46th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL SYSTEMS ICES 2016

Dithering and Apparent Dithering

A Study of
Apparent Thermostat Anomalies
on Flight Missions

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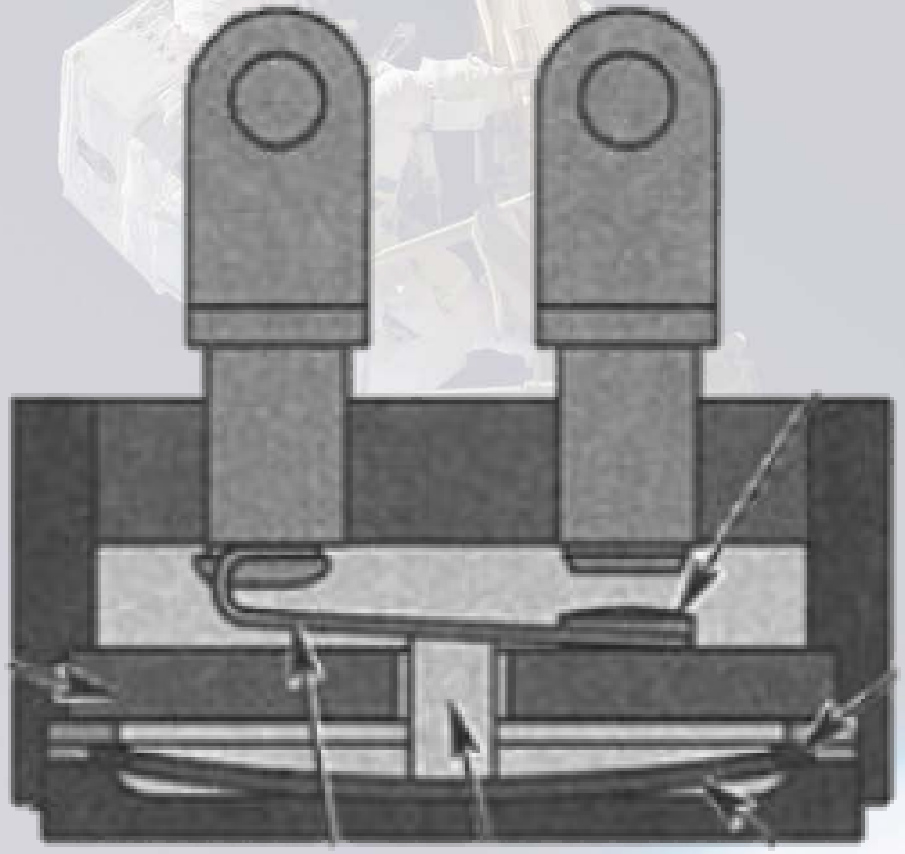
Purpose is to review Five Cases of *Apparent* Thermostat Dithering

1. Misdiagnosis
2. Dithering-like behavior
3. Dithering

Typical Thermostat Design



Terminals

Header

Bi-metallic Dis

Armature & Contacts

Pin Transfer

Figure from page 225 redacted from “The Spacecraft Thermal Control Handbook”

Overview of Dithering Symptoms

- Thermostat rapidly cycles on and off
  - Deadband 1.5 C
  - Frequency $\geq$ 1 cycle/second
- Loss of thermal control
  - Local temperatures drop below the control point of the thermostat

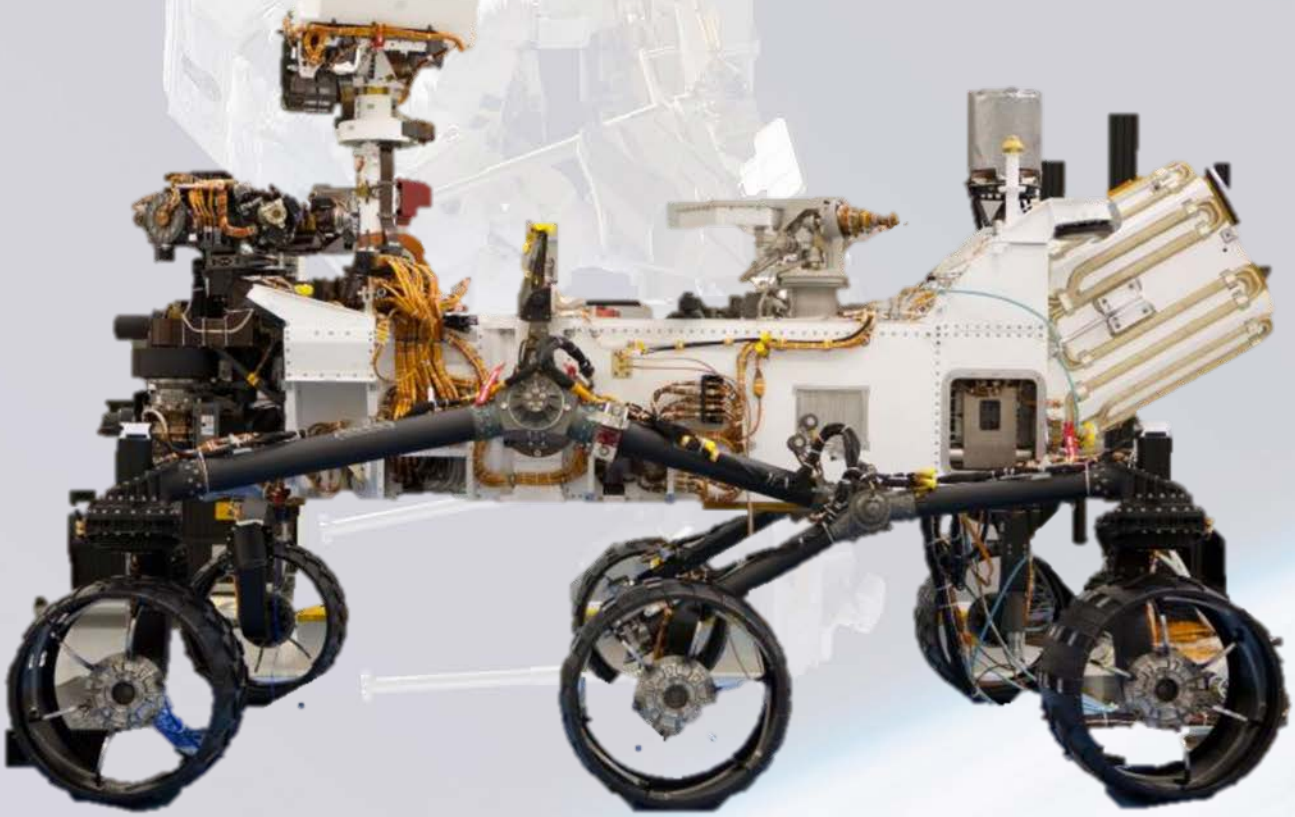
Dithering Root Causes

- Self-heating
- Internal contamination
- Temperature Gradients
- Thermal Shock
- Mechanical Shock

