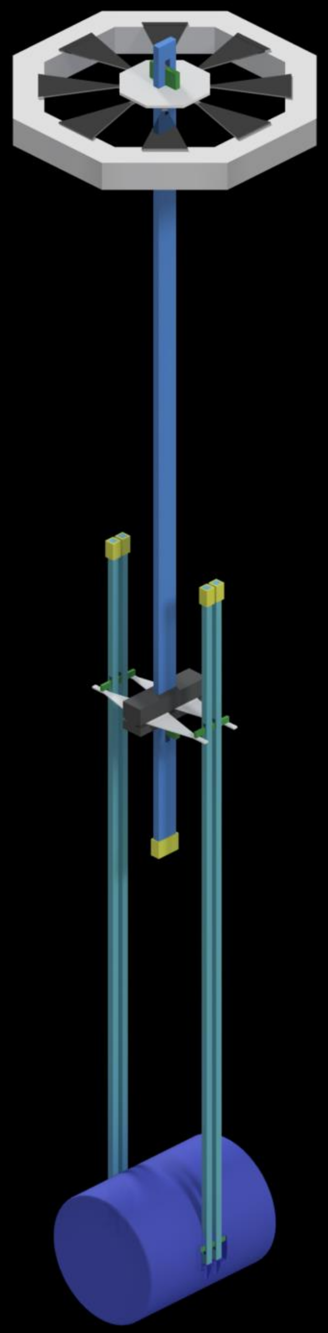
Cryogenic suspension with flexures in compression

Fabián Peña, Nelson Leon, Leonardo González, Harry Themann, Riccardo DeSalvo, Guerino Avallone, Gerardo Inannone.

University of Guadalajara, California State University, University of Salerno



Outline

- Introduction: concept and hardware description.
- Mechanical behaviour.
- Heat extraction performance.
- Displacement thermal noise.
- Conclusions and future work.

Introduction

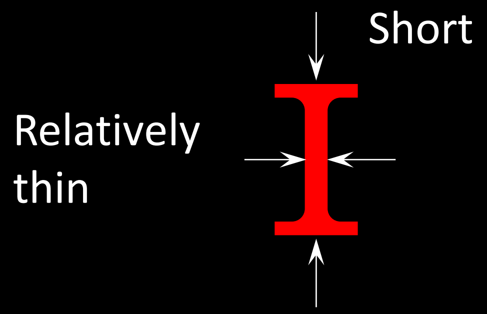
Requirements and features:

- Allow the extraction of 0.5 W in heat.
- Soft for low displacement thermal noise: pendulum mode at 356 mHz.
- Mechanically robust: safety factor of 6 in compression.
- **Damp the internal resonances with an active control system.**
- **Optical anti-spring to lower the pendulum resonance frequency.**

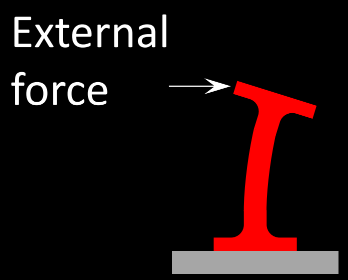
Stay tunned!

Key element: a short and thin flexure

- Its geometry is suitable for heat extraction: thin but short.



- It's a spring that can be made soft:



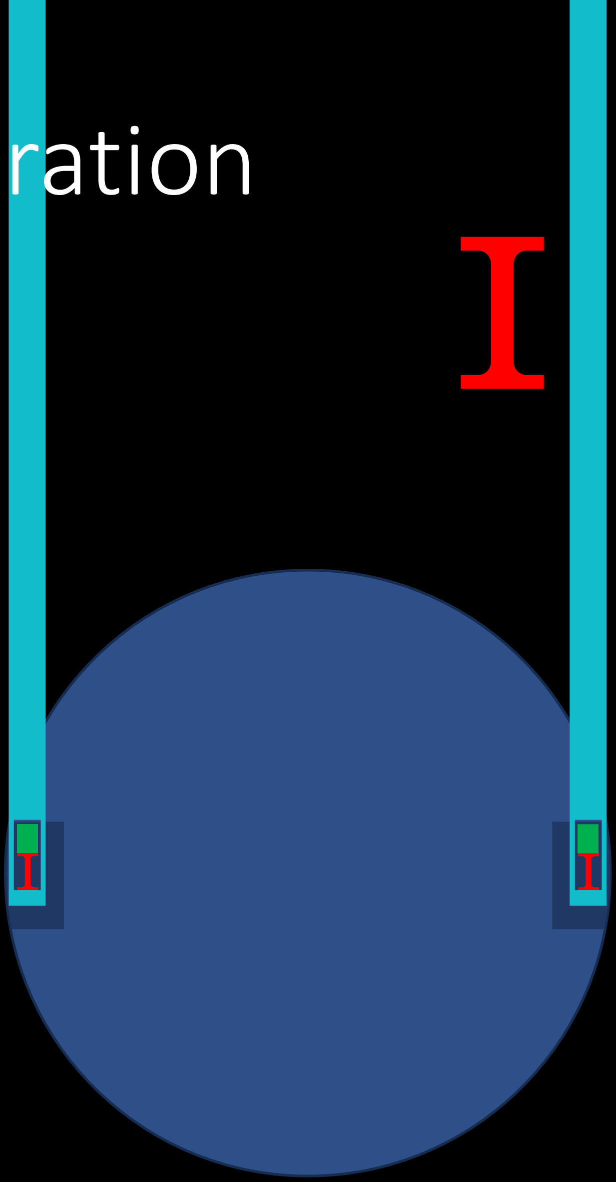
- It's robust because it works under the compression of the load: **compressive strength of silicon is 3200 MPa at room temperature.**
- For lower thermal noise, it is likely easier to achieve a good surface quality in a small flexure than in a long suspension rod.

Hardware configuration

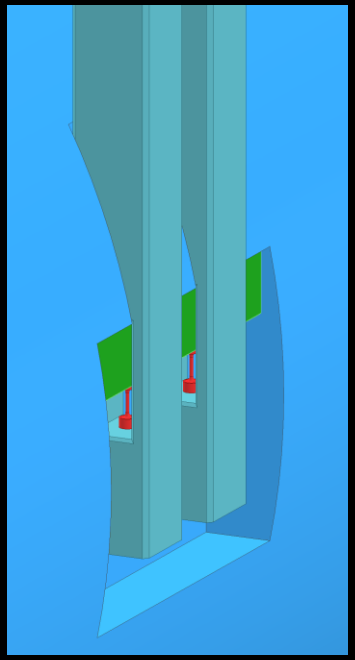
- Mirror
- Cross beam
- Side Feature
- Flexures
- Suspension beams

