TARDIS: Accelerating TVAC Transitions

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Background

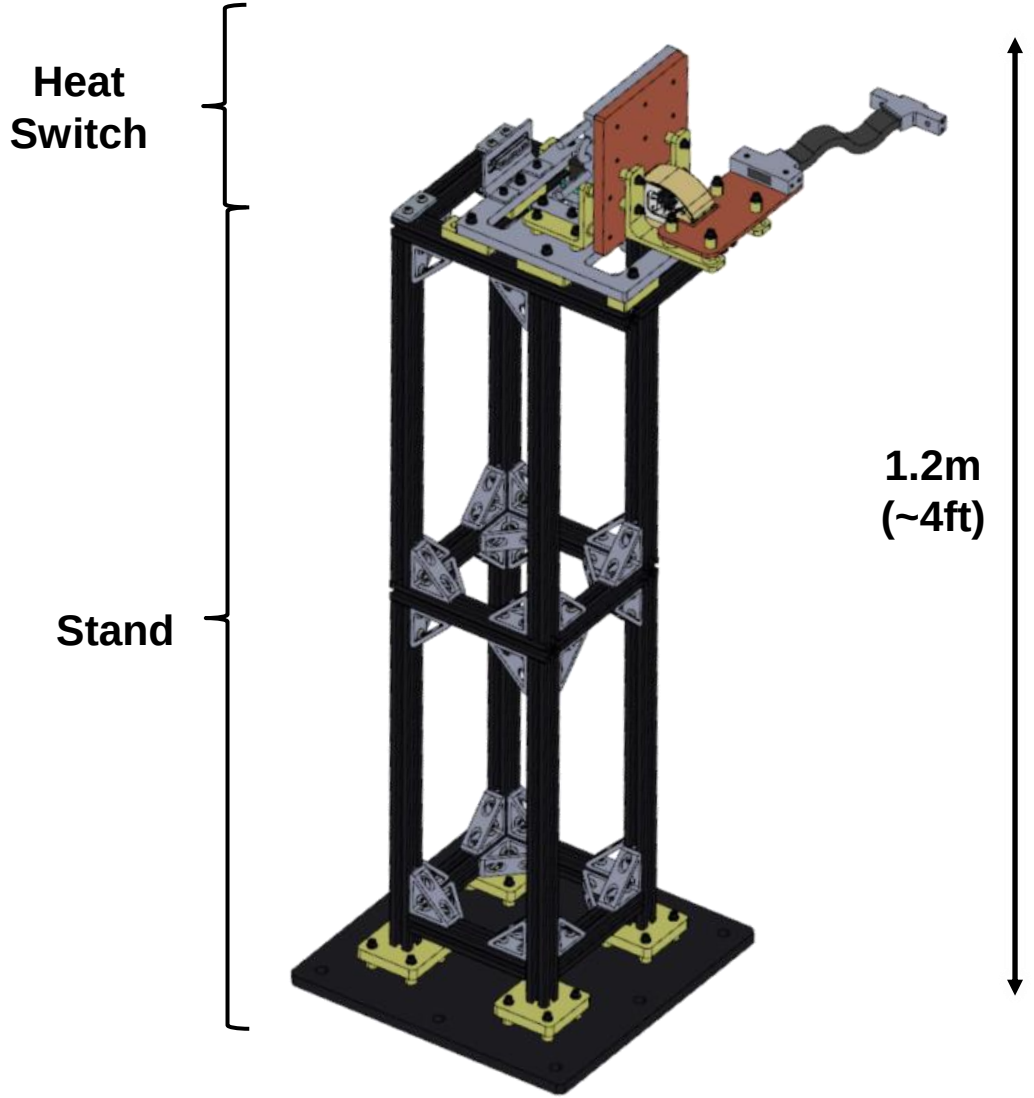
- Wide Field Instrument (WFI)
  - Cryogenic IR instrument on Roman Space Telescope (RST)
  - Undergoing instrument-level TVAC testing at Ball Aerospace in Boulder Colorado
- TVAC Transitions
  - Significant transition times during TVAC, especially for cryogenic instruments
  - Transitions via radiation heat transfer are very slow at cryogenic temperatures due to the T^4 relationship

$$\boldsymbol{Q_{rad} = \sigma \varepsilon A F_{1-2}\left(T_2^4 - T_1^4\right)}$$

Roman Space Telescope [1]

TARDIS Overview (1/2)

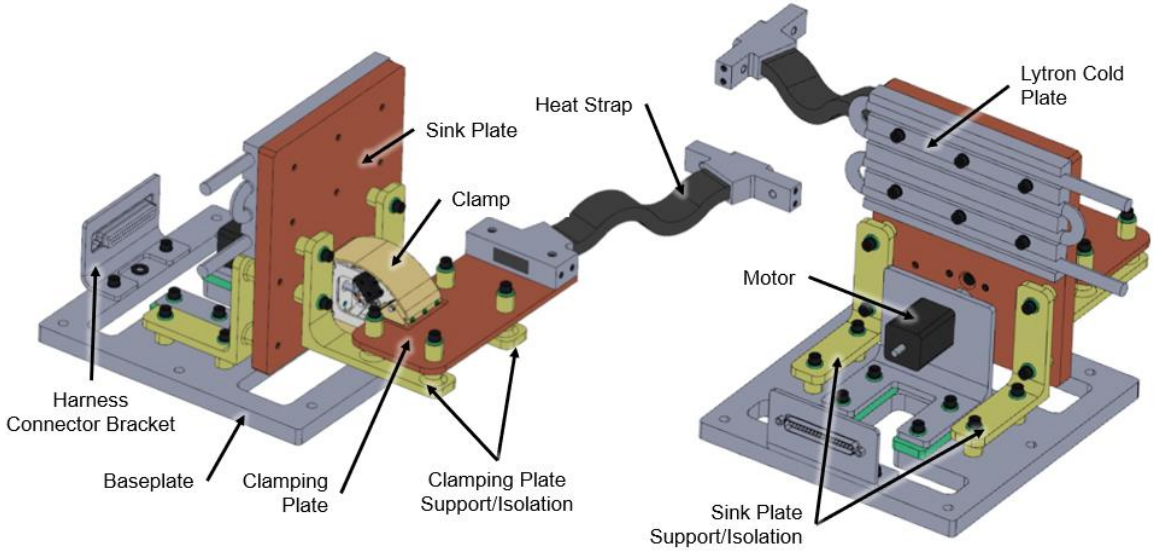
- TARDIS: Thermal Acceleration Rate Device for Integrated Systems
  - TVAC GSE heat switch based off Lucy L'Ralph AZQ (Active Zero-Q) Heat Switch Design
- Purpose
  - Decrease WFI TVAC transition times during WFI TVAC campaign while also allowing for thermal balances
  - Need for high conductance
    - Allows TARDIS to drive WFI temperatures cold/hot for transitions
  - Need for low conductance
    - Reduces TARDIS thermal influence for WFI testing and balances
    - Allows for Zero-Q operation



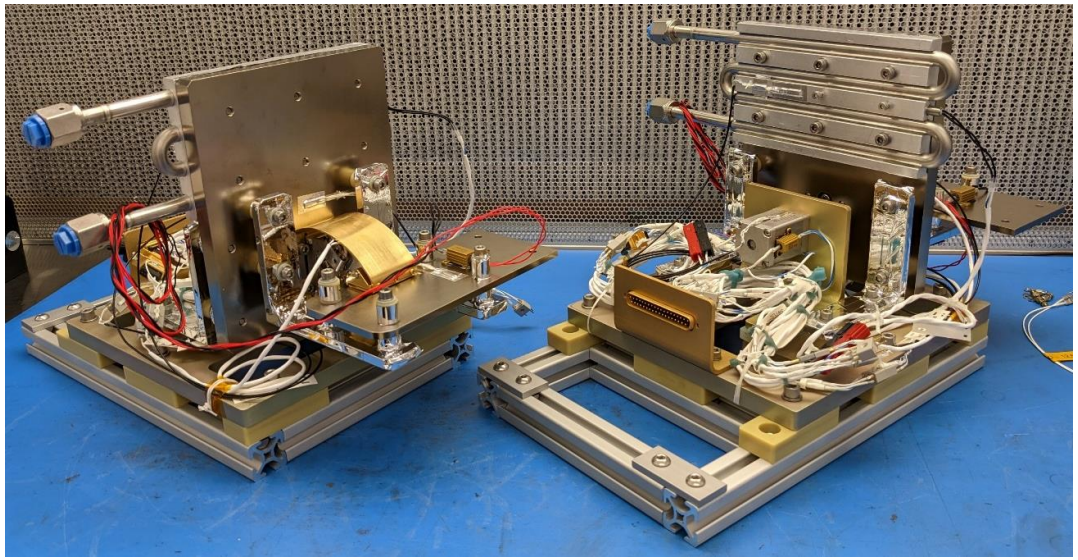
TARDIS CAD Model

TARDIS Overview (2/2)

- Pyrolytic Graphite thermal strap is attached to WFI structure
- Thermal strap attached to the clamping plate w/ e-Graf
- Clamping plate is thermally isolated from the rest of TARDIS w/ Ultem supports.
- When engaged, the clamp thermally connects the clamping plate with the controllable cold plate



