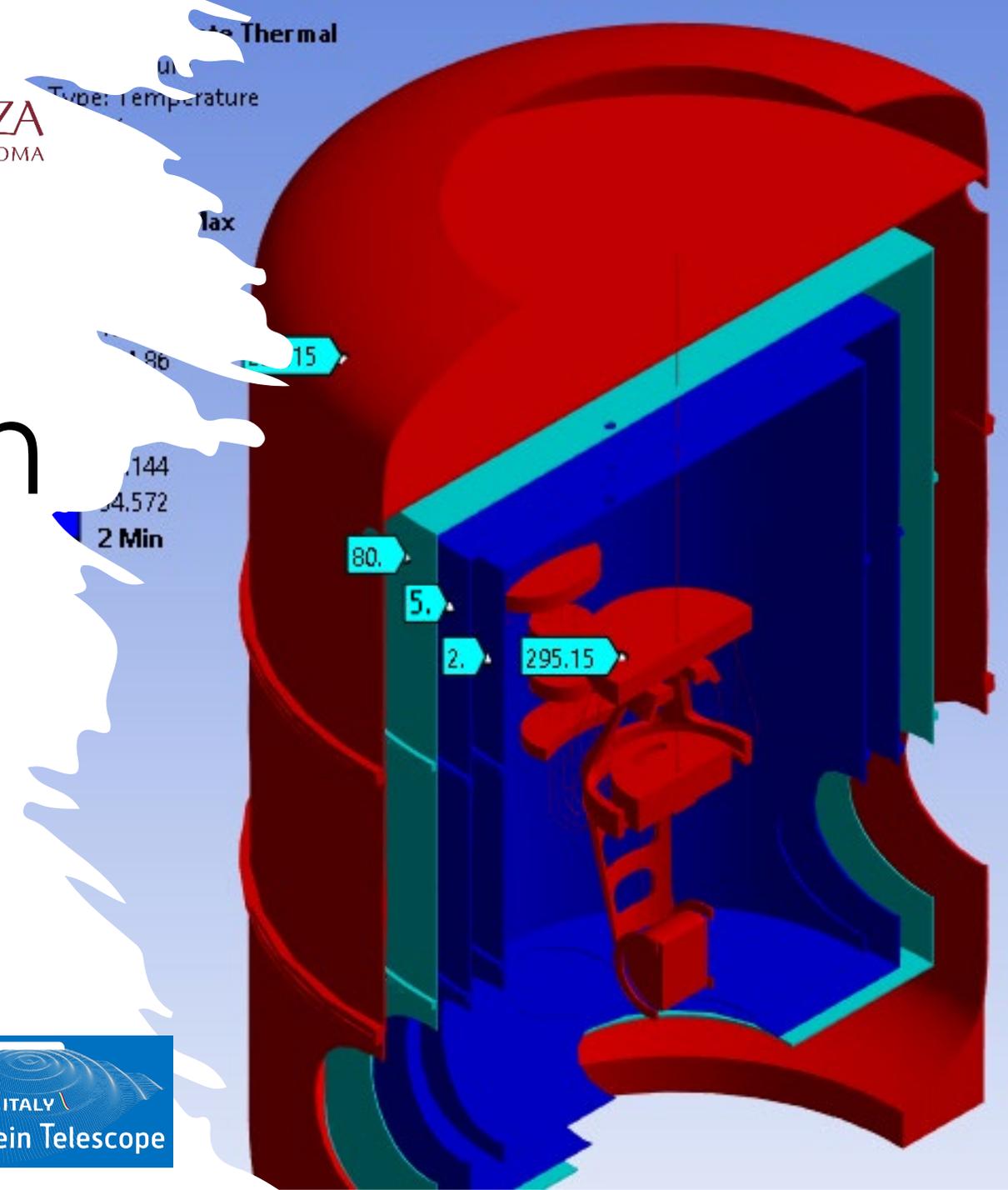
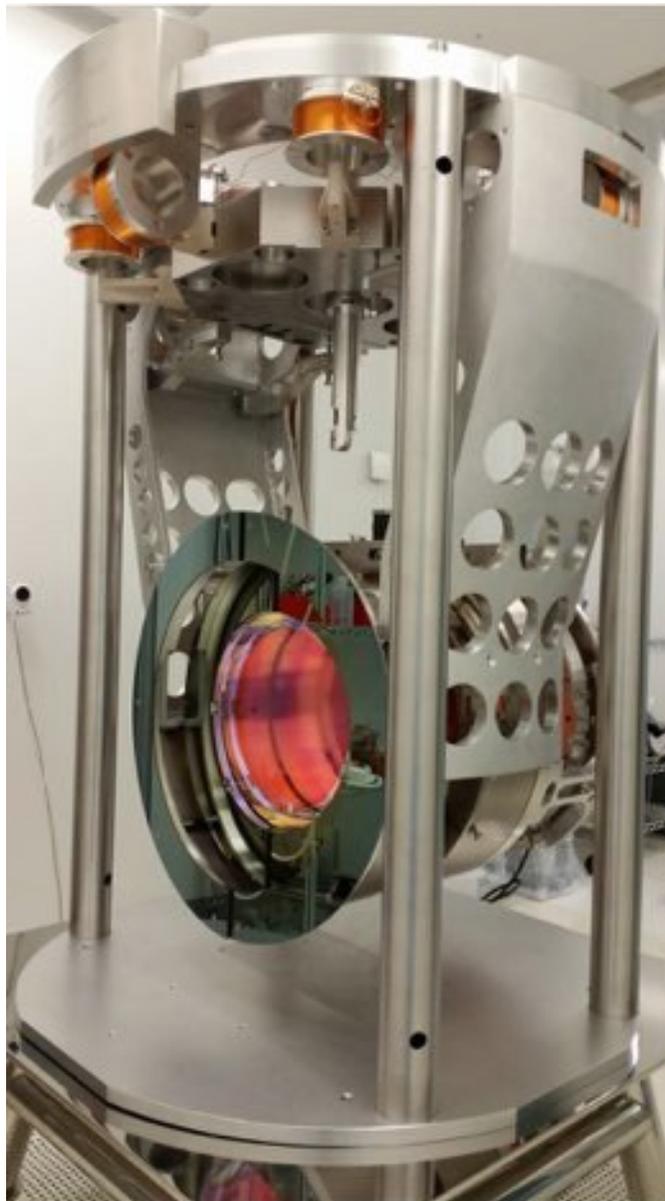


Status of Cryo-Payload work in Rome

Paola Puppo for CryoPay group
IV ET-LF TM Tower Integration
Workshop
Pisa March 18-20 2026



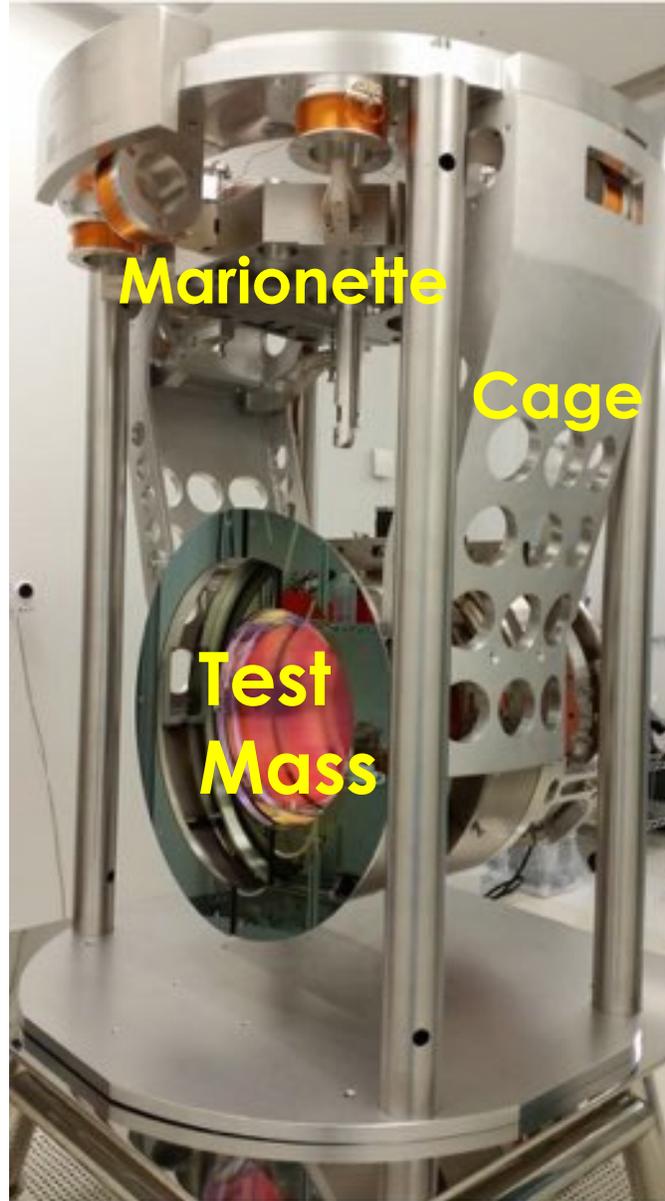


The Last Stage Suspension

The **role** of the Last Stage Suspension is

- to compensate the residual seismic noise
- to steer the optical components maintaining the relative position of the interferometer mirrors.

Bernardini A., Majorana E., Puppo P., Rapagnani P., Ricci F., Testi G. "Suspension last stages for the mirrors of the Virgo interferometric gravitational wave antenna." *Rev. Sci. Instr.* 70, no. 8 (1999): 3463.



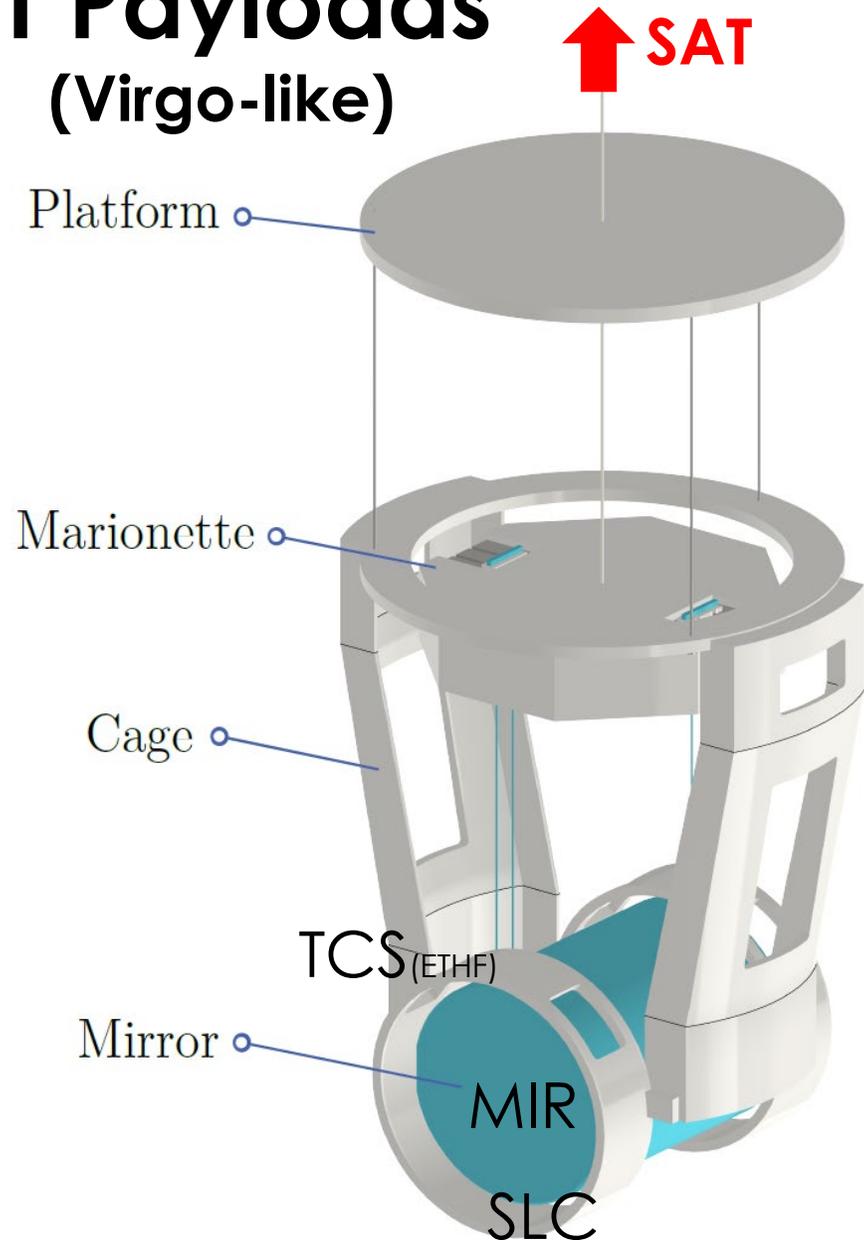
Marionette: Mirror control with actuators (coil-magnets, electrostatic) between the upper suspension stage and marionette

Cage (or Reaction Mass):

- Test mass and marionette steering with coil-magnets, electrostatic actuation;
- Support for baffle, instrumentation
- Test mass protection

Bernardini A., Majorana E., Puppo P., Rapagnani P., Ricci F., Testi G. "Suspension last stages for the mirrors of the Virgo interferometric gravitational wave antenna." *Rev. Sci. Instr.* 70, no. 8 (1999): 3463.