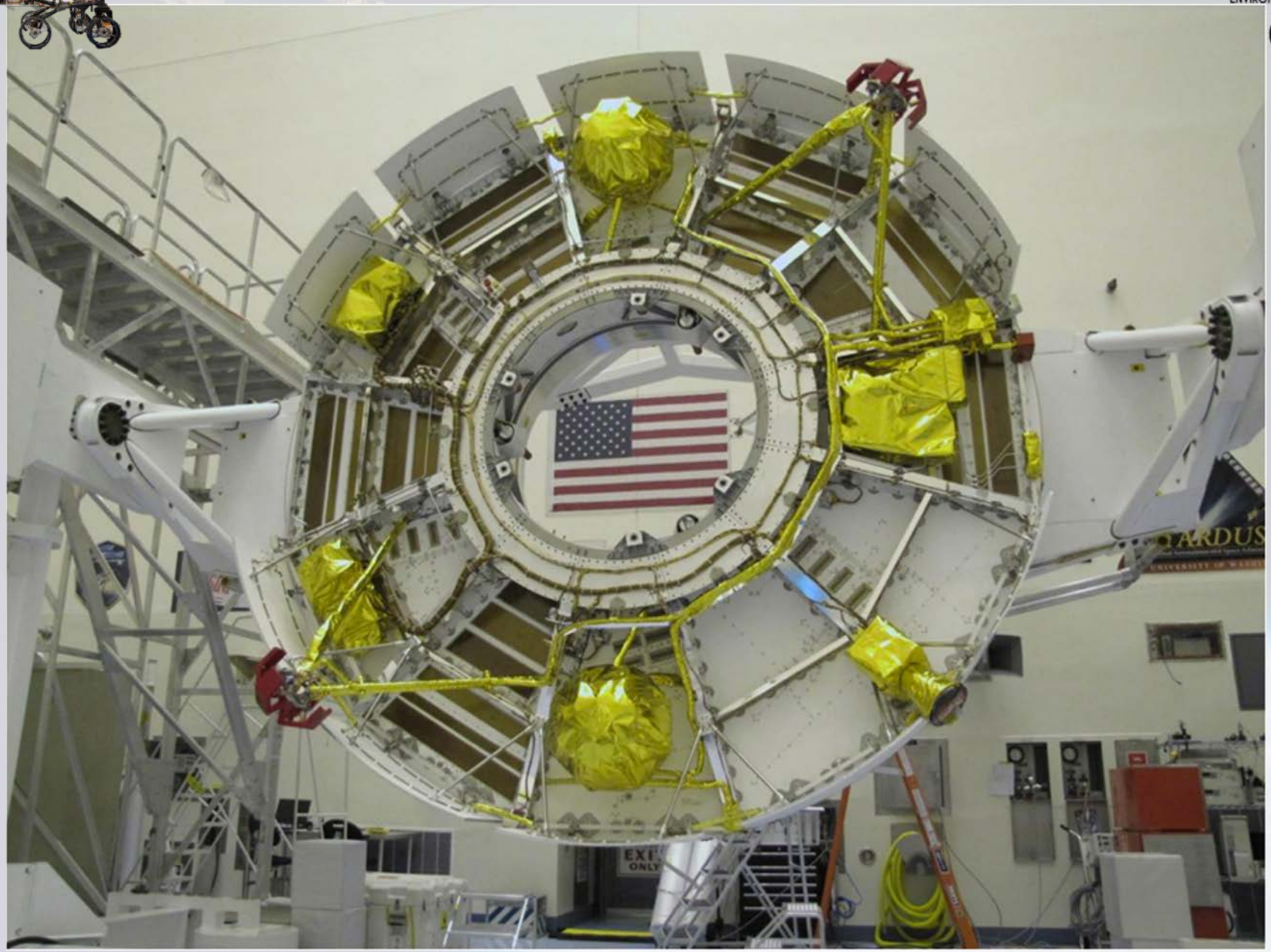
Five Case Studies

Case		Occurred During	Dithering?	Root Cause
1	MSL Cruise Stage	Testing	No	Telemetry and Control
2	SMAP Propellant Tank	Testing	No	Heater Zones Cross Talk
3	SMAP Magnetometer Boom	Testing	Maybe	Unknown
4	SMAP Deploy Actuator	Flight	Maybe	Unknown
5	MER Rover Battery	Surface Operations	Yes	Unknown

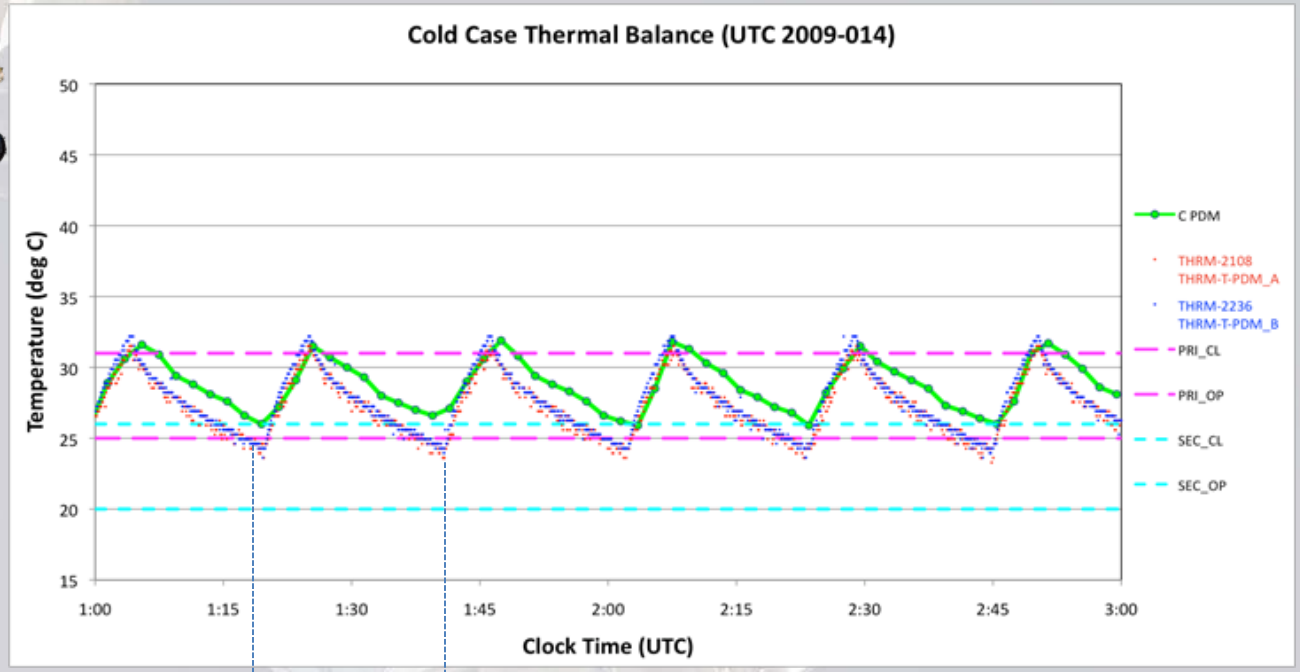
Case 1 Mars Science Laboratory (MSL) Cruise Stage Thermal Testing