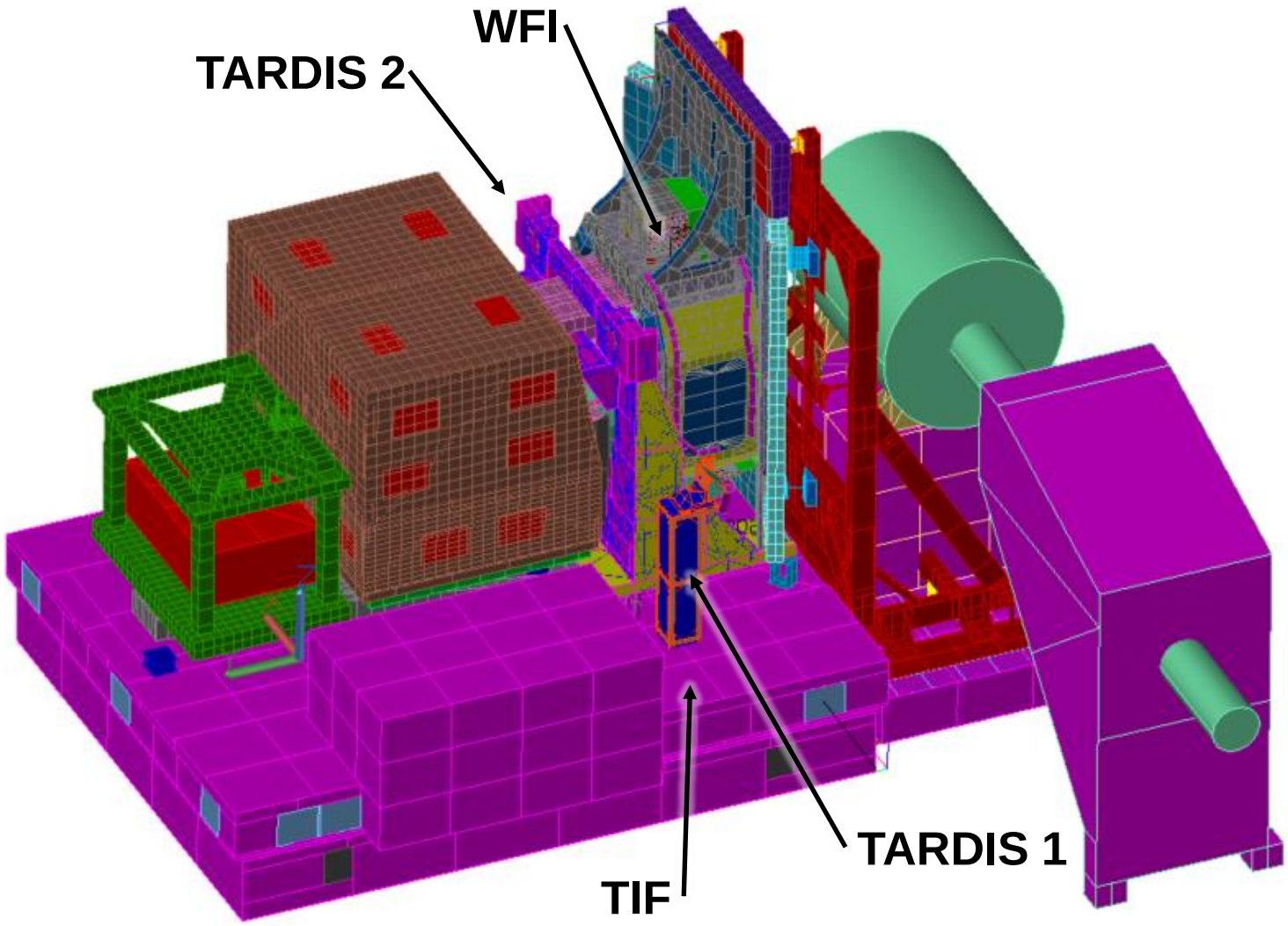
Pyrolytic Graphite Heat Strap



TARDIS units during integration

TARDIS in WFI TVAC

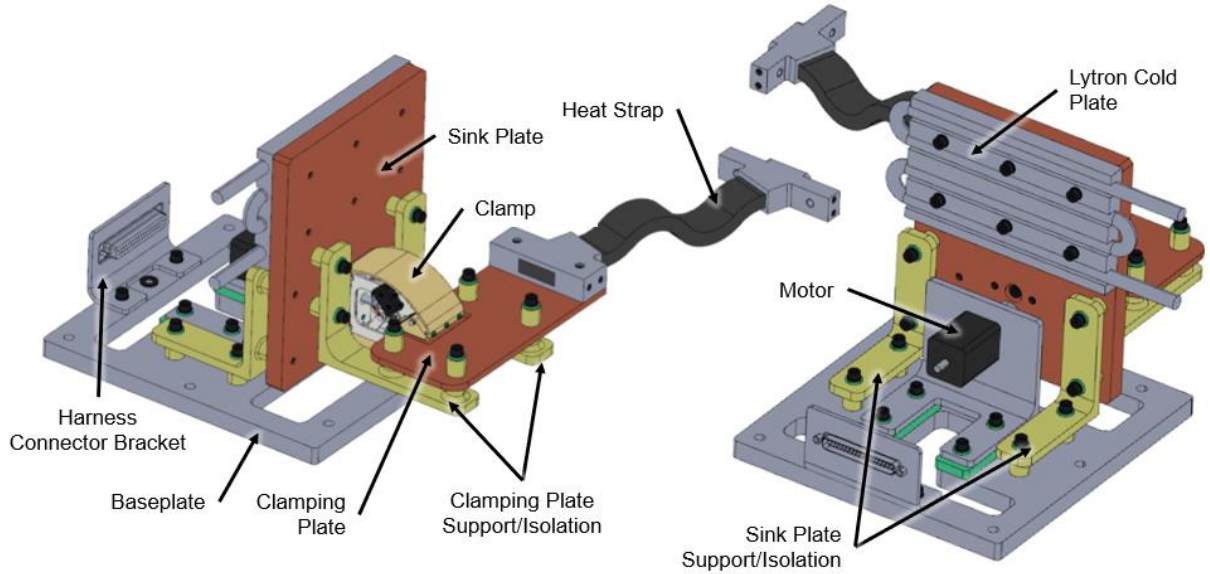
- TARDIS Position
  - TARDIS 1 and TARDIS 2 located on both sides of WFI
  - Mounted onto the Trolley Interface Plate (TIF)



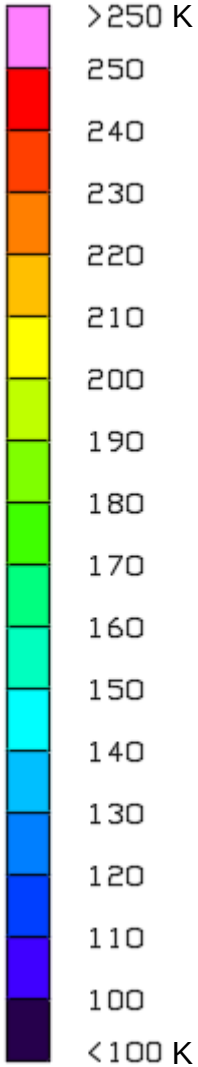
WFI TVAC Configuration

TARDIS Operating Modes

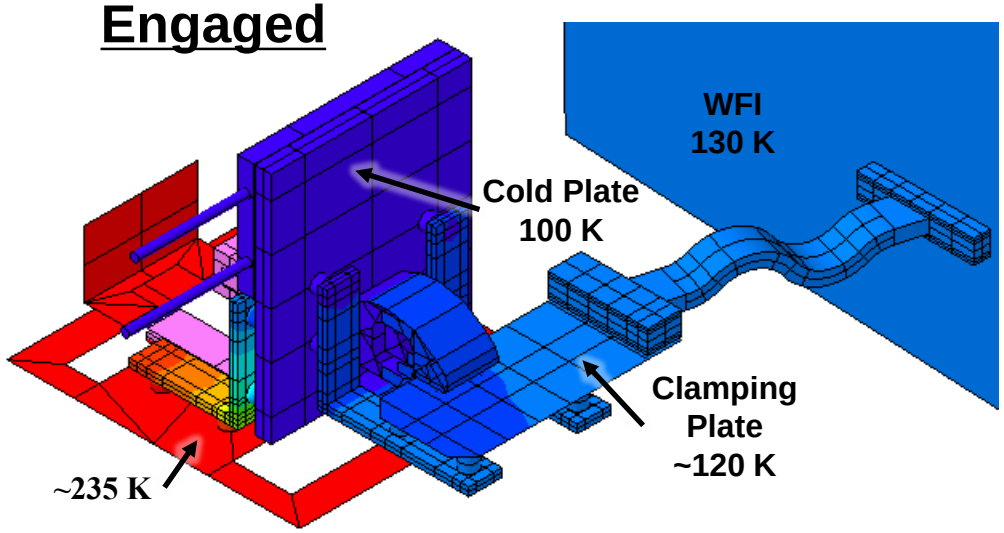
	Engaged	Disengaged	Disengaged Zero-Q
WFI TVAC Stage	WFI Transitions	WFI Testing Plateaus	WFI Balances
Vice Clamp	Engaged	Disengaged	
Cold Plate	On: Set hot/cold depending on transition (controlled with LN2/GN2 and/or heater)	Off: Temperature allowed to float	On: Set to measured WFI temperature to maintain Zero-Q



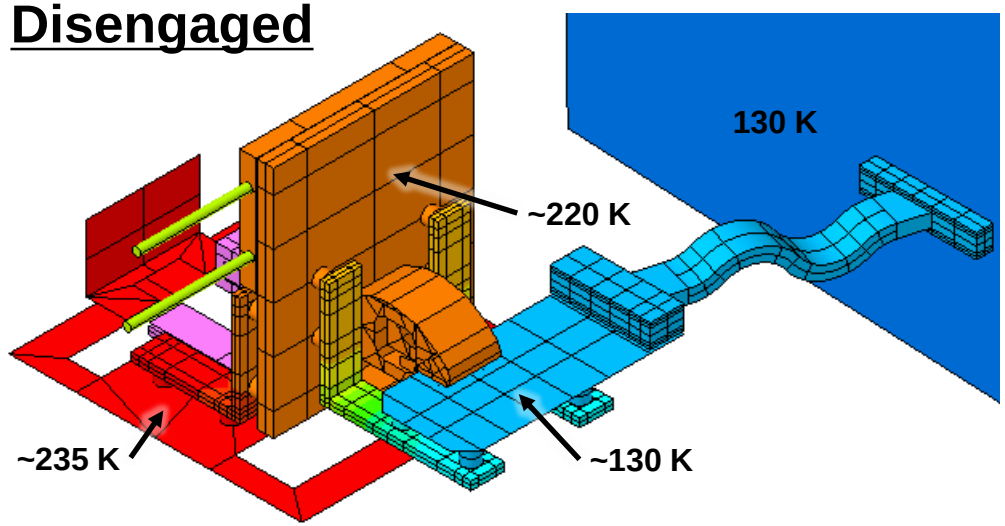
Temperature Profile (1/2)



