



CRYOGENIC RADIATIVE COOLING OF A 100KG SUSPENDED PAYLOAD: FROM DESIGN TO TEST

L. Jacques, C. Lenaerts, B. Levan, C. Collette

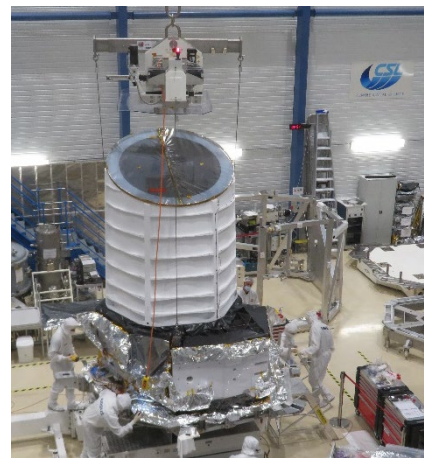


The E-TEST project

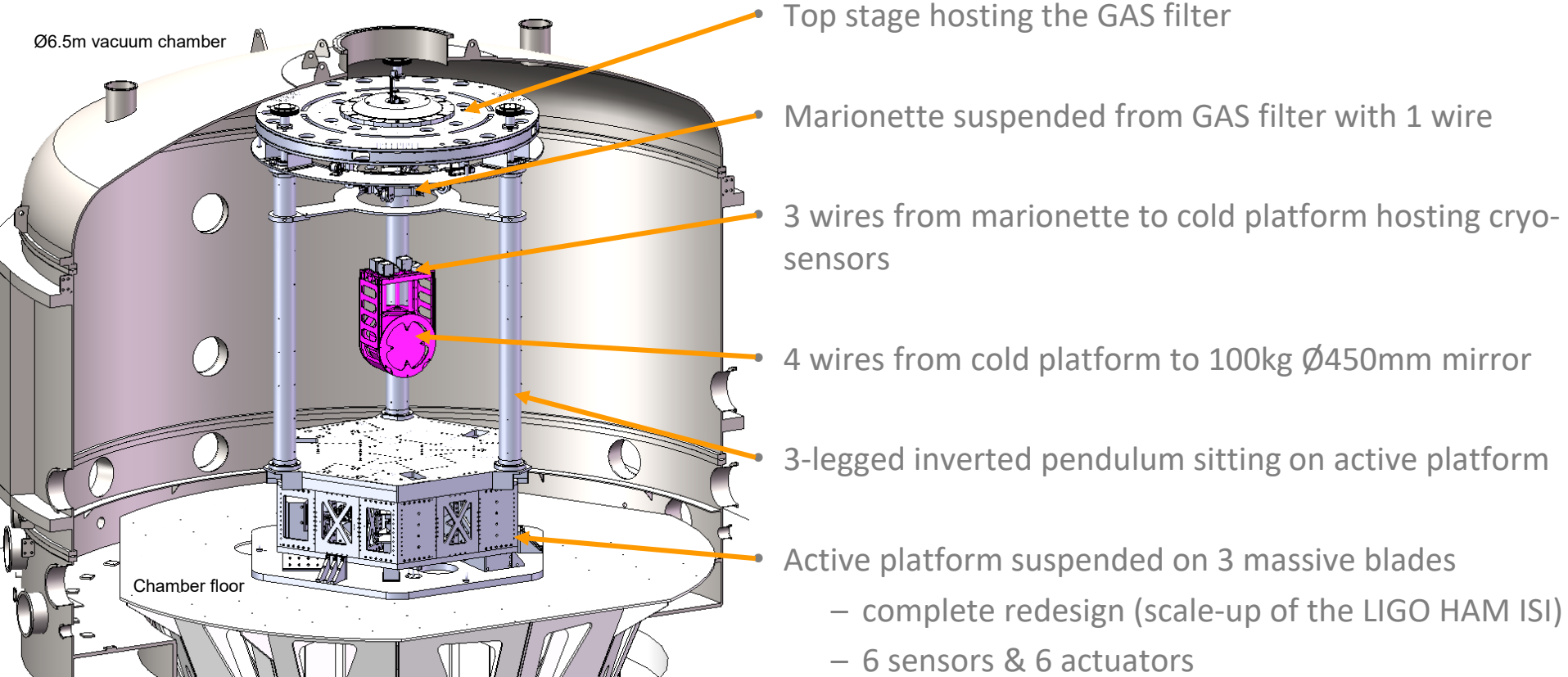


- Funded European program Interreg Euregio Meuse-Rhine.
- From 2020 to 2023
- 11 consortium members from the 3 countries (BE, NL, GE)
- 2 main research topics:
 - Eco-friendly and non-invasive imaging of the geological conditions in the EMR region
 - A prototype of large suspended cryogenic silicon mirror, isolated from seismic vibrations at low frequency

- Scientific space instrument development & testing
- Space-qualified optical coating design & charact.
- Several vacuum chambers
 - From 1.5 to 6.5m diameter (soon 7m...)
- Cryogenic optical calibration capabilities
 - 2 helium refrigerators, each providing ~300W @ 20K
 - Connected to the different chambers
- Contamination management
- Straylight management (ESA, NASA instruments)



