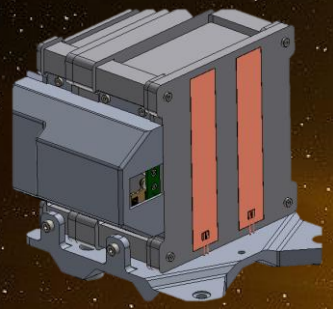
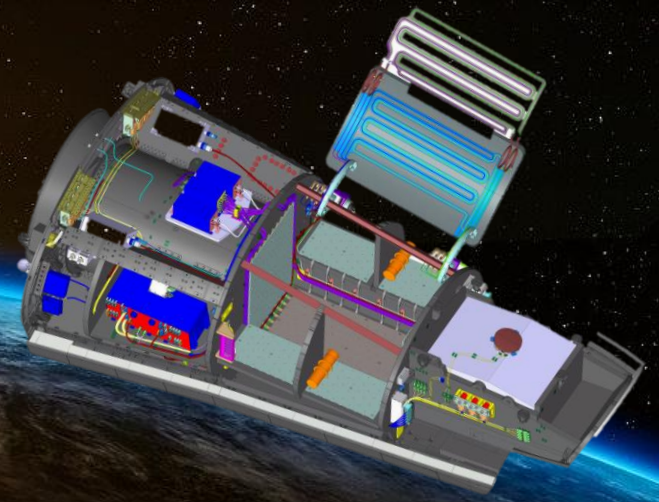
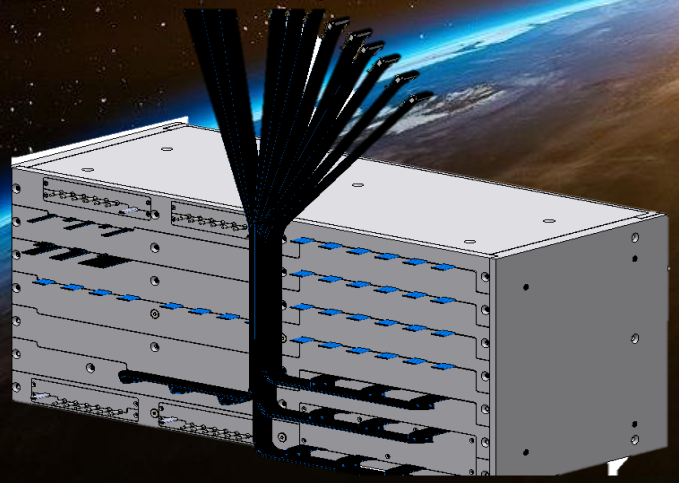
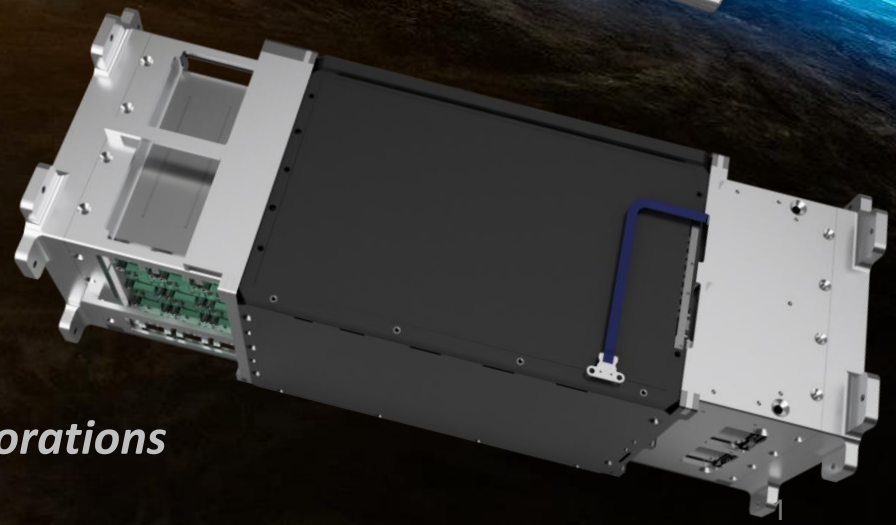
Thermal Management Analysis for NUSES & WINK Space Missions Using COMSOL Multiphysics

"Methods for Structural and Thermal Validation of Scientific Payloads" under "Innovative Technologies for Space Missions and Radiation Detection" PhD Program









Uygar Atalay

GSSI • INFN • Sophia High Tech

on behalf of the NUSES & Crystal Eye Collaborations

October 2024

Introduction to NUSES Mission: Thermal Analysis Perspective

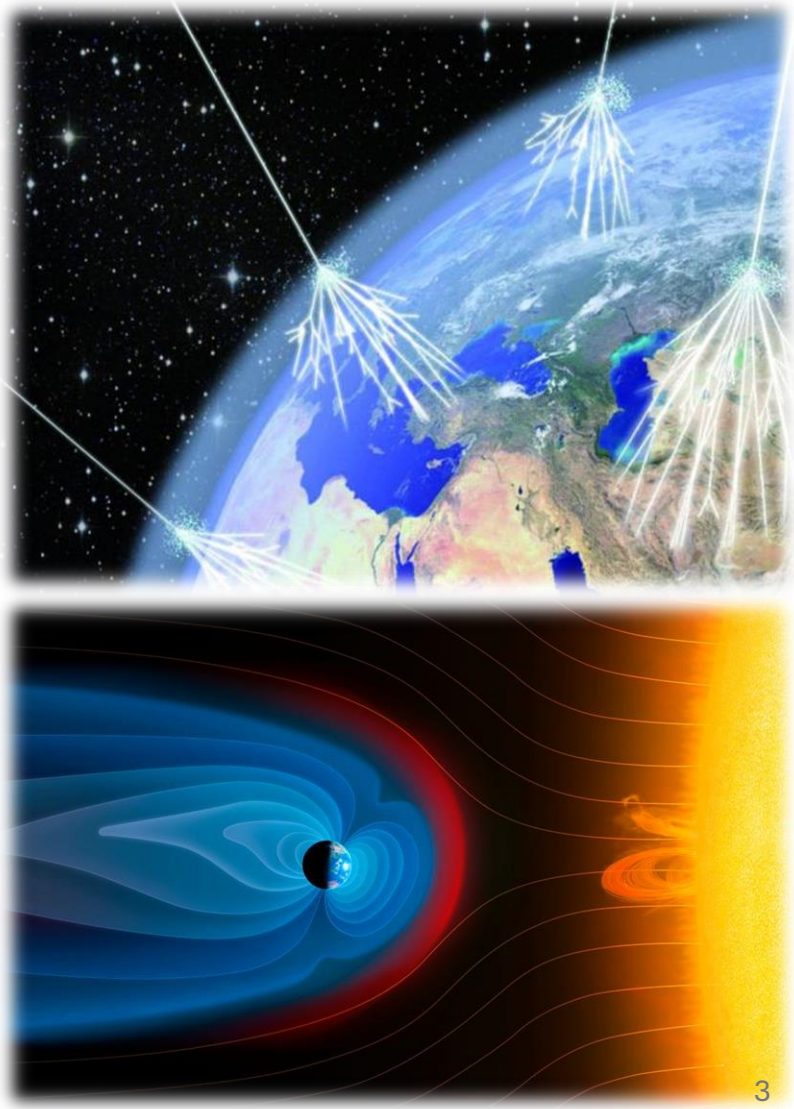
- More than 60 scientists from Italian Universities, INFN sites, and international partners, including leading research institutions and industries. The team has extensive experience from previous space missions and R&D programs, such as AMS, DAMPE, FERMI, GAPS, HERD, LIMADOU, PAMELA, and POEMMA.
- Supported by the Italian Space Agency (ASI)
- Collaboration with five industrial partners

Gran Sasso Science Institute
Gran Sasso National Laboratory
University of L'Aquila
University of Turin and INFN Turin
University of Trento and INFN-TIFPA
University of Bari and INFN Bari
University of Padua and INFN Padua
University "Federico II" and INFN Napoli
University of Salento and INFN Lecce
University of Geneva
University of Chicago

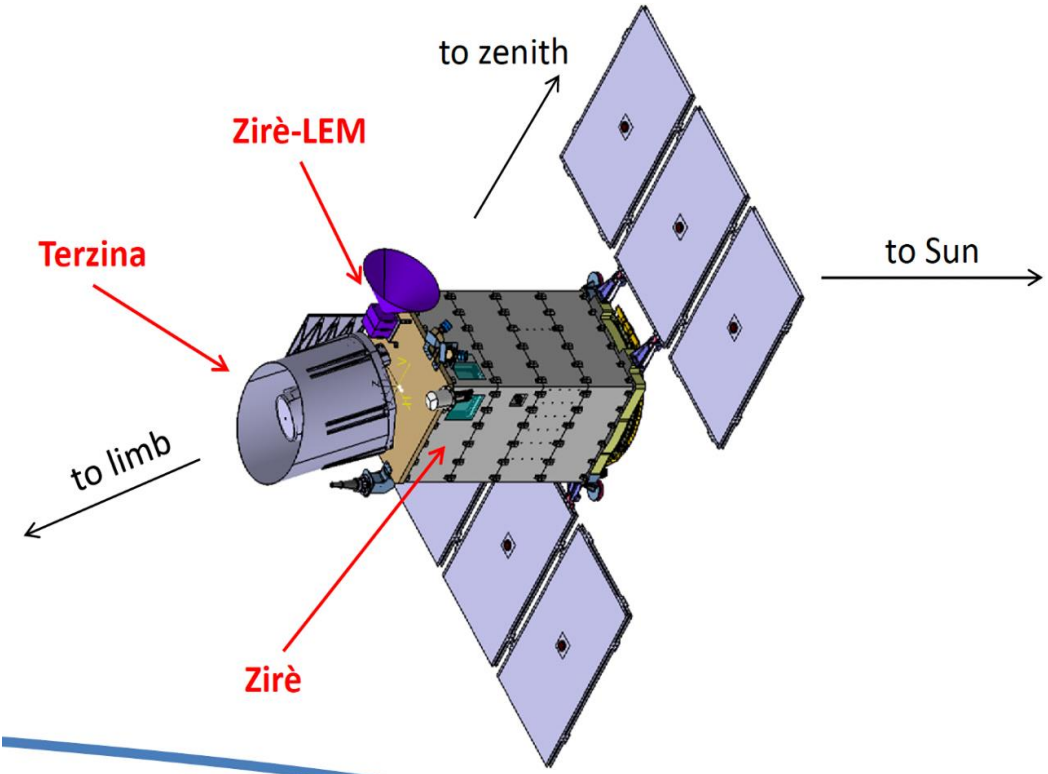
Industrial Partners:

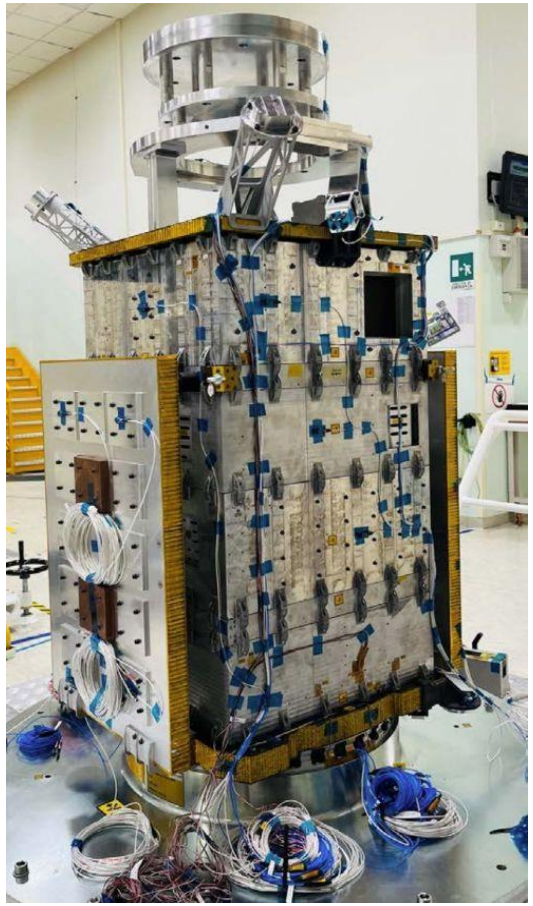
Introduction to NUSES Mission: Mission Goals

- Detect **ultra-high-energy (UHE) cosmic rays** and enable neutrino astronomy using **Cherenkov light detection** from space.
- Monitor the fluxes of low-energy particles (<300 MeV) and light nuclei from solar and galactic sources.
- Investigate the variability of cosmic radiation, focusing on the Van Allen Belts.
- Explore correlations between seismic activity and space weather events through Magnetosphere-Ionosphere-Lithosphere Coupling (MILC).



Introduction to NUSES Mission: Mission Goals





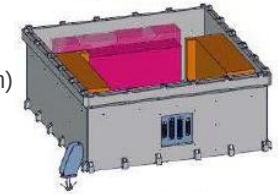
New Italian Micro BUS

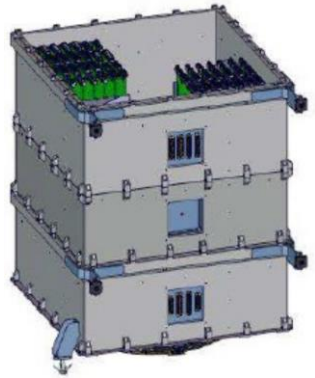
New platform concept which foresees a modular approach relying on standard trays.

AOCS, Telemetry and Telecommand (TT&C) and GPS Receiver units

AOCS (Altitude and Orbit Control System): units\actuators

EPS (Electric Power system)





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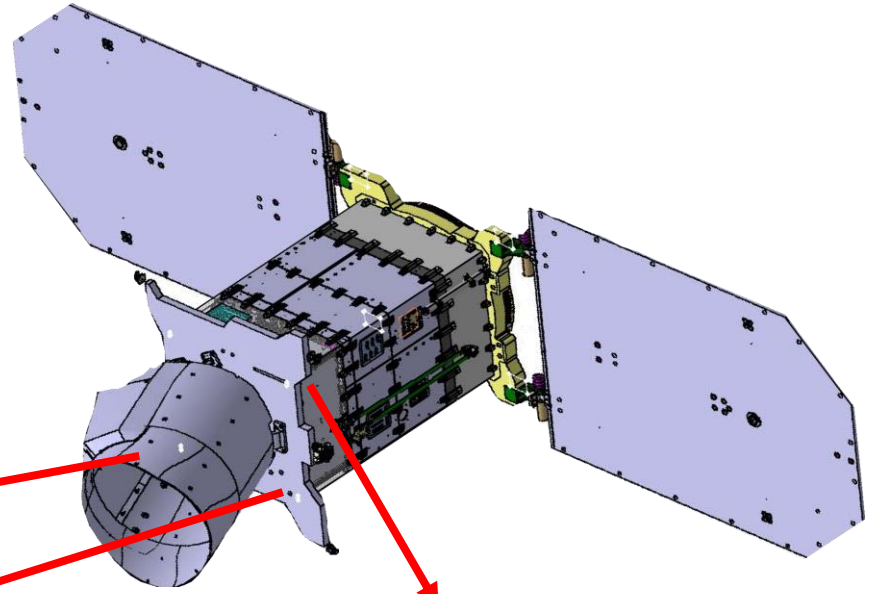
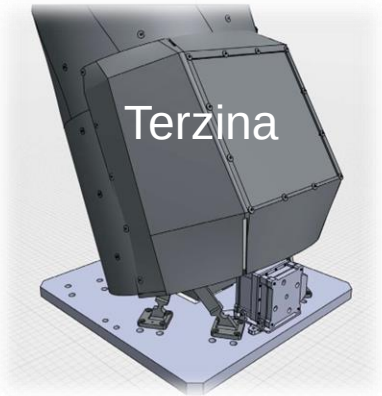
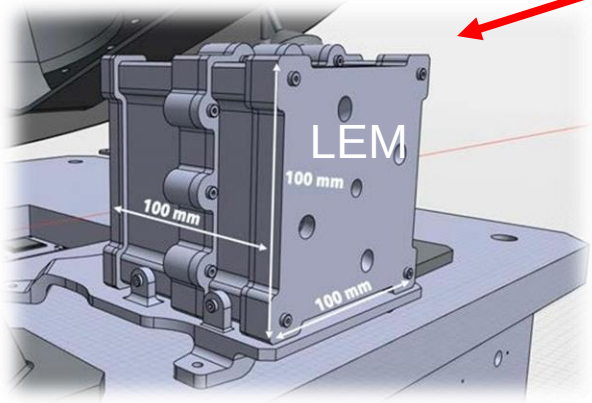
Introduction to NUSES Mission: Mission Goals

NUSES:
•Focus on thermal management for Zirè, LEM, and Electronic Box.
•Thermal stability ensures optimal performance for cosmic ray and gamma-ray detection.

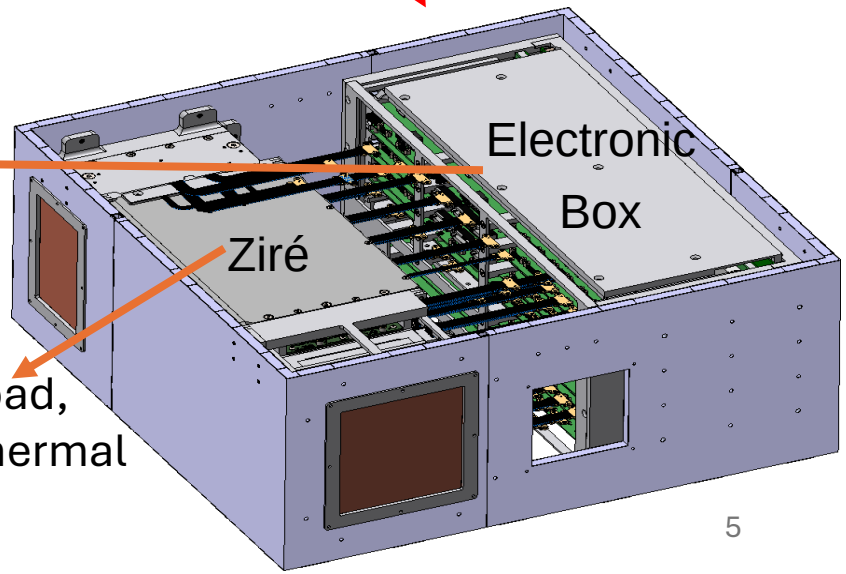
Collaboration:
•Thermal strategies were developed by **Thales Alenia Space** and **Sophia High Tech** (with special thanks to Domenico Borelli).







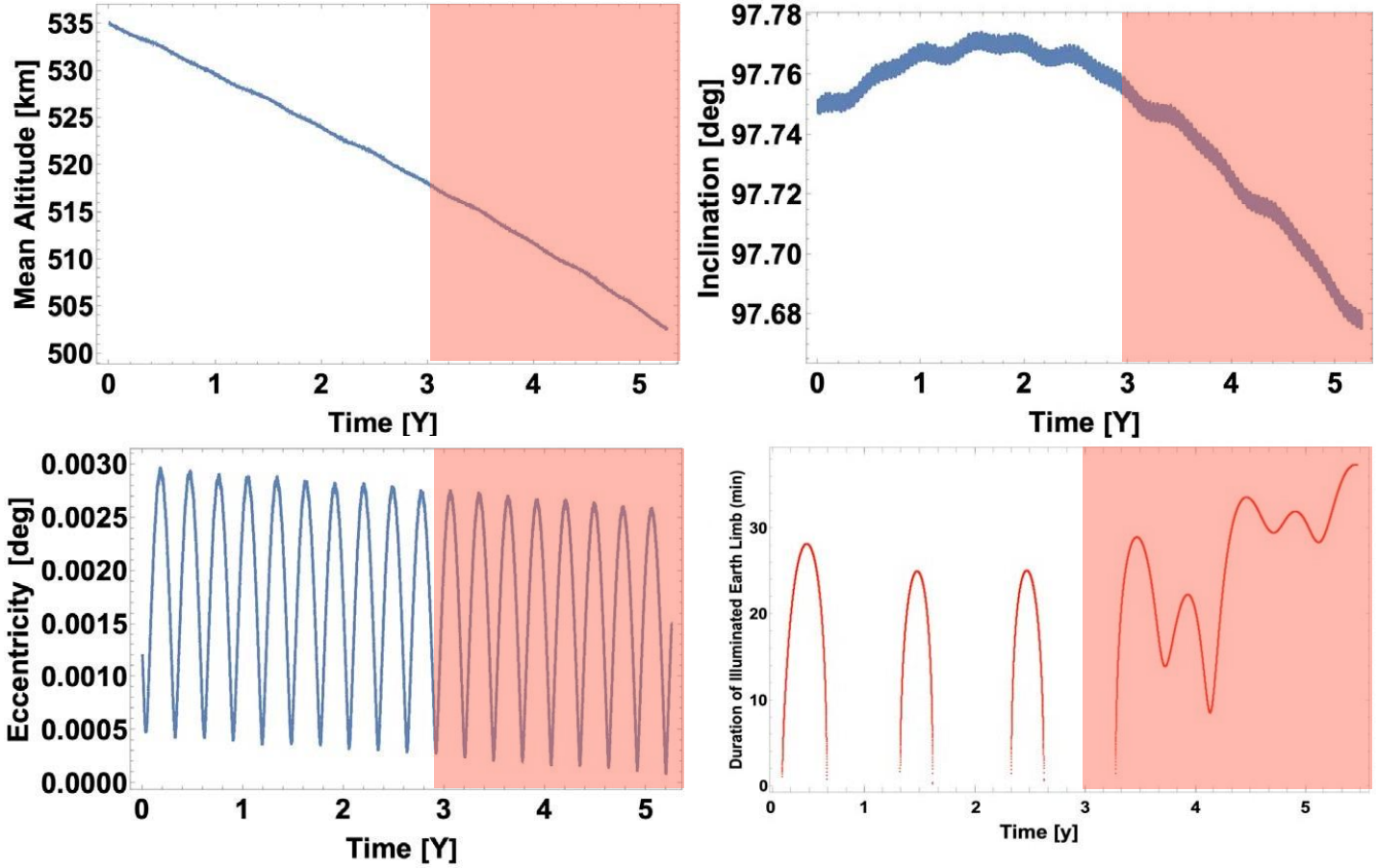
Critical for heat management & signal processing



Primary payload, sensitive to thermal fluctuations

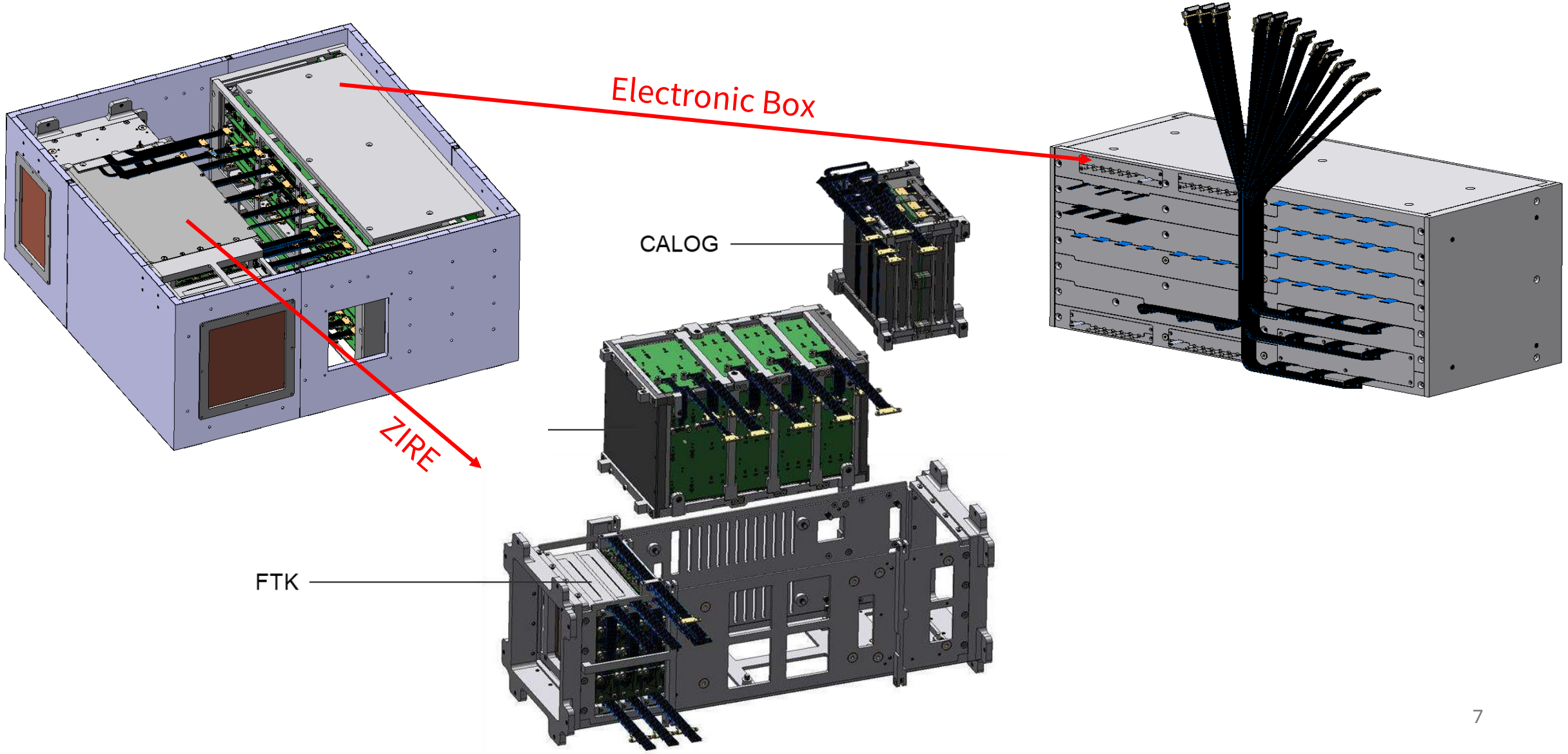
Introduction to NUSES Mission: Mission Goals

Mission Lifetime	3 y
Mean Altitude	520 km, LEO
Semi-major axis (km)	6928 km
Eccentricity	0
Inclination (deg)	97.6 deg, SunSync
LTAN	18:00:00
Pointing	< 0.1 deg

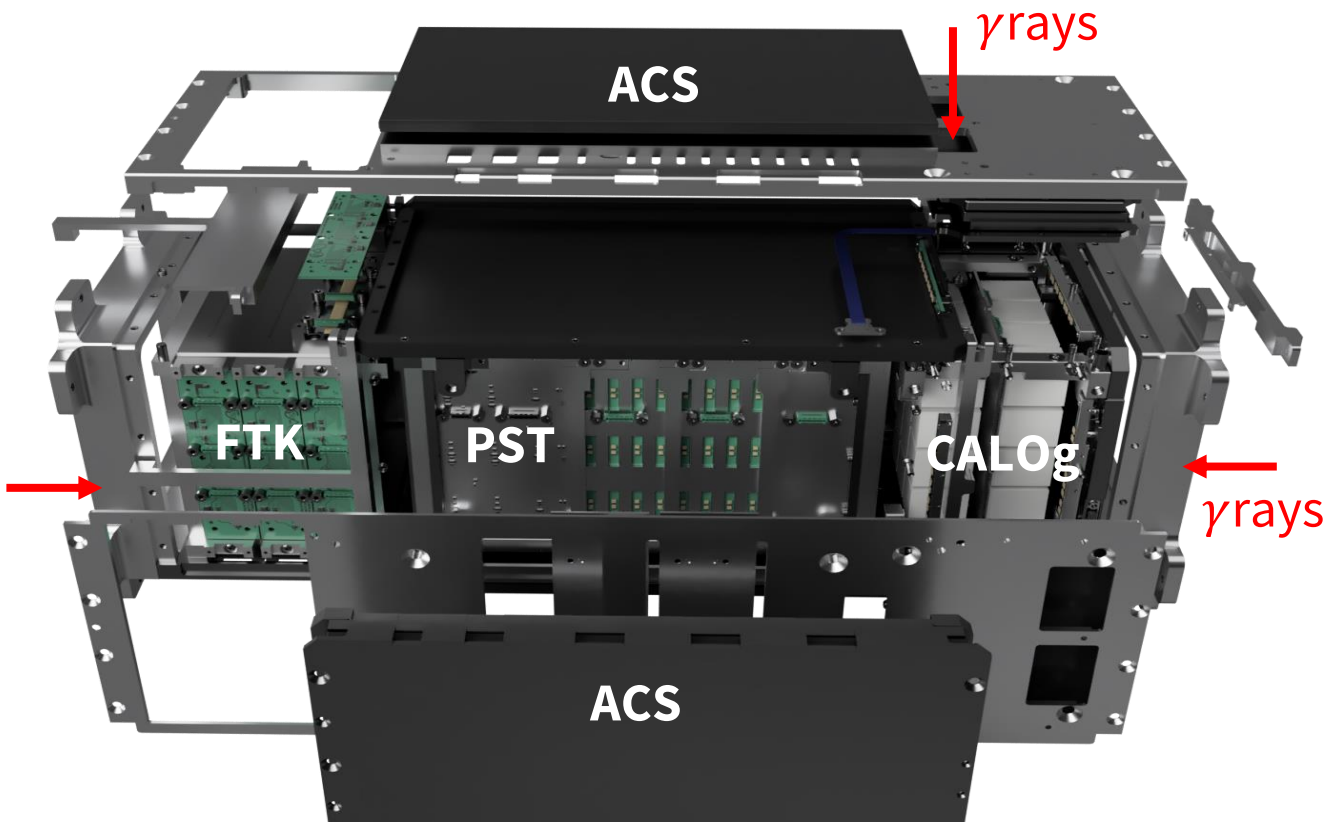


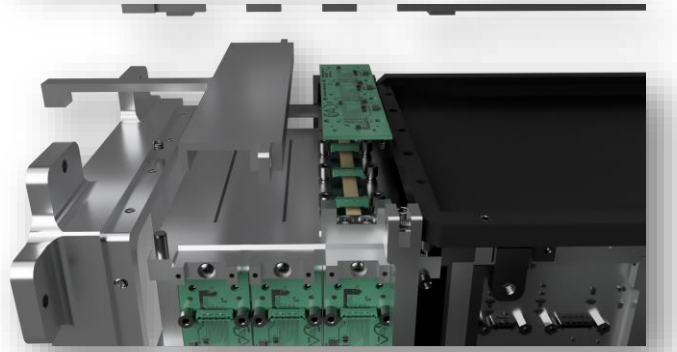
- Low Earth Orbit at high inclination, Sun-Sync orbit on the day-night border
- The orbit is tailored for the detection of Cherenkov light with precise pointing accuracy, following a ballistic trajectory without propulsion for orbital correction.
- Expected launch window: Q3 2026

ZIRE Payload's Mechanical Configuration



ZIRE Payload's Mechanical Overview: The Instrument





FTK: Fiber TracKer
ACS: Anti Coincidence System

PST: Plastic Scintillator Tower
CALOg: Calorimeter gamma

Thermal Analysis Approach for Zirè, LEM & WINK

Simulation Tools:

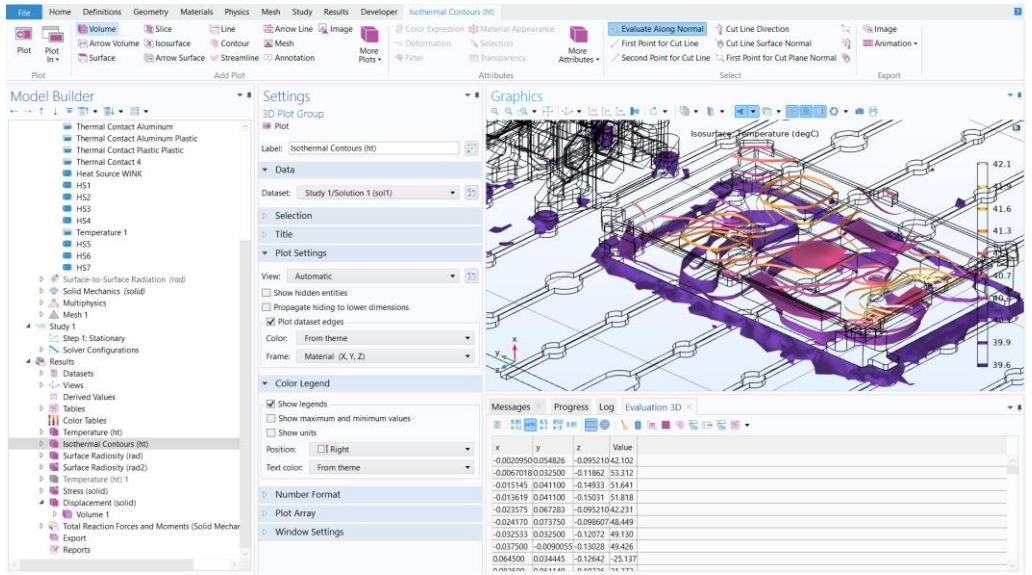
•COMSOL Multiphysics used to simulate thermal performance for Zirè, LEM, and WINK.

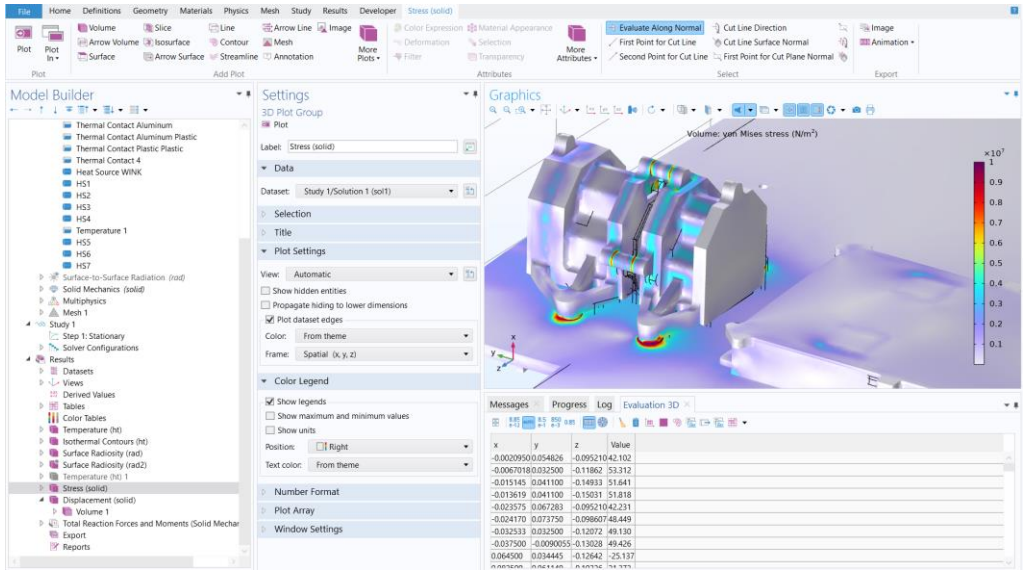
Boundary Conditions:

•Space vacuum, solar irradiance, material emissivity, and internal heat generation considered.

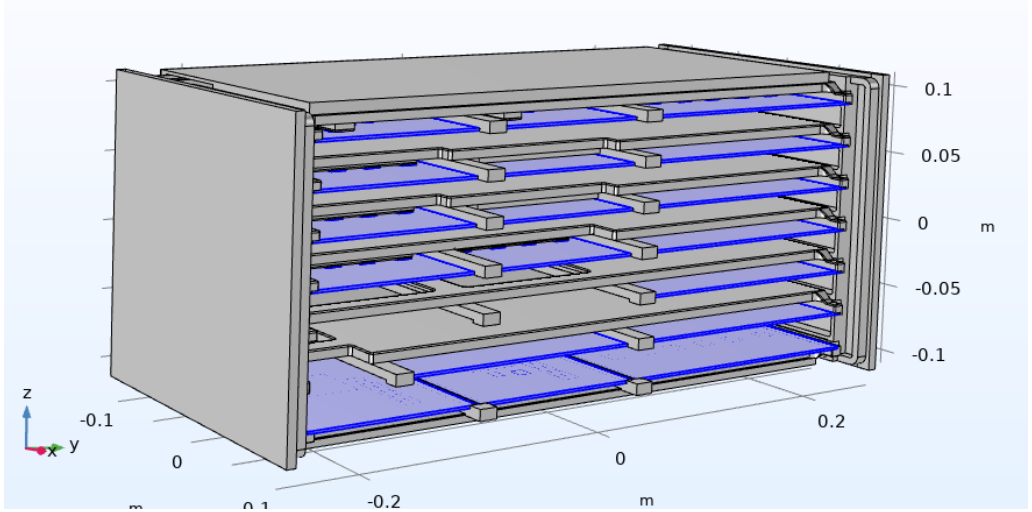
Thermal Approach:

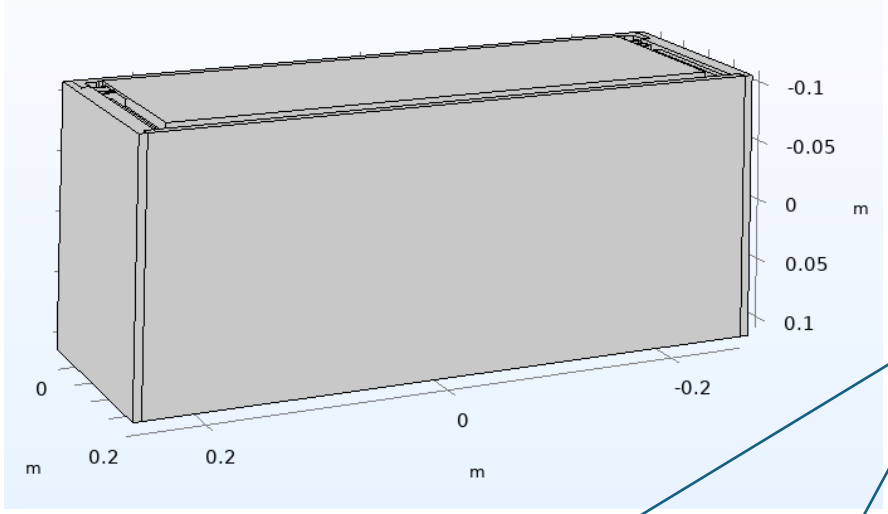
•Steady-state & Non-steady thermal simulations.
•Focused on temperature distribution and heat dissipation efficiency.