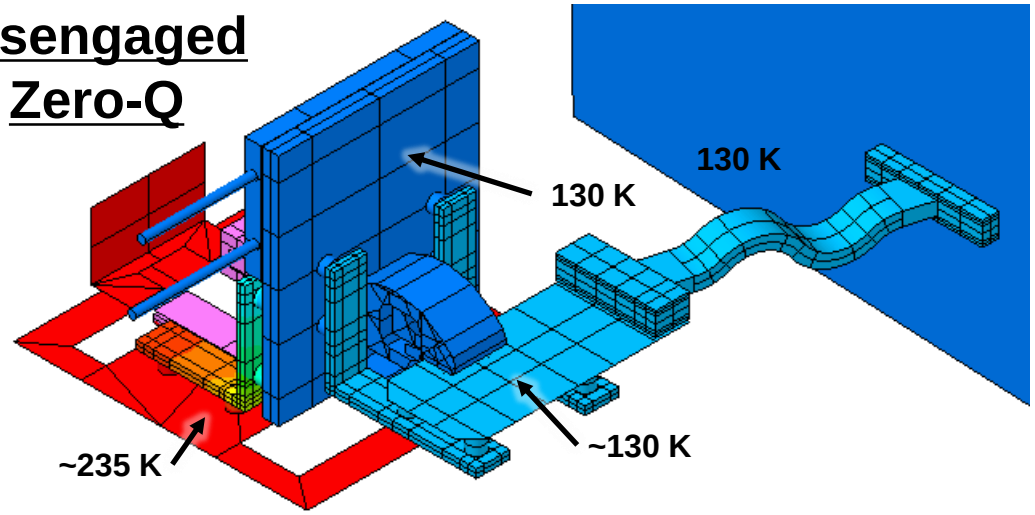
Engaged



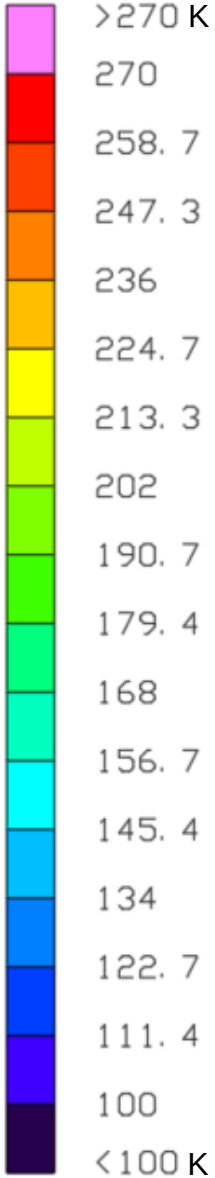
Disengaged

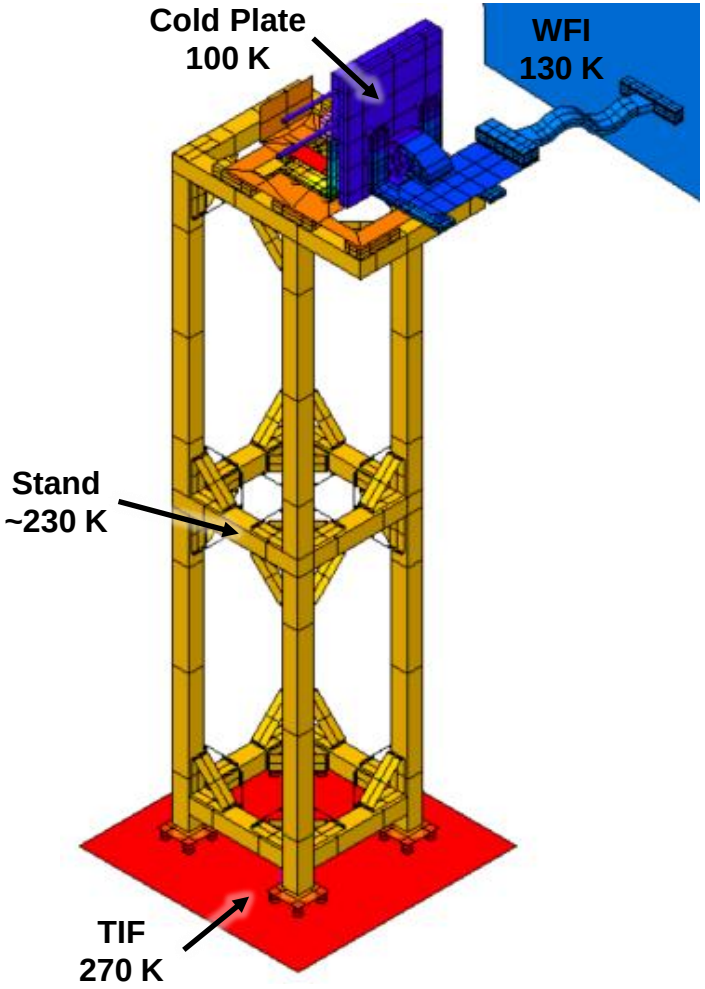


Disengaged Zero-Q

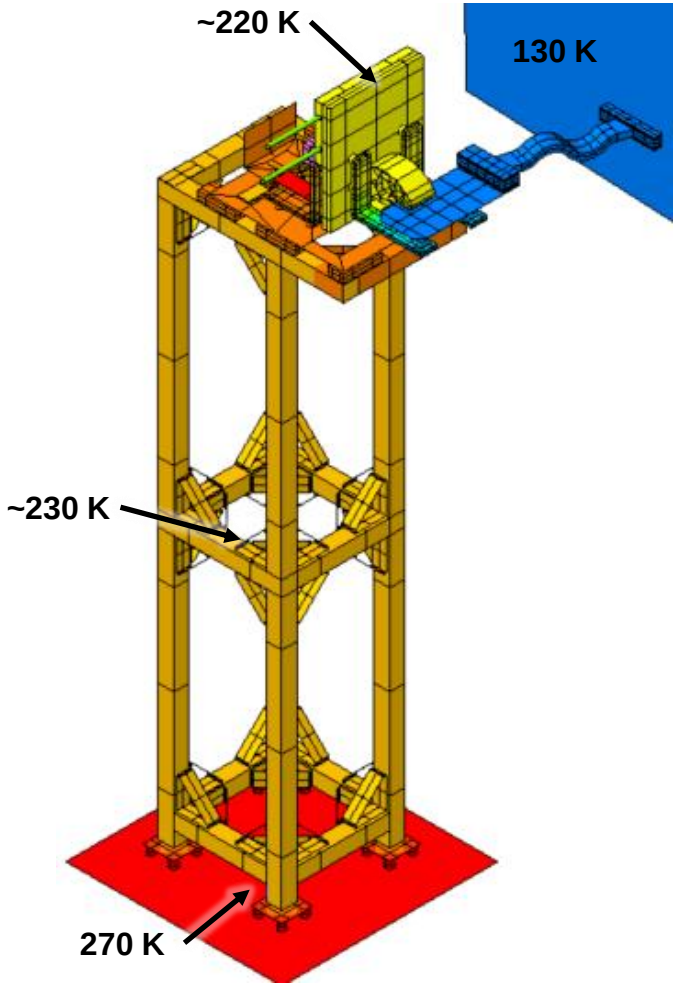


Temperature Profile (2/2)