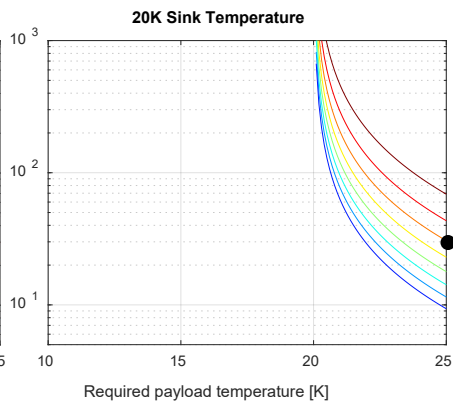
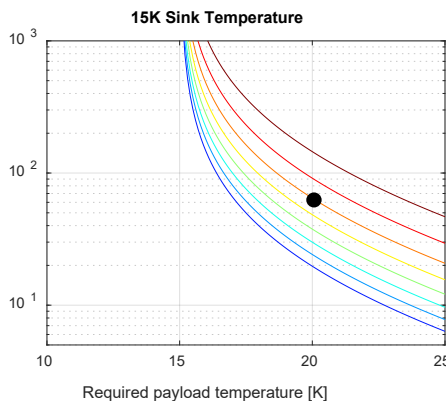
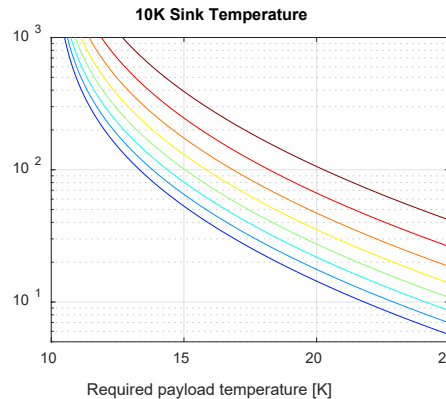
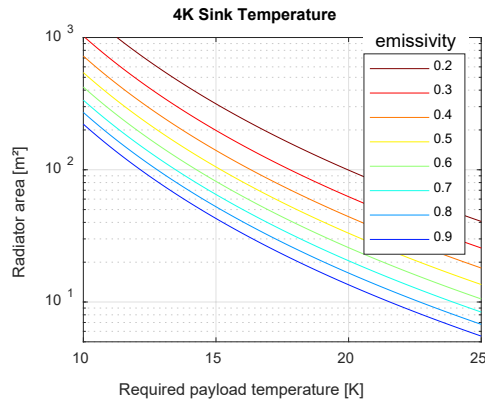
The prototype: suspension architecture



Cryogenic radiative cooling: mission almost impossible



- What is the required radiative exchange area?
 - To evacuate 100mW
 - Considering a given heat sink temperature
- The answer strongly depends on emissivity (drops with T)!
 - $\sim 30\text{m}^2$ for 0.4 emissivity, 20K sink & 25K target, $\sim 60\text{m}^2$ for 15K sink & 20K target



Assessing the heat load (devils hides in the details)



- Various contributors
 - Radiative load from nominal apertures (suspension, optical) → ~50mW
 - 3 optical + 3 suspension, adequate baffling tubes sizing
 - Radiative load from parasitic holes & defects in insulation → ~50mW
 - Experience based on spacecraft cryogenic tests (Planck, Herschel, EUCLID,...)
 - Conductive load from suspension wires from the Marionette → ~100mW
 - High tensile strength, low thermal conductivity wires: Titanium
 - Conductive load from harnesses (electrical & optical for the inertial sensors and temperature sensors) → ~50mW
 - Radiative thermalisation of the harness along the suspension wires
- Total: ~250mW

How to fit $2.5 \times 30\text{m}^2 = 75\text{m}^2$ around the payload?



- Compress the radiative heat exchanger area: interleaved fins!

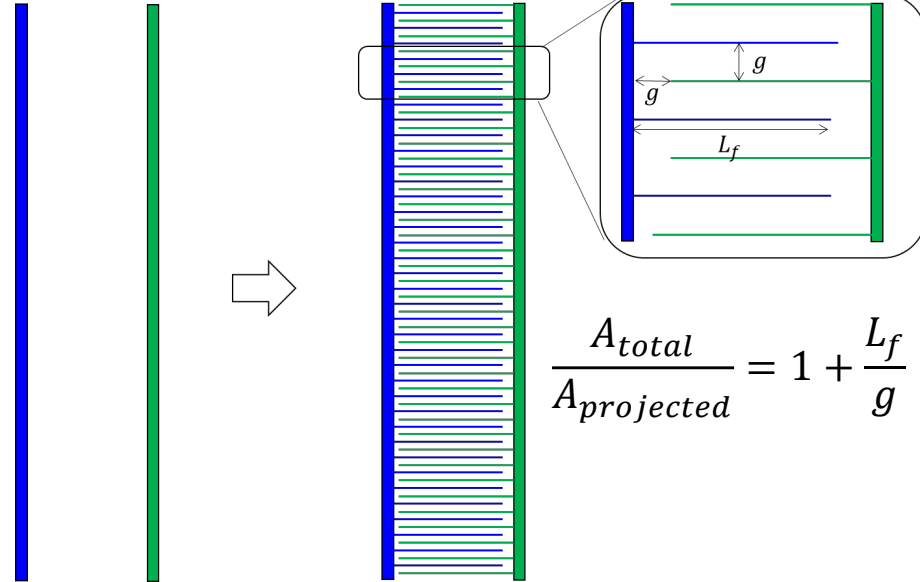
- Trade-offs:

- Fin length & thickness $\leftrightarrow$ stiffness
mass
- Gap $\leftrightarrow$ no-contact
deformation
relative motion

