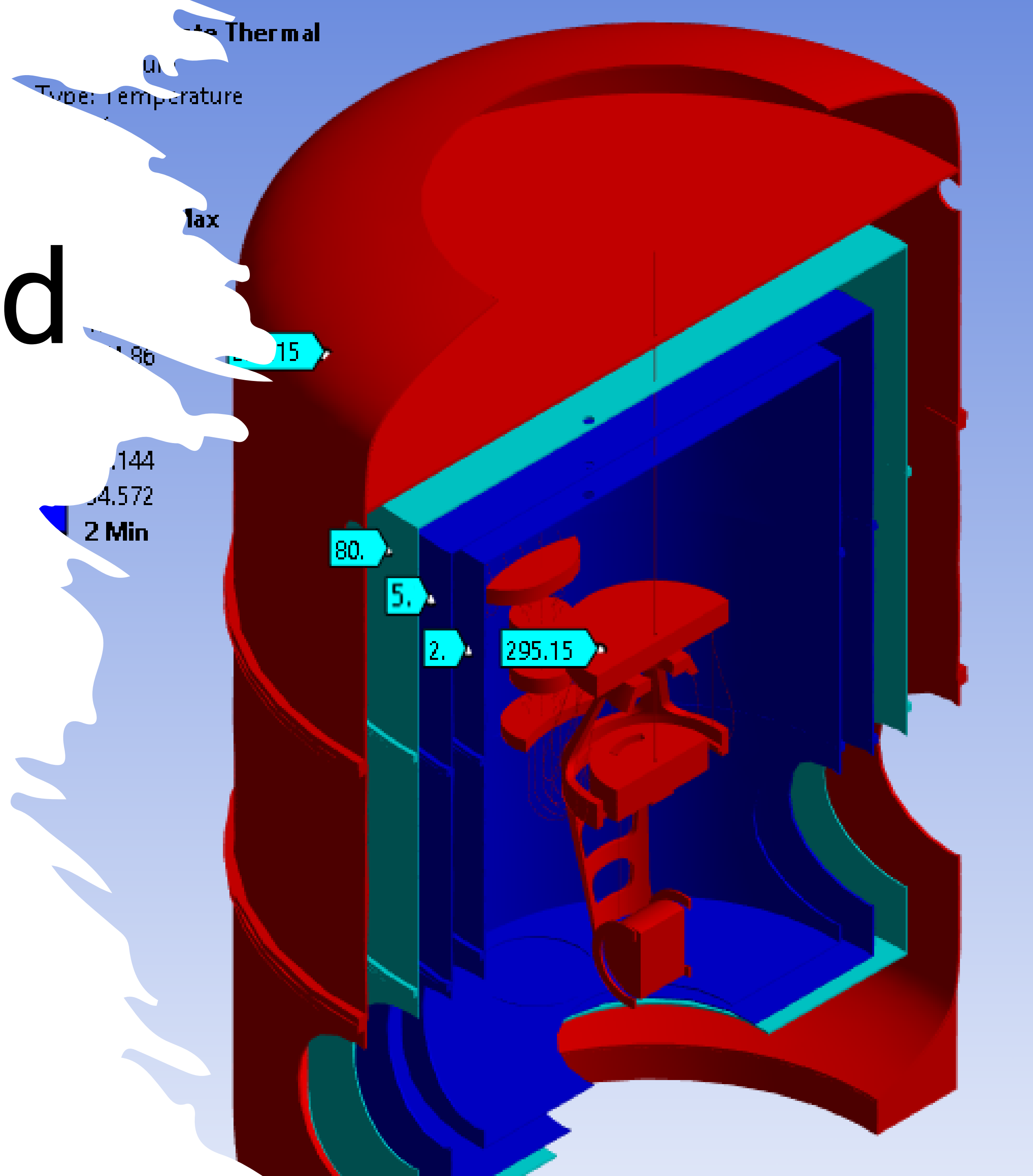
Cryogenic Payload Thermal Simulations

Marco Ricci

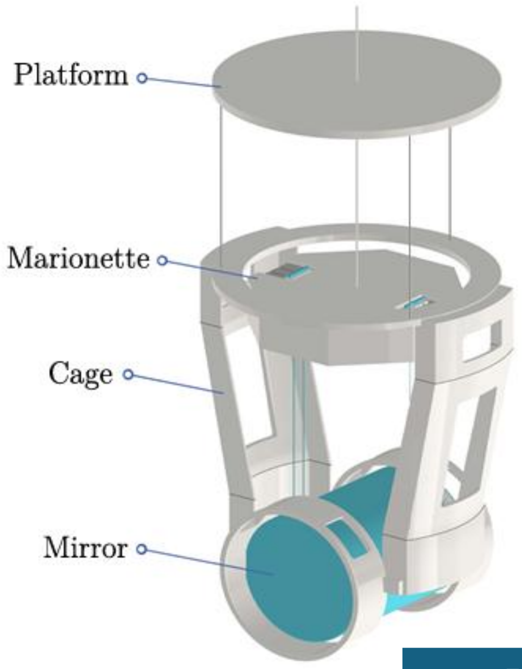
Cryostat Design Meeting

Rome 28-29 July 2025

EINSTEIN TELESCOPE

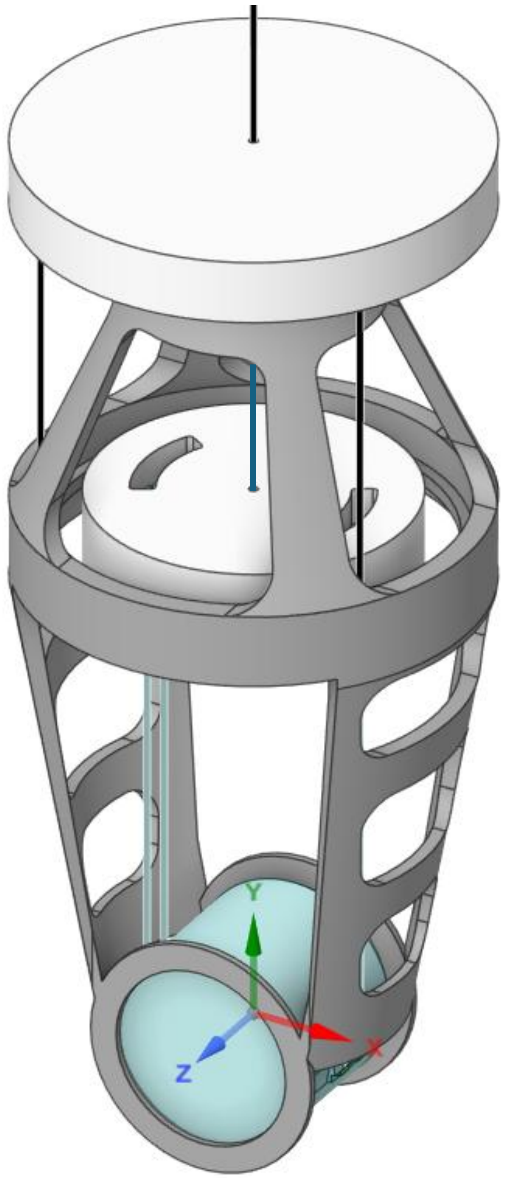


Cryogenic Payload Thermal Simulation Design

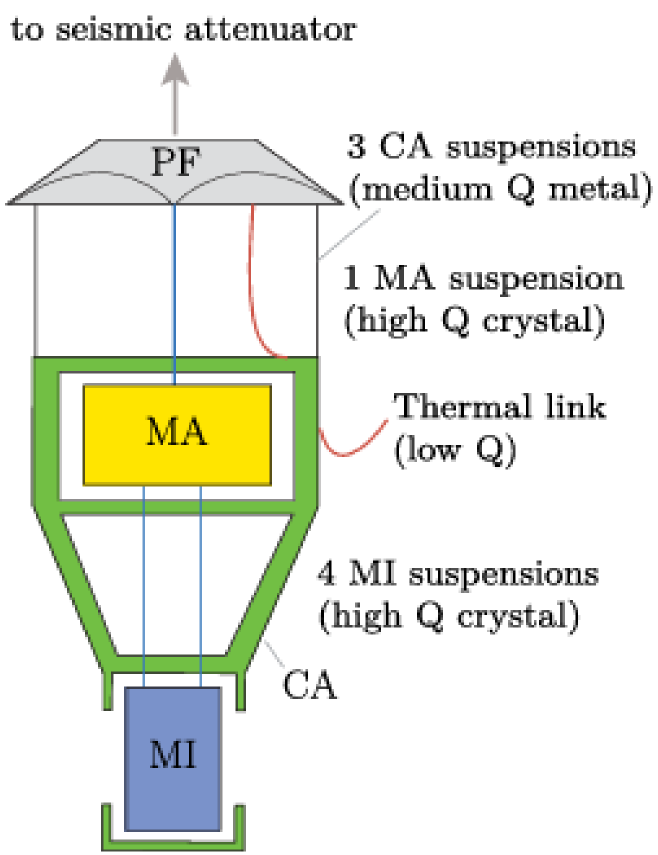


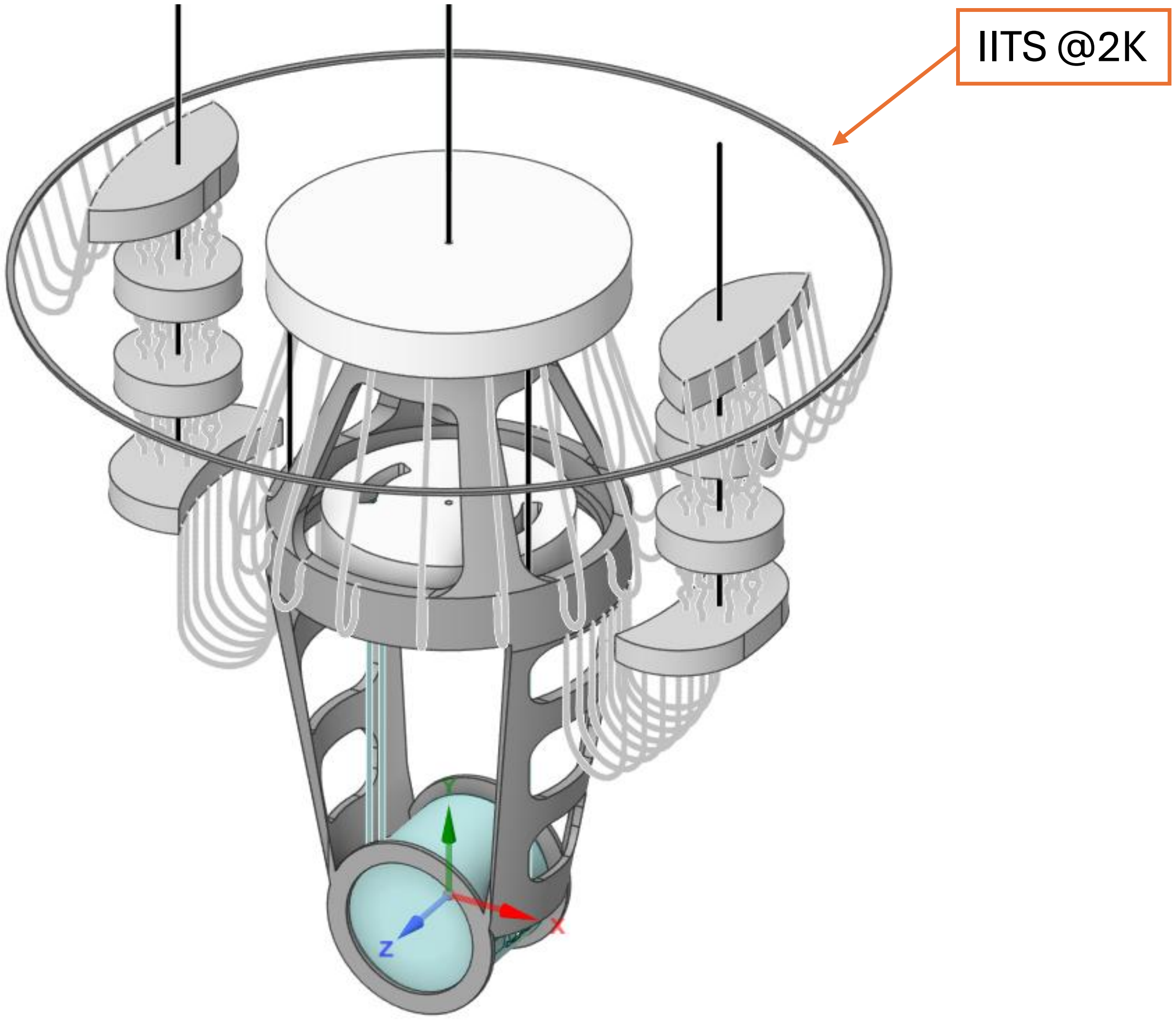
Suspension	Length $[m]$	Diameter $[mm]$	Material
MI-MA	1.2	2.3	Sapphire
MA-PF	1	6.5	Sapphire
AC-PF	0.825	1	Ti-6Al-4V
PF-SAT	2.5	5	Ti-6Al-4V