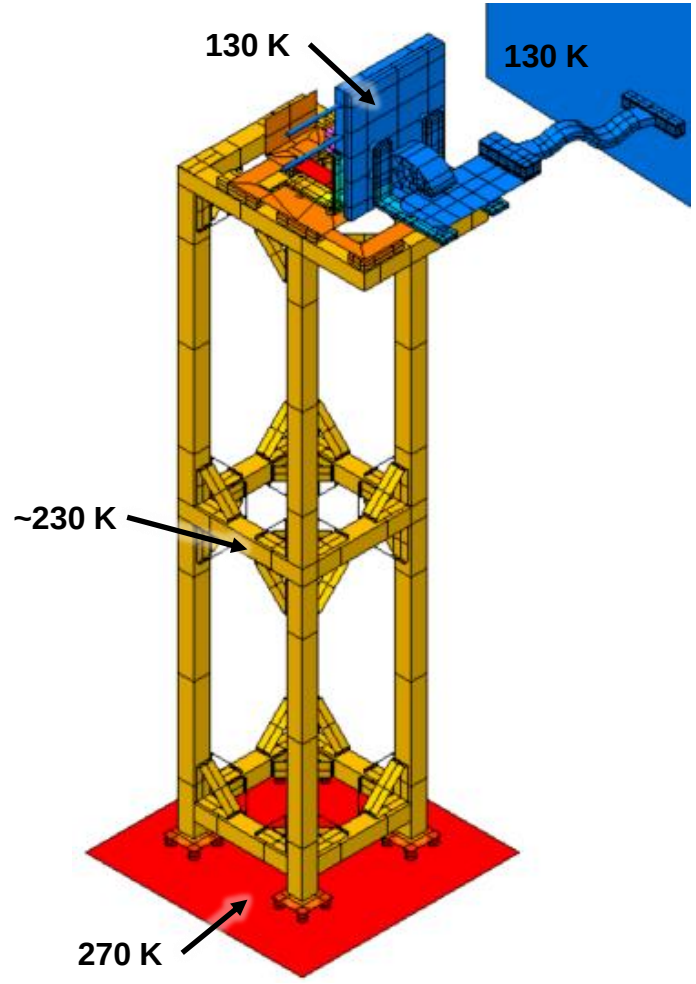




Engaged



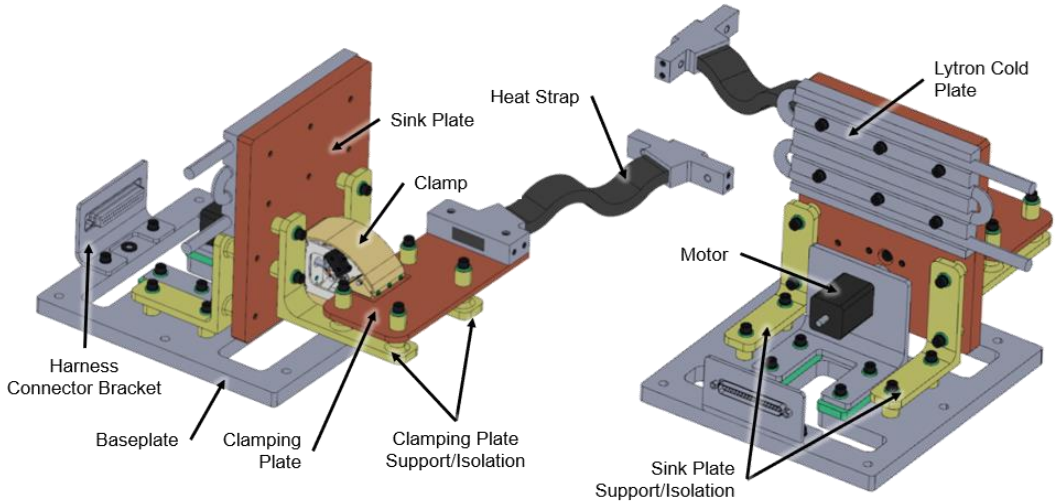
Disengaged



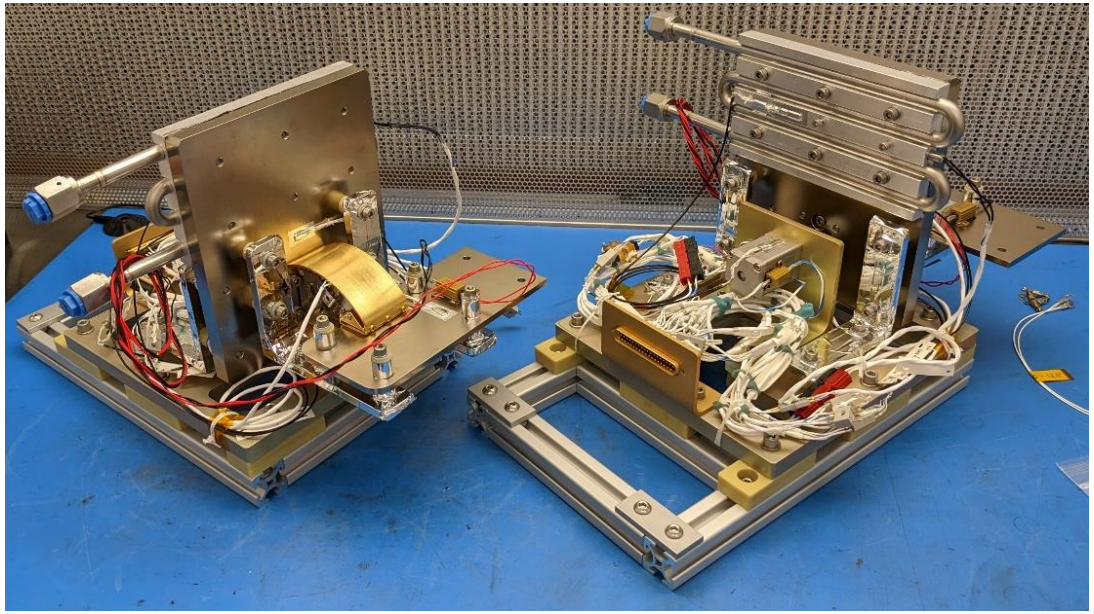
Disengaged Zero-Q

Thermal Hardware (per TARDIS)

- Temperature Sensors
  - 5 PRTs
    - Read by Lakeshore 336
  - 18 Thermocouples (only in GSFC TVAC)
    - Read by B4 LabVIEW
- Heaters
  - Cold Plate Heater
    - 50 W cartridge heater
    - PID controlled by Lakeshore 336 from a PRT
  - Motor Survival Heater
    - 10 W Vishay Dale-Ohm heater (two 15 Ω in series)
    - PID controlled by Lakeshore 336 from a PRT
  - Test Heater on Clamping Plate (only in GSFC TVAC)
    - 10 W Vishay Dale-Ohm heater (one 5 Ω)
    - Controlled by B4 LabVIEW
- Cold Plate
  - 3/8” OD VCR fitted Lytron Cold Plate
  - 40’ and 60’ flex hoses
  - Solenoids controlled from Lakeshores (controlled from B4 LabVIEW during GSFC TVAC)
- Control
  - Lakeshore 336 (3 total for both TARDIS units)
  - Computer & controllers for motors



I&T



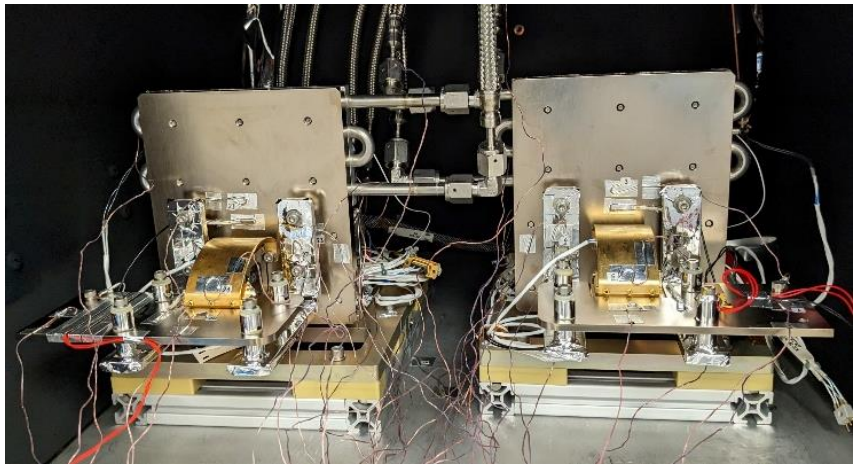
TARDIS units during I&T on a flow bench

TARDIS and LN2 flex line bakeout

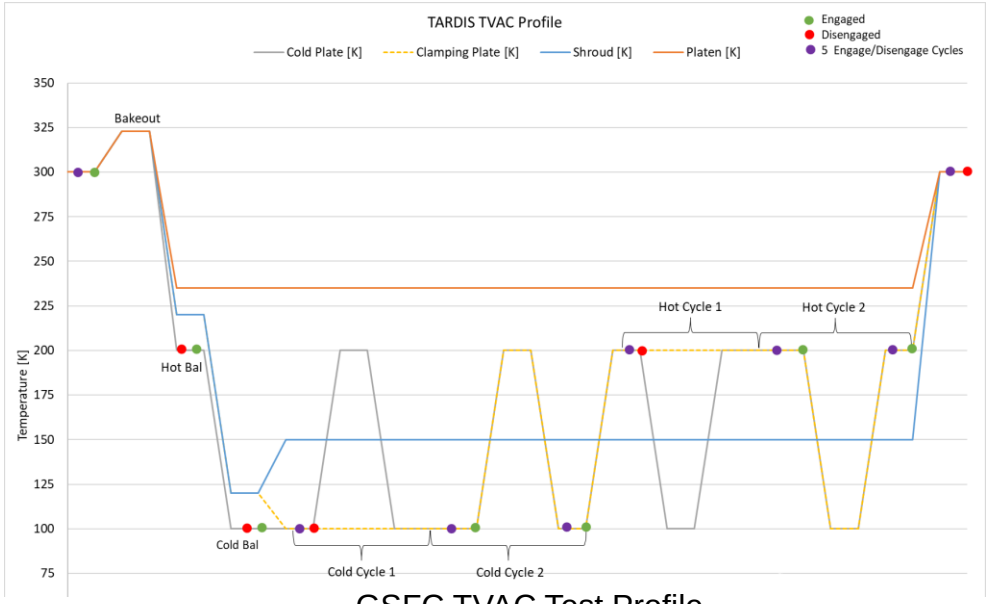
TARDIS with MLI

GSFC TVAC

- Overview
  - Purpose was to checkout TARDIS at GSFC before shipping to Ball
  - Bakeouts
    - Stand & flex hoses: 4/4– 4/17
    - Harnessing: 4/6 – 4/13
    - TARDIS: 4/24 – 5/1
  - GSFC TVAC
    - 5/1 – 5/9 in B4 MDC chamber
- Setup
  - Both TARDIS units tested together
  - Stand & PG straps not included
  - Dale-Ohm test heater used to simulate heat through strap
- Profile
  - Hot Balance (engaged & disengaged), Cold Balance (engaged & disengaged), Cold Cycles x2, Hot Cycles x2, Bakeout
  - Clamp to undergo at least 30 engage/disengage cycles across operational temperature range



