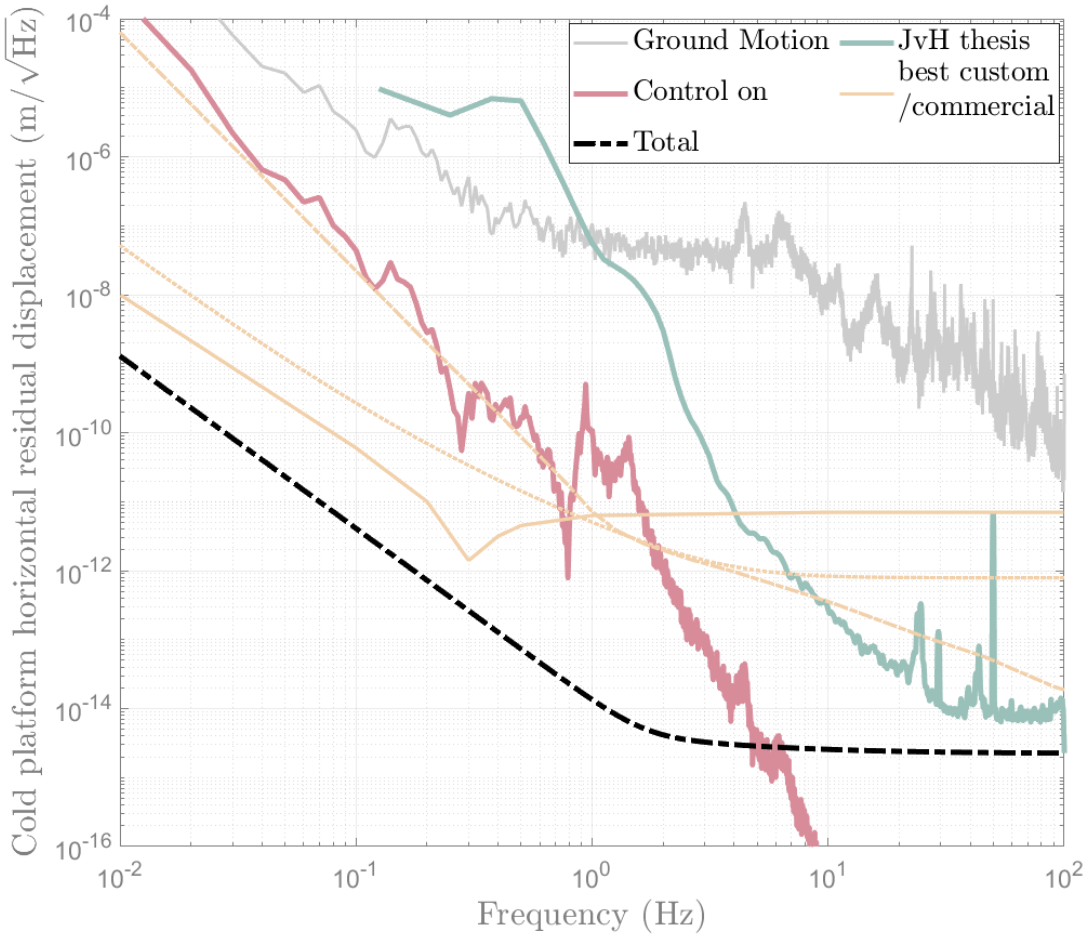
Amez-Droz L. (Loic.Amez-Droz@ulb.be)
Amorosi A. (anthony.amorosi@uliege.be)

Horizontal cryogenic inertial sensor for E-TEST





Room temperature PCB with TIA, controller and current injector

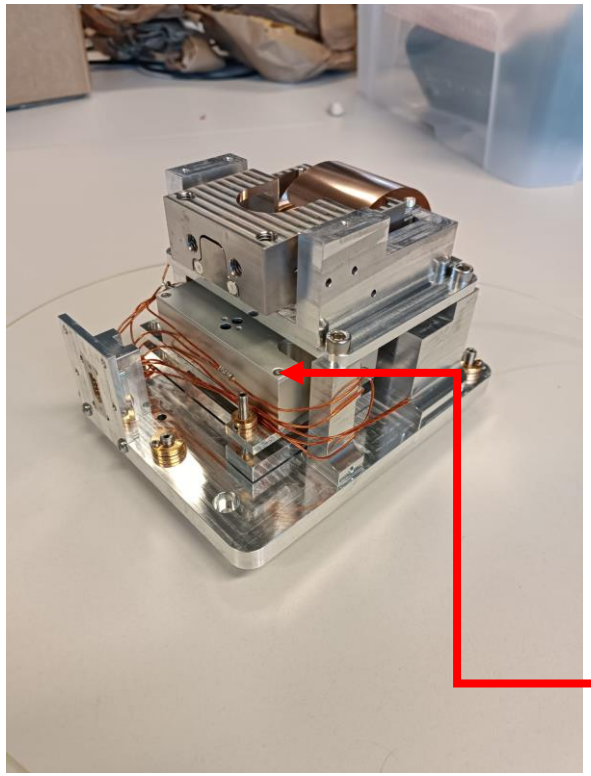


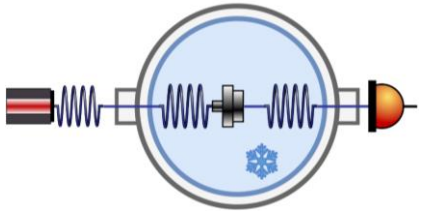
Credit: Morgane Zeoli

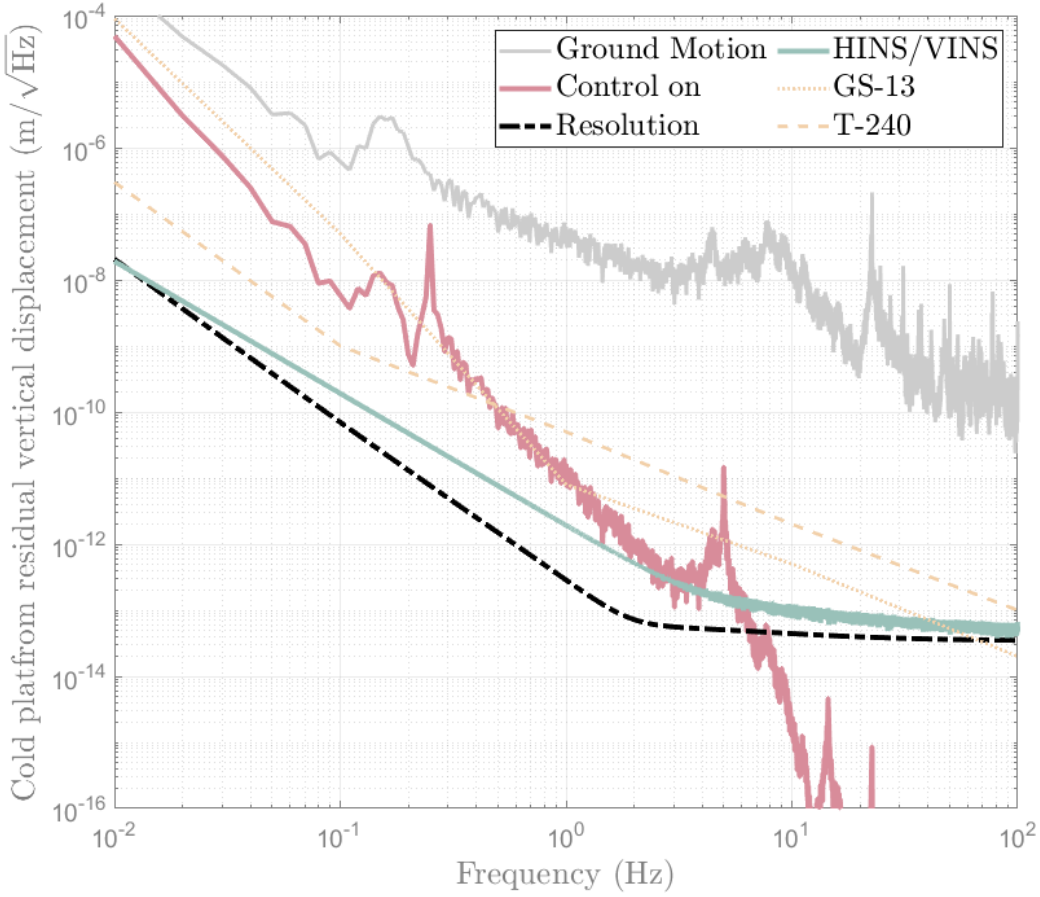
Vertical Cryogenic inertial sensor for E-TEST

E-VINS design adapted for cryogenic working conditions

A test campaign was taken in collaboration with RWTH Aachen to select the optical elements th works the best in cryogenic conditions (collimators, photodiodes, polarization, alignment, etc). The results are used for both CSIS-V and H.