Body	Mass $[Kg]$	$I_{xx}\,[Kg\,m^2]$	$I_{yy}[Kg\,m^2]$	$I_{zz}[Kg\,m^2]$
Platform (PF)	300	19.29	37.57	19.29
Actuation Cage (AC)	200	62.42	31.17	67.68
Marionette (MA)	211	7.31	12.87	7.08
Mirror (MI)	211	4.56	4.58	5.32

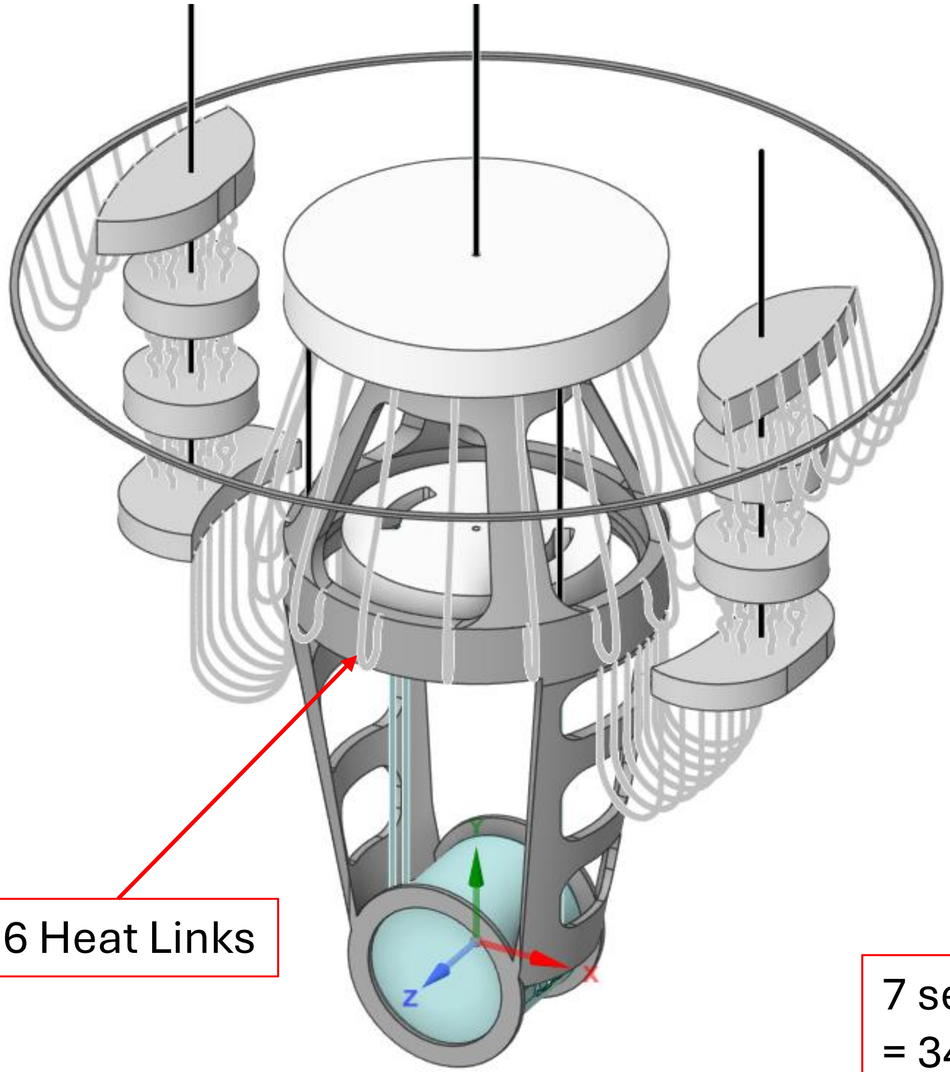


Cryogenic Payload Baseline Design

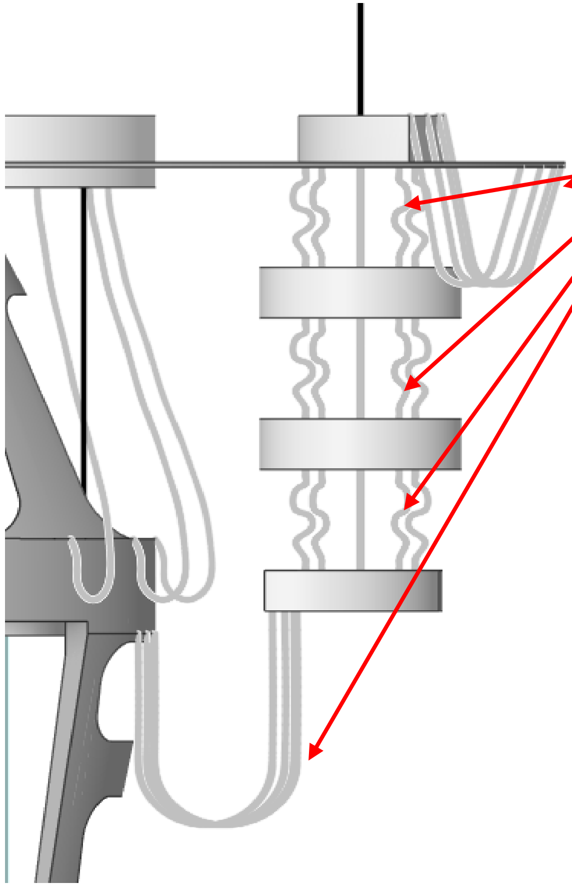




Cryogenic Payload Thermal Simulation Design



16 Heat Links

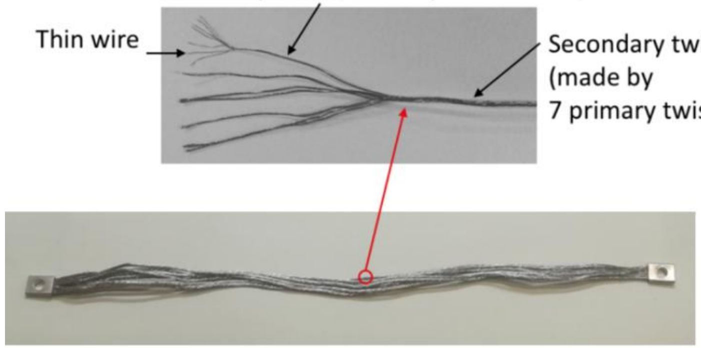


8 Heat Links

Heat
Link
Vibration
Isolation
System

Placeholder !

X 2



Heat link (7 secondary twists in parallel)

7 secondary twist = 7 x 7 primary twist = 7 x 7 x 7 thin wires $\phi = 0.15mm$
= 343 thin wires → Total cross section = 6.06 mm^2
Simulation single wire $\phi = 2.78mm$ → Cross section = 6.07 mm^2

Cryogenic Payload Thermal Simulation Design

Total mass HLVIS = 116.83 Kg

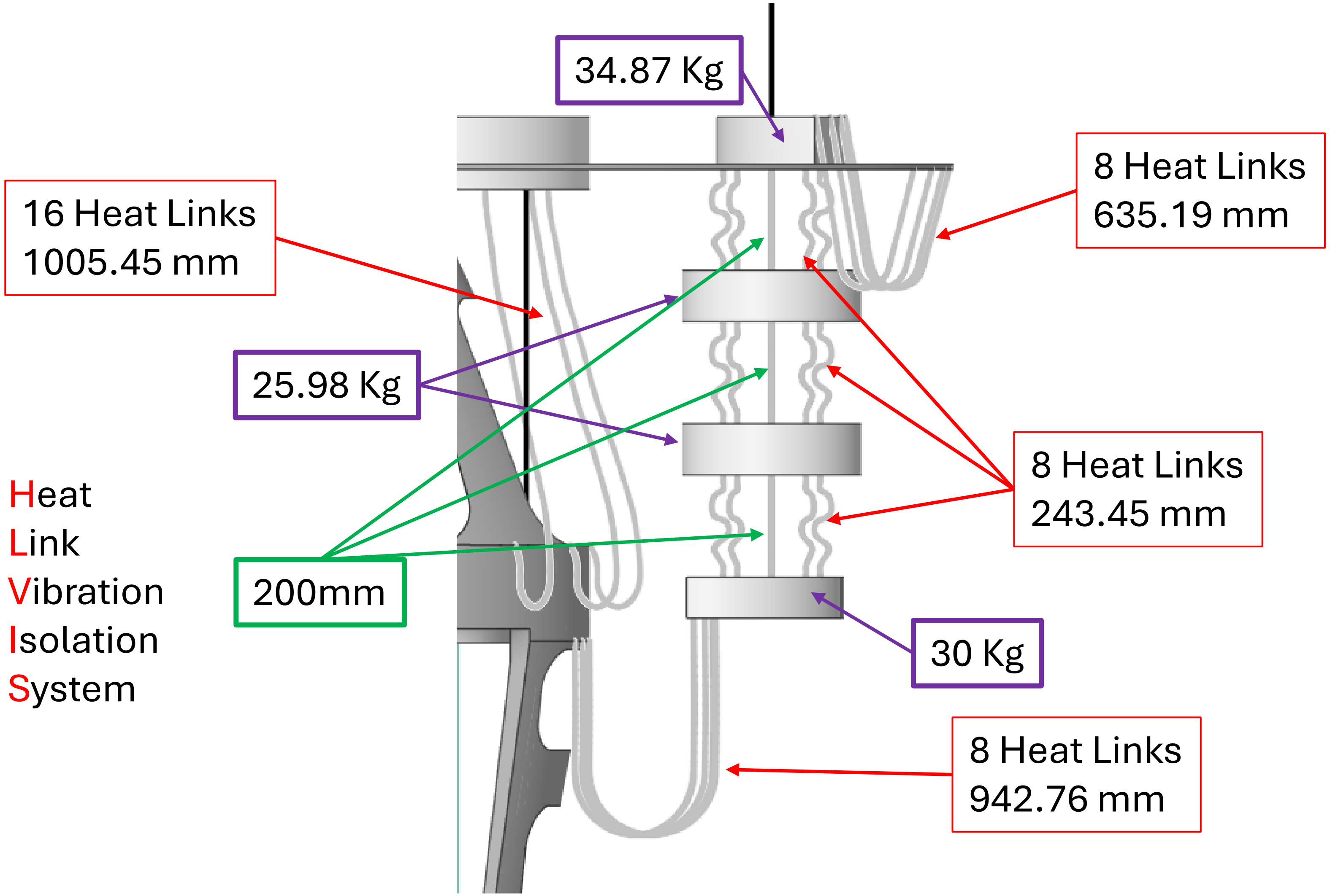
Total length (w.o. HLVIS bulks)
Ring → AC = 2308.3 mm