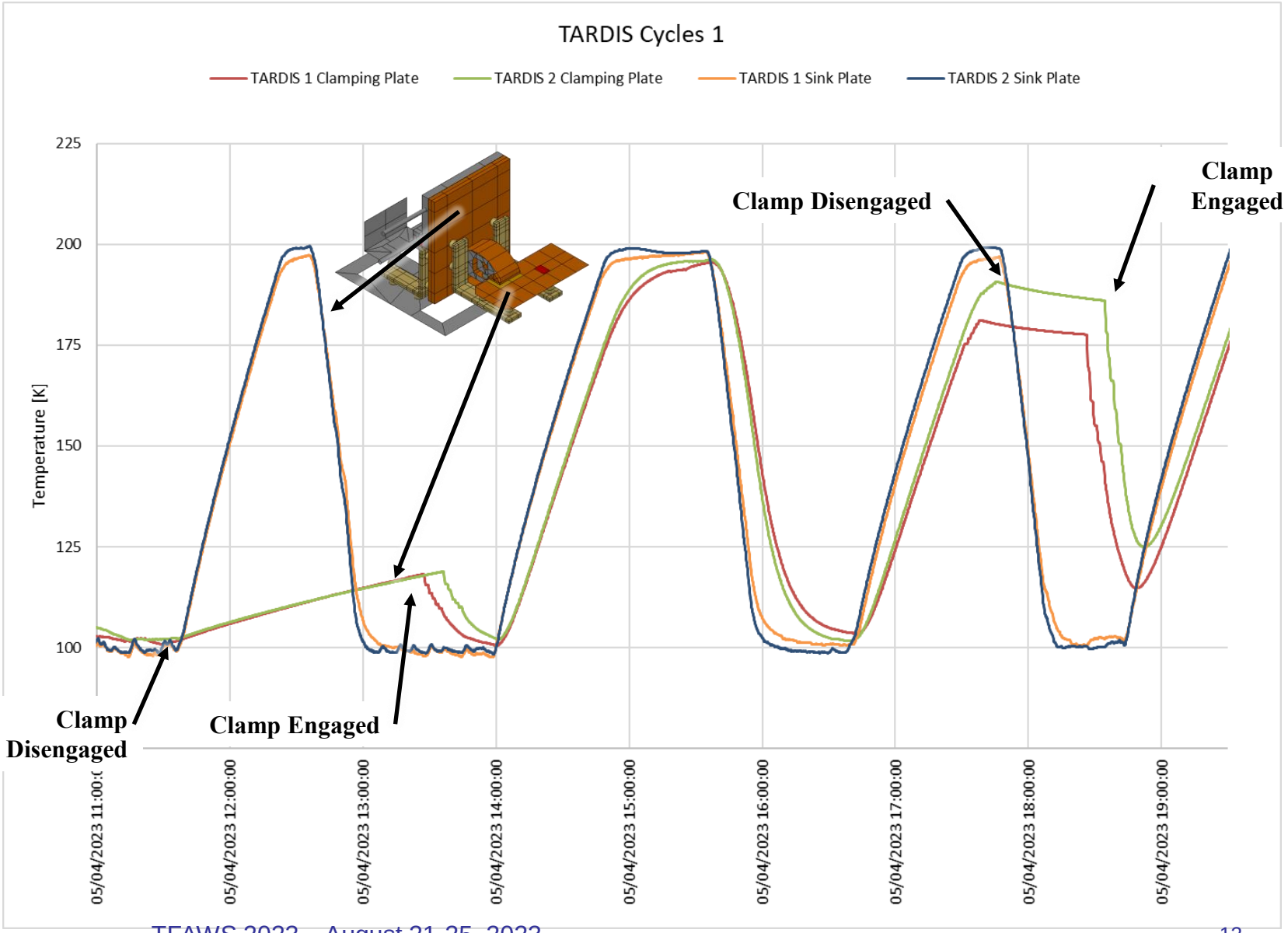
GSFC TVAC Setup



GSFC TVAC Test Profile

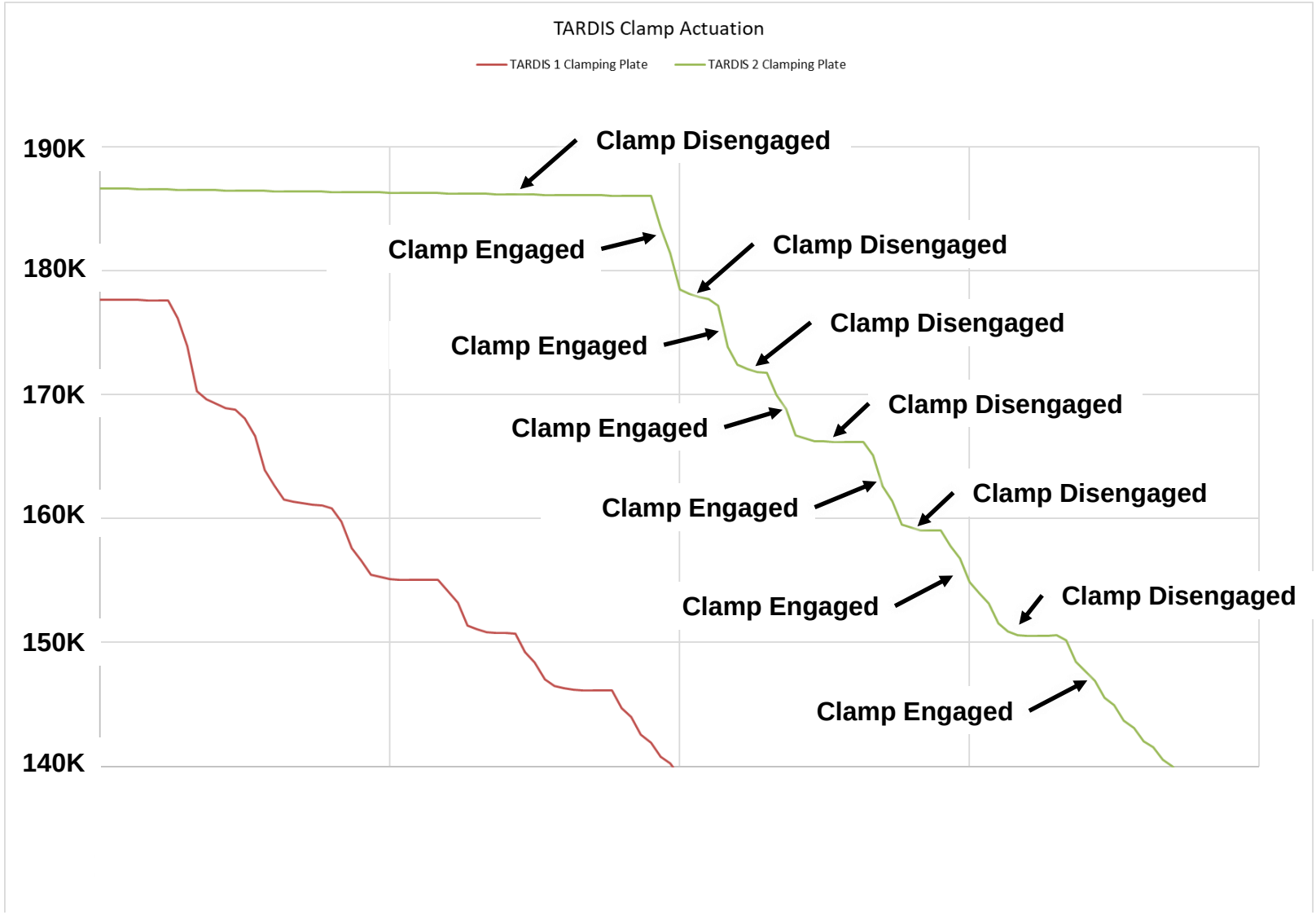
GSFC TVAC – Cycles

- Disengaged
  - No response on the clamping plate even with ~80K ΔT
  - Thermally decoupled
- Engaged
  - Clamping plate tracks with the sink plate when engaged
  - Thermally coupled



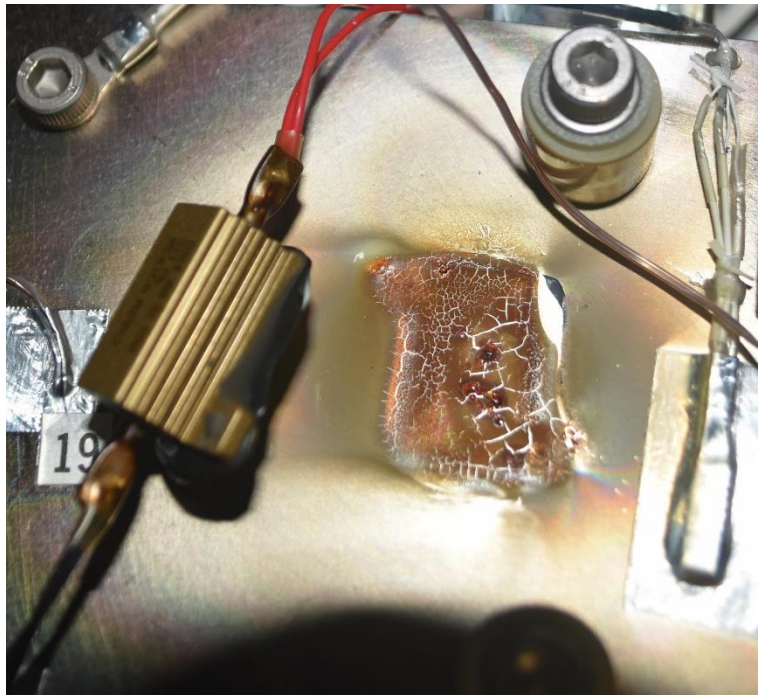
Clamp Actuations at Vacuum

- Clamp Actuations
  - Sink plate is cooler than clamping plate
  - Clamping plate quickly cools when clamp is engaged, temperature stabilizes when disengaged



GSFC TVAC Challenges/Issues

- Dale RH-10 10W 5Ω test heater de-bonded from the clamping plate on TARDIS 2
  - Bonded onto the surface with Stycast but did not have mechanical attachment with bolts
  - Broke vacuum and replaced with a Kapton film heater. Does not impact Ball TVAC.
- TARDIS 1 clamp intermittently stuck engaged
  - TARDIS 1 clamp stayed engaged after commanding it to disengage, twice. Only stuck closed on the first open command. Both times the clamp was able to be disengaged after waiting a few minutes.
  - Issue is likely that the clamp & motor shafts are misaligned causing a spot in the motor shaft rotation requiring a higher torque to overcome. To mitigate the risk the clamping torque was reduced to 80% of the motor's total torque so that we can disengage at 100% torque to unstick the clamp if needed. Benchtop testing confirmed this approach.
  - Failure of one (or both) TARDIS units during WFI TVAC will not impact baseline test plan