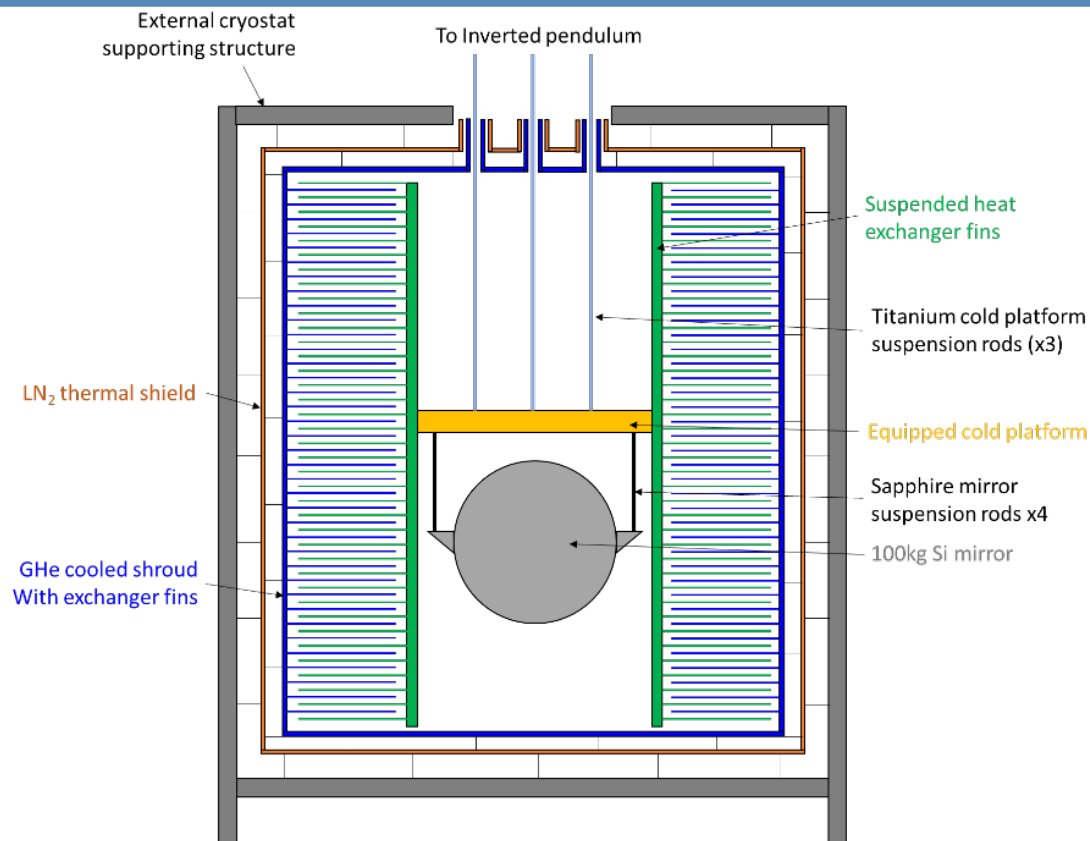
- 300mm long flat fins, 20mm gap

- Amplification factor = 16

- $75\text{m}^2 \rightarrow 5\text{m}^2$ around the cold platform, 1m^2 footprint



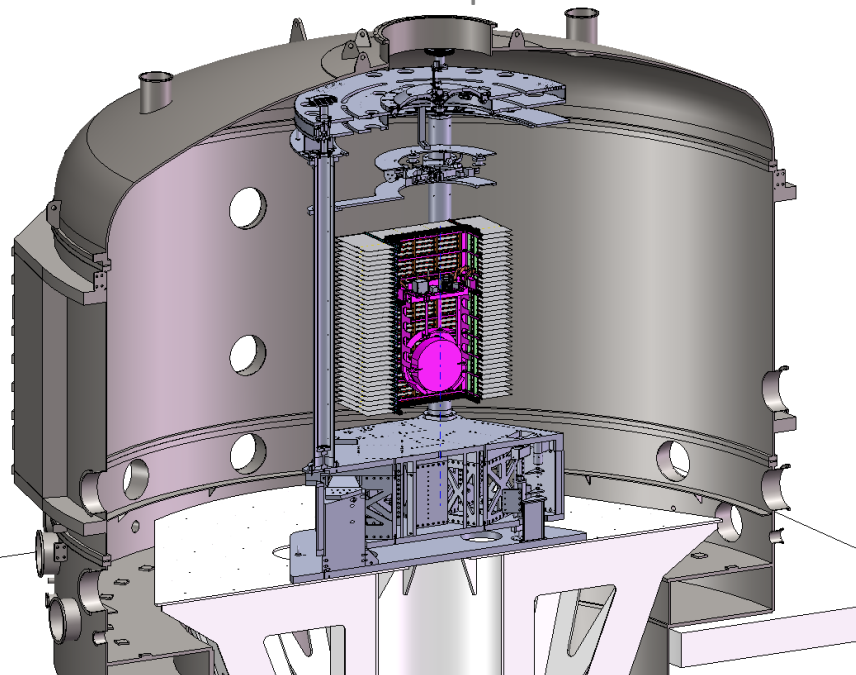
The compact radiative heat exchanger concept



Back to the prototype...