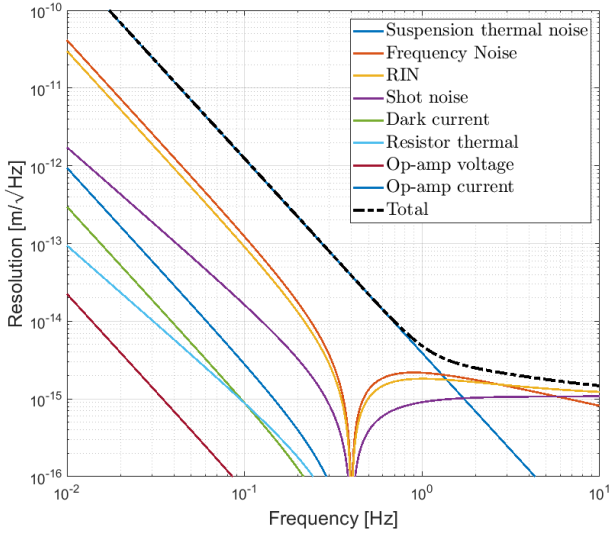
Credit: Morgane Zeoli

Final use and test bench

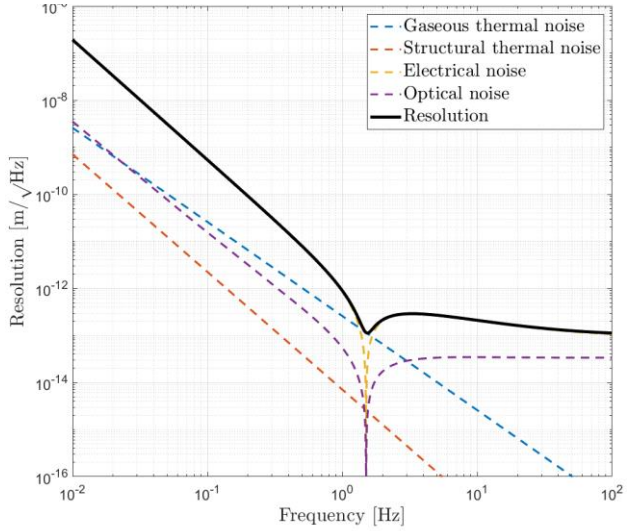
morgane.zeoli@uliege.be
Joris.vanHeijningen.uclouvain.be

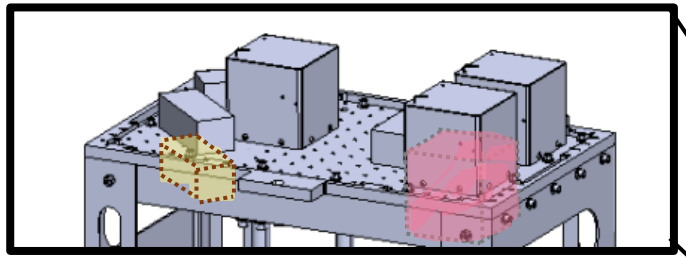
- Monitor residual motion with fm/√Hz sensitivity down to 1 Hz
- Exploit E-TEST cold platform low-vibration cryogenic environment to perform a self-noise measurement

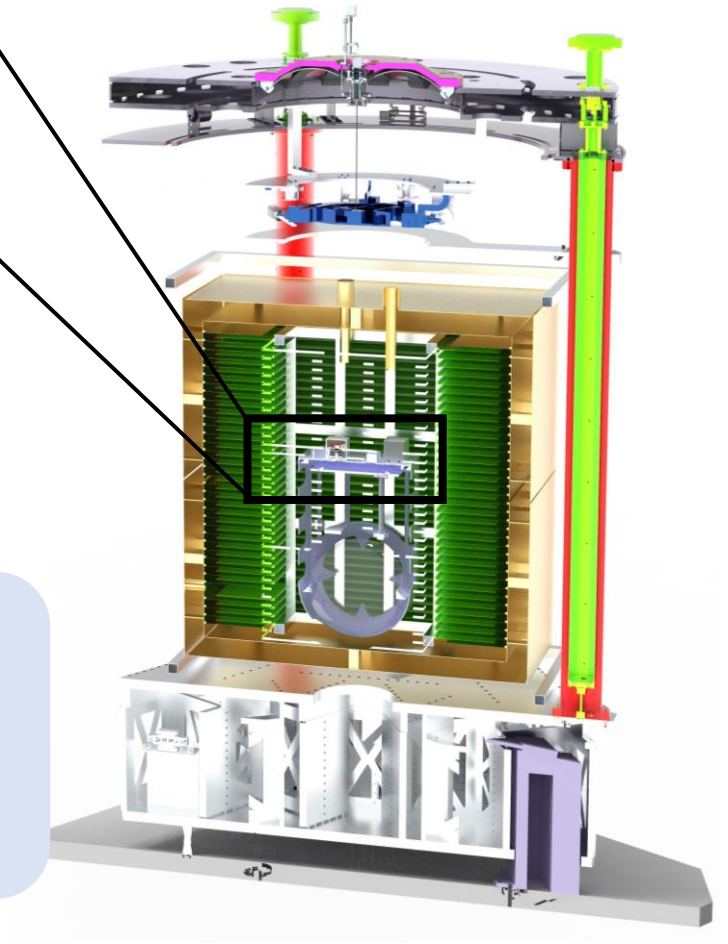
Horizontal



Vertical







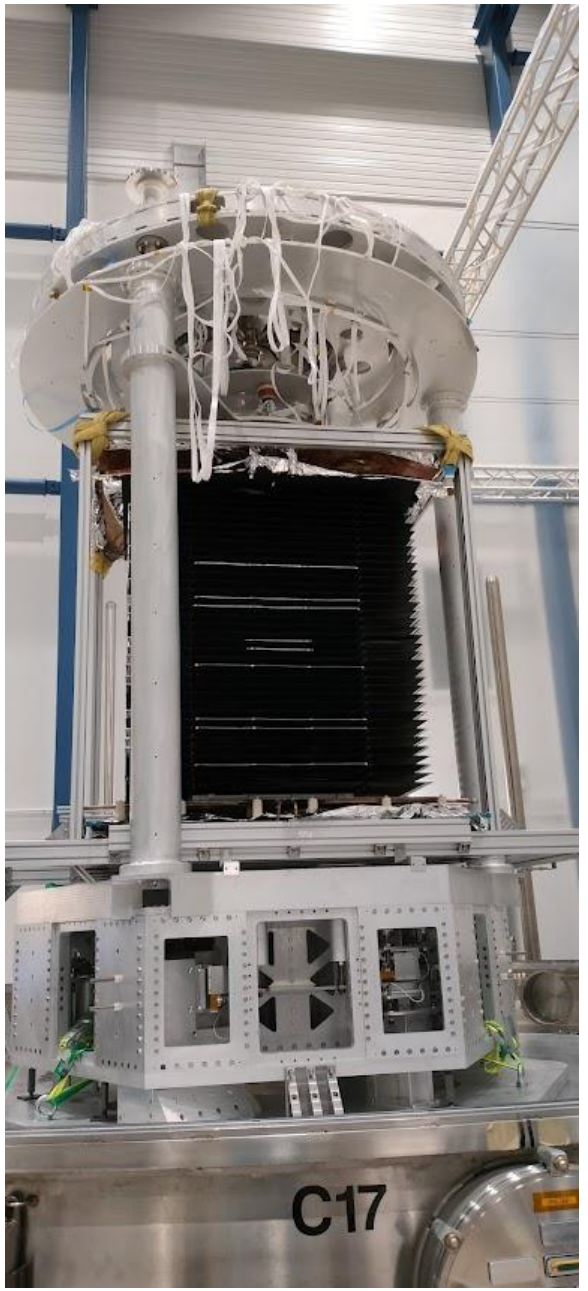
After the CSIS validation with E-TEST, an adaptation of this sensor will be embedded in the **LGWA (Lunar Gravitational Wave Antenna)**

GOAL:

Measure the GW passing by the Moon

- New GW spectrum
- Selene physics

Current status of E-TEST



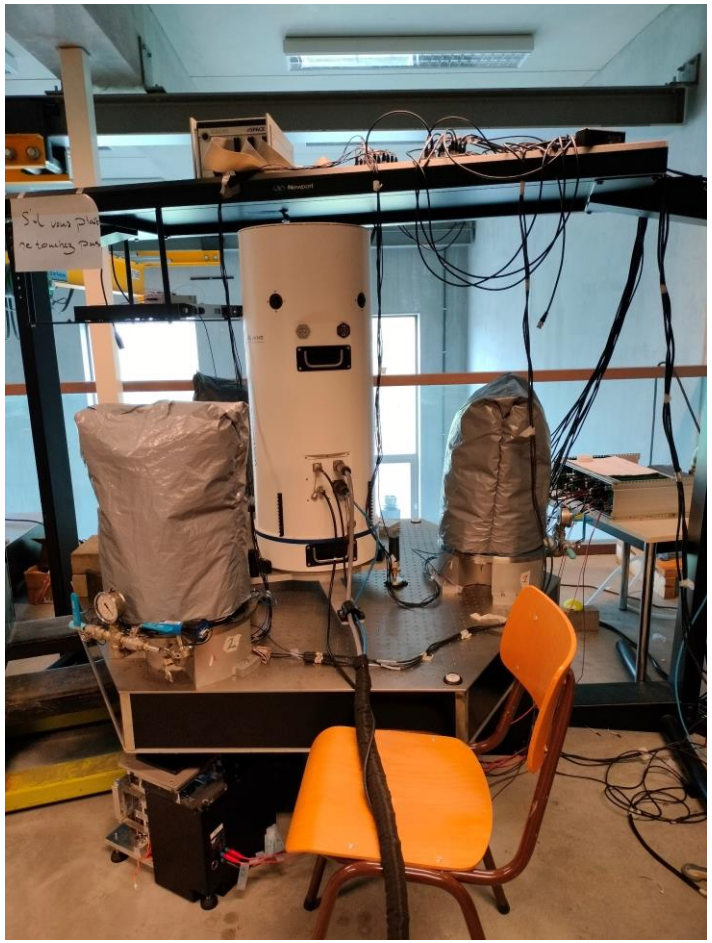
Vacuuming and cooling started and it's going to take 3 weeks (N done, He started. T = 90 K).