TARDIS Performance

- TARDIS 1 and TARDIS 2 Average Calculated Conductance
  - Engaged: 0.3068 W/K
  - Disengaged: 0.0026 W/K
  - Turndown Ratio: 117:1
- Performance is as expected, and TARDIS should operate as planned during WFI TVAC Campaign

$$G = \frac{Q_{test\ heater}}{T_{clamping\ plate} - T_{cold\ plate}}$$

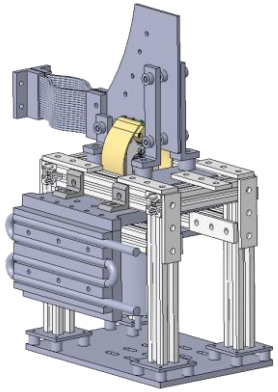
$$Turndown = \frac{G_{engaged}}{G_{disengaged}}$$

		Disengaged		Engaged	
		Cold	Hot	Cold	Hot
TARDIS 1	Test Heater [W]	0.10	0.10	5.00	5.00
	Clamping Plate [K]	174.20	225.07	126.17	212.30
	Cold Plate [K]	108.39	199.35	107.70	197.85
	Conductance [W/K]	0.0015	0.0039	0.2707	0.3459
	Average Conductance [W/K]	0.0027		0.3083	
	Turndown Ratio	114 : 1			
TARDIS 2	Test Heater [W]	0.10	0.10	5.00	5.00
	Clamping Plate [K]	176.68	227.27	125.12	212.39
	Cold Plate [K]	108.14	199.24	107.59	197.01
	Conductance [W/K]	0.0015	0.0036	0.2853	0.3251
	Average Conductance [W/K]	0.0025		0.3052	
	Turndown Ratio	121 : 1			

TARDIS vs L'Ralph AZQ Heat Switch

	TARDIS	L'Ralph AZQ [2]
Approximate Height	1.2m	0.4m
QTY in TVAC	2	1
Motor Survival Temp	253 K	77 K
TVAC Interface Temperature	> Payload	< Payload
Heat Strap	Pyrolytic Graphite x1	Braided Copper x2
Clamping Plate Orientation	Horizontal	Vertical
Engaged Conductance	0.3068 W/K	0.416 W/K
Disengaged Conductance	0.0027 W/K	0.0008 W/K
Turndown Ratio	117	520

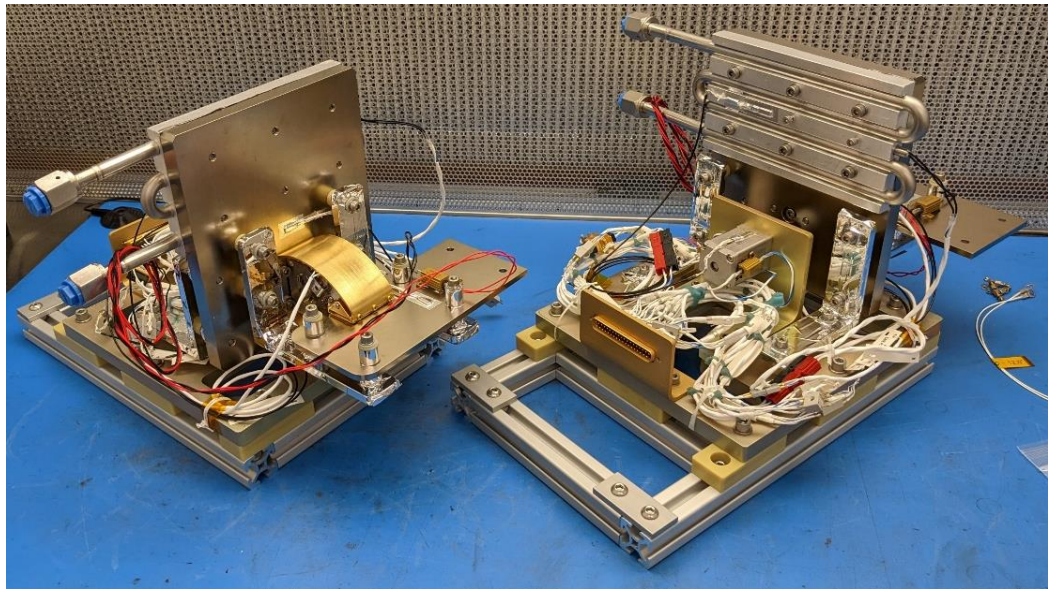
TARDIS



L'Ralph AZQ

Conclusion

- Summary
  - TARDIS is a GSE heat switch designed to speed up transition times for the RST WFI TVAC test campaign
  - Design is based off the L'Ralph AZQ Heat Switch
  - TARDIS is estimated to save at least 2 days of test time during the WFI TVAC test campaign
  - TARDIS can be used for future missions needing faster TVAC transitions
- Predicted Savings
  - Based on analysis, TARDIS predicted to save at least 2 days of test time in TVAC-1 and TVAC-2 during WFI transitions
- Additional Savings
  - TARDIS will be useful with nudging the system along to thermal balance



Acknowledgements

- TARDIS
  - Bryan Matonak
  - Ben Abresch
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  - Mark Klappenberger
- WFI
  - John Leanza
  - Hume Peabody
- Lucy L'Ralph AZQ
  - Juan Rodriguez-Ruiz
  - Daniel Bae
- B4 TVAC
  - Frank Robinson
  - Colton Cohill
  - Elliot Schwartz
  - Mike Chapman
- Moral Support
  - Eric Yee

References

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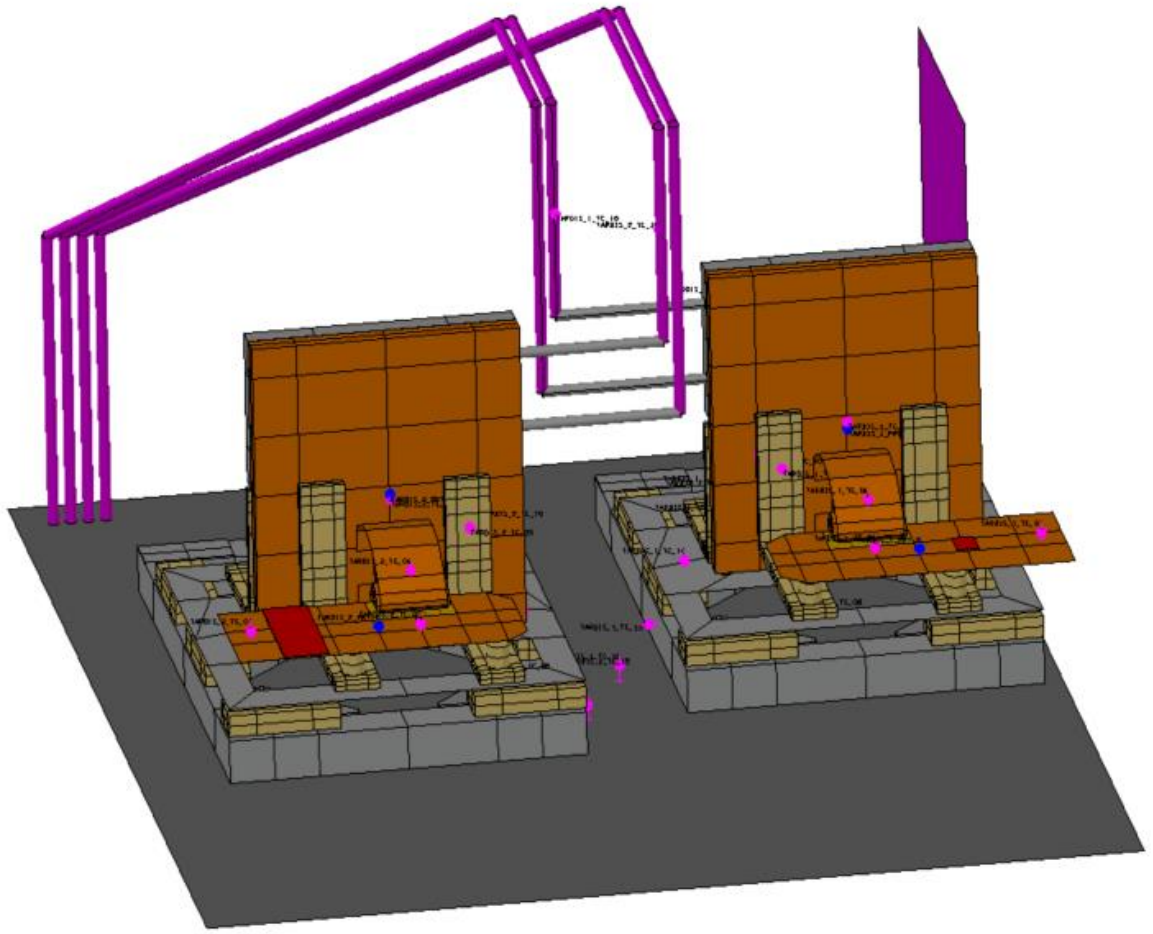
3. D. G. Gilmore, Spacecraft Thermal Control Handbook Volume 1: Fundamental Technologies, 2 ed., El Segundo, CA: The Aerospace Press, 2002.