ET Payloads (Virgo-like)



Requirements (common)

- Thermal noise limit (low losses: materials, connections)
- Frequencies outside control band and sensitivity band

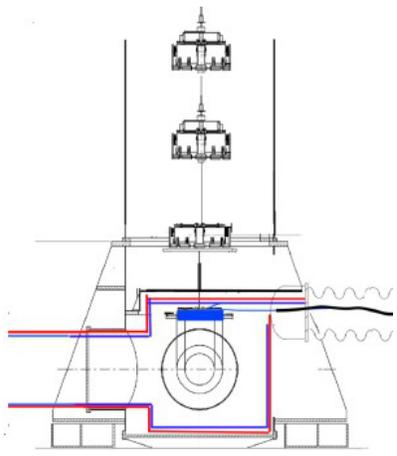
LF and HF

- Design compliant with the :
 - TM weight (MIR)
 - Thermal Compensation System (TCS) **(for HF)**
 - Baffles (SLC)

LF (cryogenics)

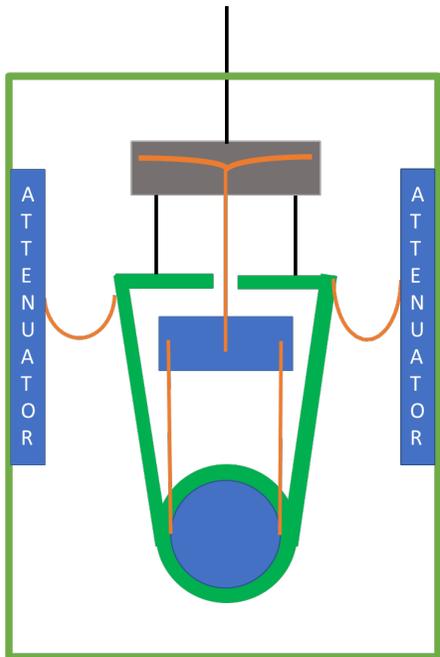
- Heat links connection (low vibrations)
- Thermal Properties, heat inputs, compliance with low cooling time
- Cryostat environment: assembly issues

Cold Payload (ET-LF) Activities & Projects



ARC-ETCryo and LoVeC-ET projects at Rome Sapienza University

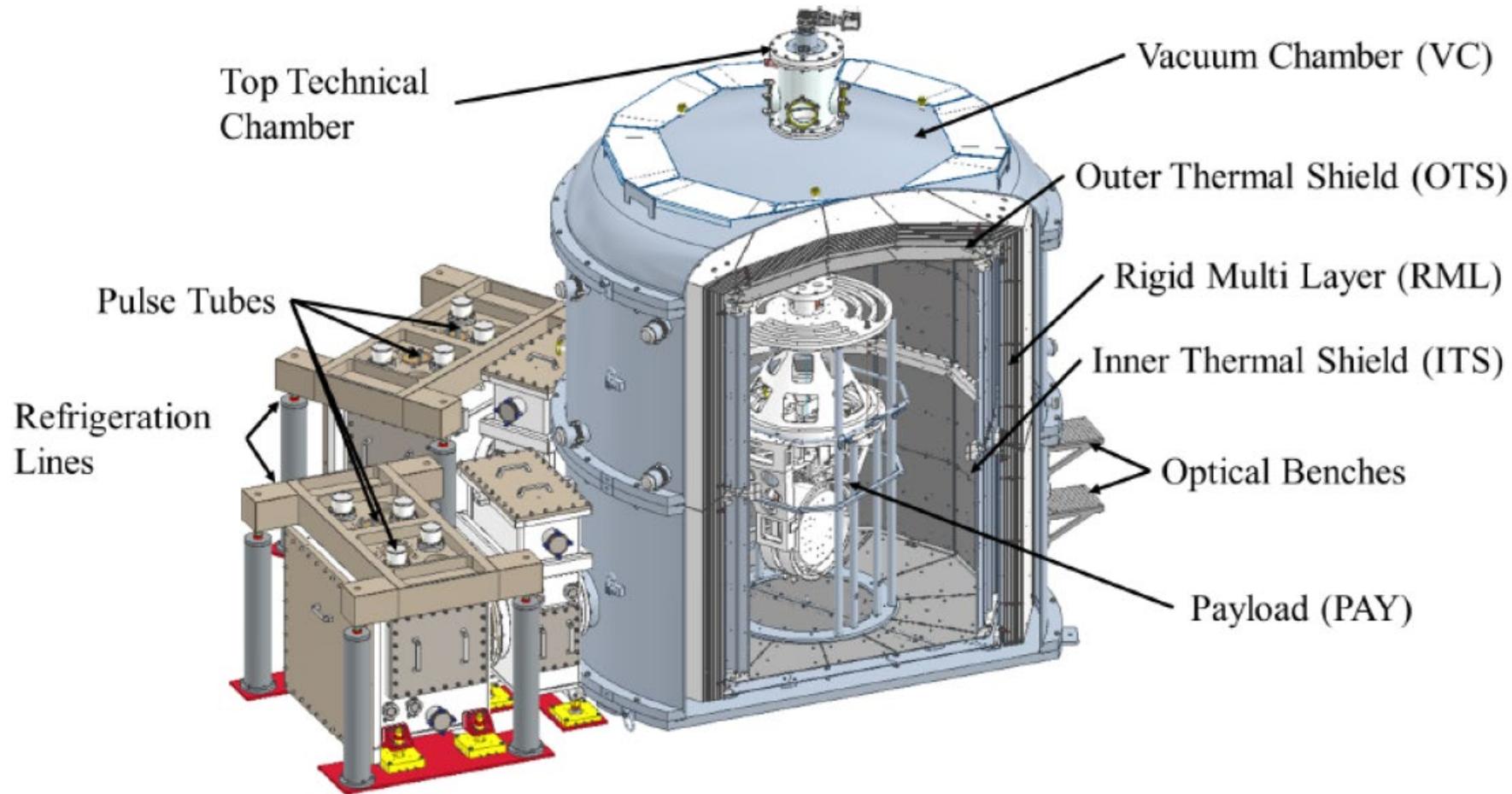
- *Payload prototype-Virgo-like, 75% scale.*
- *Cryostat prototype*



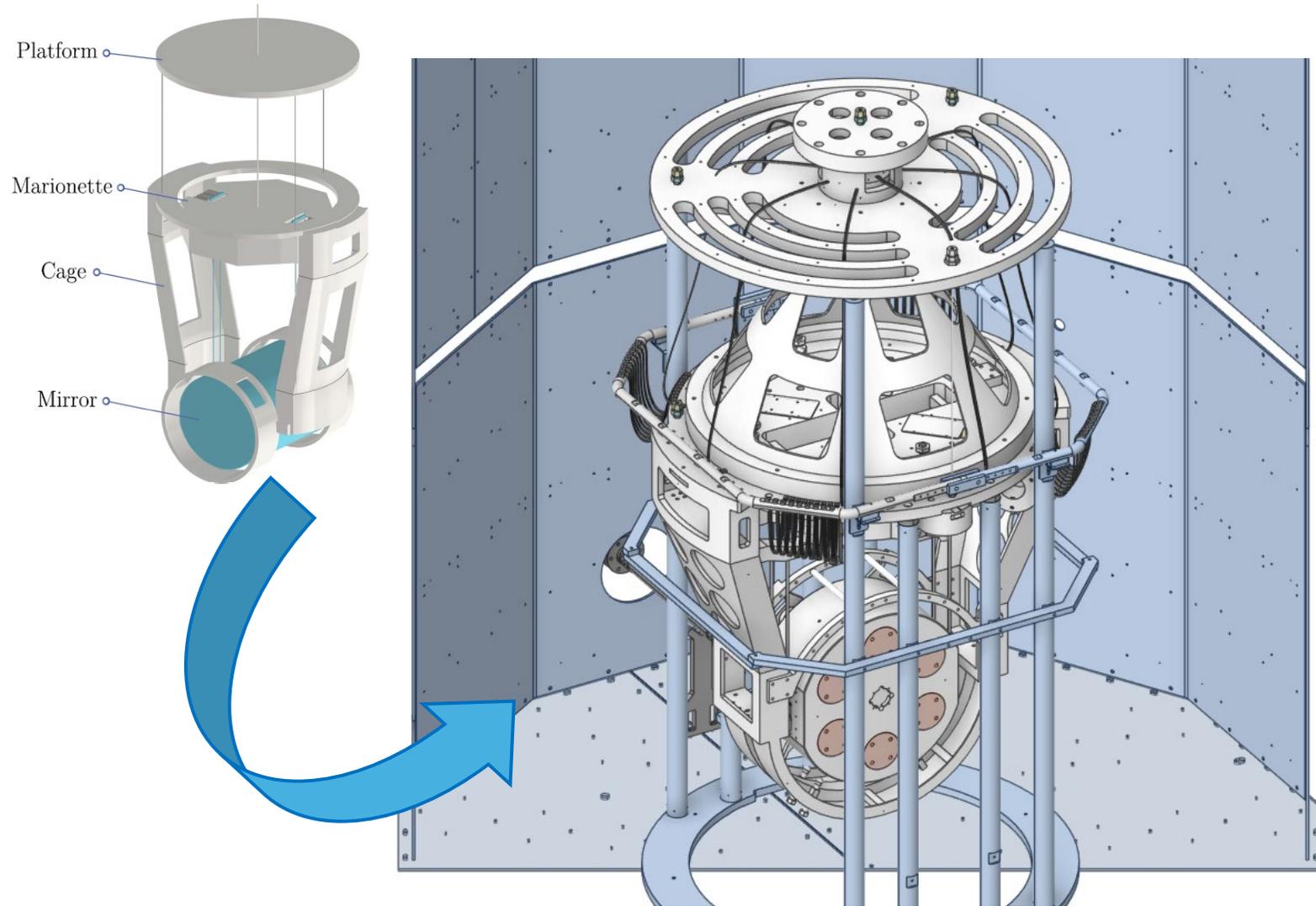
People involved in the Virgo-like payload:

- **Rome:** A. Cruciani, E. Majorana, L. Naticchioni, S. Pirro, P. Puppo, P. Rapagnani, F. Ricci, M. Ricci, E. Tofani Eng: E. Benedetti, F. Hoang, M. Orsini, D. Pasciuto.
- **EGO:** P.Ruggi, M. Pinto
- **KIT** (*Karlsruhe Institute of Technology*)
- **KAGRA collaborators**

ARC-ETCRYO: prototype of Cryostat+Payload



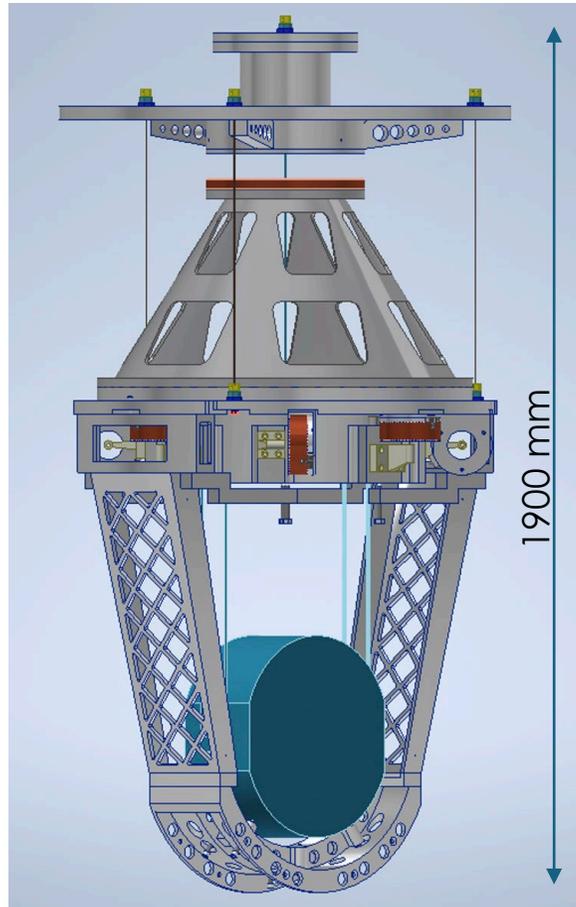
ARC-ETCRYO: Payload prototype



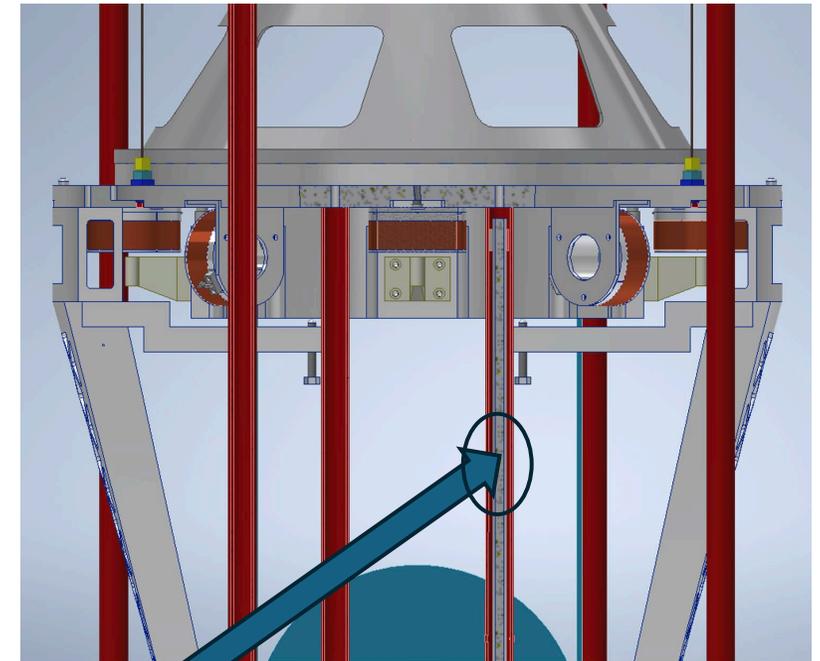
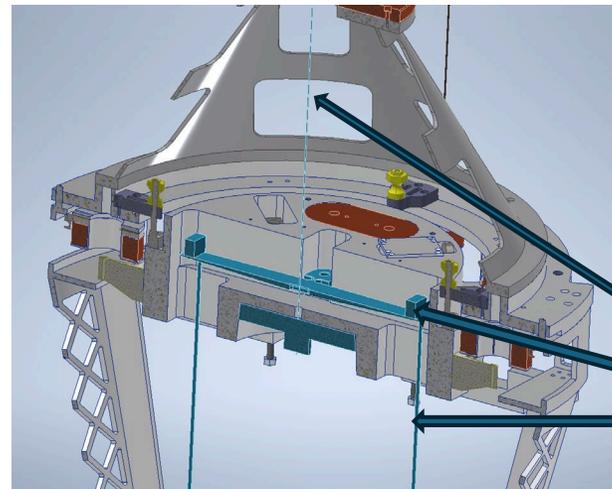
Cryogenic payload:

- Designed following the ET-LF requirements
- Sapphire employed to suspend mirror (ribbons) and marionette
- The crystalline mirror is replaced by an aluminum dummy test mass

ARC-ETCRYO: Payload



- Height: 1900 mm
- Payload max diam: 1000 mm
- Mass : 490 kg
 - Marionette: 120kg
 - Actuation cage: 134kg
 - Mirror (dummy)+ Al_2O_3 ribbon suspension: 132kg
 - Platform: 104 kg