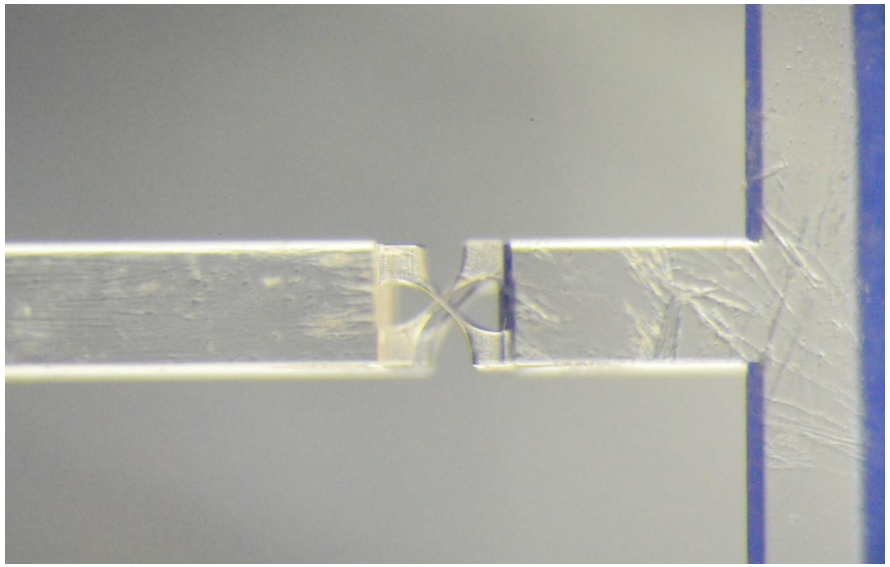
During that time, we monitor the sensors, apply control and test the responses.

After that, we will dismount the cryostat and move E-TEST to another lab for suspension and seismic tests.

End 2024: installation of the silicon mirror and rods.

Other than E-TEST

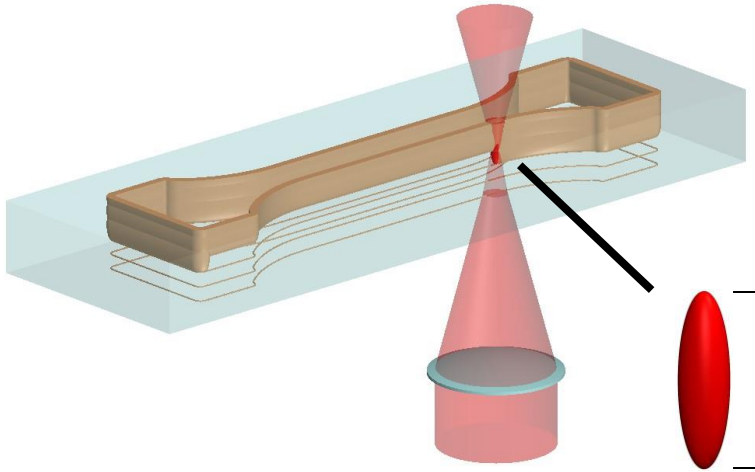


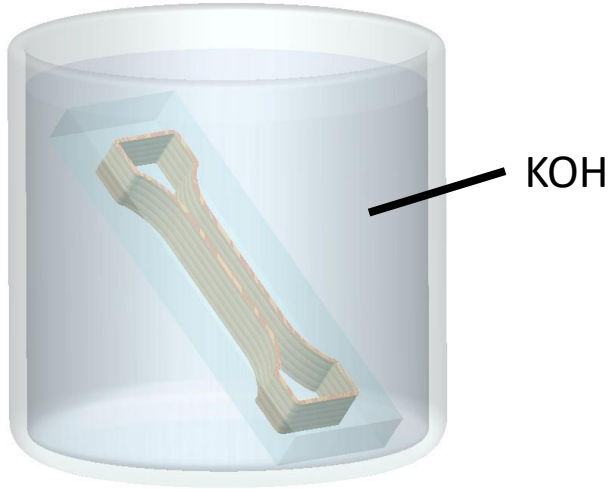


Glass structure manufacturing: laser assisted etching

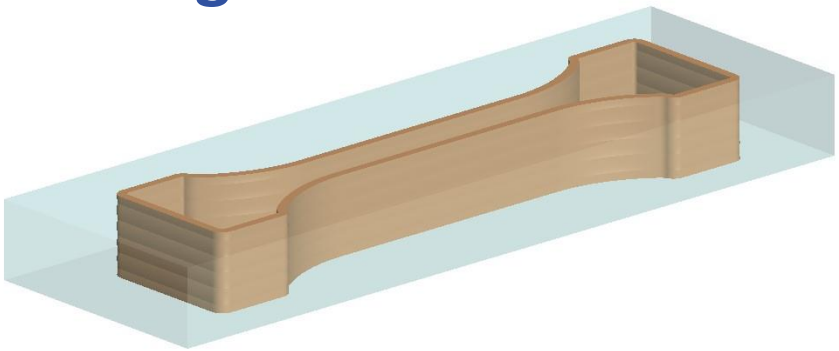
Laser objective

Substrate

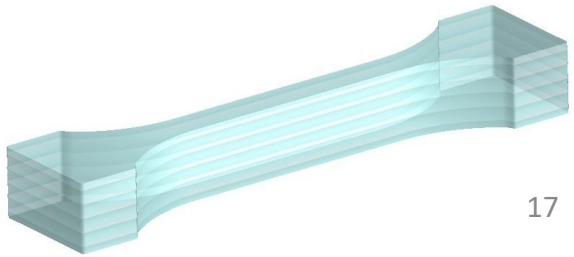




KOH

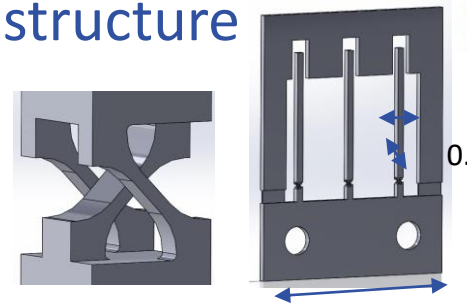


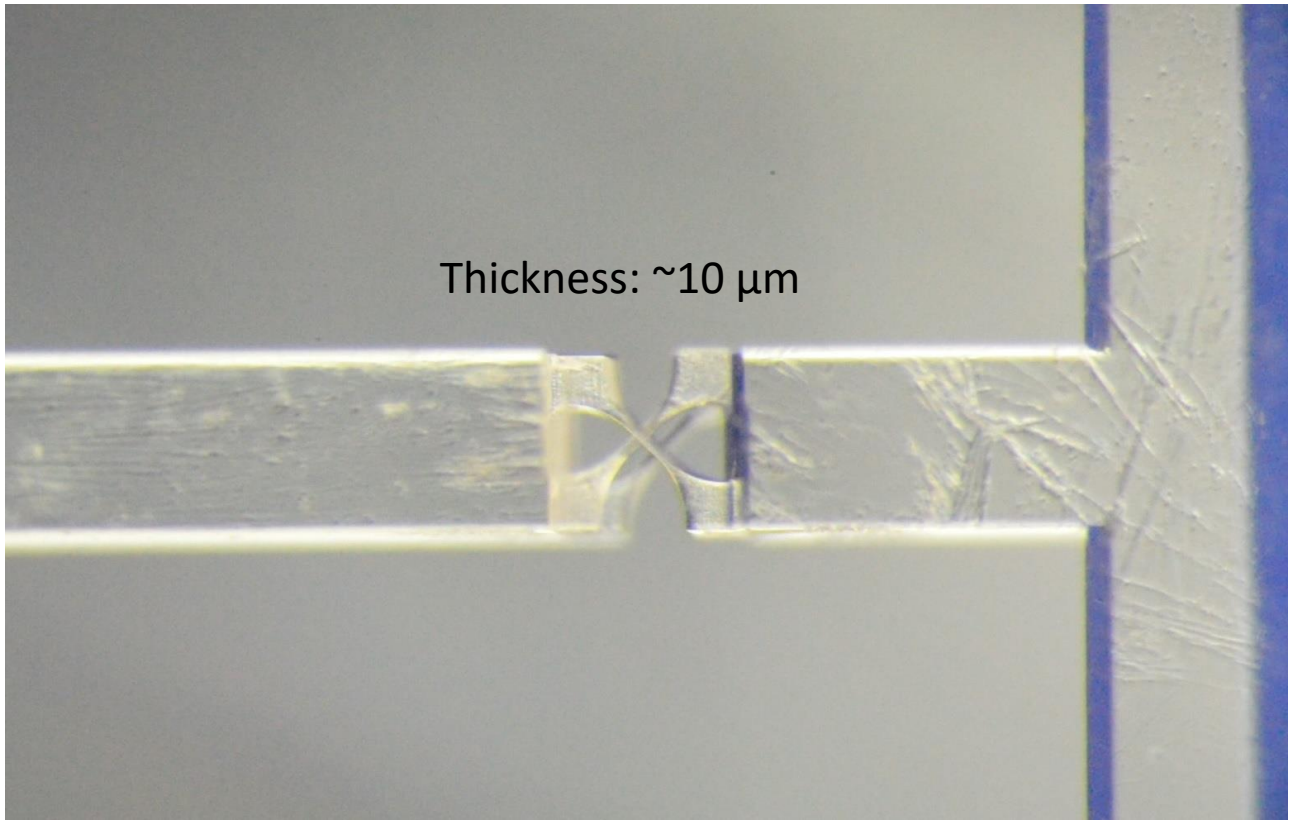
- The laser path is defined to expose the shape of the desired part in a glass substrate
- Then, the substrate is placed in a KOH bath. Laser-exposed glass is etched 100x faster than non-exposed glass