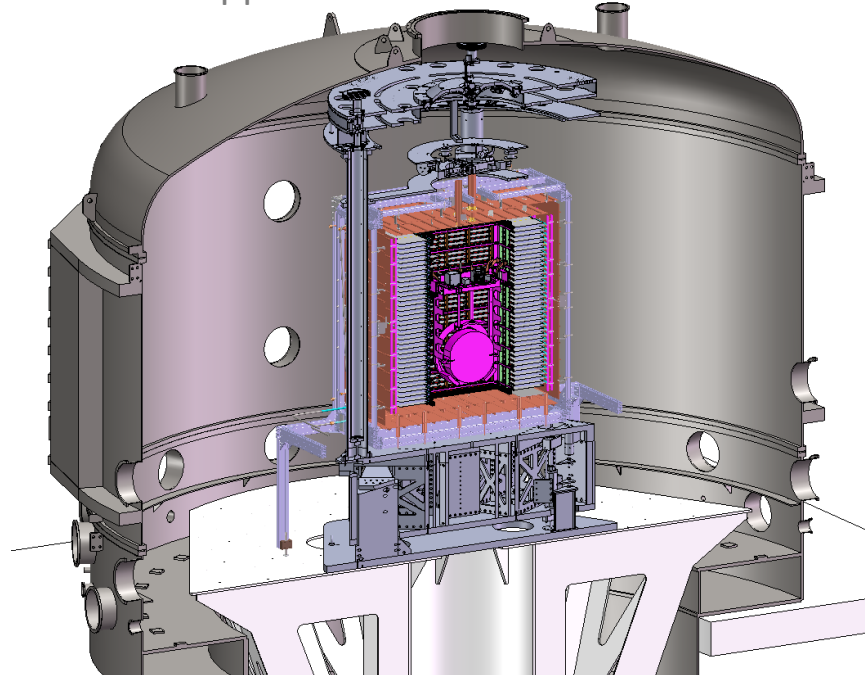
Suspended inner cryostat

mounted to cold platform

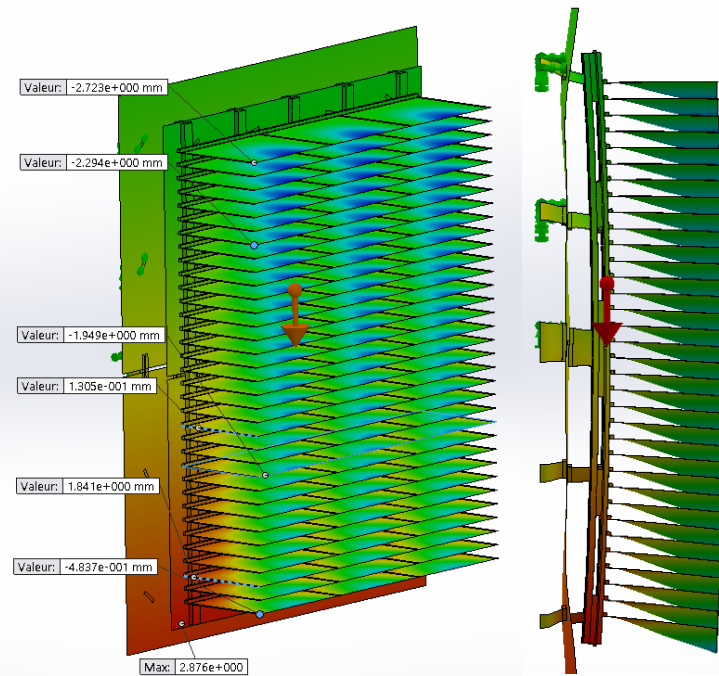
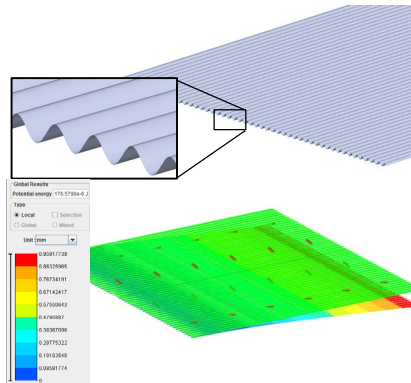


actively cooled external cryostat

supported from chamber floor



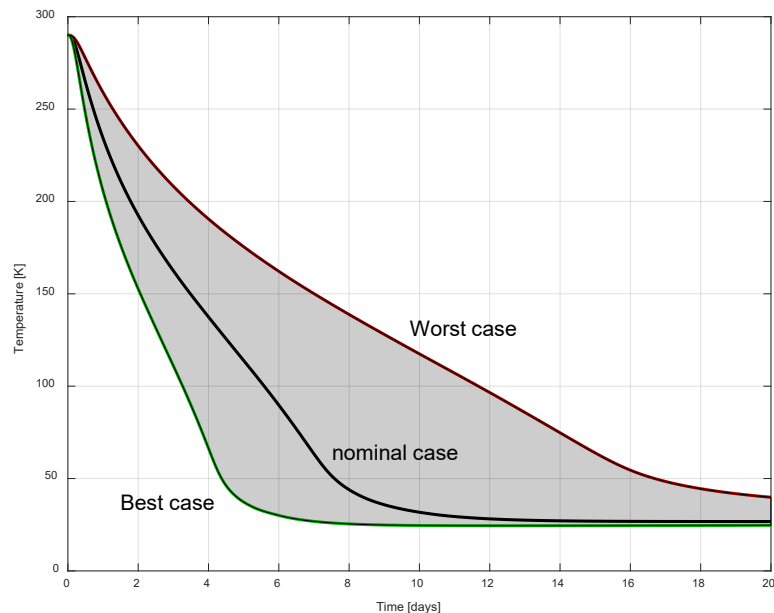
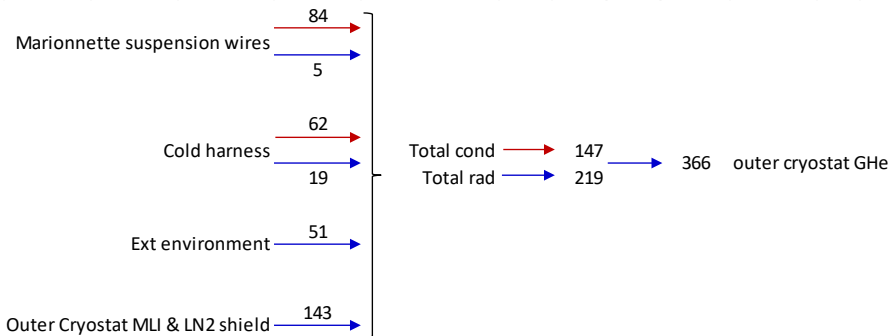
- Gap sizing confirmation
 - T-E & gravity deformations
 - Buoyancy effects
 - Manufacturing & assembly tolerances
- Fin stiffness
 - Flat vs. corrugated