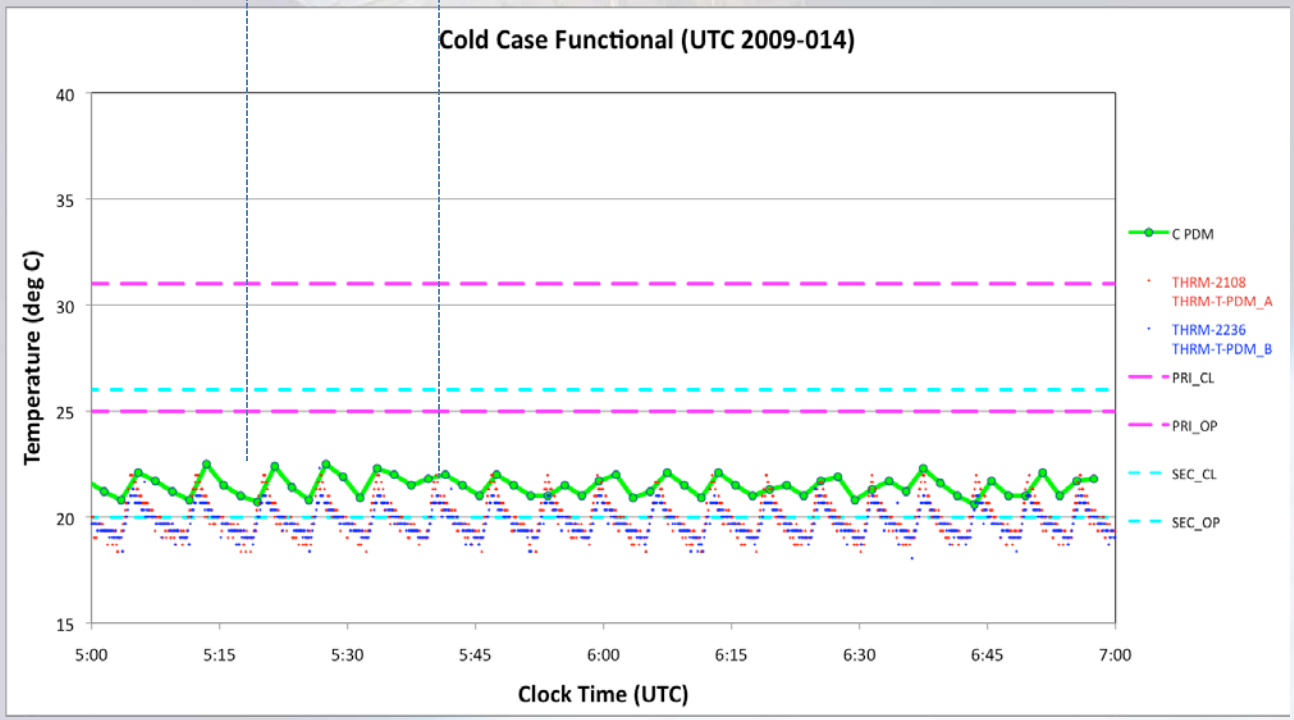


NASA/JPL-Caltech



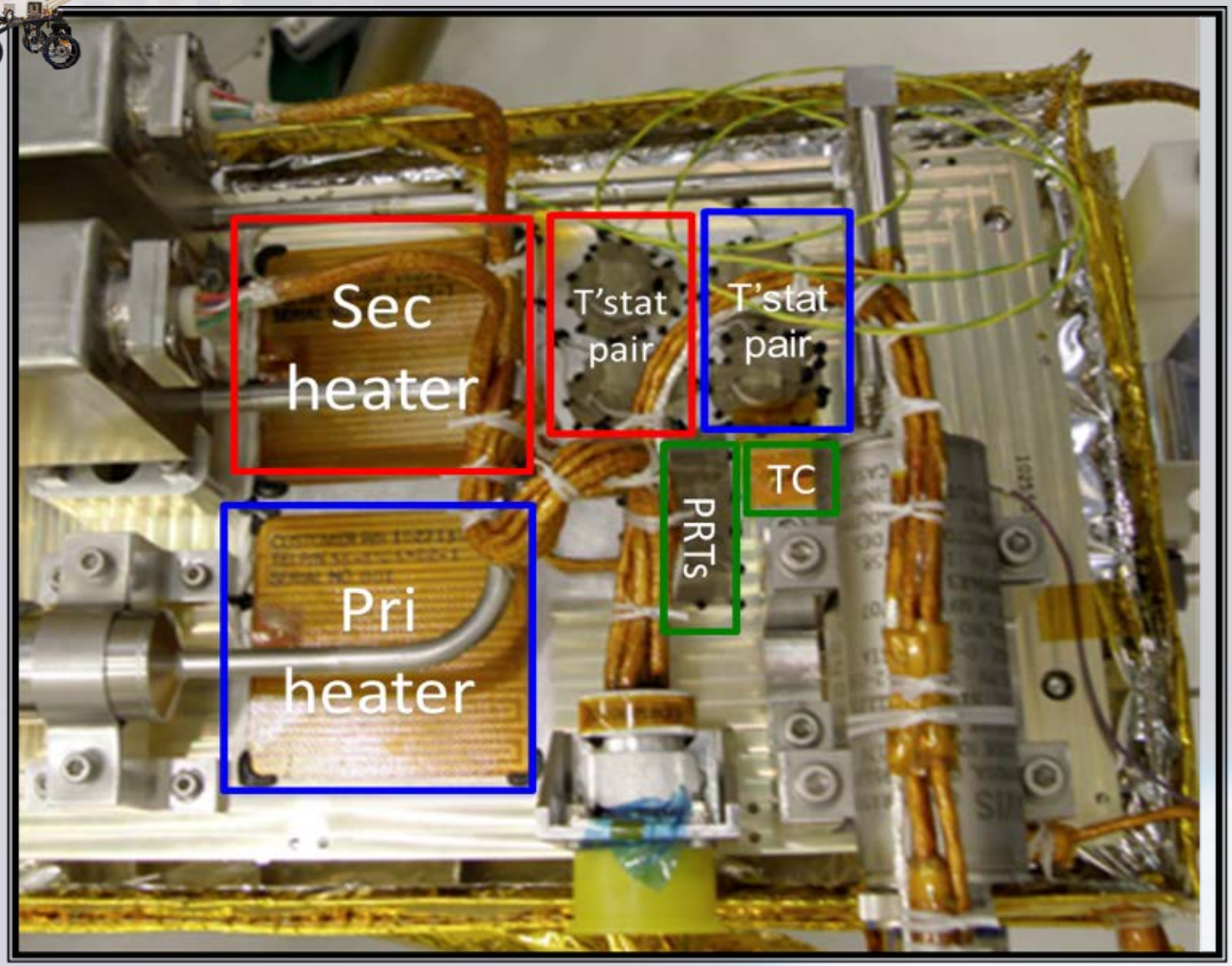
NASA/JPL-Caltech


Cold Case Thermal Balance (UTC 2009-014)
Temperature (deg C)
50
45
40
35
30
25
20
15
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
Clock Time (UTC)
C PDM
THRM-2108
THRM-T-PDM_A
THRM-2236
THRM-T-PDM_B
PRI_CL
PRI_OP
SEC_CL
SEC_OP


Cold Case Functional (UTC 2009-014)
Temperature (deg C)
40
35
30
25
20
15
5:00
5:15
5:30
5:45
6:00
6:15
6:30
6:45
7:00
Clock Time (UTC)
C PDM
THRM-2108
THRM-T-PDM_A
THRM-2236
THRM-T-PDM_B
PRI_CL
PRI_OP
SEC_CL
SEC_OP

Dithering?

Sensor	Primary	Secondary
Thermocouple	4.5°C to 6.0°C	1.3°C to 1.7°C
PRTs	6.0°C to 8.5°C	3.4°C to 3.6°C
Cycle time	21-min	5.5-min