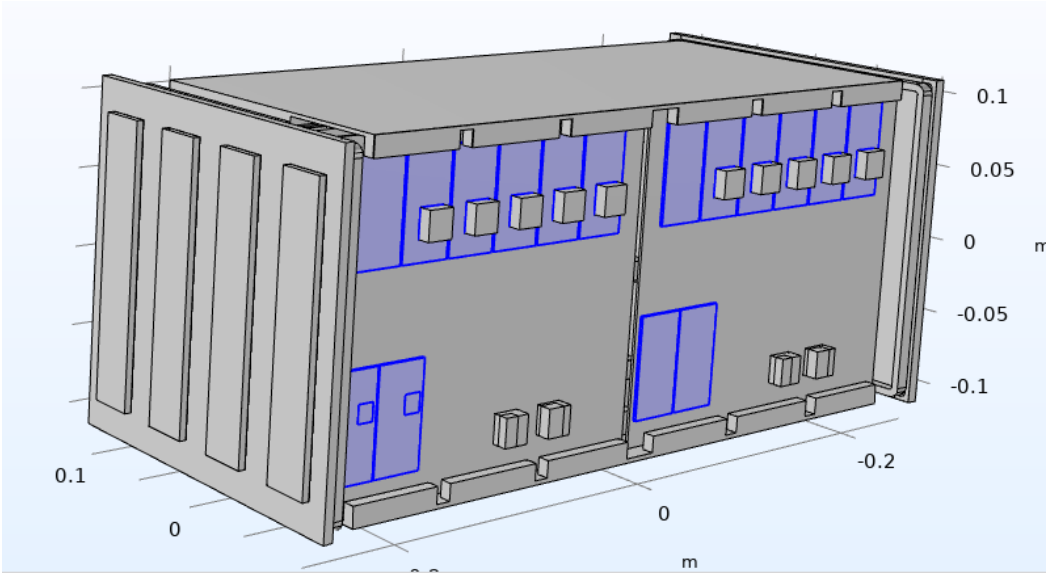


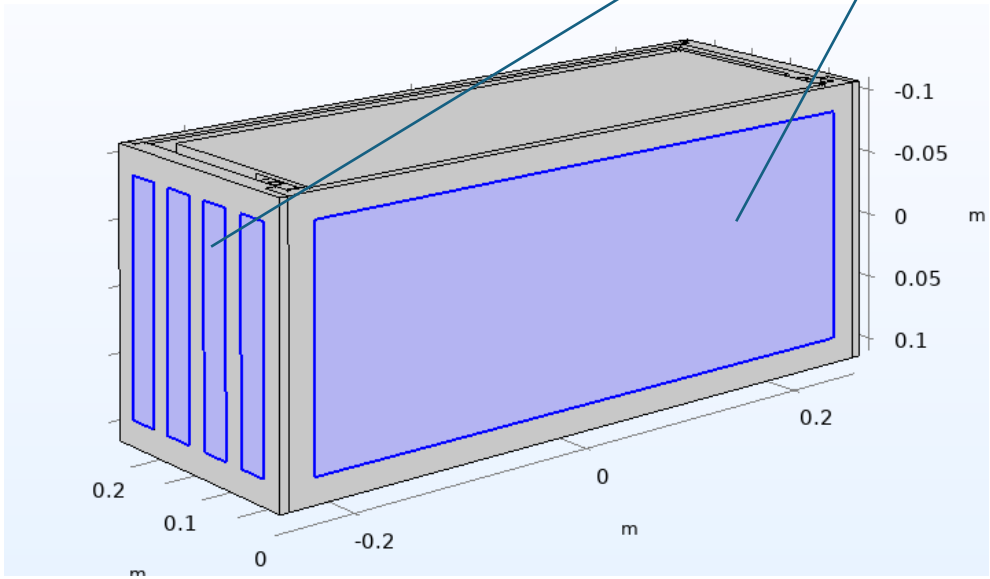


Electronic Box – Model Boundary Conditions- Power Distribution & Thermal Contact Interfaces









Direct Thermal Contact On Tray For Heat Transfer

Electronic Box – Model Boundary Conditions- Power Distribution & Thermal Contact Interfaces

HOT OPERATIVE

CONFIG 1 - ALL ON (BoL)		
Zire conc hot	ZIre conc cold	FTK1
Zire_DAQ_r	Lem_hot	FTK2
CALOg_ACS_DAQ	Lem_cold	FTK3
PST_DAQ_2	PST_DAQ_1	FTK4
		Terzina_DAQ_B1
Terzina_DAQ_B4		Terzina_DAQ_B2
Terzina conc hot	Terzina conc cold	Terzina_DAQ_B3

•First board configuration

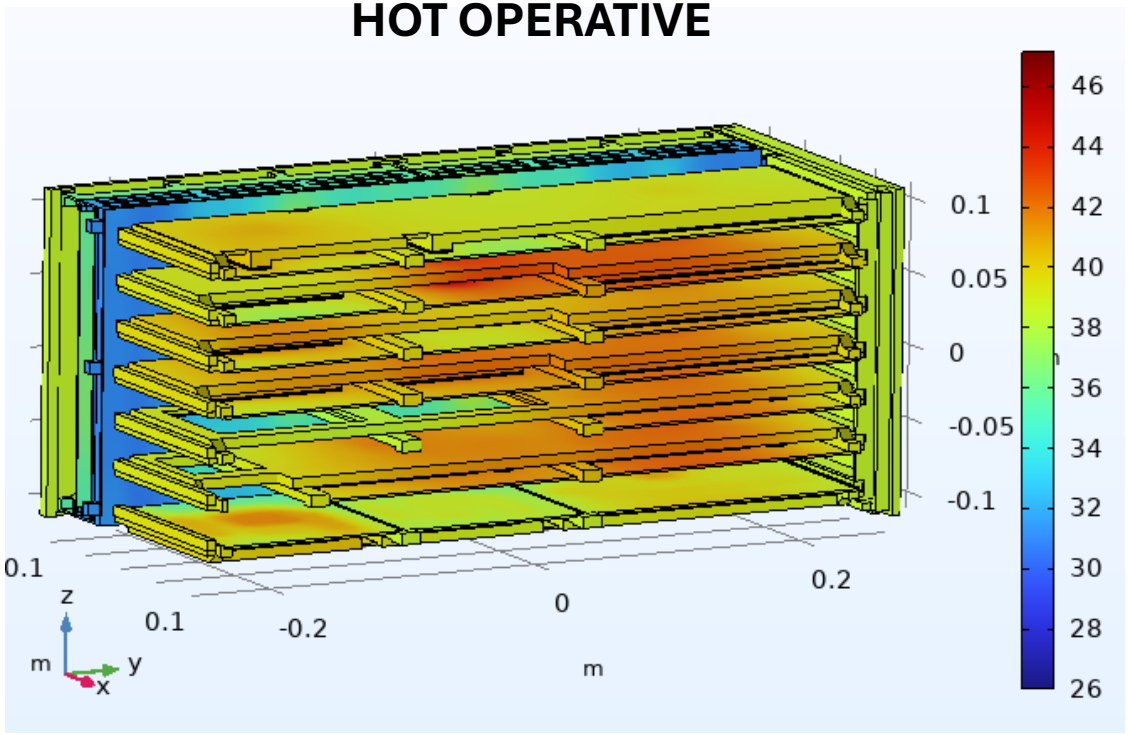
COLD OPERATIVE

CONFIG C		
Zire conc hot	ZIre conc cold	FTK1
Zire_DAQ_r	Lem_hot	FTK2
CALOg_ACS_DAQ	Lem_cold	FTK3
PST_DAQ_2	PST_DAQ_1	FTK4
		Terzina_DAQ_B1
Terzina_DAQ_B4		Terzina_DAQ_B2
Terzina conc hot	Terzina conc col	Terzina_DAQ_B3

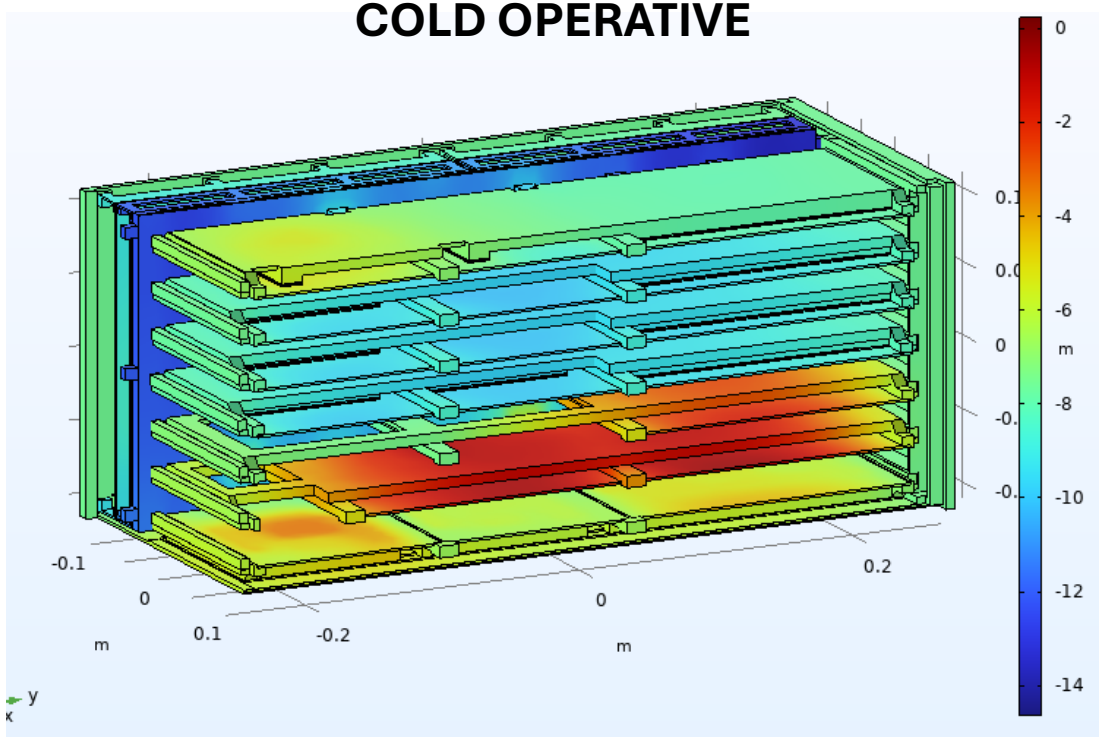
•Second board configuration

Electronic Box – Thermal Simulation Results

HOT OPERATIVE



COLD OPERATIVE



- Boundary calculated by Thales with +10 °C qualification

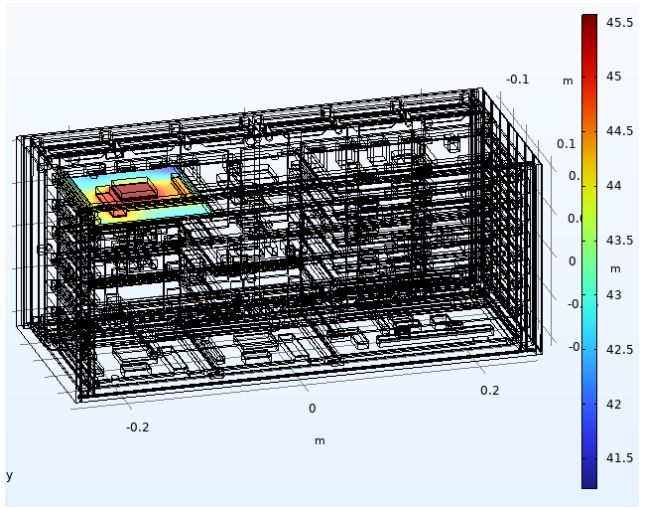
Hot Operative Conditions	Calculated (°C)	Qualification (°C)	Total (°C)	Total (K)
Box Walls	33.88	+10	43.88	317.03
TSINK	26.8	+10	36.8	309.95

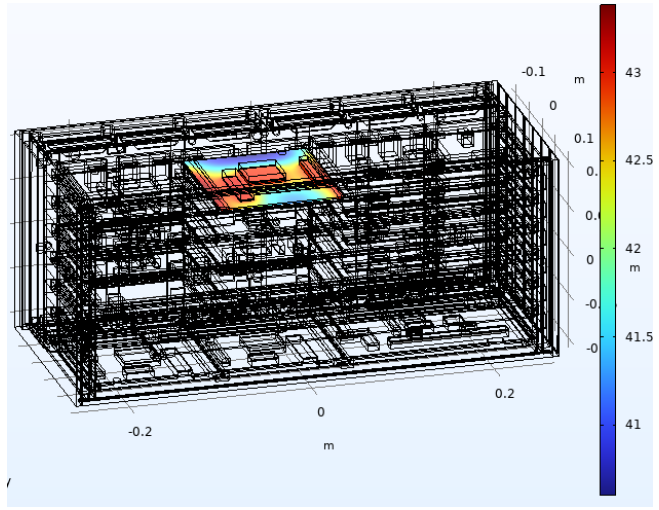
- Boundary calculated by Thales with -10 °C qualification

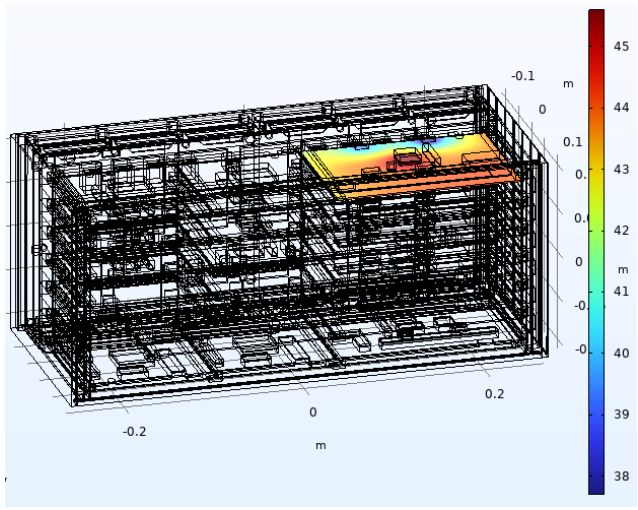
Cold Operative Conditions	Calculated (°C)	Qualification (°C)	Total (°C)	Total (K)
Box Walls	2.44	-10	-7.56	265.59
TSINK	2.2	-10	-7.8	265.35

Electronic Box – Thermal Simulation Results

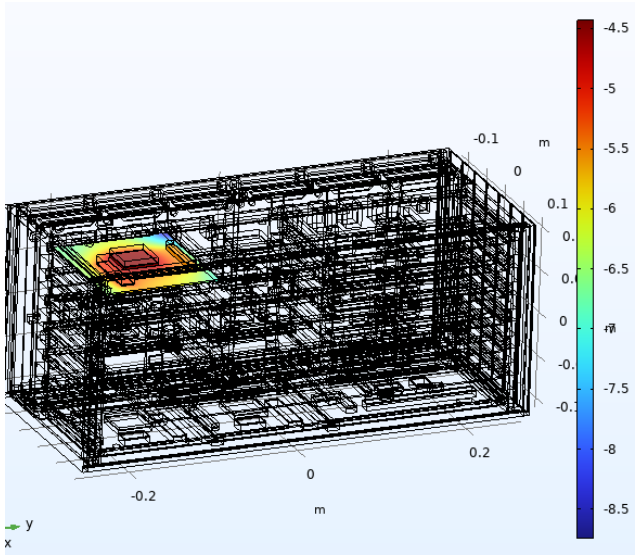
HOT OPERATIVE

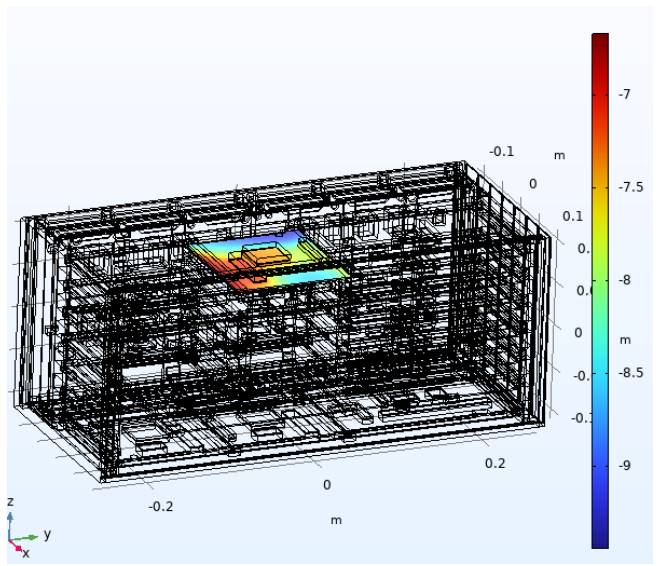


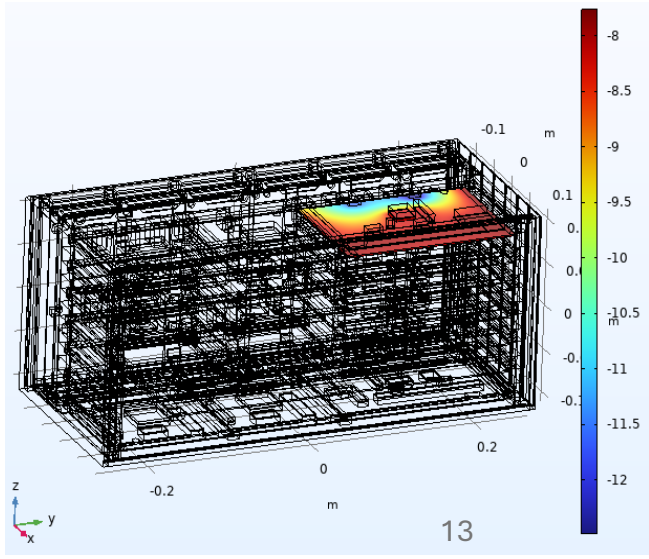




COLD OPERATIVE

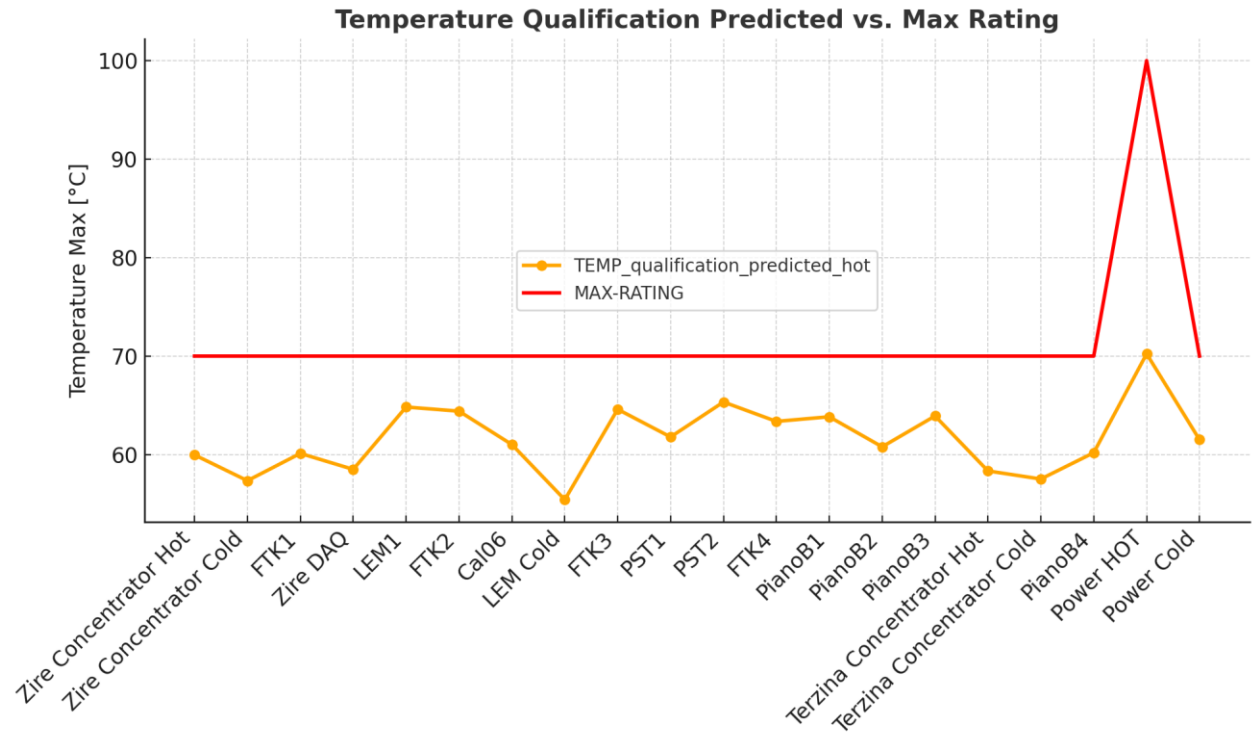




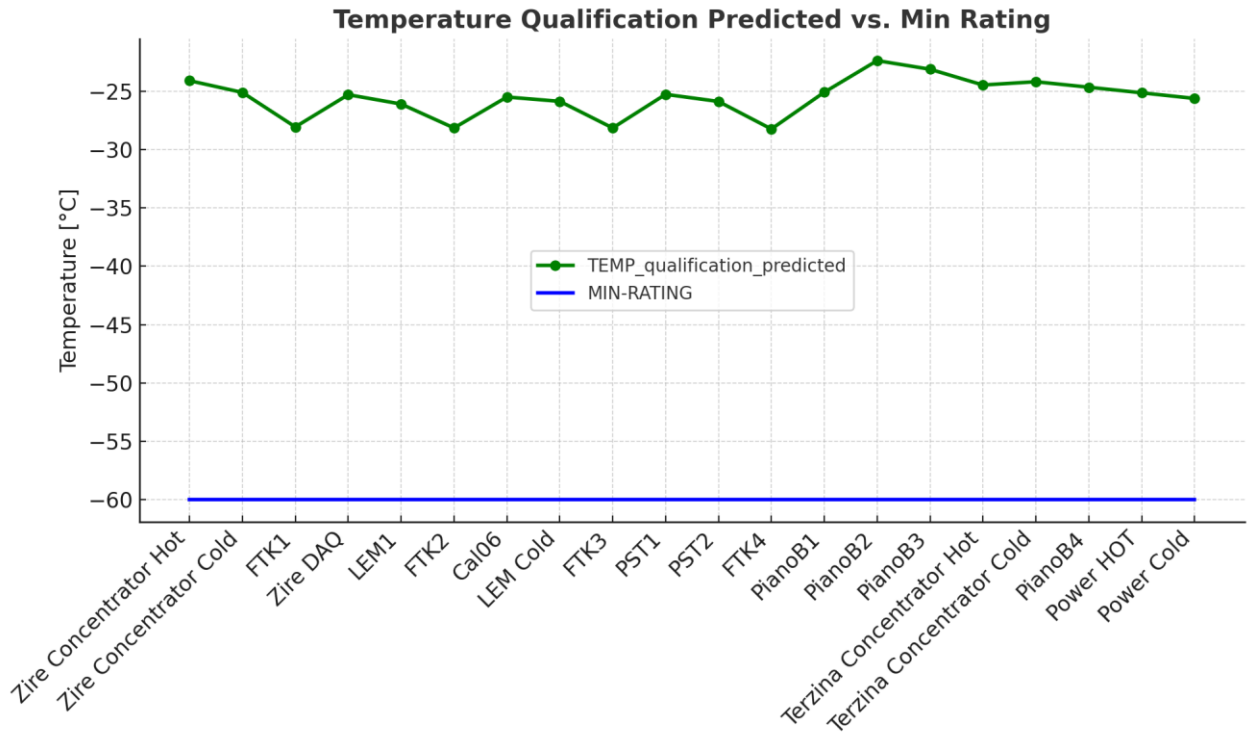


Electronic Box – Thermal Simulation Results

HOT OPERATIVE



COLD OPERATIVE



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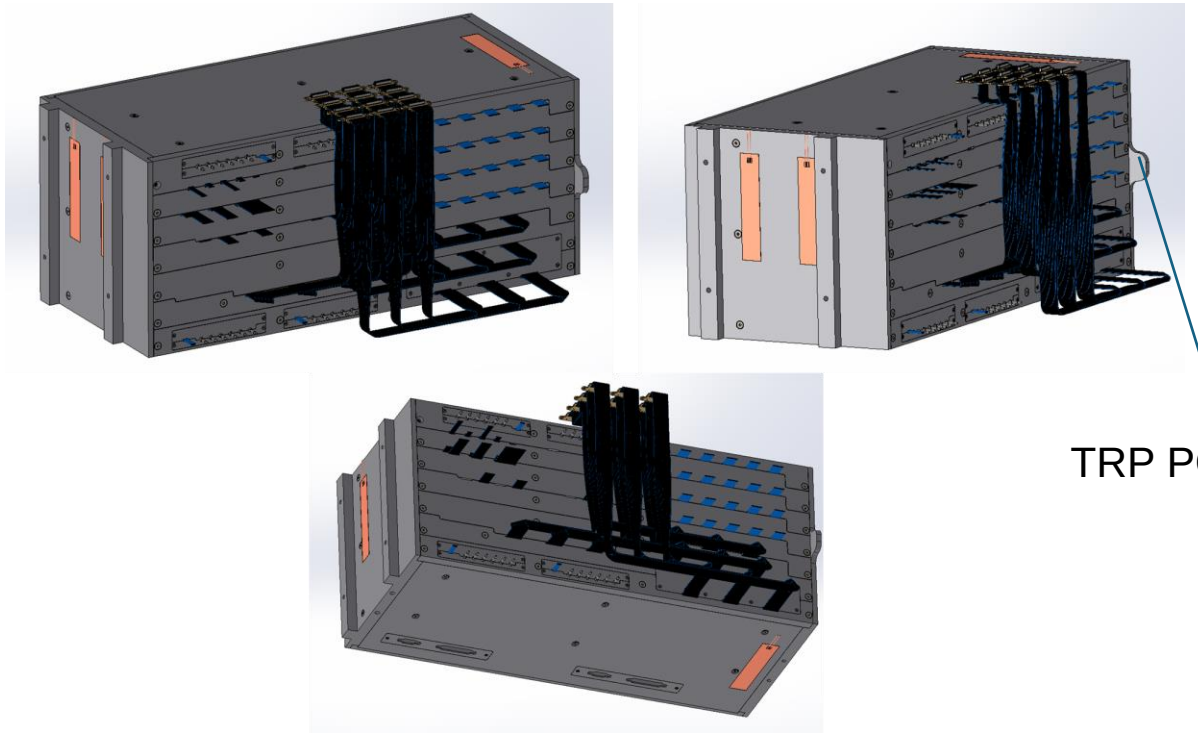
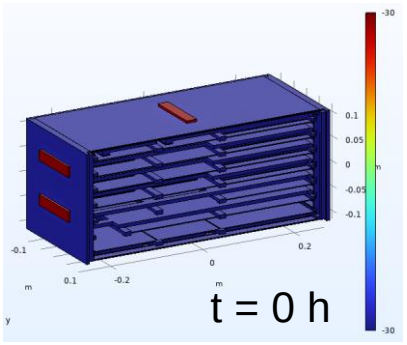


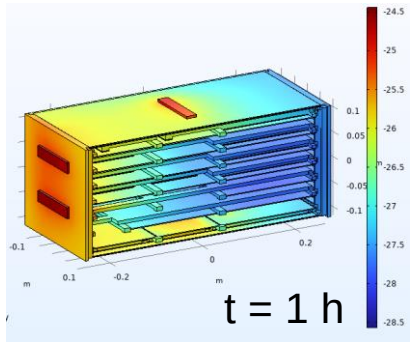
- **Box Interface**: -30°C
- **Initial Temperature**: -30°C

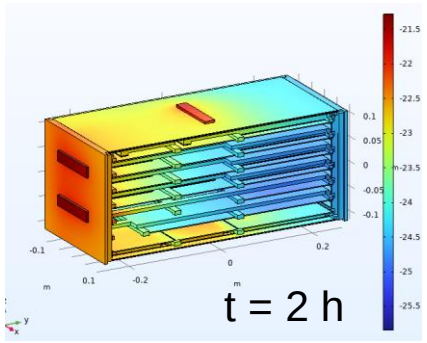
- **Heater Power**:
  - Heater: 21.37 W (40.7 V)
  - 75% Duty Cycle: 16.02 W
- **Power considered for SAFE analysis.**

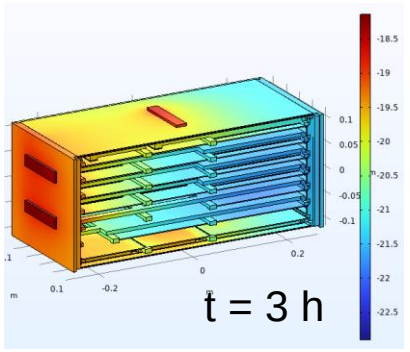
- **Heater Positioning**:
  - One heater is positioned on the top and one on the bottom lateral surfaces (close to the heat pipe position).
  - The other two heaters are positioned on the lateral surface (not thermally coupled with the tray).
- **No MLI covering.**

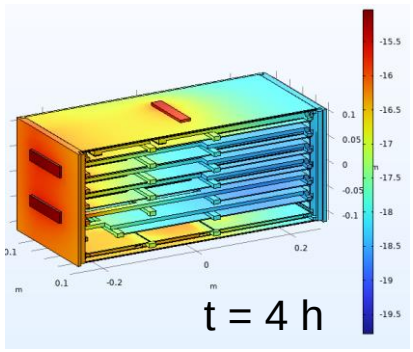
Electronic Box – Thermal Simulation Results

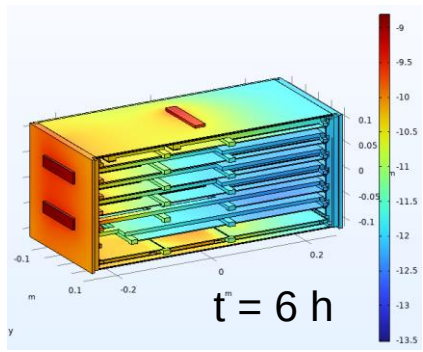






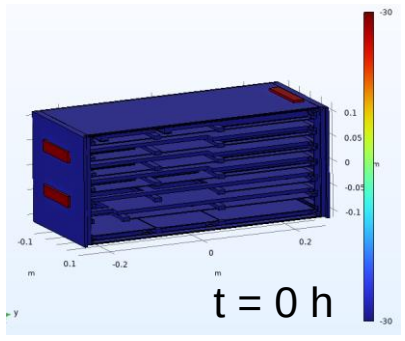


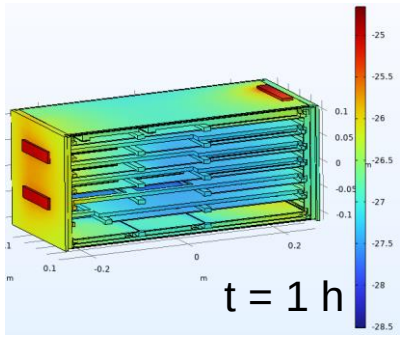


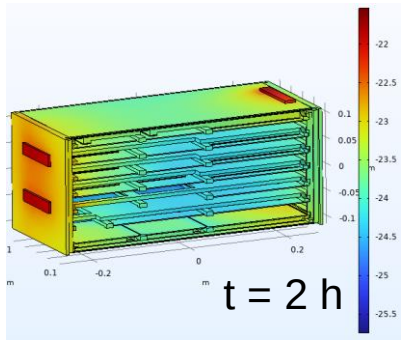


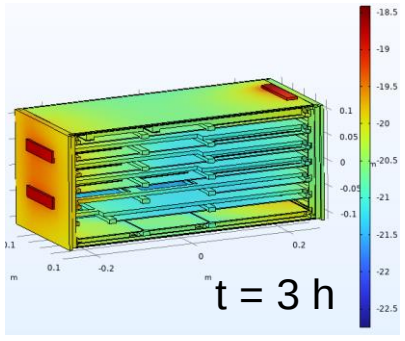
•1° Heater Configuration

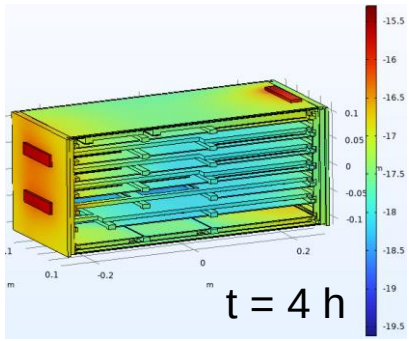
•2° Heater Configuration

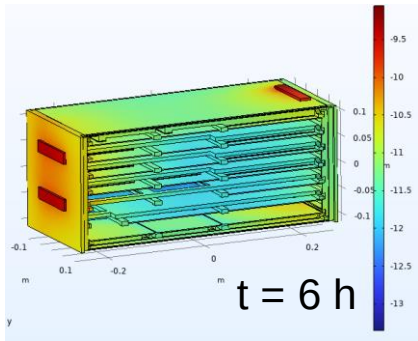












Electronic Box – Thermal Simulation Results

- **HOT CONDITION (+10°C):**

All boards analyzed for sensitivity do not present values exceeding the Max-rating.

- **COLD CONDITION (-10°C):**

All boards analyzed for sensitivity do not present values below the Min-rating.

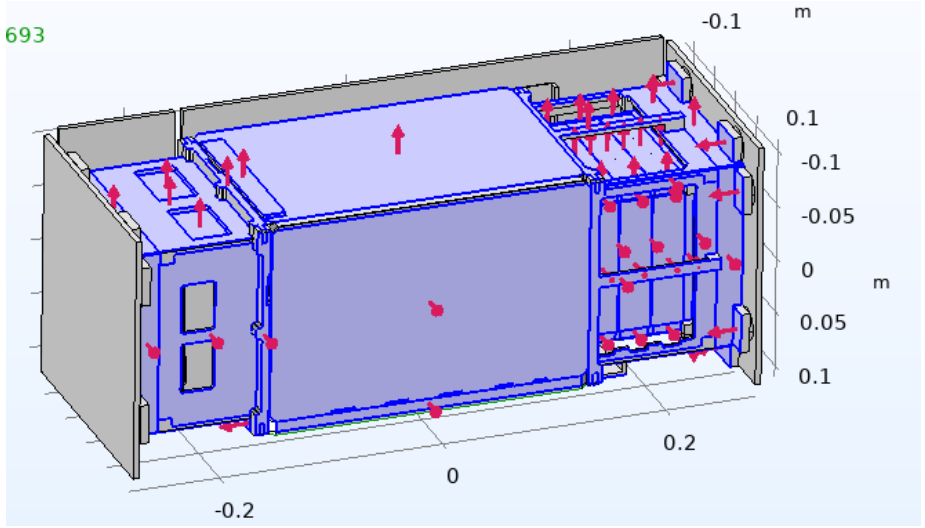
- **Heater System Analysis:**

Exiting from the SAFE state should occur within approximately 6 hours. This condition needs to be rechecked on the integrated Thales model, as it is conductively coupled with the entire dissipation system (radiator + heat pipe), dimensioned for the maximum load (116 W). It must be verified if the 21.37 W is sufficient for safe exit.

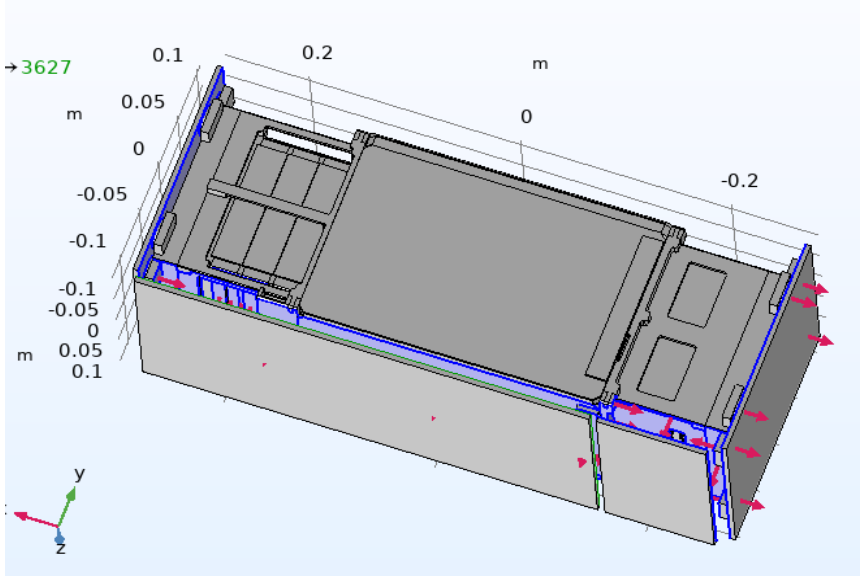
- **Cold Orbital Condition:**

The orbital calculation in the COLD condition does not foresee the use of additional heaters during operational conditions.

ZIRE – Model Boundary Conditions-
Power Distribution & Thermal Contact Interfaces



MLI (all around except -Y) → 0,01 Emissivity



NO MLI Y- → 0,8 Emissivity

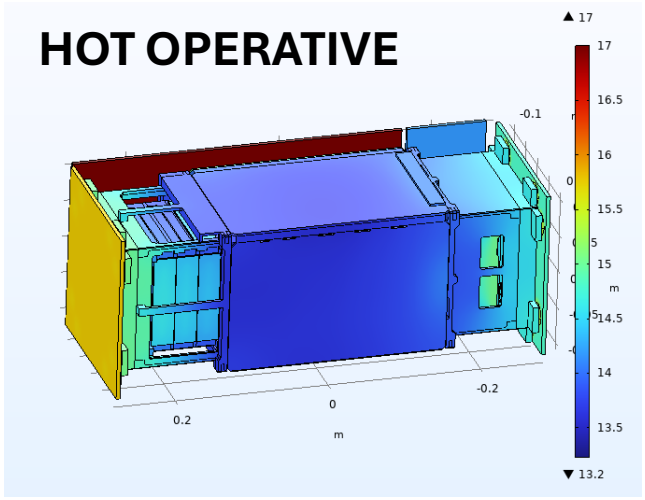
1	PST	0,422	W
2	FTK	0,27	W
3	Calog	0,394	W
4	ACS	0,158	W

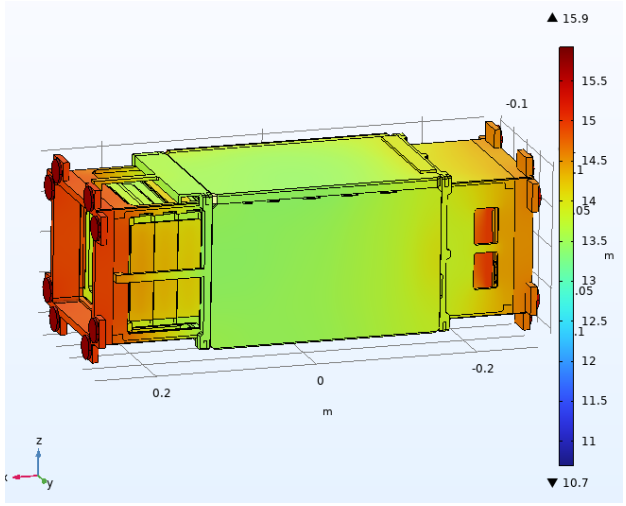
EoL	**TOT.**	**1,244**	**W**

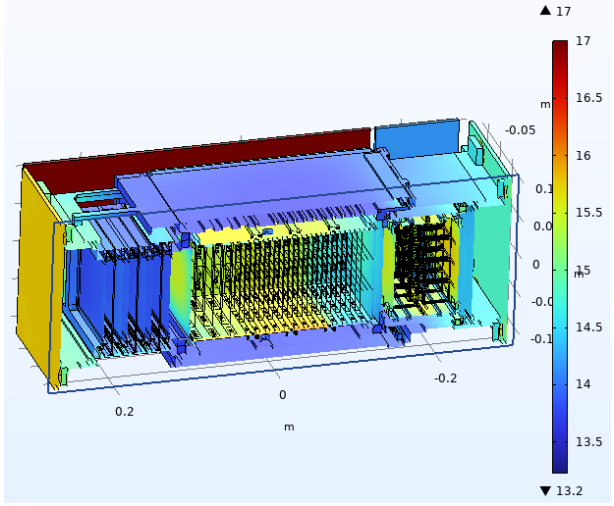
Contact Resistance		
Aluminum - Aluminum	0,0004	m2 K / W
Aluminum - Plastic	0,003	m2 K / W
Plastic-Plastic	0,1	m2 K / W