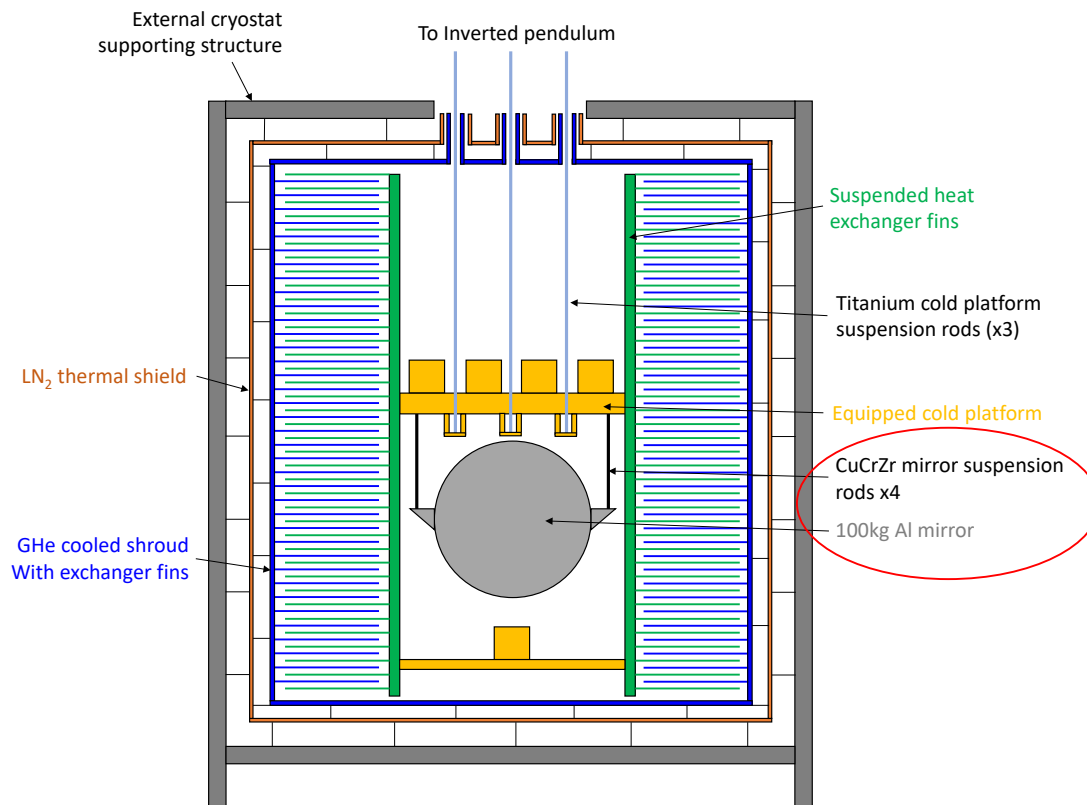


Cooling predictions

- ESATAN-TMS (space standard thermal analysis software)
- Temperature-dependent properties
- Heat load confirmation
- Uncertainties

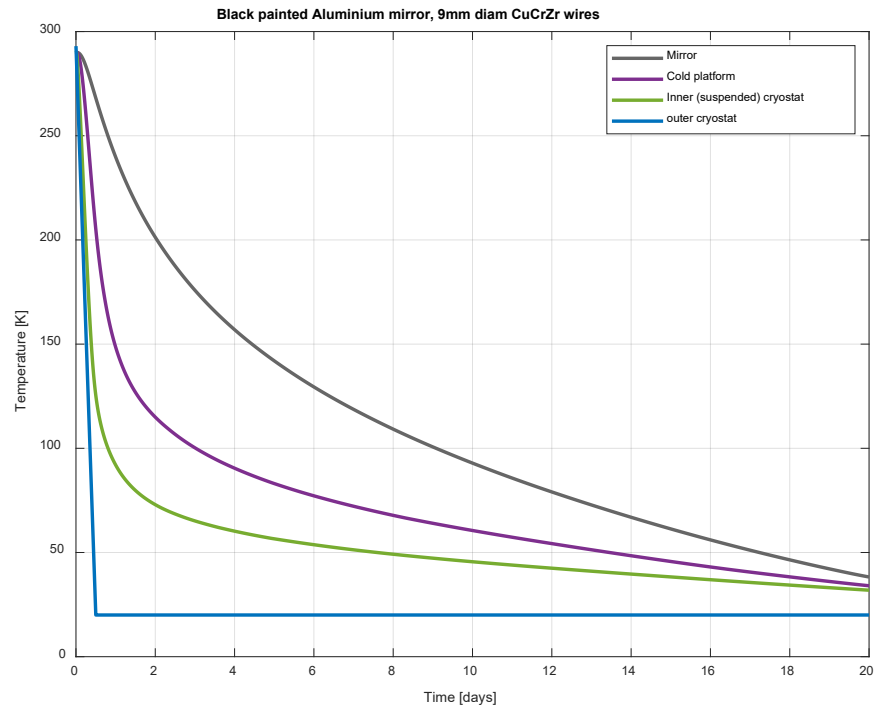


As-built design (programmatic constraints)