Total mass Pay = 921.8 Kg

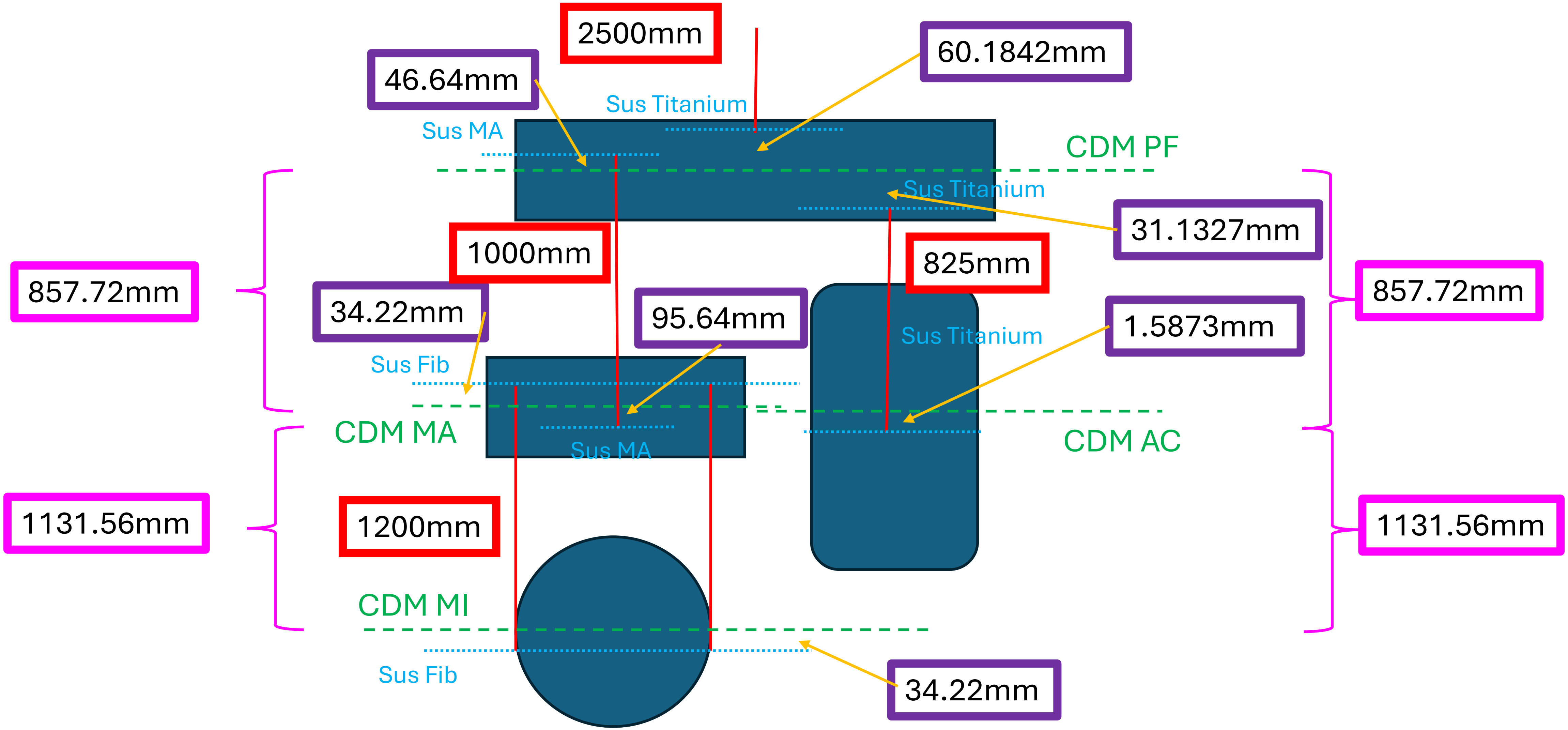
HLVIS ~ 1/8 Pay

KAGRA design requirement = 1/10 Pay

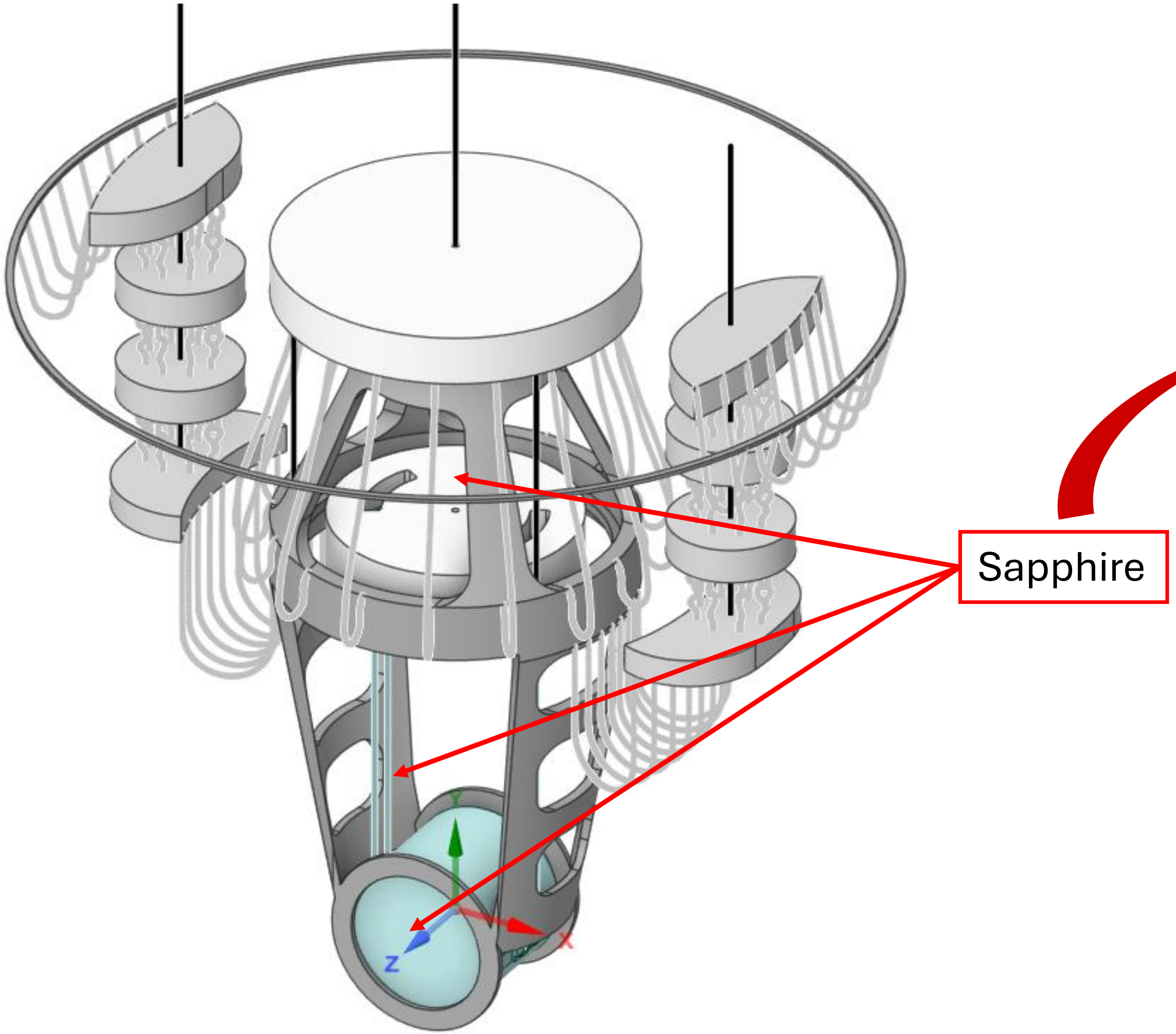
Heat
Link
Vibration
Isolation
System



Cryogenic Payload Suspension Diagram

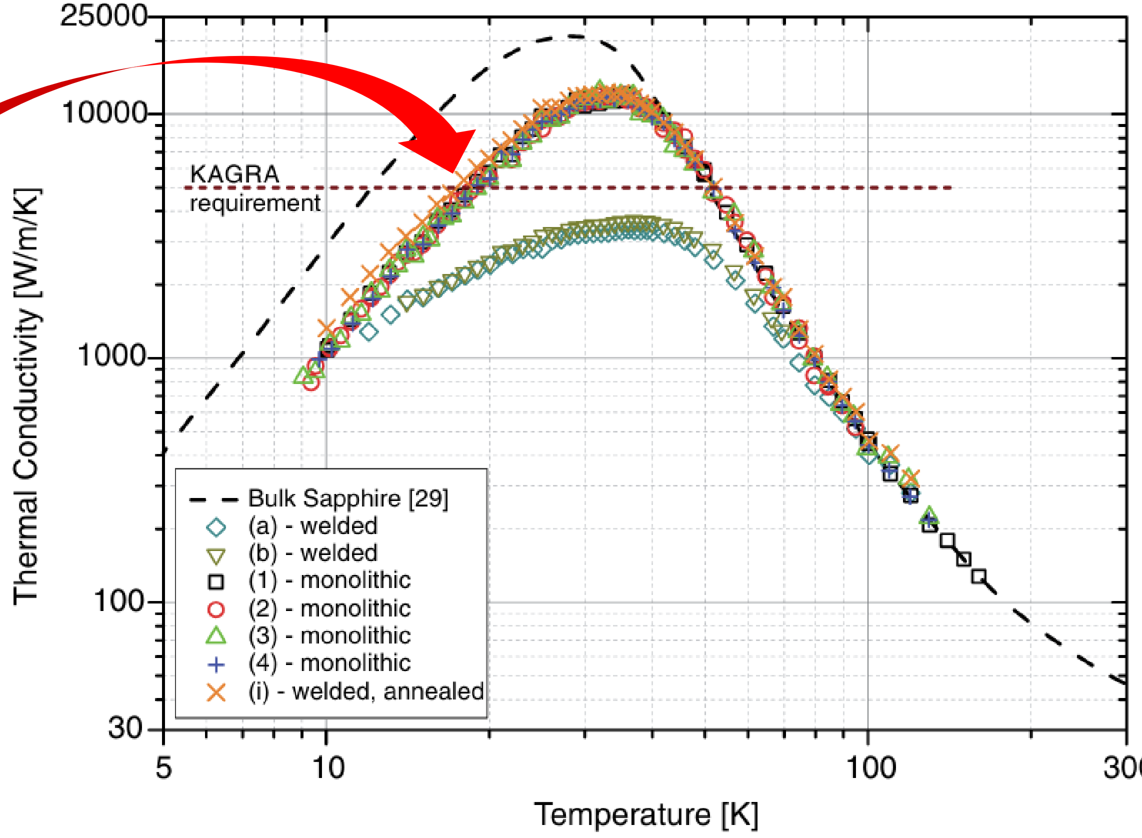


Cryogenic Payload Materials

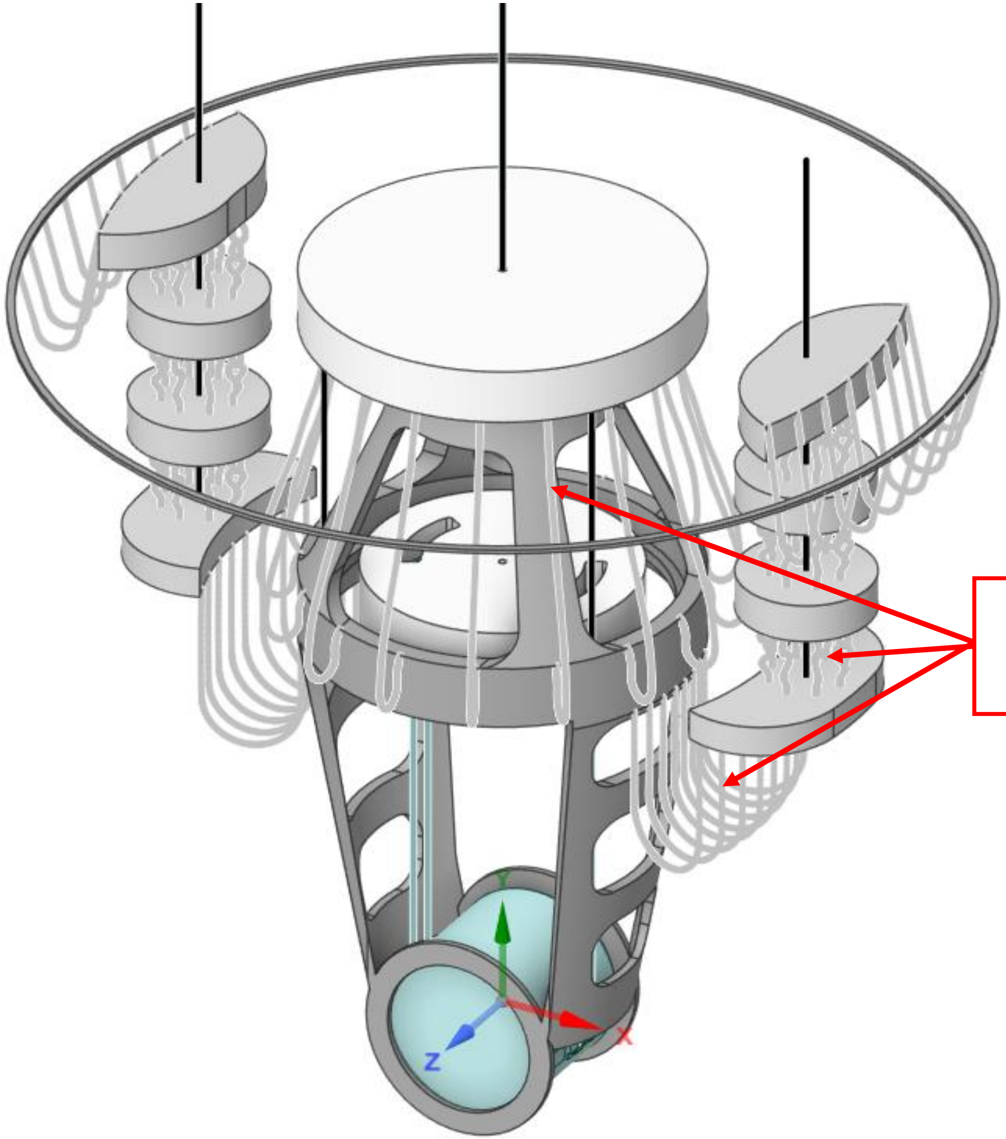


Evaluation of heat extraction through sapphire fibers for the GW observatory KAGRA

A Khalaidovski[1], G Hofmann[2], D Chen[1], J Komma[2], C Schwarz[2], C Tokoku[1], N Kimura[3], T Suzuki[3], A O Scheie[4], E Majorana[5], R Nawrodt[2] and K Yamamoto[1]