Based on Joris' presentation last year

Side view



Front cross section view

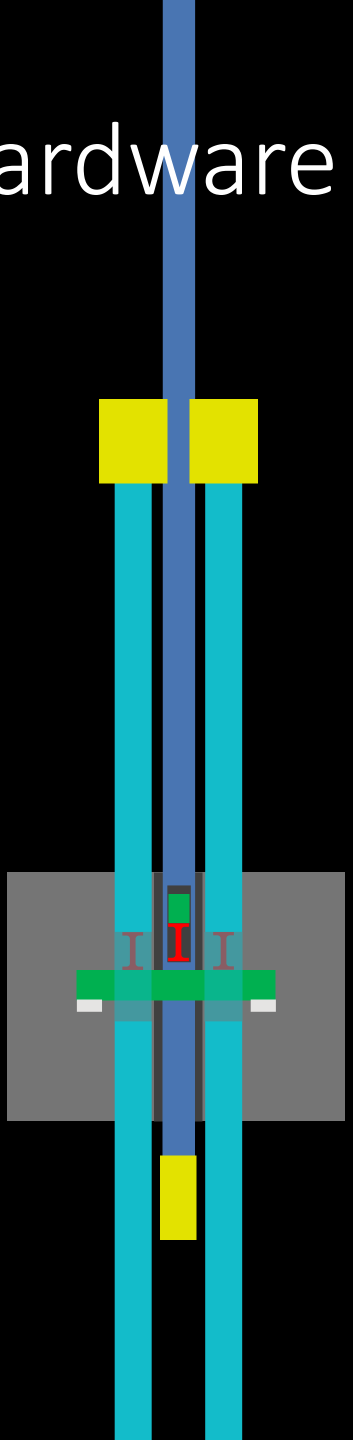


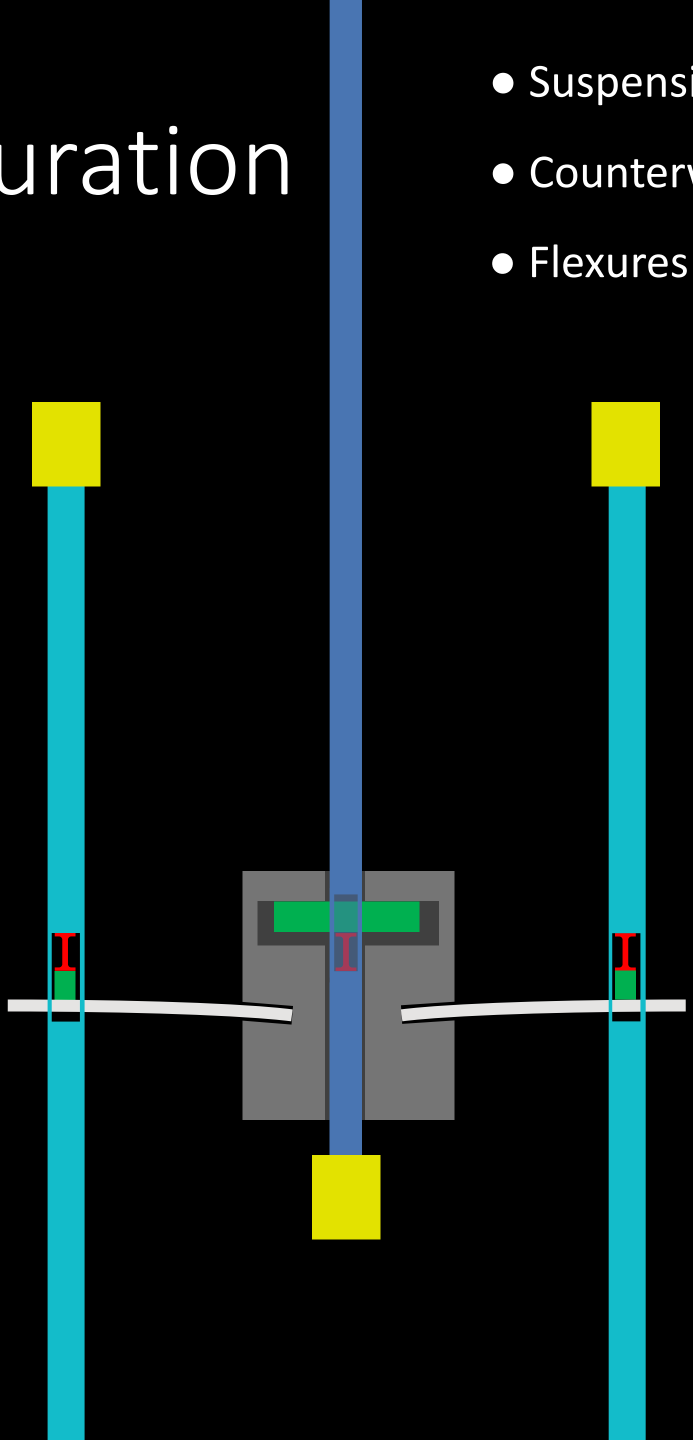
Mirror side 3D-CAD

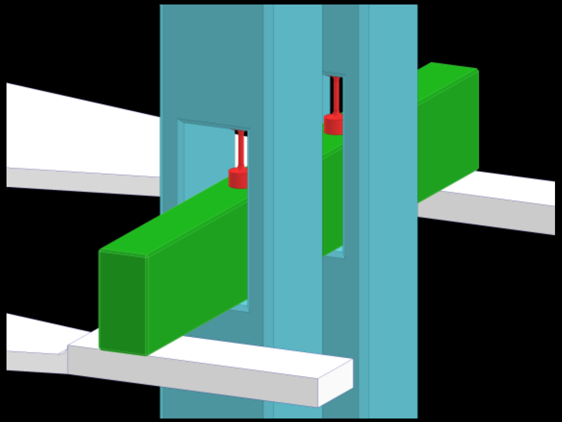
Hardware configuration

- Suspension beams
- Counterweight
- Flexures
- Cross beam
- Spring blades
- Intermediate body