Primary Circuit

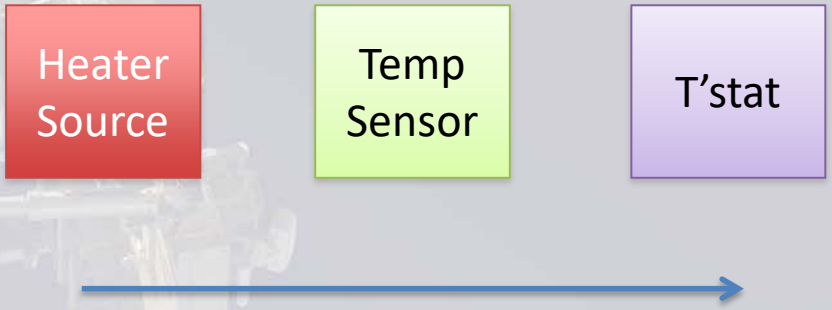
Secondary Circuit

Temp Sensors

Sensing & Control Configuration Problem

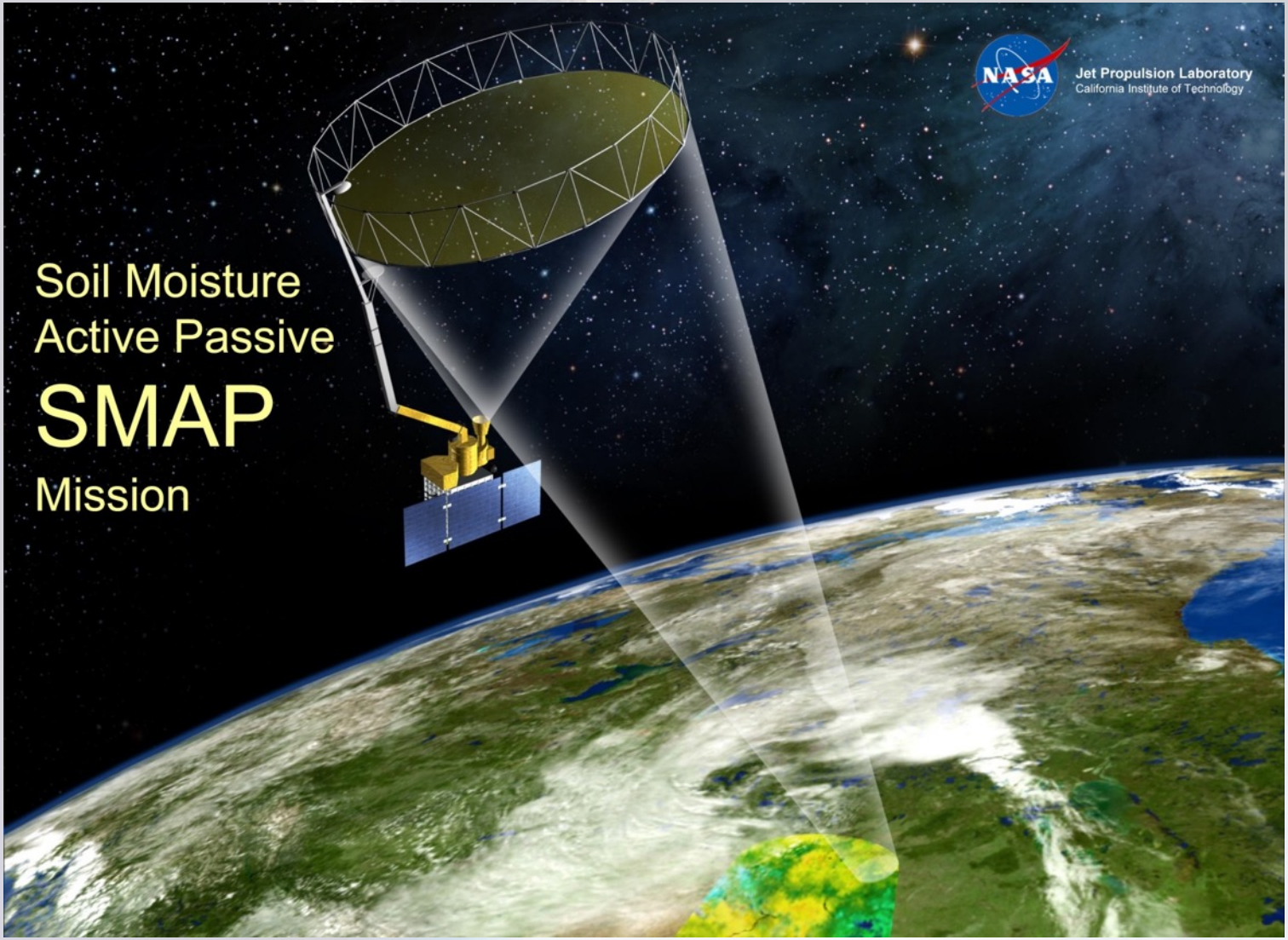
NOT DITHERING

- The **primary circuit** is arranged so that the temperature sensors will get hotter than the thermal switches.



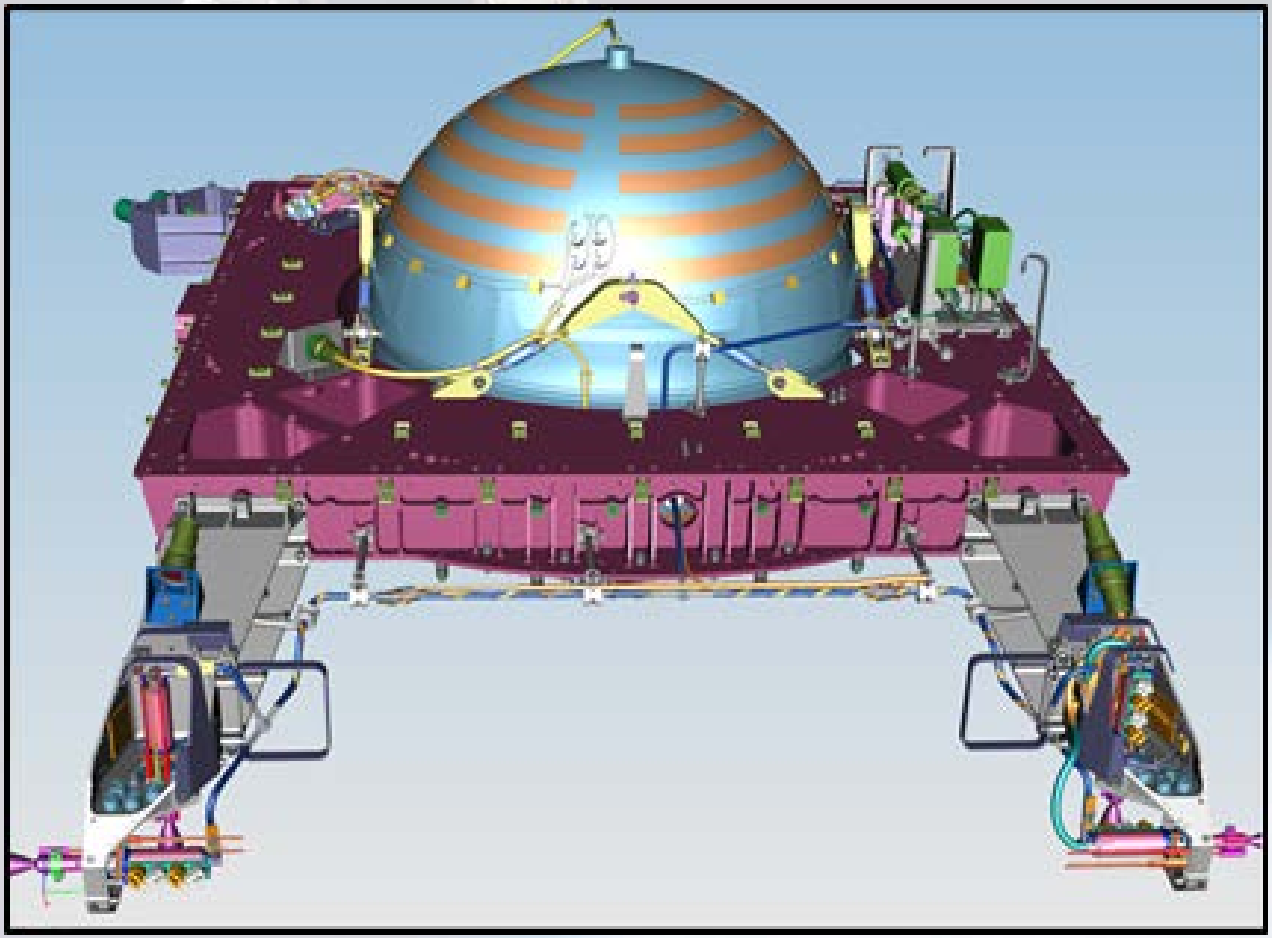
- The **secondary circuit** is arranged so that the thermal switches get hotter than the temperature sensors.