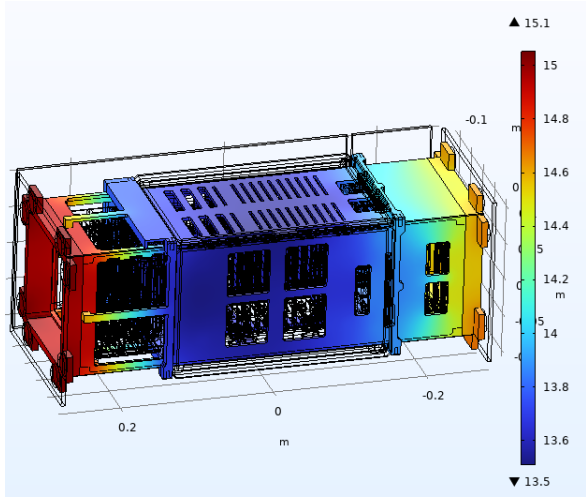
ZIRE – Thermal Simulation Results

HOT OPERATIVE

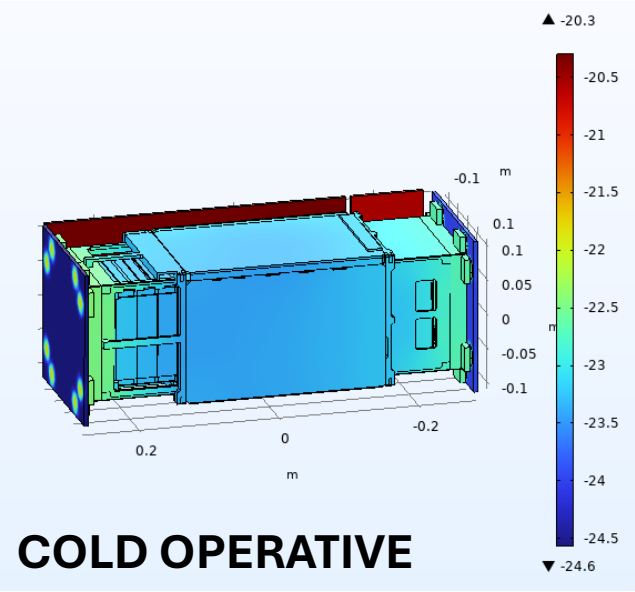


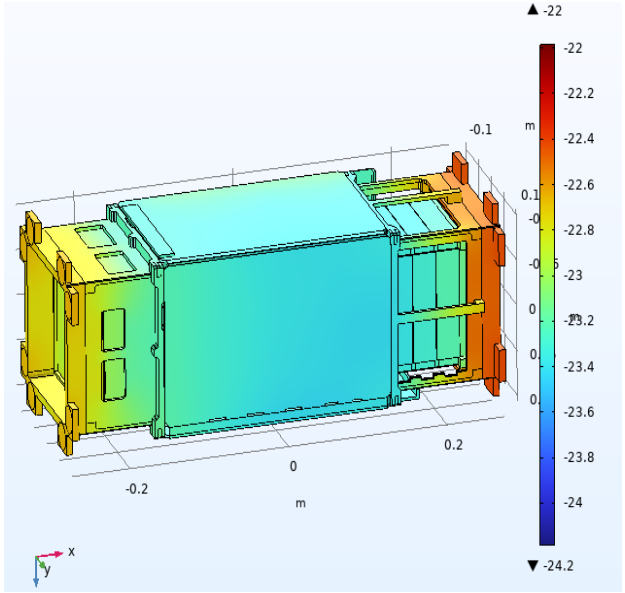


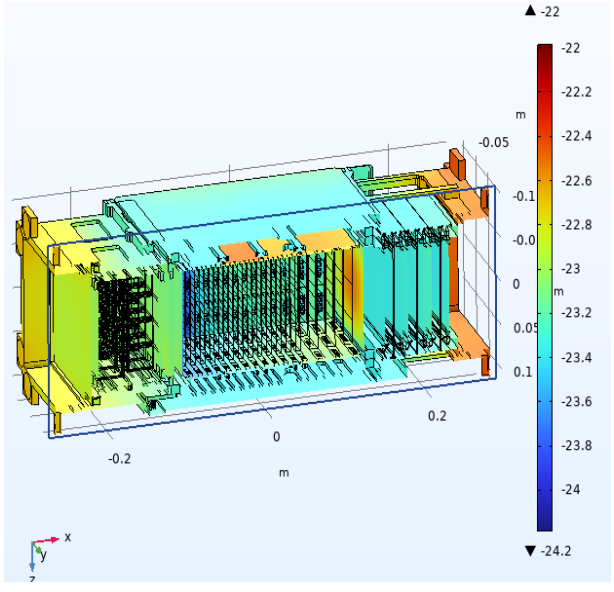


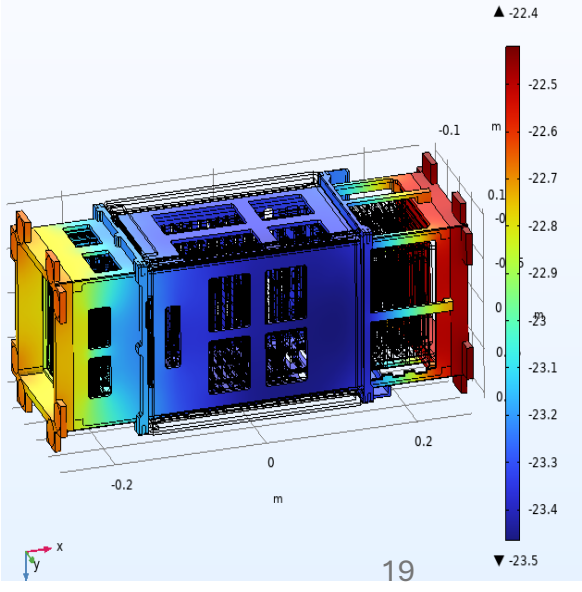


COLD OPERATIVE

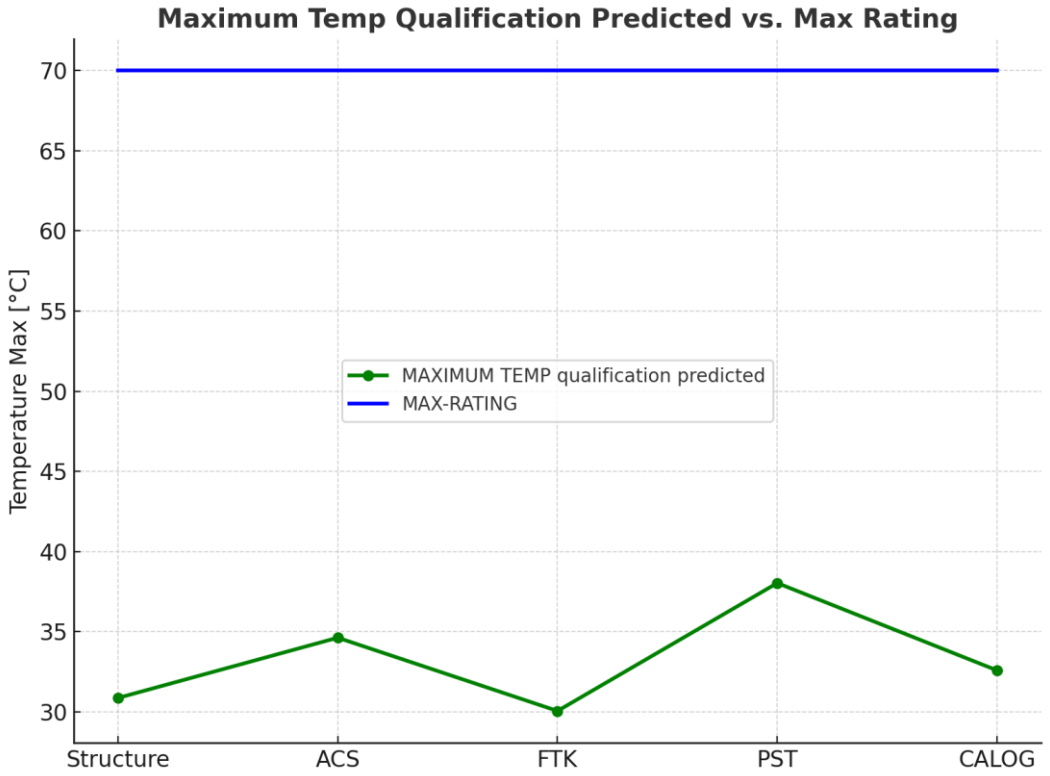


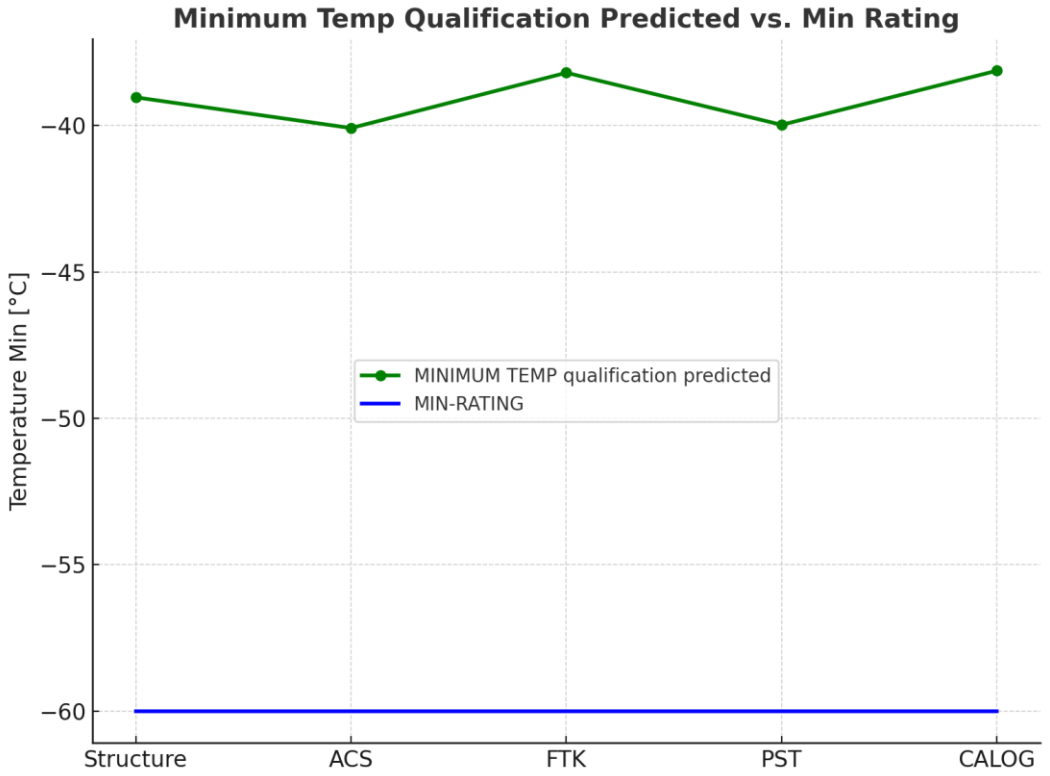




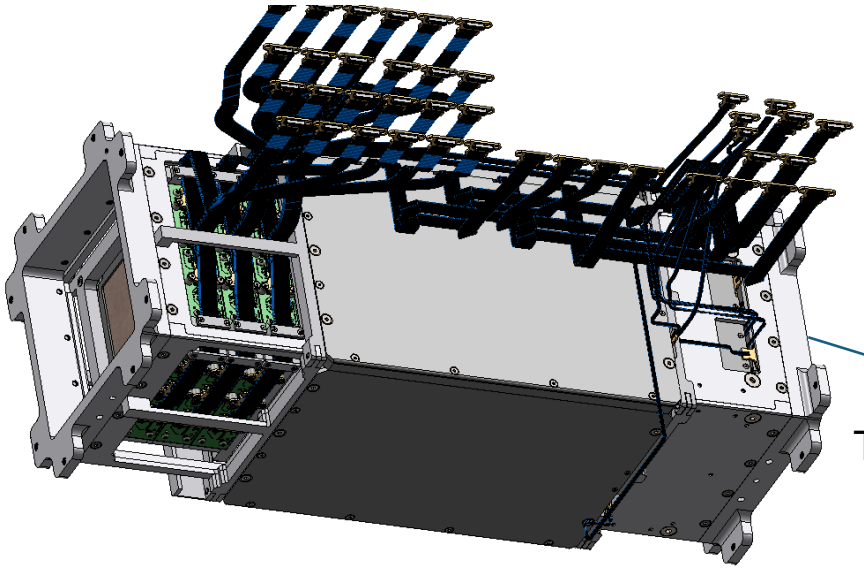


ZIRE – Thermal Simulation Results

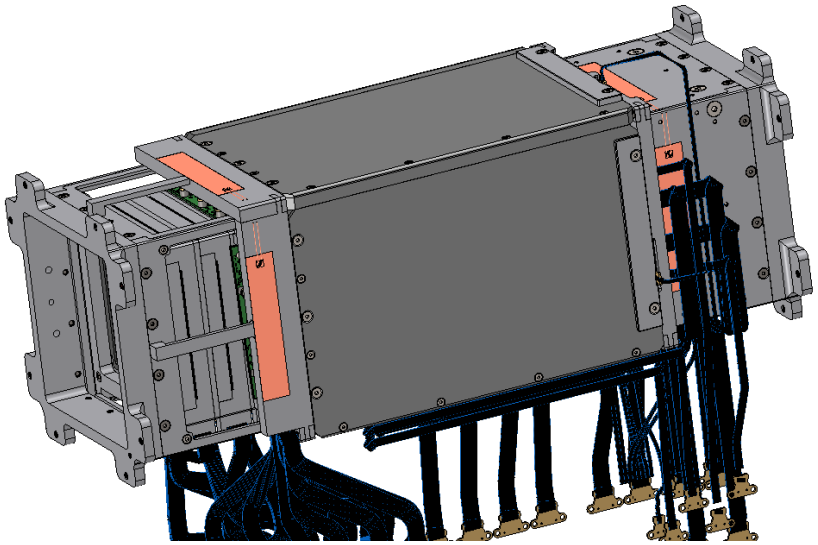




ZIRE – Thermal Simulation Results



TRP POSITION

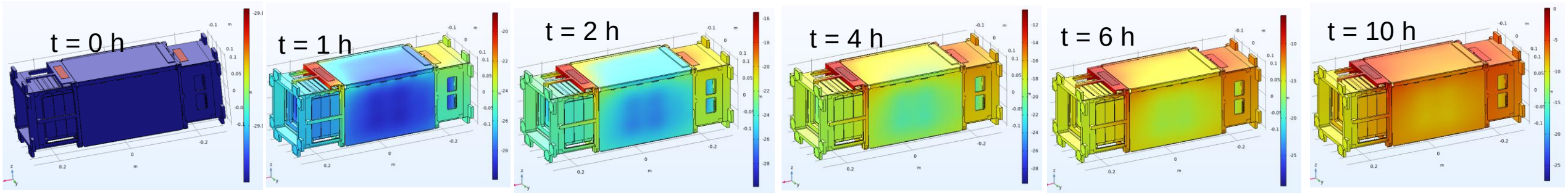


Zire Interface: -30°C
Initial Temperature: -30°C
TSINK: -30°C

•**Heater Power**:
Heater: 21.37 W (40.7 V)
75% Duty Cycle: 16.02 W
•**Power considered for SAFE analysis.**

•**Heater Positioning**:
Positioned on aluminum surfaces (Z+ and Y- sides) as shown in the picture.
All sides covered by MLI, including X+ and X- (with less coverage on the Y- side).

ZIRE – Thermal Simulation Results



•Heater Configuration

ZIRE – Thermal Simulation Results

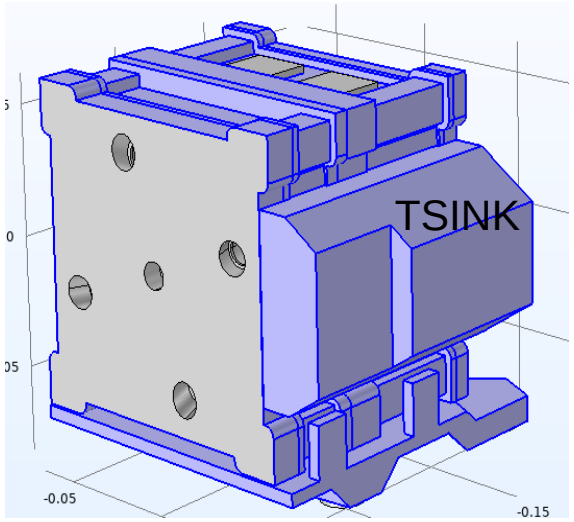
- **HOT CONDITION +10°C:**
All boards analyzed for sensitivity do not show values exceeding the Max-rating.

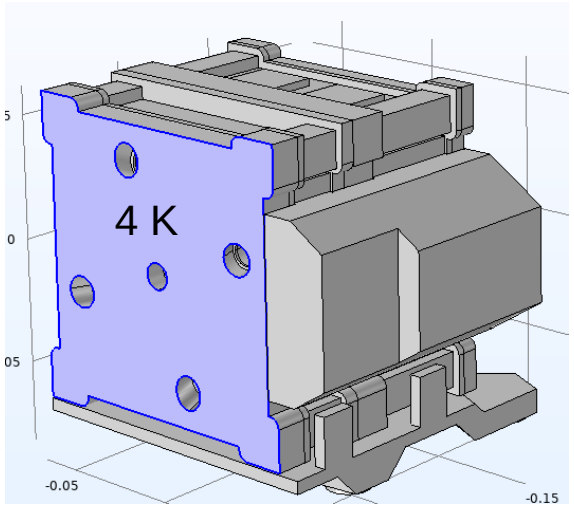
- **COLD CONDITION -10°C:**
All boards analyzed for sensitivity do not show values below the Min-rating.

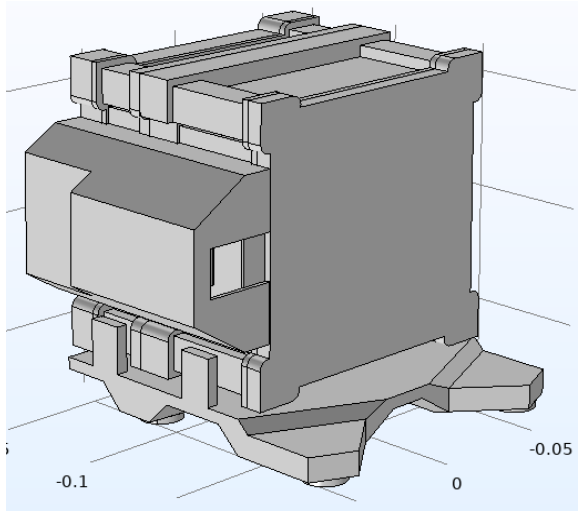
- **Considering the heater system**, exiting from the SAFE state should occur within approximately 10 hours.

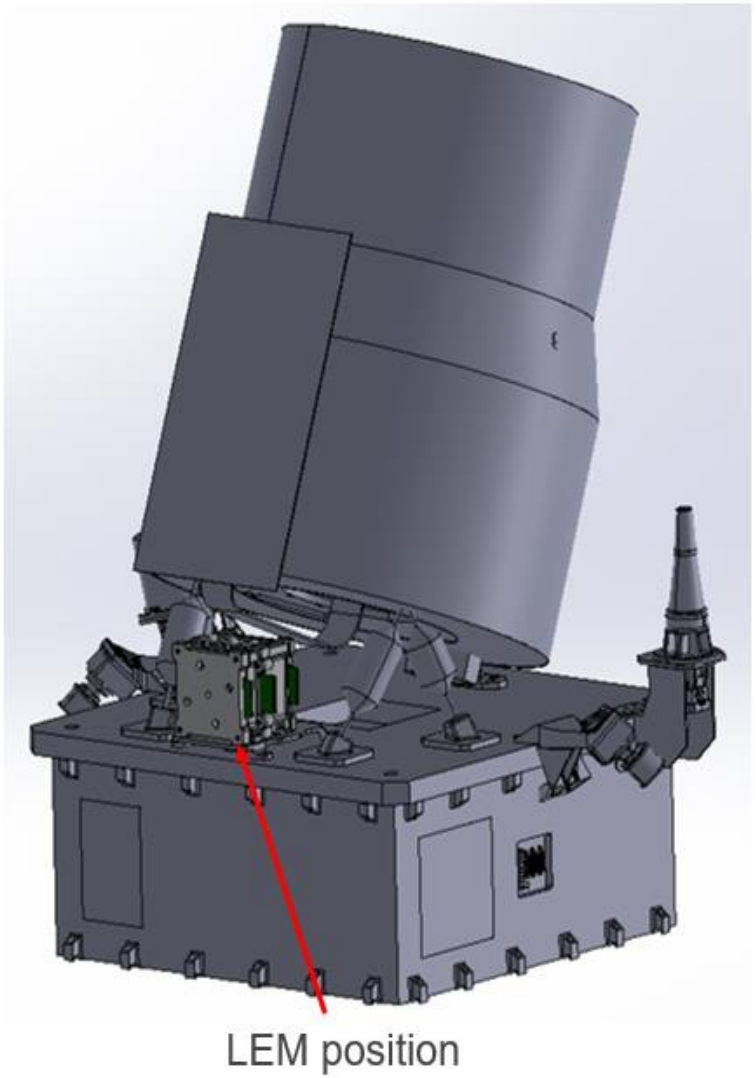
- **The orbital calculation** in the COLD condition, without any temperature uncertainty delta, does not foresee the use of heaters in operational conditions. More detailed analysis of the platform's heater budget will be referred to.

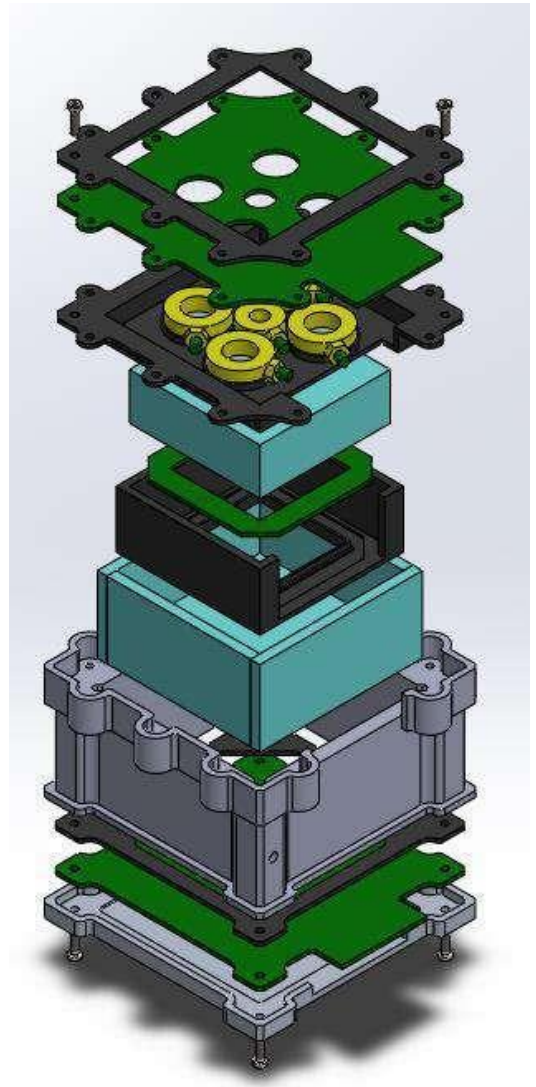
LEM's Mechanical Configuration & Boundary Conditions





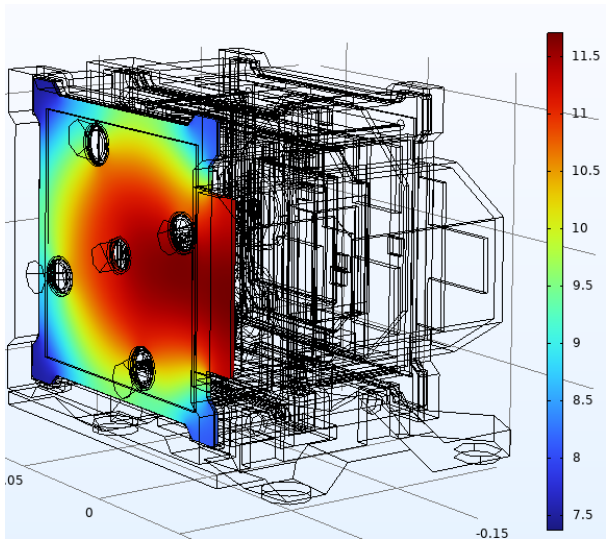


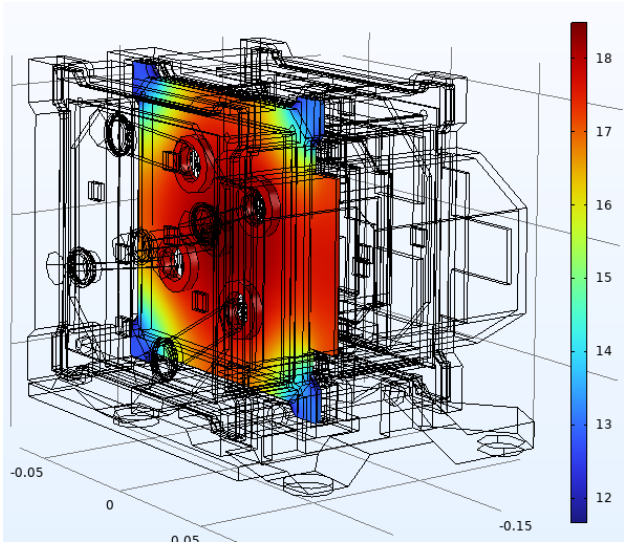


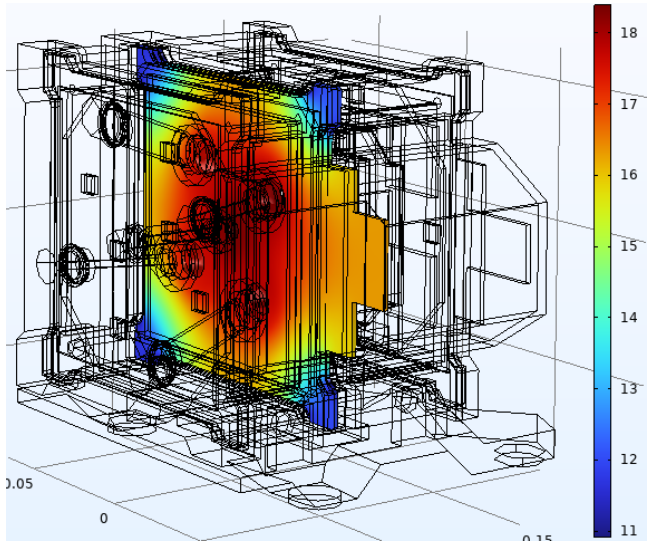


LEM – Thermal Simulation Results

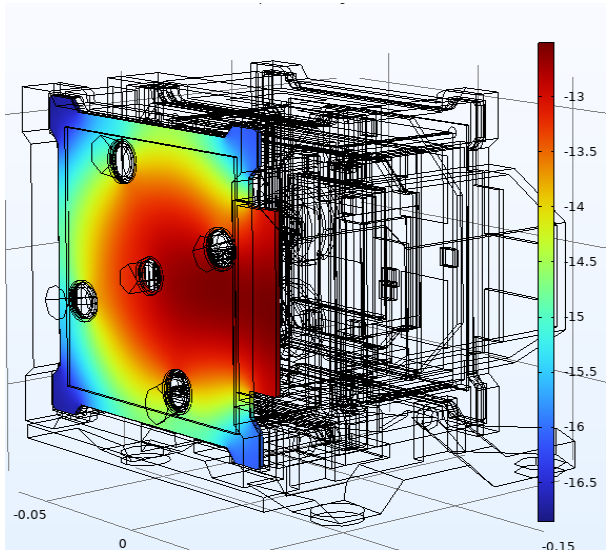
HOT OPERATIVE

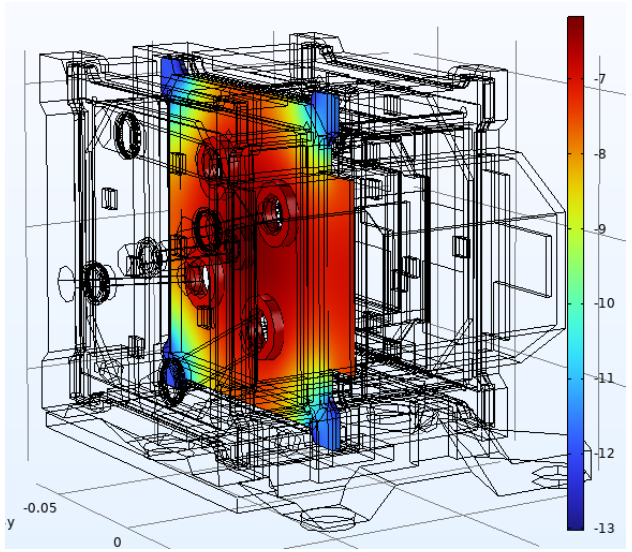


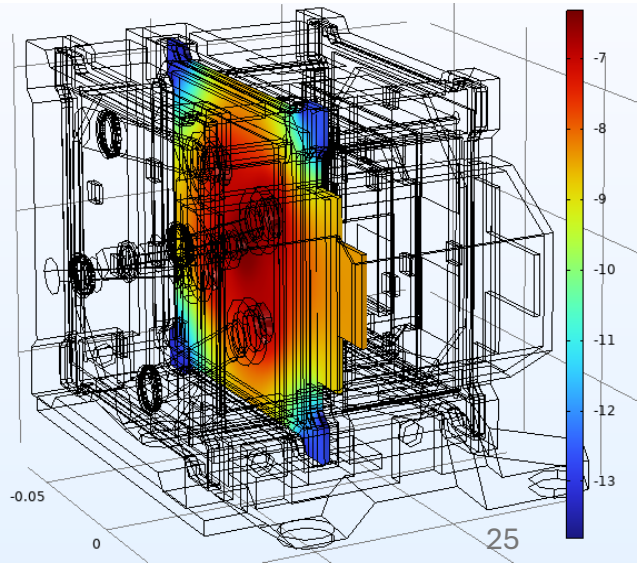




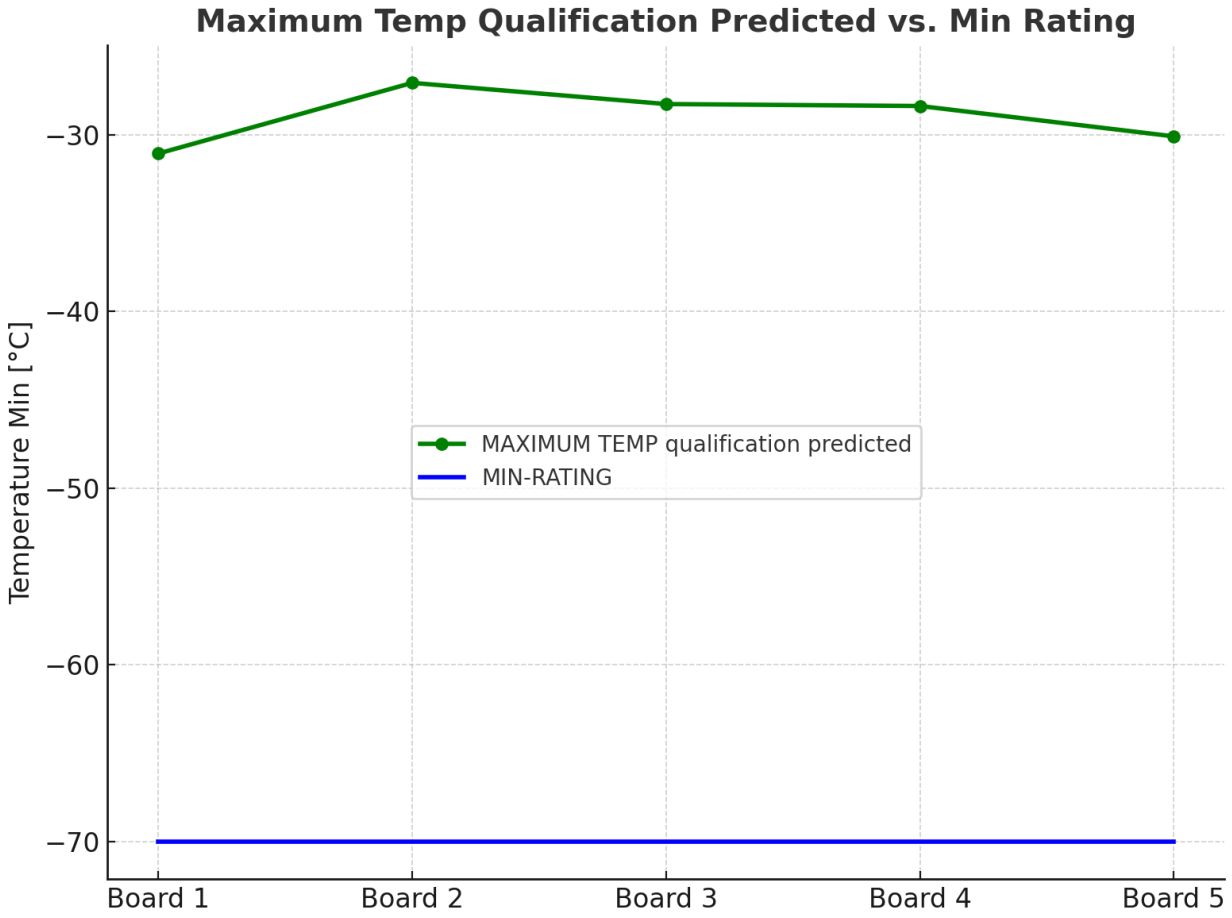
COLD OPERATIVE

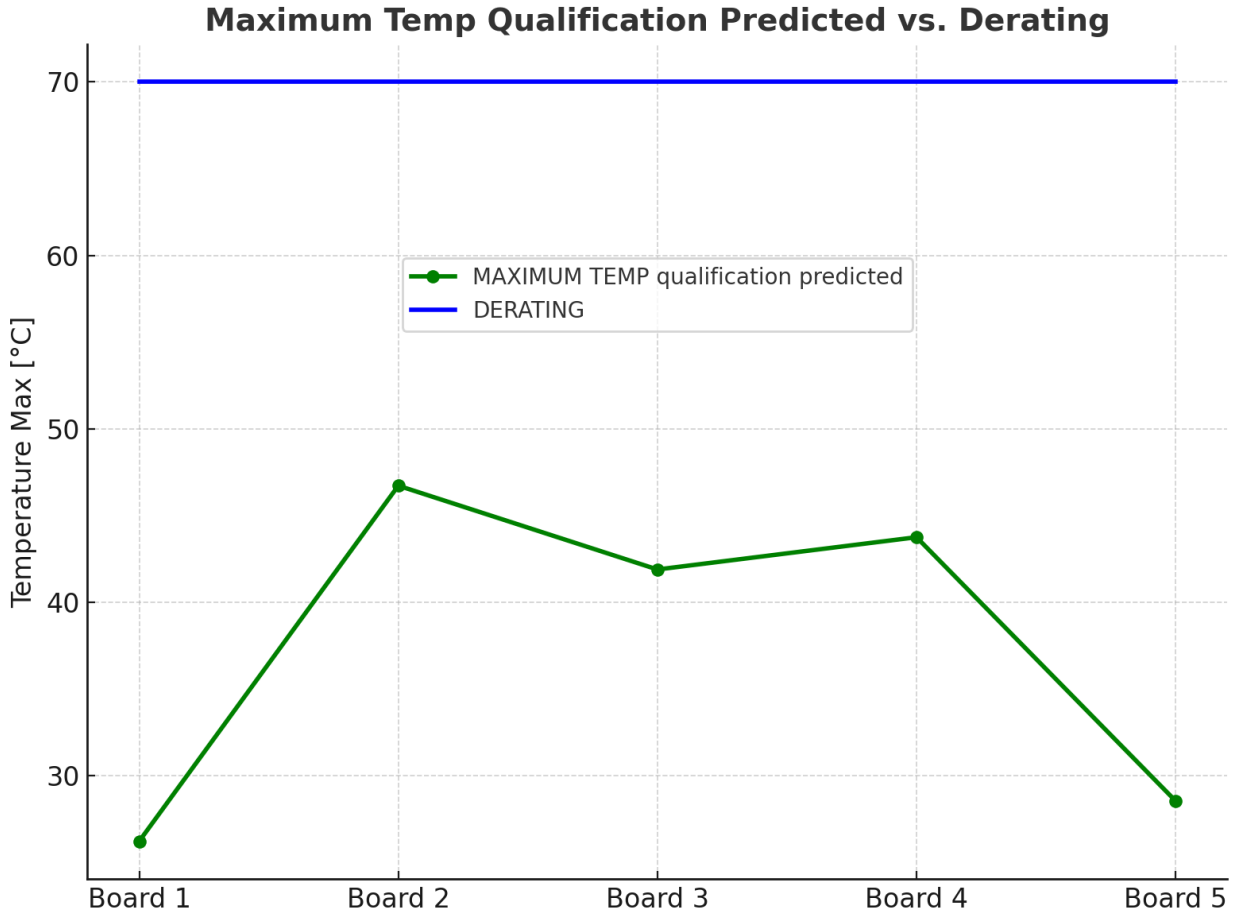




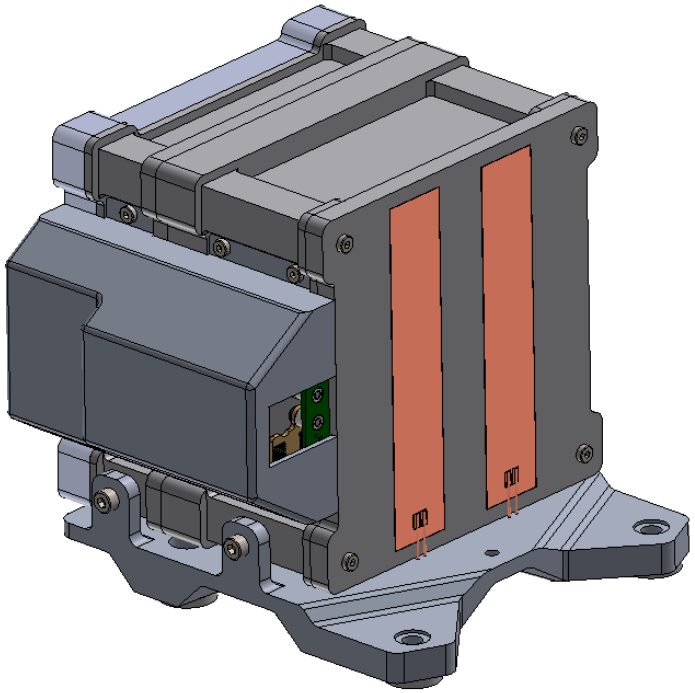


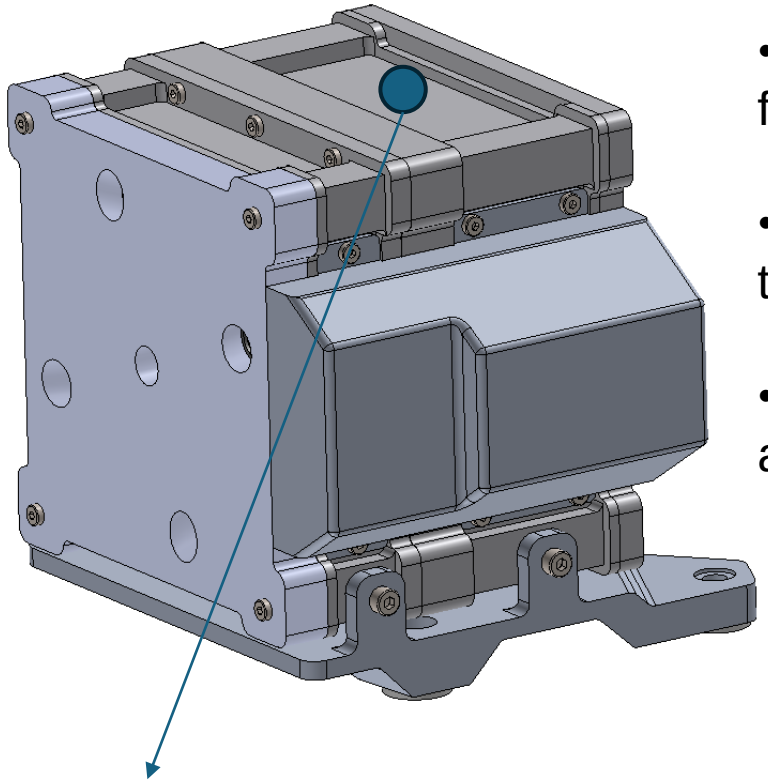
LEM – Thermal Simulation Results





LEM – Thermal Simulation Results



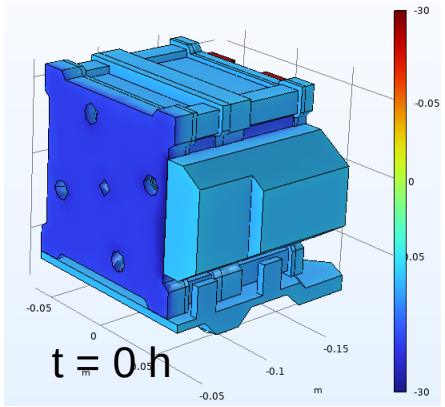


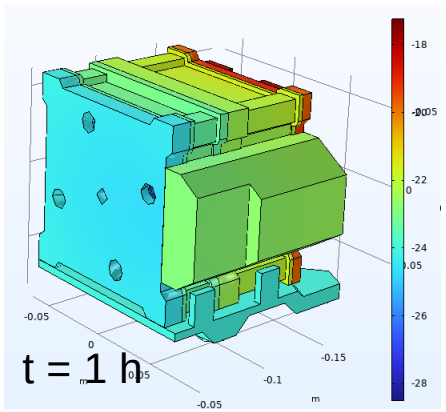
- **The entire body**, except for the FOV face, is inside a **tent of MLI**.
- **Decoupled** using a thermal washer from the support bracket.
- The **support bracket** is decoupled with a thermal washer from the top plane.

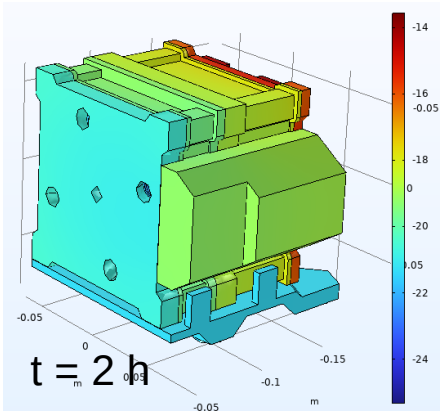
- **Heater Power**: 10.68 W (40.7 V)
- 75% Duty Cycle: 8.01 W

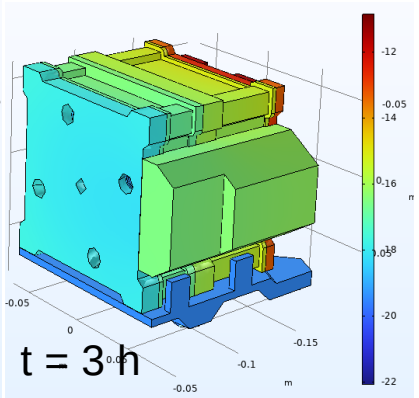
LEM Interface: -30°C
Initial Temperature: -30°C

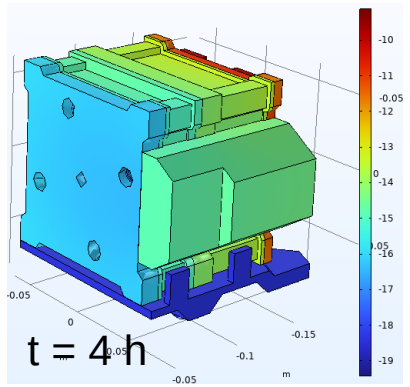
LEM – Thermal Simulation Results

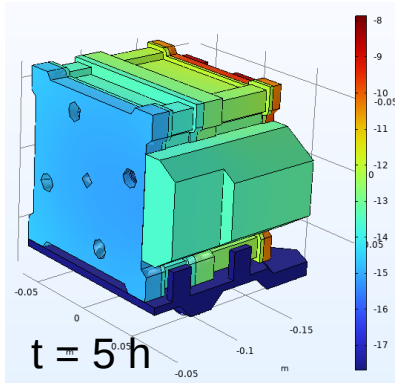












LEM – Thermal Simulation Results

•**HOT CONDITION +10°C**:

All boards analyzed for sensitivity do not present values higher than the Max-rating.

•**COLD CONDITION -10°C**:

All boards analyzed for sensitivity do not present values lower than the Min-rating.

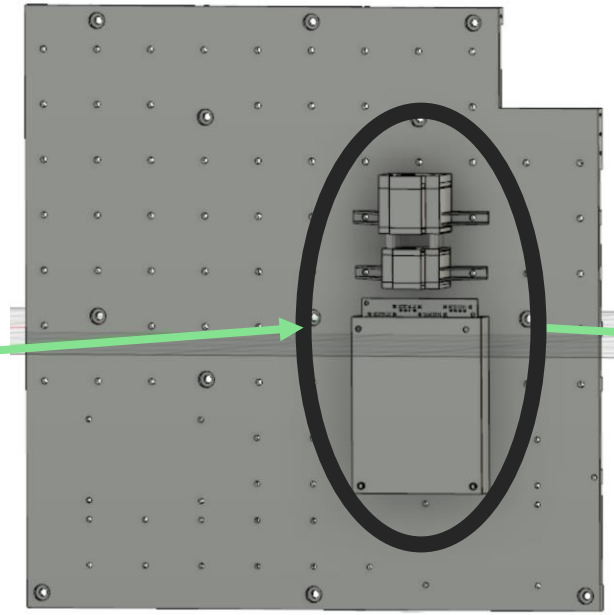
•Exiting SAFE mode should occur within approximately 5 hours.

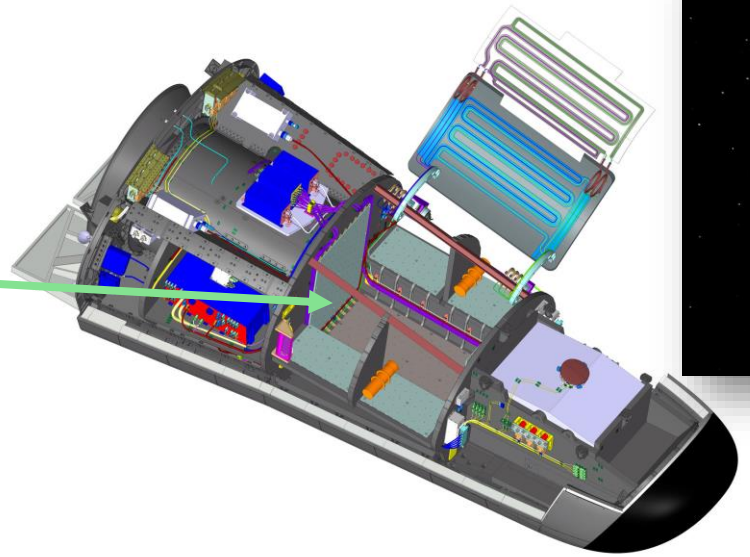
•Despite the delta regarding the interface temperature, in the COLD case (calculated without uncertainty temperature delta), the system has a heater consumption of zero. A recalculation with a higher confidence level is needed, referring to the platform's thermal analysis to determine the heater budget in COLD conditions.

Introduction to WINK Mission: Thermal Analysis Perspective

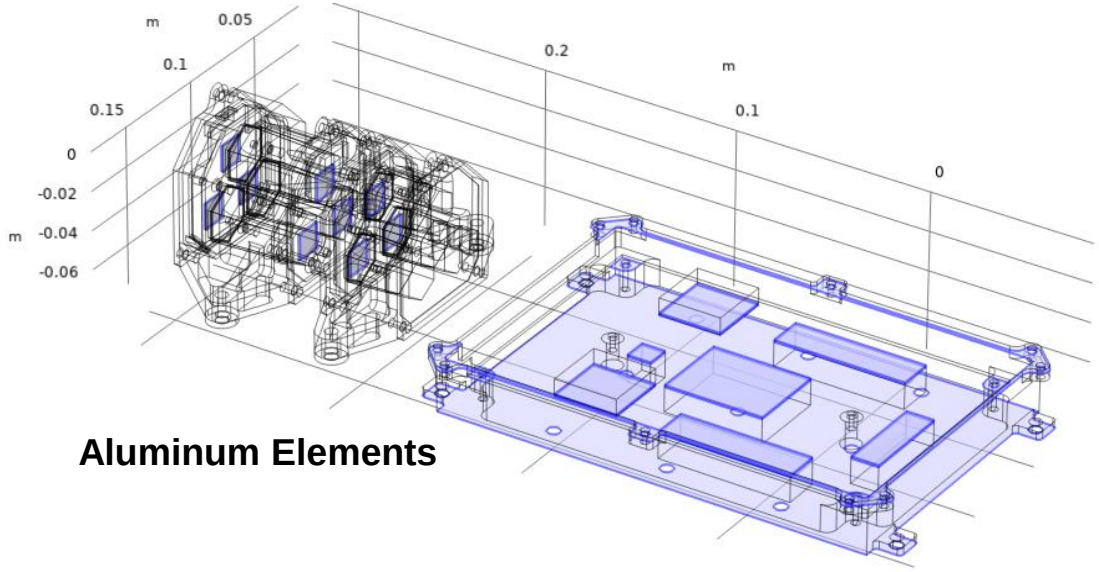
WINK:

- Pathfinder of the Crystal Eye, which is a wide sight on the Universe for X and gamma ray detection
- Thermal analysis for the detectors onboard ESA's Space Rider.
- Maintaining consistent temperatures under space conditions.