- Cross beam
- Flexure
- Suspension beam
- Counterweight



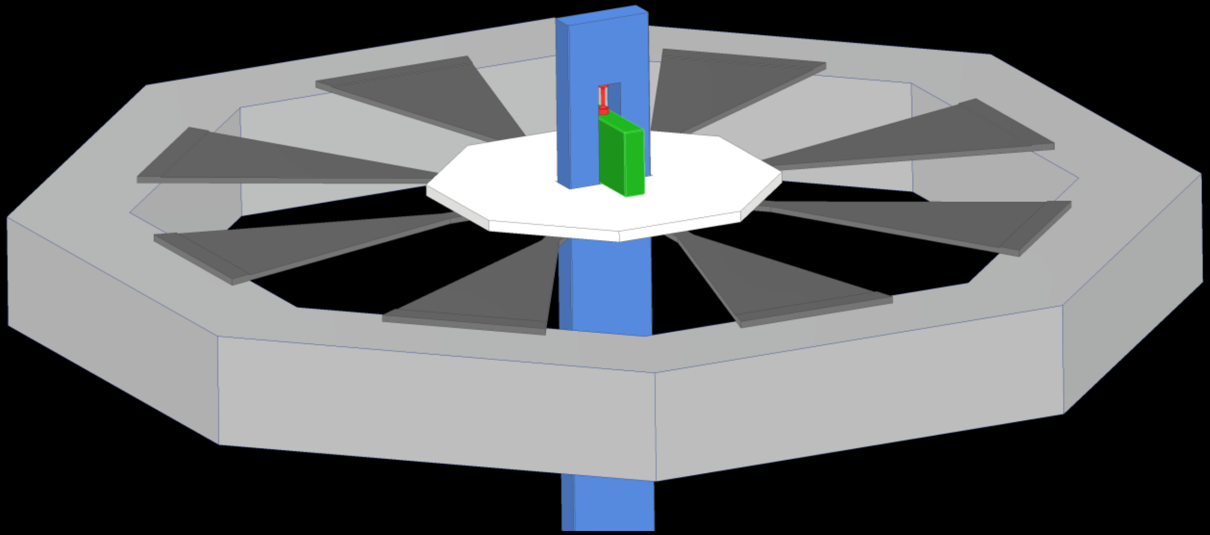


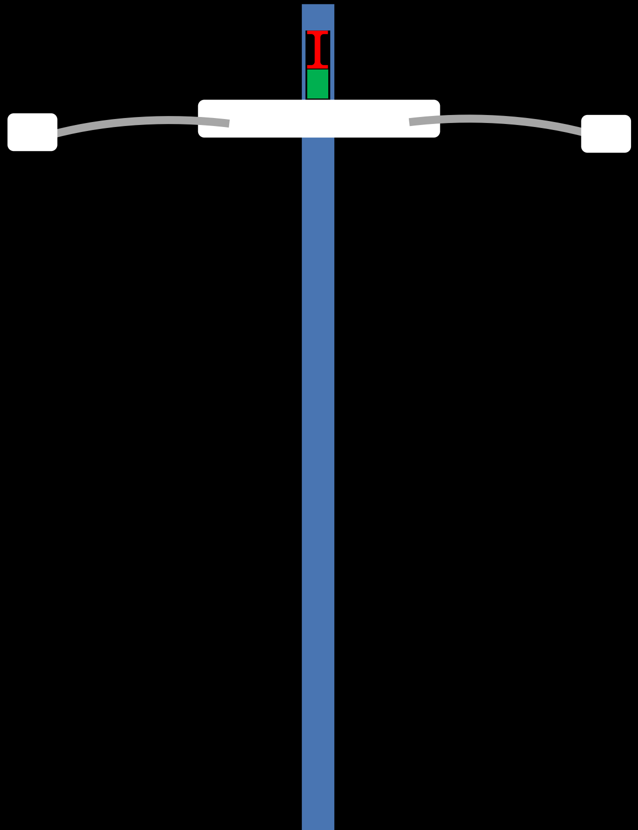


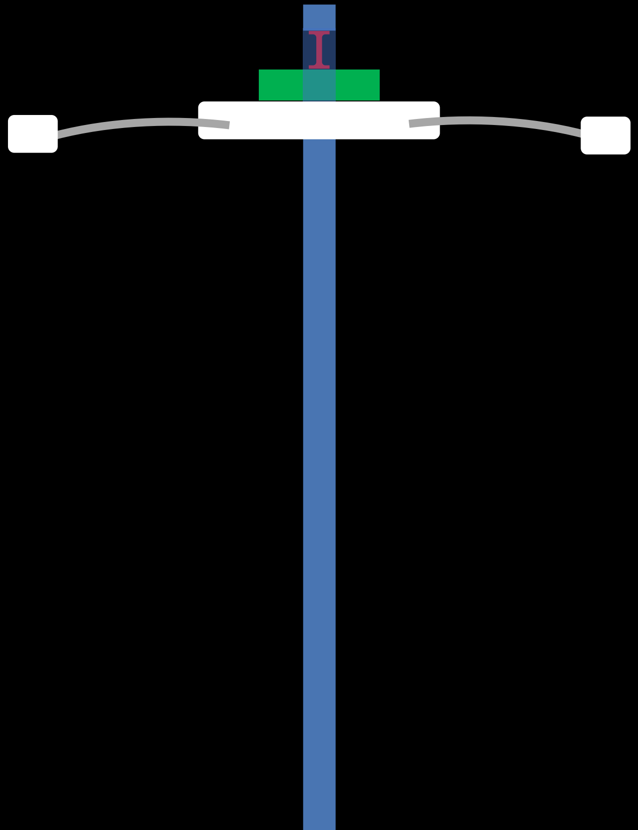
3D-CAD

Based on Joris' presentation last year

Hardware configuration





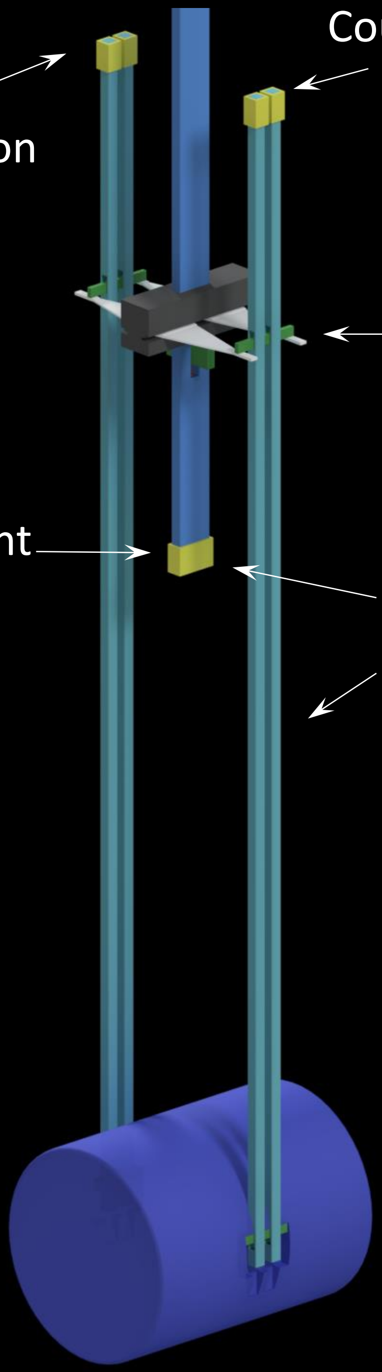


- Suspension beam
- Flexure
- Cross beam
- Vertical filter

Based on Joris' presentation last year

Hardware configuration

- Active control system from the Intermediate Mass:
  - Mirror general control.
  - Damping the pendulum and unwanted resonant modes.
  - A recoil mass around the mirror is not needed.
- Optical anti-spring to lower the resonance frequency.
- Joints with Gallium brazing: it can be disassembled.
- The counterweights are useful to modify mechanical behaviour.
- Leonardo will talk about the spring blades.