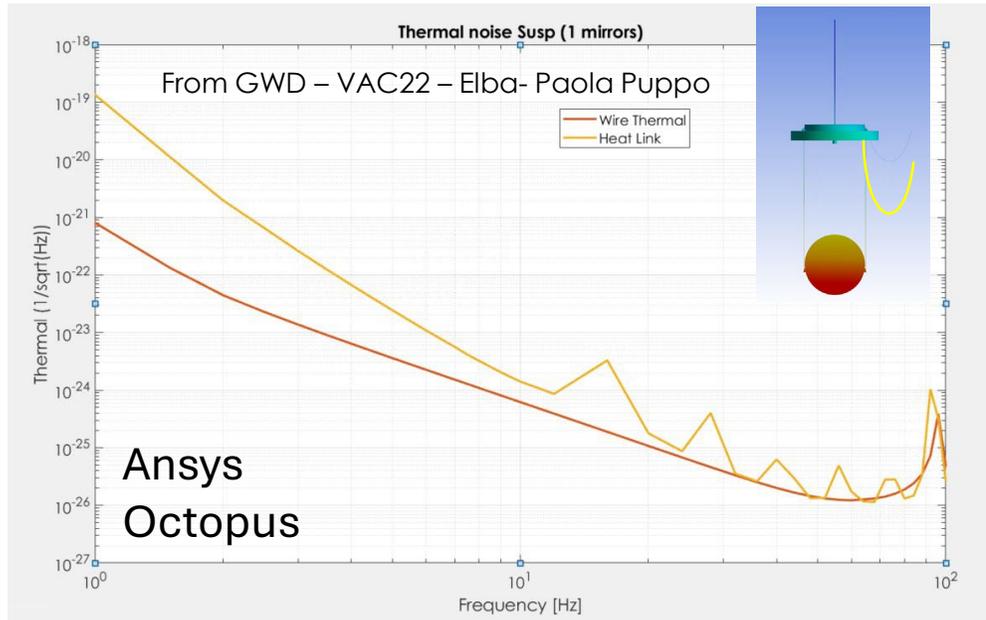


Pure Al core into the assembly structure (concept)

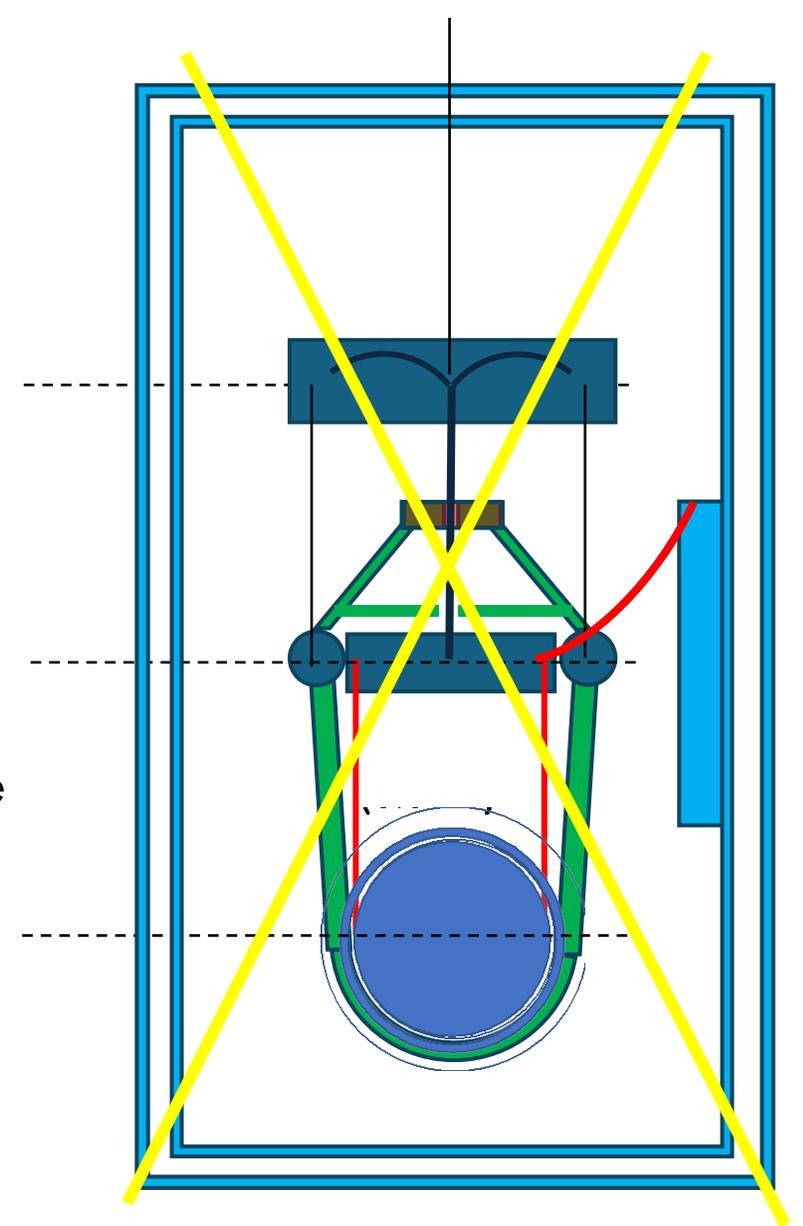
Al_2O_3 , high Tconductivity, high quality factor, high strength

Issue on heat links

Pure Aluminum Heat Link (loss angle: 0.5)



- The Heat Links cannot be directly connected to the marionette, they introduce vibrations and also increase the STN



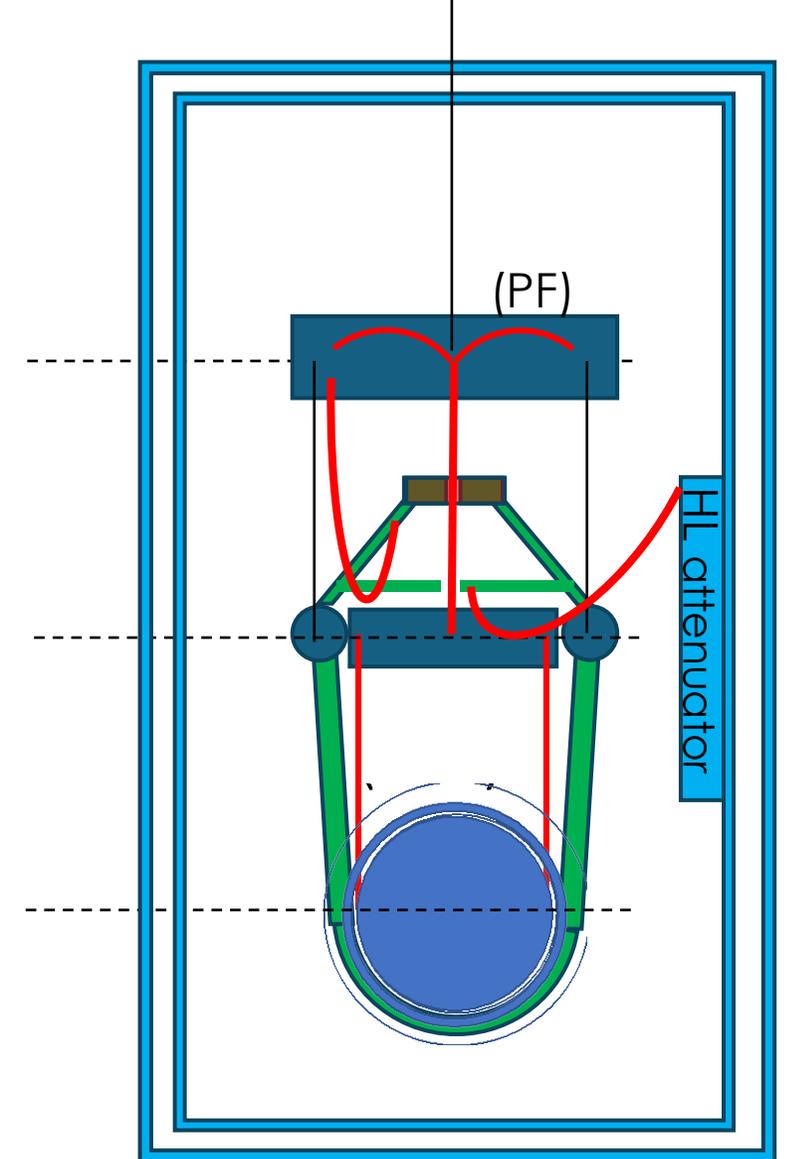
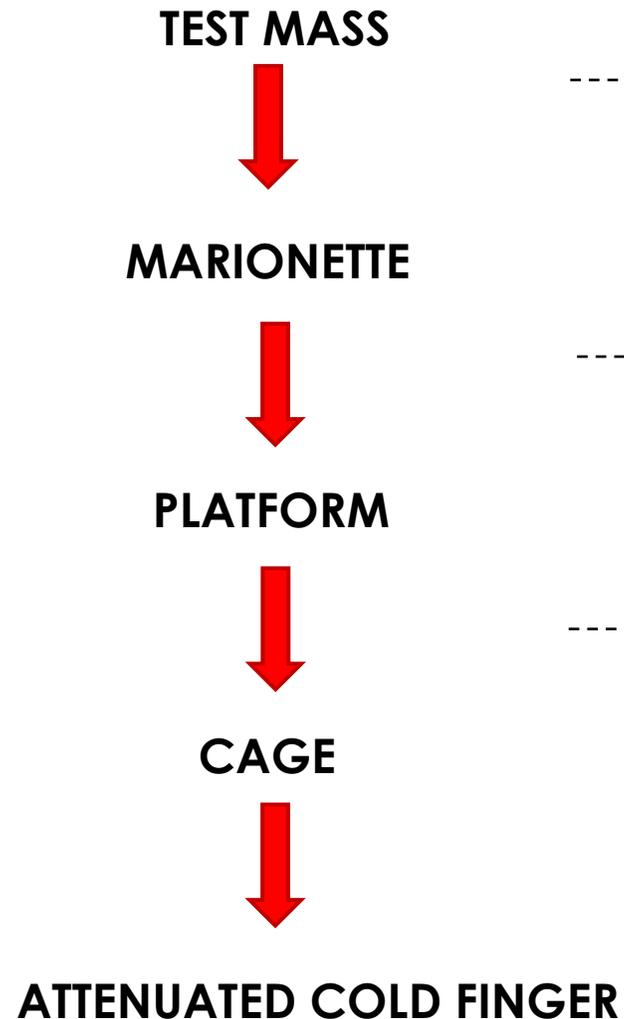
Heat extraction during operation

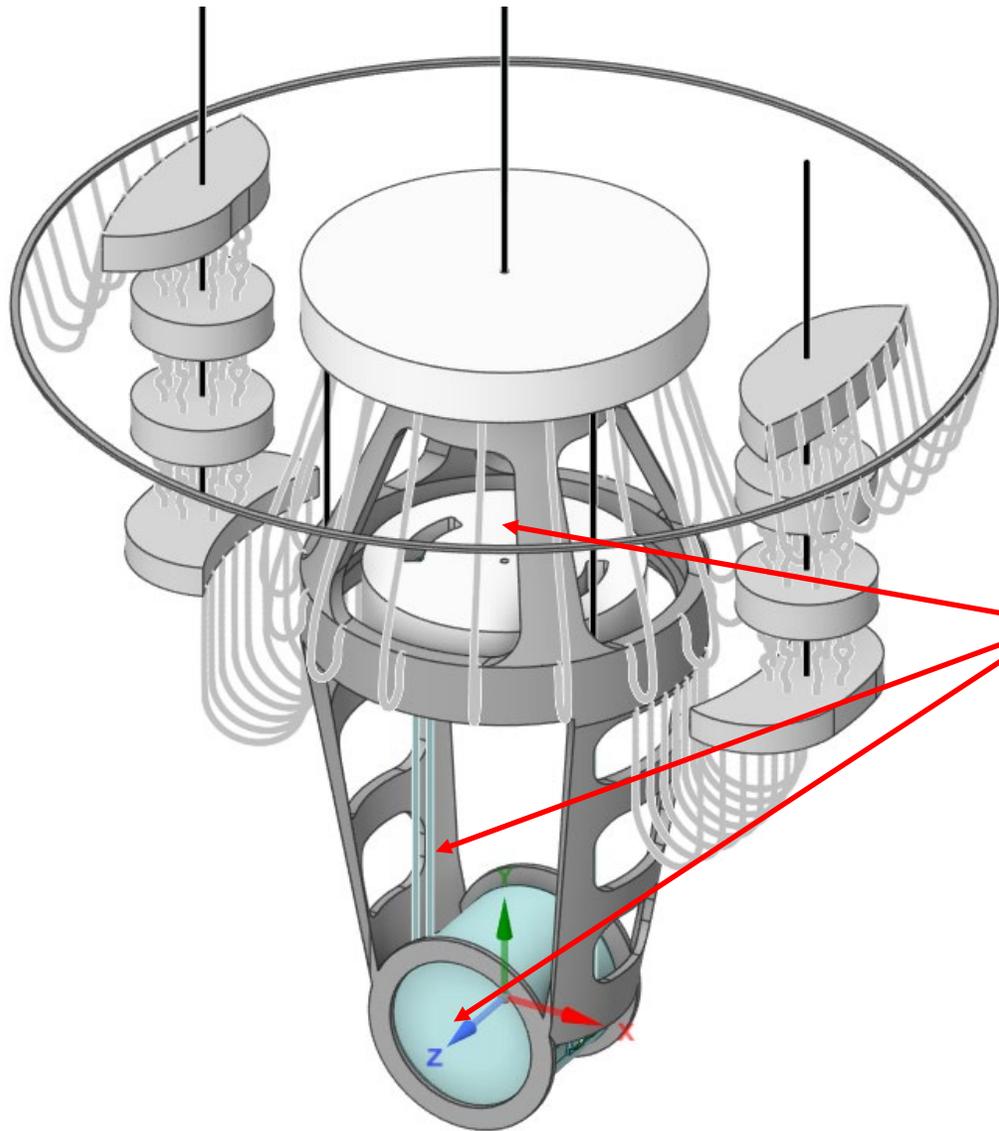
A conservative heat value of **500 mW** is used for the payload design.
(laser and stray heat (electrical cables, heat from the tubes...))