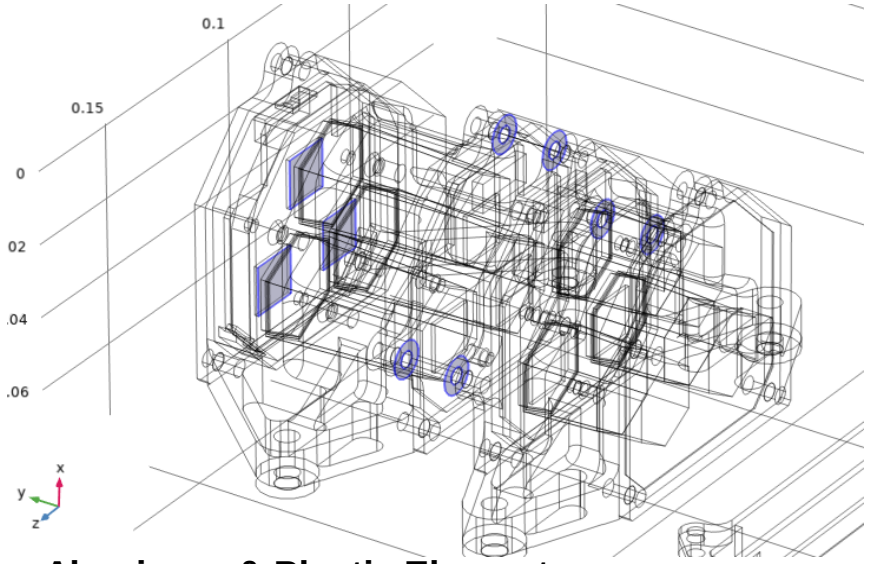




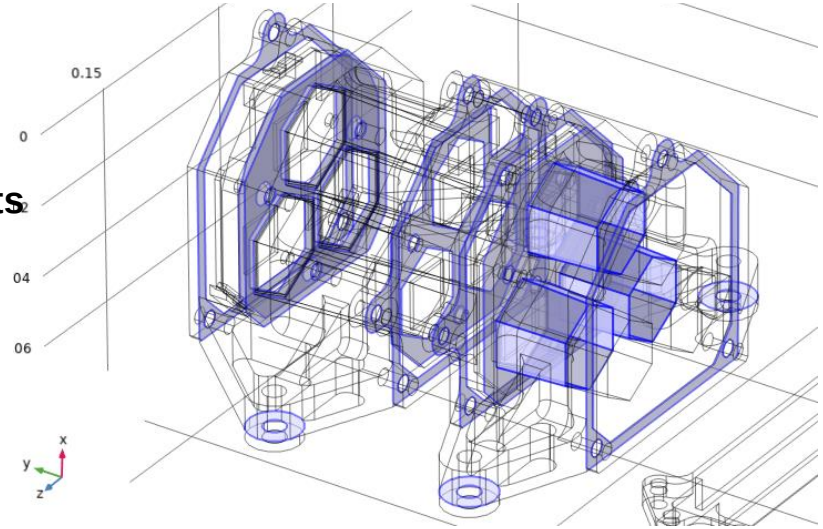
WINK – Model Boundary Conditions- Thermal Contact Interfaces



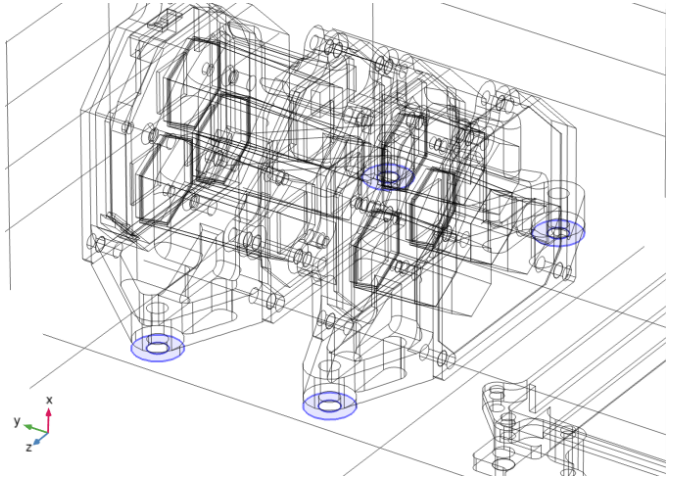
Aluminum Elements



Aluminum & Plastic Elements

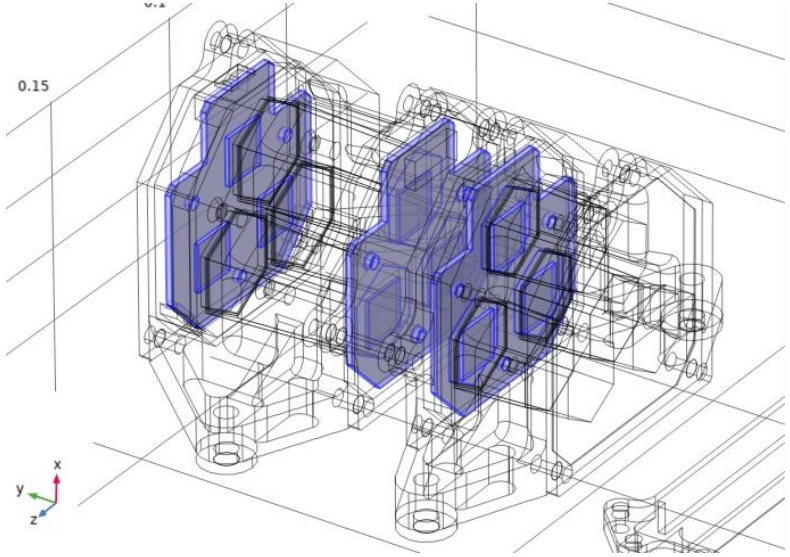


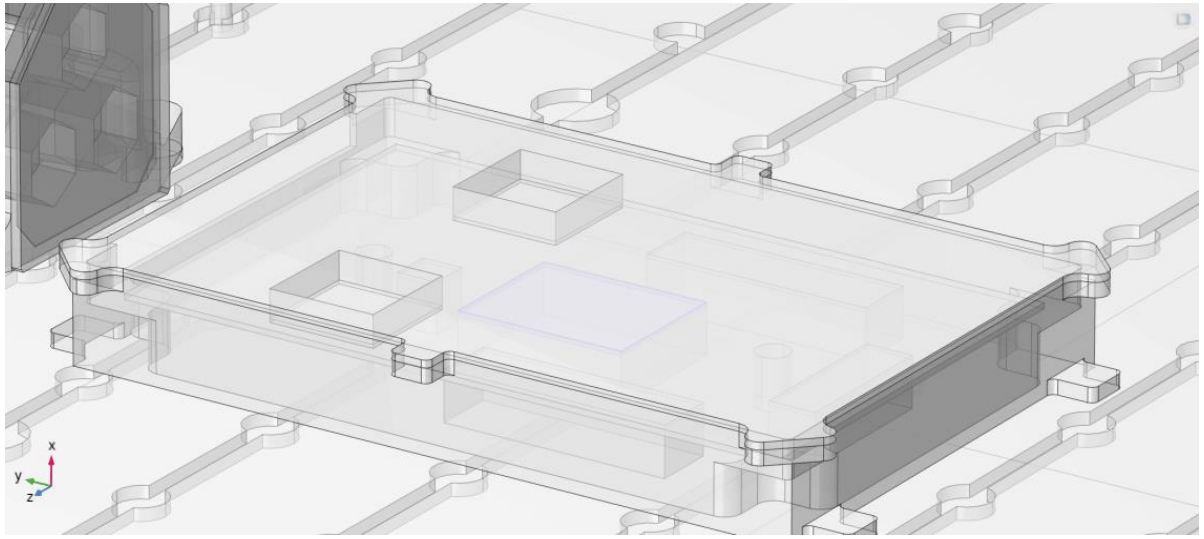
Plastic Elements



Thermal Decoupling Between Detector & Plate

WINK – Model Boundary Conditions- Thermal Contact Interfaces





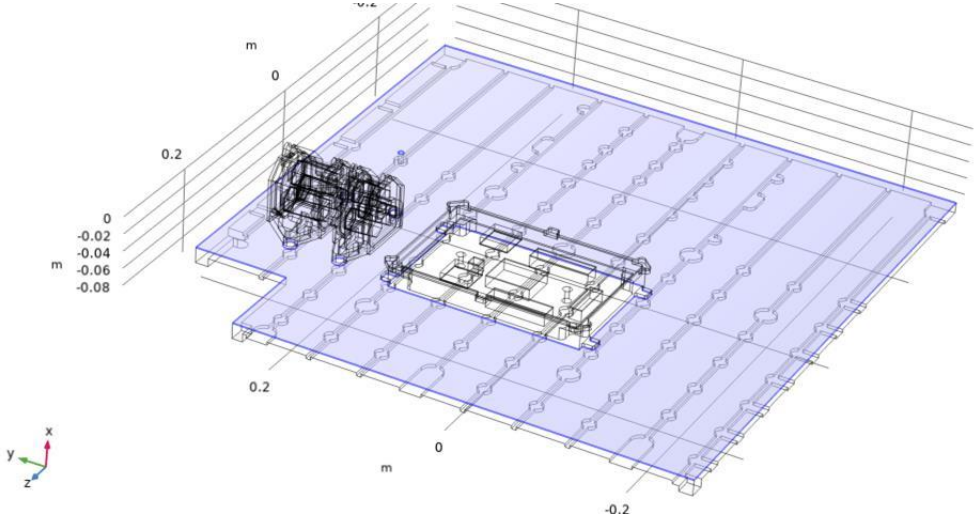
0.0003 W is distributed among the detector boards

11.725 W is distributed across the main power board chips

	Layer Resistance (K.m2/W)	Surface Emissivity
Aluminum & Aluminum	0.0004	0.77
Aluminum & Plastic	0.03	0.4
Plastic & Plastic	0.1	0.1

	Thermal Conductivity (W/m.K)	Layer Thickness (m)	Surface Emissivity
Thermal Decoupling Interface between Detector & Plate	0.1	0.003	1

WINK – Model Boundary Conditions- Thermal Contact Interfaces

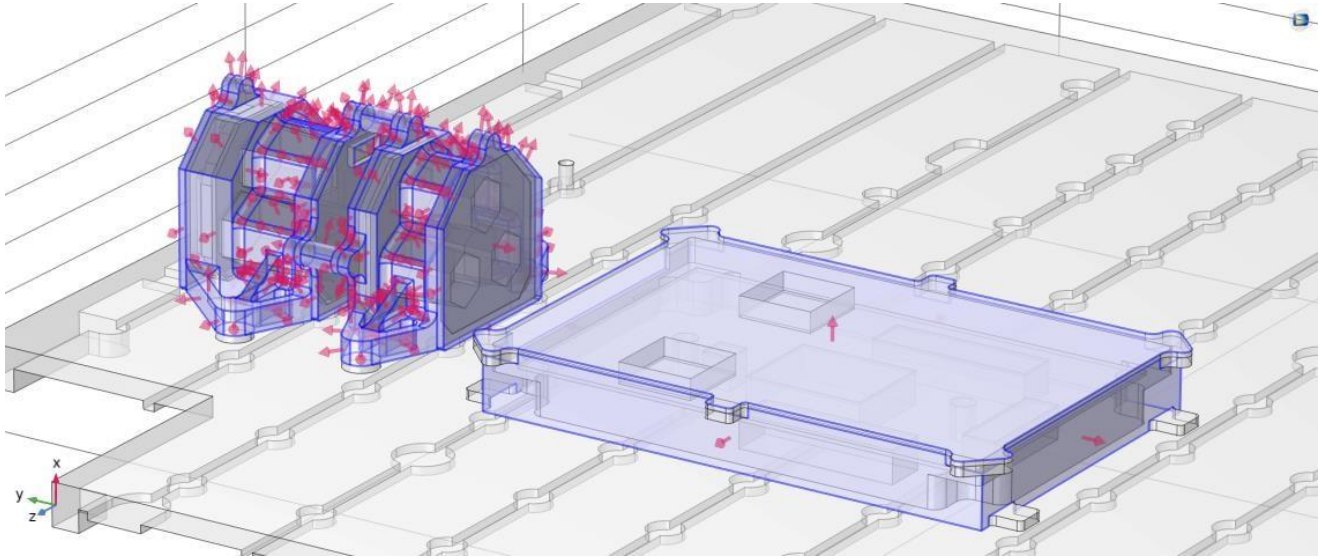


Temperature Defined at the Plate Interface: **+40 °C**

Diffuse Surface 2 Radiation With Blackbody

Surface Emissivity: **0.7 (Aluminum)**

Ambient Temperature: **4K**

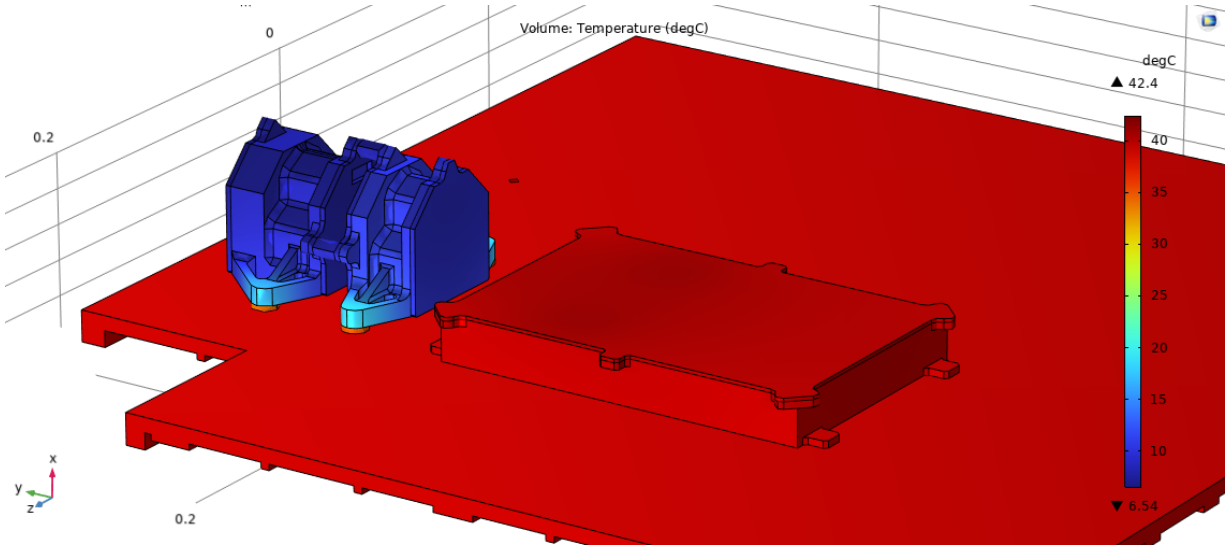


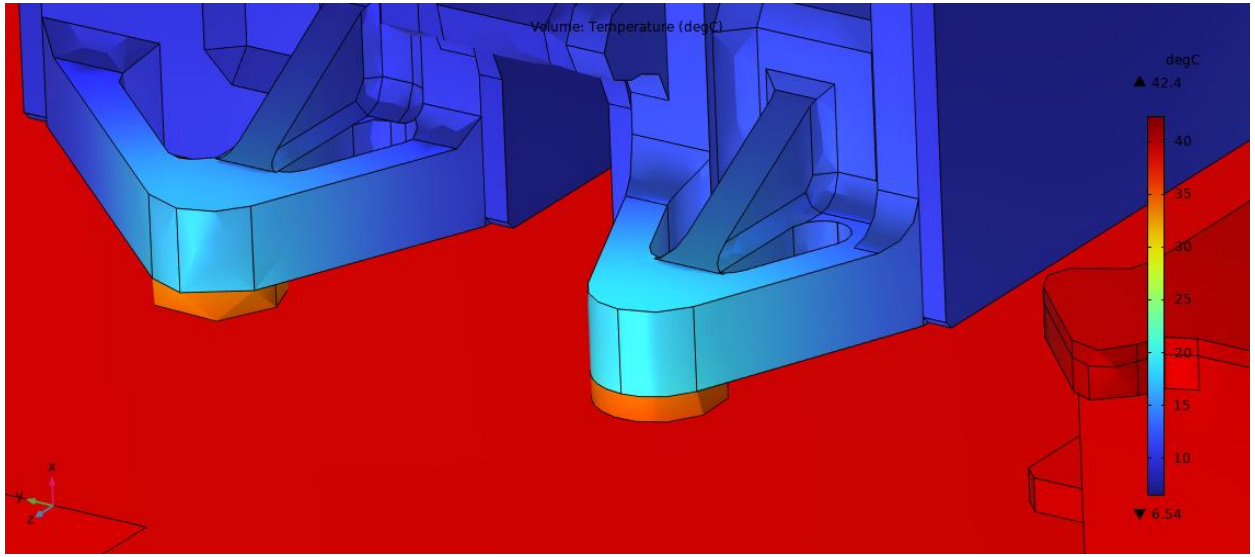
Diffuse Surface 1 Radiation With Blackbody

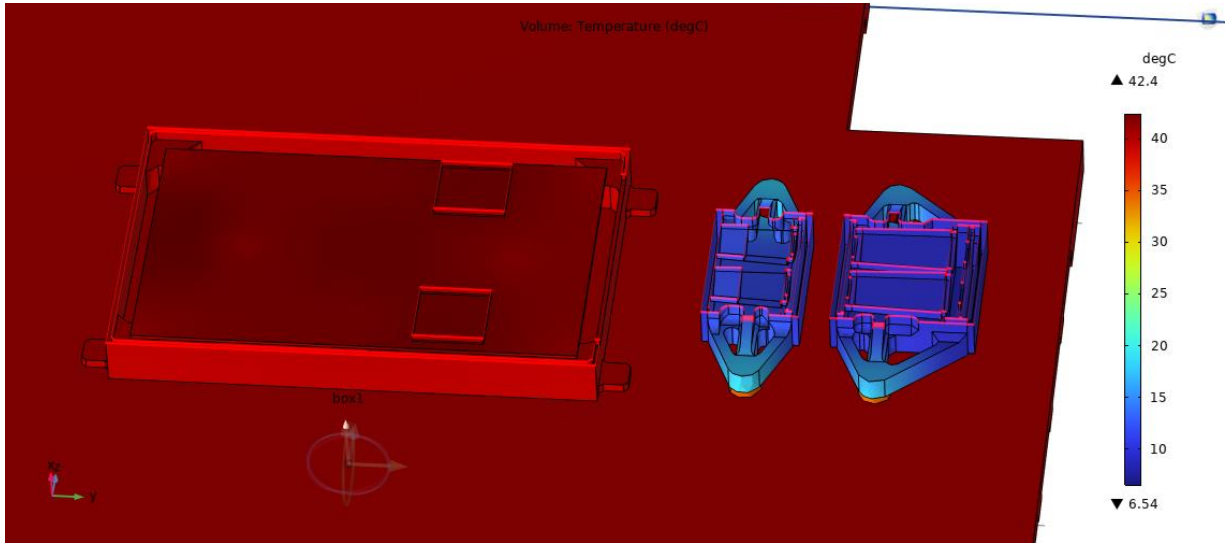
Surface Emissivity: **0.01 (MLI)**

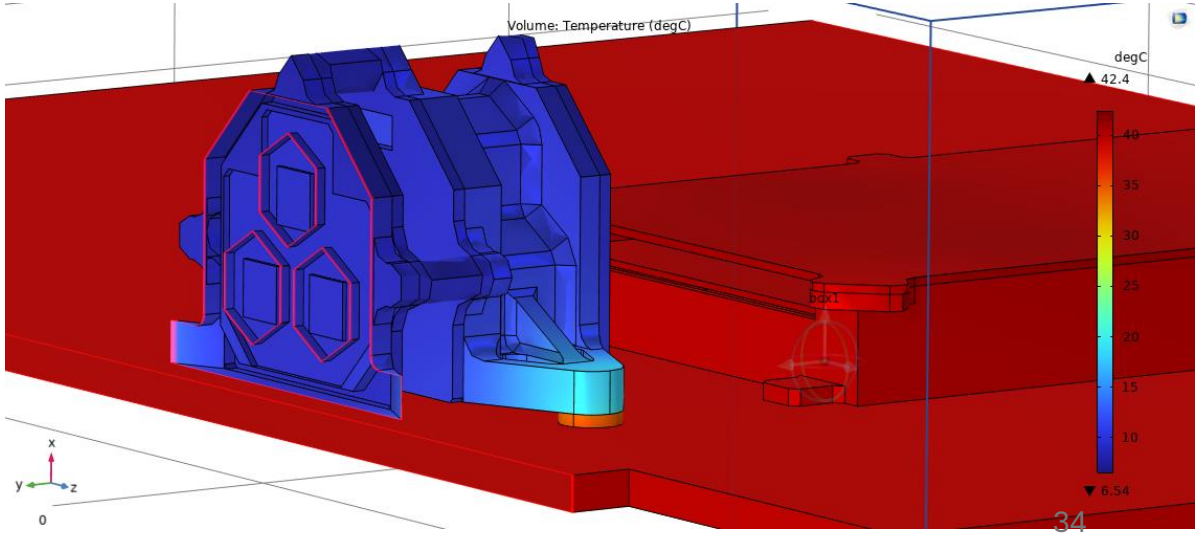
Ambient Temperature: **4K**

WINK – Thermal Simulation Results

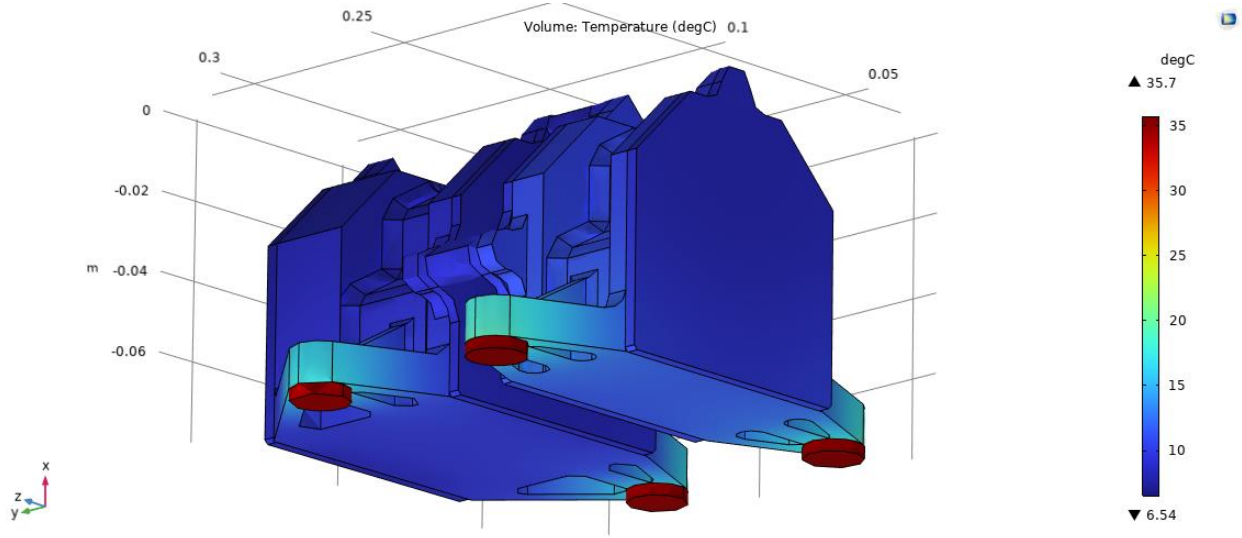


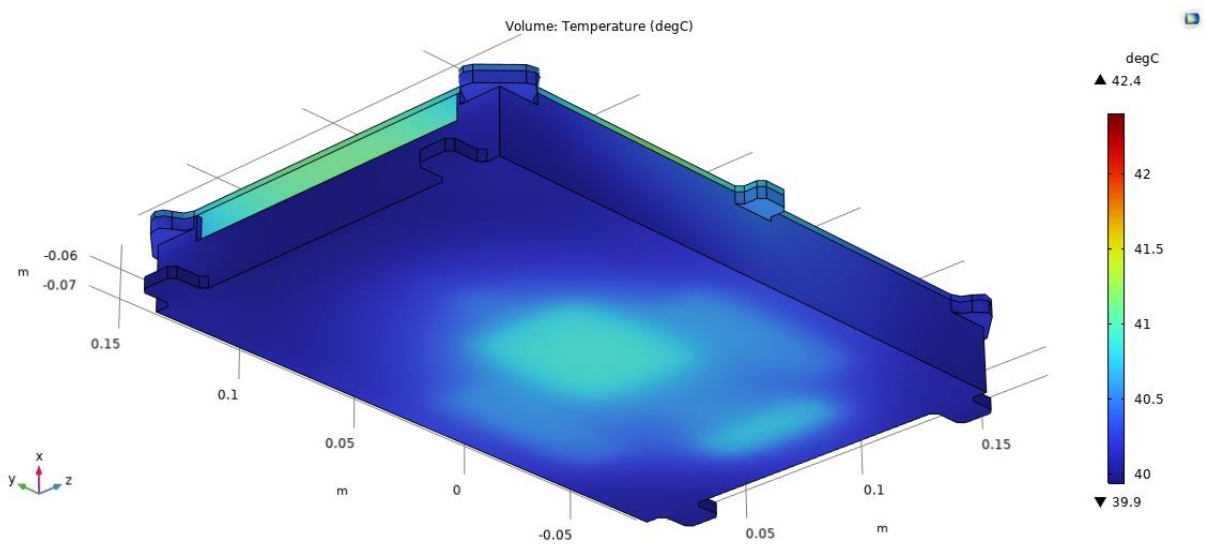


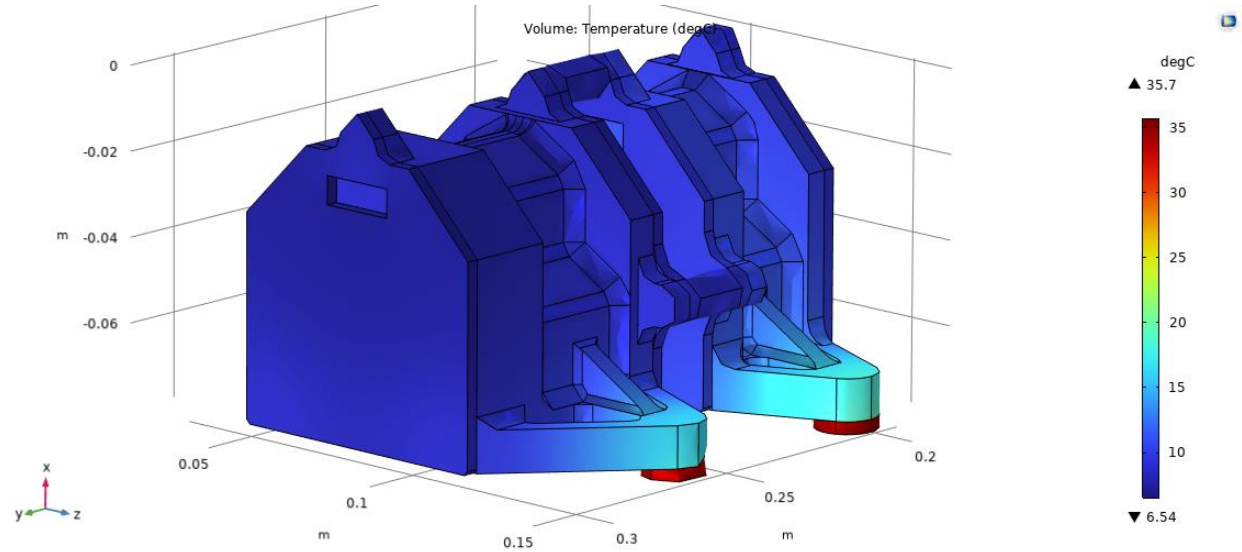


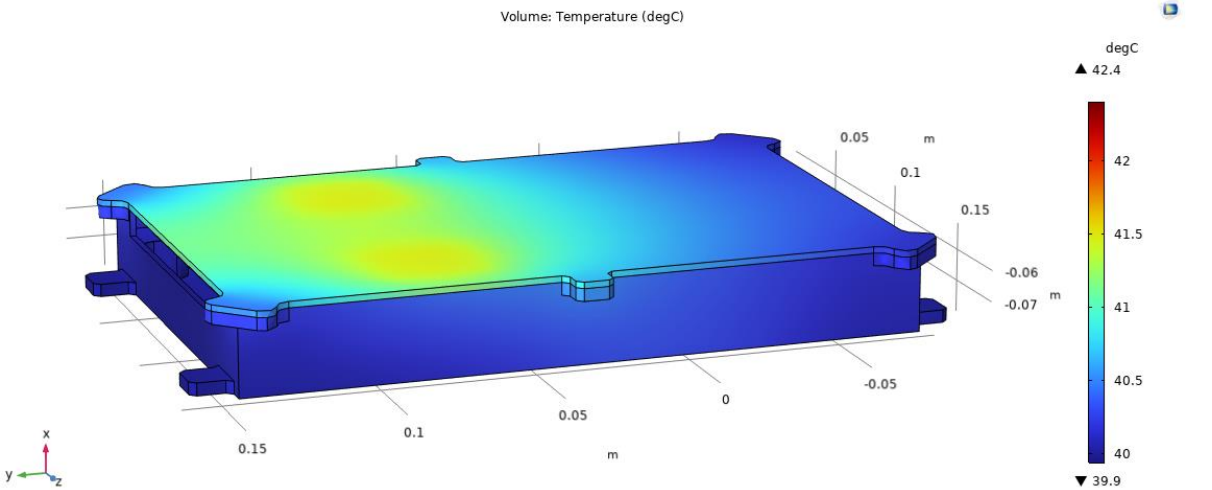


WINK – Thermal Simulation Results - Subsystems

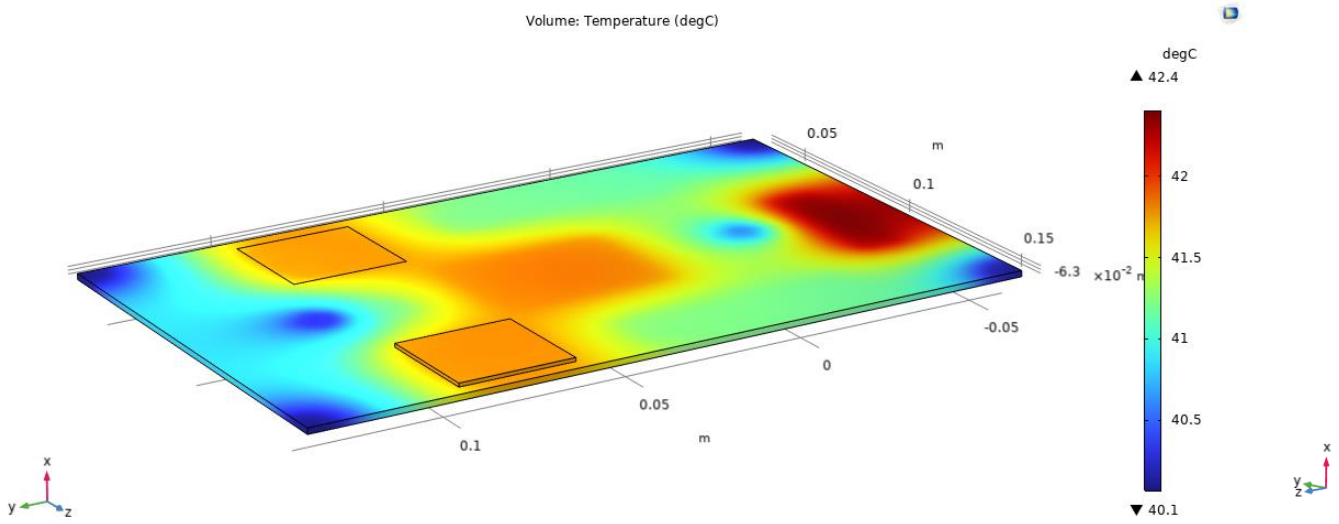


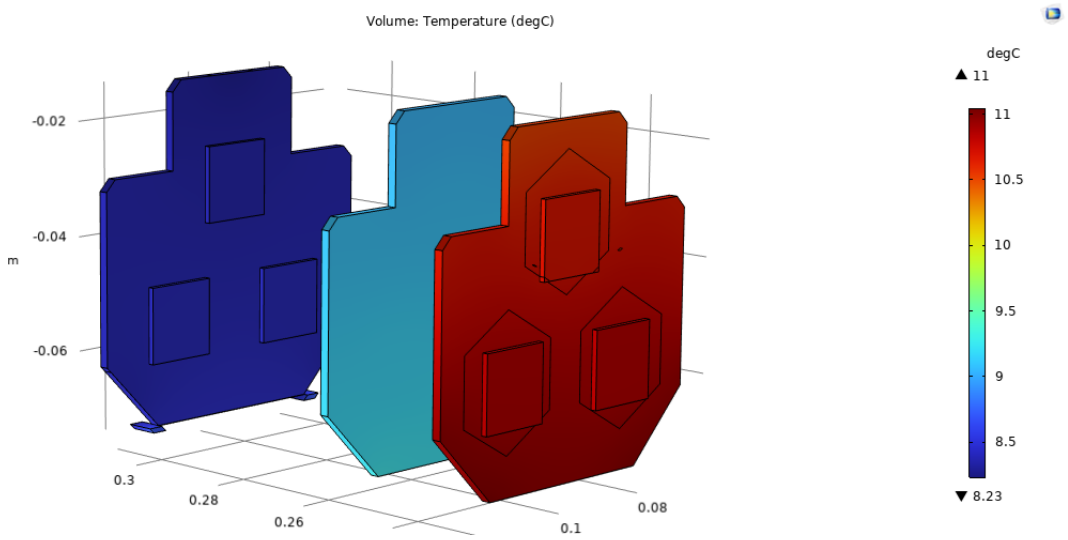


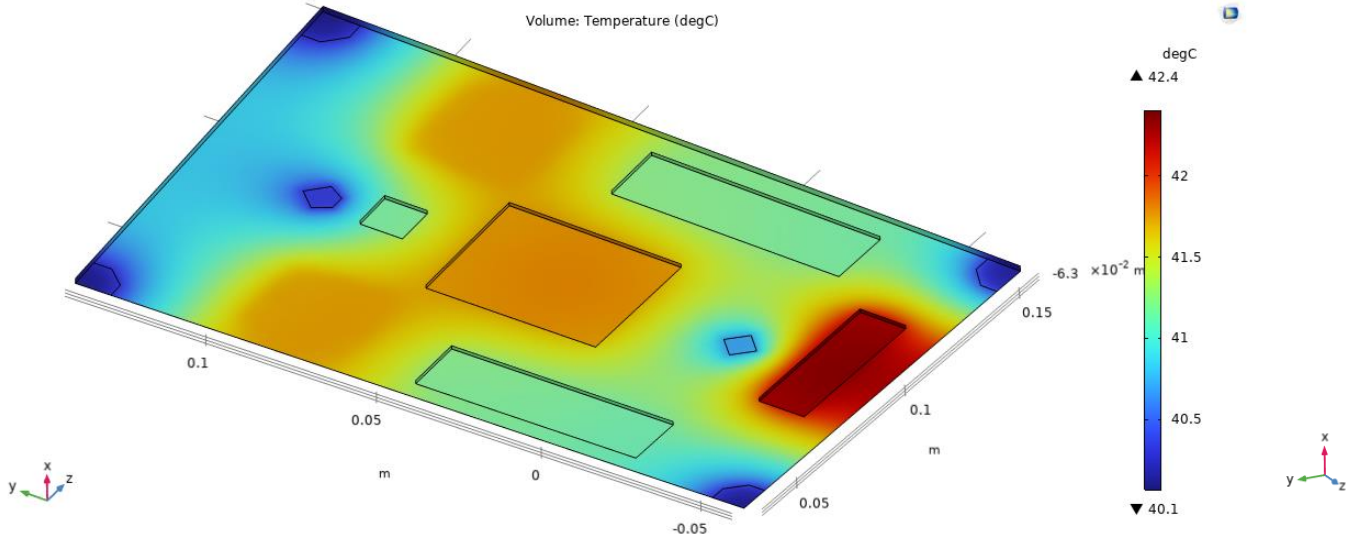


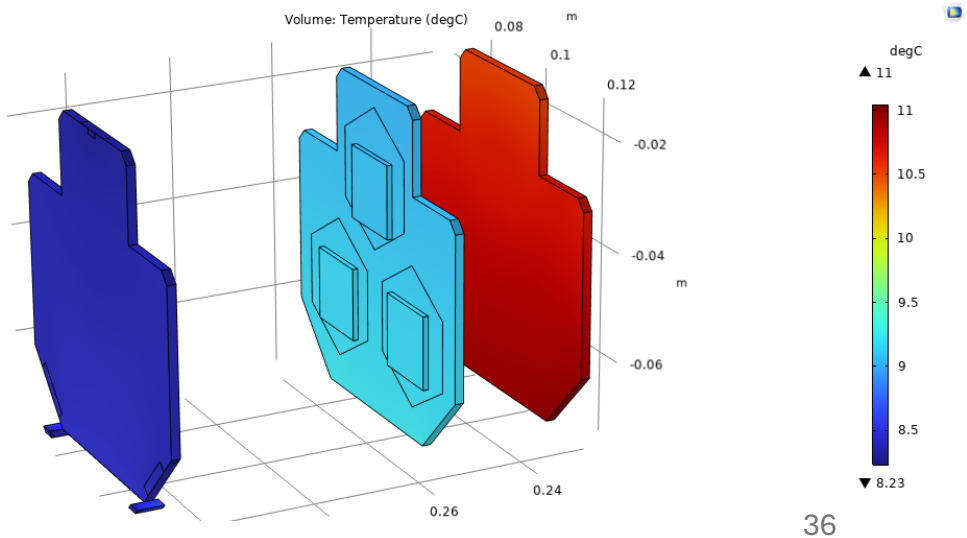


WINK – Thermal Simulation Results - Subsystems

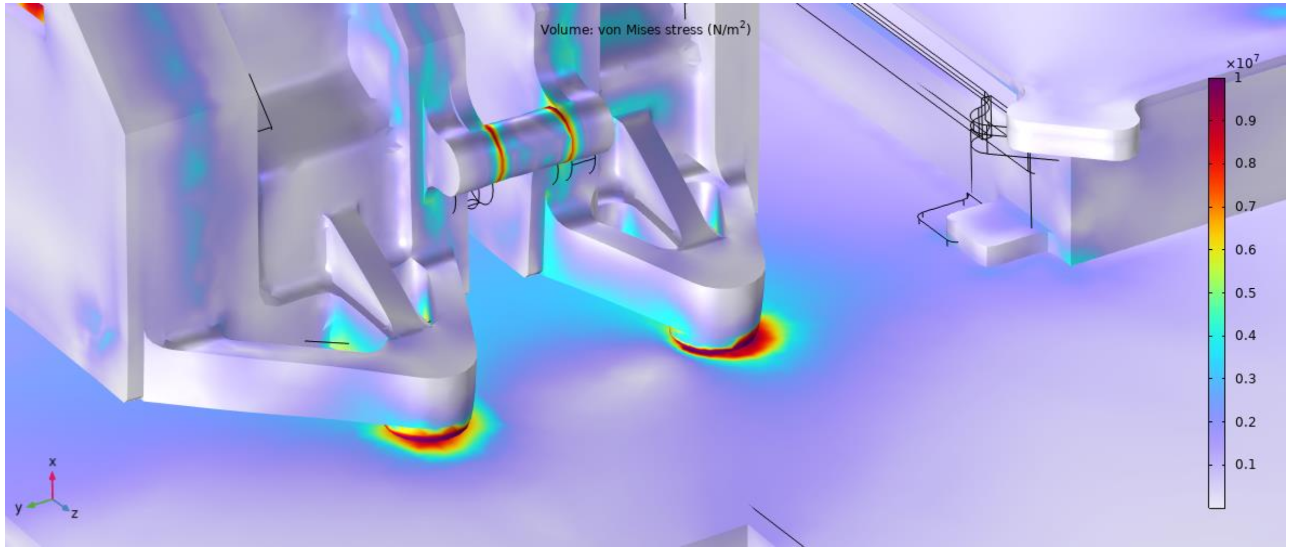


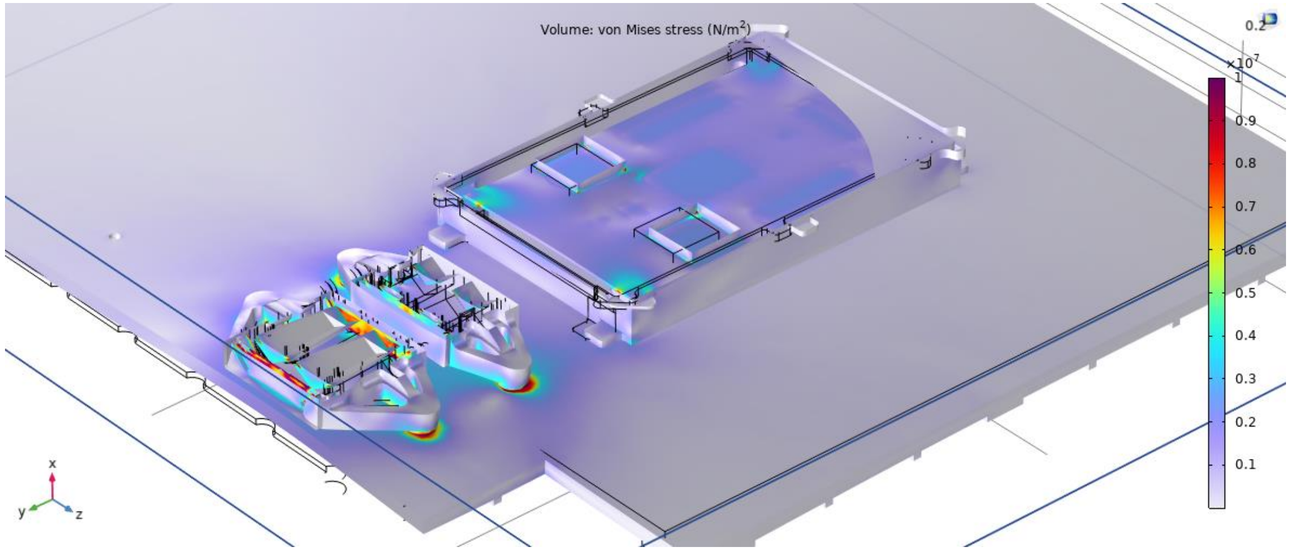


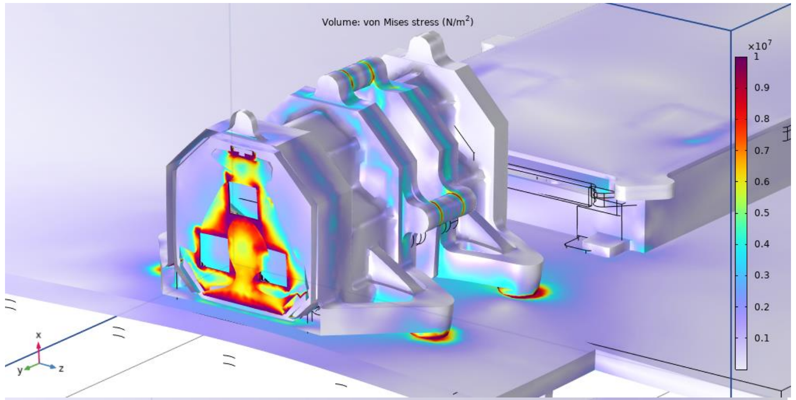


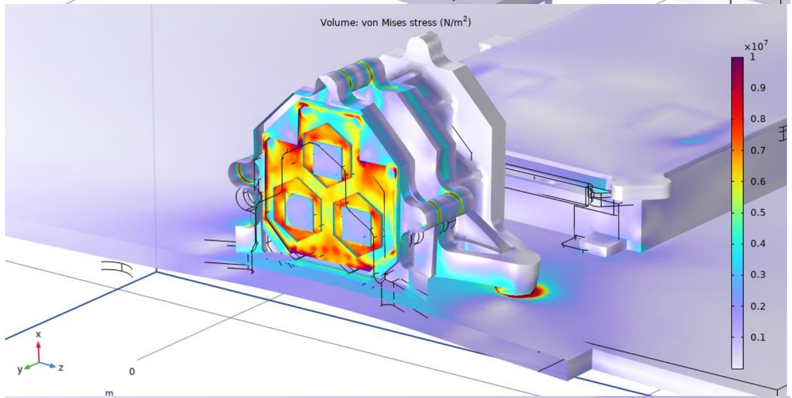


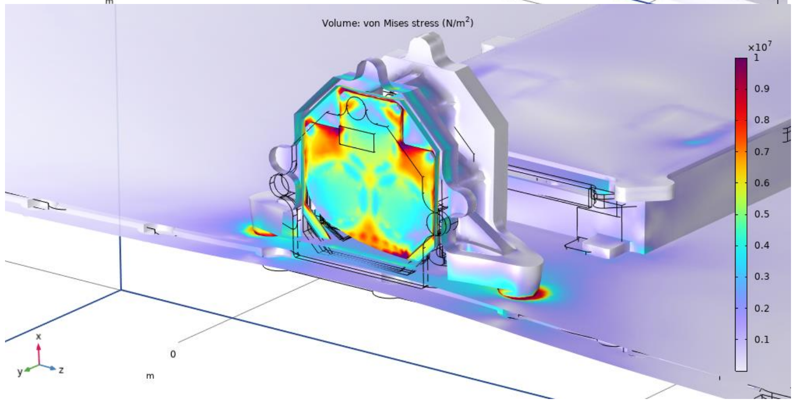
WINK – Thermal Simulation Results – Thermal Expansion