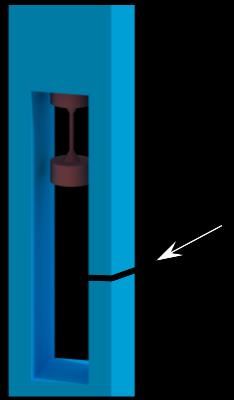


What we analyzed

- We present results for 1 particular flexure out of 9 analyzed.
- Displacement transfer functions, suspension thermal noise: one pendulum

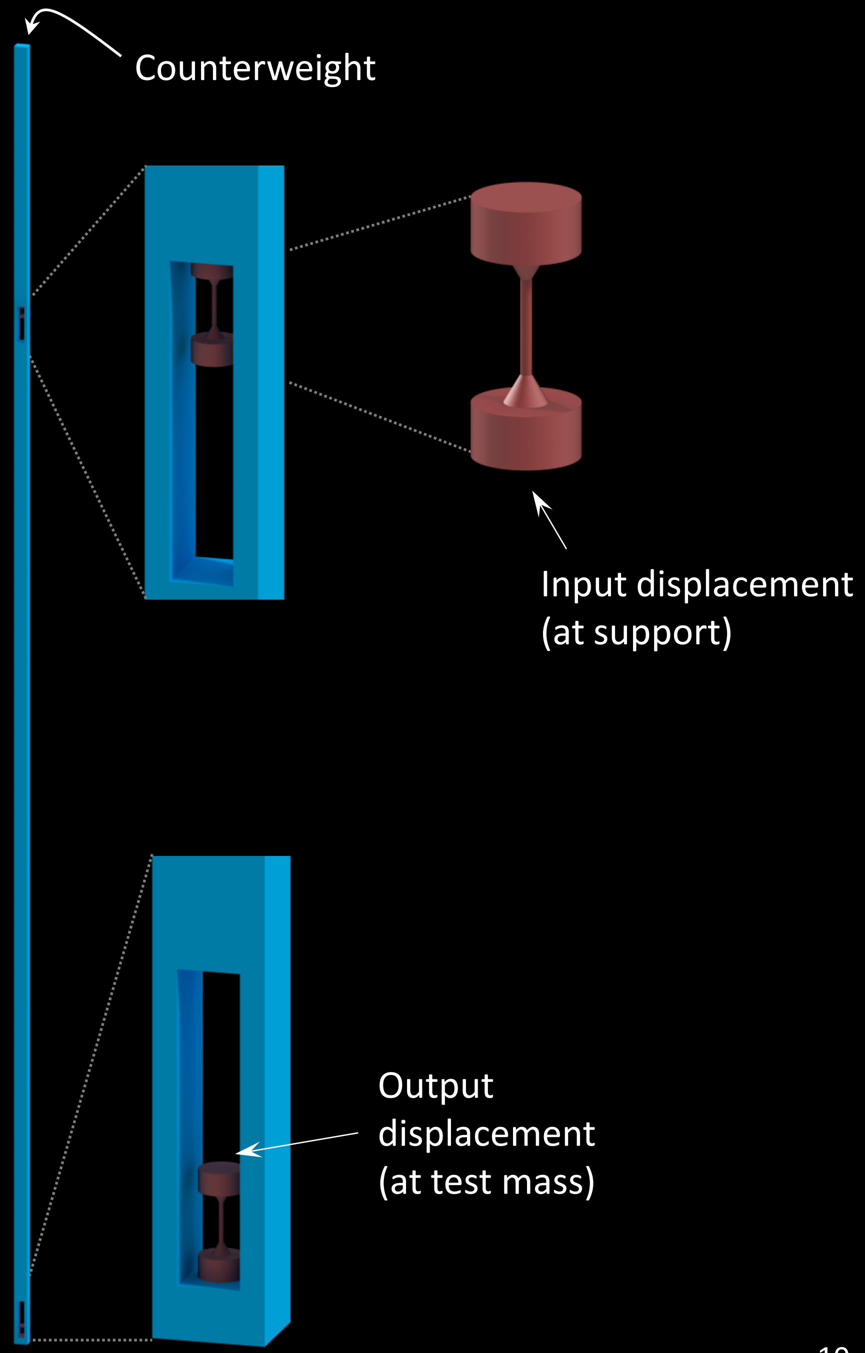
  1 × suspension beam, 2 × flexures, load of 50 kg.
- Heat extraction: cryogenic payload
- **Material strength in compression: 3200 MPa.**
- The safety factor in tension is ~50.

- Buckling: we checked that none of the resonant mode frequencies goes to zero.
- We compared with a suspension rod *whose ends have not been engineered*:
  - Safety factor 6 and 2 metres.
  - **Material strength in tension: 120 MPa.**