Mirror mass 220 kg
P in the arms 18 kW

	Sapphire Mirror	Silicon Mirror
Thickness (cm)	35 (diam 450mm)	36 (diam 550mm)
Substrate (ppm/cm)	50	10
Coating (ppm)	1	1
Pcoat (mW)	18	18
Psubstrate (mW)	112	12
Ptot (on ITMs)	130	30
Ptot (on ETMs)	18	18

Heat Path (Conduction)

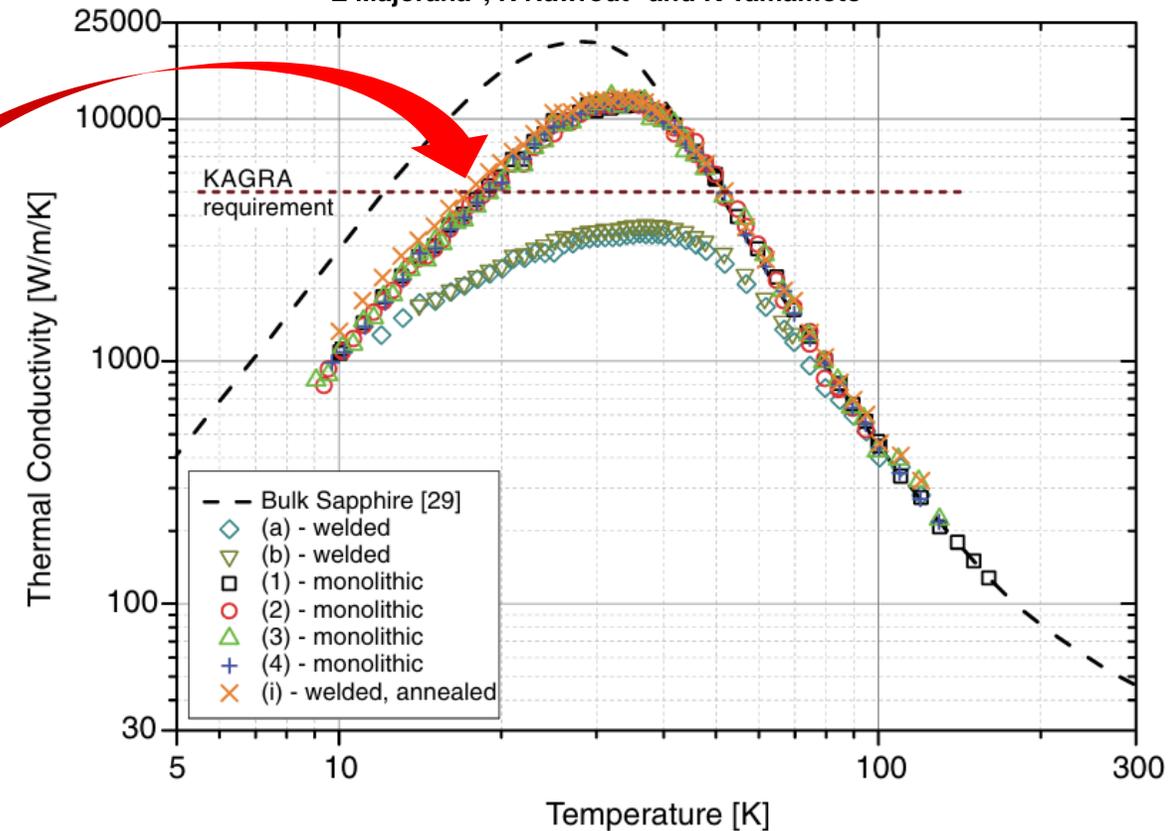




Sapphire

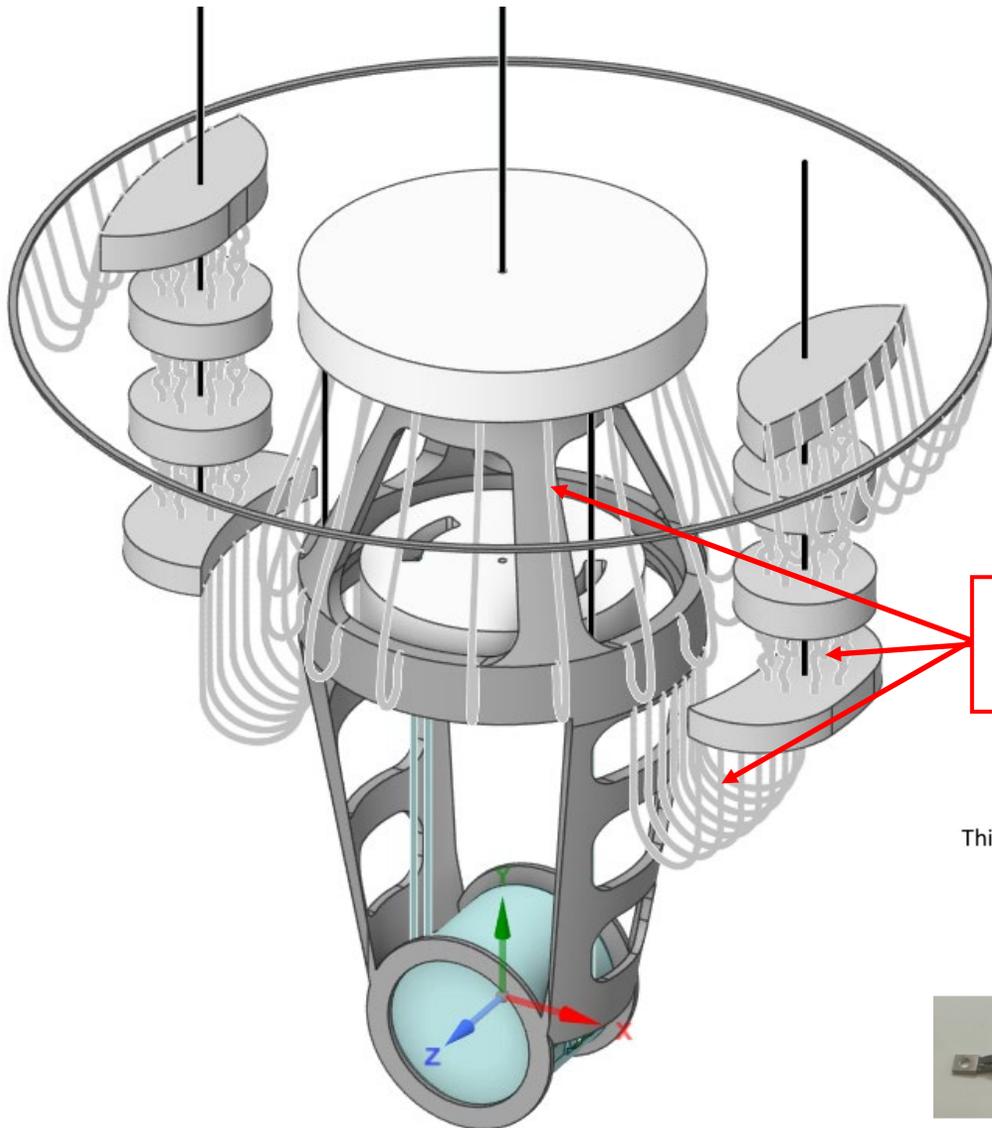
Evaluation of heat extraction through sapphire fibers for the GW observatory KAGRA

A Khalaidovski¹, G Hofmann², D Chen¹, J Komma²,
 C Schwarz², C Tokoku¹, N Kimura³, T Suzuki³, A O Scheie⁴,
 E Majorana⁵, R Nawrodt² and K Yamamoto¹

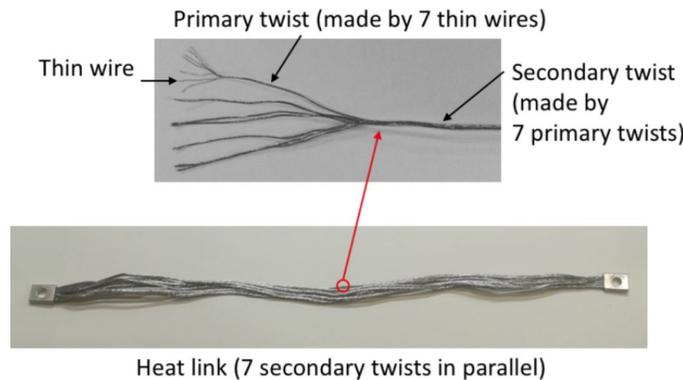
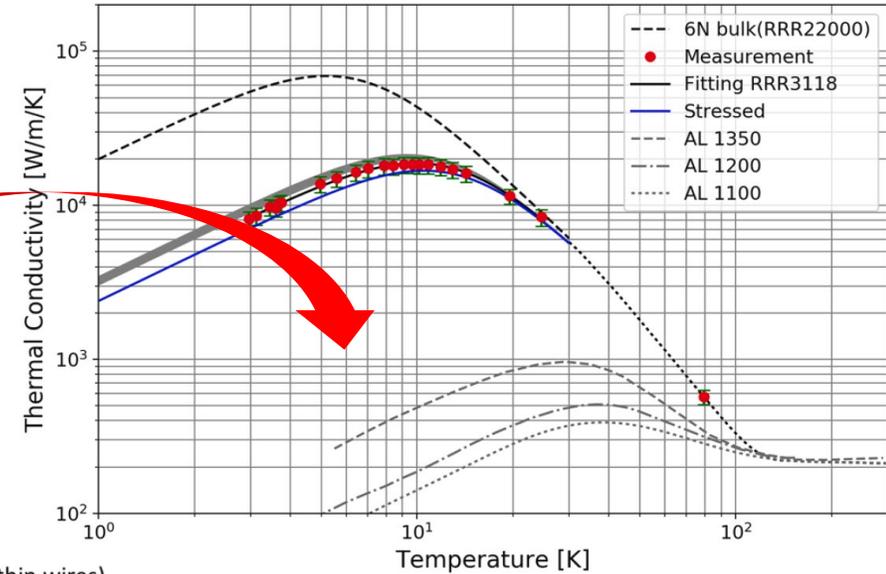


High performance thermal link with small spring constant for cryogenic applications

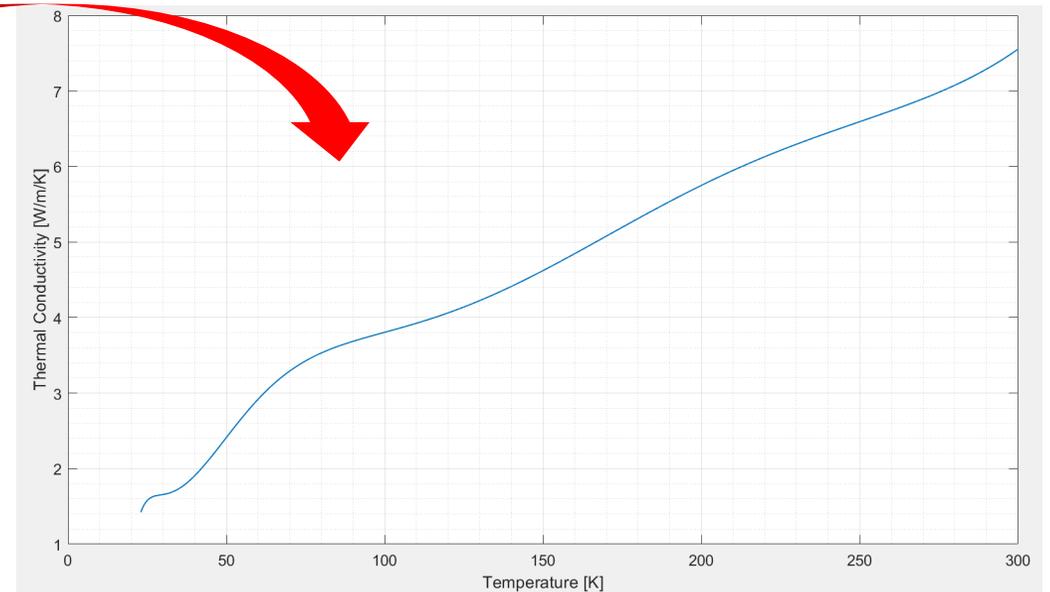
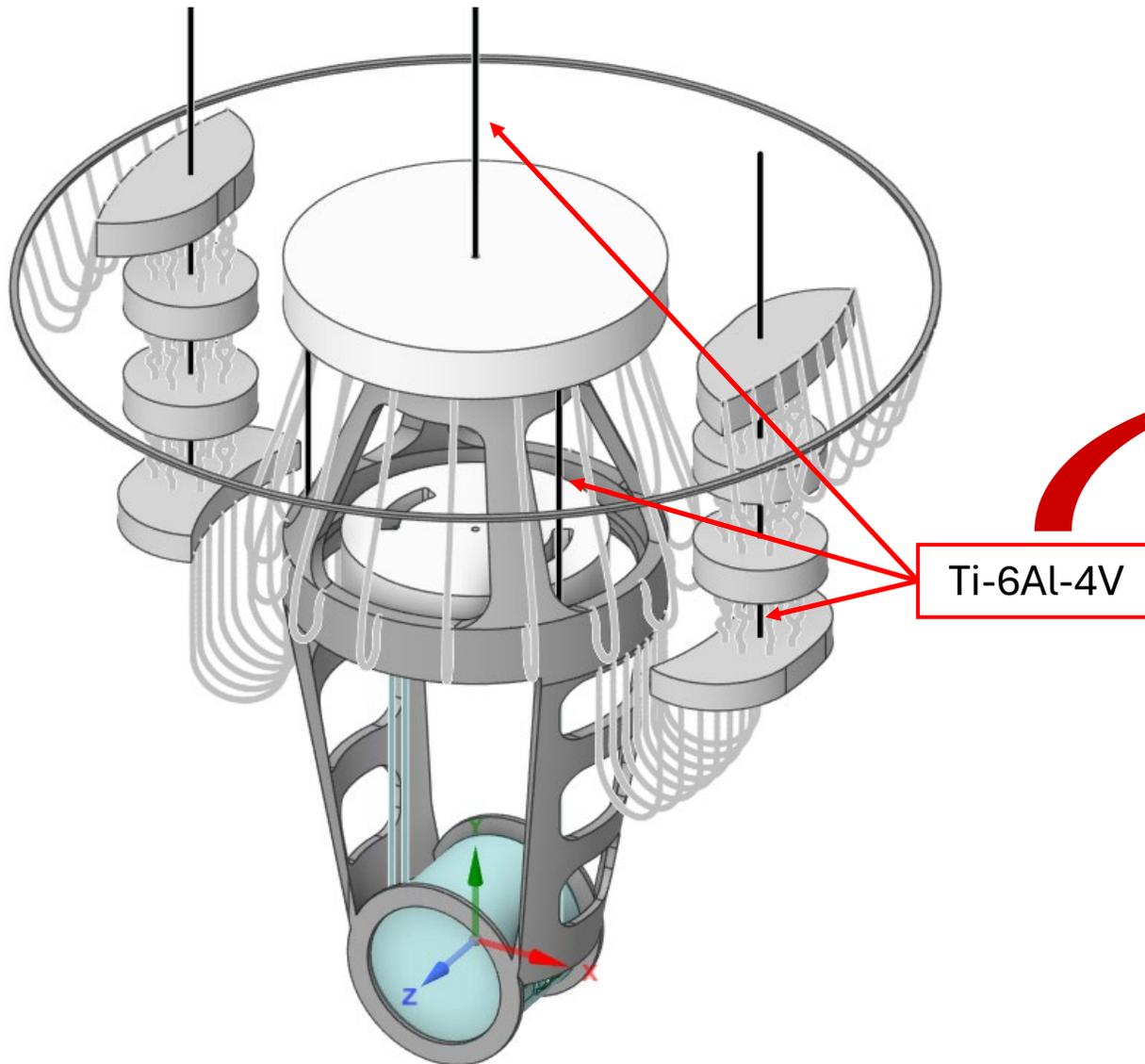
Tomohiro Yamada^{a,*}, Takayuki Tomaru^{b,c}, Toshikazu Suzuki^c, Takafumi Ushiba^d, Nobuhiro Kimura^{c,e}, Suguru Takada^f, Yuki Inoue^{e,g,h}, Takaaki Kajita^a