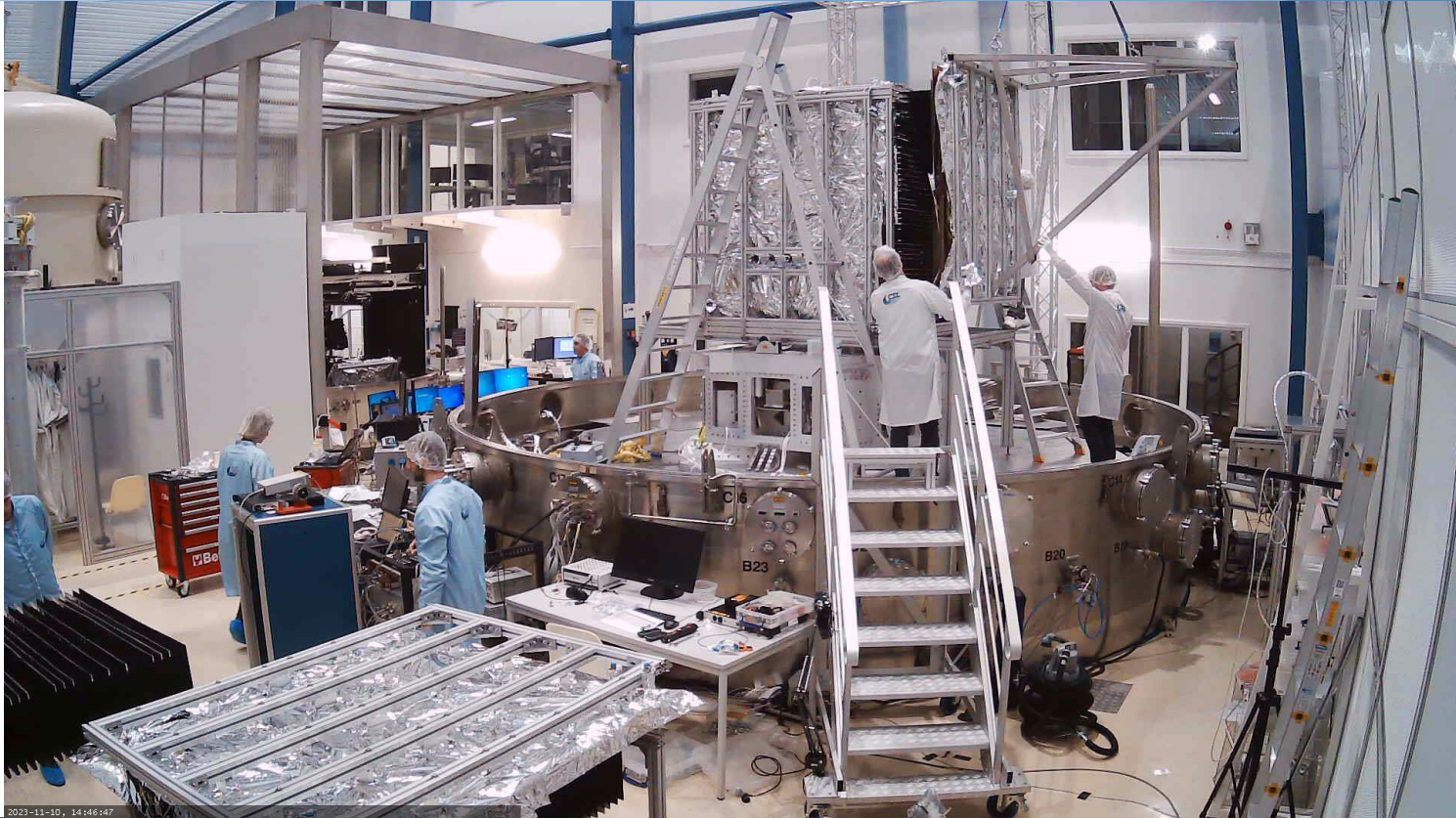
- Aluminum dummy mass specific heat is detrimental
- CuCrZr suspensions is the bottleneck



In practice: active platform & inner cryostat



Closing the outer cryostat (integration is tricky)