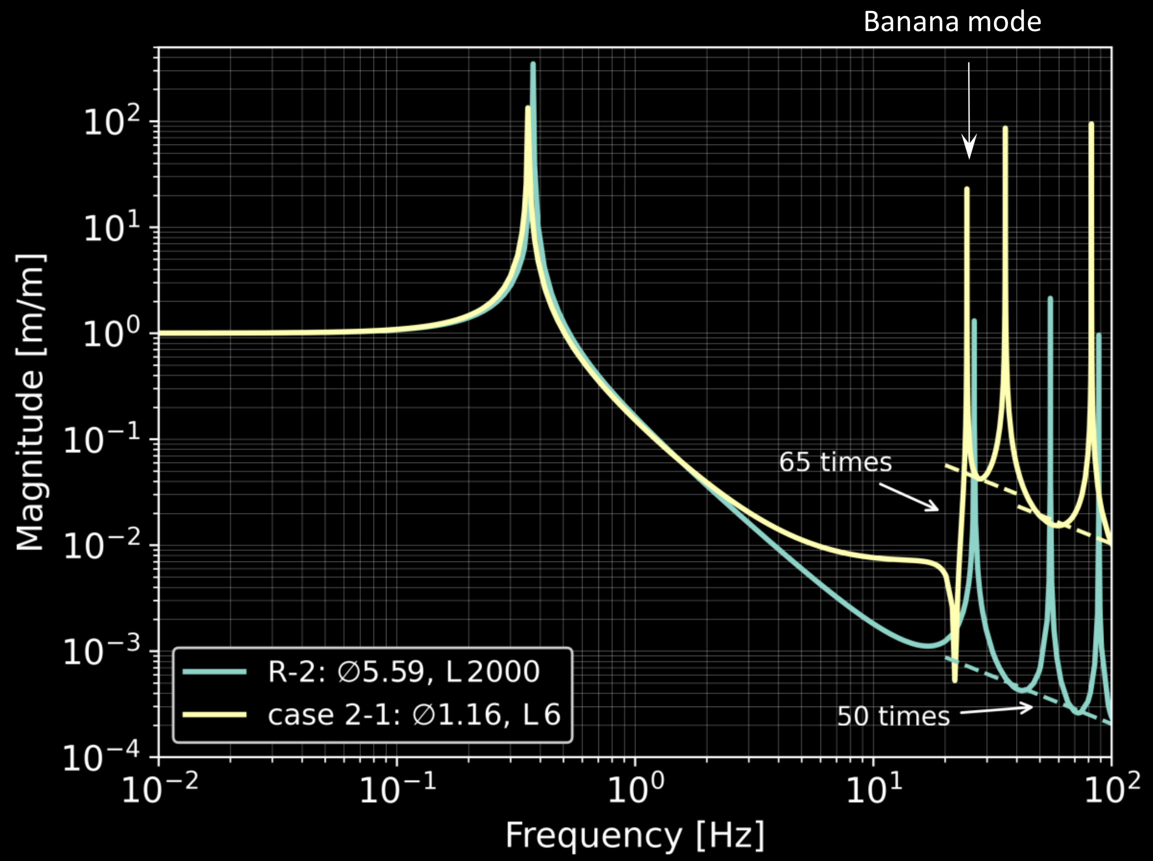


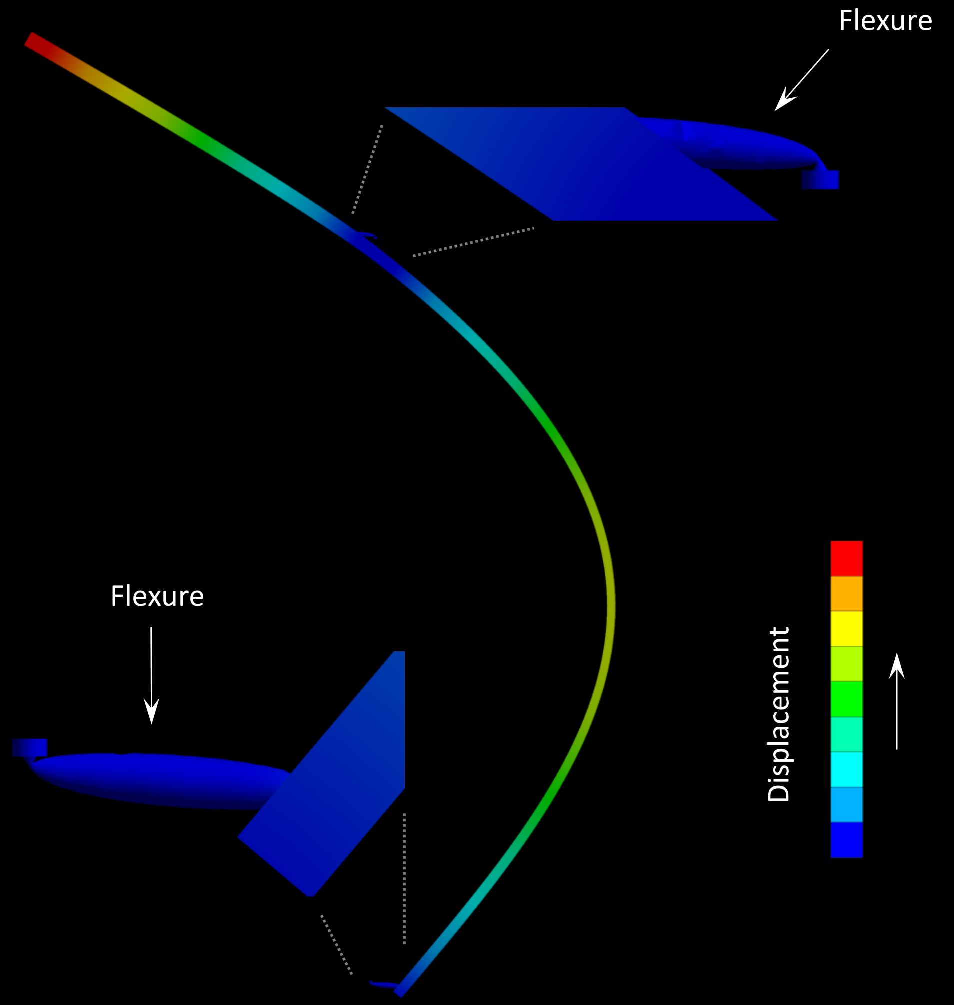
Mechanical behaviour

- **Displacement transfer functions**
- Silicon anisotropic stiffness matrix.
- Direction [100] pointing upwards for all components.
- Bulk loss angle: $\phi = 1 \times 10^{-9}$.
- We used Ansys and COMSOL.



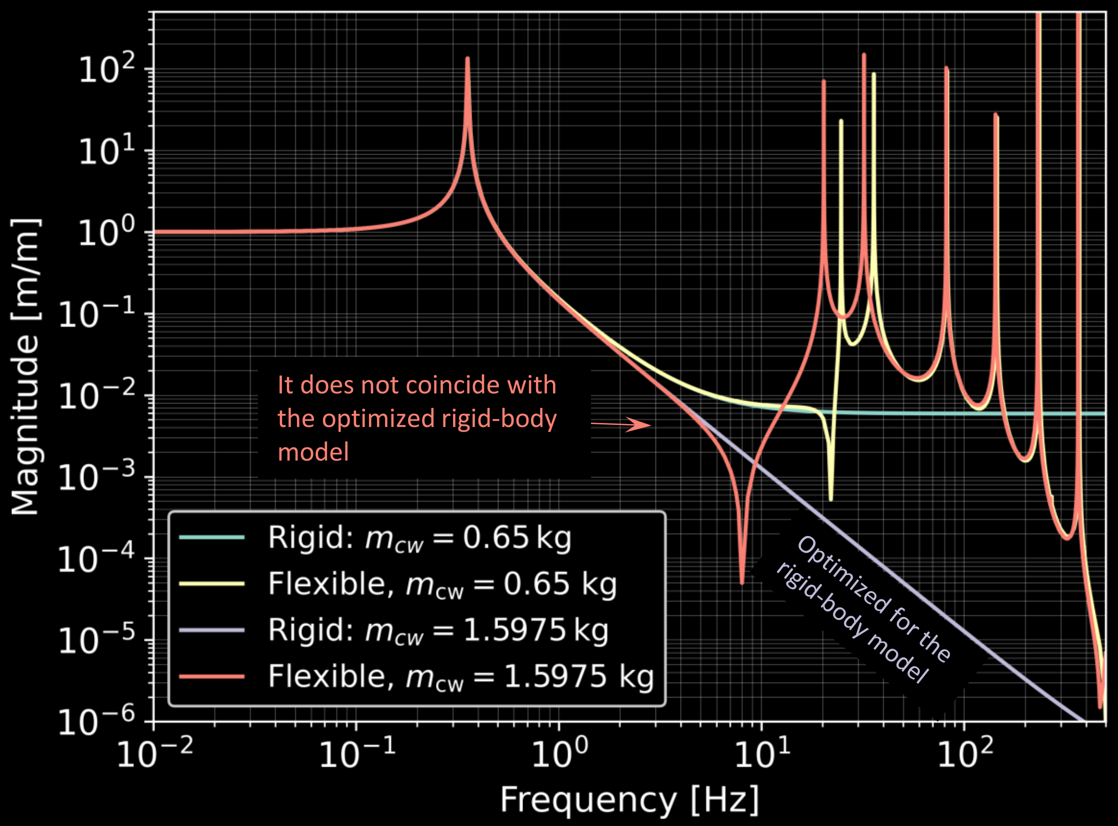
Displacement transfer functions (3)