AL 6N KAGRA Braids

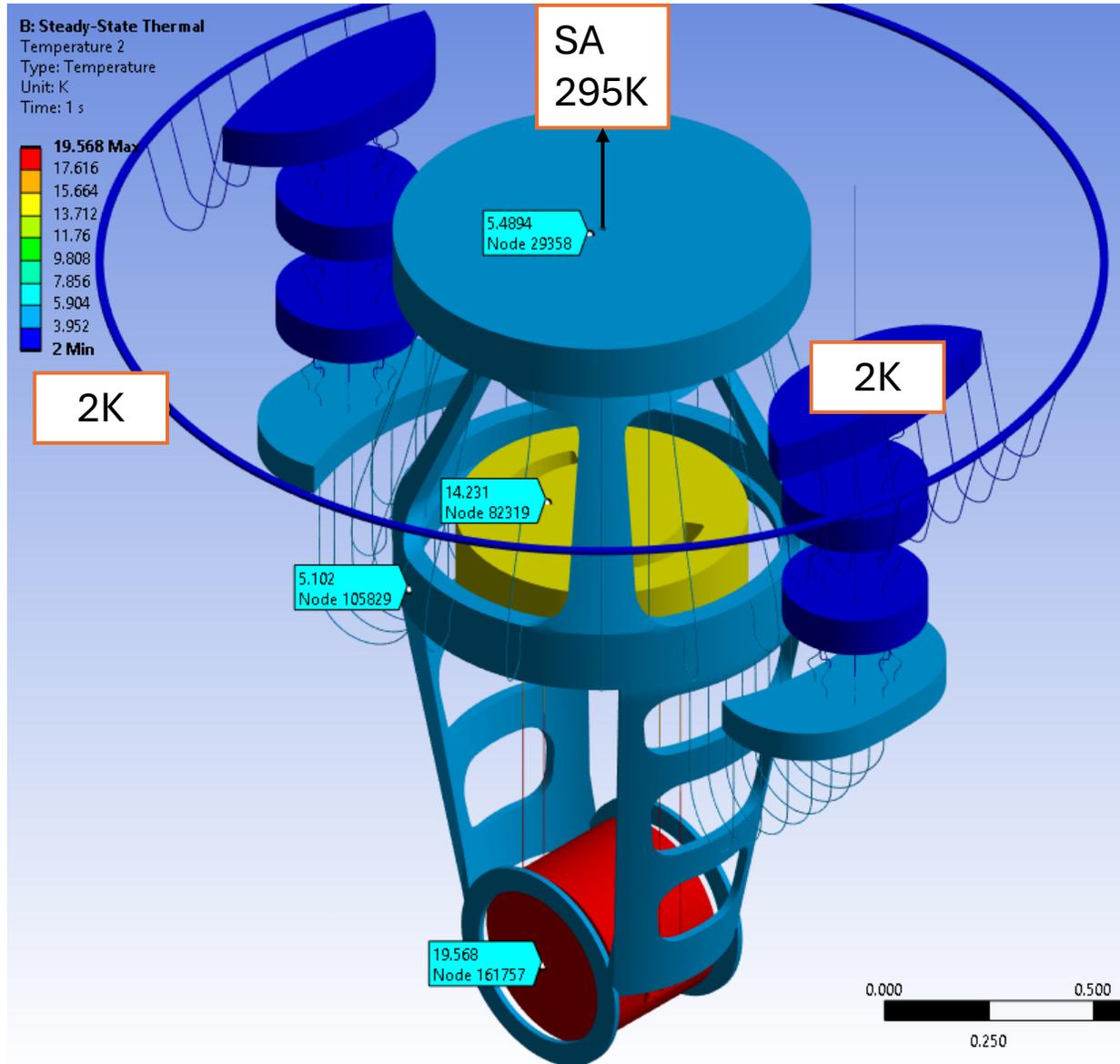


Platform to SA heat insulated cable



https://trc.nist.gov/cryogenics/materials/Ti6Al4V/Ti6Al4V_rev.htm

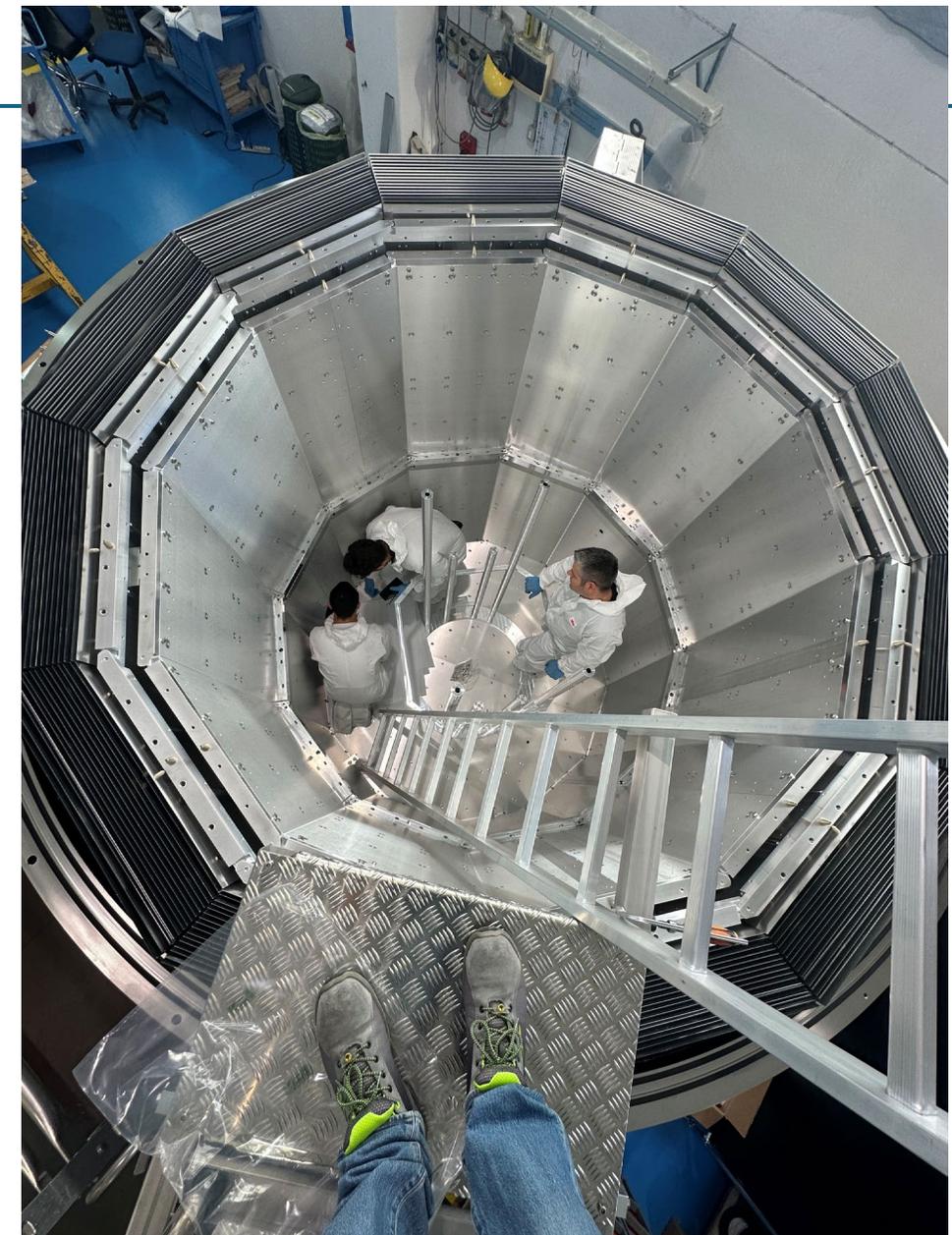
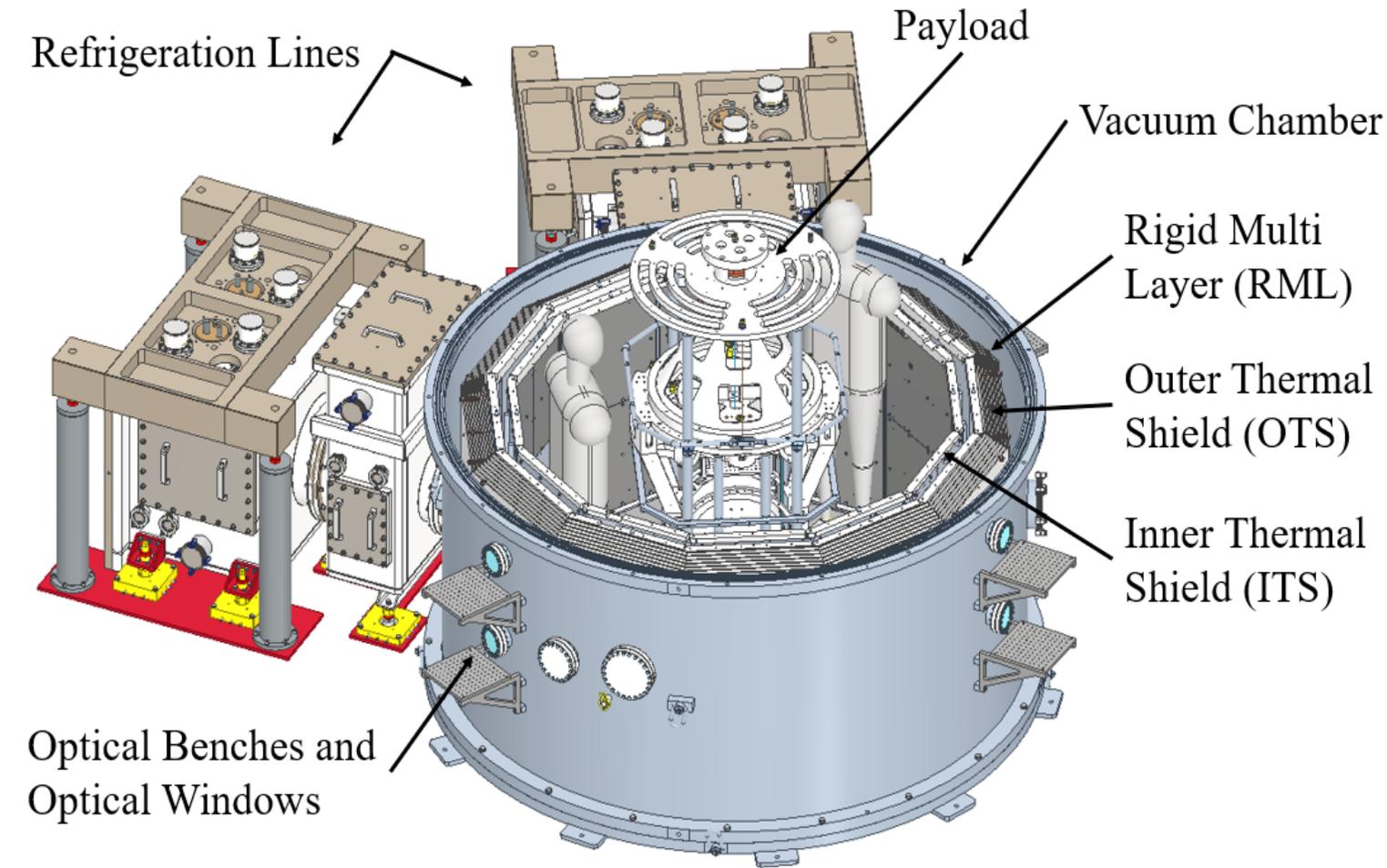
Cryogenic Payload Steady-State