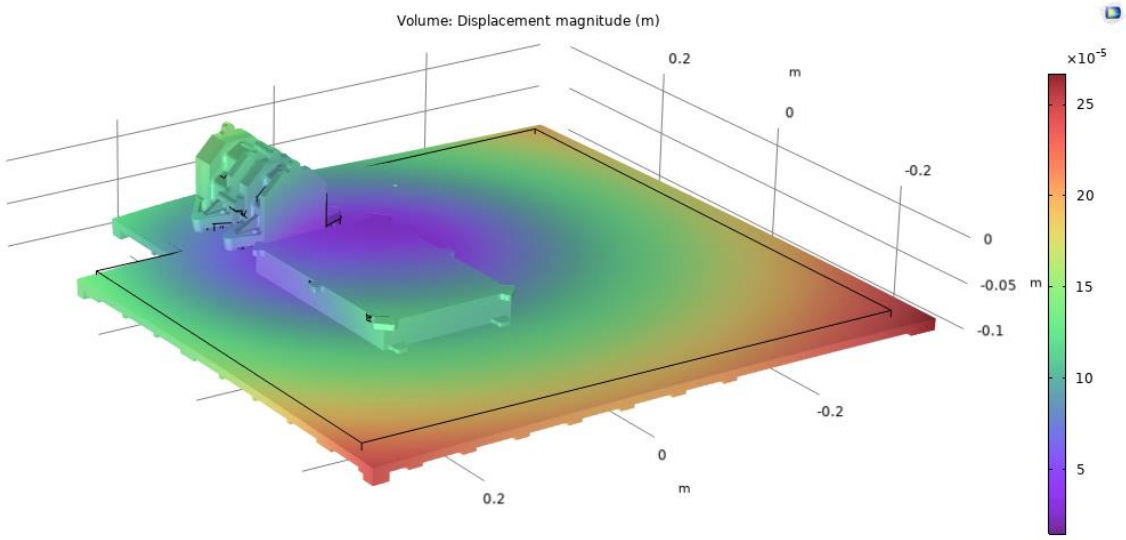


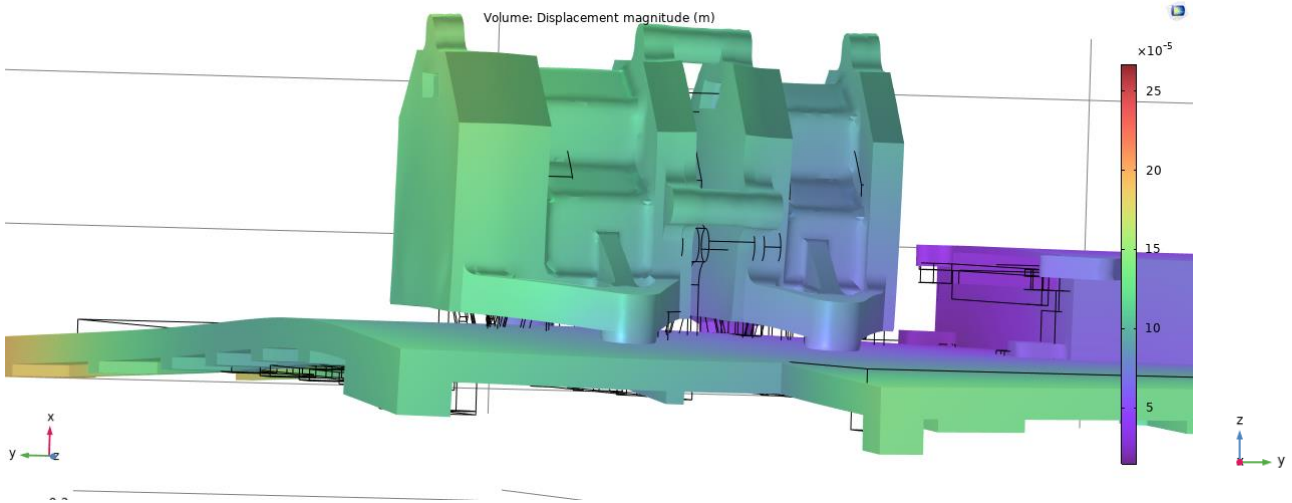


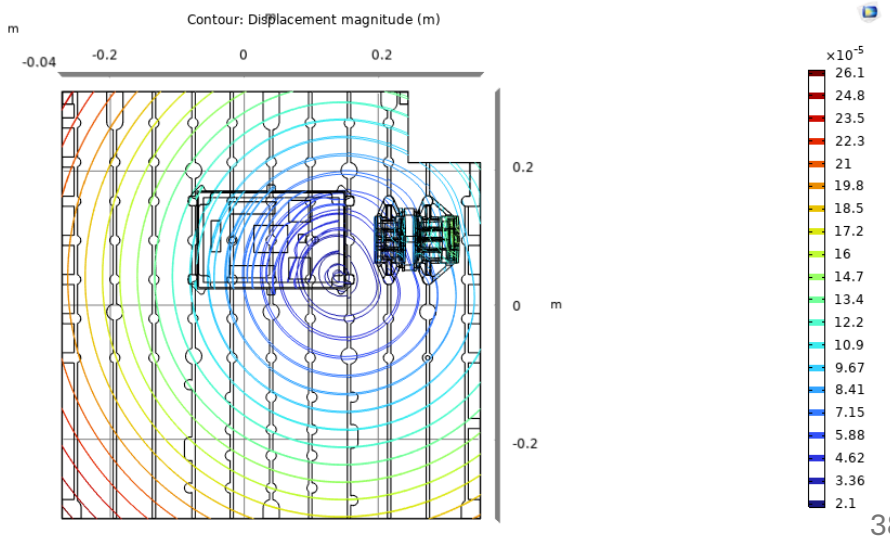




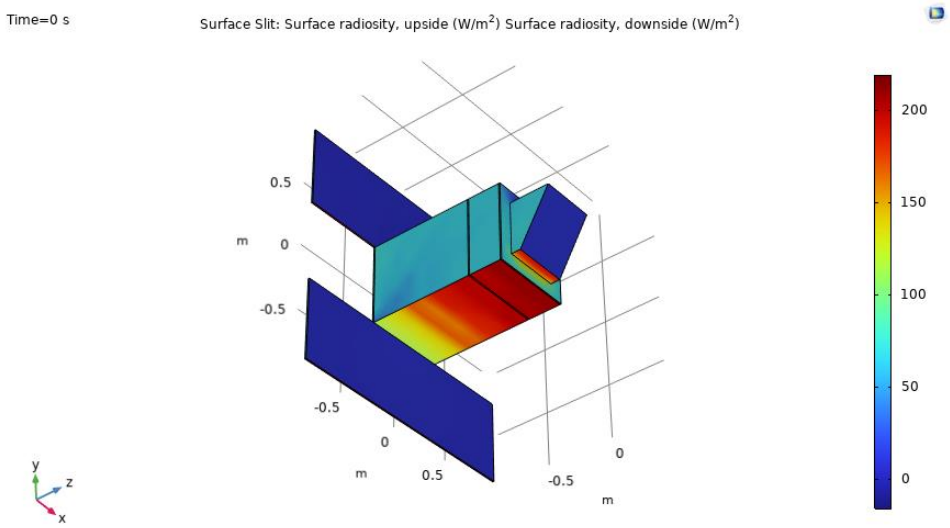
WINK – Thermal Simulation Results – Thermal Expansion

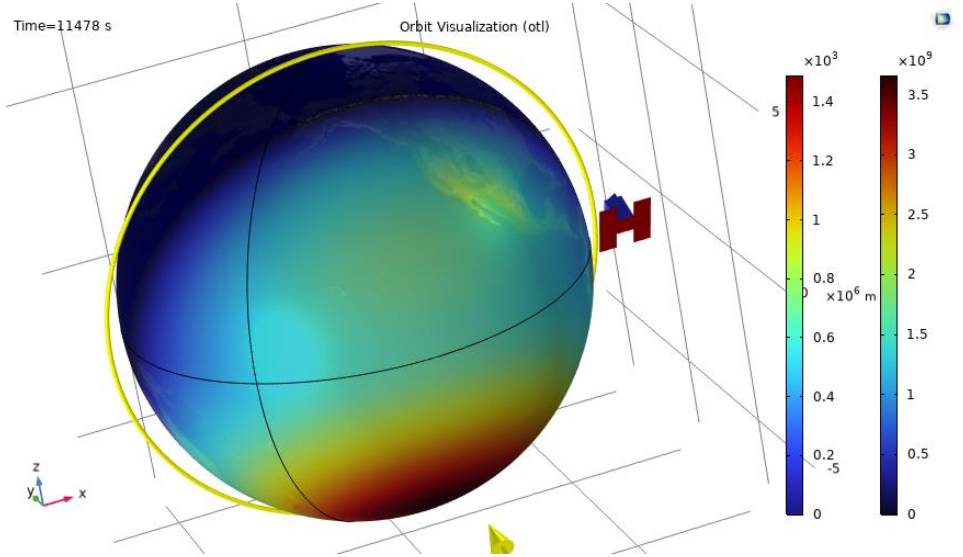


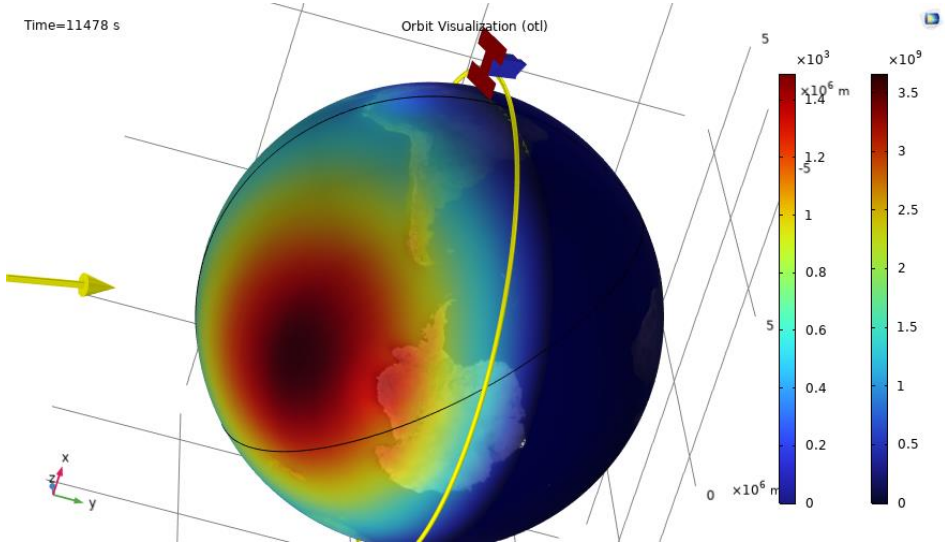


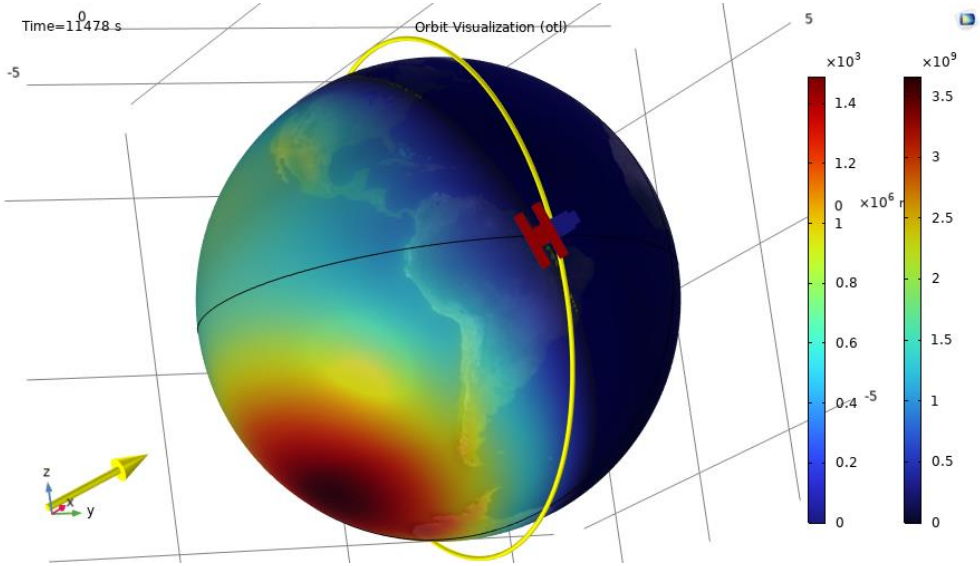


NUSES Orbital Simulation Results

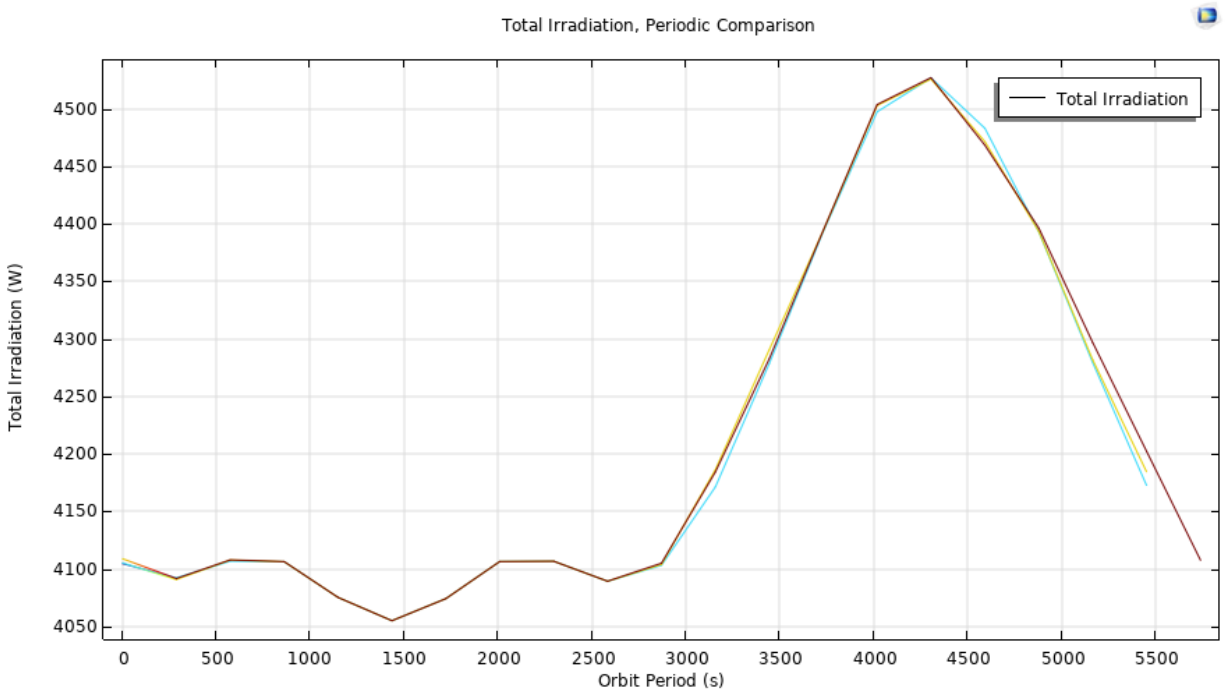


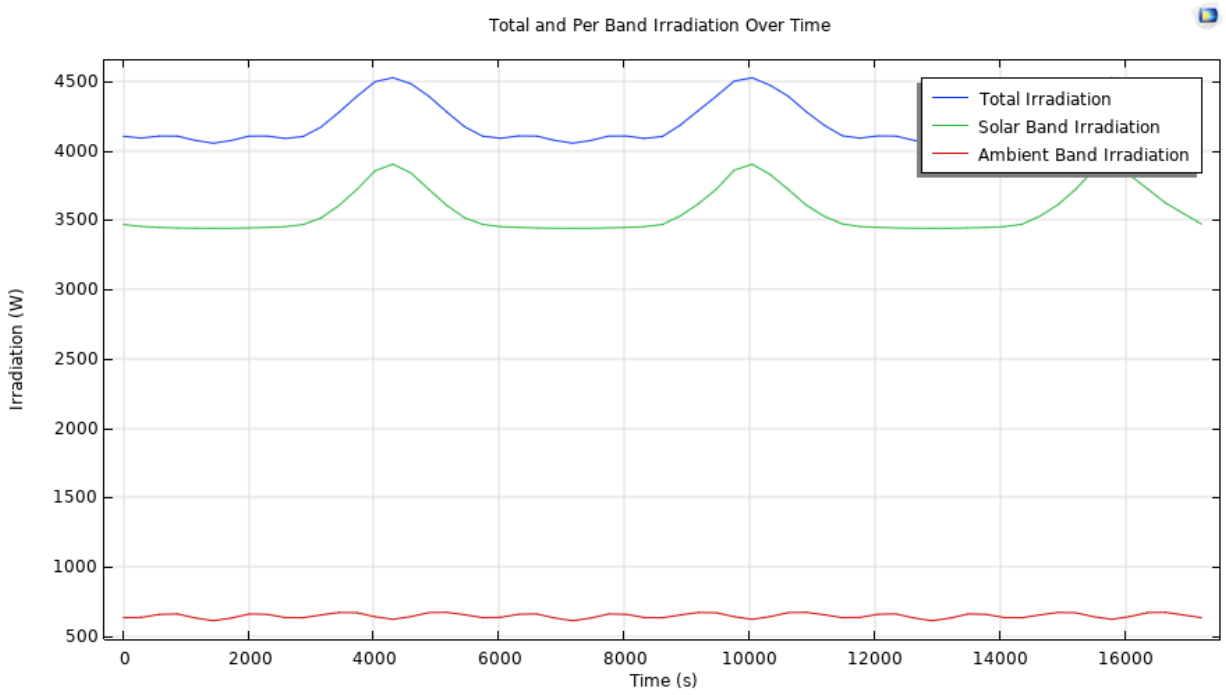




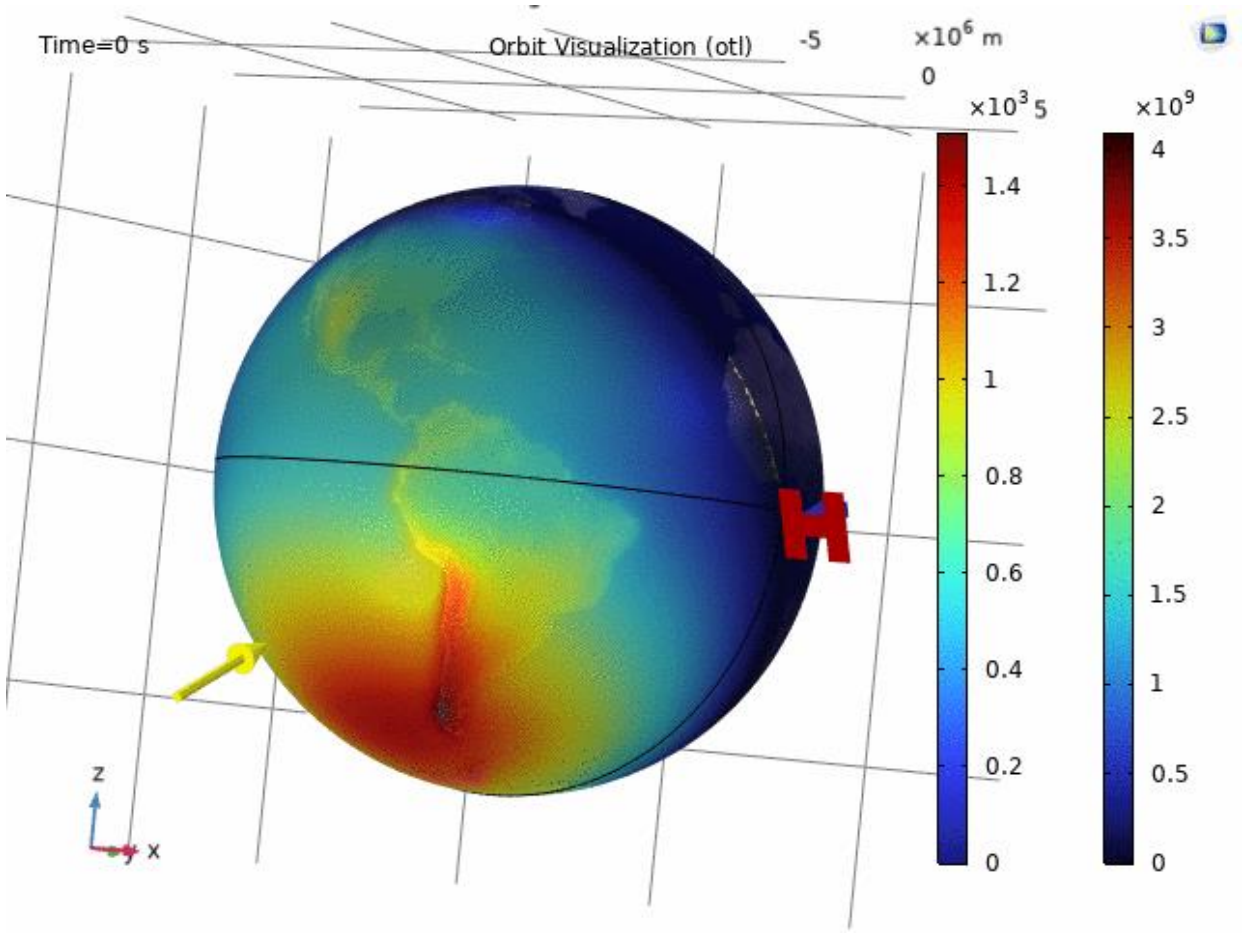


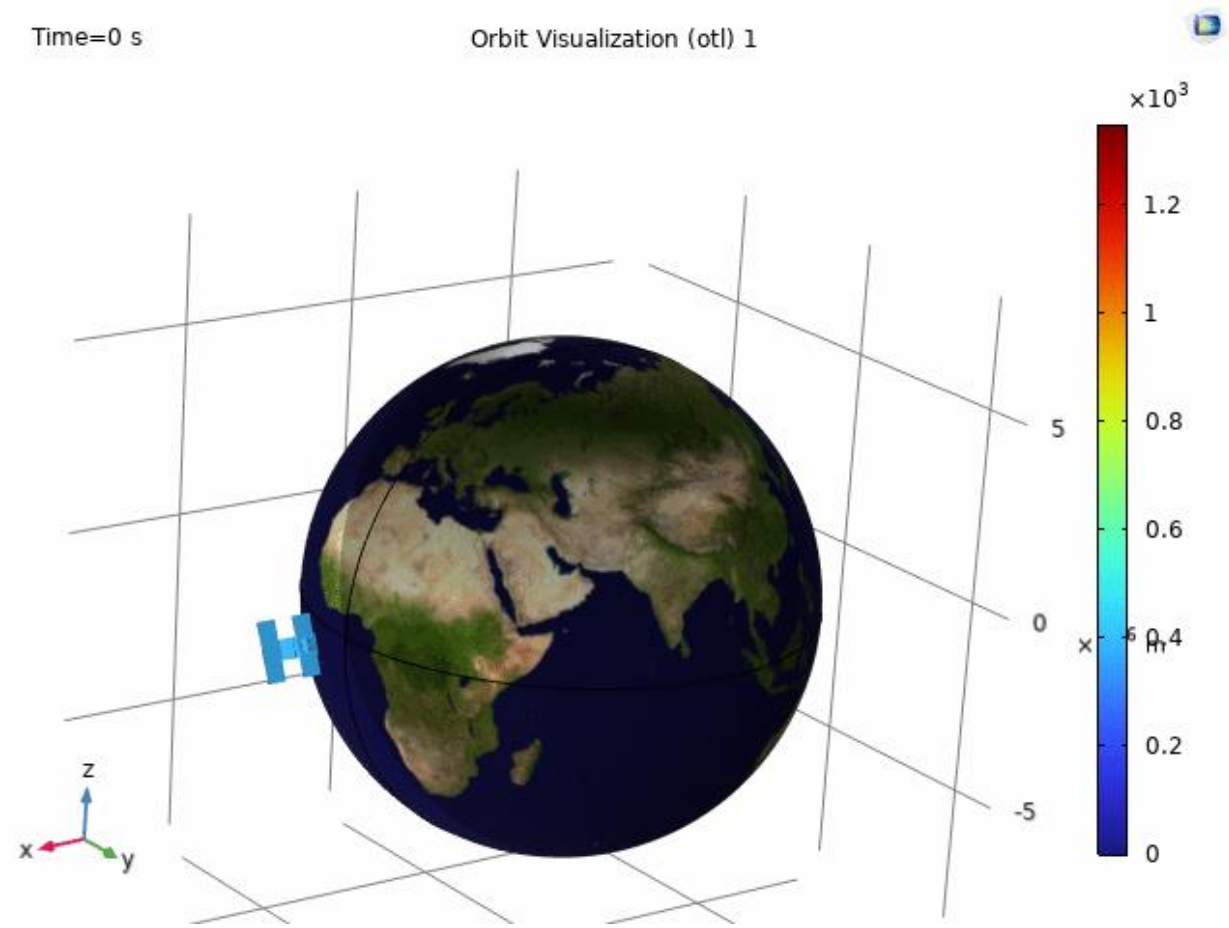
NUSES Orbital Simulation Results



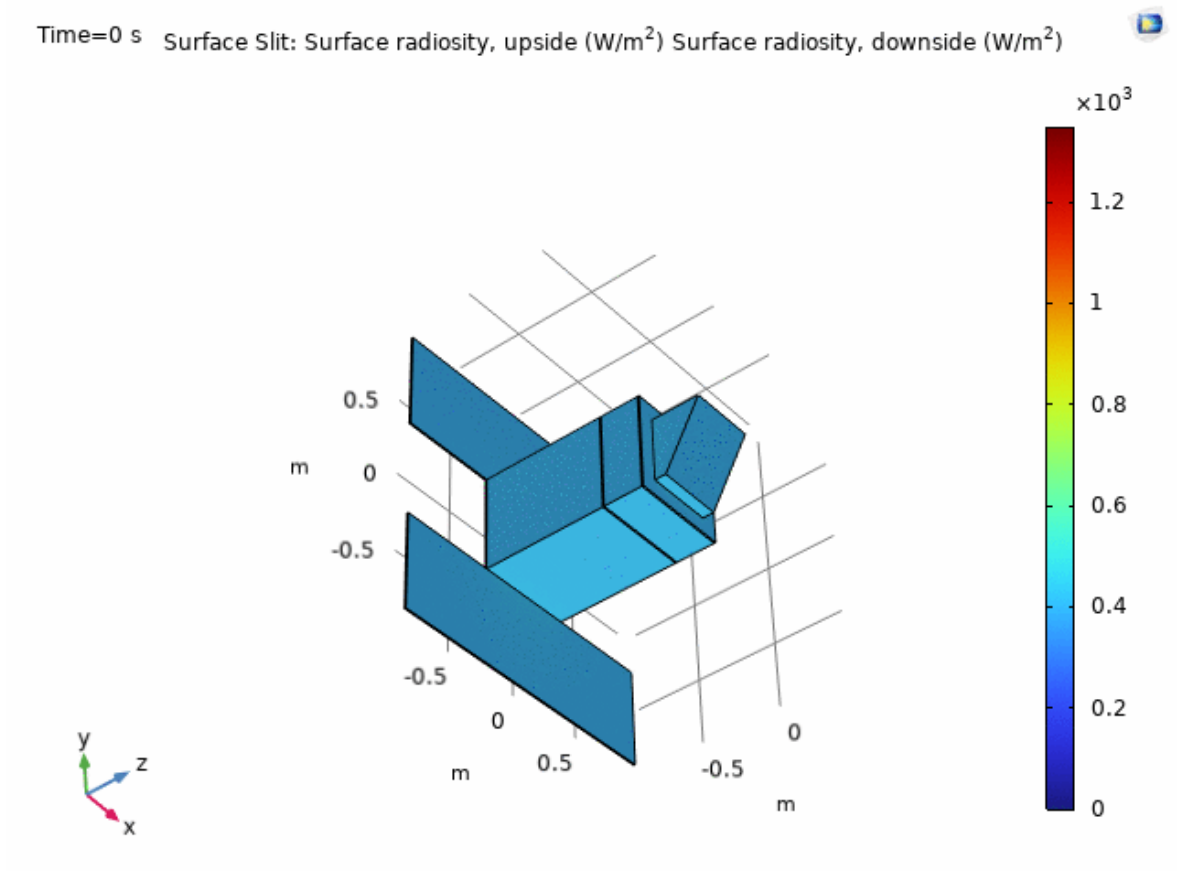


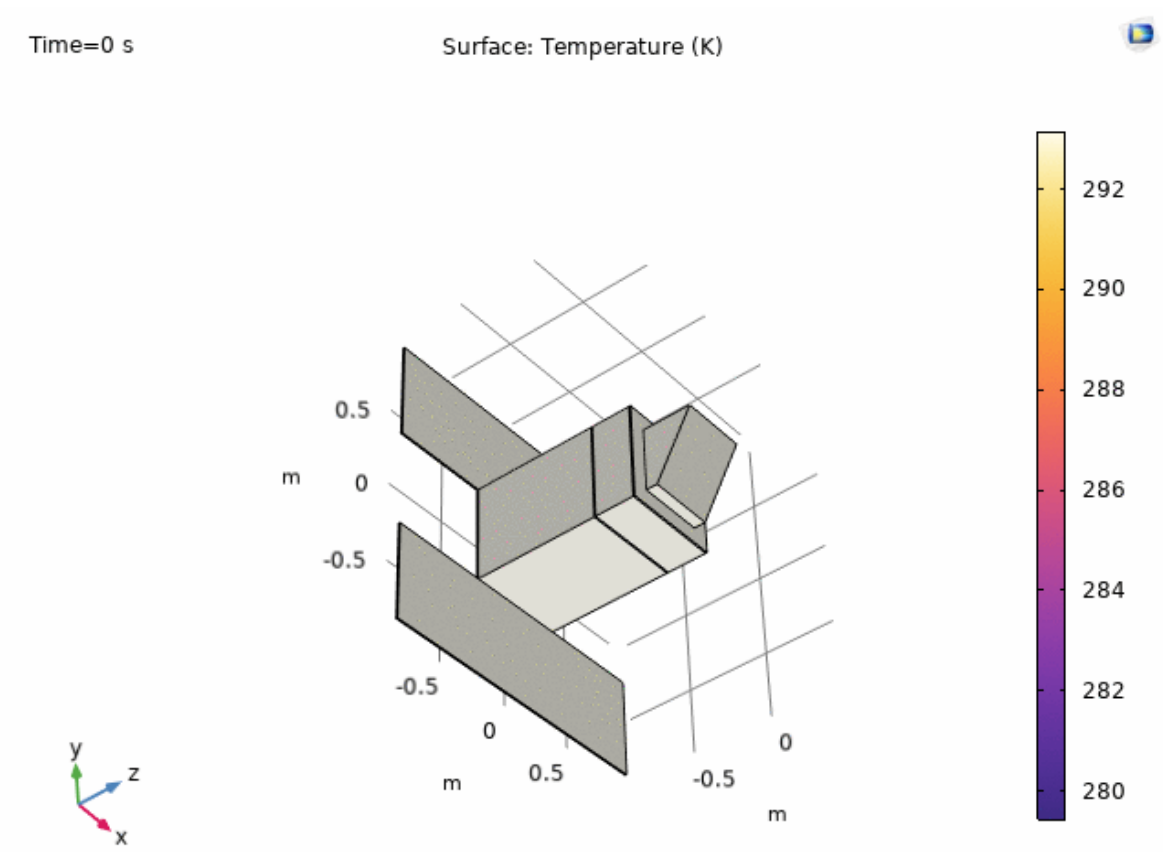
NUSES Orbital Simulation Results





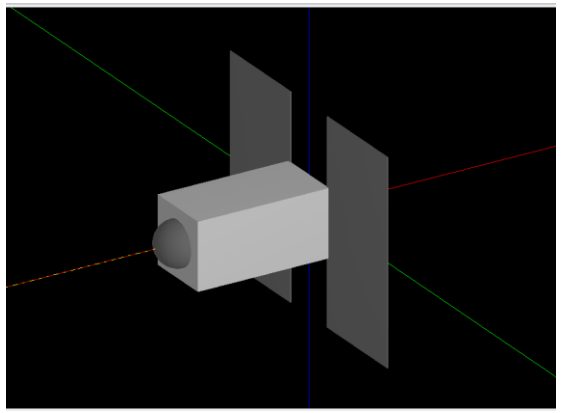
NUSES Orbital Simulation Results



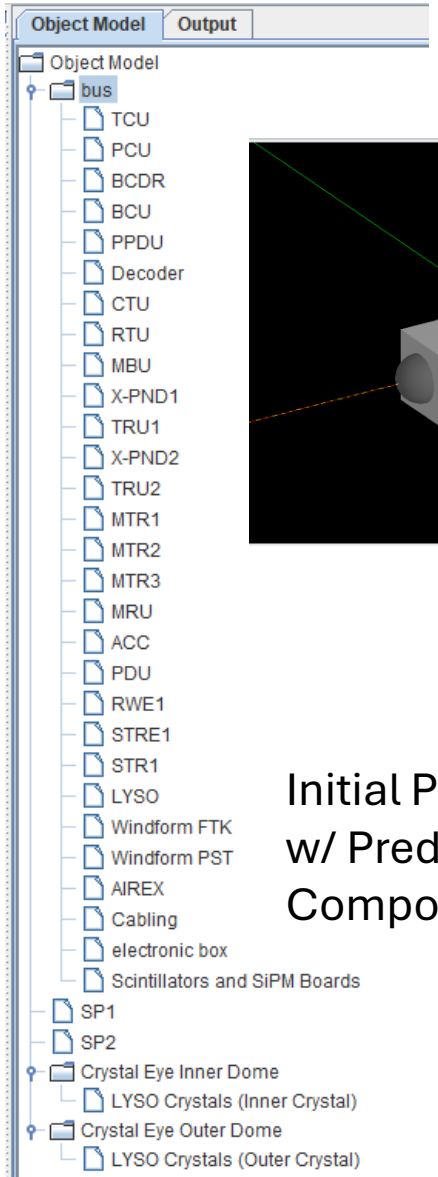


Crystal Eye Debris Assessment Reentry Analysis

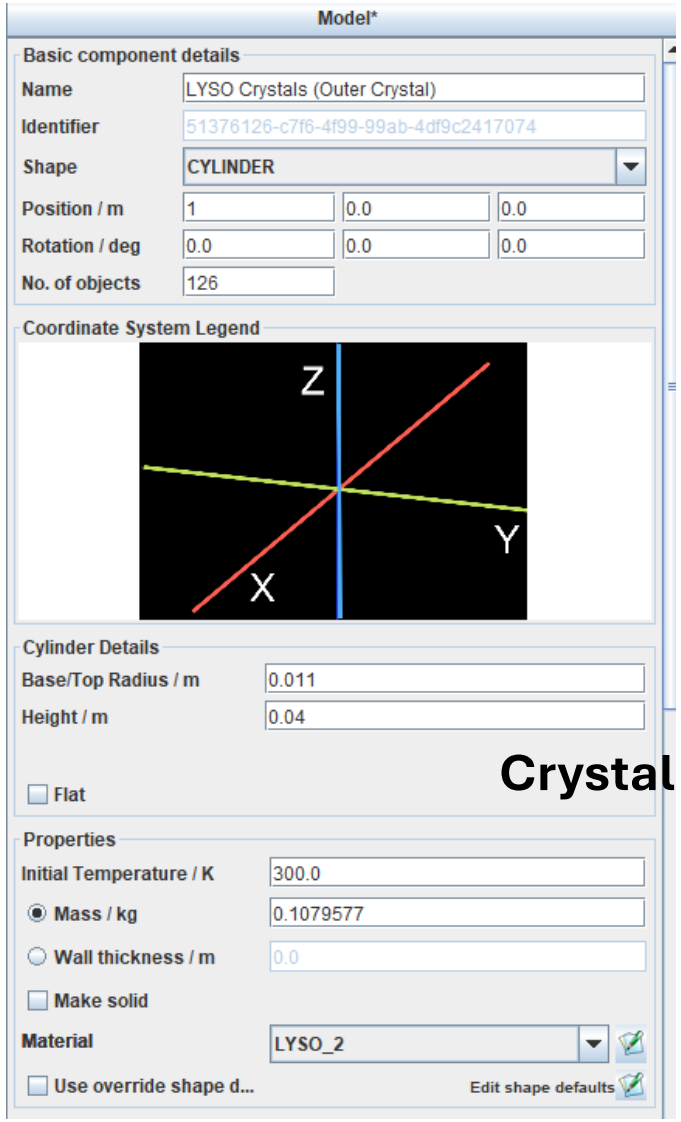
Satellite Model

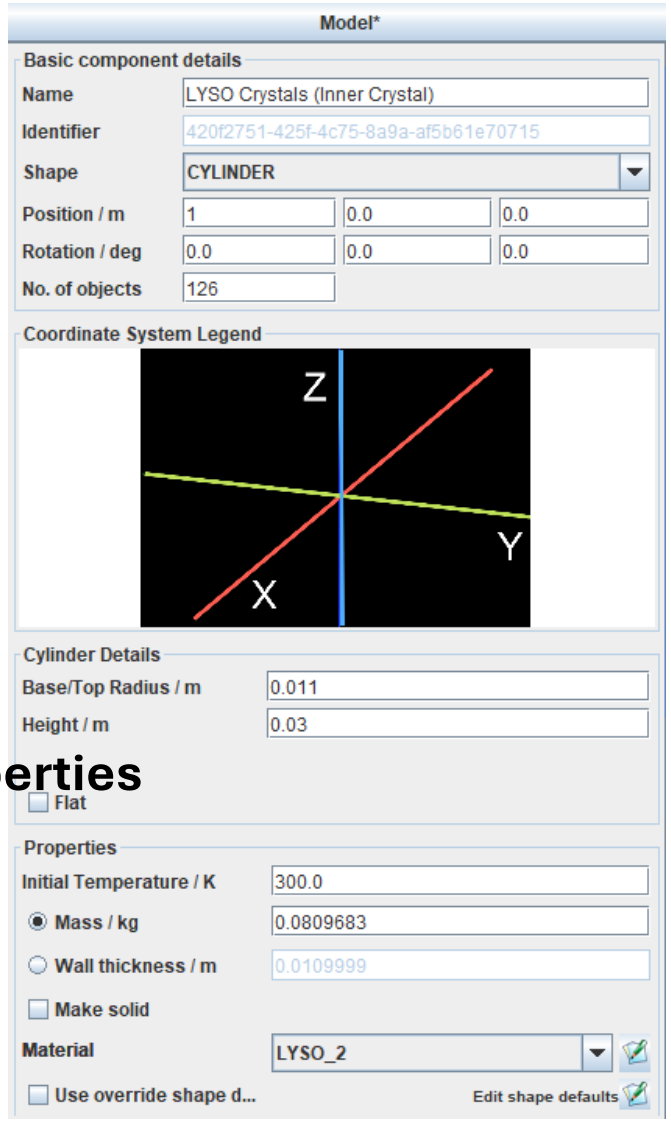


Initial Parameters w/ Predefined Components



Crystal Properties





Crystal Eye Debris Assessment Reentry Analysis

Heat Flux of 70k W/m2

Child release trigger

Temperature / K	2100
Altitude / m	78000.0
Heat flux / W/m^2	70000
Dynamic pressure / Pa	1000
Load factor / g	100