Case 2 SMAP Propellant Tank

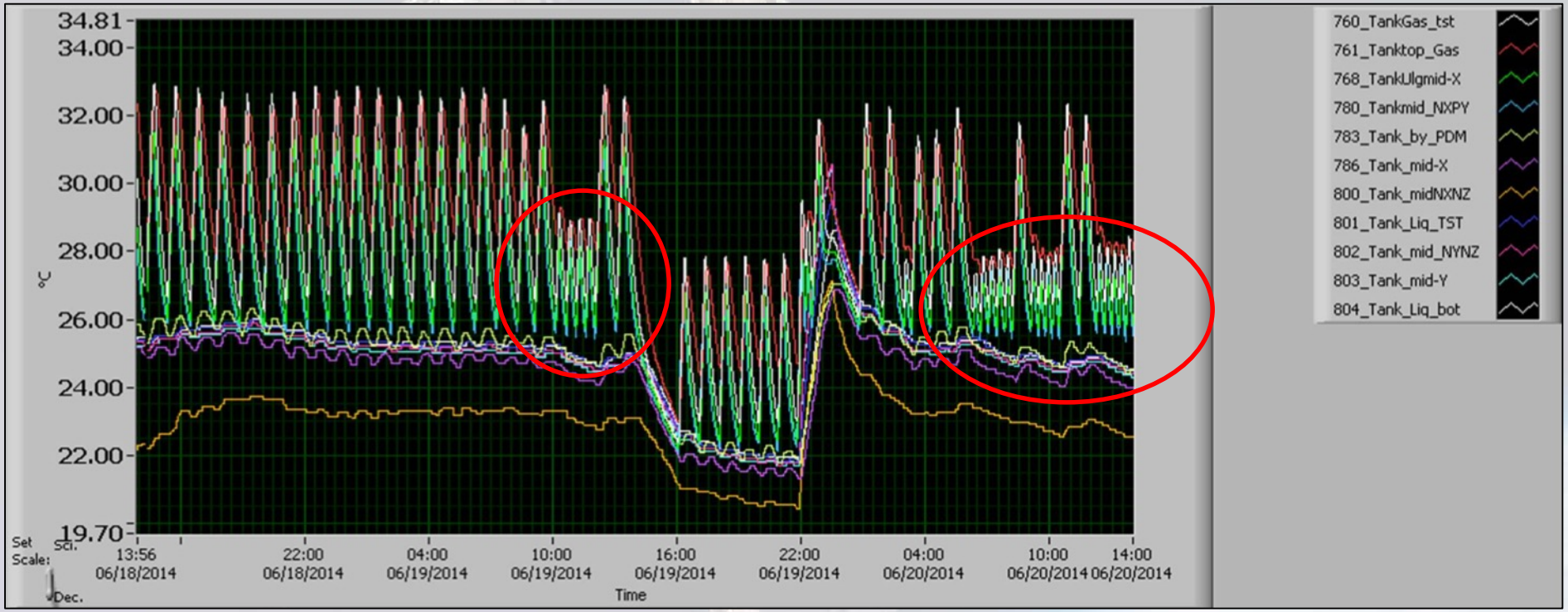


NASA/JPL-Caltech

SMAP Propellant Tank Thermostats

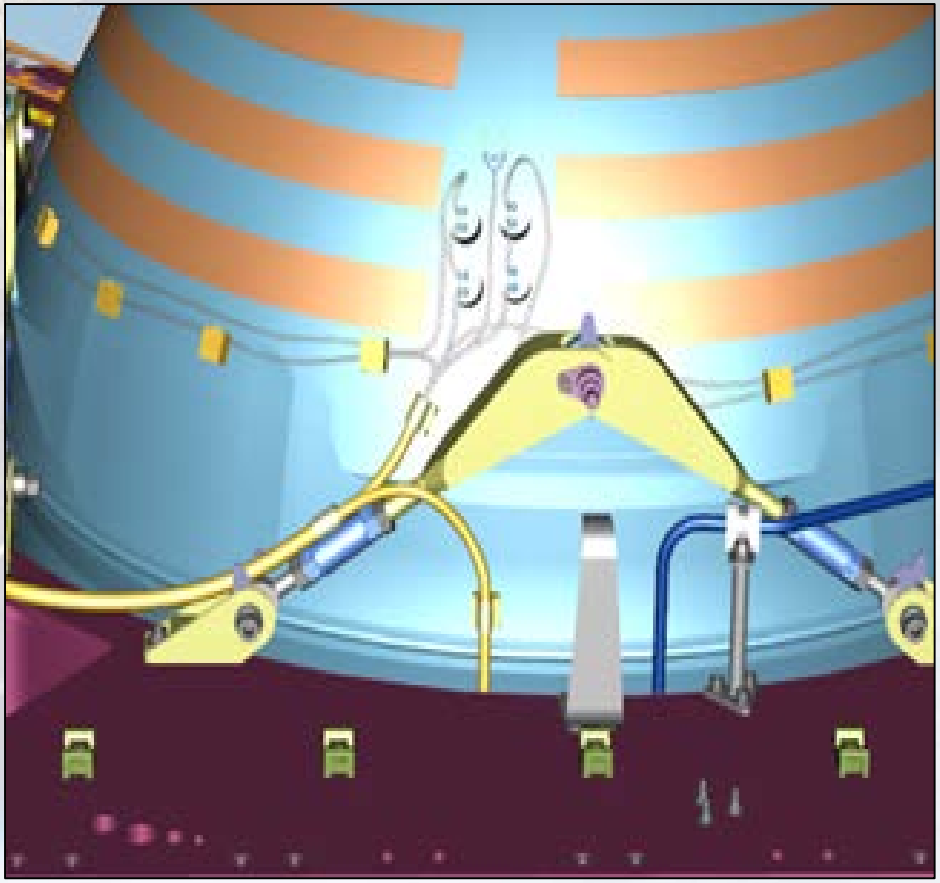


Dithering Signature?