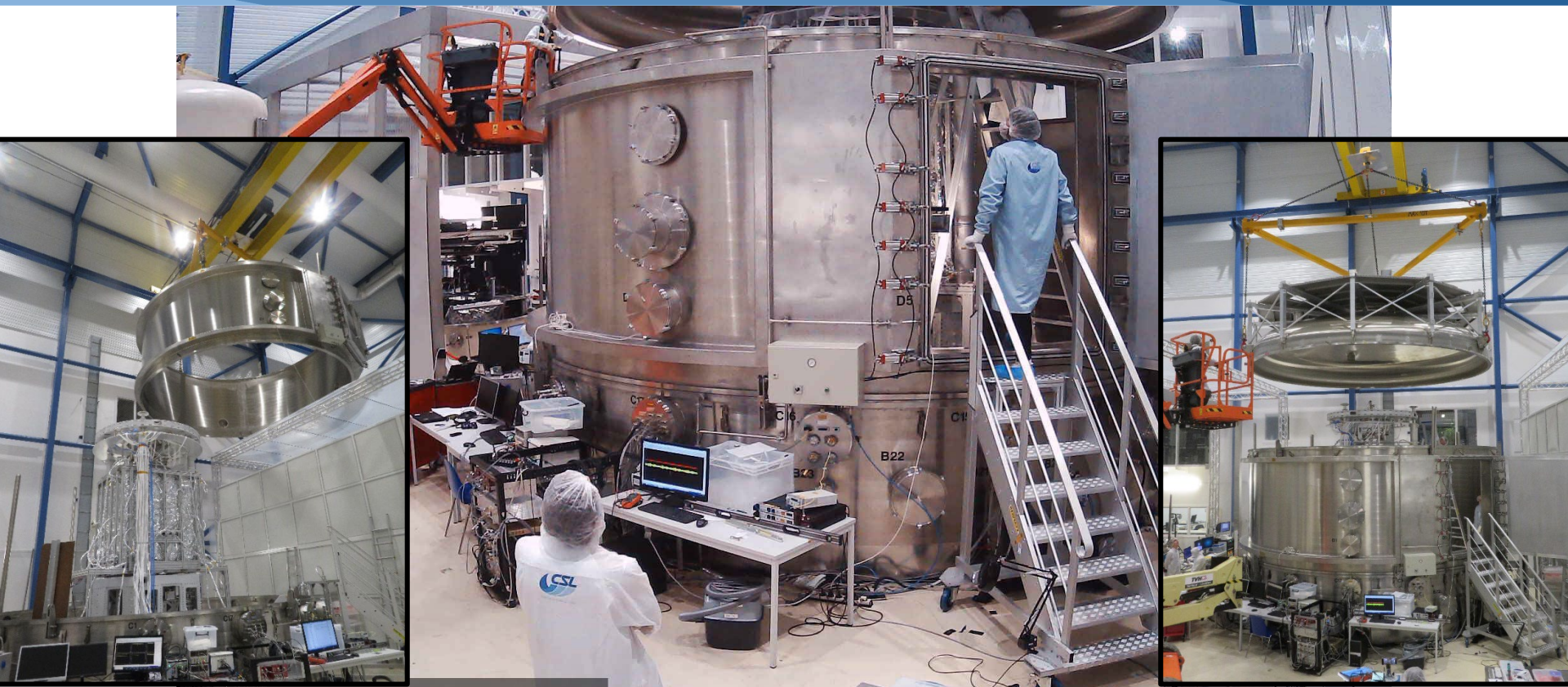


The inverted pendulum and the suspension



2023-11-10, 17:16:49

Closing the chamber (& crossing the fingers)



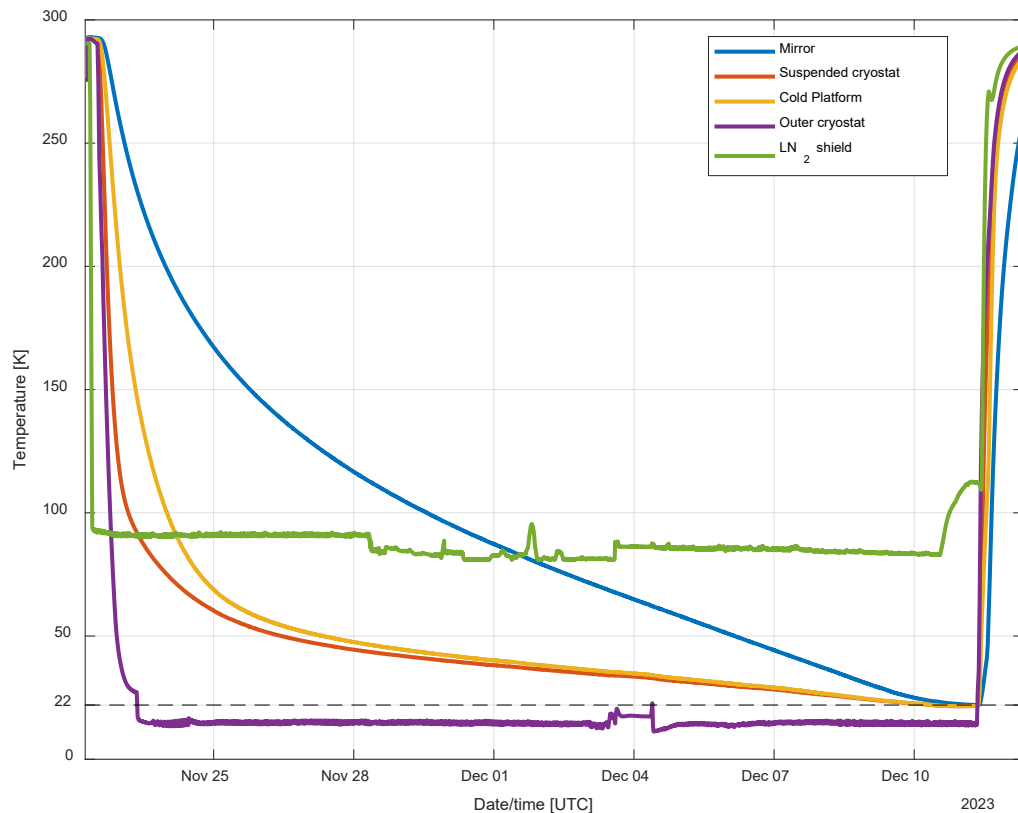


In practice

- 2-3 months assembly & integration
- 20 days under vacuum Nov.-Dec. 2023
- 18 days of cooling
- $\sim 10^{-7}$ mbar