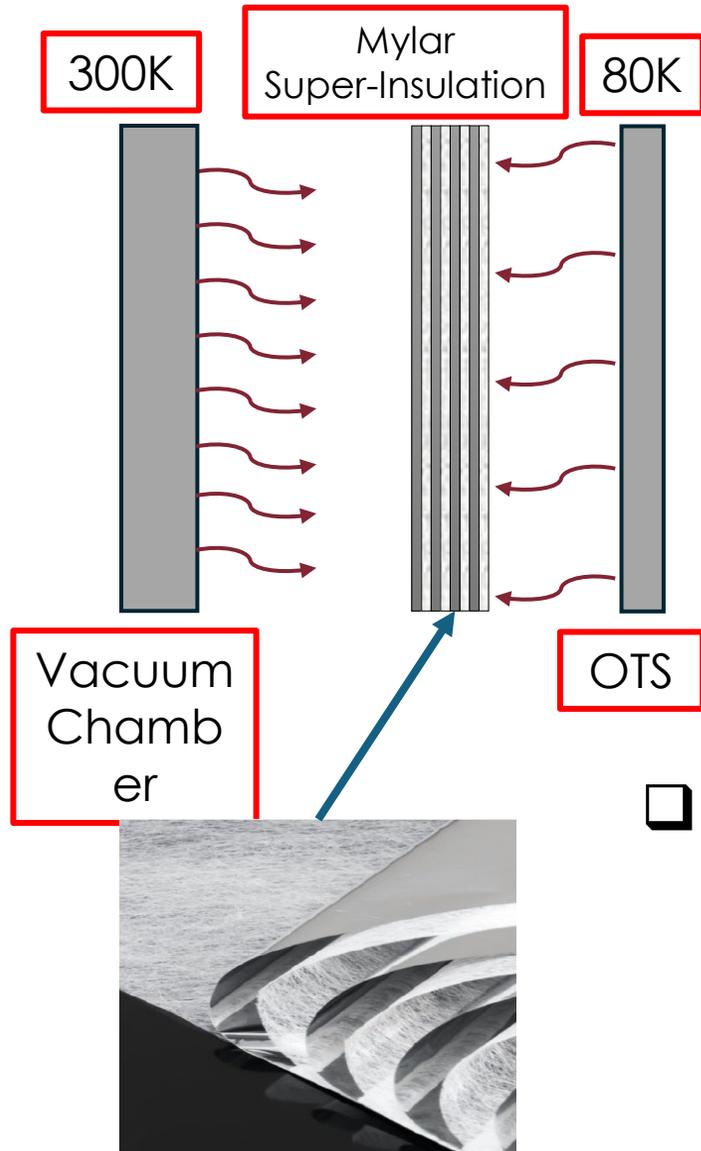
Body	Working Temp [K]
Cage	5.1
PF	5.5
MA	14.2
MI	19.6

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ARC-ETCRYO: Cryostat C75

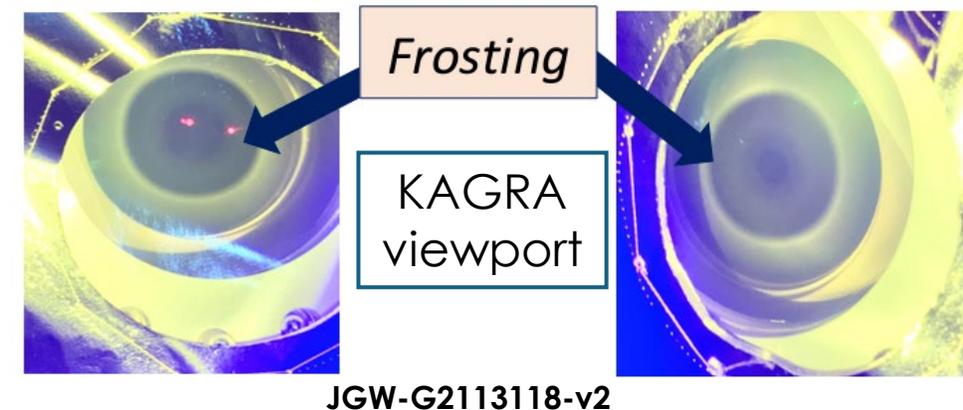


Mylar Super-Insulation

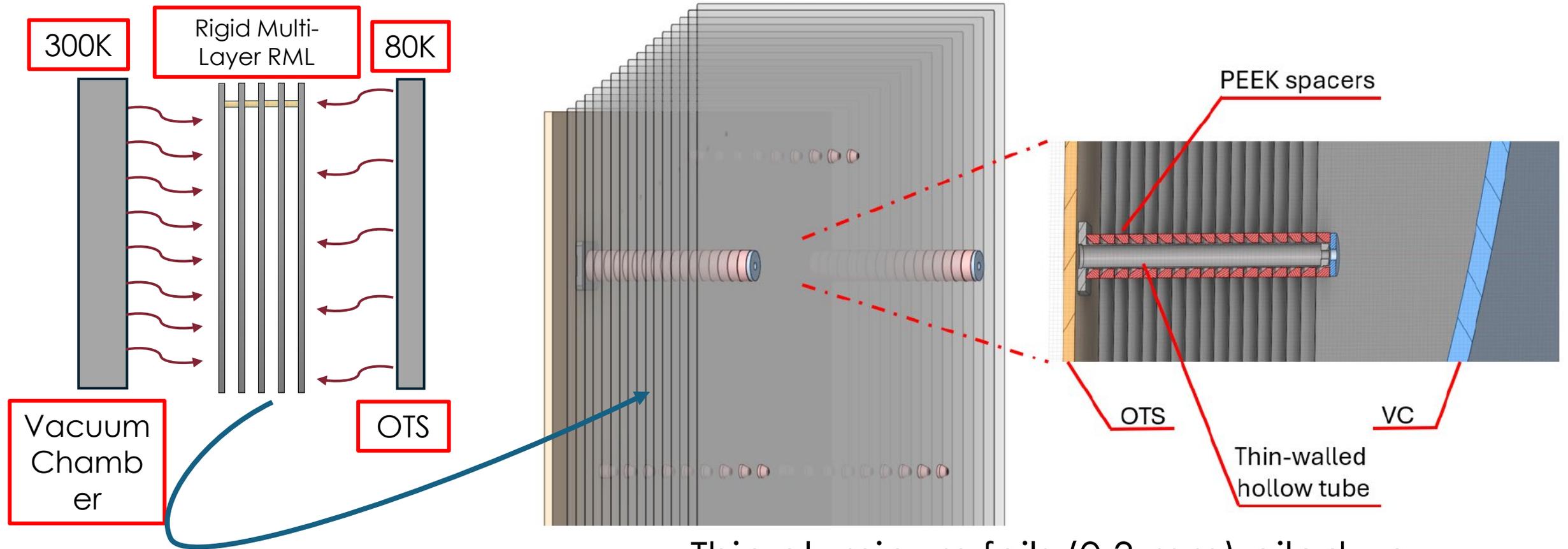


- Cryogenic experiments use Mylar Super-Insulation to shield radiation coming from room temperature surfaces.
- It consists of thin aluminized mylar sheets alternated by insulating foils (polyester, ...).
- Typical Heat Flux considered on the cold surface $\sim 2 \frac{\text{W}}{\text{m}^2}$

- KAGRA experience with Mylar Super-Insulation:
 - Particle & Gas contamination resulting in frost in the optics.



Rigid Multi-Layer

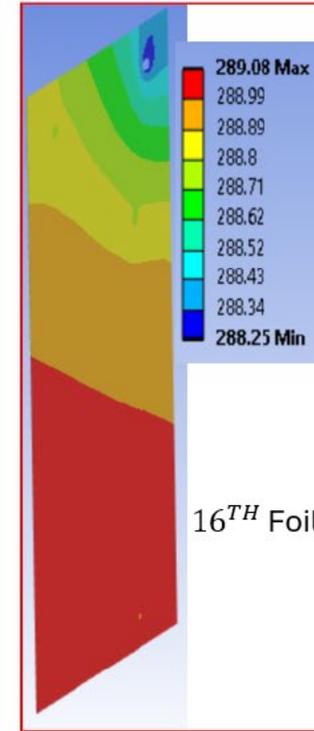
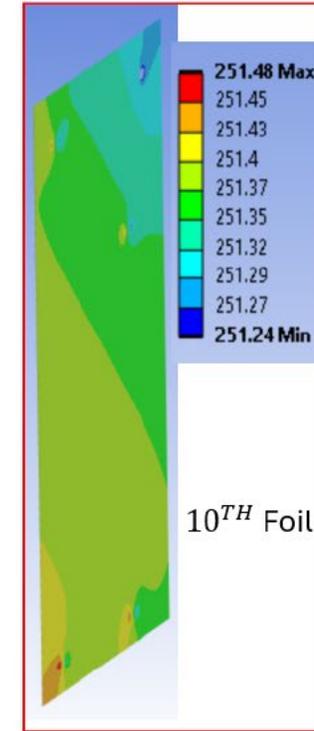
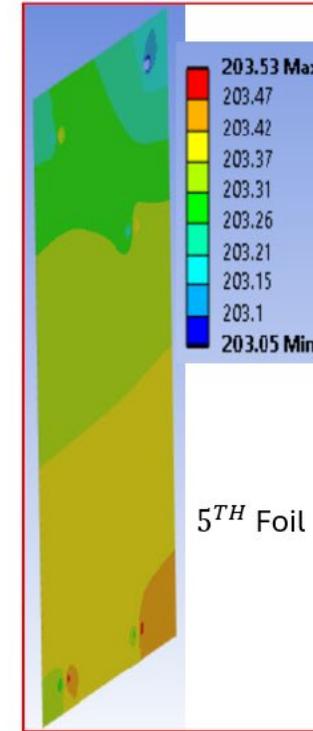
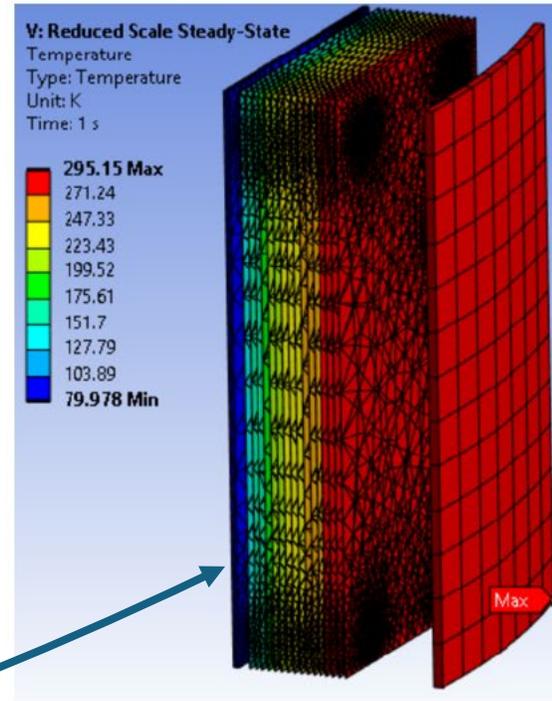


- Thin aluminum foils (0.3 mm) piled up on the external surfaces of the OTS
- Expected Heat Flux $\sim 1.5 \frac{W}{m^2}$ with 16 foils

* Simulations performed considering the radiative and conduction contributions of the supports

Rigid Multi-Layer

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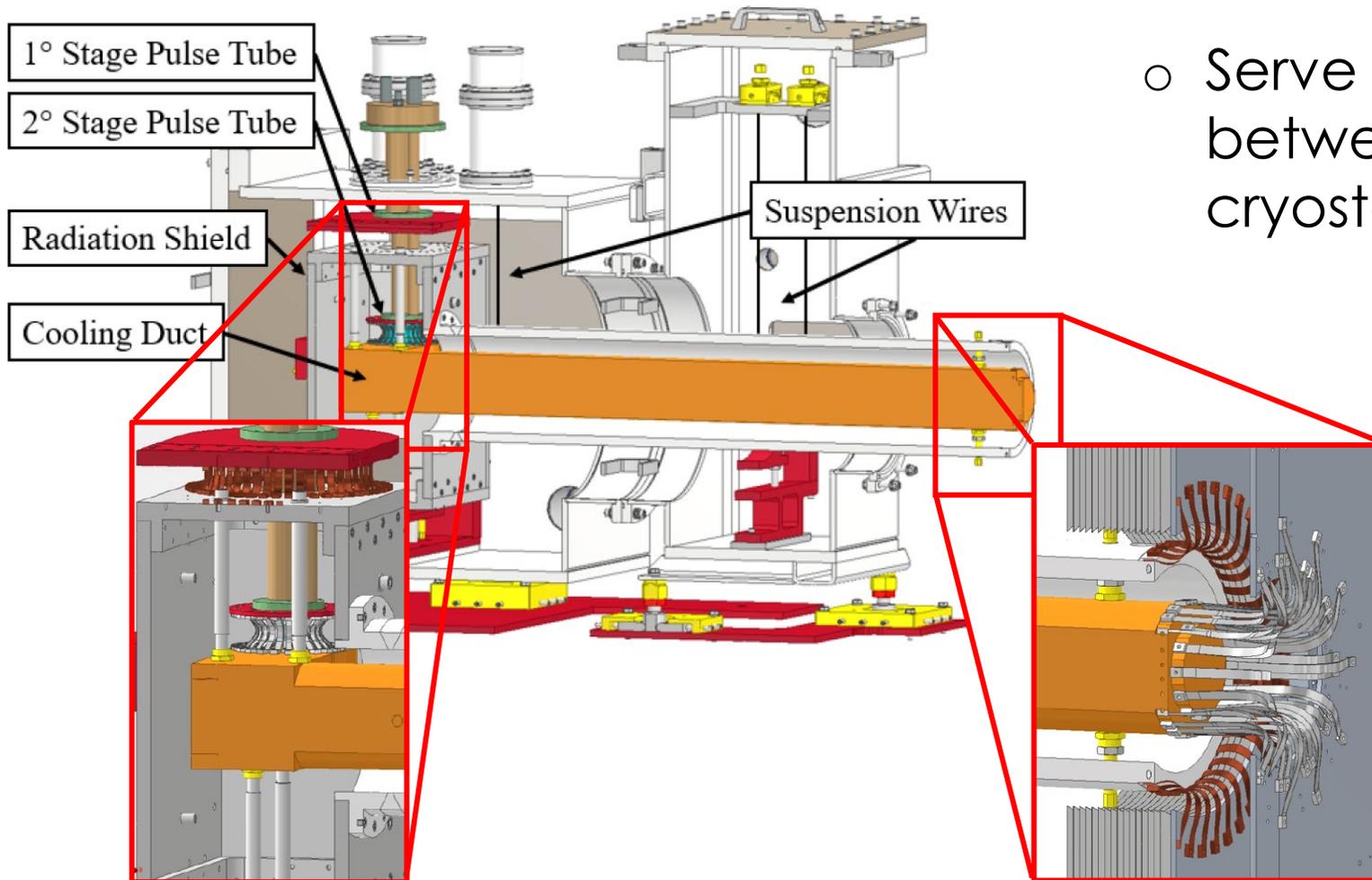
- Thin aluminum foils (0.3 mm) piled up on the external surfaces of the OTS
- Expected Heat Flux $\sim 1.5 \frac{\text{W}}{\text{m}^2}$ with 16 foils