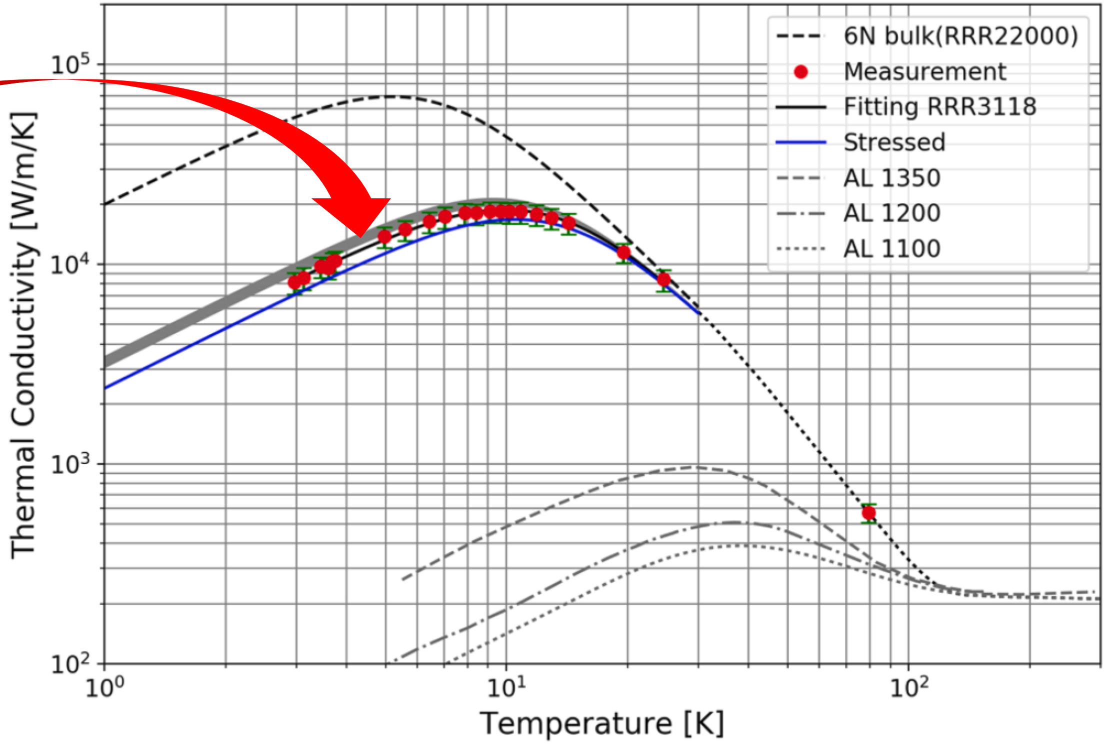
Cryogenic Payload Materials



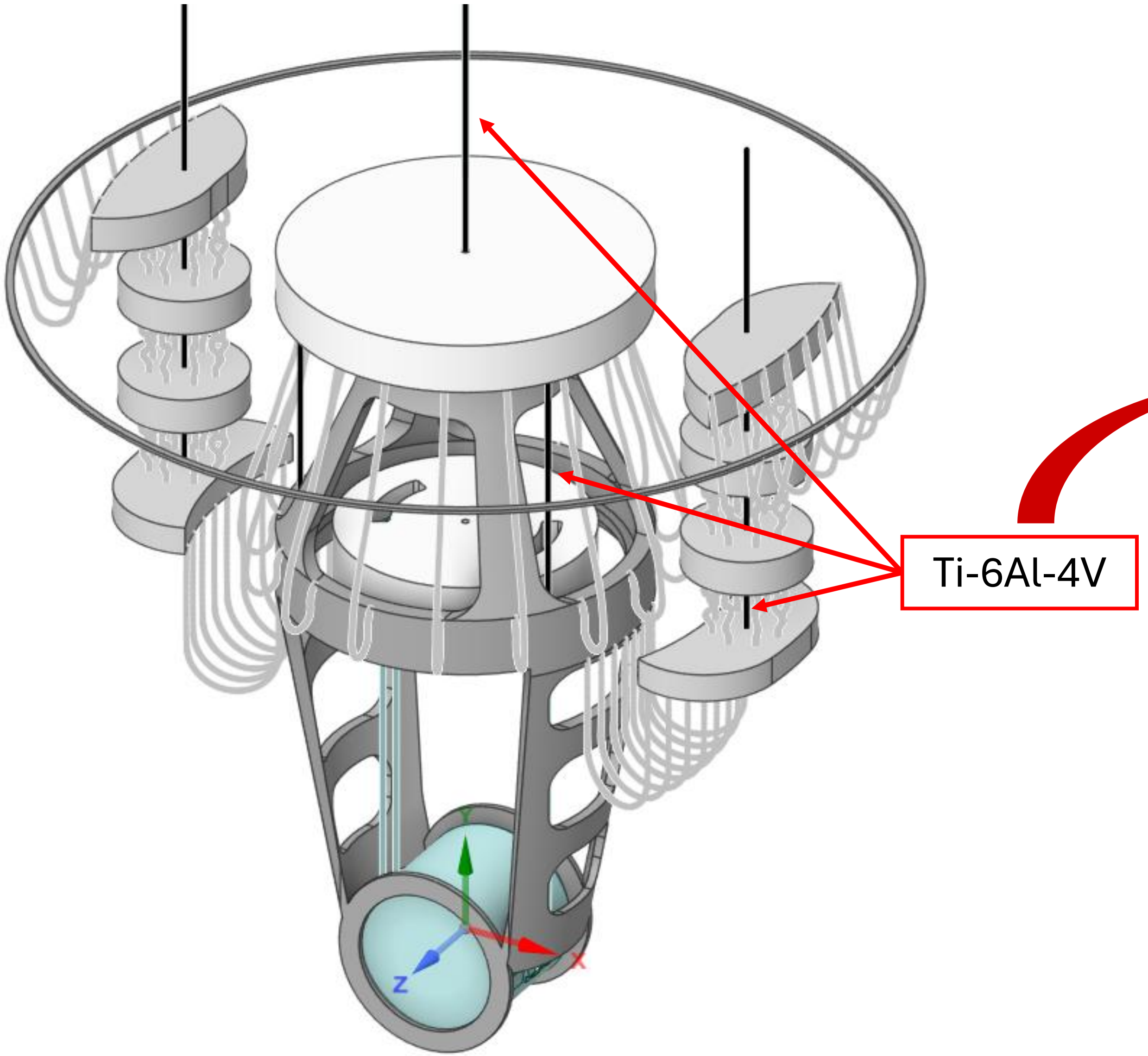
Al 6N KAGRA Braids

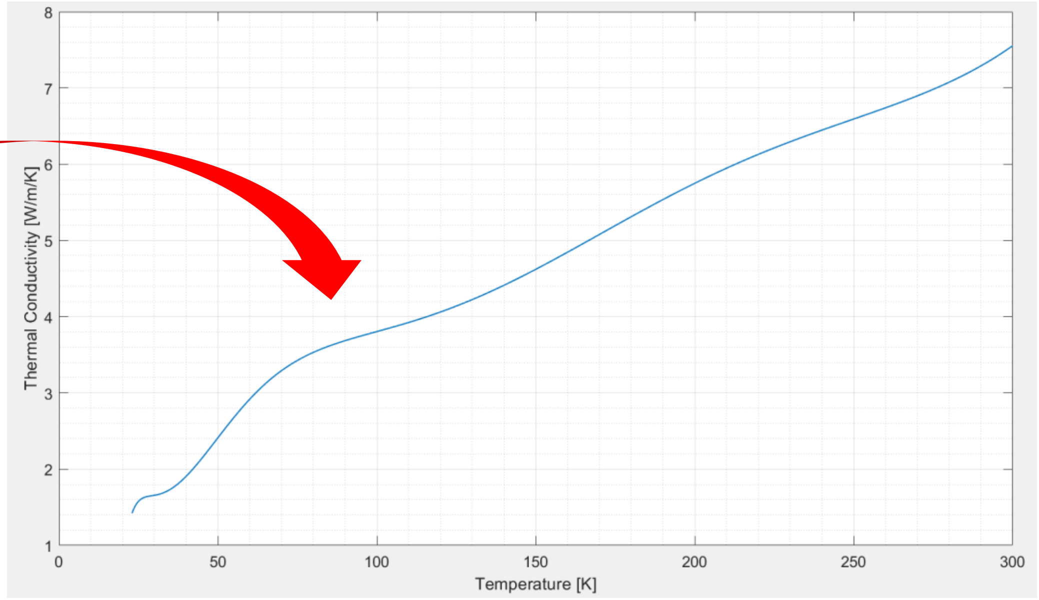
High performance thermal link with small spring constant for cryogenic applications

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]



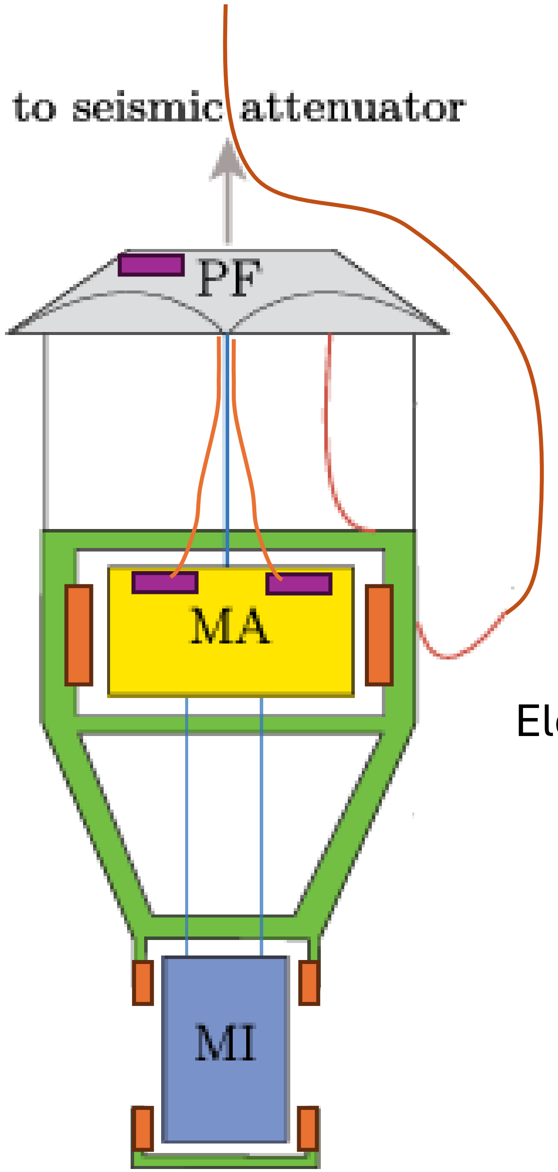
Cryogenic Payload Materials





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

Cryogenic Payload Electrical Wires Connections



Electrical Wires
(low Q)