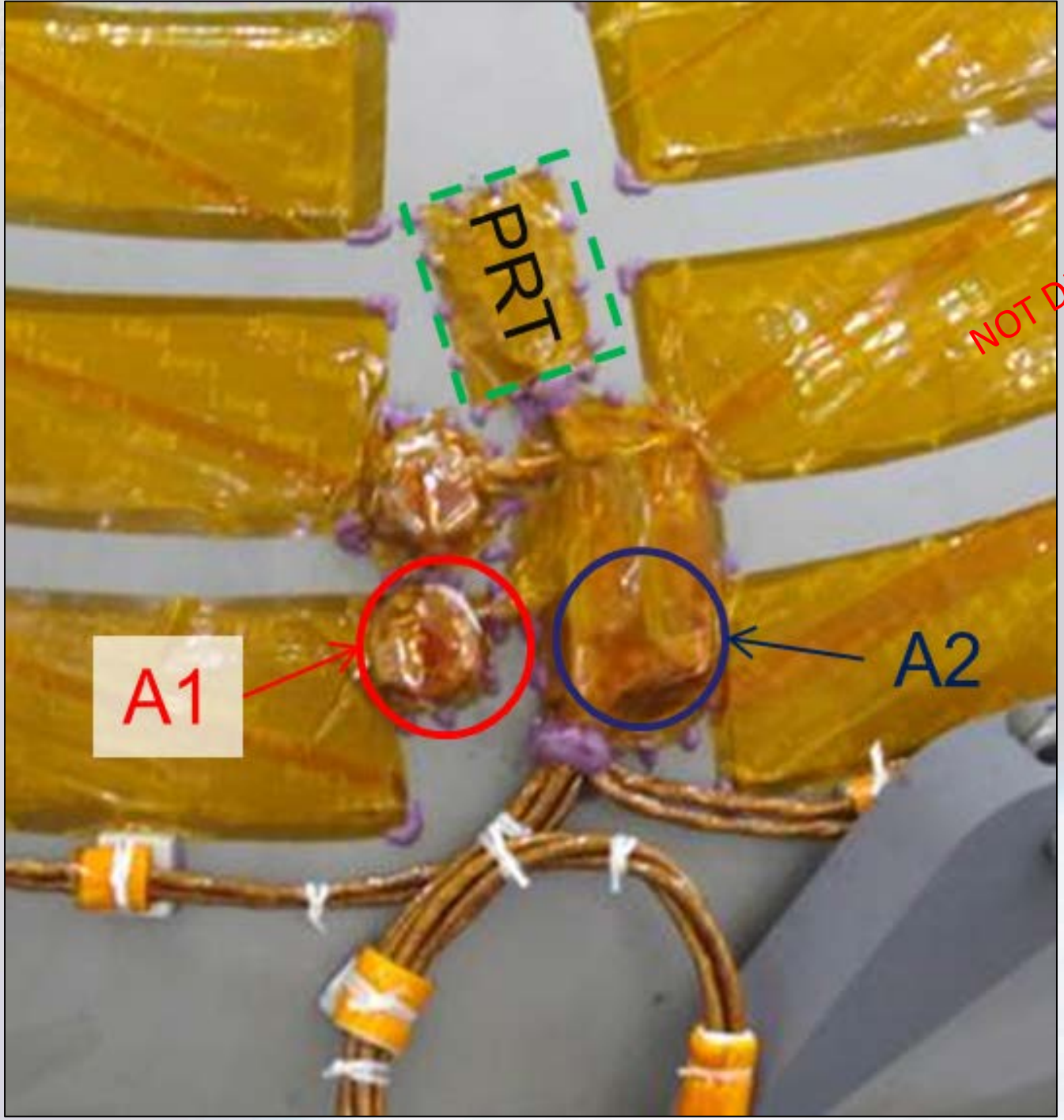
Propellant Tank

- Titanium Substrate
- Empty Tank
- Near Heat Leak



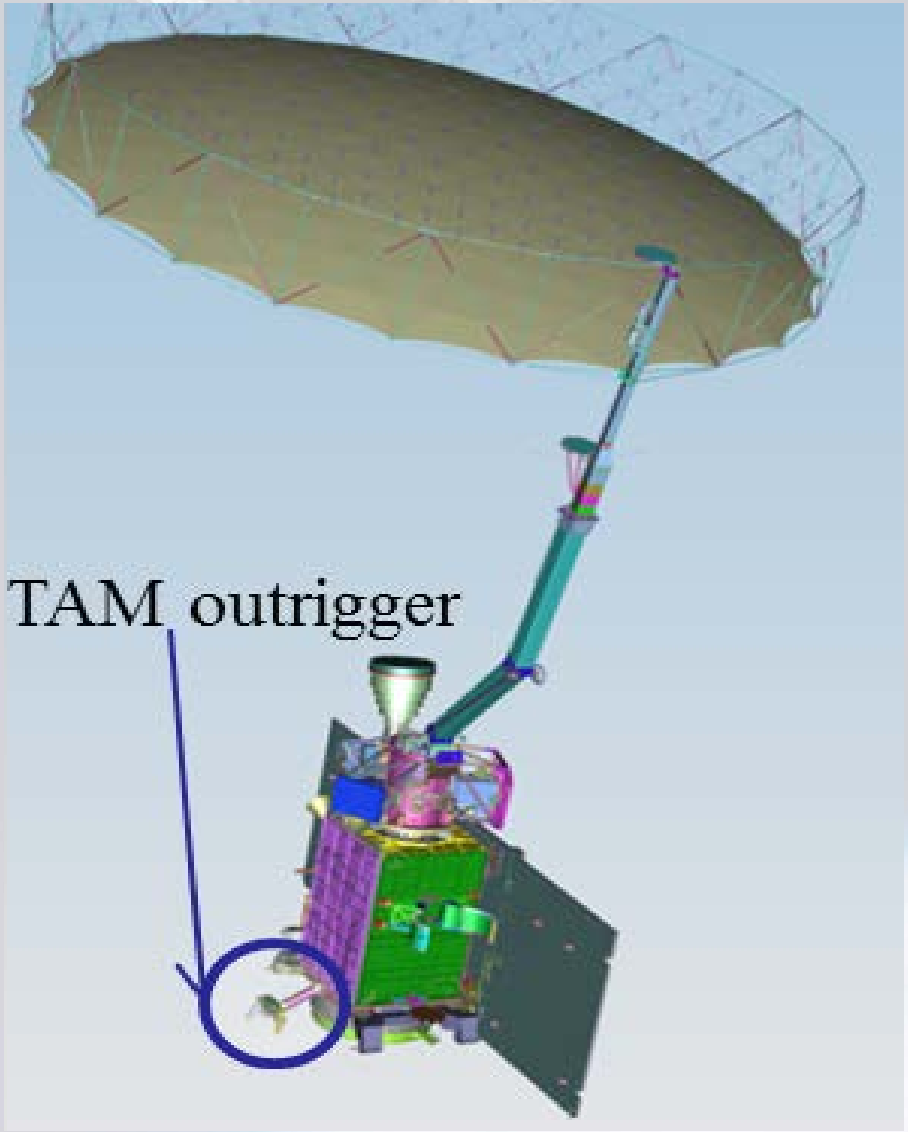
Diagnosis

- **Control** The thermostat control varied
- **Configuration** The temperature sensors had some sufficient distance from the two thermostats.
- **Variablility** Secondary influence by other local heaters on the mid-deck and bottom of the tank.

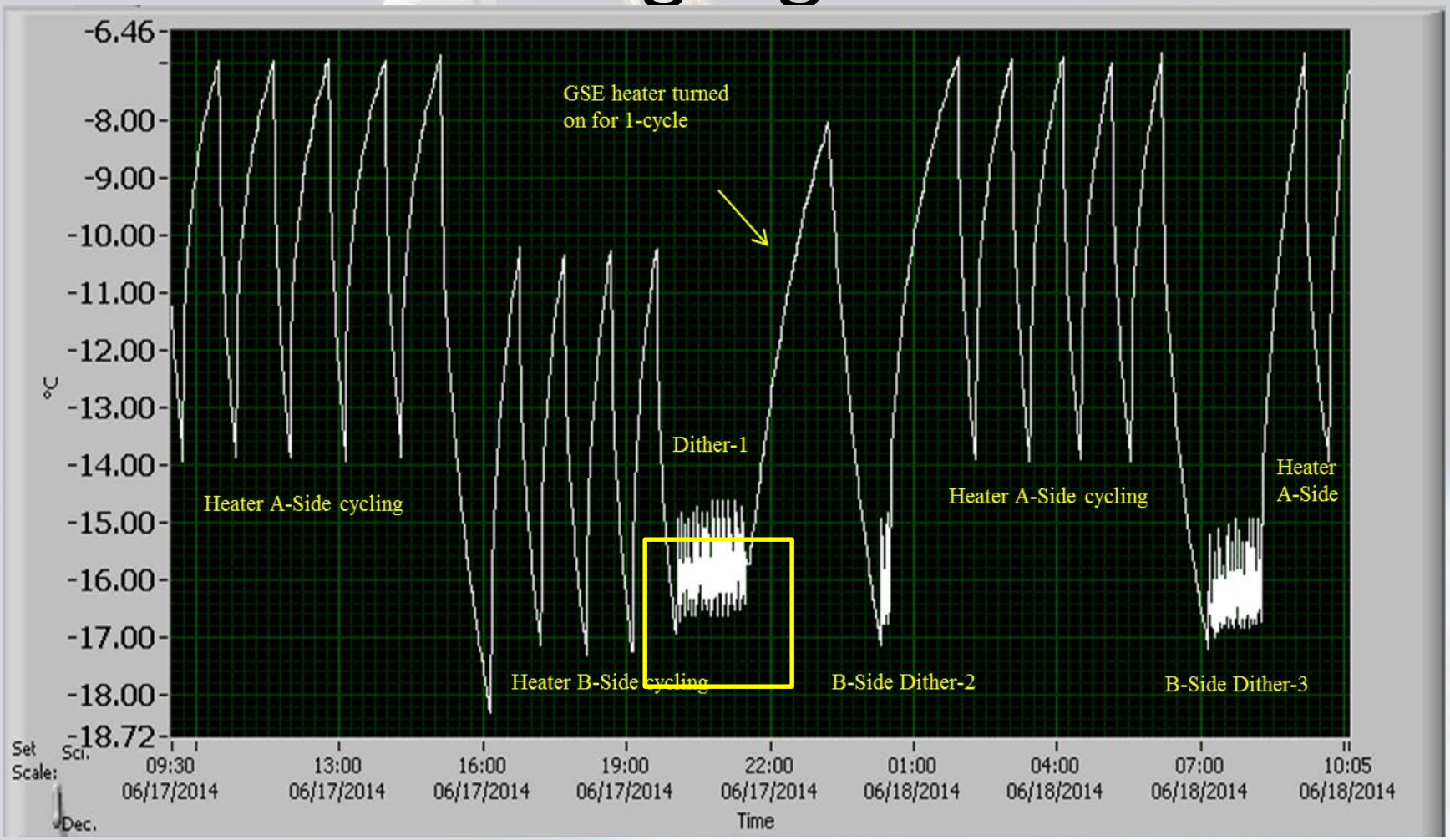


NOT DITHERING

Case 3: SMAP Three-Axis Magnetometer (TAM) Outrigger

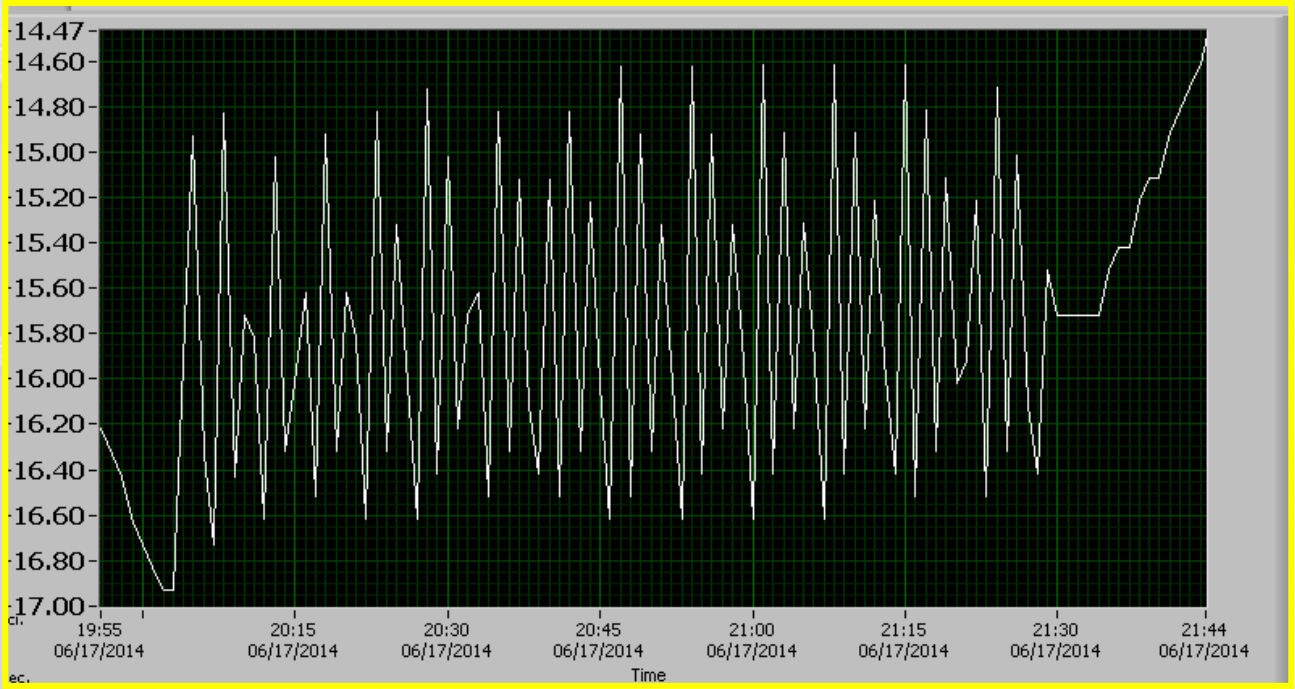


Dithering Signature?