* Simulations performed considering the radiative and conduction contributions of the supports

ARC-ETCRYO: The 2 refrigeration Lines

Refrigeration lines:

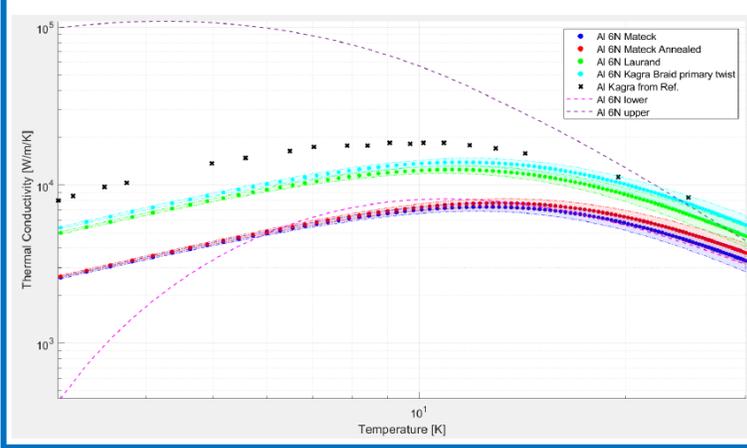
- Serve as a solid thermal connection between the PTs and the cryostat/payload



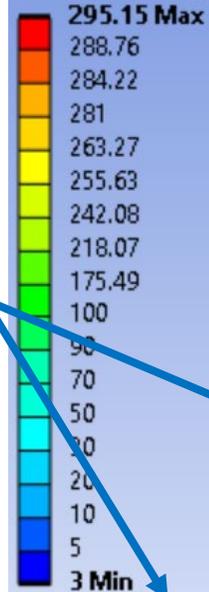
- Composed by suspended components
- Thermal connections with high-purity soft heat links

Overall Thermal extraction system

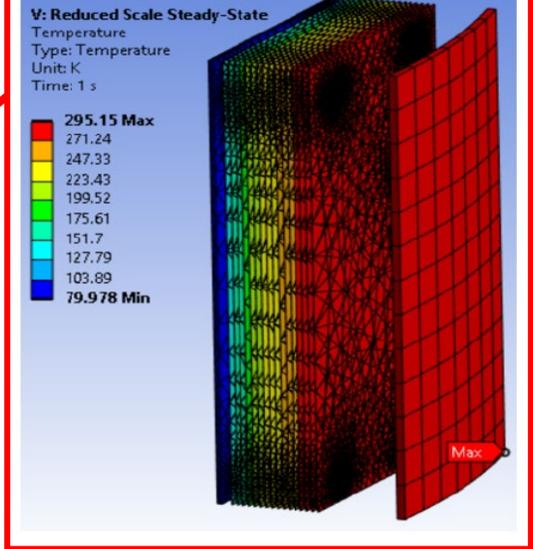
Thermal conductivity



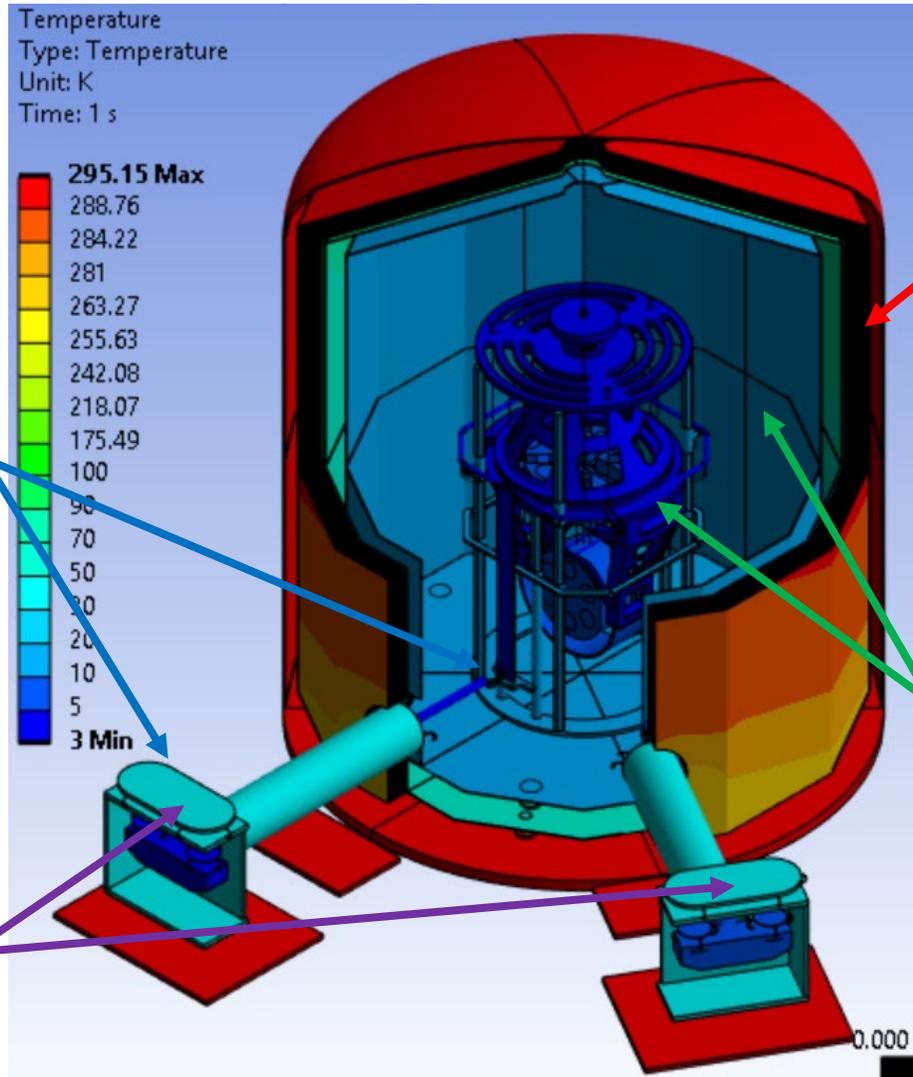
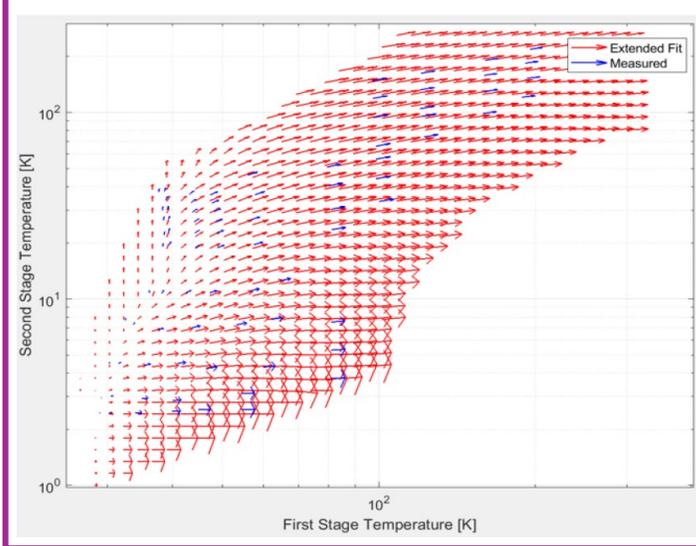
Temperature
Type: Temperature
Unit: K
Time: 1 s



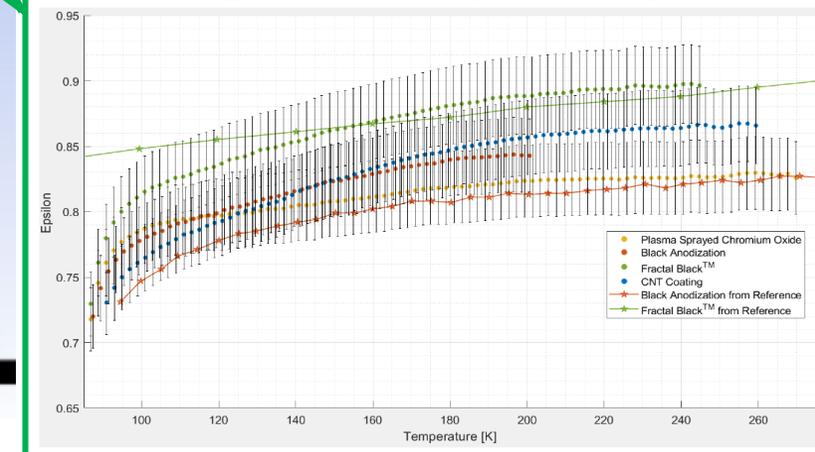
RML Optimization



Pulse Tube Capacity Curve

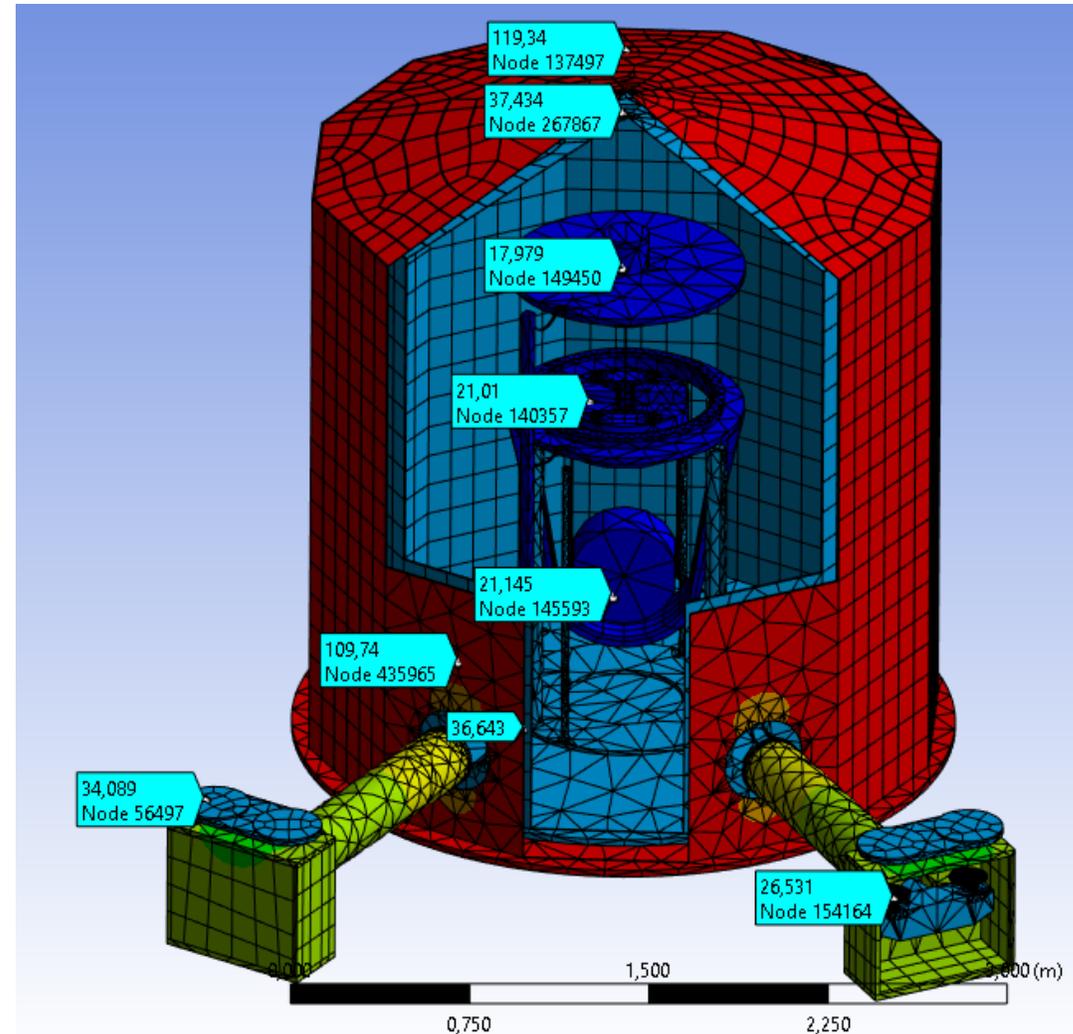


High-Emissivity Coatings

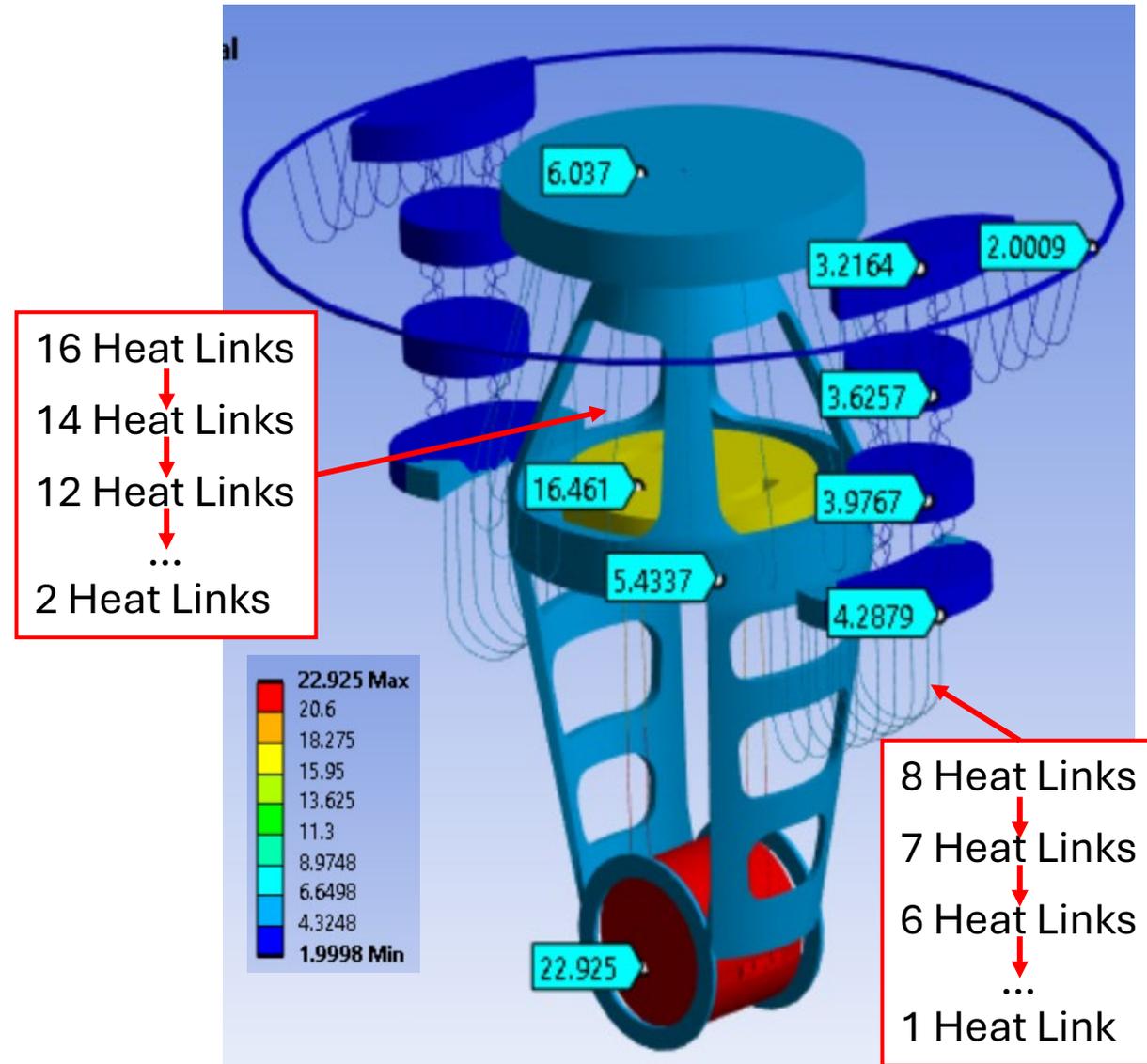


Cooling time

- Time for the cooling the cryostat ~ 27 days
- It can be reduced by increasing the number of heat links