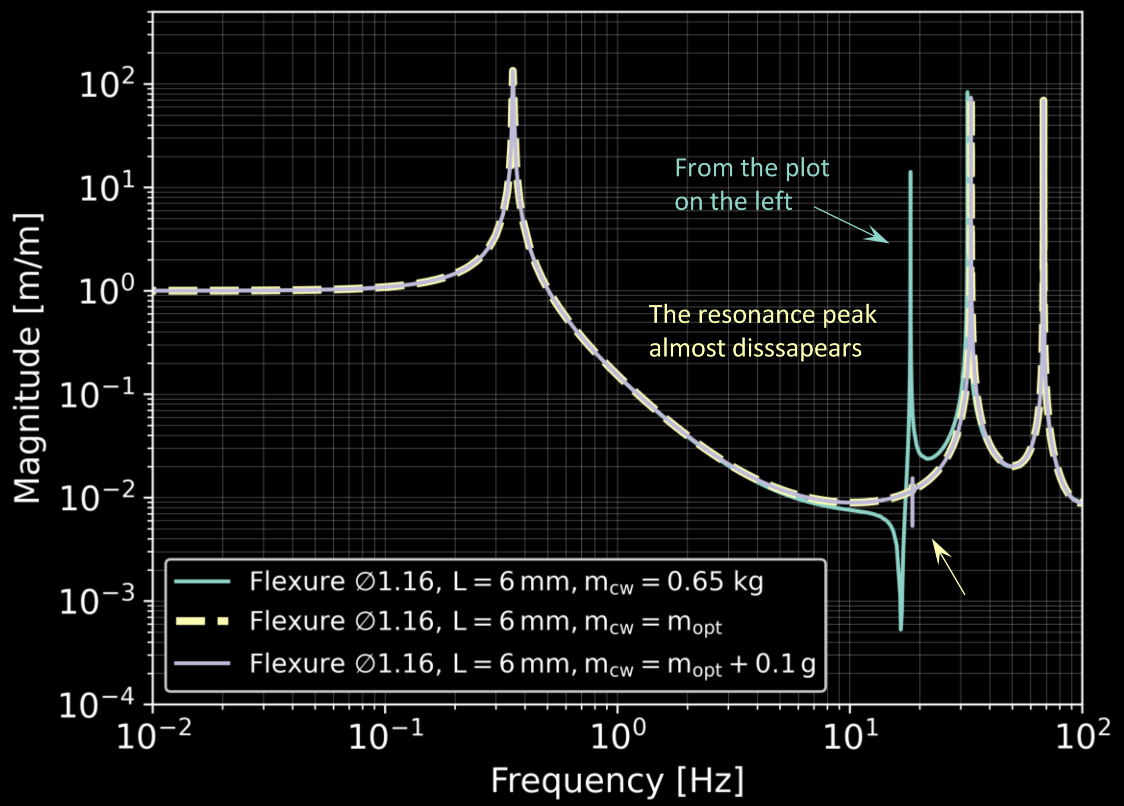




- Below 4 Hz they coincide.
- The rods are better between 20 and 35 Hz by 65 times and above 40 Hz by 50 times.

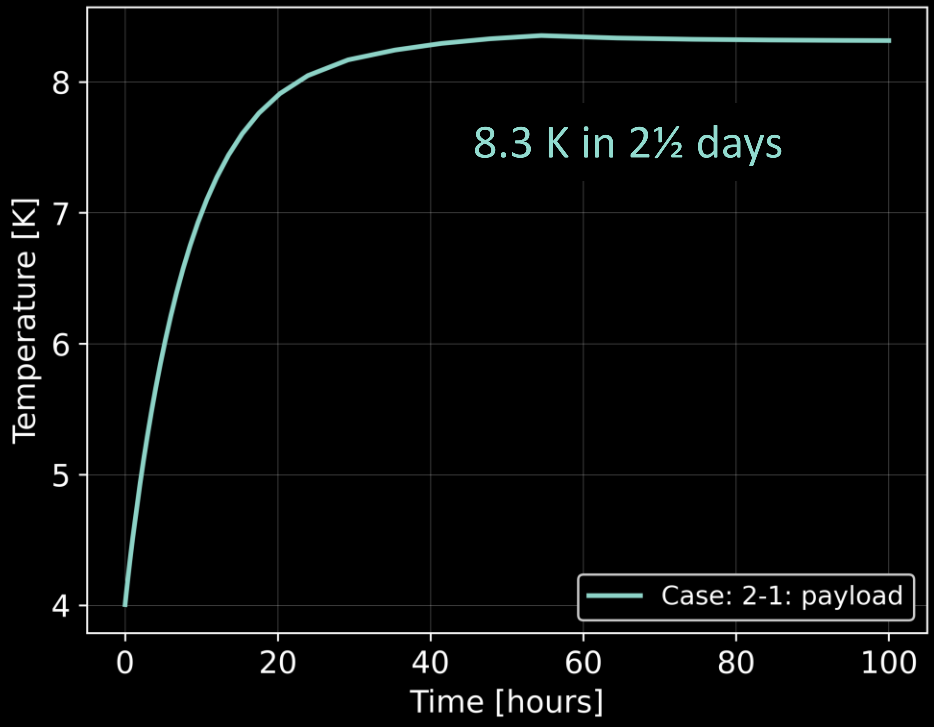
Displacement transfer functions: counterweight