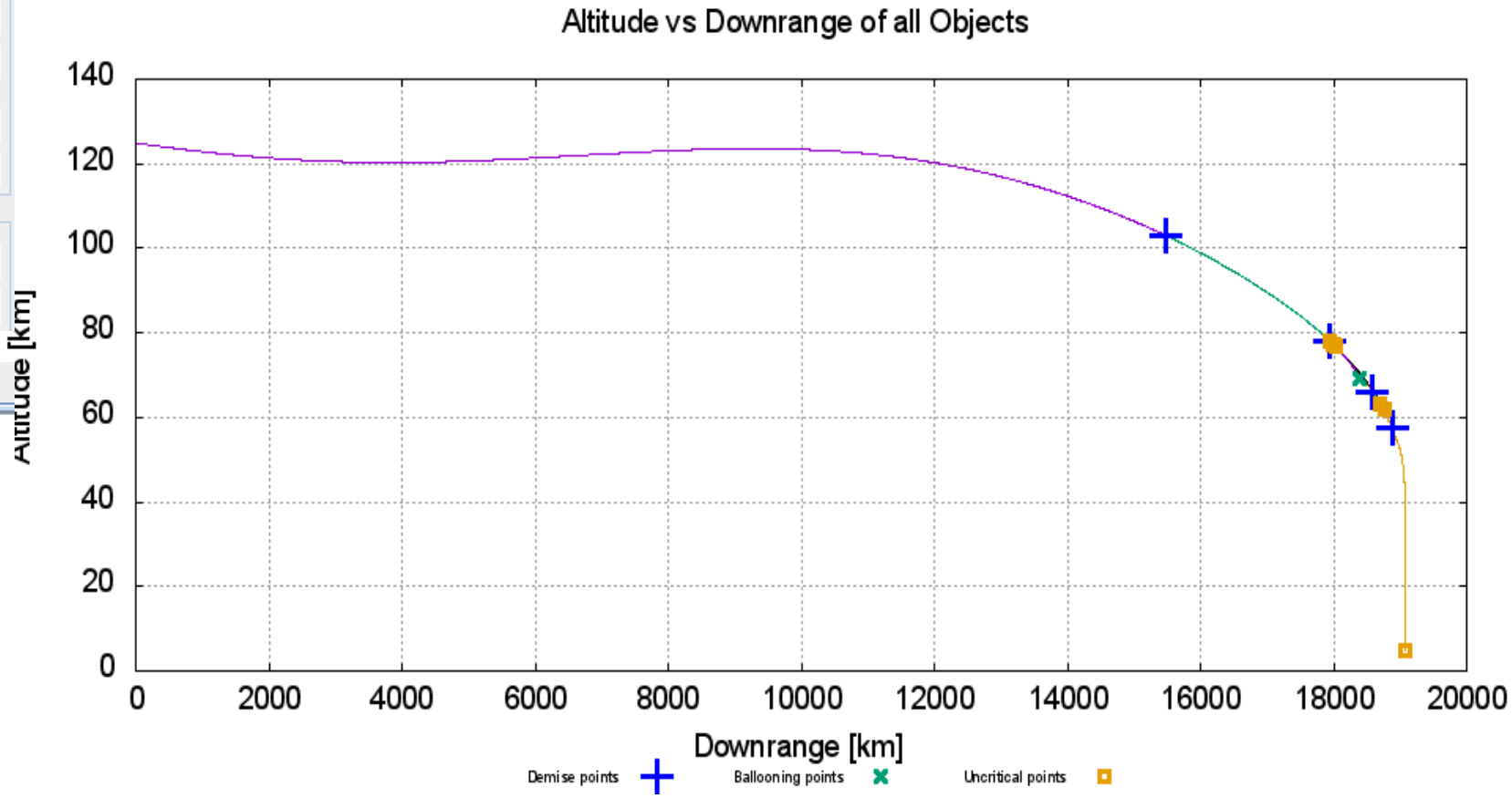
Explosion trigger

Temperature threshold ...	2000.0
Altitude threshold / m	78000.0

Object Model | Output

- Object Model
  - bus
    - Windform FTK
    - Windform PST
    - AIREX
    - Cabling
    - electronic box
    - Scintillators and SiPM Boards
  - SP1
  - SP2
  - Crystal Eye Inner Dome
    - LYSO Crystals (Inner Crystal)
  - Crystal Eye Outer Dome
    - LYSO Crystals (Outer Crystal)

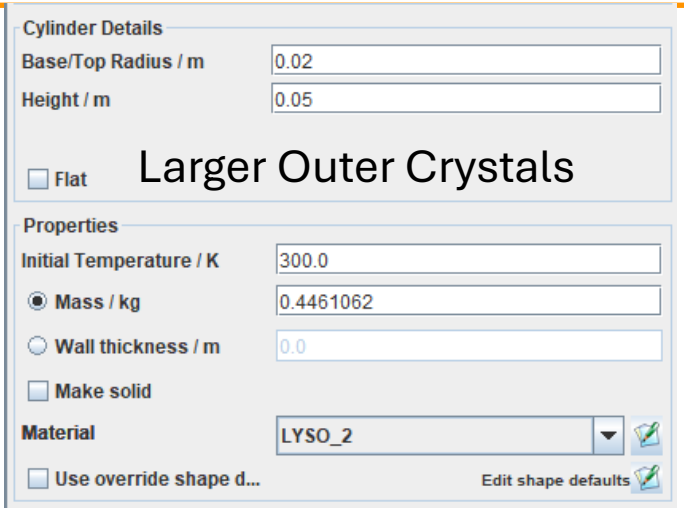
Adjusted component weights for a more realistic Crystal Eye satellite



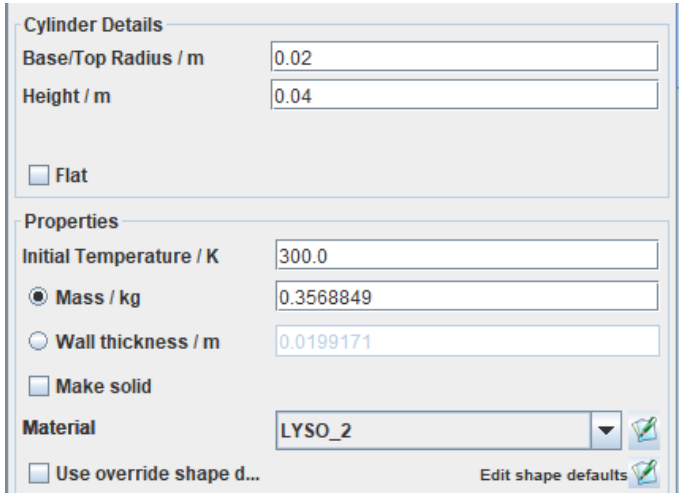
Reduced Components

No Impact!

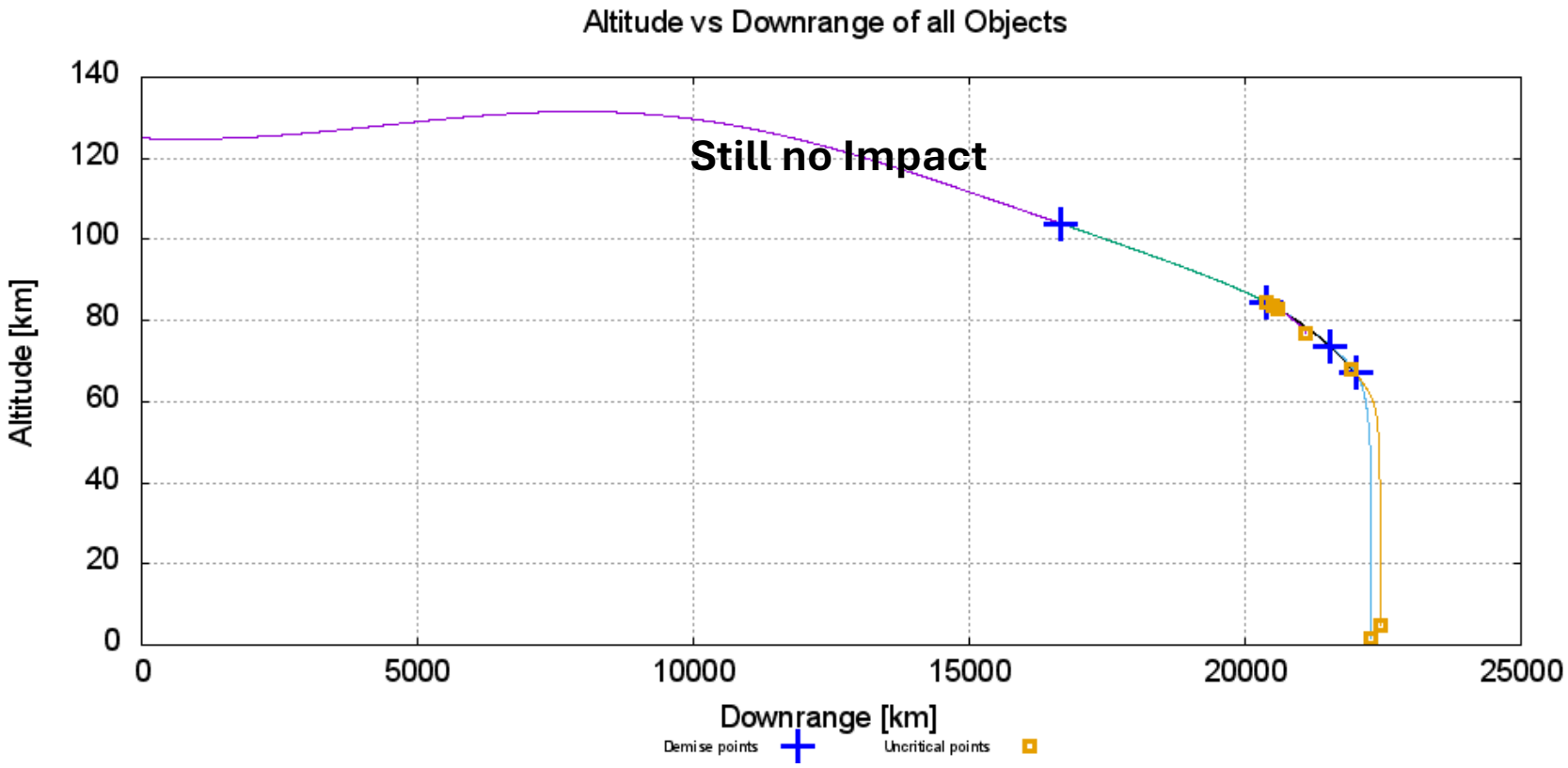
Crystal Eye Debris Assessment Reentry Analysis

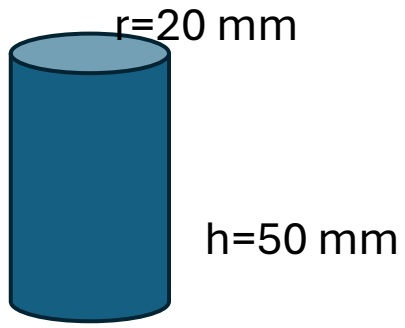


Larger Outer Crystals



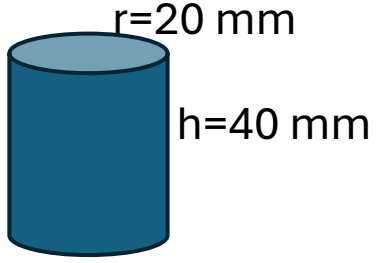
Larger Inner Crystals





Outer Crystals

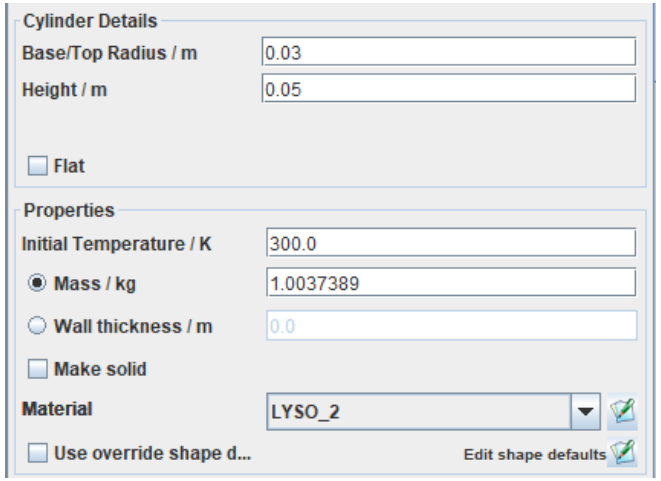
MAX Dimensions for non-impact scenario

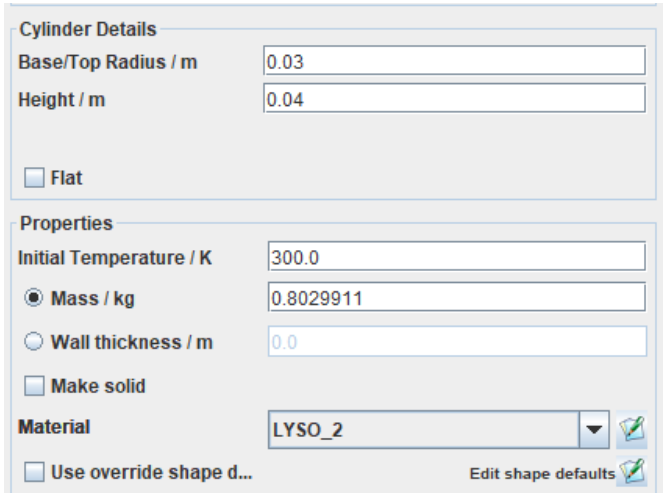


Inner Crystals

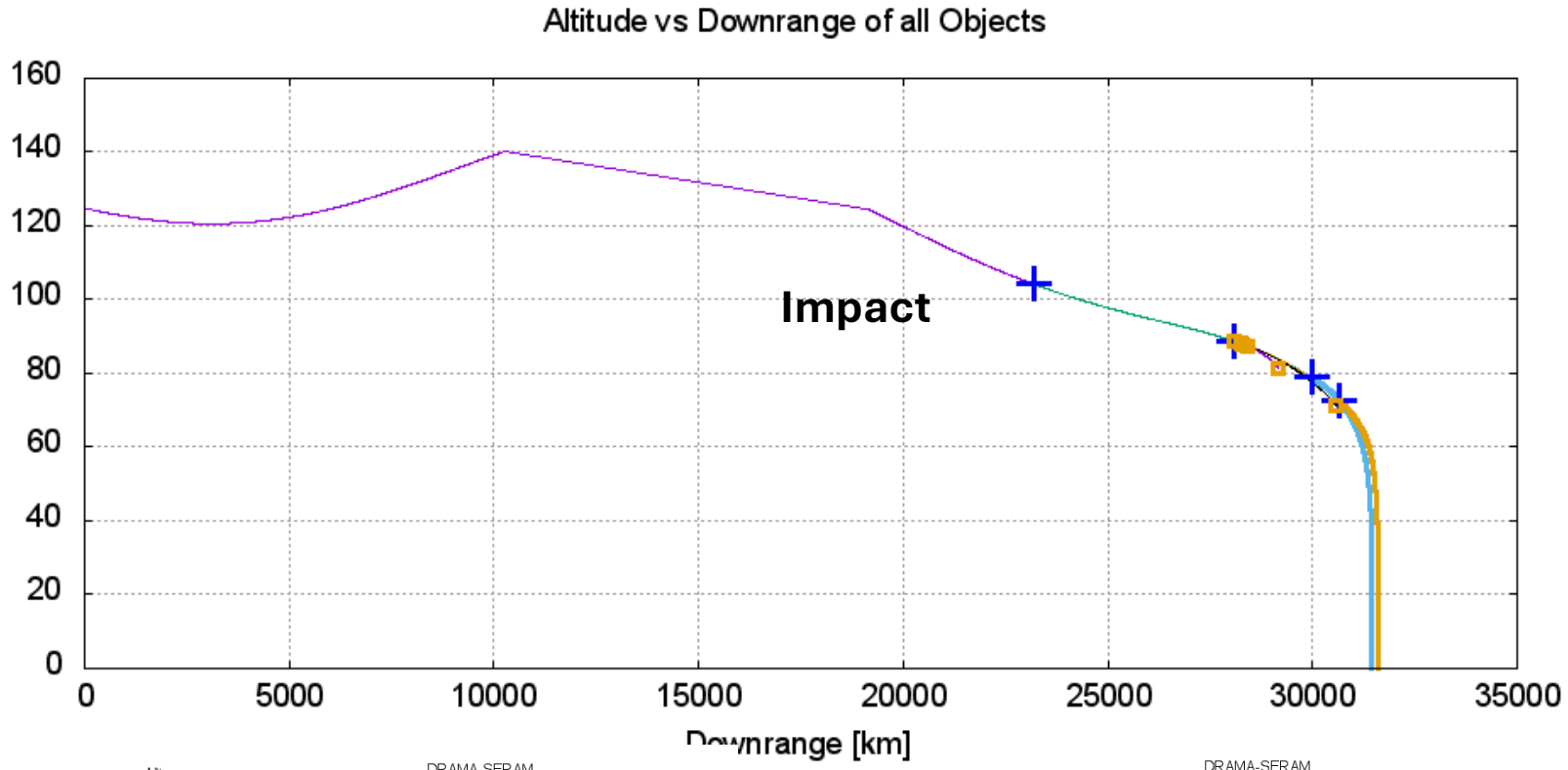
Crystal Eye Debris Assessment Reentry Analysis

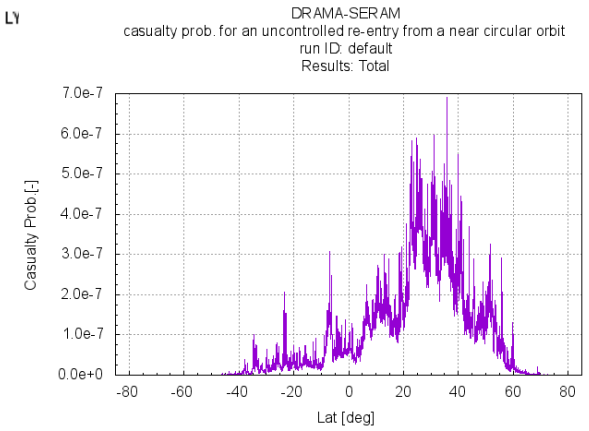
Larger Outer Crystals

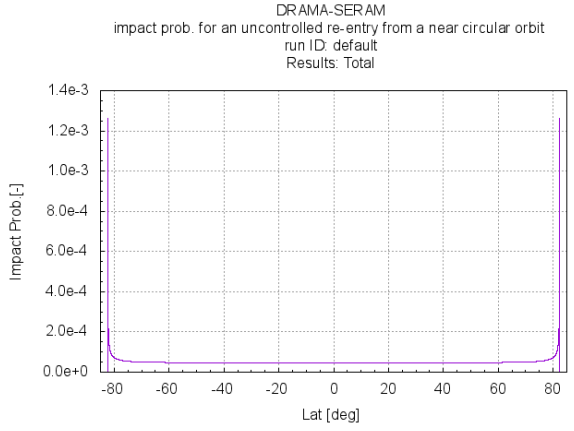




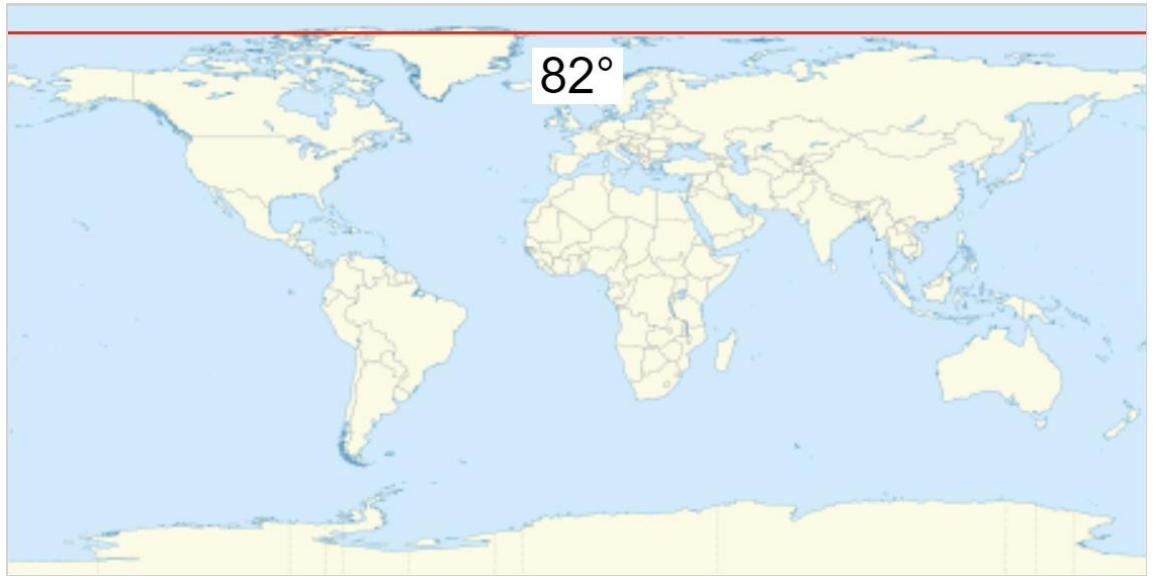
Larger Inner Crystals

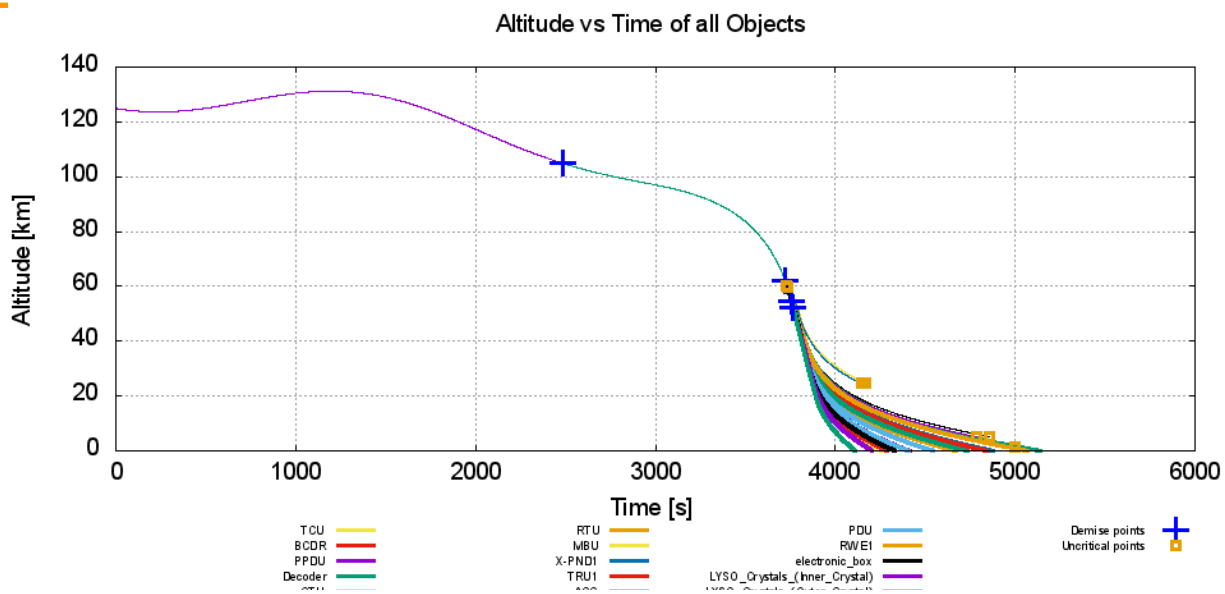


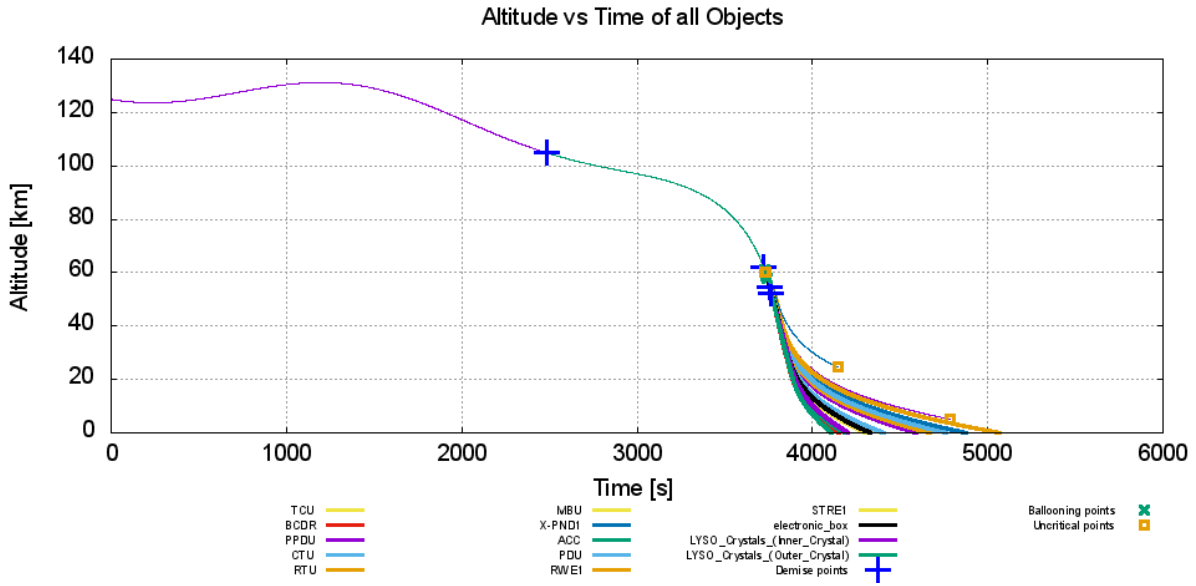




Crystal Eye Debris Assessment Reentry Analysis



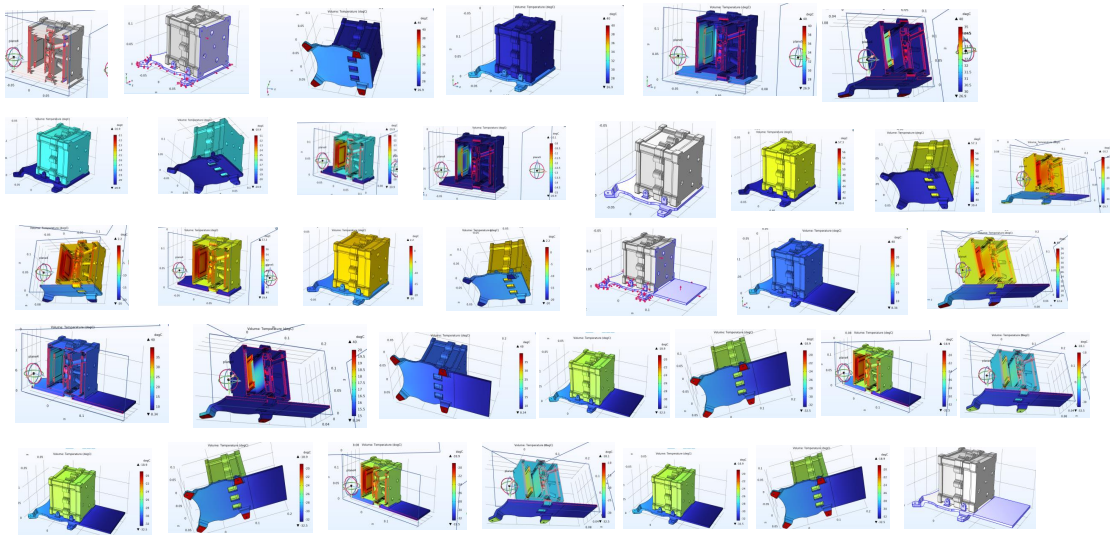




Conclusion & Future Work

Summary of Findings:

•Robust thermal management for Zirè, LEM, and WINK.
•Simulations demonstrated effective heat dissipation and temperature control.
•Flexible capabilities of COMSOL Multiphysics



Key Takeaways:

•Passive cooling and material selection were critical.
•Thermal decoupling ensured minimal thermal stress.

Future Analysis:

•***Thermal vacuum tests***
•***Ensuring results with other analysis software***
•***Update on thermal model for more robust results***
•***Combining thermal results of different projects into one thermal approach***

Questions & Answers

Thank you for your attention!

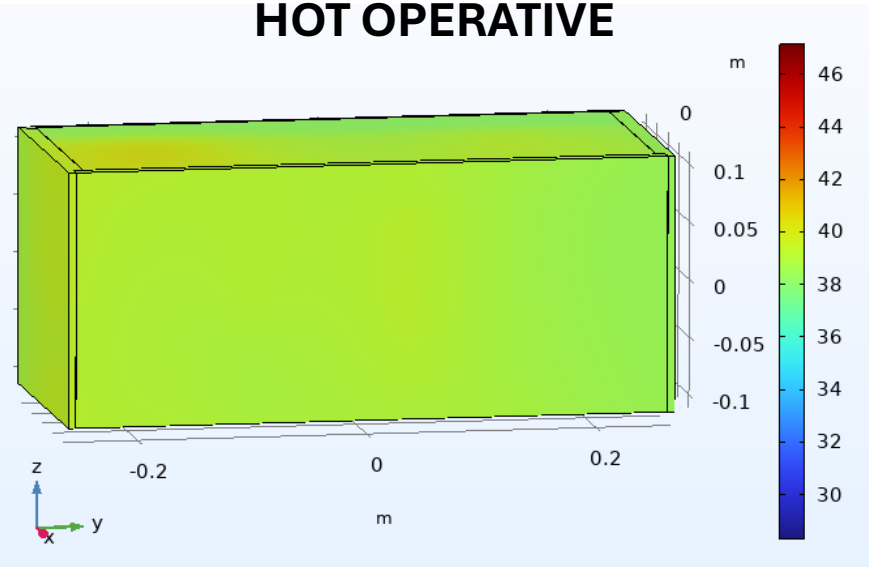
Backup

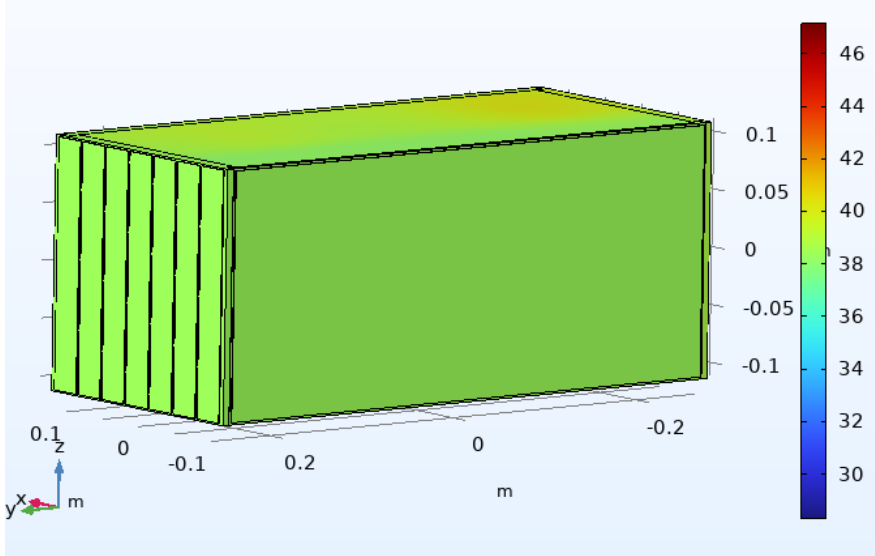
Electronic Box – Model Boundary Conditions- Power Distribution & Thermal Contact Interfaces

Component	Hot Operative Power (W)	Cold Operative Power (W)
Zirè Concentratore Hot	9	9
Zirè Concentratore Cold	0	0
FTK1	7	0
Zirè DAQ_r	0	0
LEM1	5.5	0
FTK2	7	0
Calog	5.5	0
LEMCold	0	0
FTK3	7	0
PST1	4	0
PST2	4	0
FTK4	7	7
PianoB1	7	7
PianoB4	7	7
PianoB2	7	7
Terzina Concentratore Hot	9	9
Terzina Concentratore Cold	0	0
PianoB3	7	7
Power HOT	23.89	14
Power Cold	0	0
Total Power	**116.89**	**60**

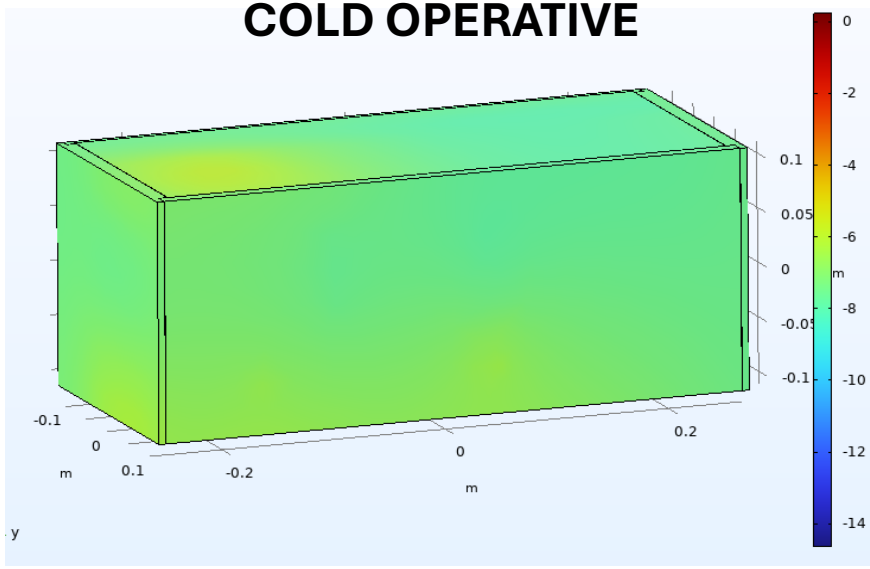
Electronic Box – Thermal Simulation Results