As well as thermal links, electrical wires are connected (and thermalized) to the Actuation Cage

Cryogenic Payload Electrical Wires Connections

Thermal design study of the electrical cabling system of cryogenic payloads in the Einstein Telescope

Defne Çelik, Xhesika Koroveshi, Steffen Grohmann

ET-ISB Division IV: Vacuum and Cryogenics

Table A.2: Optimized heat load results for Case 1: 300 K → Payload with monolithic cooling

Input	Instrument Type	Total Wire	I_0 [mA]	AWG	d_{min} [mm]	L_{max} [mm]	$\dot{Q}_e$ [W]	Total $\dot{Q}_e$ from all wires of the input [W]	Total $\dot{Q}_e$ per section [W]
Platform $T_{PF} = 13$ K									
1	~~Piezo Actuator~~	~~6~~	~~100~~	~~35~~	~~0.1426~~	~~560~~	~~0.005070~~	~~0.030420~~	0.899448
2	~~*LVDT~~	~~12~~	~~100~~	~~35~~	~~0.1426~~	~~560~~	~~0.005070~~	~~0.060840~~	
3	Stepper Motor	16	1000	25	0.4547	570	0.050511	0.808179	
4	Cernox	4	0.01	56	0.0125	610	0.000002	0.000010	
Marionette $T_{PF} = 17$ K									
5	~~Photodiode~~	~~24~~	~~10~~	~~40~~	~~0.0799~~	~~1720~~	~~0.000505~~	~~0.012126~~	
6	~~LED~~	~~12~~	~~350~~	~~25~~	~~0.4547~~	~~1590~~	~~0.017707~~	~~0.212484~~	0.635474
7	Stepper Motor	8	1000	20	0.8118	1780	0.050645	0.405163	
8	Coil	12	9.4	40	0.0799	1830	0.000474	0.005685	
9	Cernox	8	0.01	52	0.0199	1850	0.000002	0.000016	
Test Mass $T_{PF} = 20$ K									
10	~~Photodiode~~	~~24~~	~~10~~	~~37~~	~~0.1131~~	~~3370~~	~~0.000506~~	~~0.012139~~	
11	~~LED~~	~~12~~	~~350~~	~~22~~	~~0.6438~~	~~3110~~	~~0.017748~~	~~0.212970~~	0.233887
12	Coil	8	1.7	45	0.0447	3100	0.000086	0.000686	
13	~~*Picomotor TM~~	~~8~~	~~10~~	~~36~~	~~0.1131~~	~~3370~~	~~0.000506~~	~~0.004046~~	
14	~~*Picomotor CP~~	~~8~~	~~10~~	~~36~~	~~0.1131~~	~~3370~~	~~0.000506~~	~~0.004046~~	
15	Cernox	8	0.01	52	0.0251	3340	0.000002	0.000014	
Total Payload									1.768809

Stepper Motor (input 3): AWG 25 → AWG 29 ($\phi = 0.284mm$)

Stepper Motor (input 7): AWG 20 → AWG 29 ($\phi = 0.284mm$)

Coil (input 8): AC

Coil (input 12): AC

Worst Case scenario:
No Thermalization

$Q_{Stepper\ Motor}$ = 0.3649W

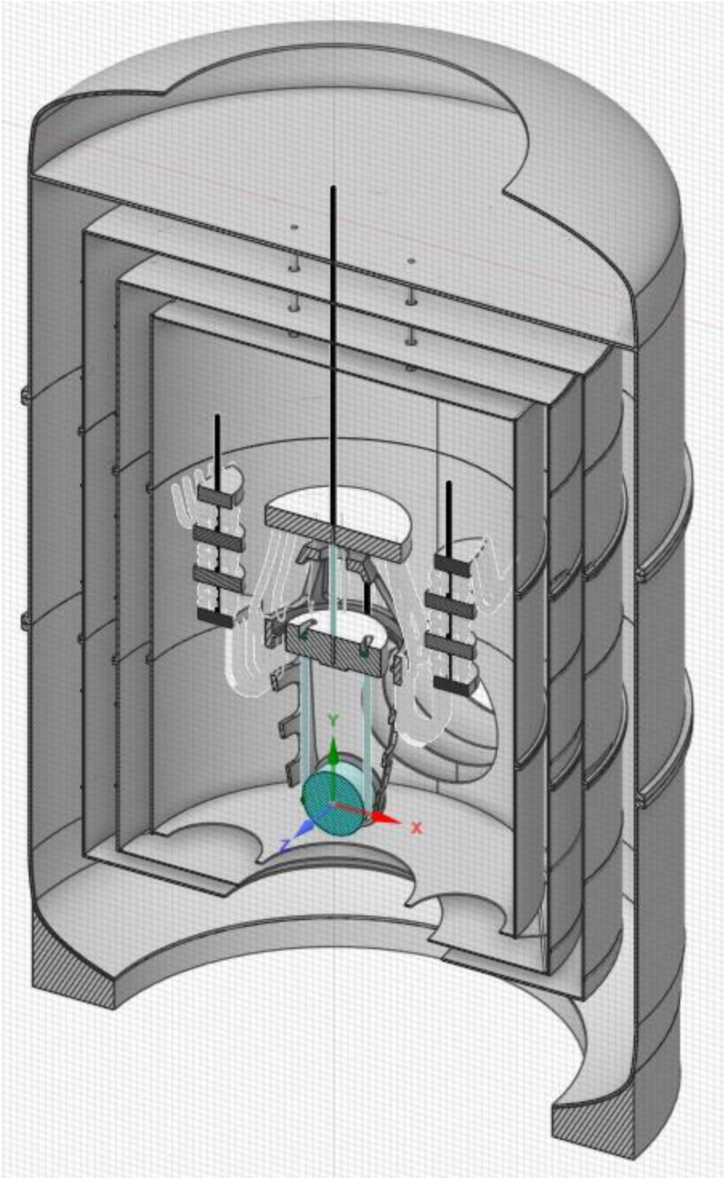
+

Q_{Coil} = 0.0064W

=

Q^{AC}_{TOT} = 0.38W

Cryogenic Payload Initial Temperature

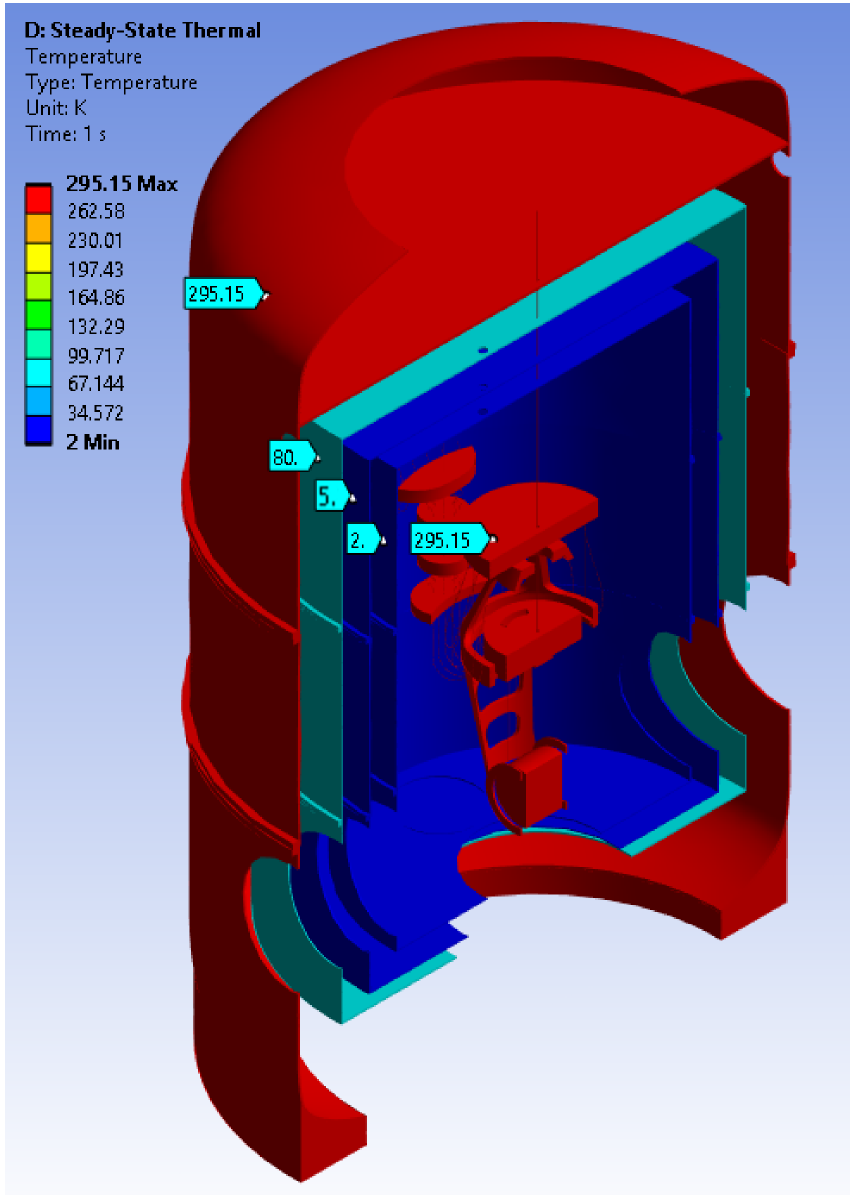


Thermal Simulations consider:

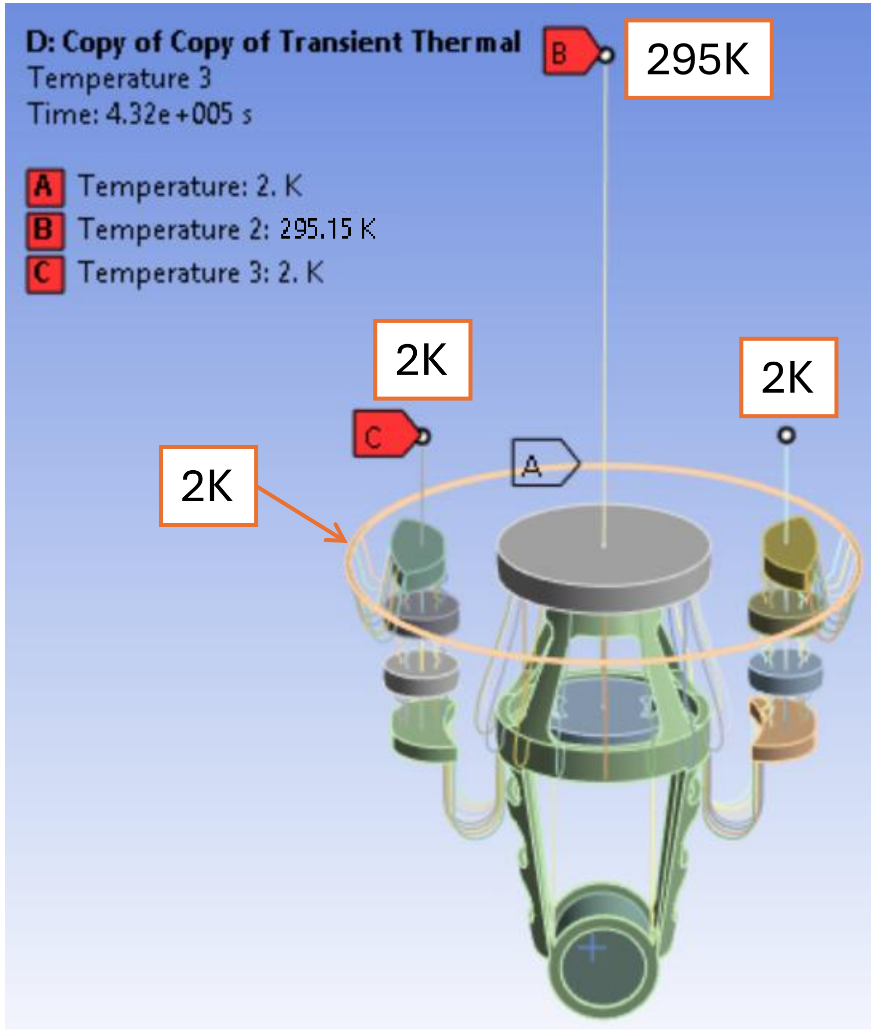
- Cryostat completely cooled

1. OTS @ 80K
2. ITS @ 5K
3. IITS@ 2K

- Payload @ Room Temperature



Cryogenic Payload Boundary Conditions



Boundary Conditions:

- 2K fixed temperature on the connection to the IITS
- 295.15K fixed temperature on the connection to the SAT
- 2K fixed temperature on the connection of the HLVIS to the IITS

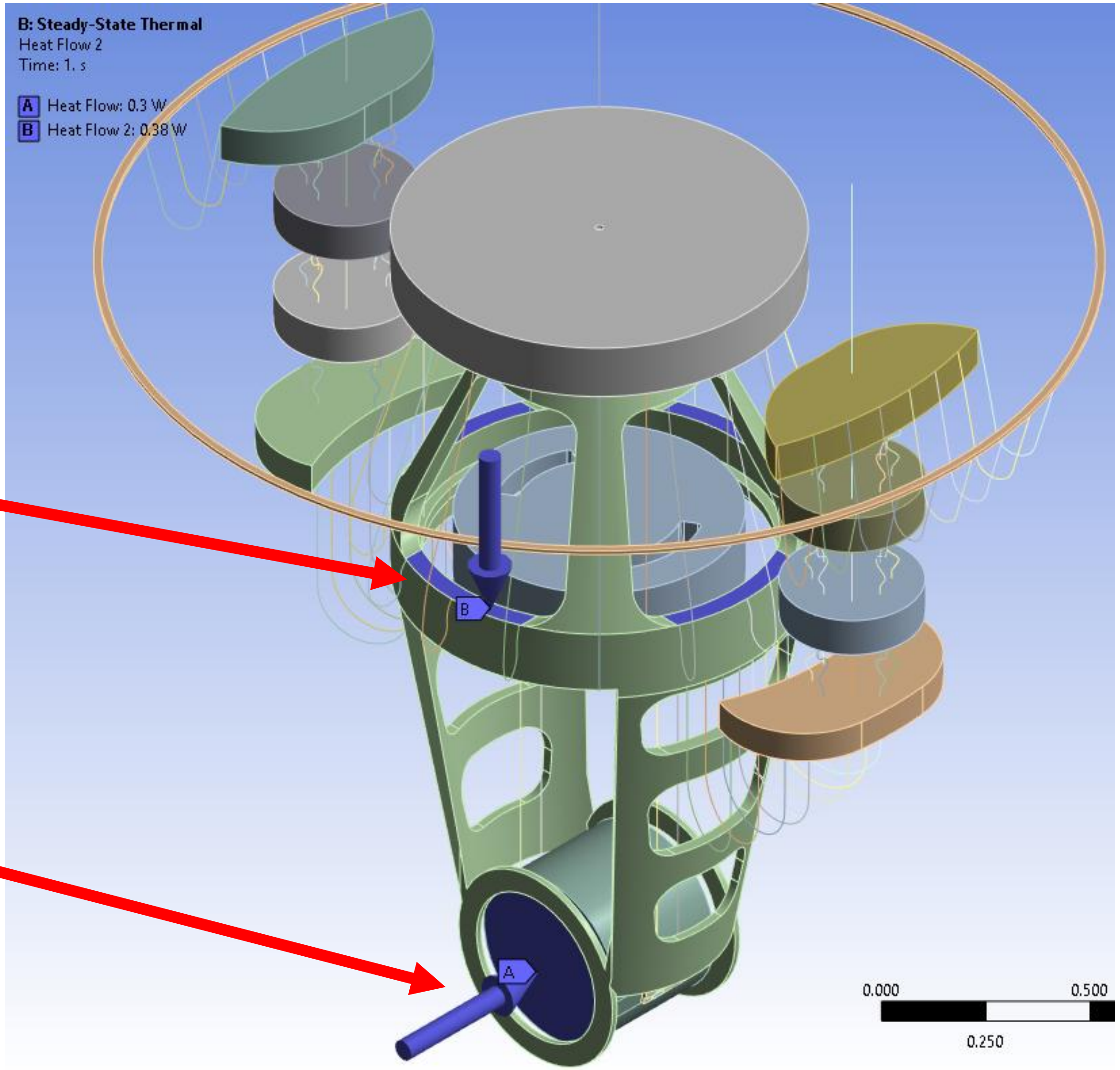
Radiation to ambient @2K

- Emissivity Mirror : $\epsilon = 0.5$
- Emissivity other bodies : $\epsilon = 0.8$

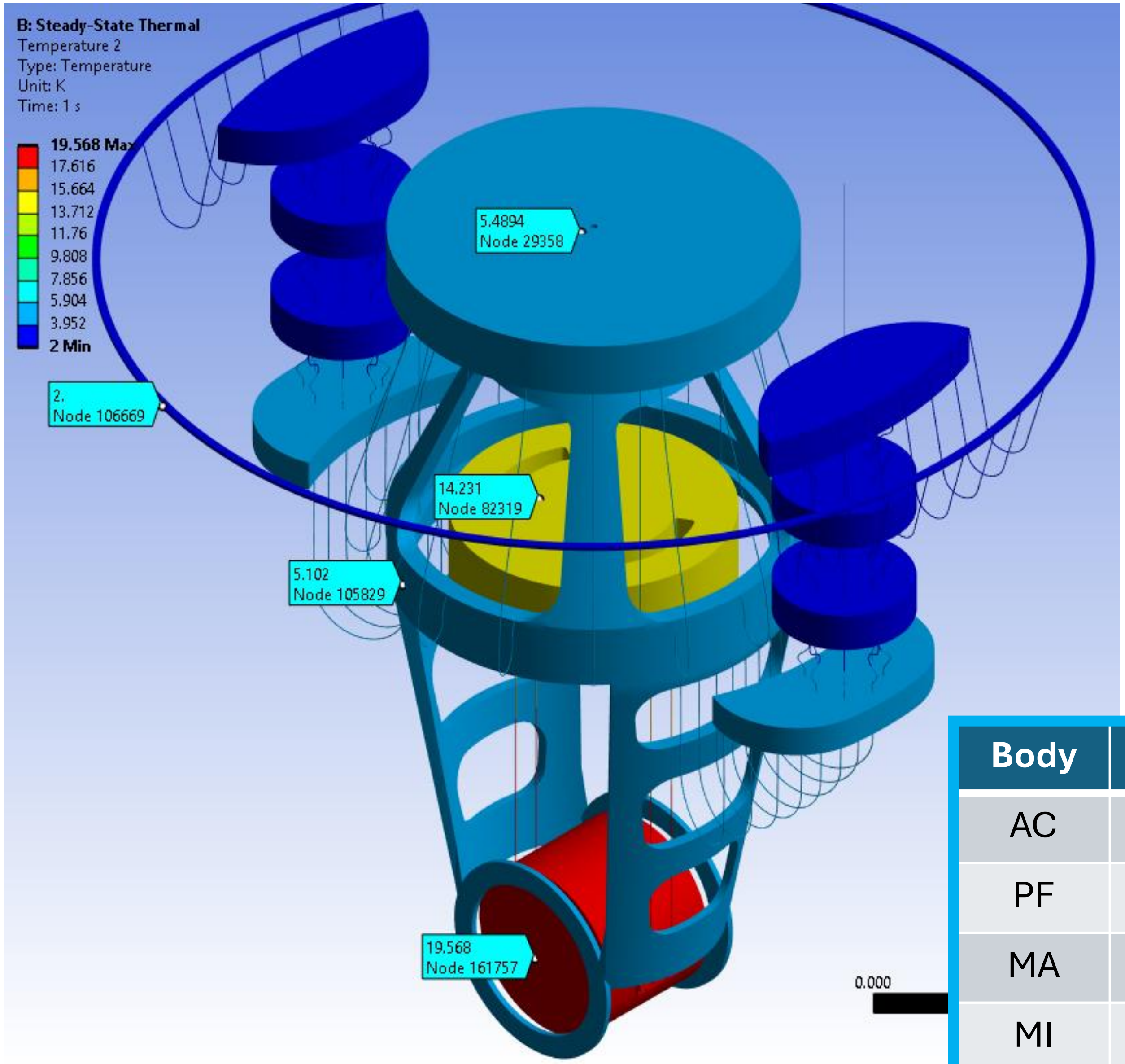
Cryogenic Payload Boundary Conditions Steady-State