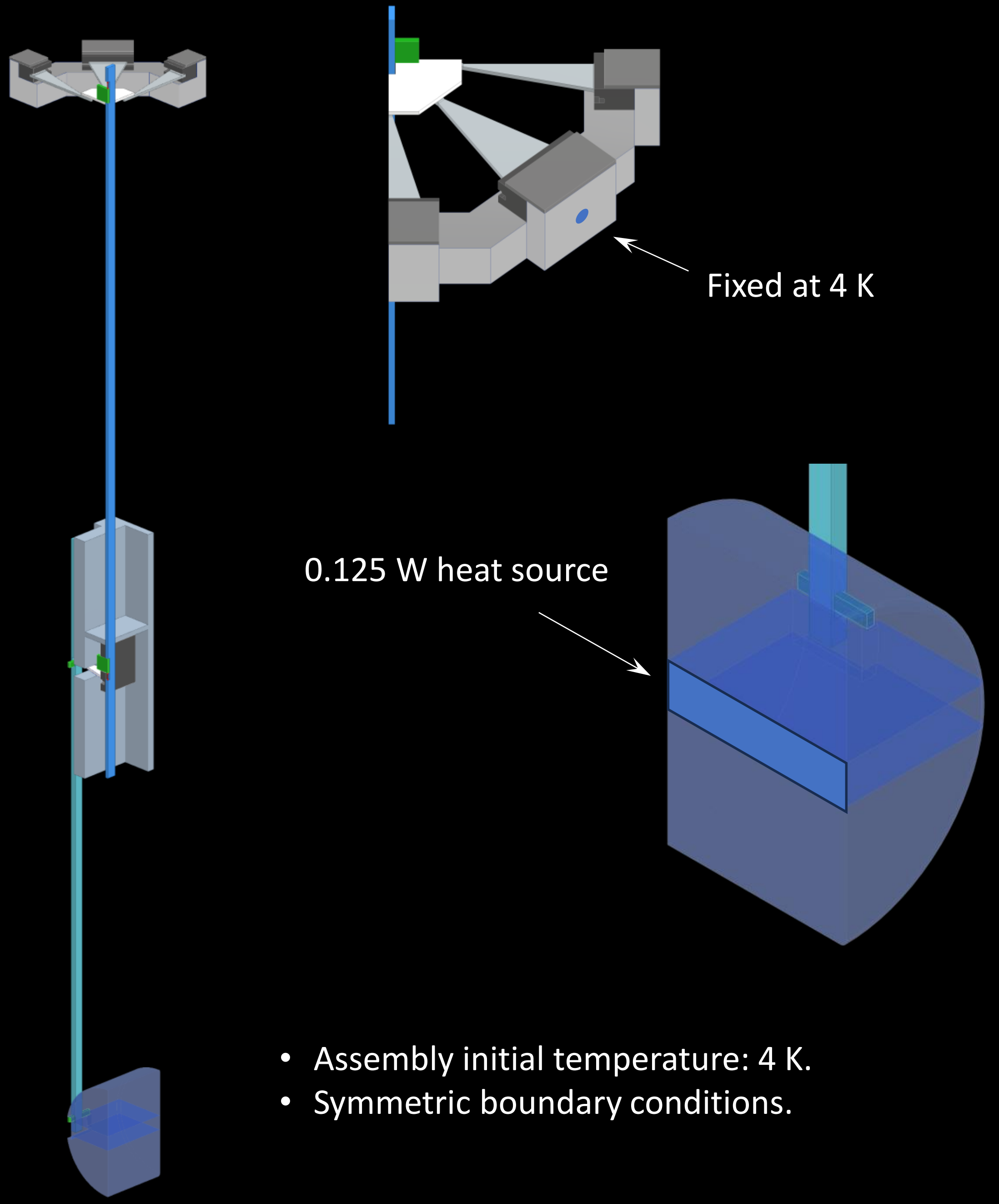




Transverse transfer function

Heat extraction with the payload

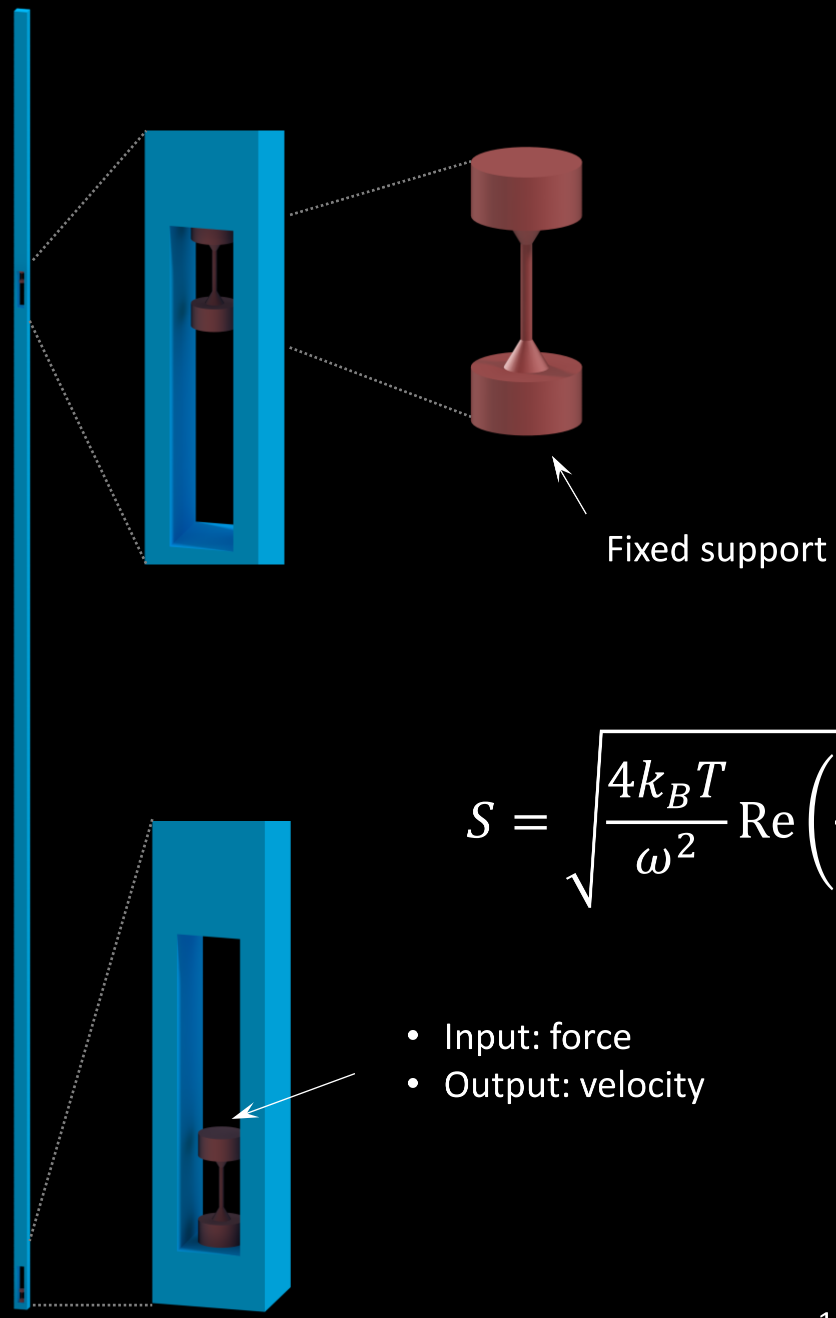




- Assembly initial temperature: 4 K.
- Symmetric boundary conditions.