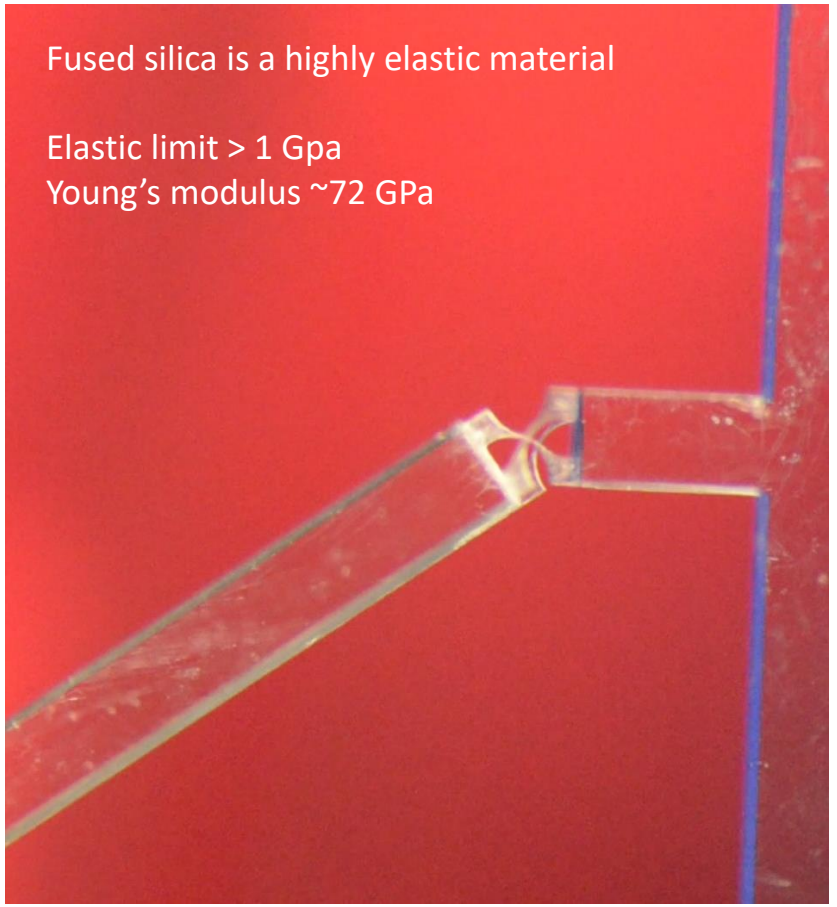


Instrumented flexible glass structure

Cross-spring pivot hinge



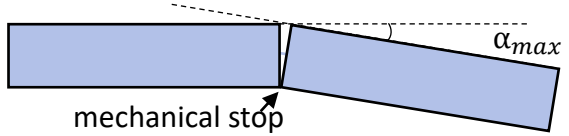




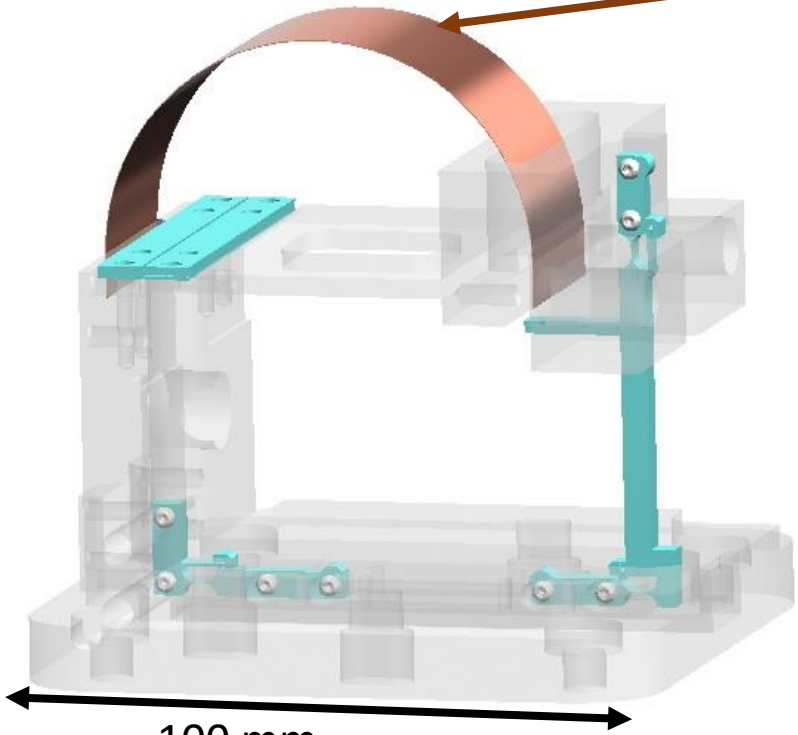
Thanks to the high aspect ratio of the manufacturing process, we are able to produce monolithic compliant mechanisms

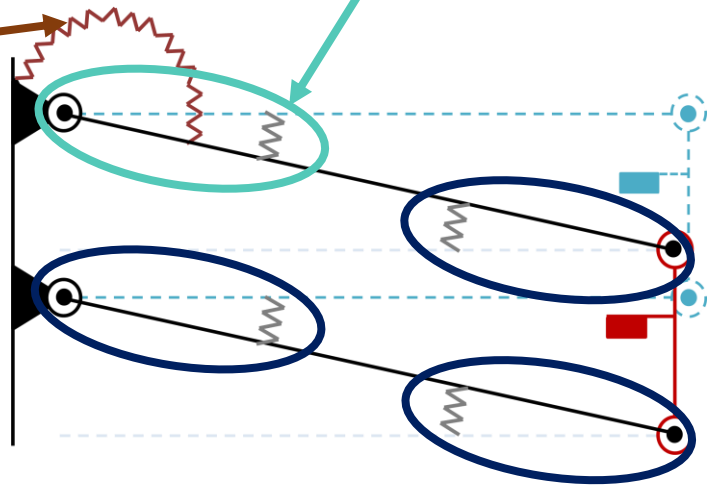
Inertial sensor µVINS

Inertial mass leaf-spring hinge



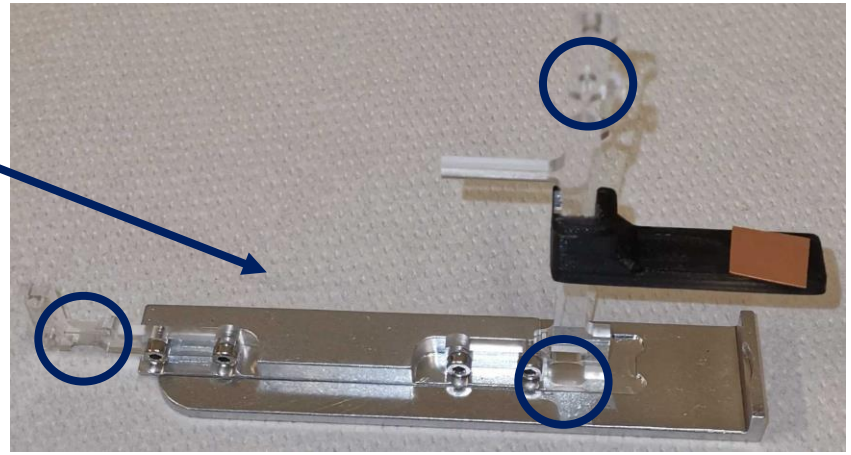
Inertial mass suspension



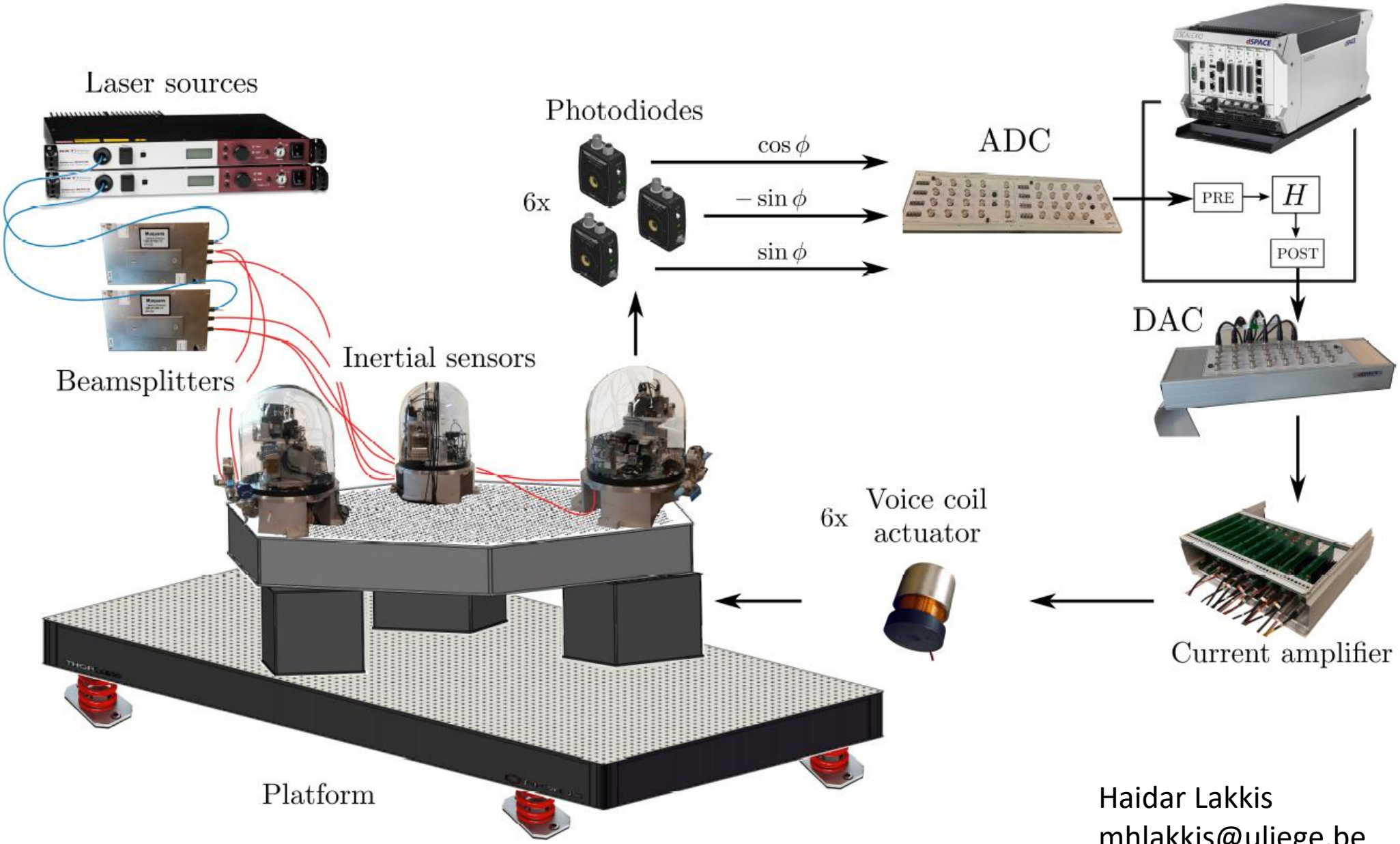


- Glass can be used for compliant joints to reduce drift and thermal noise (depending on the stress ratio between the joint and the suspension)