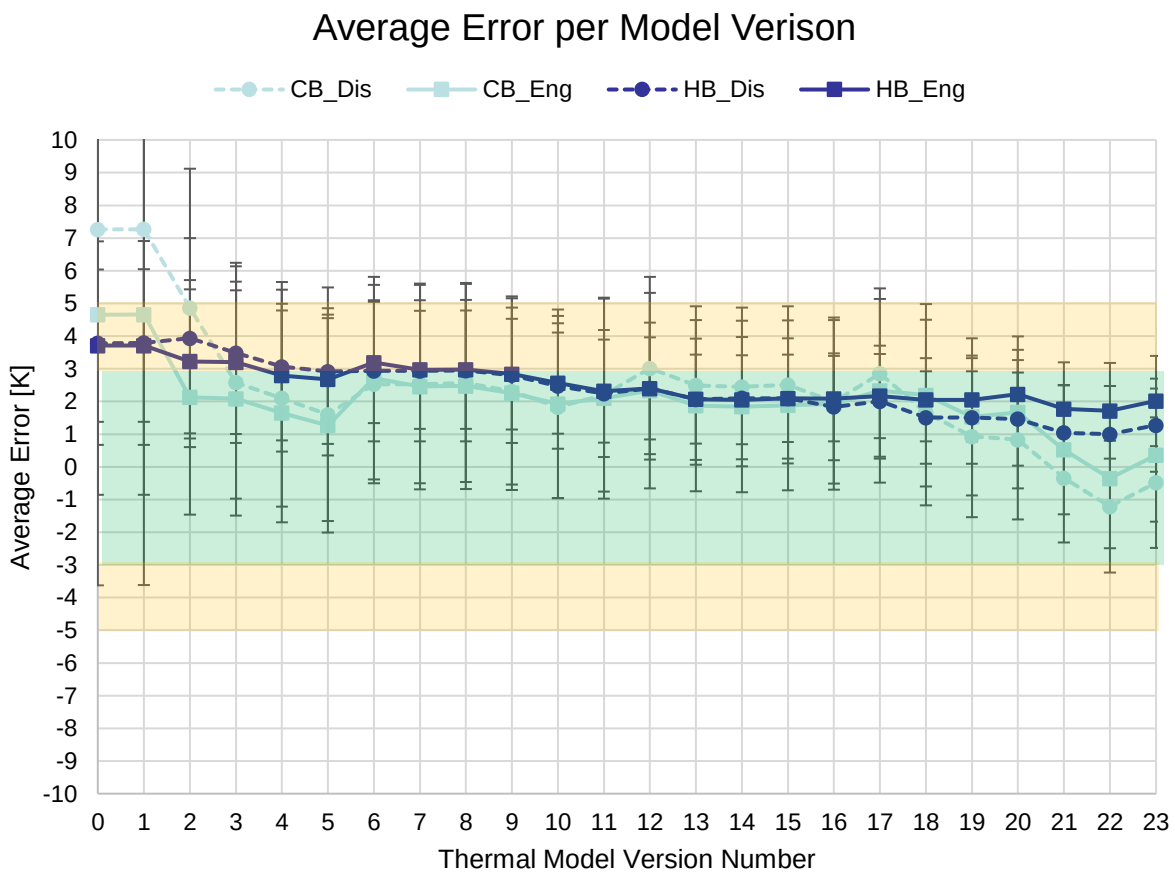
Acronyms

AZQ	Active Zero-Q
CSM	Cold Sensing Module
GN2	Gaseous Nitrogen
GSFC	Goddard Space Flight Center
ICES	International Conference on Environmental Systems
JSC	Johnson Space Center
LN2	Liquid Nitrogen
PG	Paralytic Graphite
PRT	Platinum Resistance Thermometer
RST	Roman Space Telescope
TARDIS	Thermal Acceleration Rate Device for Integrated Systems
TC	Thermocouple
TFAWS	Thermal & Fluids Analysis Workshop
TVAC	Thermal-Vacuum
WFI	Wide Field Instrument