Displacement thermal noise

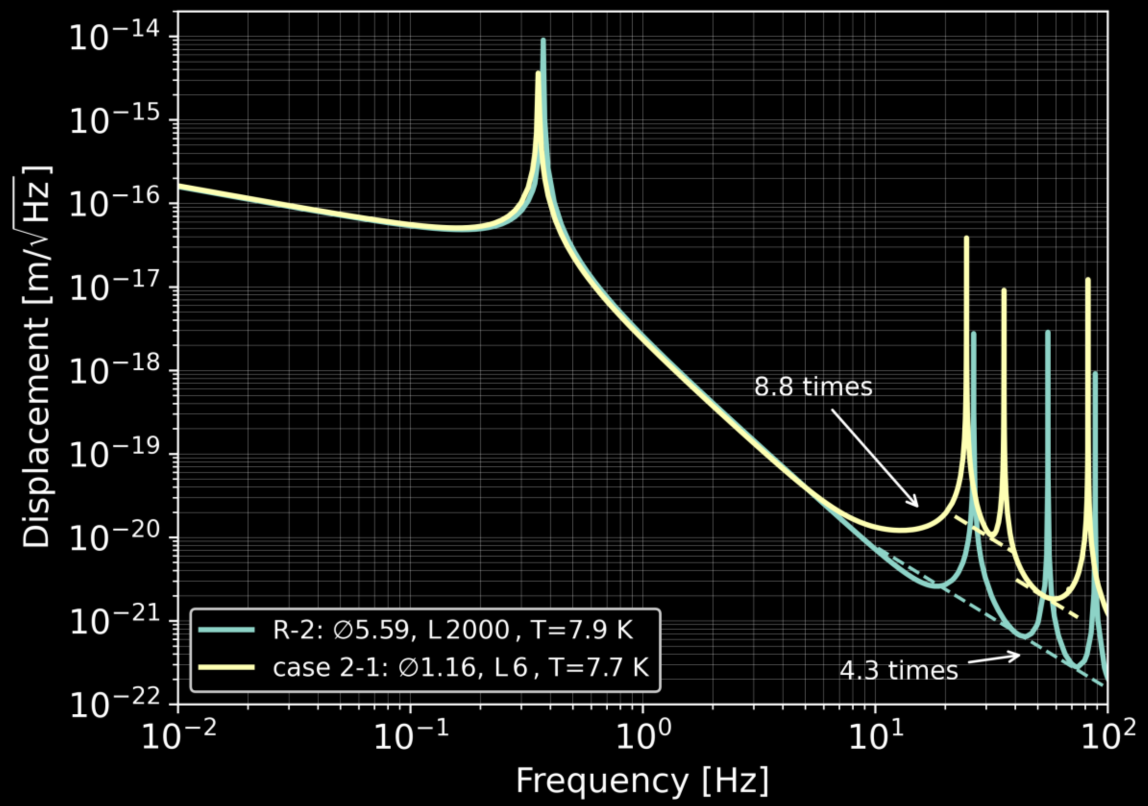
- Admittance transfer function: $A = \frac{V}{F}$
  - V: velocity
  - F: force
- Bulk loss angle: $\phi = 1 \times 10^{-9}$ (constant in temperature).
- Temperature is assumed to be uniform.
- The average temperature was used.

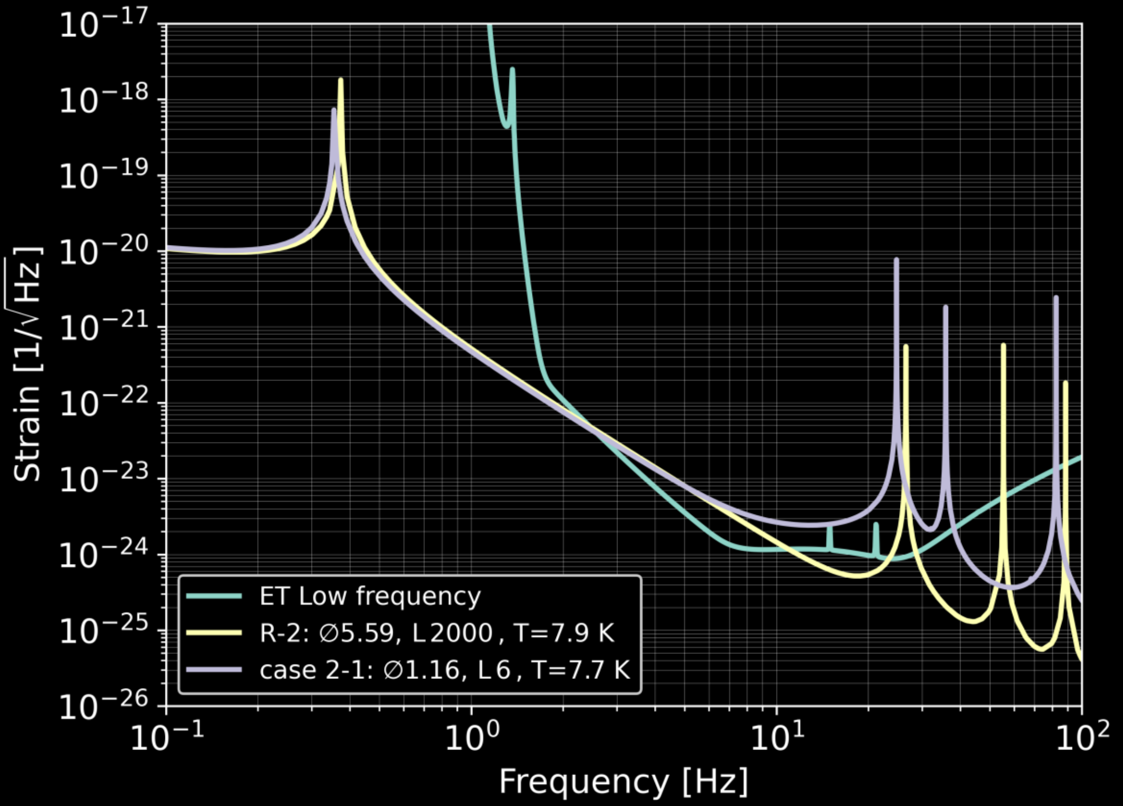


$$S = \sqrt{\frac{4k_B T}{\omega^2} \mathrm{Re}\left(\frac{V}{F}\right)}$$

- Input: force
- Output: velocity

Displacement thermal noise





30 and 50 Hz: ~8.8 and 4.3 times respectively.

Future work

- Analysis of an optical anti-spring to lower the pendulum resonance frequency.
- Cooling time from room temperature (including movable cold fingers).
- Complete the design of the mechanical design of the payload.
- Consider small flexures made of ^{28}Si: its thermal conductivity is ten times larger.
- Spring blade design.
- Consider different Si crystal orientations for components.
- Consider contributions to the loss angle other than the bulk's.
- Calculate requirements for sensors and actuators.
- Design a prototype

Conclusions

- Flexures are robust and soft components with good heat extraction qualities.
- The system would be easy to assemble and disassemble.
- Their use requires using suspension beams with internal resonances that must be damped.
- The configuration allows the implementation of an active control system.
- A recoil mass around the test mass mirror is not necessary.
- We likely require a two-level payload to achieve the required displacement thermal noise.