Mirror guiding



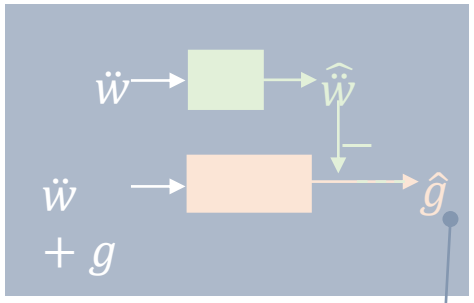
Low-frequency isolation of 6DOF systems using inertial sensors



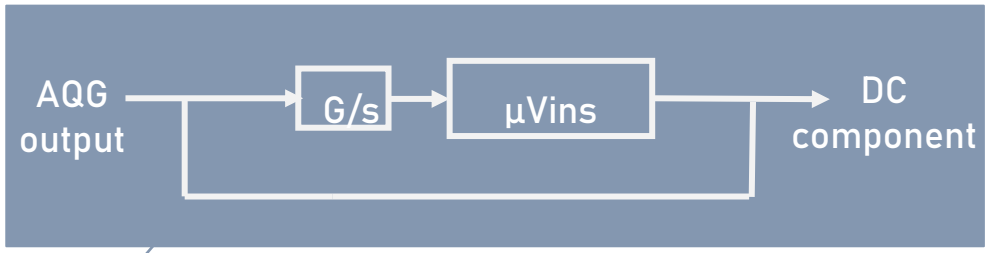
Haidar Lakkis
mhlakkis@uliege.be

Atomic Quantum Gravimeter ibridization

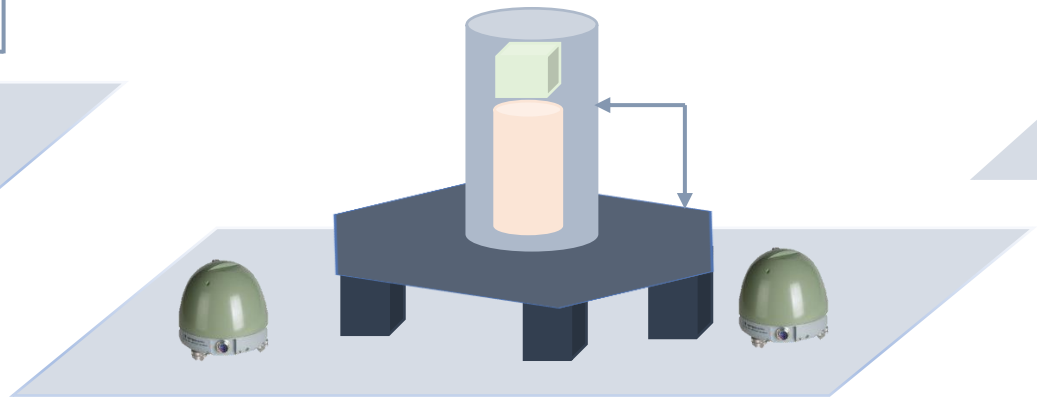
1. Improve the gravimeter



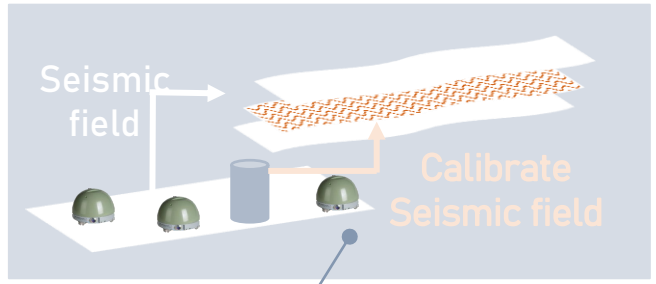
2. Double hybridization

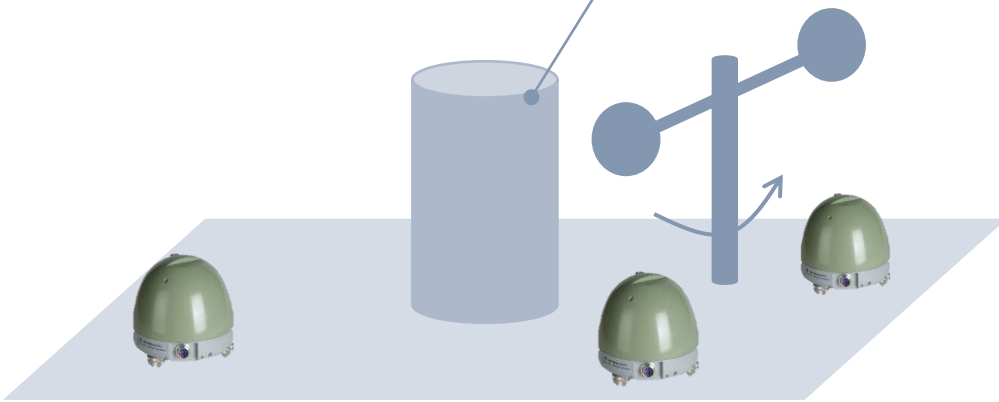


3. Active Isolation



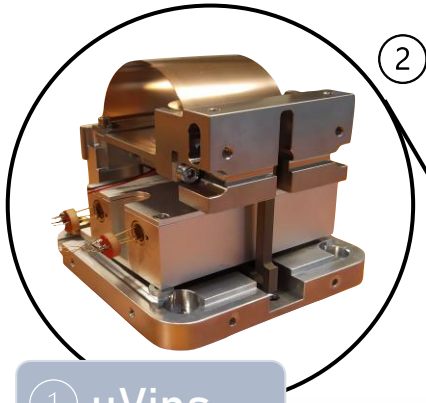
4. Seismic Newtonian Noise Calibration





Mayana Teloi
mayana.teloi@uliege.be

Overview

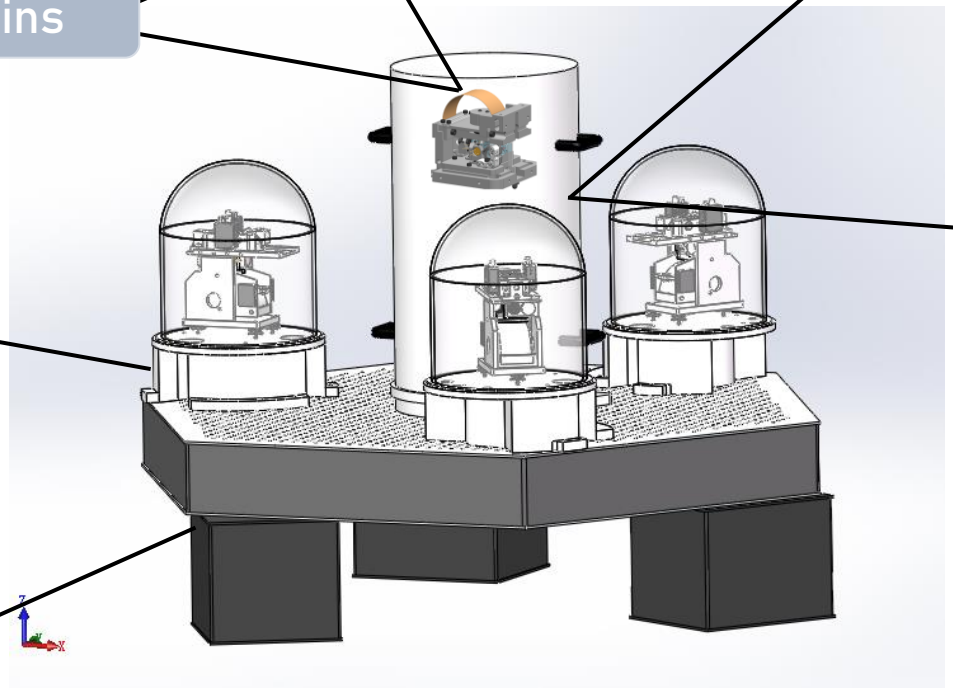


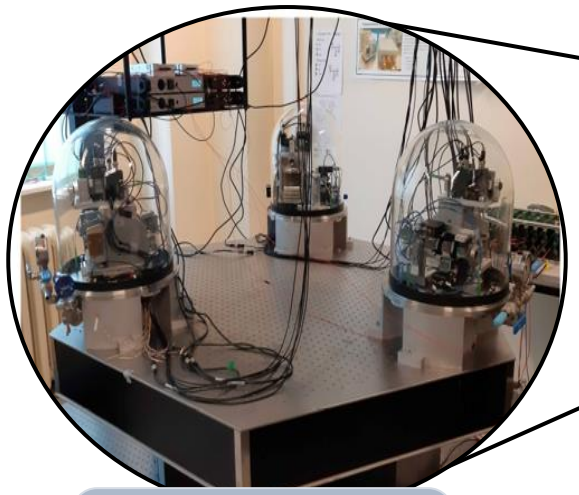
① µVins

② Hybrid sensor: AQG + classical accelerometer

Broad bandwidth
Continuous
Long-term stability

Atomic Quantum Gravimeter





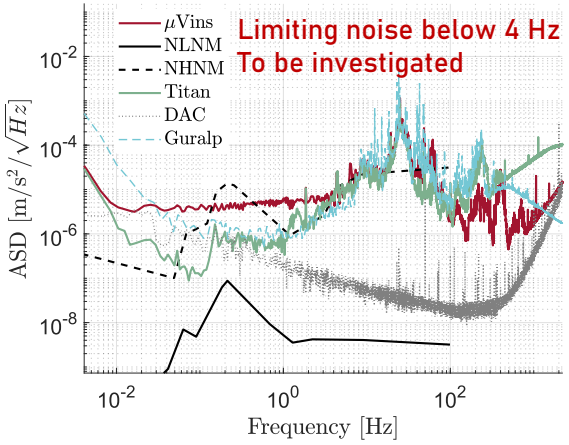
③ Active platform

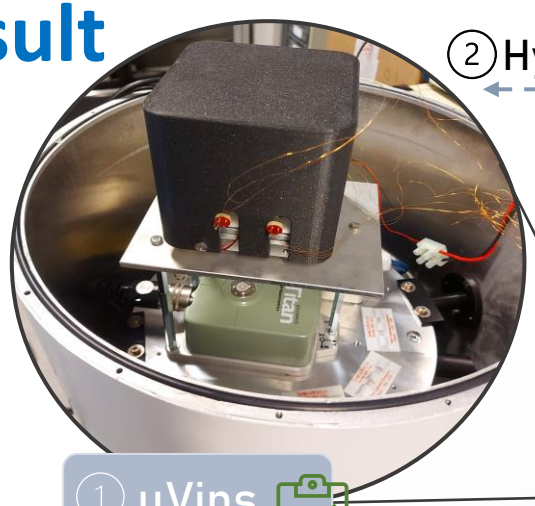
④ Newtonian Noise

Active isolation

Mayana Teloi
mayana.teloi@uliege.be