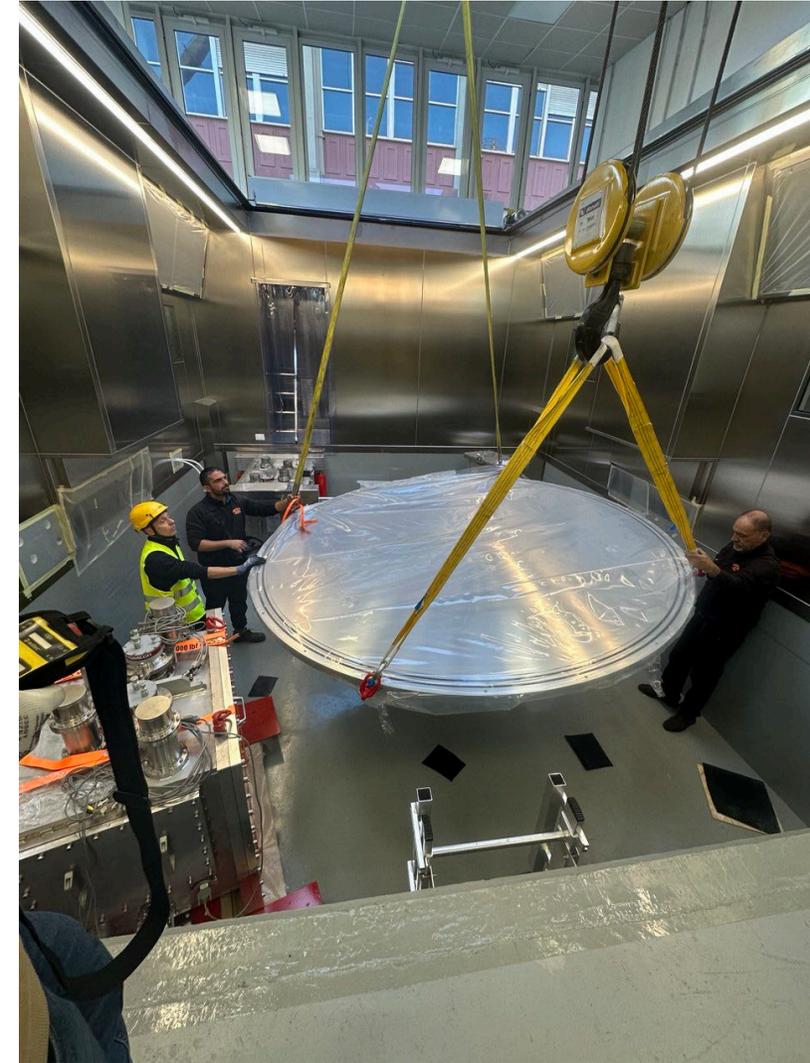
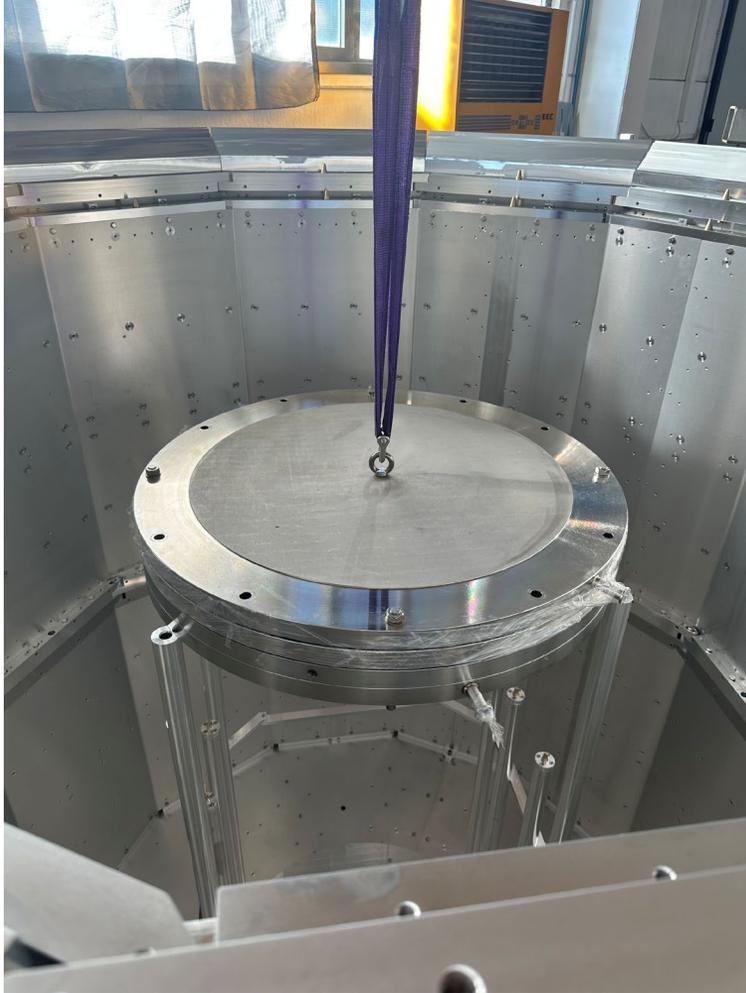
ET-LF Payload: Transient Thermal Simulation



Heat Link Number	Mirror Cooling Time #1 [days]
16	16.2
14	17.1
12	18.4
10	20.0
8	21.8
6	24.0
4	27.8
2	36.0

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Cryostat at Rome Sapienza Lab ARC





Thermal Noise: Thermal Gradients

Thermal Noise

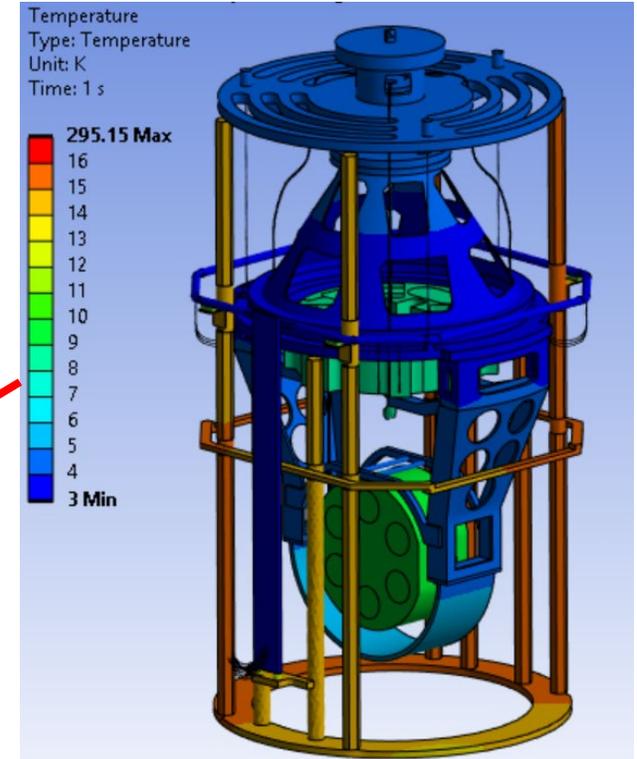
$$\tilde{x}^2(\omega) = \frac{4k_B T}{\omega} \text{Im}[H(\omega)]$$

Levin approximation

$$\begin{cases} \tilde{x}^2(\omega) = \frac{8k_B T}{\omega^2} \frac{W_{diss}}{F_0^2} \\ W_{diss} = \omega \int \epsilon(r) \phi(r) \partial V \end{cases}$$

+ Steady-State Thermal Simulation Results

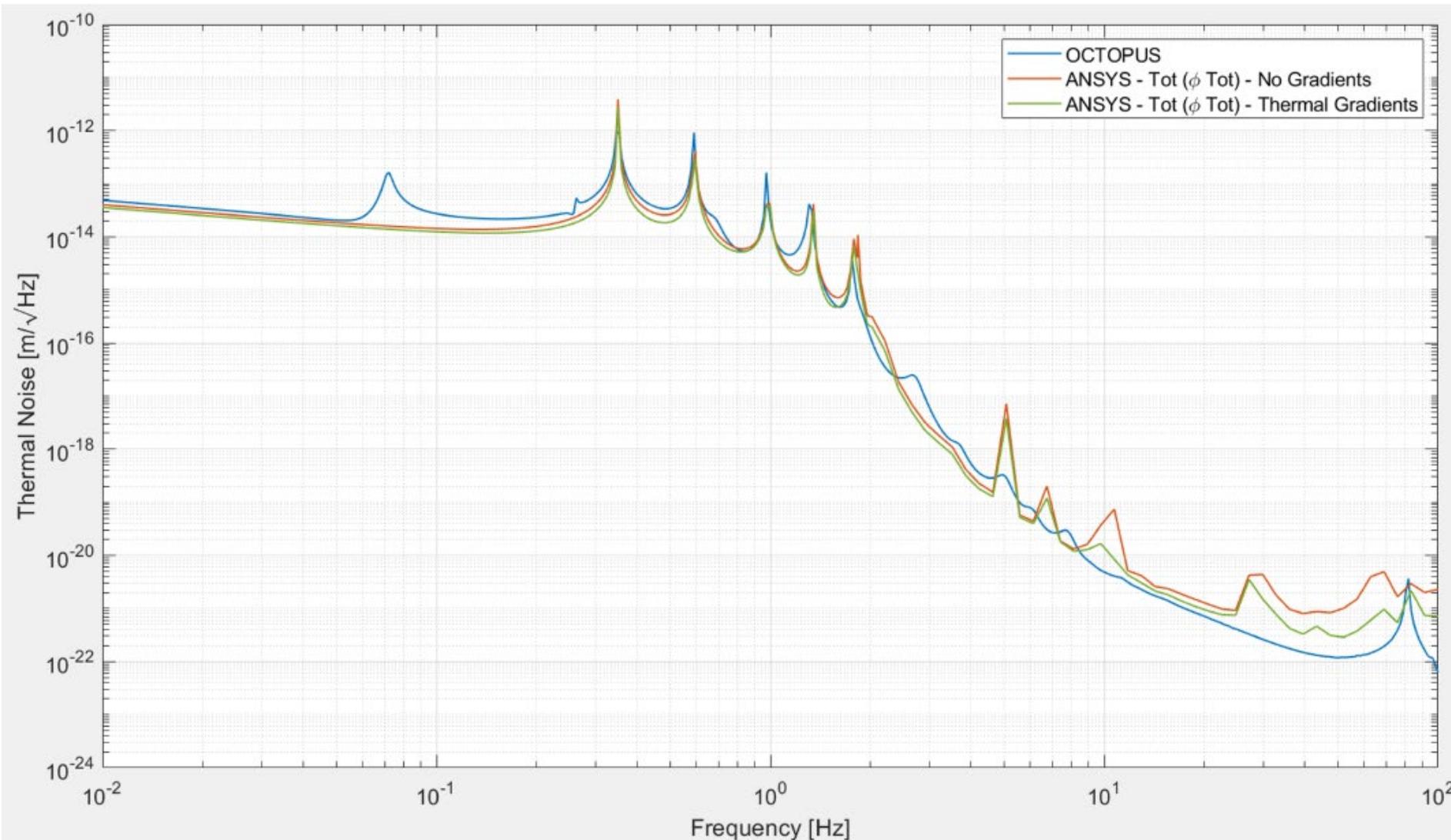
$$\tilde{x}^2(\omega) = \sum_n^{NBody} \left[\frac{8k_B T}{\omega} \frac{\int \epsilon(r) \phi(r) \partial V}{F_0^2} \right]_n = \sum_n^{NBody} \left[\frac{8k_B}{\omega F_0^2} \sum_i^{NElem} T_i \left(\int \epsilon(r) \partial V \right)_i \phi(T)_i \right]_n$$



- Temperature and Stress Distribution

GWD Vac22 - Elba - P. Puppo

Thermal Noise



- Thermal noise estimation at 20K with OCTOPUS
- ANSYS Thermal noise estimation with thermal gradients → study changing number, length and Q of the heat links for optimization

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Conclusions

- Comprehensive **thermal characterization of cryogenic systems for next-generation GW detectors** was performed, using the **ARC-ETCRYO facility**
- ARC-ETCRYO successfully reproduces ET-LF operating conditions on a reduced scale, representing the perfect testbed for technological upgrades to be applied in ET
- **In the Thermal noise analysis** soft heat links are considered in the estimation
- **Cryostat is on site and being assembled and in the near future it will be ready to experimentally test the foreseen results.**