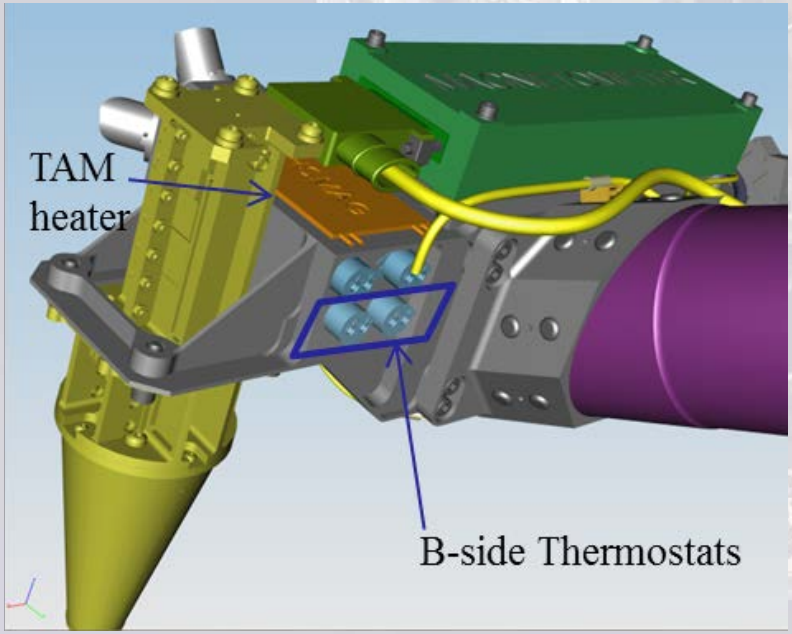


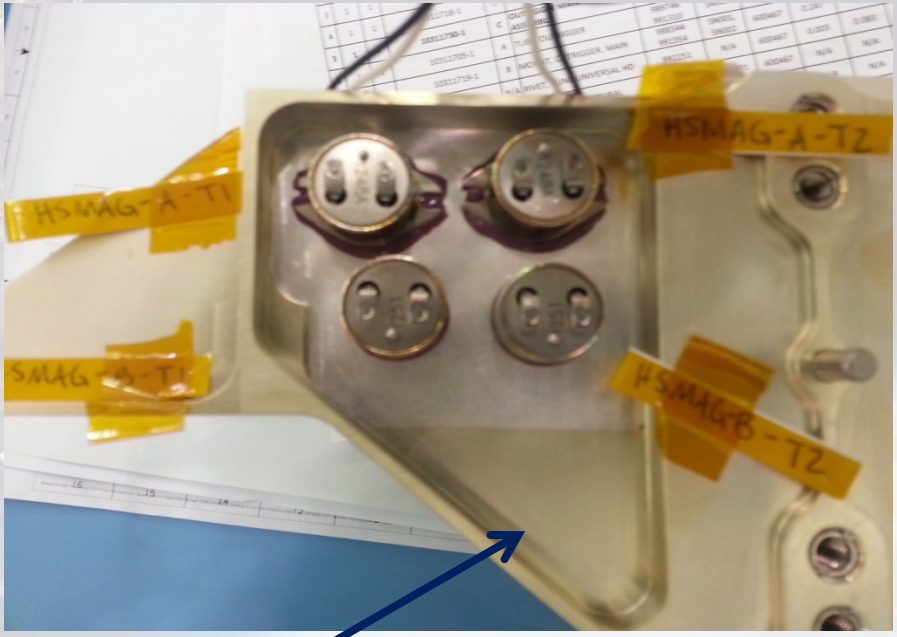
Dithering Symptoms

- 1°C to 2°C amplitude
- 1-3 minute cycles (dithering range)
- [But…] Maintained thermal control