Preliminary result



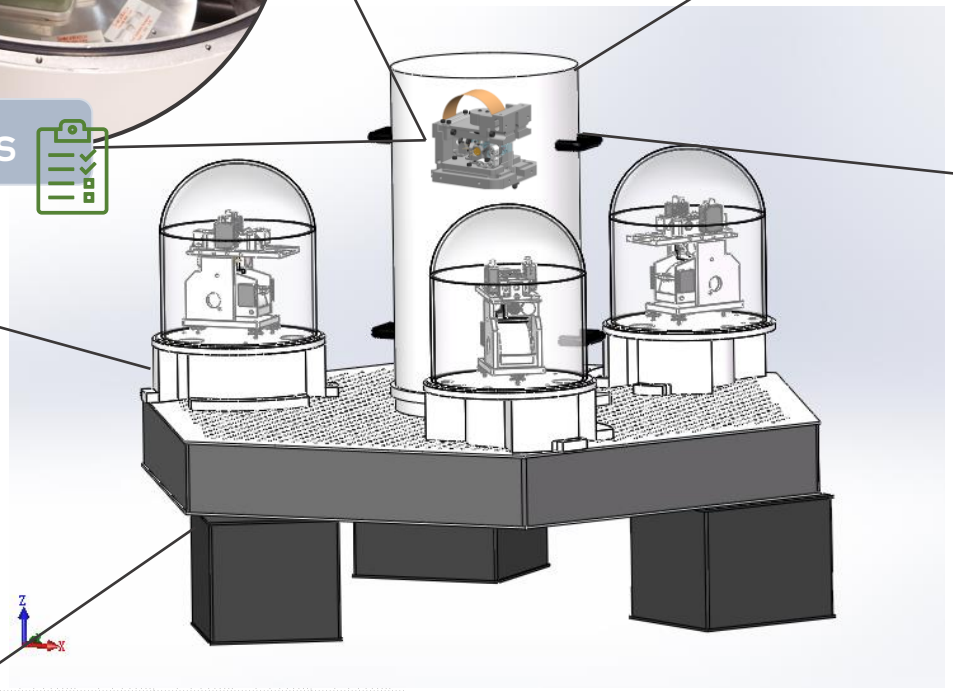


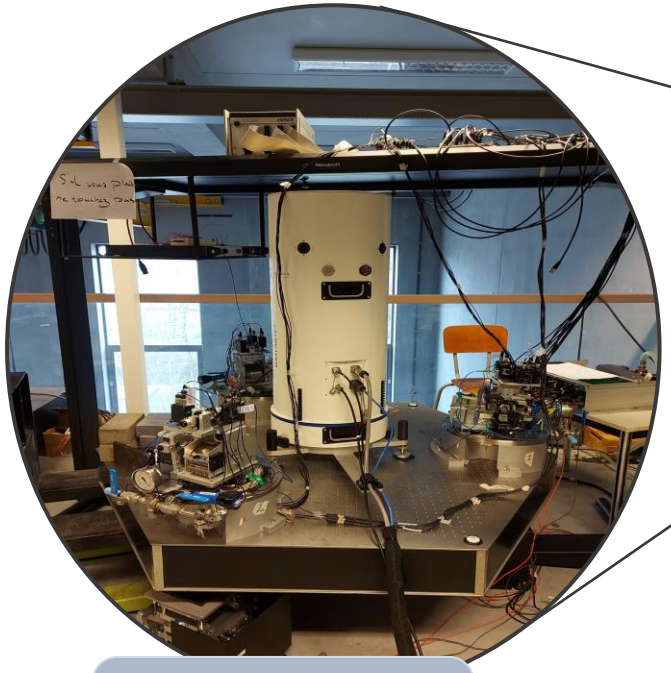
① μVins

② Hybrid sensor: AQG + classical accelerometer

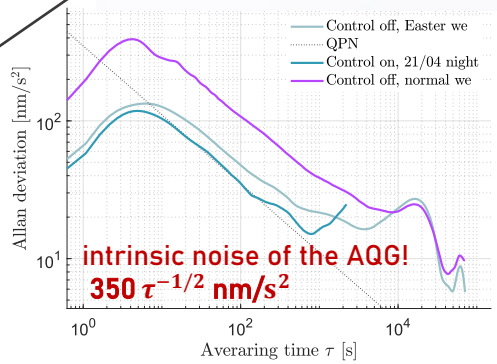
Atomic Quantum Gravimeter

Performance limited by ground vibrations in noisy environment





③ Active platform



④ Newtonian Noise

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.

General contacts and uni network

- Head of the group: Prof. Christophe Collette christophe.collette@uliege.be
- Postdocs:

  Dr. Chiara Di Fronzo cdifronzo@uliege.be

  Dr. Rasa Jamshidi R.Jamshidi@uliege.be
- PhD students ULiege and ULB

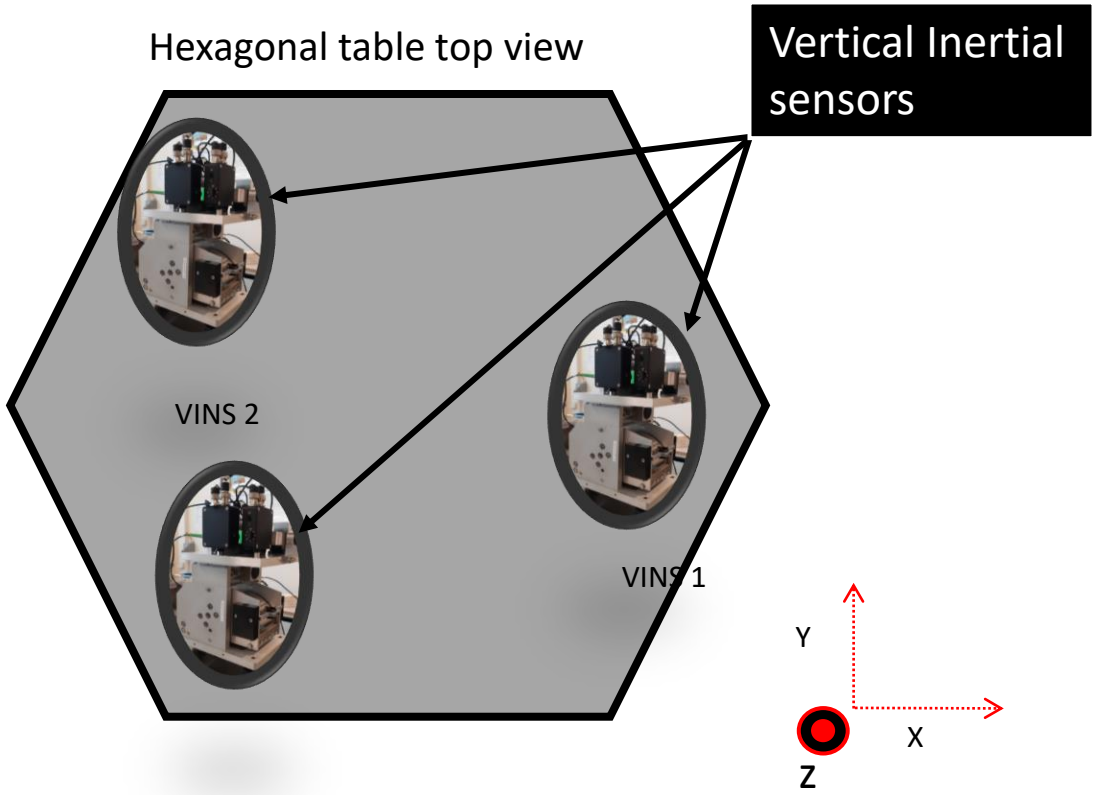
  M. Haidar Lakkis mhlakkis@uliege.be
  Mayana Teloi Mayana.Teloi@uliege.be
  Anthony Amorosi Anthony.Amorosi@uliege.be
  Ameer Sider asider@uliege.be
  Loic Amez-Droz lamezdroz@uliege.be
  Thomas Dehaeze tdehaeze@uliege.be
  Morgane Zeoli morgane.zeoli@uliege.be
  Brieux Thibaut Brieux.Thibaut@uliege.be