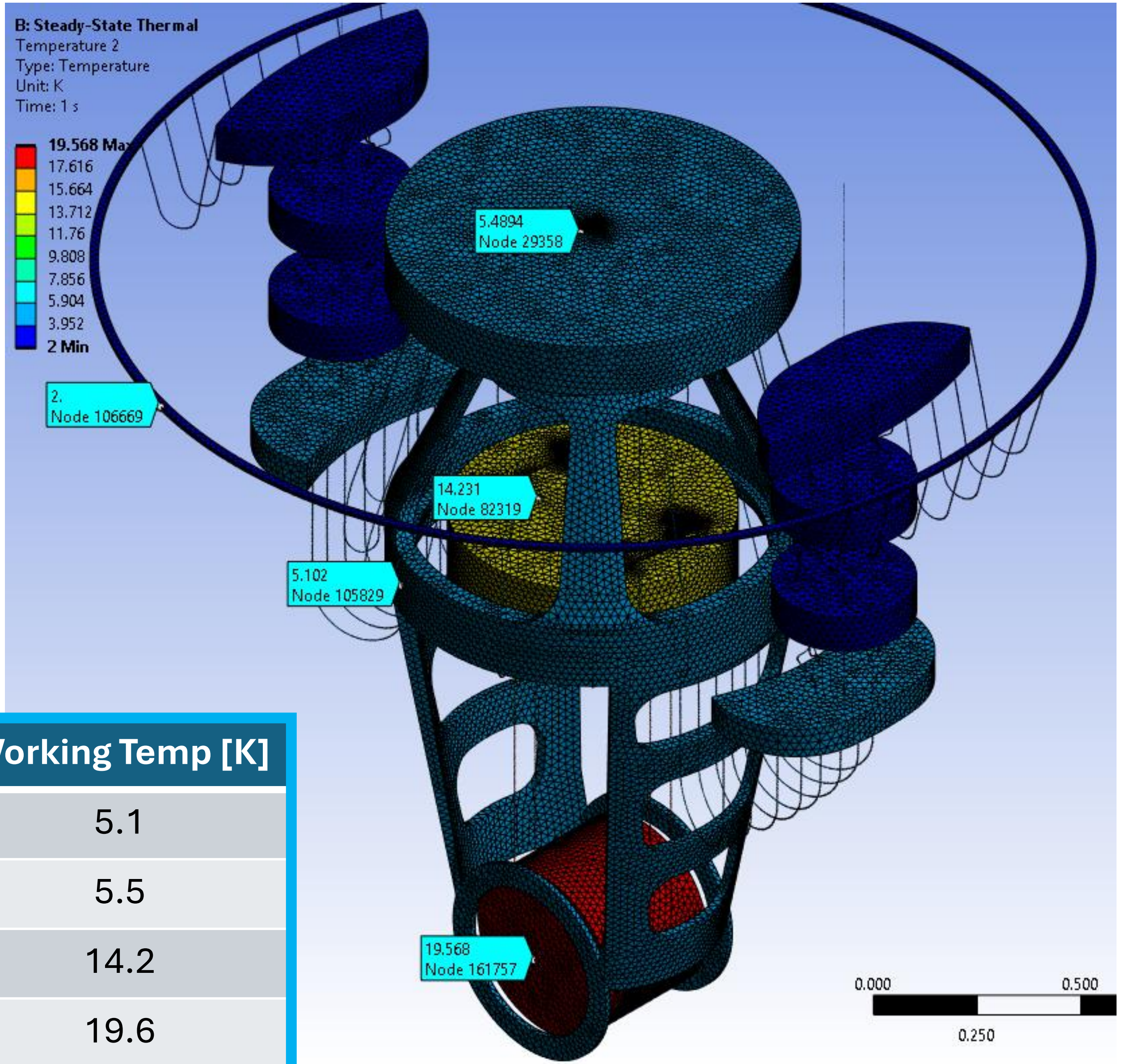
Electrical Wire Thermalization

Laser Power



Cryogenic Payload Steady-State Simulation

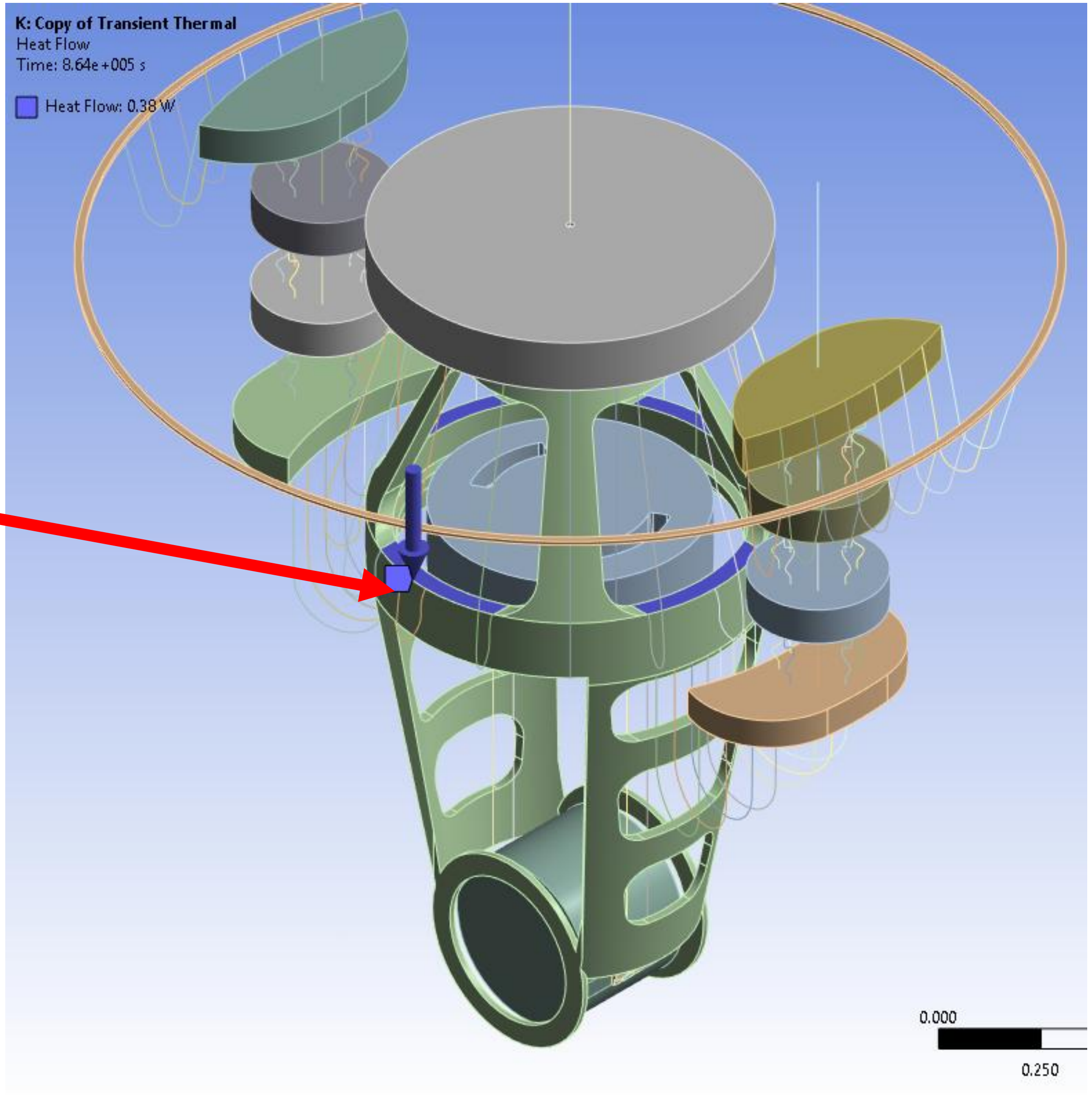




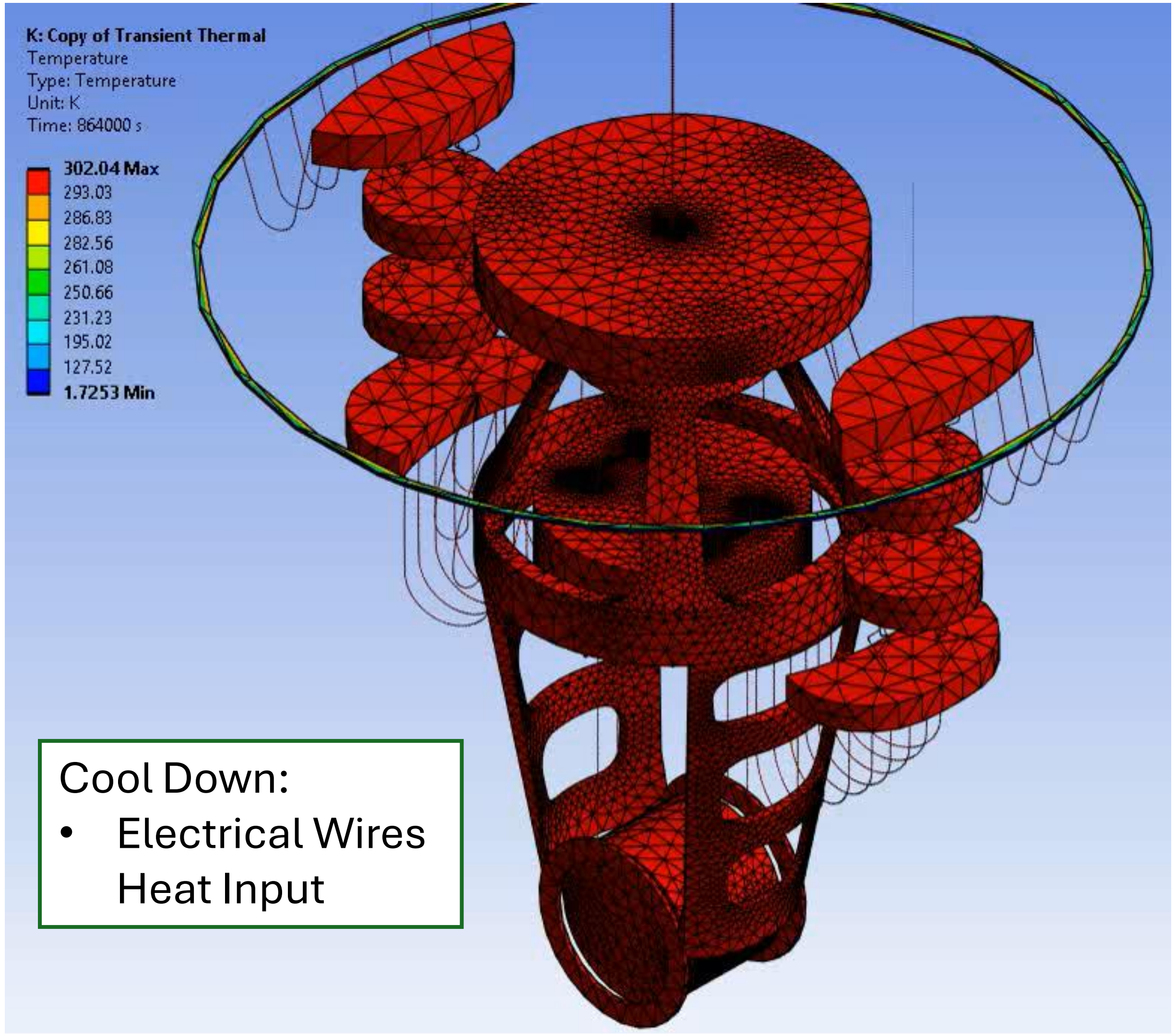
Body	Working Temp [K]
AC	5.1
PF	5.5
MA	14.2
MI	19.6