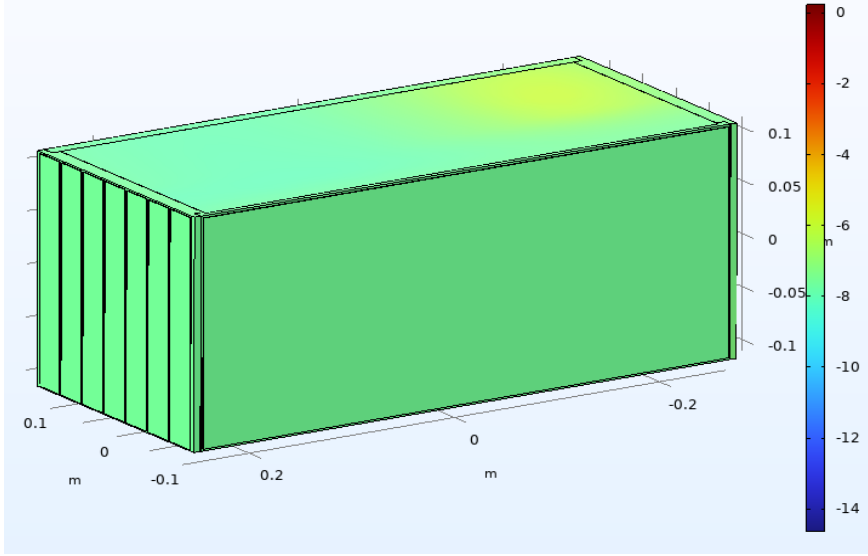
HOT OPERATIVE





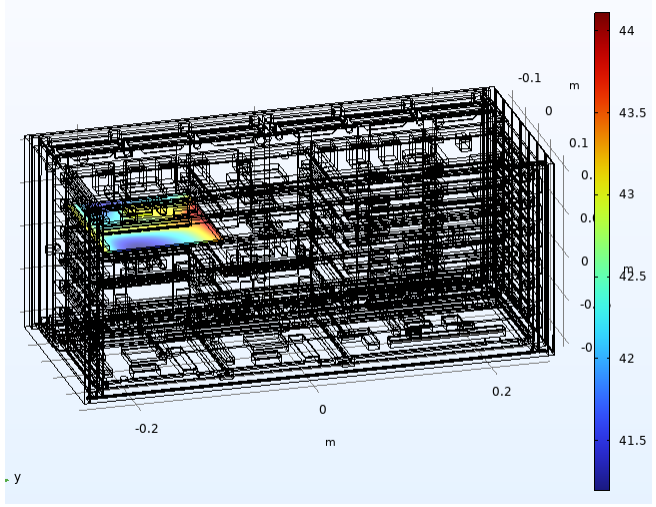
COLD OPERATIVE

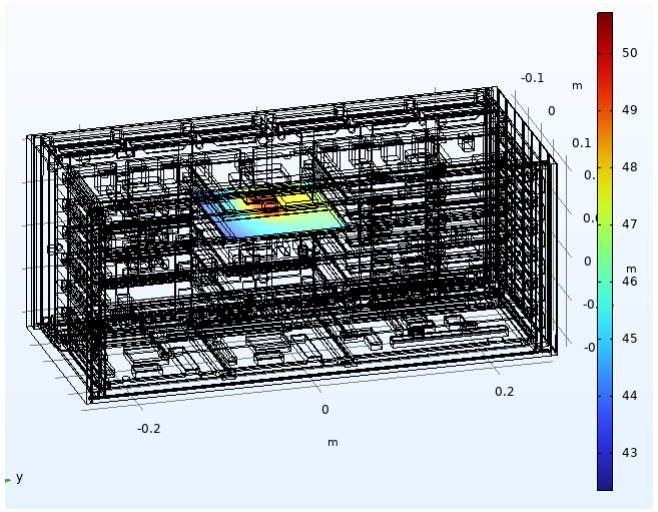


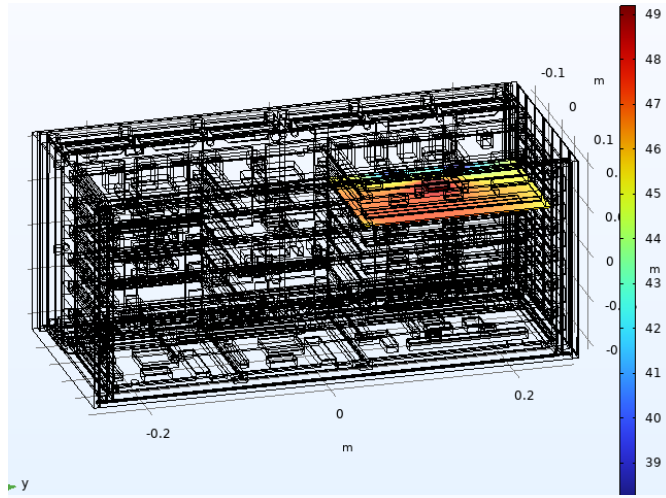


Electronic Box – Thermal Simulation Results

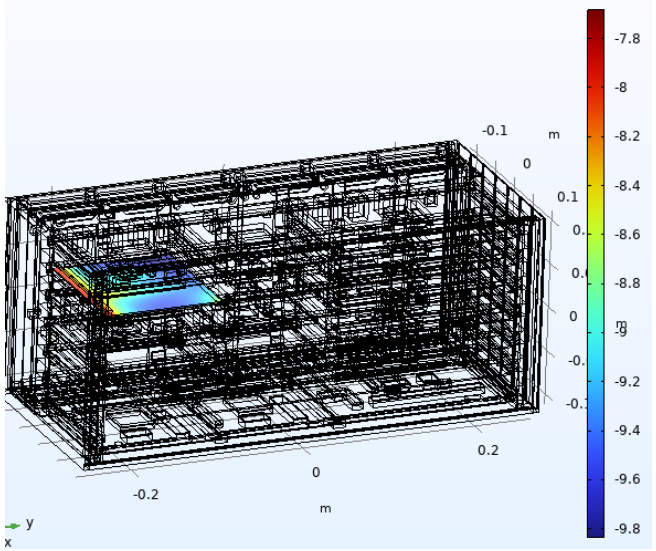
HOT OPERATIVE

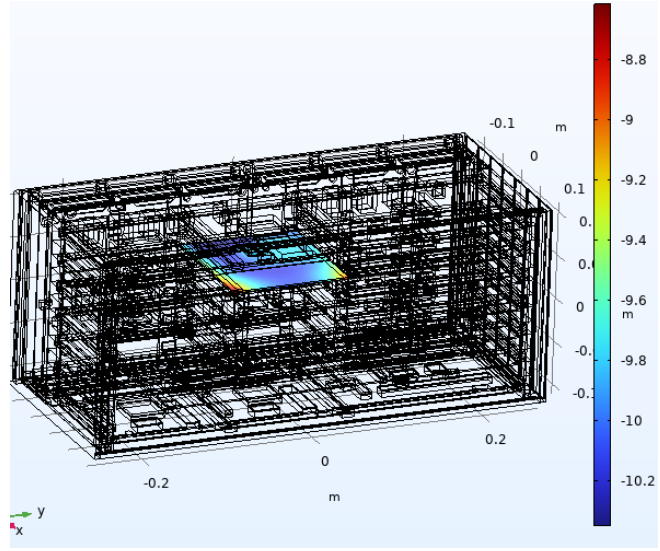


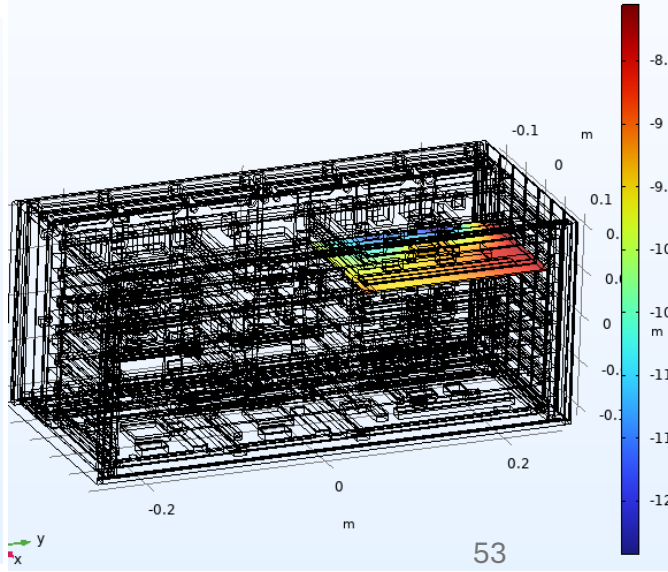




COLD OPERATIVE

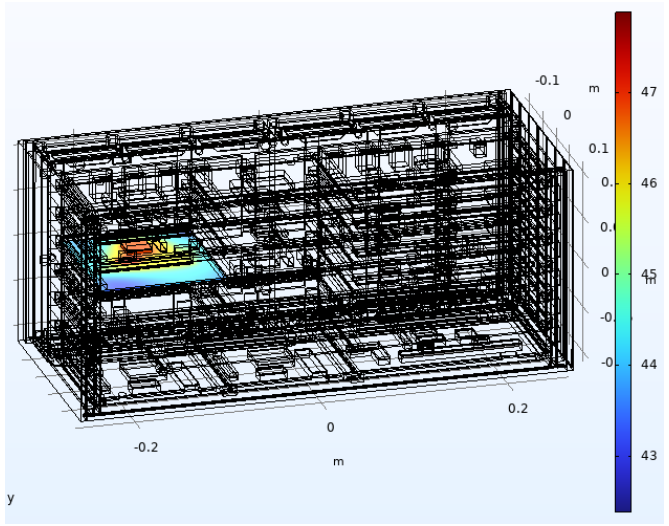


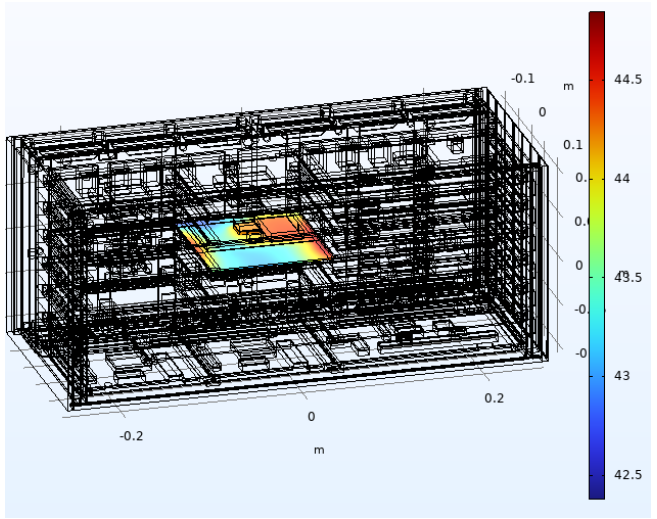


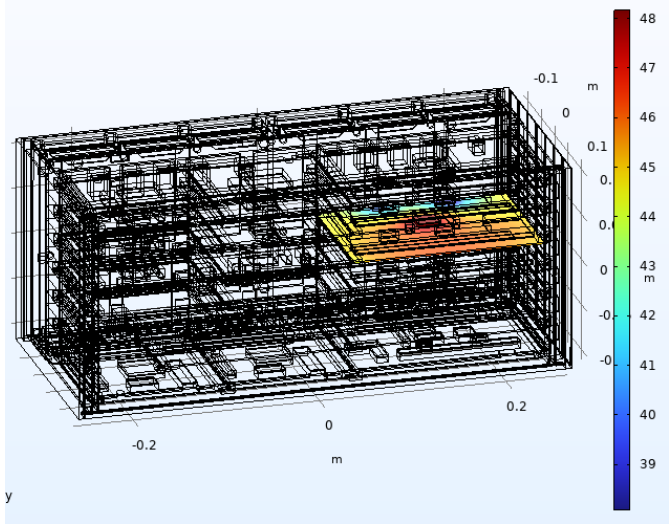


Electronic Box – Thermal Simulation Results

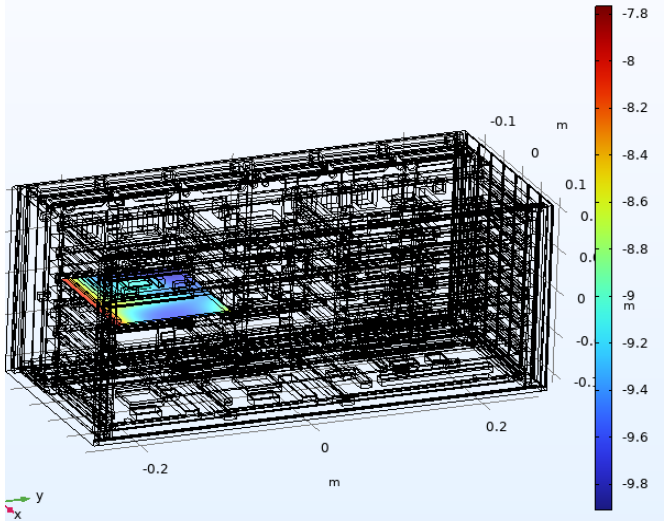
HOT OPERATIVE

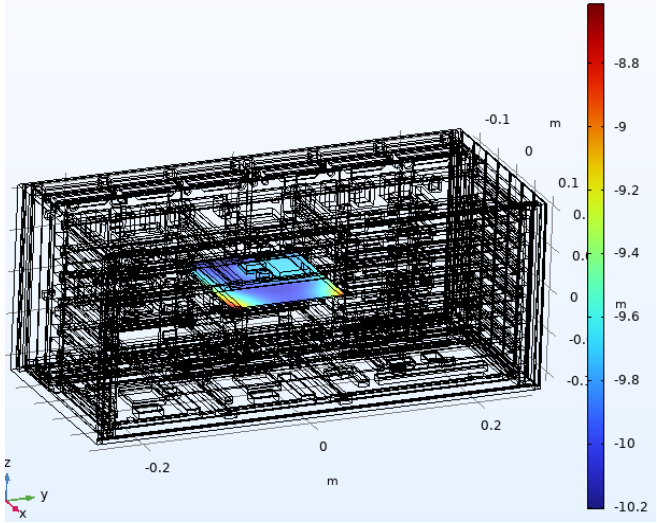


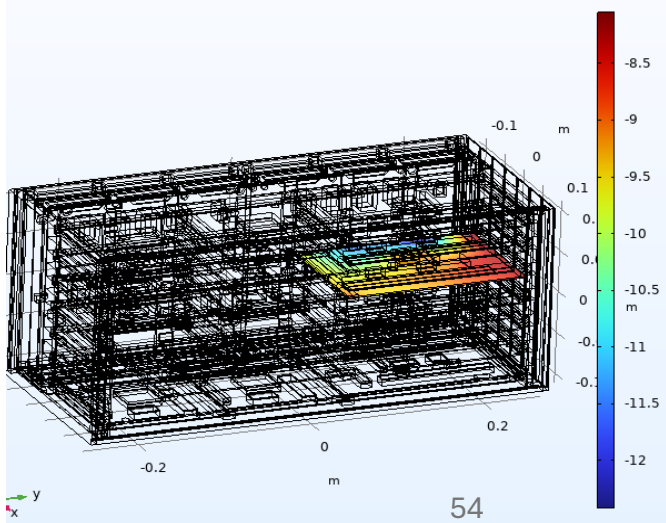




COLD OPERATIVE

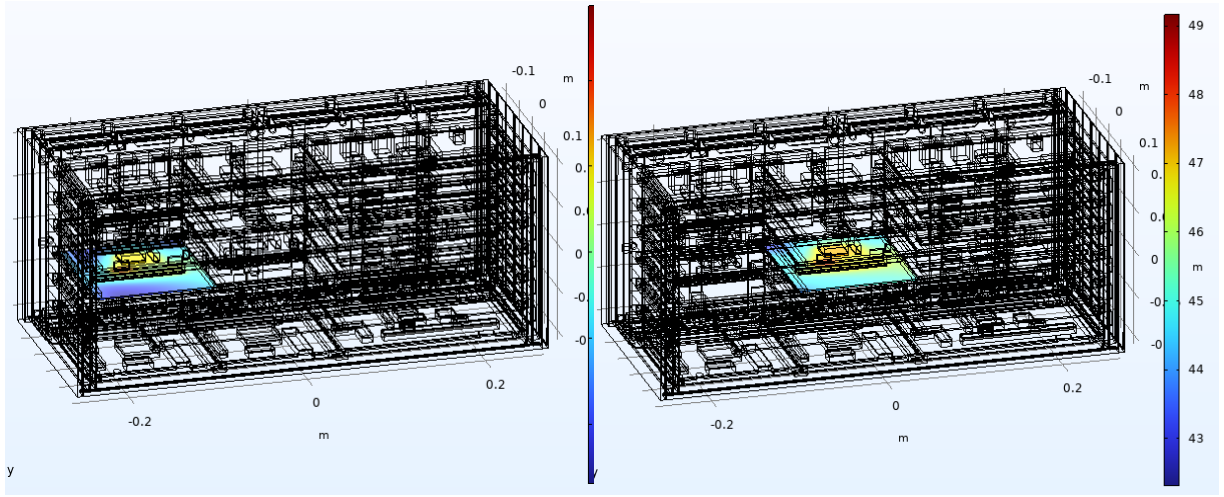


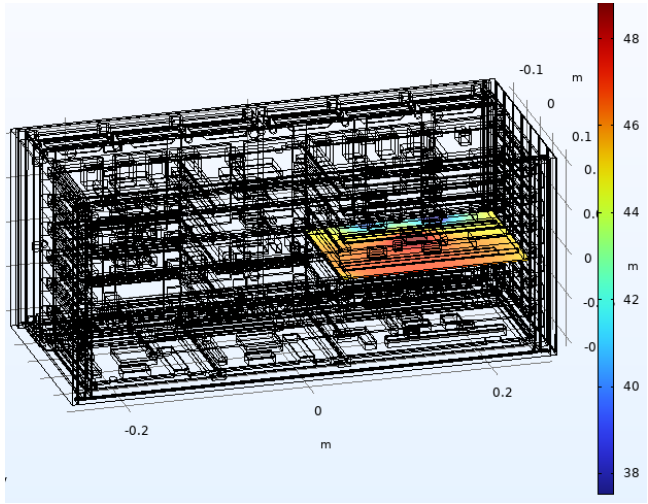




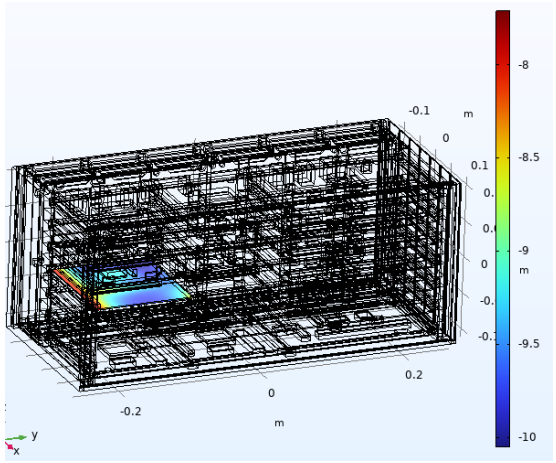
Electronic Box – Thermal Simulation Results

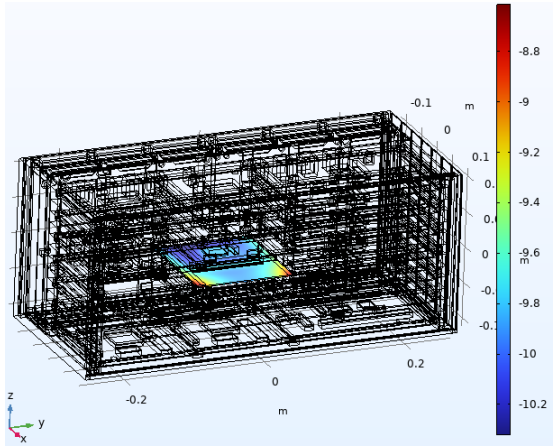
HOT OPERATIVE

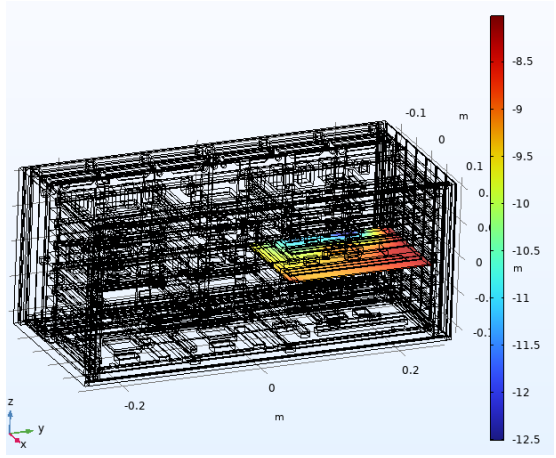




COLD OPERATIVE

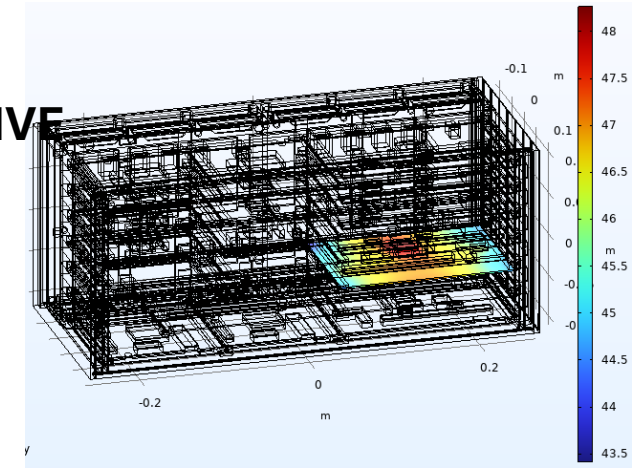


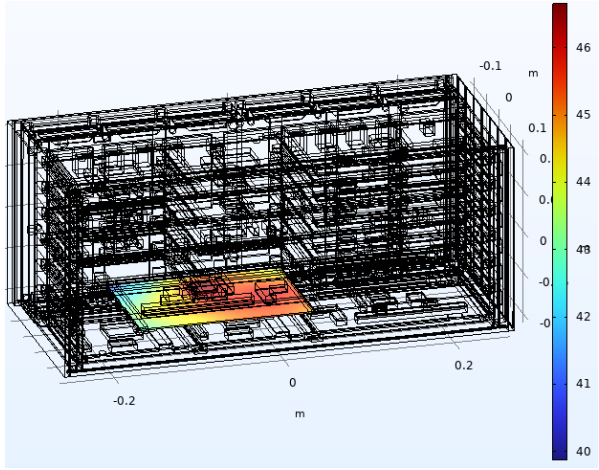


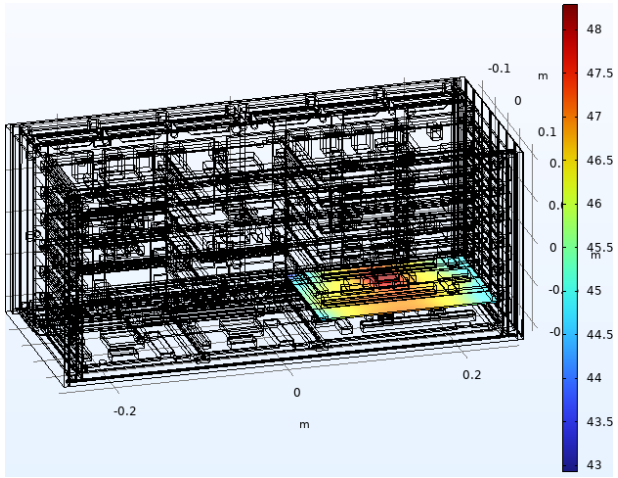


Electronic Box – Thermal Simulation Results

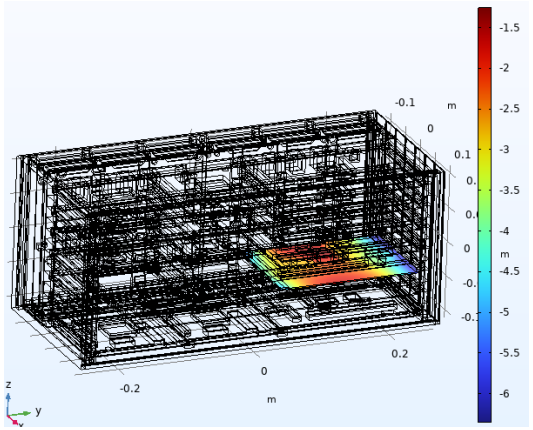
HOT OPERATIVE

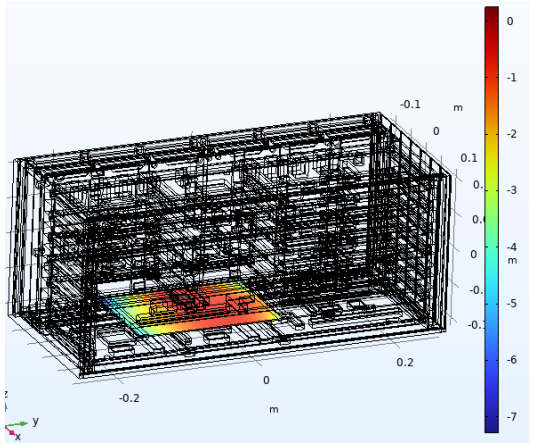


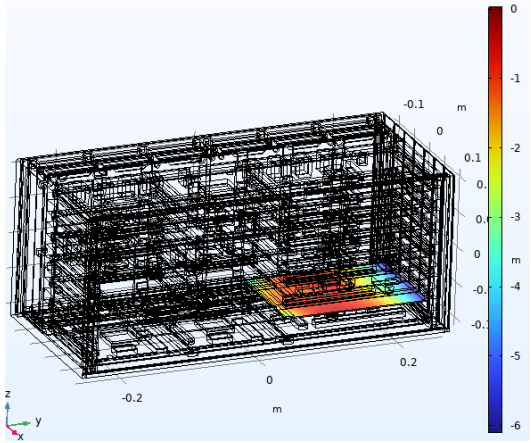




COLD OPERATIVE

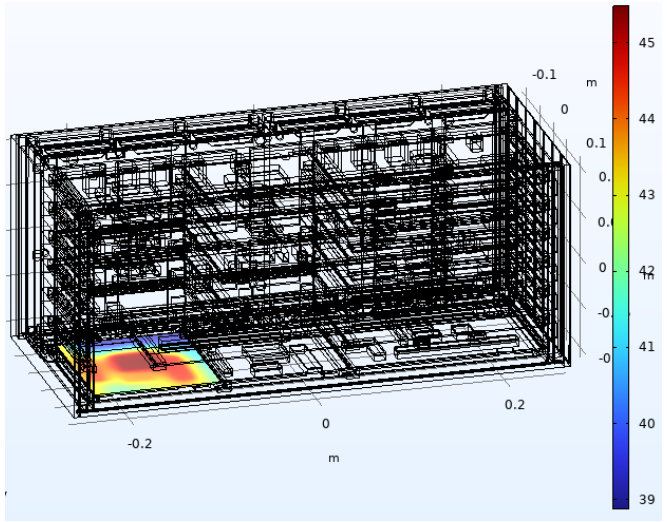


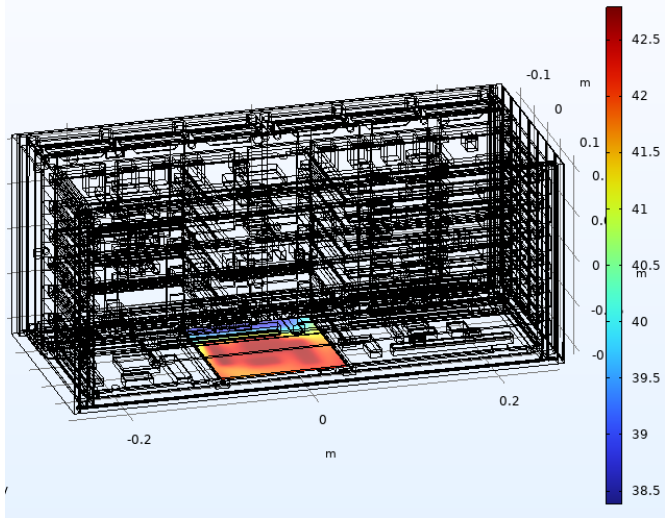


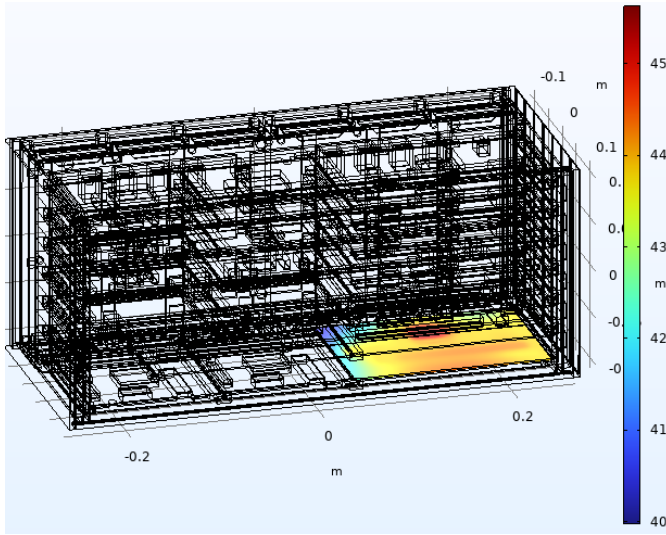


Electronic Box – Thermal Simulation Results

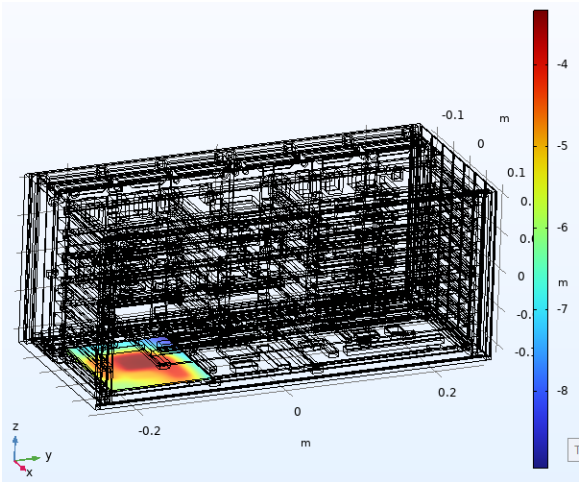
HOT OPERATIVE

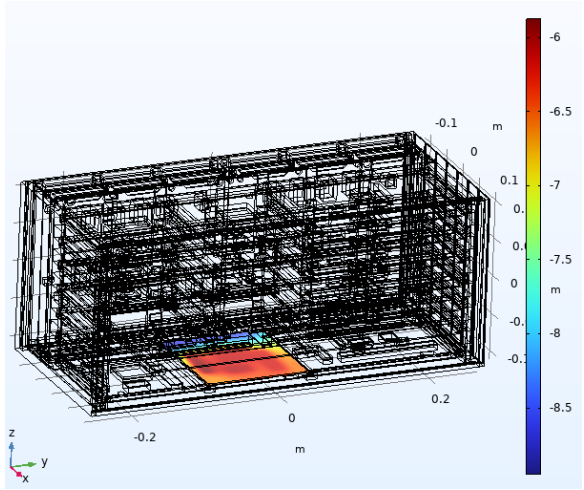


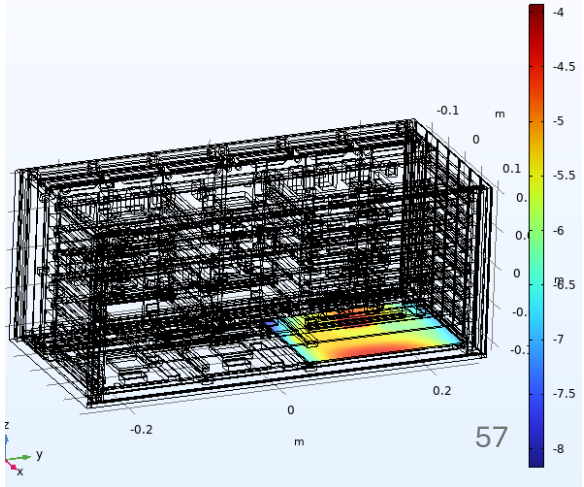




COLD OPERATIVE

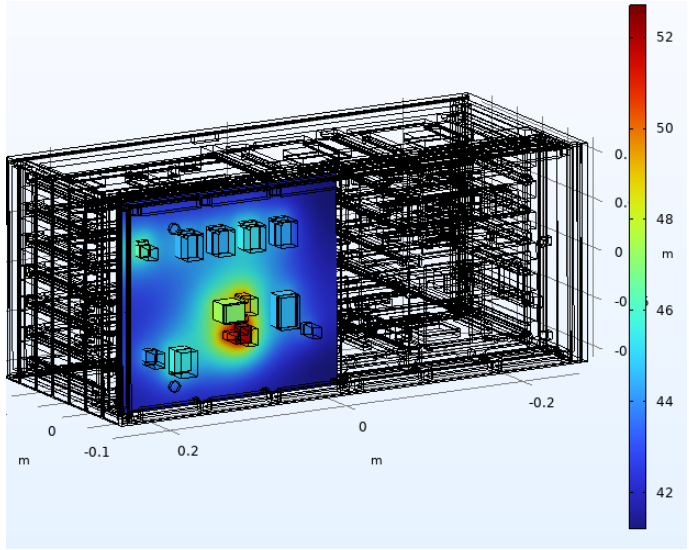


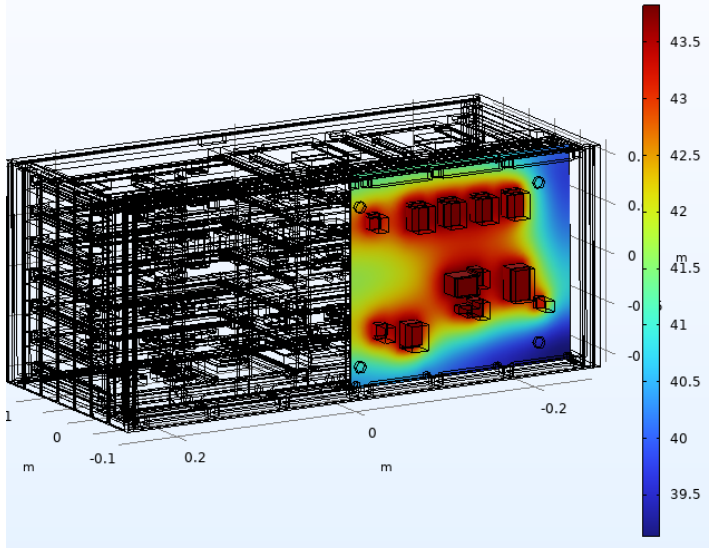




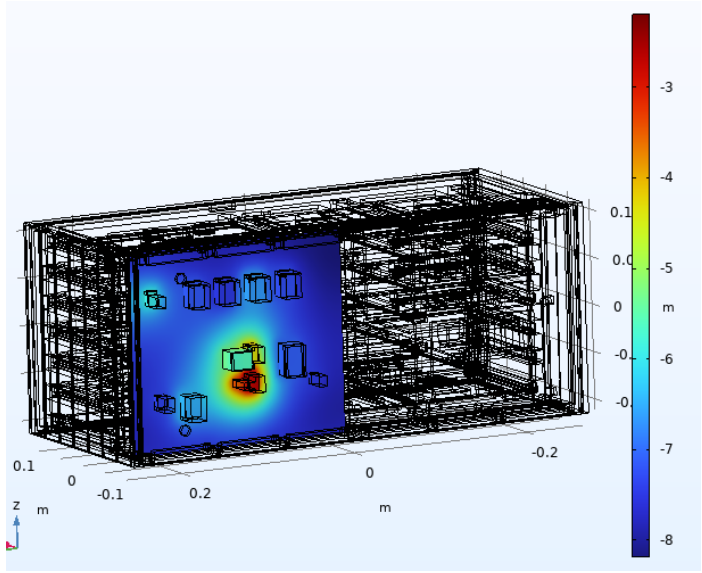
Electronic Box – Thermal Simulation Results

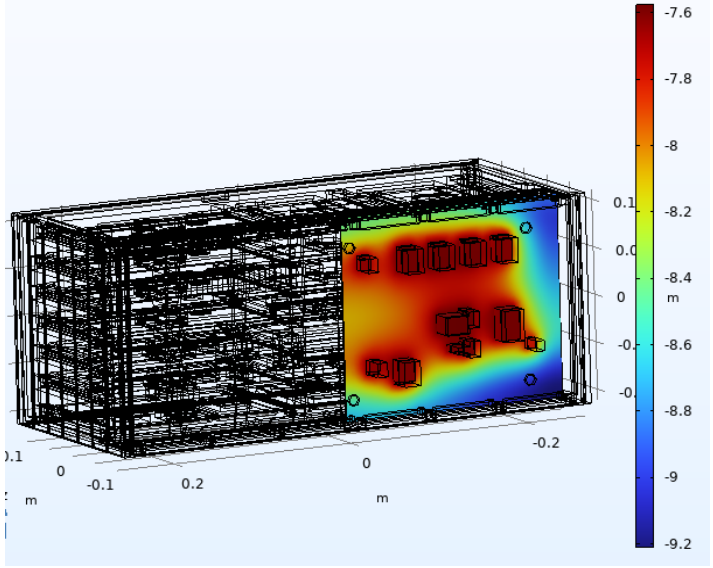
HOT OPERATIVE





COLD OPERATIVE





ZIRE – Model Boundary Conditions- Power Distribution & Thermal Contact Interfaces

HOT OPERATIVE

1	PST	0,422	W
2	FTK	0,27	W
3	Calog	0,394	W
4	ACS	0,158	W
EoL	**TOT.**	**1,244**	W

COLD OPERATIVE

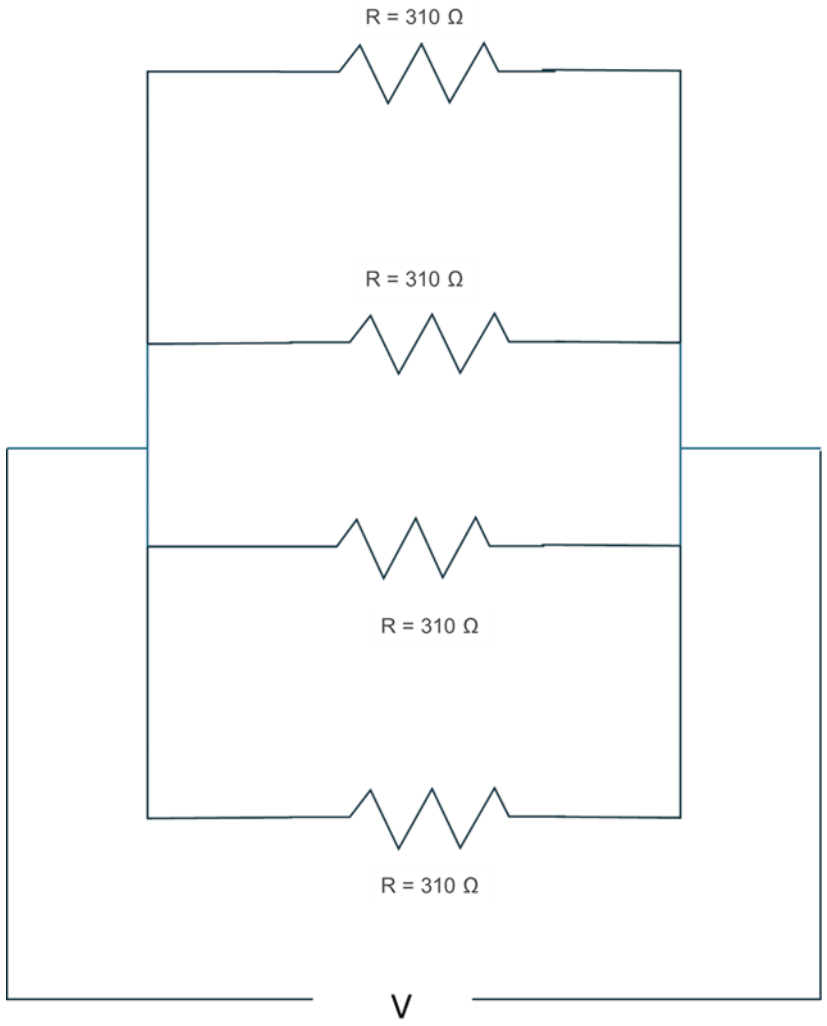
1	PST	0,0014	W
2	FTK	0,0009	W
3	Calog	0,0013	W
4	ACS	0,0005	W
EoL	**TOT.**	**0,0041**	W

Electronic Box – Thermal Simulation Results

ID	Description	Nominal Hot	Nominal Cold	Epsilon -30% (Hot)	Epsilon 30% (Cold)	Thermal Conductivity -10% (Hot)	Thermal Conductivity 10% (Cold)	Contact Resistance 375% (Hot)	Contact Resistance 0.30% (Cold)	Internal Dissipation +20% (Hot)	Internal Dissipation -20% (Cold)	Tcontact +15°C (Hot)	Tcontact -15°C (Cold)	Tradiative +15°C (Hot)	Tradiative -15°C (Cold)	Deviation Hot (°C)	Deviation Cold (°C)	Temp Qualification Predicted Hot (°C)	Temp Qualification Predicted Cold (°C)
1	Zirè Concentrator Hot	45.5	-8.5	46.5	-8.5	45.5	-8.5	46.5	-8.5	47	-9	56.5	-21	48	-10	14.46734	15.5996	59.97	-24.1
2	Zirè Concentrator Cold	43	-9	43.5	-9.5	43	-9	42.5	-9	44	-9.5	54	-22	45.5	-10.5	14.34681	16.10534	57.35	-25.11
3	FTK1	45	-12	45	-12.5	45	-12.5	46	-12.5	46	-12.5	57	-25	46	-13	15.12436	16.0756	60.12	-28.06
4	Zirè DAQ_r	44	-9.8	45	-10	44	-9.6	44	-9.4	46	-10.6	55	-22.2	46.5	-11.2	14.5	15.5028	58.5	-25.3
5	LEM1	50	-10.2	51	-10.4	51	-10.4	52	-9.8	53	-10.8	61	-23	52	-11.6	14.83216	15.89961	64.83	-26.1
6	FTK2	49	-12	50	-12.4	49	-12.5	51	-12.5	51	-12.5	60	-25	50	-13	15.40967	16.14572	64.41	-28.15
7	Calog	47	-9.8	47.5	-10	46.5	-9.6	48.5	-9.4	49.5	-10.6	57.5	-22	48.5	-11.2	14.0227	15.70433	61.02	-25.5
8	LEMCold	44.5	-10.2	45.2	-10	44.5	-10	45	-9.8	46.2	-10.6	52	-22.8	46.2	-11.4	10.92275	15.67281	55.42	-25.87
9	FTK3	48	-12	49	-12.4	48	-12.5	49	-12.5	50	-12.5	61	-25	49	-13	16.60147	16.14572	64.60	-28.15
10	PST1	47	-9.8	48	-10	47	-9.8	48	-9.5	50	-10.5	58	-22	49	-11.4	14.78983	15.26784	61.79	-25.27
11	PST2	49	-10.2	51	-10.4	50	-10.4	52	-9.8	53	-10.8	61	-23	51	-11.6	16.34166	15.68069	65.34	-25.88
12	FTK4	48	-12.5	48	-10.4	48.5	-10.4	50	-9.8	50	-10.6	60	-25	49	-13.5	15.36932	15.74402	63.37	-28.24
13	PianoB1	48	-7	49	-12.5	48.5	-12.5	49.5	-6.5	50	-7.5	60.5	-21	50	-7	15.8355	18.09139	63.84	-25.09
14	PianoB4	46	-6	48	-12	46.5	-6.5	49	-6.5	49	-6.5	60.5	-21.5	49	-8	14.78983	18.3799	60.79	-22.38
15	PianoB2	46	-7	48	-7	48.5	-7	49.5	-6	50.5	-6.5	61	-21	49	-7	15.92285	16.1244	63.92	-23.12
16	Terzina Concentrator Hot	45	-8	46	-6	45	-6	45	-6.5	46	-8	55	-21	46	-10	13.34408	16.47219	58.34	-24.47
17	Terzina Concentrator Cold	42.5	-8.5	43.5	-9	42.5	-9	42.5	-8.5	45	-8.5	54	-21.5	45.5	-9.5	15.02082	15.68858	57.52	-24.19
18	PianoB3	46	-8	46	-8	46.5	-8	47	-8	46.5	-9	57	-21.5	46.5	-9.6	15.15806	16.6565	60.19	-24.66
19	Power HOT	52	-8	58	-8	52	-8	58	-8	52	-8	66	-22.5	58	-11	18.23155	17.14214	70.23	-25.14
20	Power Cold	43.5	-9.2	43.5	-9.2	43.5	-9.2	43.5	-9.2	44.1	-9.2	58.5	-22.5	44.1	-11	18.012	16.42423	61.51	-25.62

Electronic Box – Thermal Simulation Results

Heater Scheme



$$Electrical\ Heater\ Calculations:$$

$$Equivalent\ Resistance\ \ Req = \ 77.5\ \Omega$$

$$Maximum\ Power\ (Pmax)\ at\ 67.2\ V, \qquad Pmax\ = \frac{(67.2\ V)^2}{Req} = \ 58.27\ W$$

$$Minimum\ Power\ (Pmin)\ at\ 49\ V, \qquad Pmin\ = \frac{(49\ V)^2}{Req} = \ 30.98\ W$$

$$Safe\ Minimum\ Power\ (Pmin_{SAFE})\ at\ 40.7\ V, \qquad Pmin_{SAFE} = \frac{(40.7\ V)^2}{Req} = \ 21.37\ W$$

ZIRE – Model Boundary Conditions- Power Distribution & Thermal Contact Interfaces

HOT OPERATIVE

Boundary Calculated by Thales with +10 °C Qualification

	CALCULATED	QUALIFICATION	TOTAL °C	TOTAL K
ZIRE	5,74	10	15,74	288,89
WIN +X	5,8	10	15,8	288,95
WIN - X	4,8	10	14,8	287,95
WIN -Y	4,2	10	14,2	287,35
TSINK Uninsulated Side	7	10	17	290,15
TSINK MLI Side	7	10	17	290,15

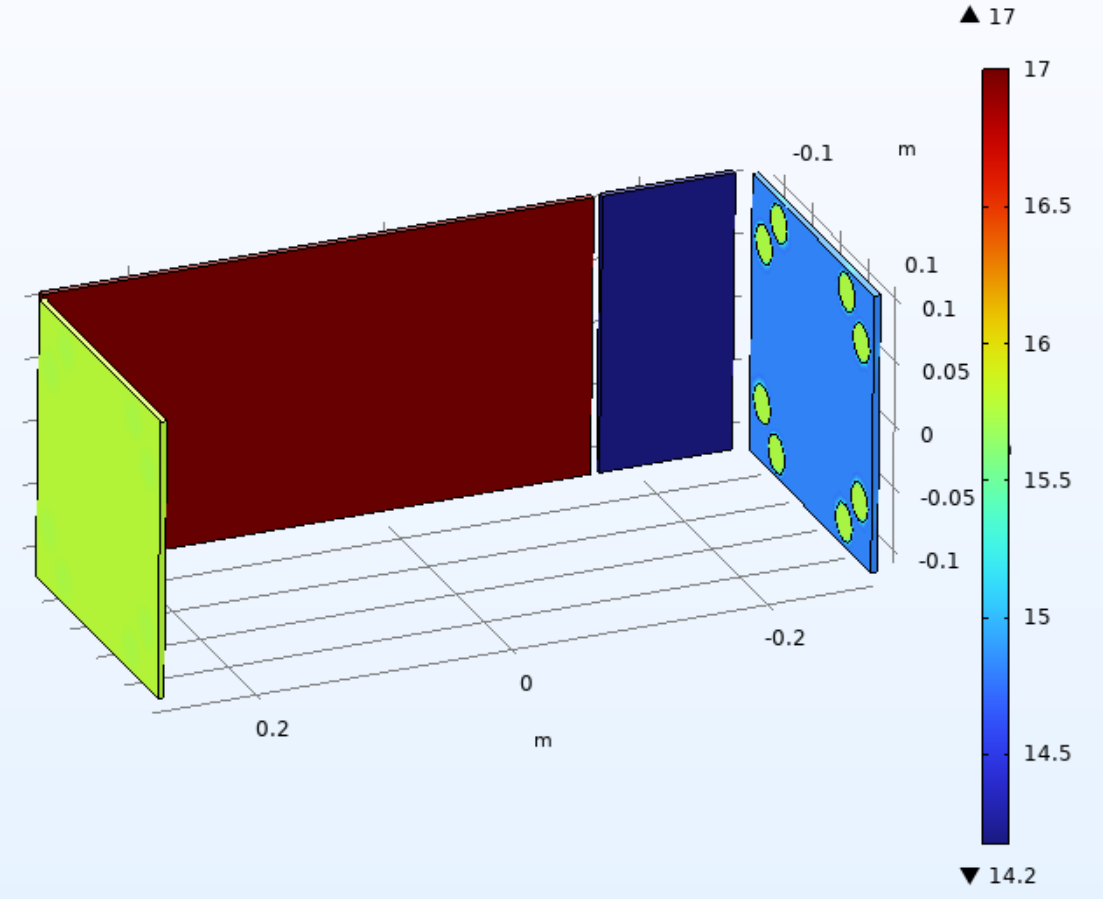
COLD OPERATIVE

Boundary Calculated by Thales with -10 °C Qualification

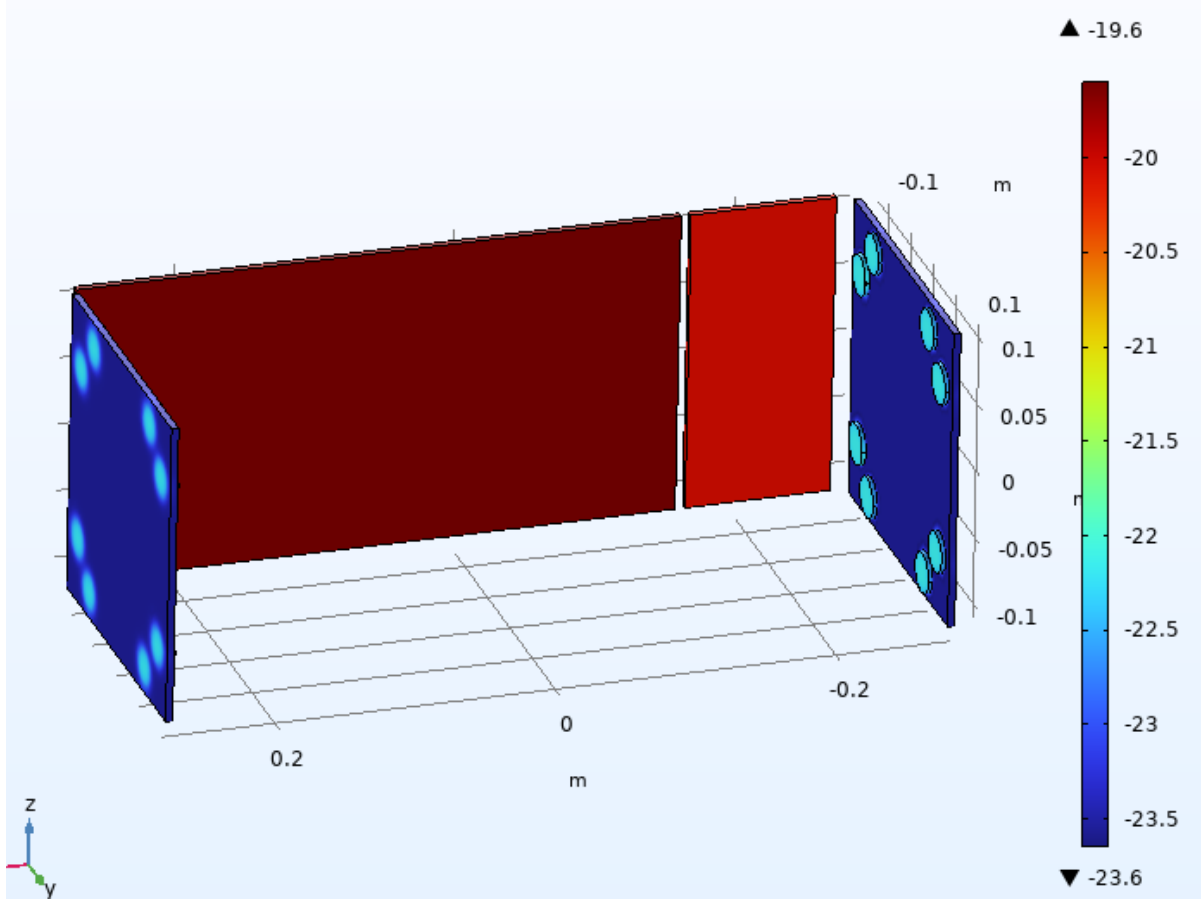
	CALCULATED	QUALIFICATION	TOTAL °C	TOTAL K
ZIRE	-11,76	-10	-21,76	251,39
WIN +X	-14,6	-10	-24,6	248,55
WIN - X	-14	-10	-24	249,15
WIN -Y	-10,7	-10	-20,7	252,45
TSINK Uninsulated Side	-10,3	-10	-20,3	252,85
TSINK MLI Side	-10,3	-10	-20,3	252,85