Backup

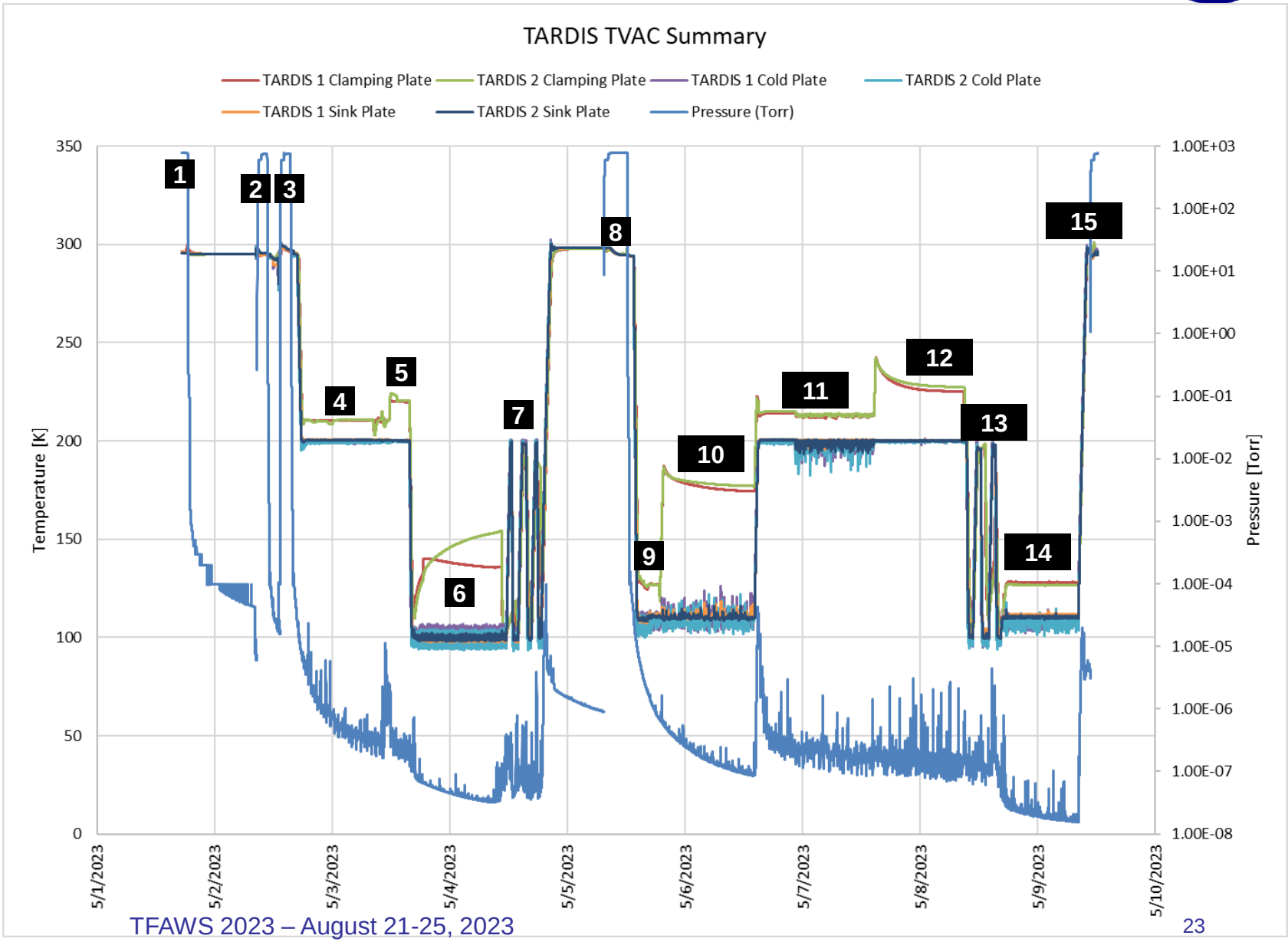
Thermal Model Correlation





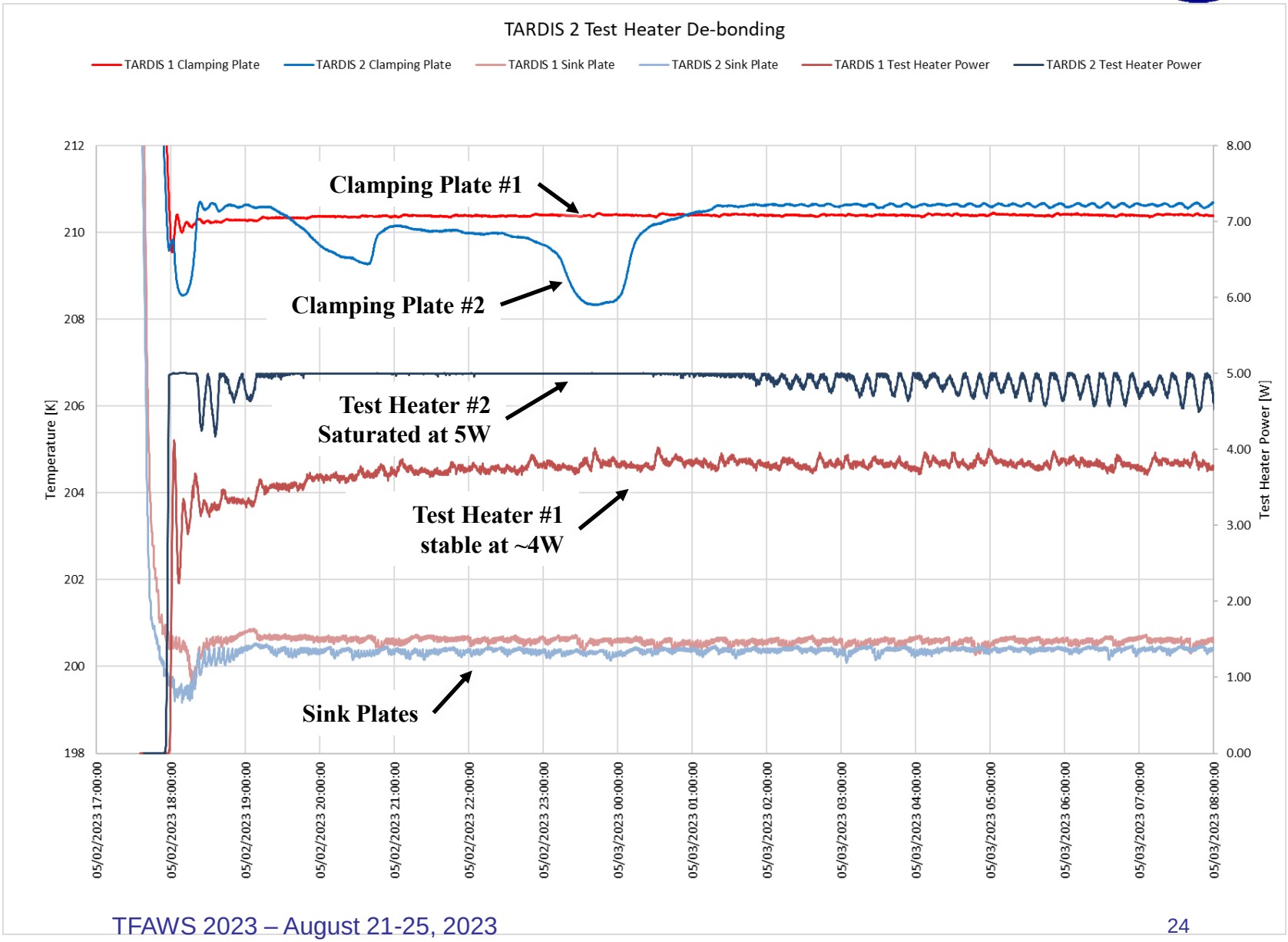
GSFC TVAC – Actual Profile

1. Initial pump down
2. Return to ambient to fix leak #1
3. Return to ambient to fix leak #2
4. Hot Bal Engaged, Attempt 1
5. Hot Bal Disengaged, Attempt 1
6. Cold Bal Disengaged, Attempt 1
7. Cycles
8. Return to ambient to replace de-bonded test heater
9. Cold Bal Engaged, Attempt 1
10. Cold Bal Disengaged, Attempt 2
11. Hot Bal Engaged, Attempt 2
12. Hot Bal Disengaged, Attempt 2
13. Cycles
14. Cold Bal Engaged, Attempt 3
15. Return to ambient & end of test

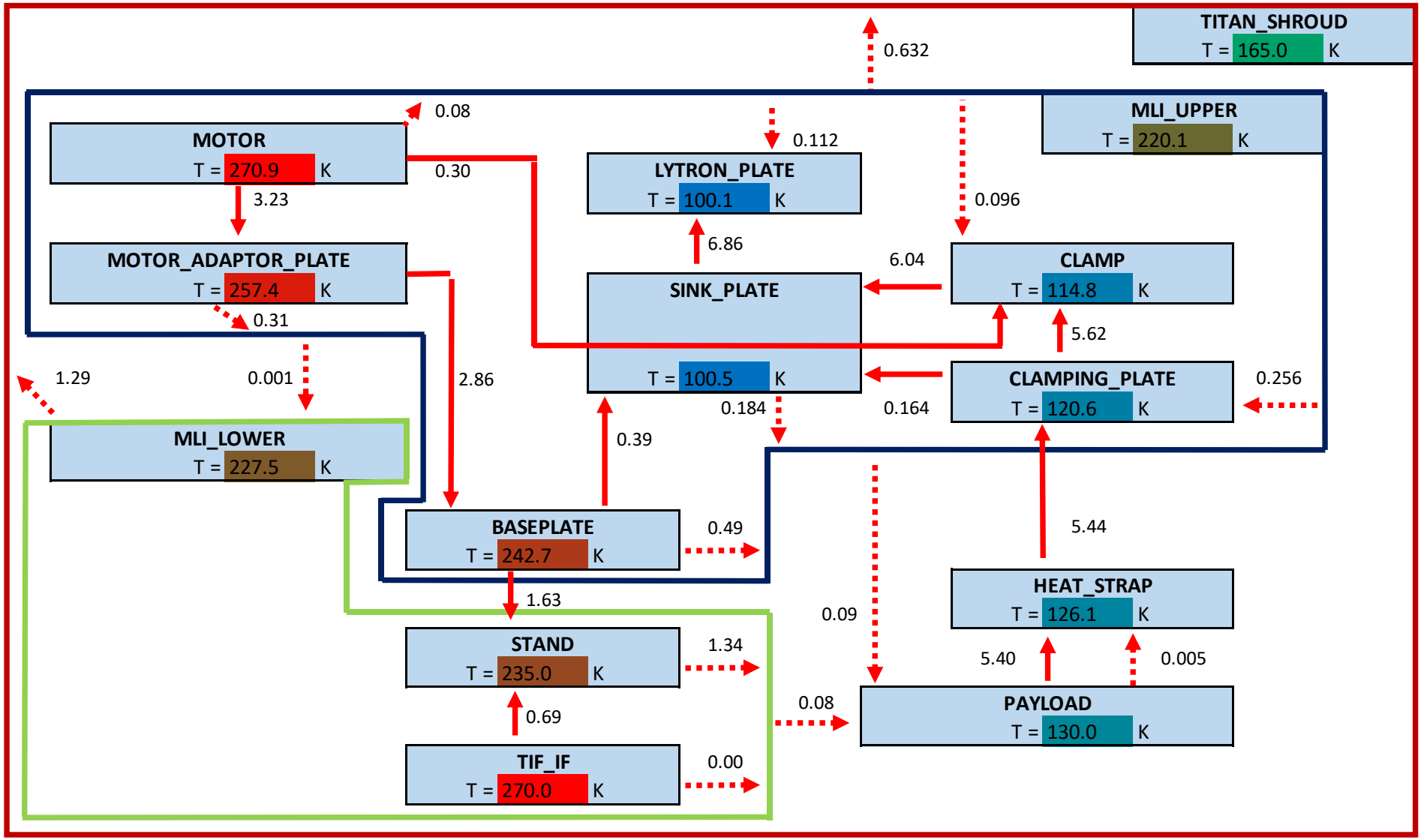


TARDIS 2 Test Heater De-bonding

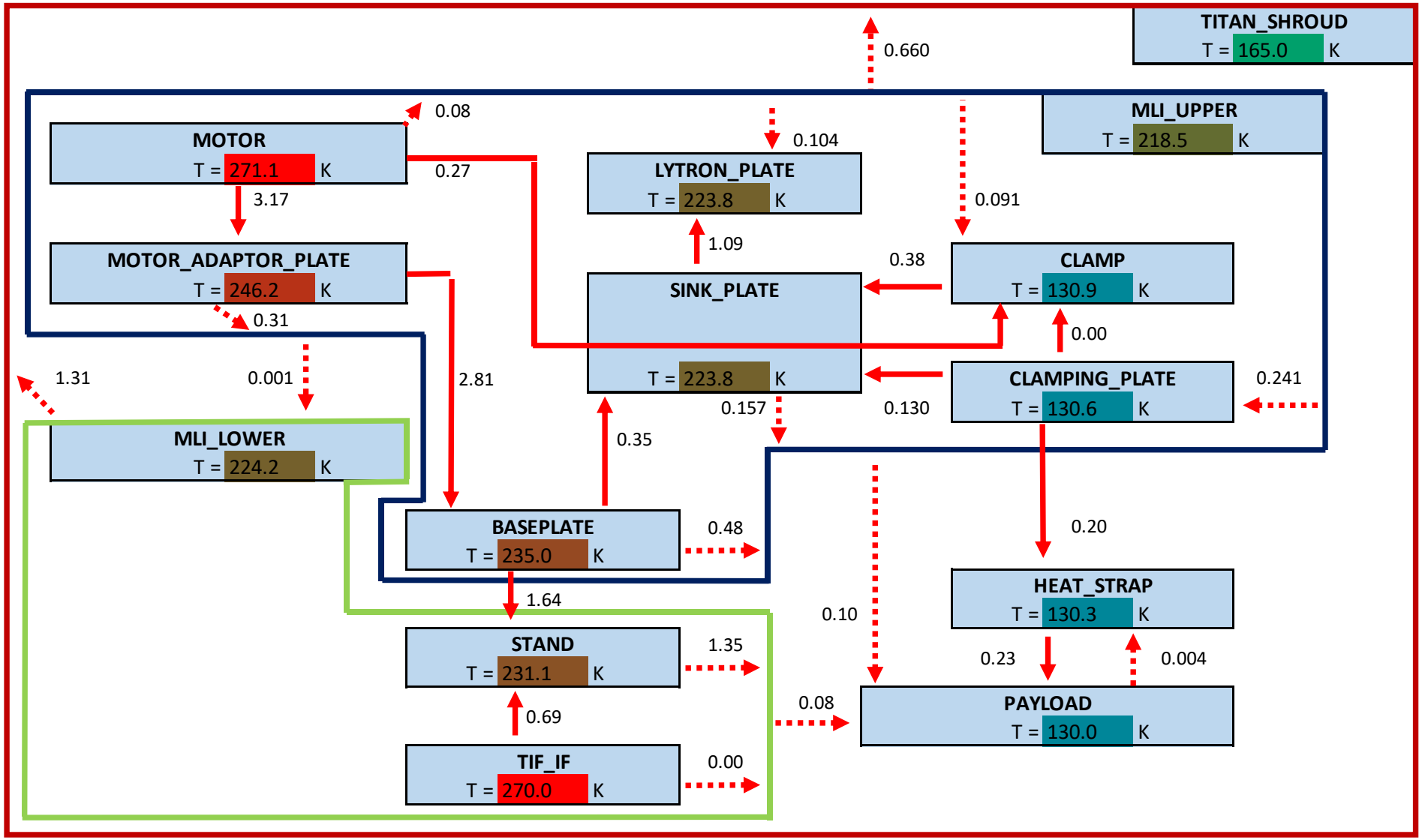
- Test heaters set to PID control, 210K setpoint at clamping plates
- Everything appeared to be reaching steady state when we left for the night at 19:00
- Overnight, clamping plate #2 cooled to ~208K even with test heater saturated at 5W
- Test heater #2 regained control around 1:00



Heat Map: Engaged



Heat Map: Disengaged



Heat Map: Disengaged Zero-Q