Cryogenic Payload Boundary Conditions Transient

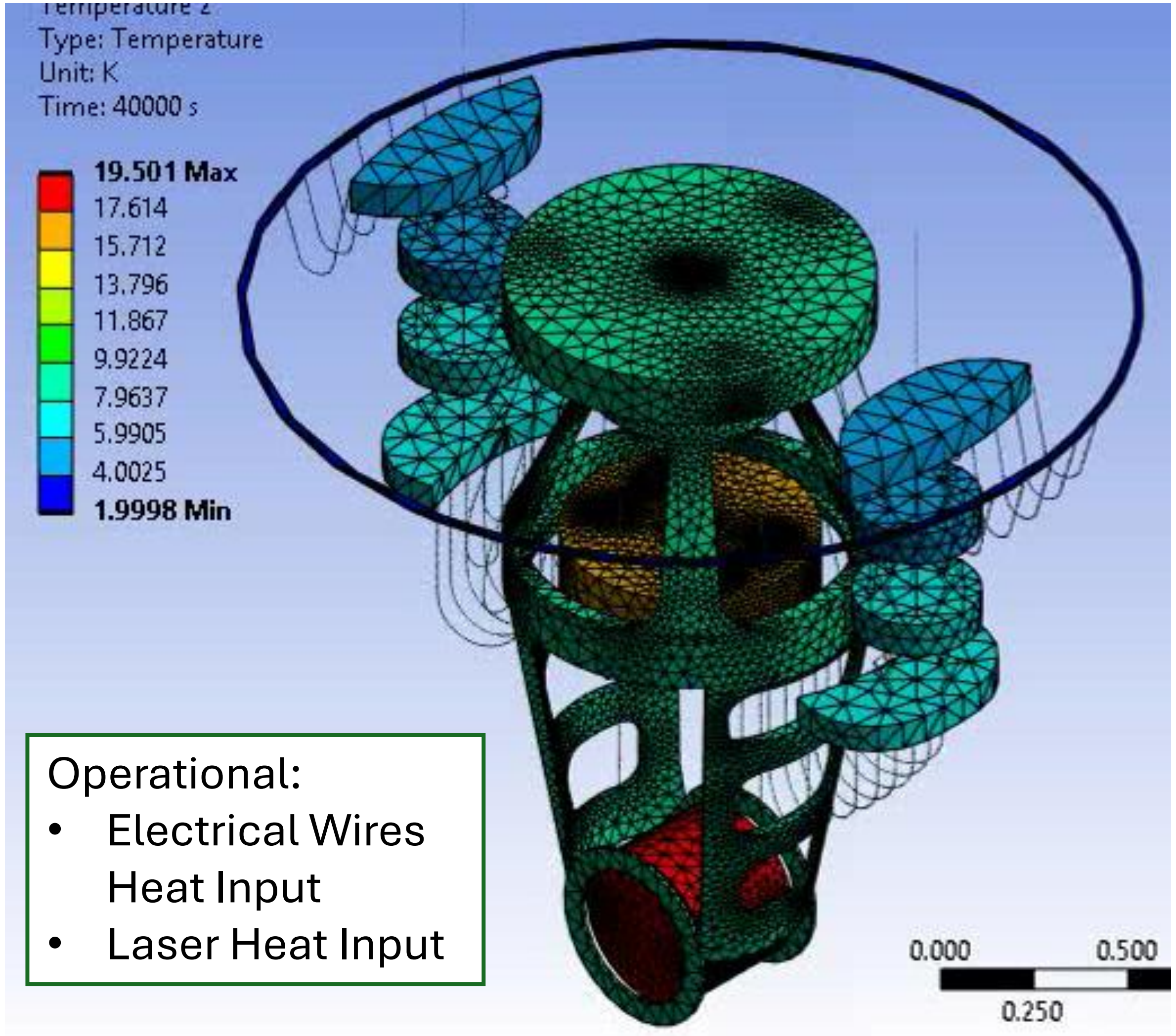
Electrical Wire Thermalization



Cryogenic Payload Transient Solution

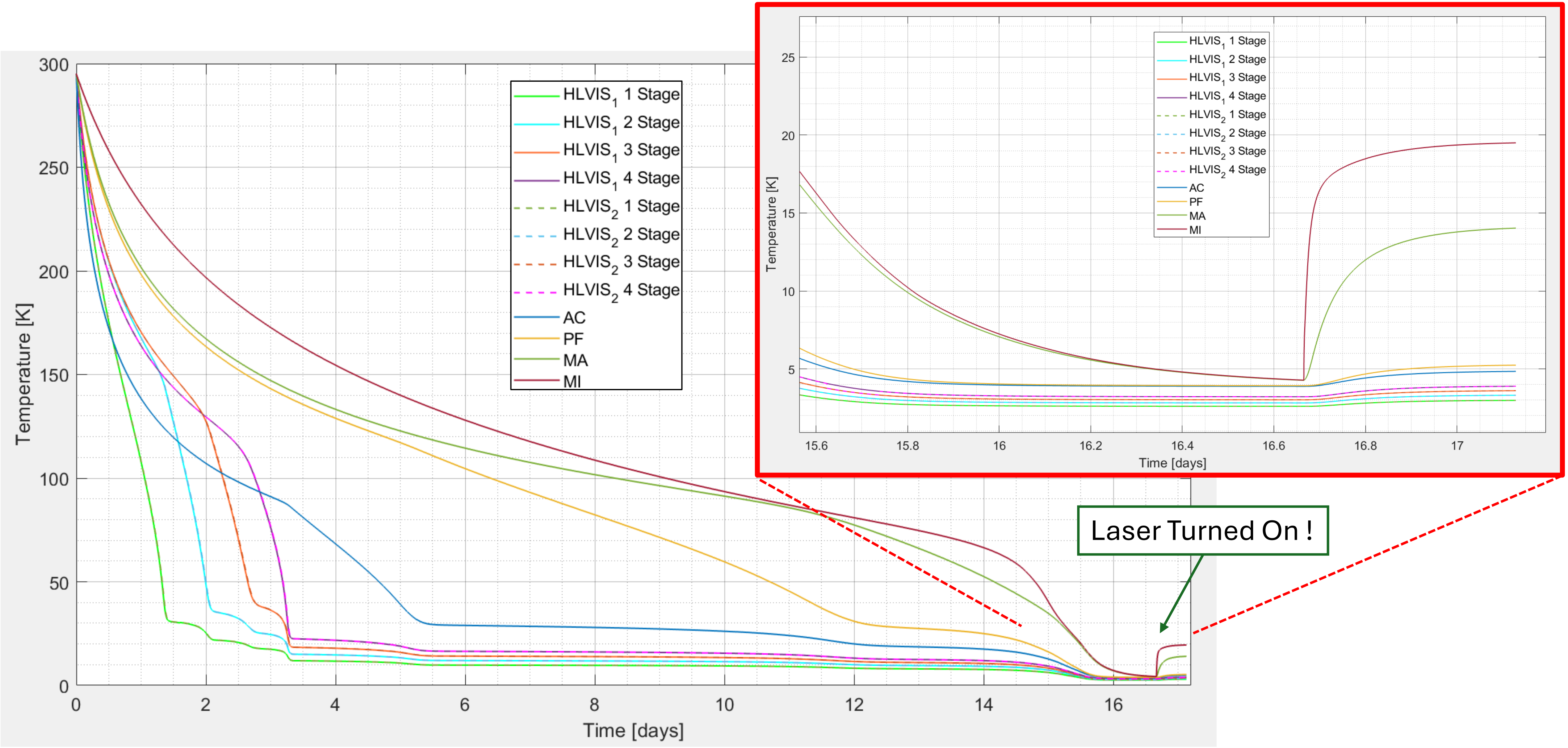


Cool Down:
- Electrical Wires Heat Input

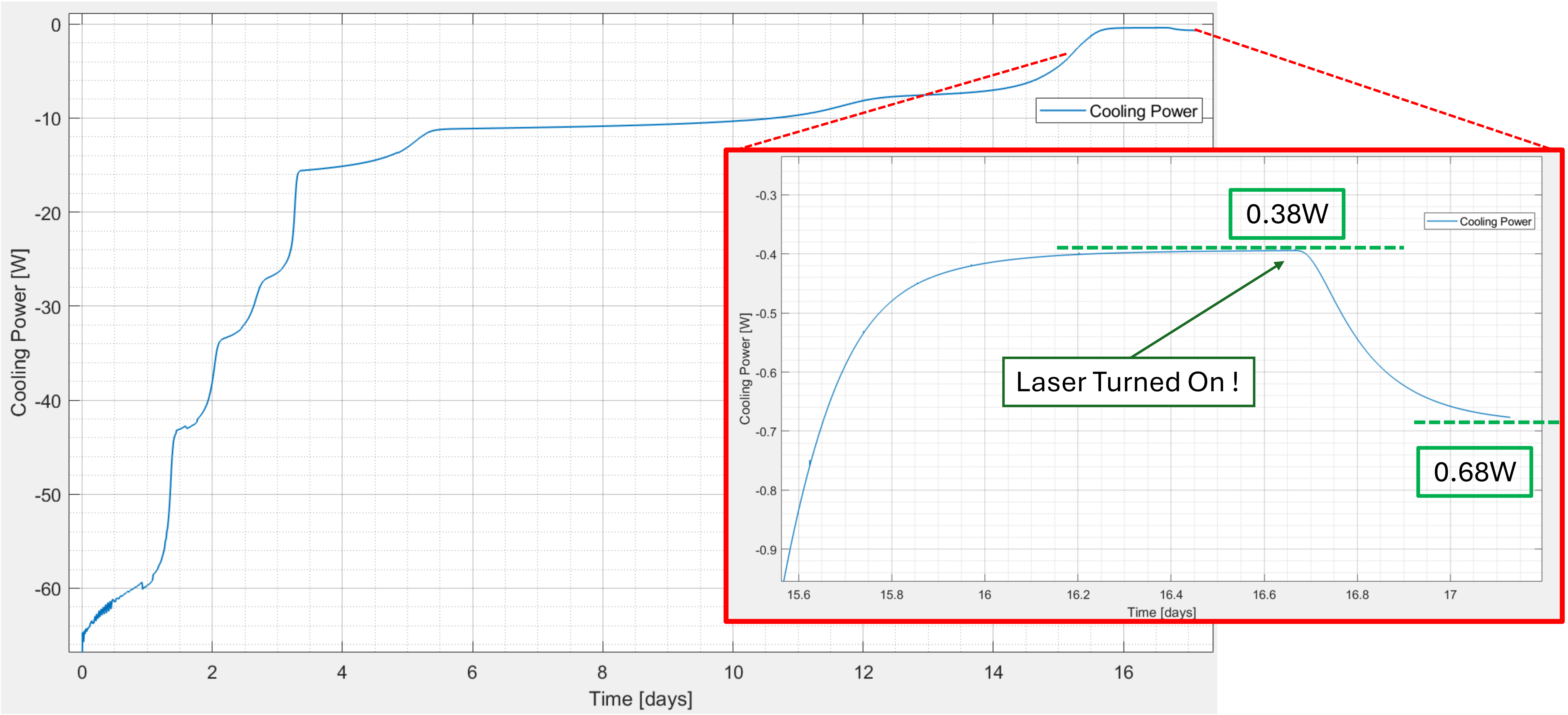


Operational:
- Electrical Wires Heat Input
- Laser Heat Input

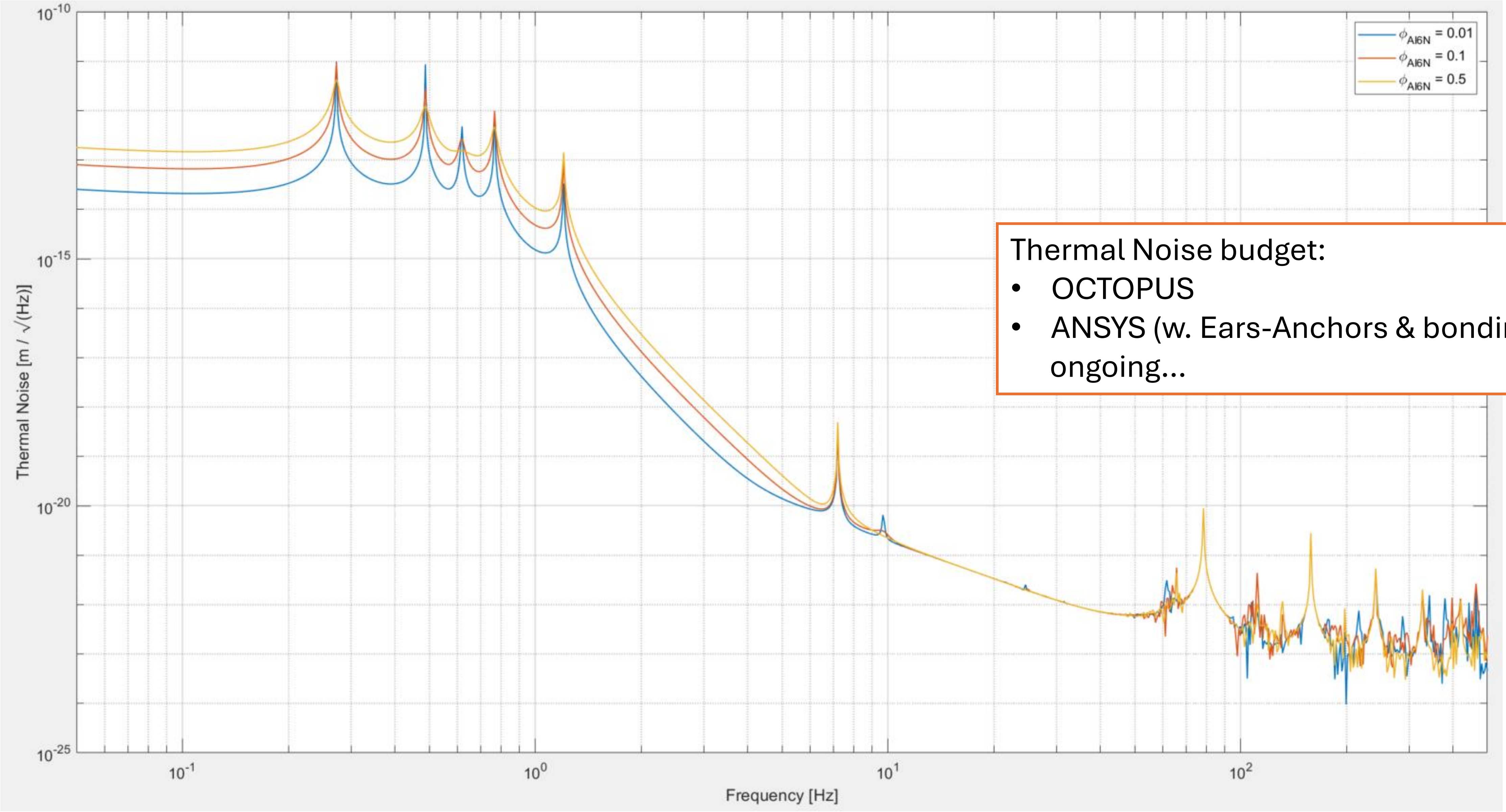
Cryogenic Payload Transient Solution



Cryogenic Payload Transient Solution



Cryogenic Payload Thermal Noise Modeling



Thermal Noise budget:

- OCTOPUS
- ANSYS (w. Ears-Anchors & bonding) ongoing…