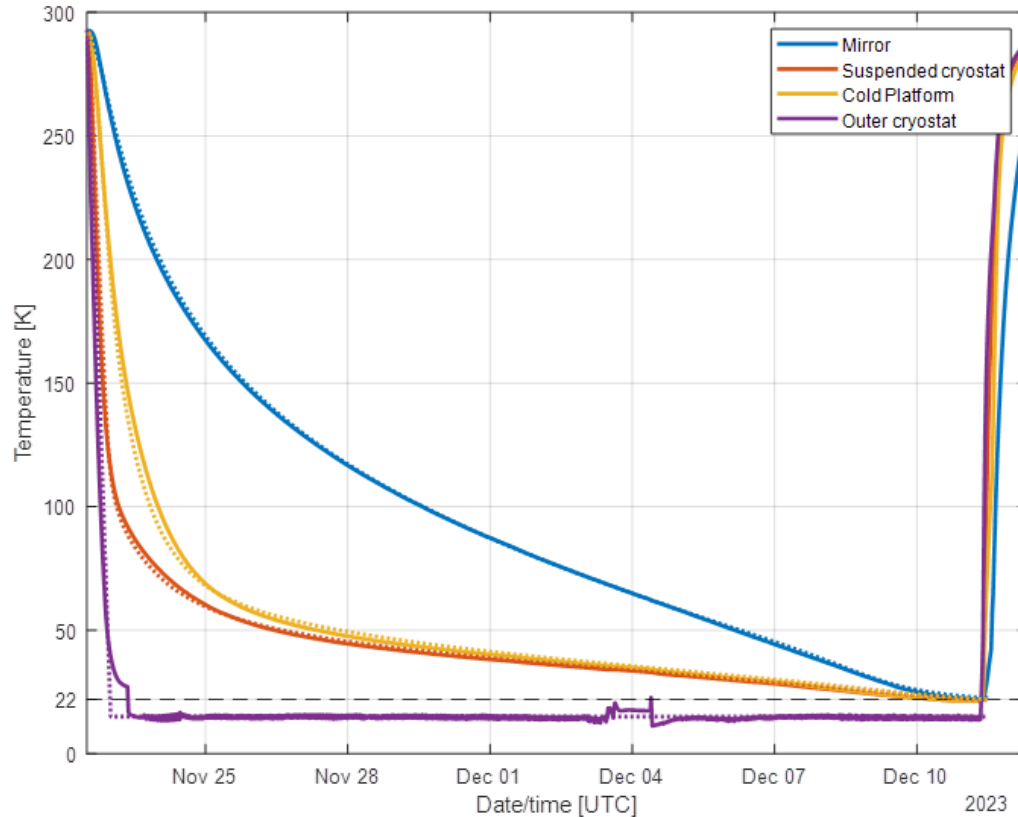


Actual results: 22K payload with 15K sink in 18days





Correlating the ESATAN model (dashed line)





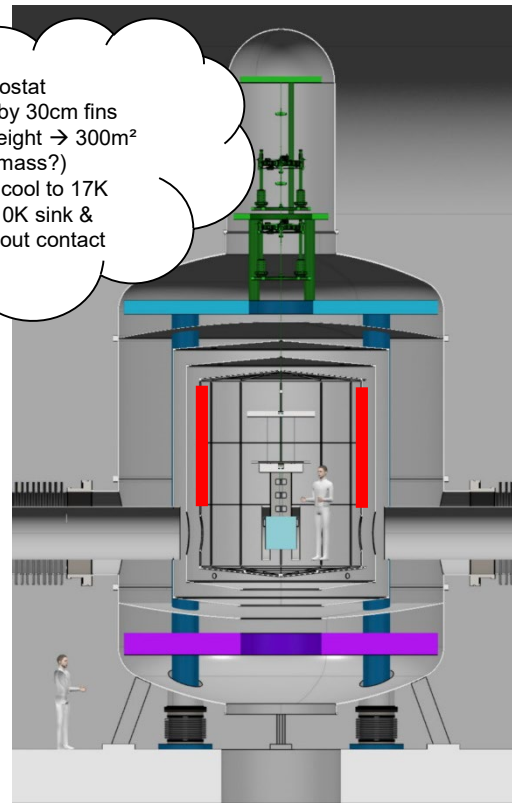
- We are new (not to say dummies ;-) in the ET GW community
- Integrated project: suspension + cryogenics
- Lots of lessons learned
- System engineering is very important: gathering the requirements from various disciplines

What we have to do...



- Integrate the 450mm diam 270mm Si mirror
- Suspended cryostat is not optimized for stiffness
 - Modal analysis required (standard in space industry)
- Sizing for >500mW + include integration constraints
- Contamination (mostly H₂O) management:
 - Drives optical load from laser for each monolayer
 - Cryostat radiative exchanger area provides a very good trapping area (always cooler than mirror, warm-up strategy heating the mirror first)
 - E-TEST was not requiring UHV
 - MLI was used (standard for spacecraft testing) but alternative (less prone to H₂O trapping) solutions exist in the space industry and could be adapted
- Cryogenic emissivity enhancement
 - Experience for Planck/EUCLID where >0.95 @ 20K was achieved through texturation

2m diam cryostat
surrounded by 30cm fins
over 3.5m height → 300m²
exch. area (mass?)
Sufficient to cool to 17K
with $\epsilon=0.5$, 10K sink &
500mW without contact



- FOCAL7 CSL extension project allows future E-TEST developments
 - 2 new buildings: 1 large cleanroom hosting $\varnothing 7\text{m} \times 12\text{m}$ chamber + 1 new hangar
 - CRISTAL lab located in second building and will include
 - $\varnothing 3\text{m}$ chamber
 - Cleanroom
 - Cryogenic (LN_2 , GHe) facilities connections



Thank you for your attention