Useful links:

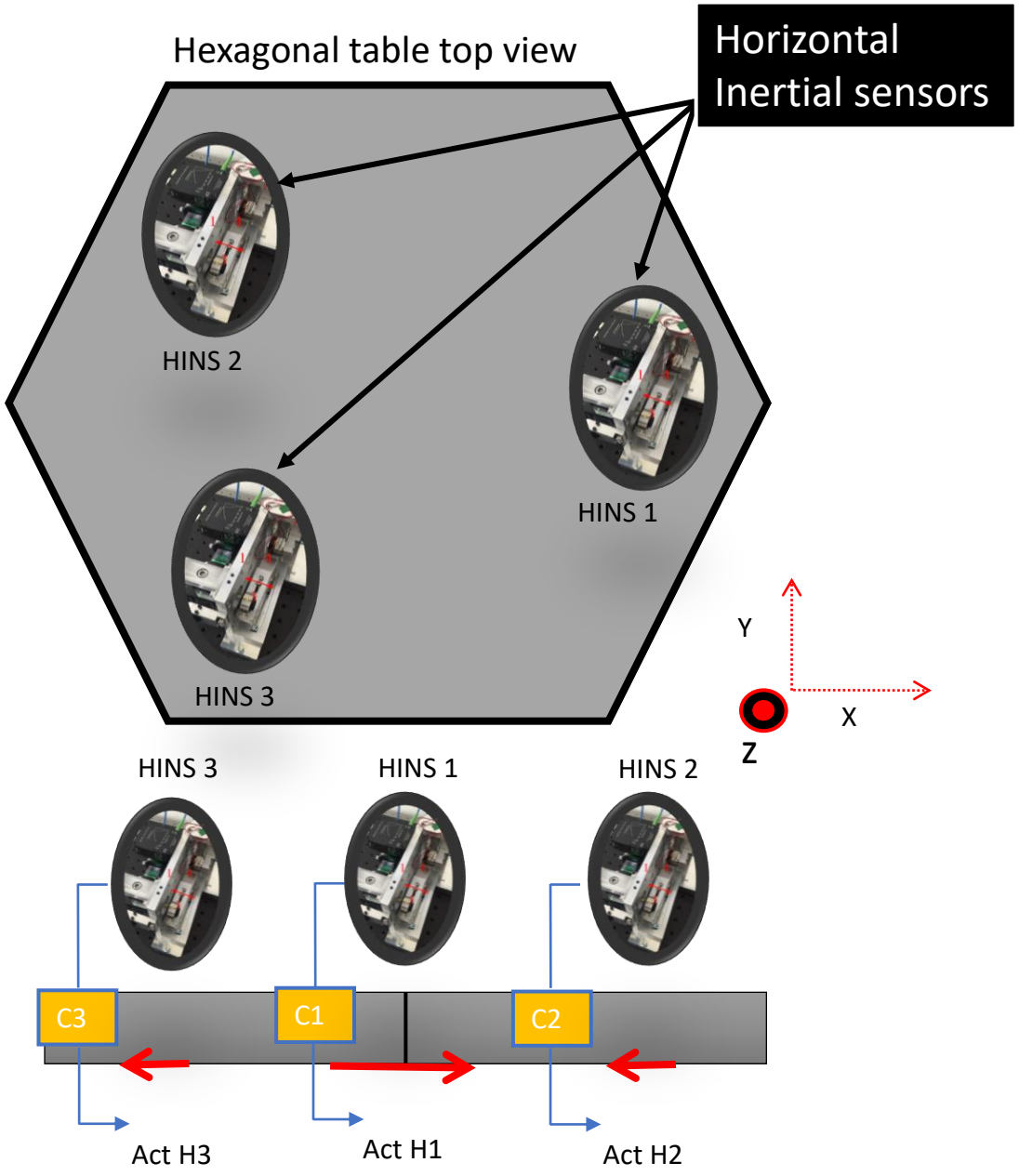
TDR
https://arxiv.org/abs/2212.10083
E-TEST Project website
https://www.etest-emr.eu/
PML website
http://www.pmlab.be/

Back up

Decentralized Control :



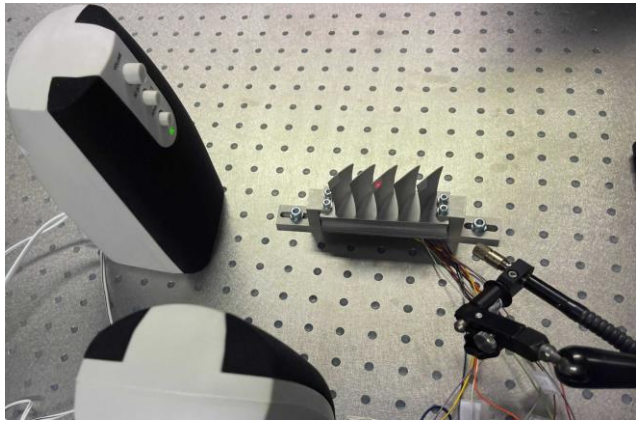
Vertical loops closed in a decentralized way