ZIRE – Model Boundary Conditions- Power Distribution & Thermal Contact Interfaces

HOT OPERATIVE

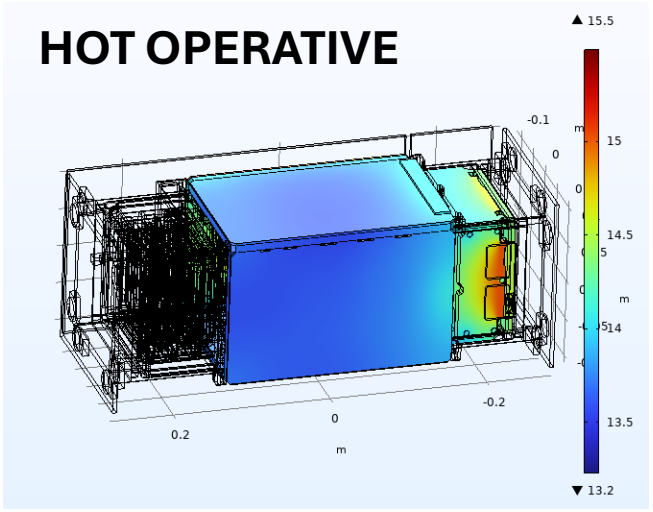


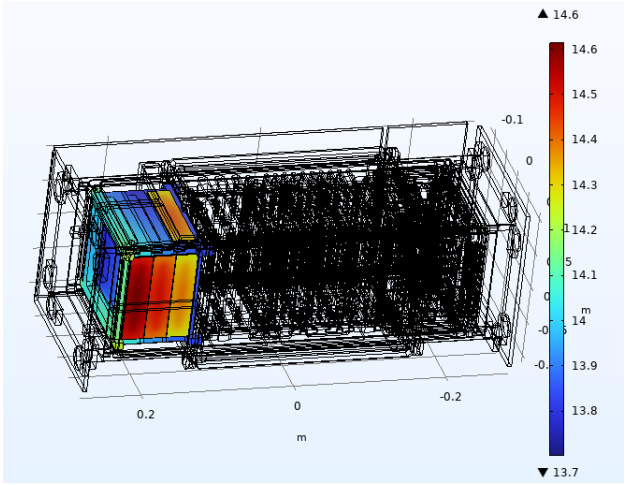
COLD OPERATIVE

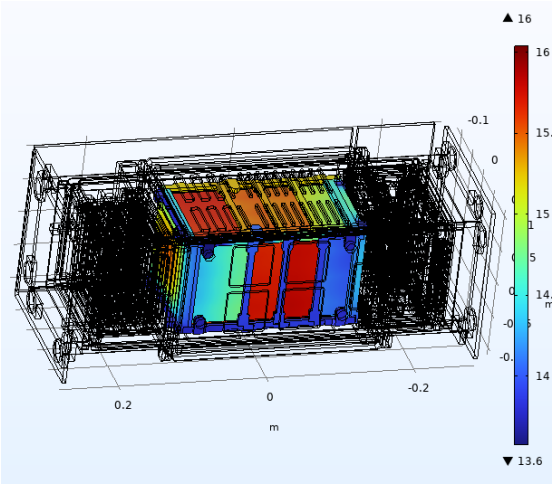


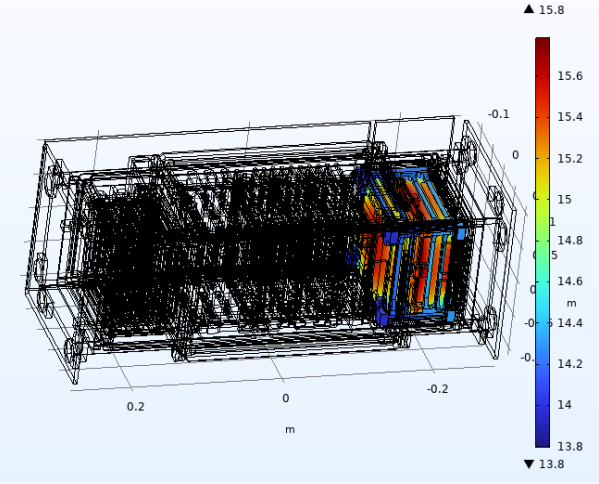
ZIRE – Model Boundary Conditions- Power Distribution & Thermal Contact Interfaces

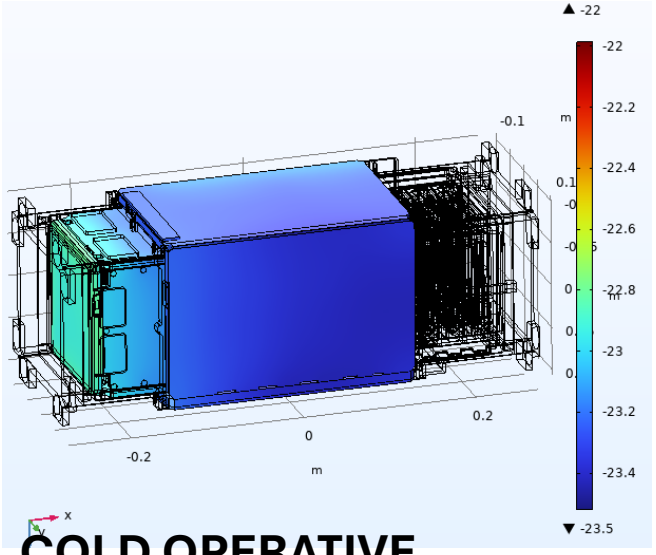
HOT OPERATIVE

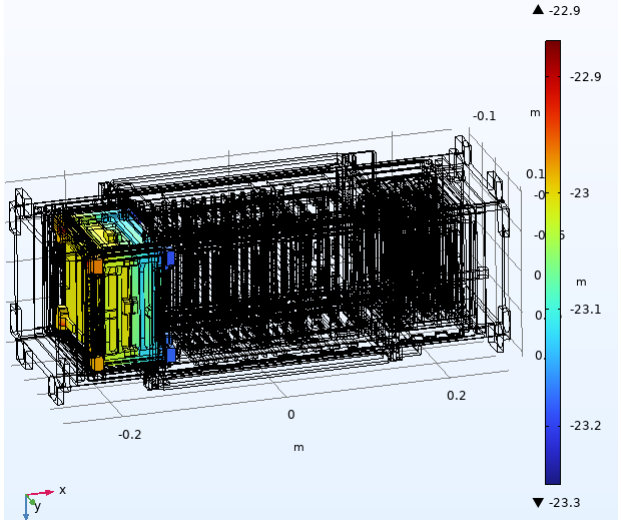


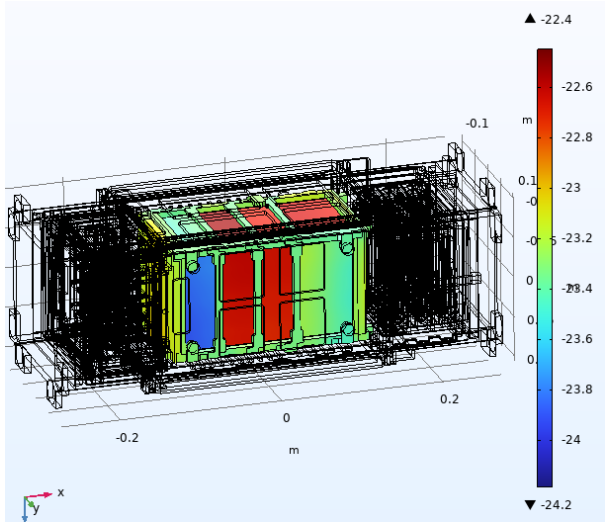


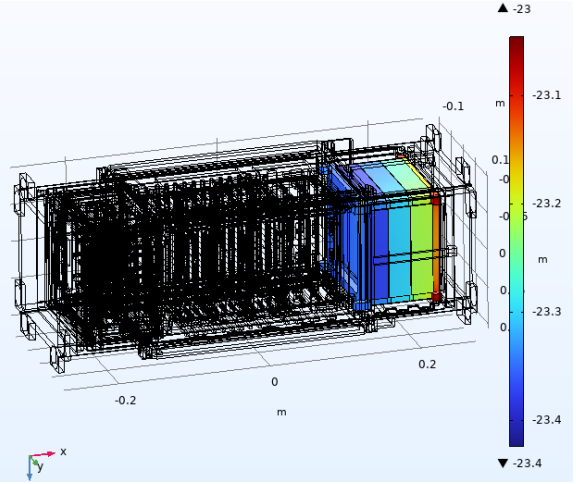












COLD OPERATIVE

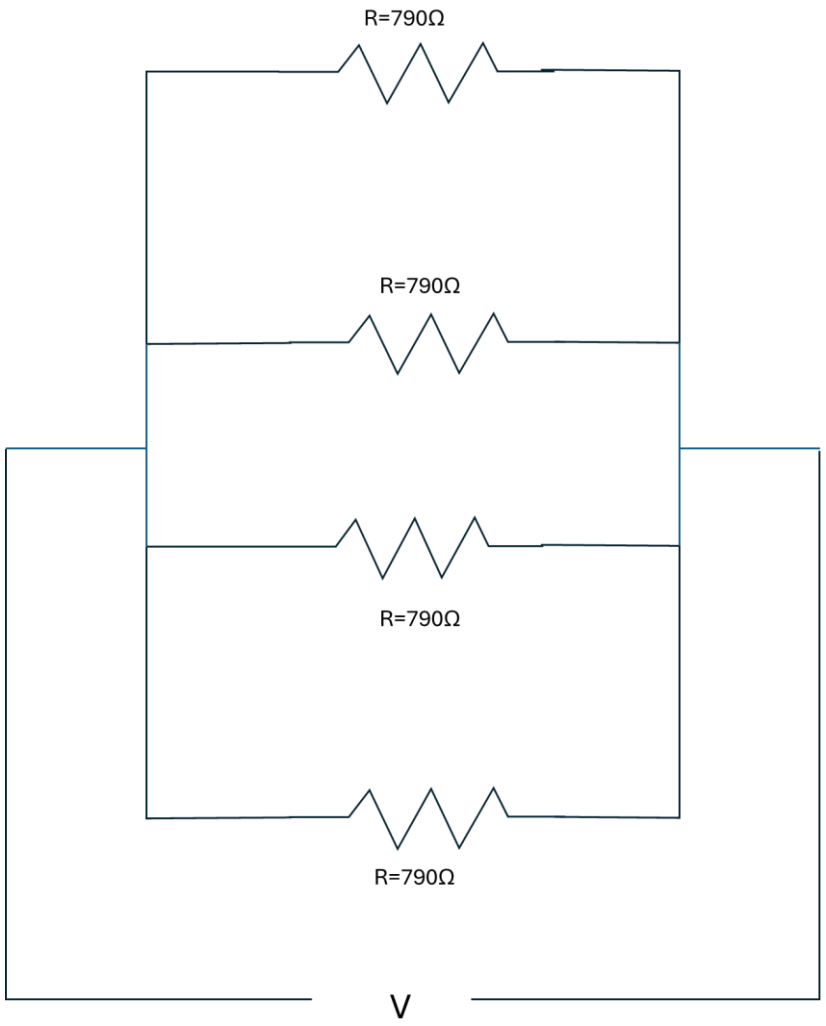
ZIRE – Model Boundary Conditions- Power Distribution & Thermal Contact Interfaces

MAXIMUM TEMPERATURE									
DESCRIPTION	NOMINAL	Epsilon	Thermal Conductivity	Contact Resistance	Internal Dissipation	Tcontact (boundary)	Tradiative (boundary)		MAXIMUM TEMP qualification predicted
		-30%	-10%	375%	20%	+ 15 °C	+ 15 °C		
	T0	T1	T2	T3	T4	T5	T6	DEV ST	
Structure	16,8	17,2	16,8	17,5	17,2	25,4	23,7	14,06255	30,86
ACS	17,7	18,1	17,8	19,8	18,3	26,2	28,5	16,92228	34,62
FTK	16,4	17,1	16,4	17,1	16,9	24,6	23,1	13,64707	30,05
PST	23	23,5	23,5	28,4	24,7	31,2	29,7	15,0283	38,03
CALOG	18,4	18,8	18,5	21,6	19,1	26,8	25	14,18123	32,58

MINIMUM TEMPERATURE									
DESCRIPTION	NOMINAL	Epsilon	Thermal Conductivity	Contact Resistance	Internal Dissipation	Tcontact (boundary)	Tradiative (boundary)		MINIMUM TEMP qualification predicted
		30%	10%	0,30%	-20%	- 15 °C	- 15 °C		
	T0	T1	T2	T3	T4	T5	T6	DEV ST	
Structure	-23,5	-23,1	-22,9	-23	-23	-35,4	-27,3	15,53276	-39,03
ACS	-23,5	-23,3	-23	-23,1	-23,2	-34,8	-31	16,58234	-40,08
FTK	-23,4	-23,1	-22,8	-22,8	-23	-34,7	-26,6	14,78558	-38,19
PST	-24,2	-23,1	-22,8	-22,9	-23	-34,3	-31,6	15,76989	-39,97
CALOG	-23,3	-22,9	-22,7	-22,8	-22,8	-34,6	-26,6	14,81524	-38,12

ZIRE – Model Boundary Conditions-
Power Distribution & Thermal Contact Interfaces

Electric Heater Scheme



- **Req** = 77.5 Ω
- **Pmax** (67.2V) = 58.27 W
- **Pmin** (49V) = 30.98 W
- **Pmin_SAFE** (40.7V) = 21.37 W

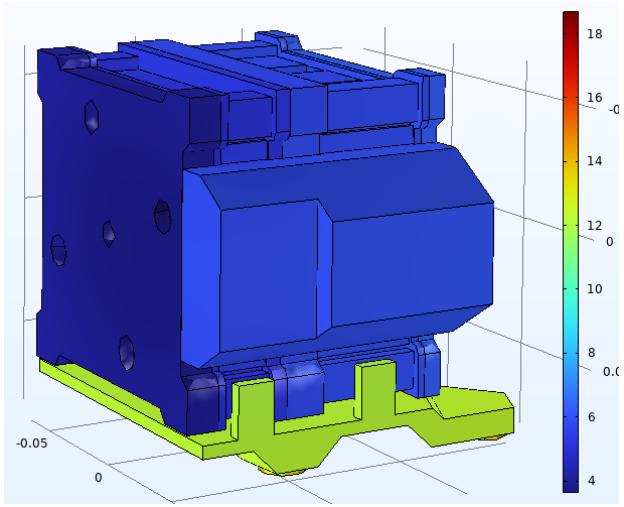
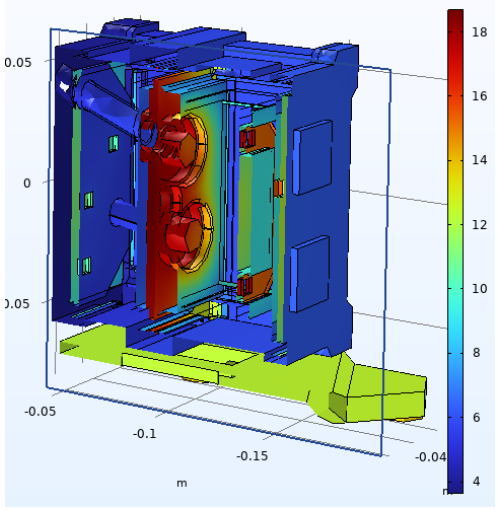
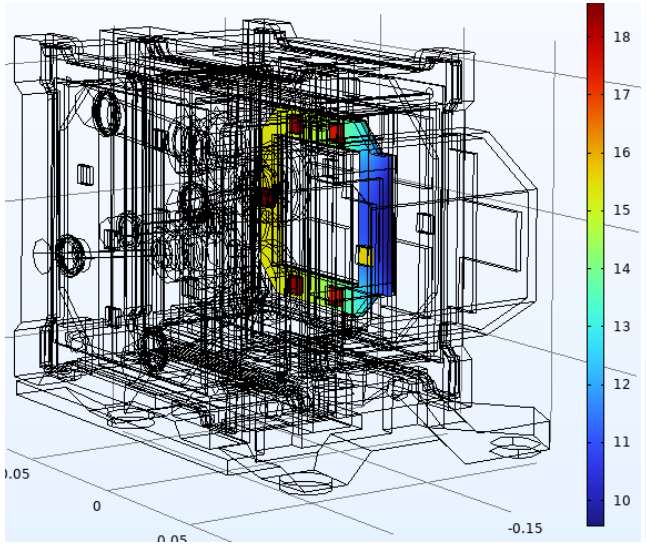
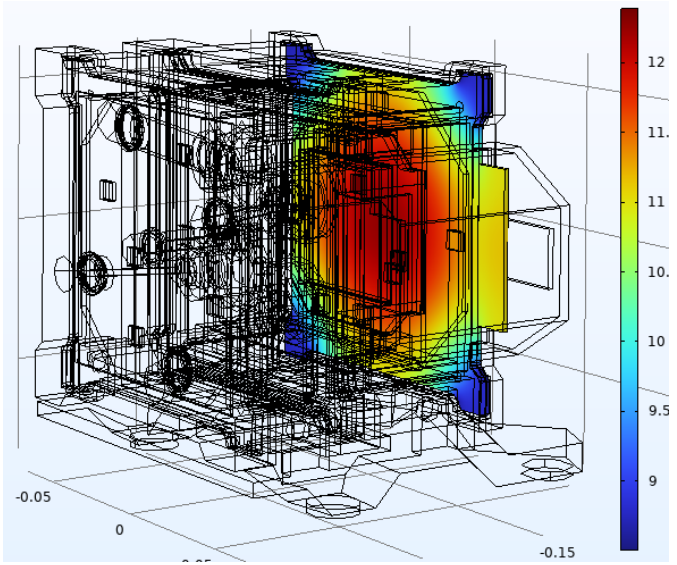
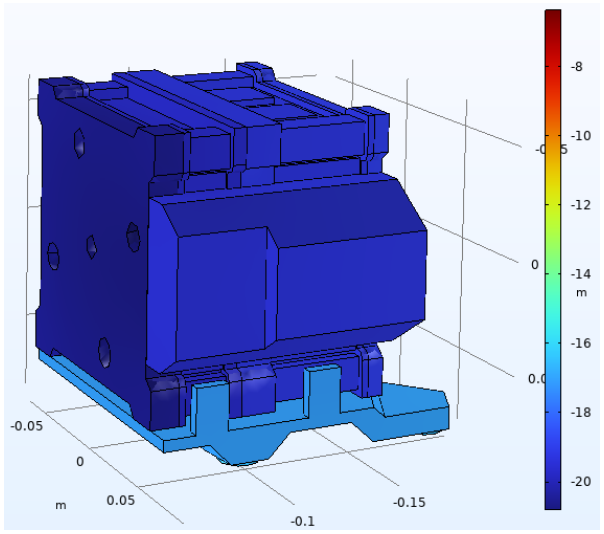
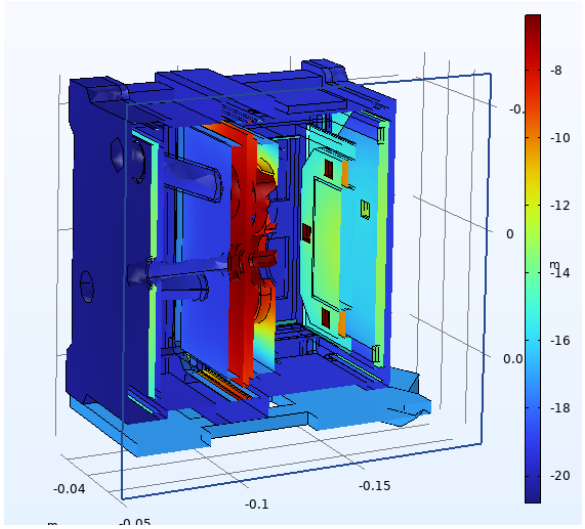
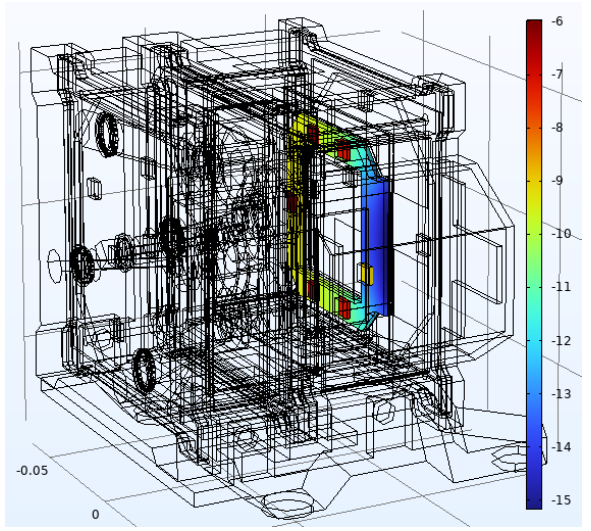
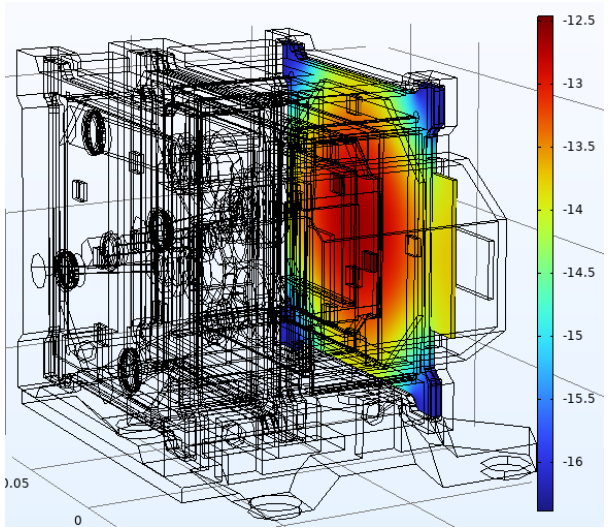
LEM– Model Boundary Conditions- Power Distribution & Thermal Contact Interfaces

HOT OPERATIVE				
	CALCULATED	QUALIFICATION	TOTAL °C	TOTAL K
TOP PLANE	3,8	10	13,8	286,95
MLI Side	4,8	10	14,8	287,95

COLD OPERATIVE				
	CALCULATED	QUALIFICATION	TOTAL °C	TOTAL K
TOP PLANE	-4,2	-10	-14,2	258,95
MLI Side	-5,4	-10	-15,4	257,75

Internal Dissipation		
Board1	0,6	W
Board2	0,75	W
Board3	0,75	W
Board4	0,6	W
Board5	0,6	W
TOTAL	**3,3**	**W**

LEM– Model Boundary Conditions- Power Distribution & Thermal Contact Interfaces

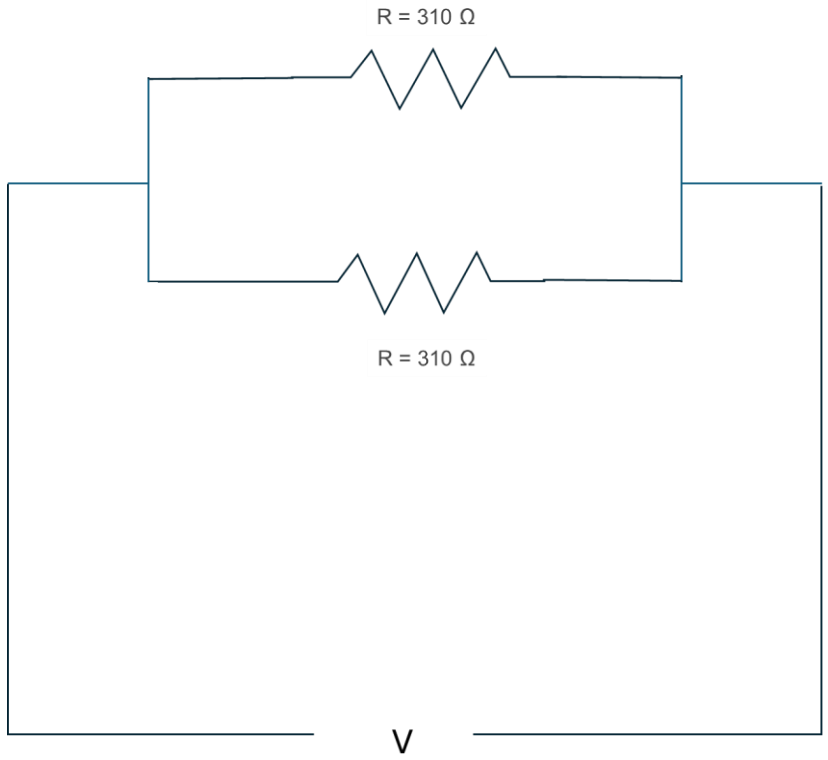









LEM– Model Boundary Conditions- Power Distribution & Thermal Contact Interfaces

MAXIMUM TEMPERATURE									
DESCRIPTION	NOMINAL	Epsilon	Thermal	Contact	Internal	Tcontact	Tradiativ		MAXIMUM TEMP qualification predicted
		-30%	-10%	375%	20%	+ 15 °C	+ 15 °C		
	T0	T1	T2	T3	T4	T5	T6	DEV ST	
Board 1	11,5	15,5	12	22	14,5	10	22	14,73669	26,24
Board 2	18	22	19	43	22	16	29	28,72936	46,73
Board 3	18	22	19	38	22	16	29	23,90454	41,90
Board 4	18	22	19	40	22	17	29	25,75961	43,76
Board 5	12	16	12,5	24,5	15	10,5	23	16,55544	28,56

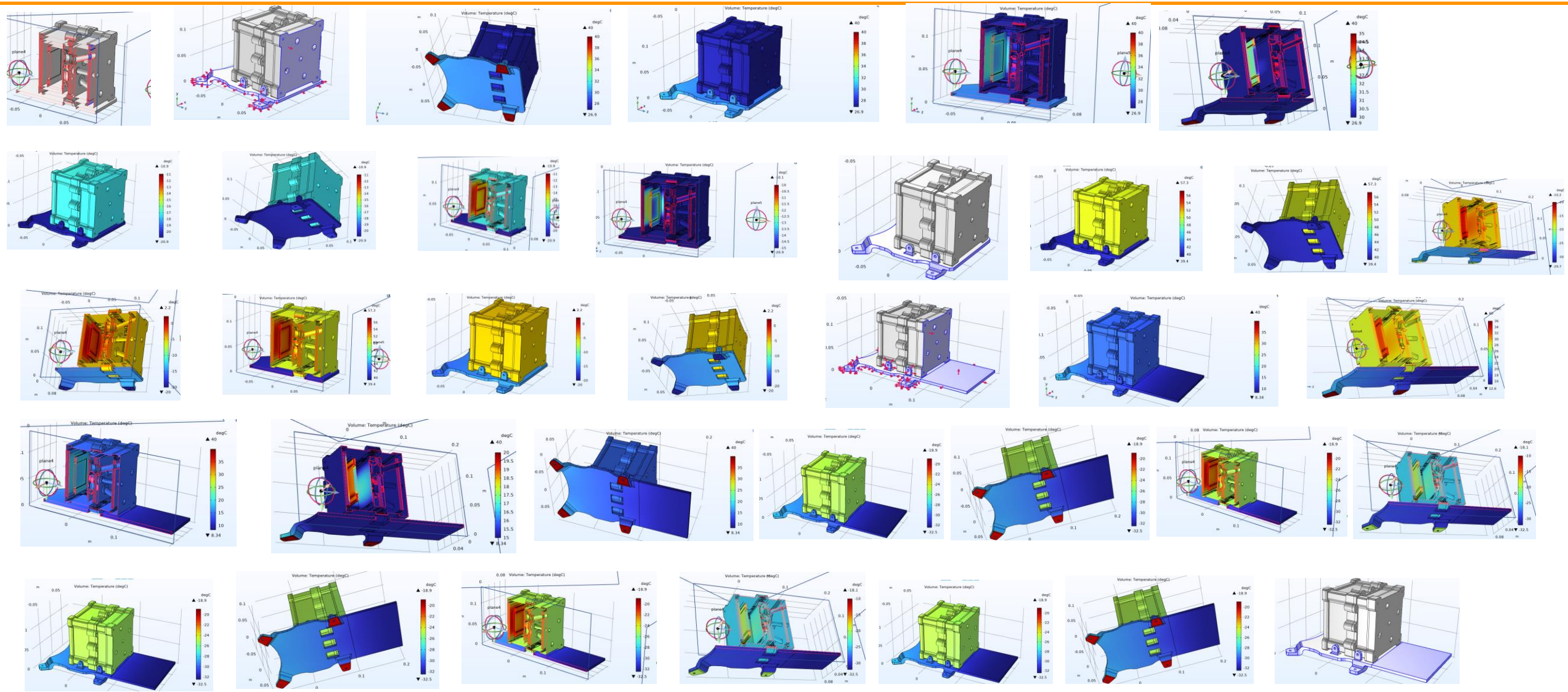
MINIMUM TEMPERATURE									
DESCRIPTION	NOMINAL	Epsilon	Thermal Conductivity	Contact Resistance	Internal Dissipation	Tcontact (boundary)	Tradiative (boundary)		MAXIMUM TEMP qualification predicted
		30%	10%	0,30%	-20%	- 15 °C	- 15 °C		
	T0	T1	T2	T3	T4	T5	T6	DEV ST	
Board 1	-16,5	-18	-16,5	-18,5	-27,5	-19	-26	14,55422	-31,05
Board 2	-13	-14	-12	-17	-23	-15	-22	14,04536	-27,05
Board 3	-13	-15	-13	-17	-24	-16	-23	15,24745	-28,25
Board 4	-15	-16	-15	-16,5	-25	-17	-24	13,35616	-28,36
Board 5	-16	-17,5	-16	-18	-26,5	-18,5	-25,5	14,07926	-30,08

LEM– Model Boundary Conditions-
Power Distribution & Thermal Contact Interfaces

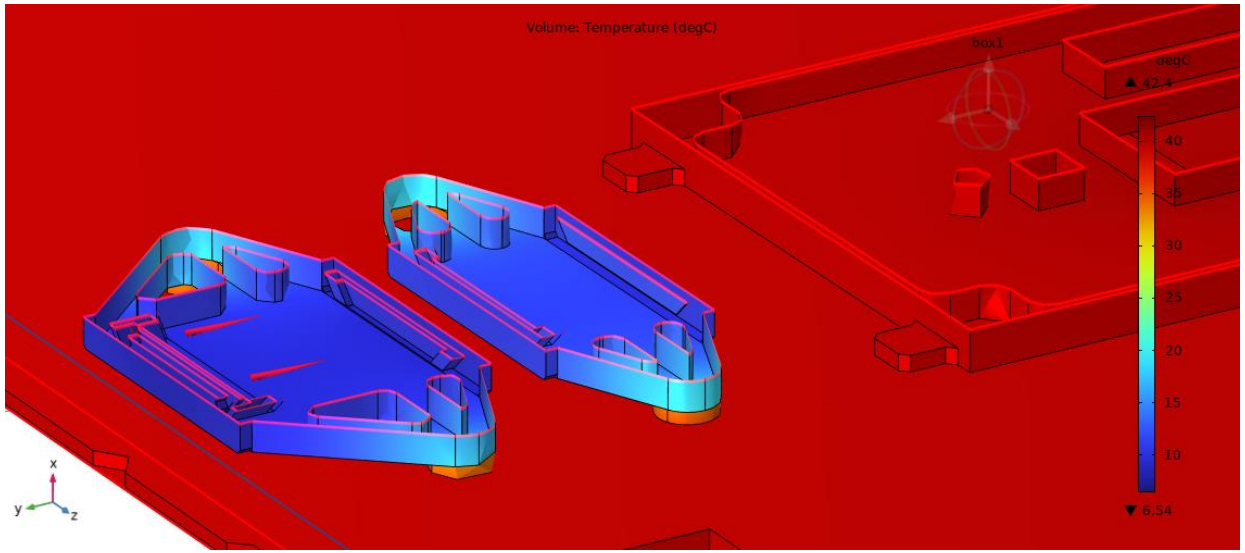


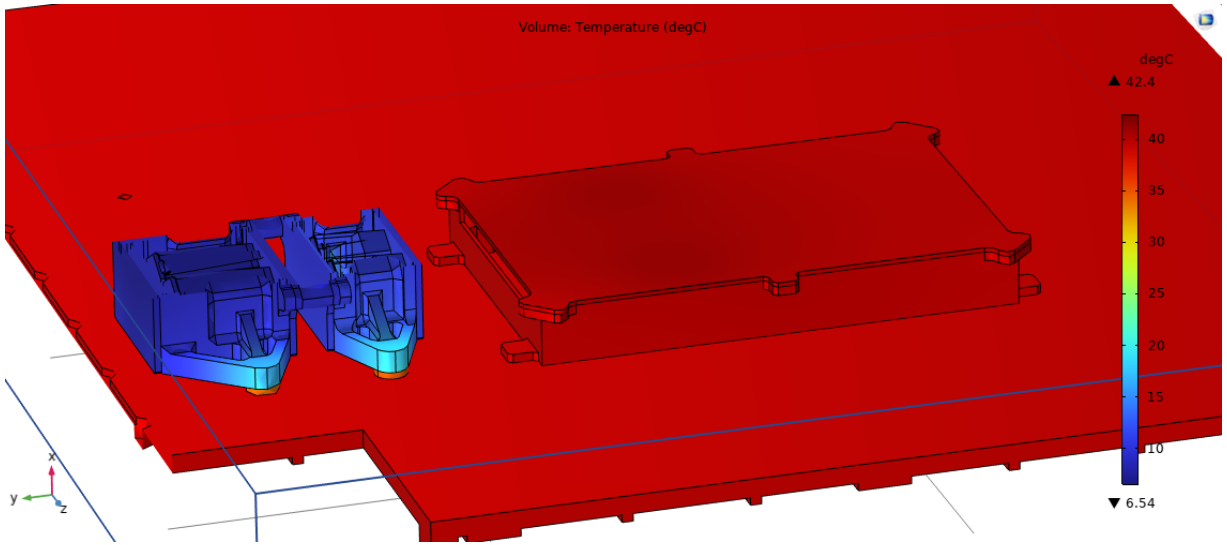
- **Req** = 155 Ω
- **Pmax** (67.2V) = 29.13 W
- **Pmin** (49V) = 15.49 W
- **Pmin_SAFE** (40.7V) = 10.68 W

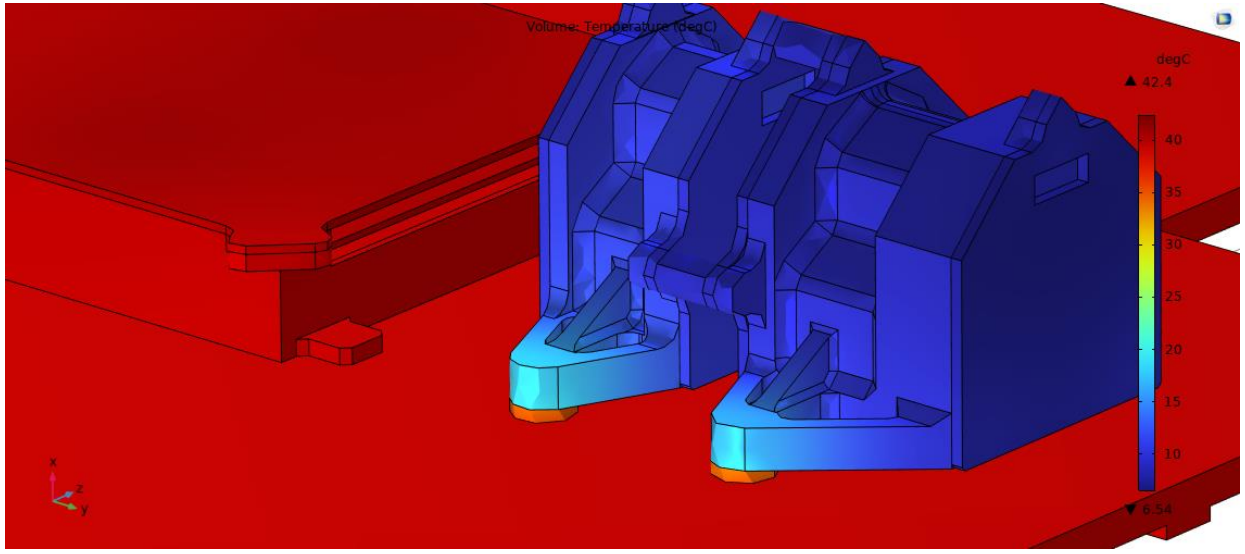
LEM– Model Boundary Conditions-
Power Distribution & Thermal Contact Interfaces

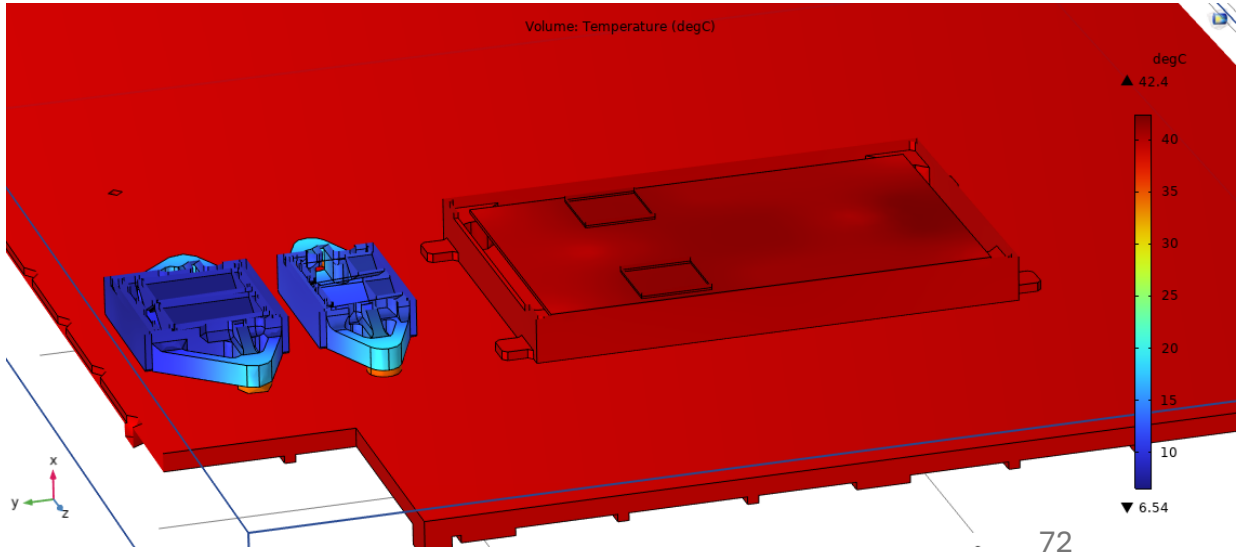


WINK – Thermal Simulation Results









Thermo-Elastic Considerations & Material Expansion

Zirè Payload:
•Stable temperature distribution across detectors and electronic box.
•Efficient heat dissipation to maintain operational limits.

LEM:
•Material selection and surface emissivity control heat flow.
•Stable temperature management for key components.

WINK:
•Preliminary results show the need for thermal decoupling and managing contact resistance.
•Temperature regulation ensures reliability of gamma-ray detection system.

Thermo-Elastic Considerations & Material Expansion

Thermal Expansion:
•Effects of temperature changes on structural components were analyzed.
•Material deformations were within acceptable tolerances, ensuring structural integrity.

Key Findings:
•Zirè: Minimal thermal expansion, no significant mechanical stress.
•LEM: Material properties helped control expansion effects.
•WINK: Thermal decoupling is critical for minimizing expansion impact.

Performance Impact:
•Controlled thermal expansion ensures long-term stability and reliable performance of the systems.

Guidelines for Thermal Management & Design Recommendations

Thermal Management:
•Passive thermal control and material selection are key to managing temperatures.
•Thermal decoupling reduces thermal stress and expansion effects.

Design Recommendations:
•Use materials with low thermal expansion and high conductivity.
•Enhance surface emissivity through treatments and coatings.
•Improve thermal interfaces to optimize heat transfer.

Future Considerations:
•Evolving missions will require more advanced thermal management solutions for long-term success.

Conclusion & Summary

Summary of Findings:
•Robust thermal management for Zirè, LEM, and WINK.
•Simulations demonstrated effective heat dissipation and temperature control.

Key Takeaways:
•Passive cooling and material selection were critical.
•Thermal decoupling ensured minimal thermal stress.

Future Analysis:
•*Thermal test and comparison…*