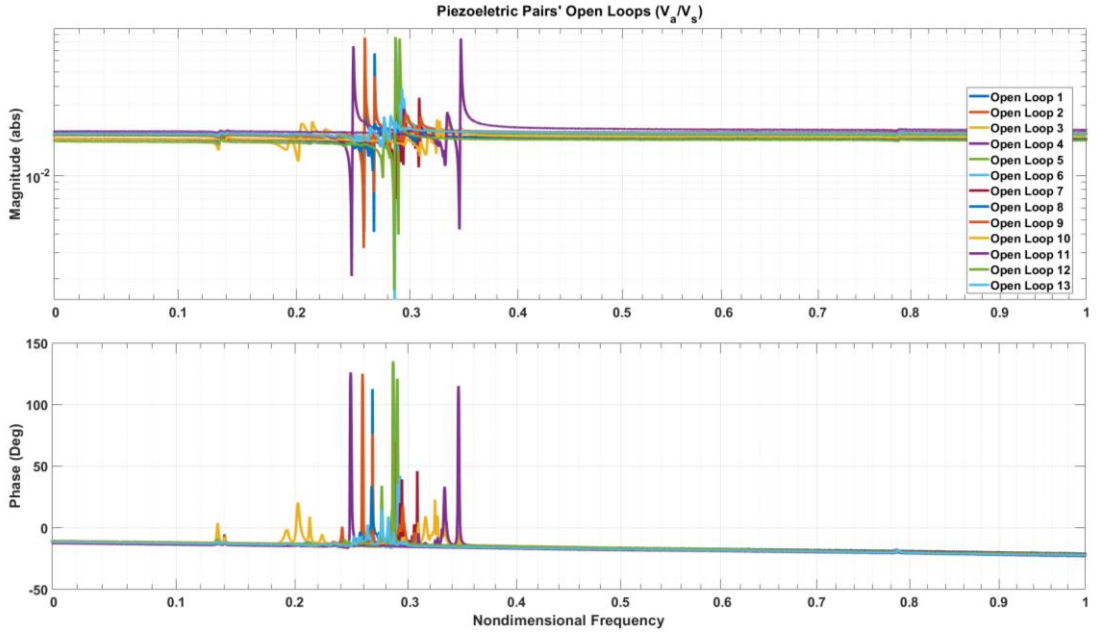


Horizontal loops closed in a decentralized way

Maverick experiment

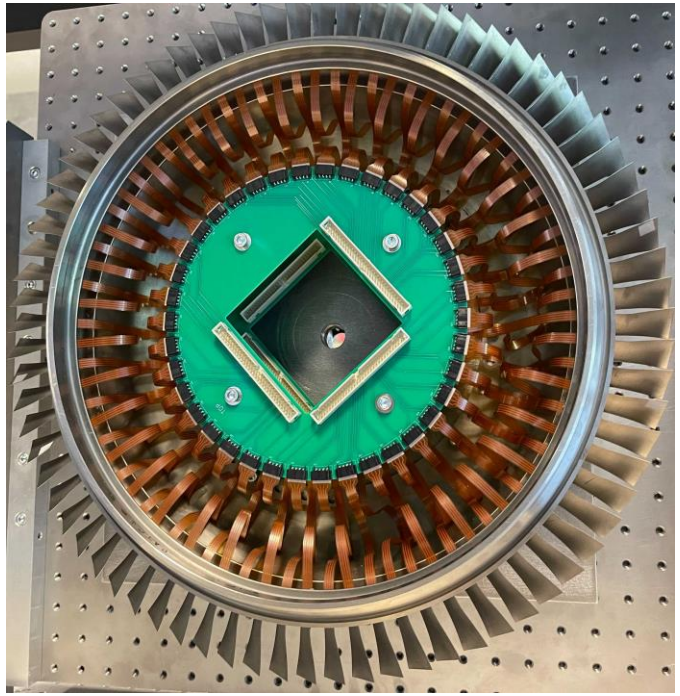
Bladed Rail



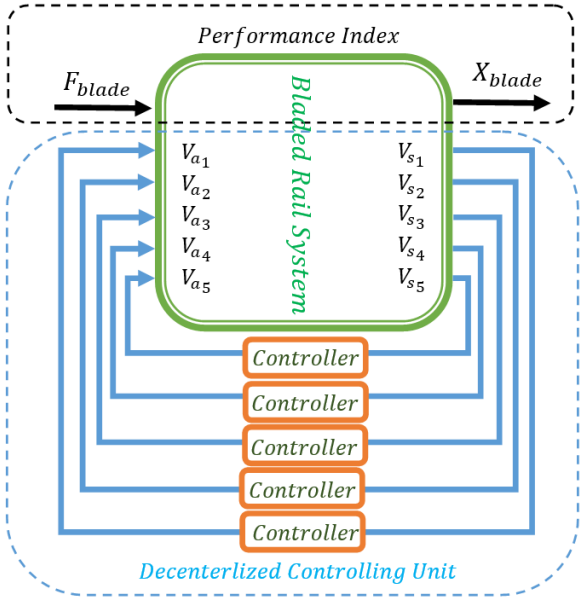


Open Loops of BLUM

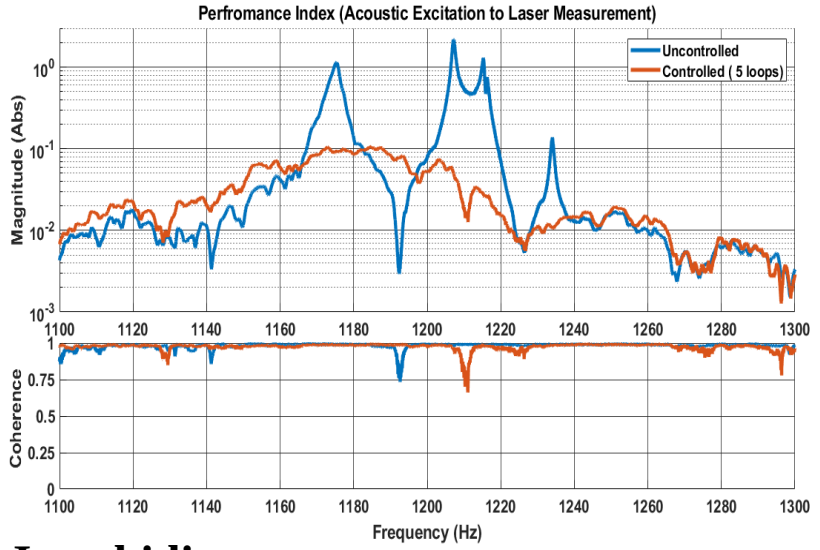
BLUM



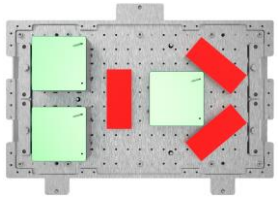
Open Loops of Bladed Rail

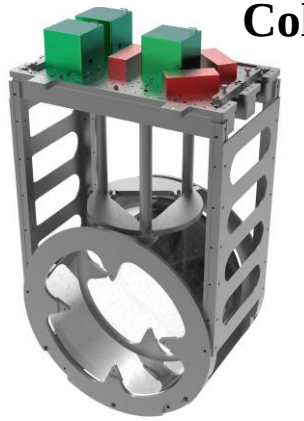


Performance Index of Bladed Rail



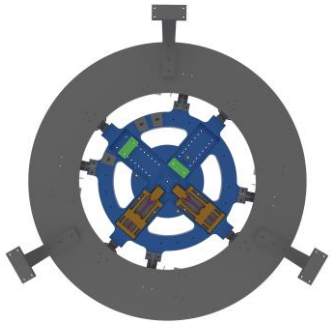
Rasa Jamshidi
r.jamshidi@uliege.be



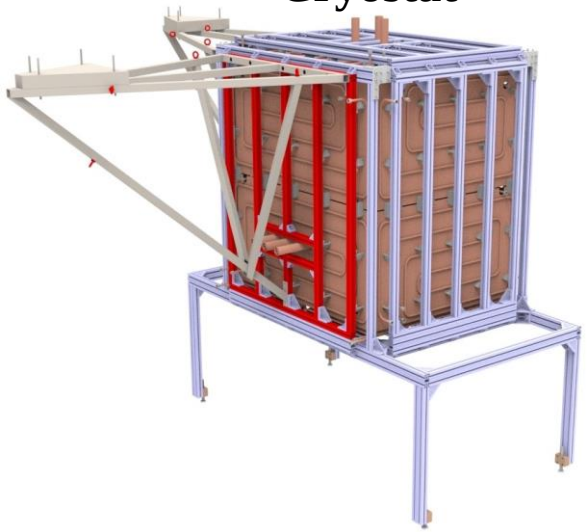


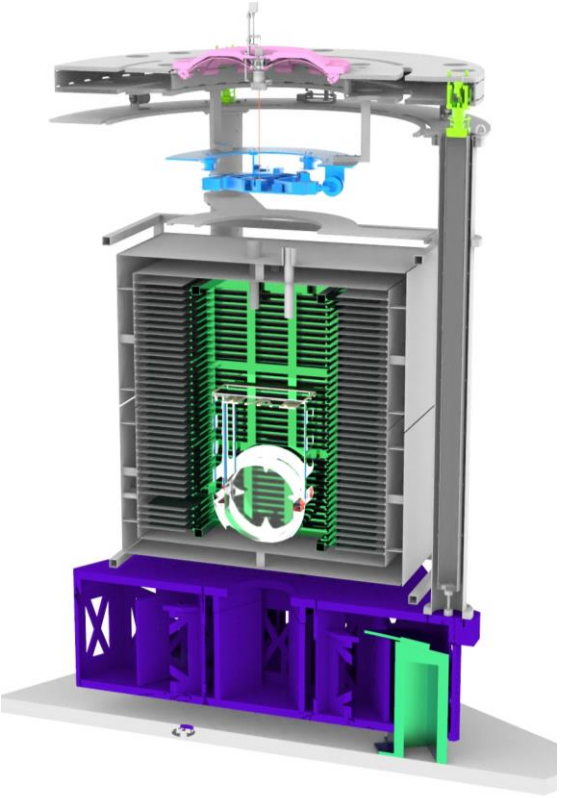
Cold platform & Mirror

Marionette



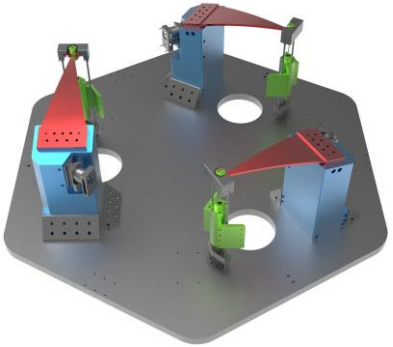
Cryostat

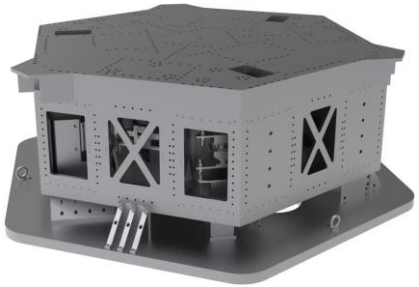




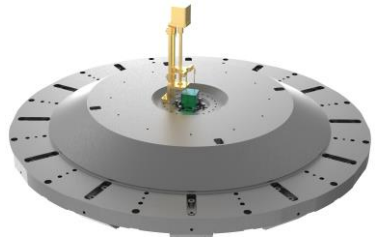
Inverted Pendulum

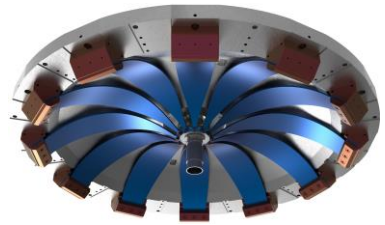
Active platform





GAS filter





Ameer Sider (PML)
asider@uliege.be

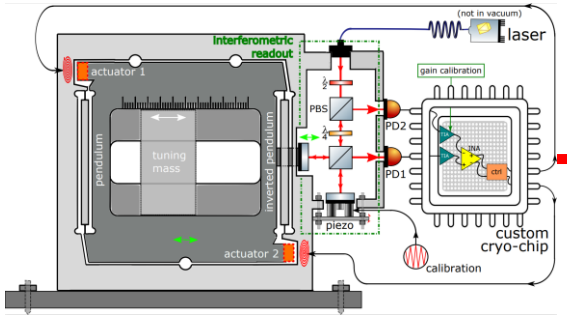
Sensors & Actuators (vacuum compatible)

4 Optical Sensors

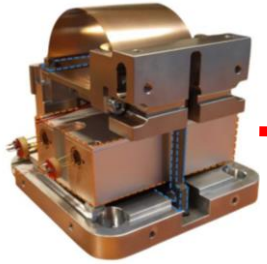
4 Voice coil actuators

Temperature sensors

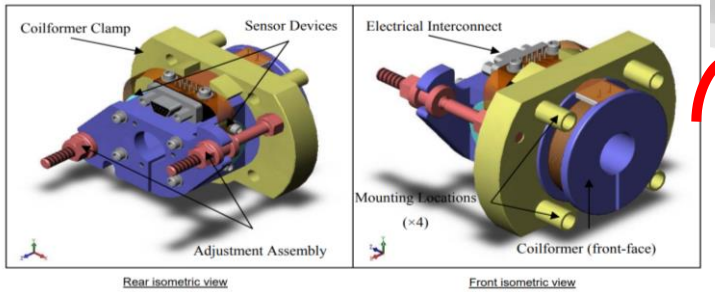
6 Cryogenic inertial sensors



6 Inertial sensors



6 voice coil Actuators



6 BOSEMs

Cross-spring pivot hinge