No Configuration Issues



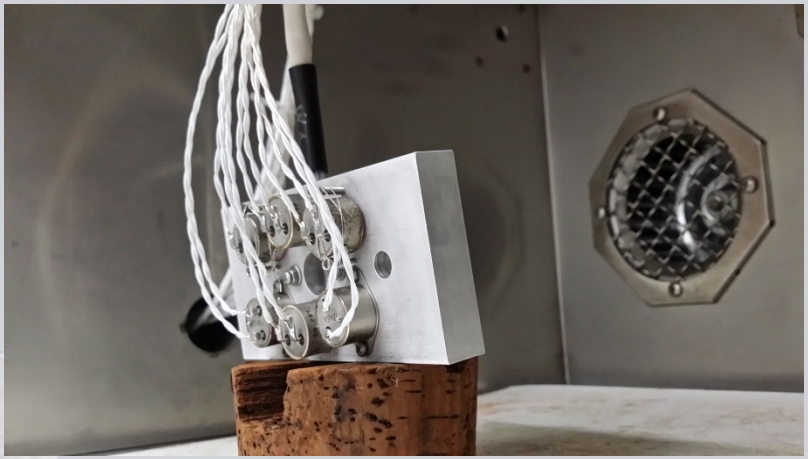


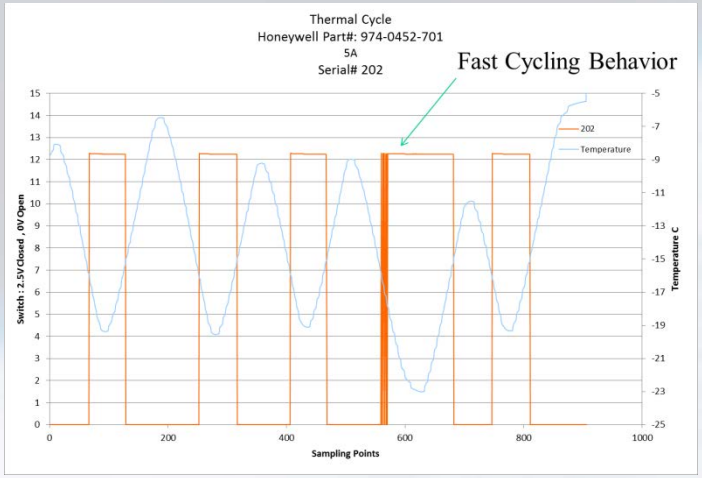
Approximate location of thermocouple

Strong Bond

Case 3 Investigation

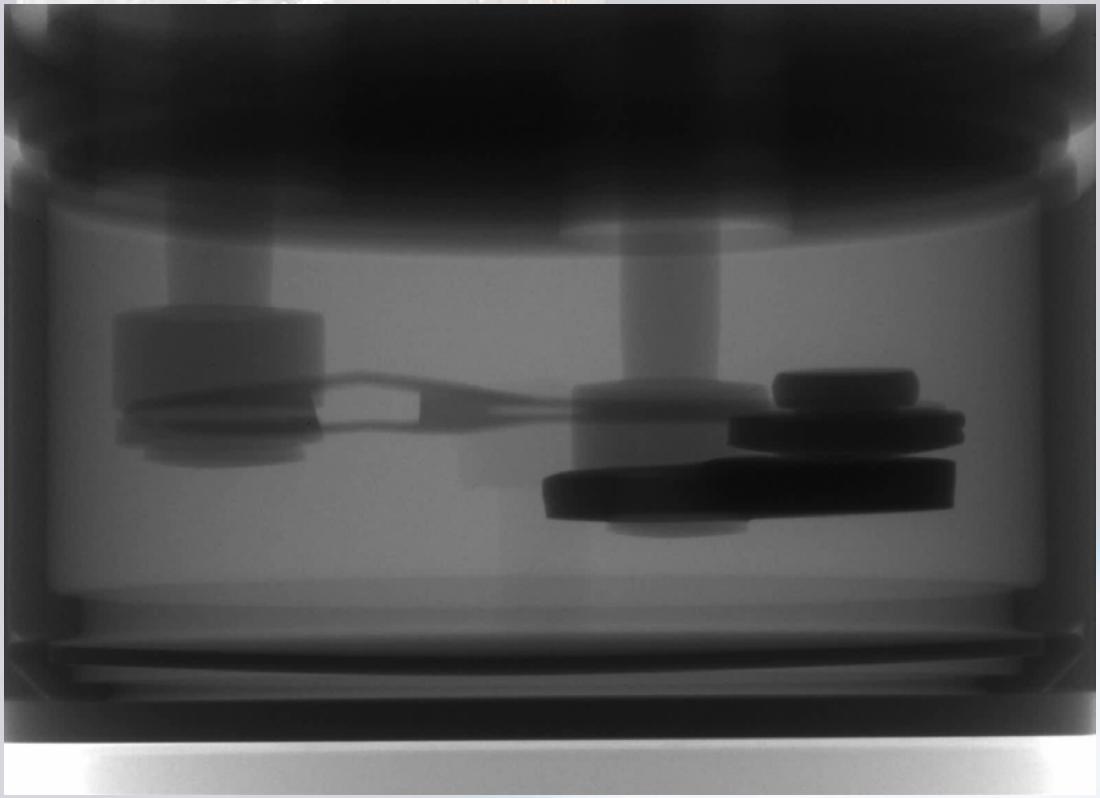
- Eliminated root-causes
  - Configuration
  - Bonds were strong
  - No shorting across leads
  - High current, only 0.5 Amp draw
- Subsequent testing
  - Could induce dithering at high 5-Amp current in one of the two thermostats removed.
  - Suspected Internal Problem
  - Vendor replicated dithering behavior using their screening test at higher amperage.





X-rays of Thermostat

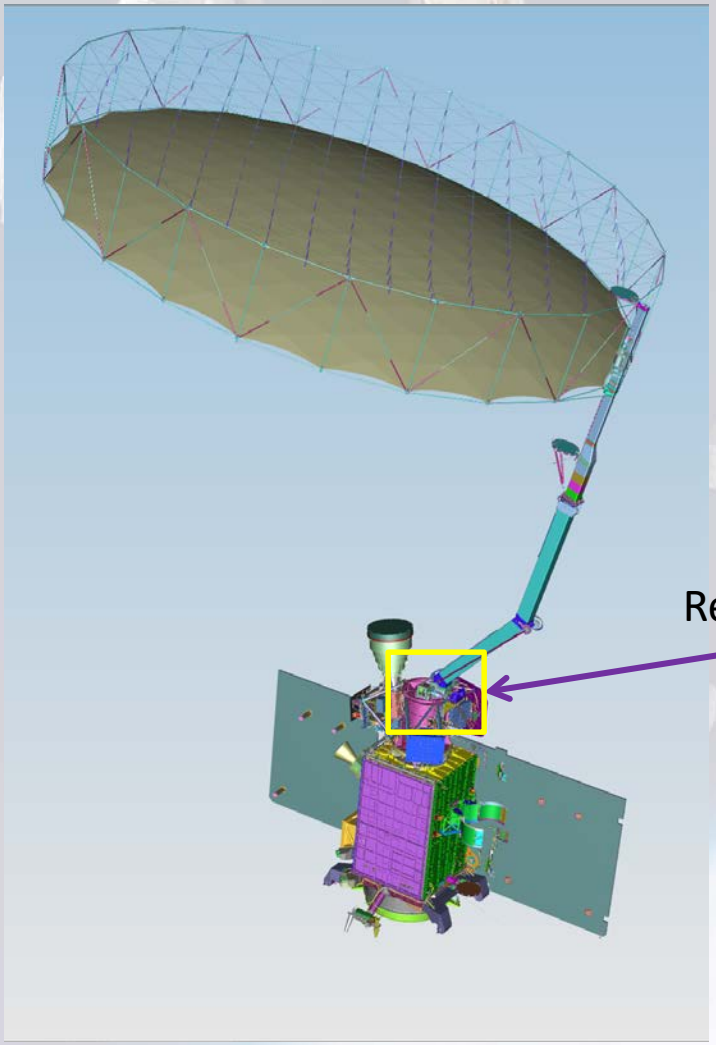
X-ray of Actuation

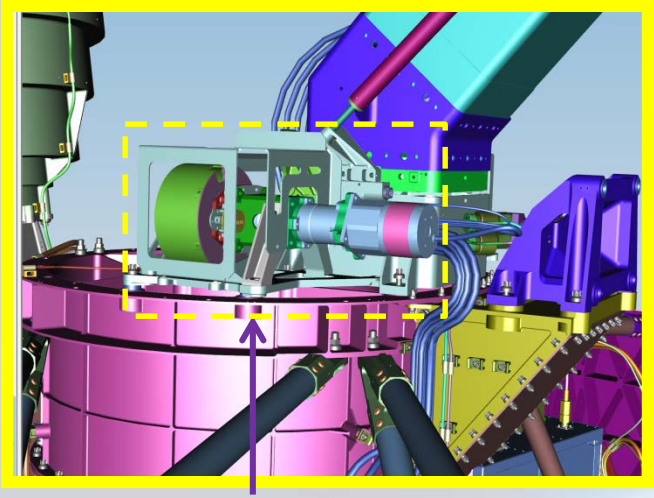


Case 3 Diagnosis

- An internal fault induced a dithering-like anomaly
  - No obvious root cause
- Maintained thermal control for > 2.5 hours
  - Uncertain how many cycles it could have continued to cycle, but likely would have exceeded the 100,000 life cycles.

Case 4 SMAP RBAA

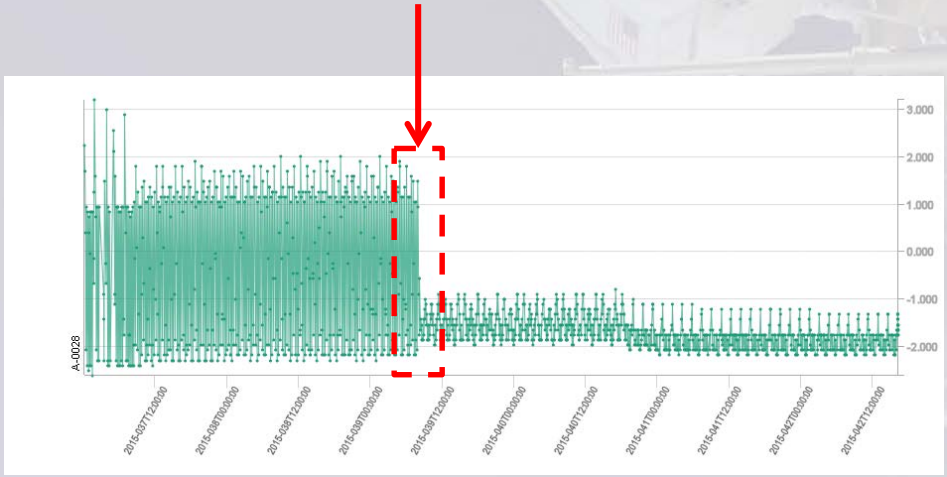


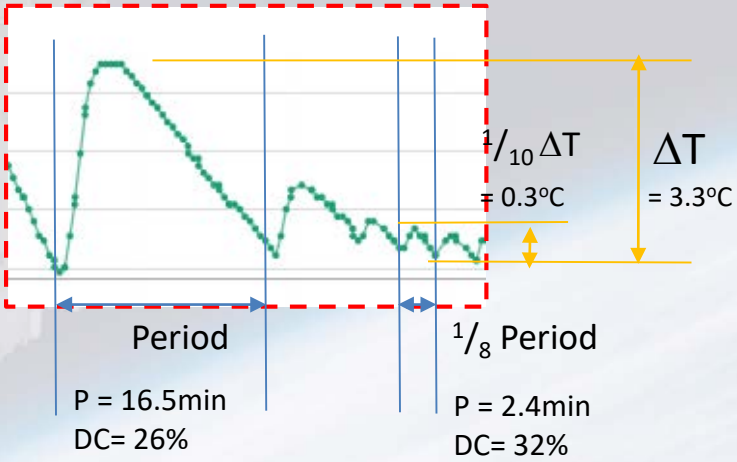


Reflector Boom Assembly Actuator (RBAA)

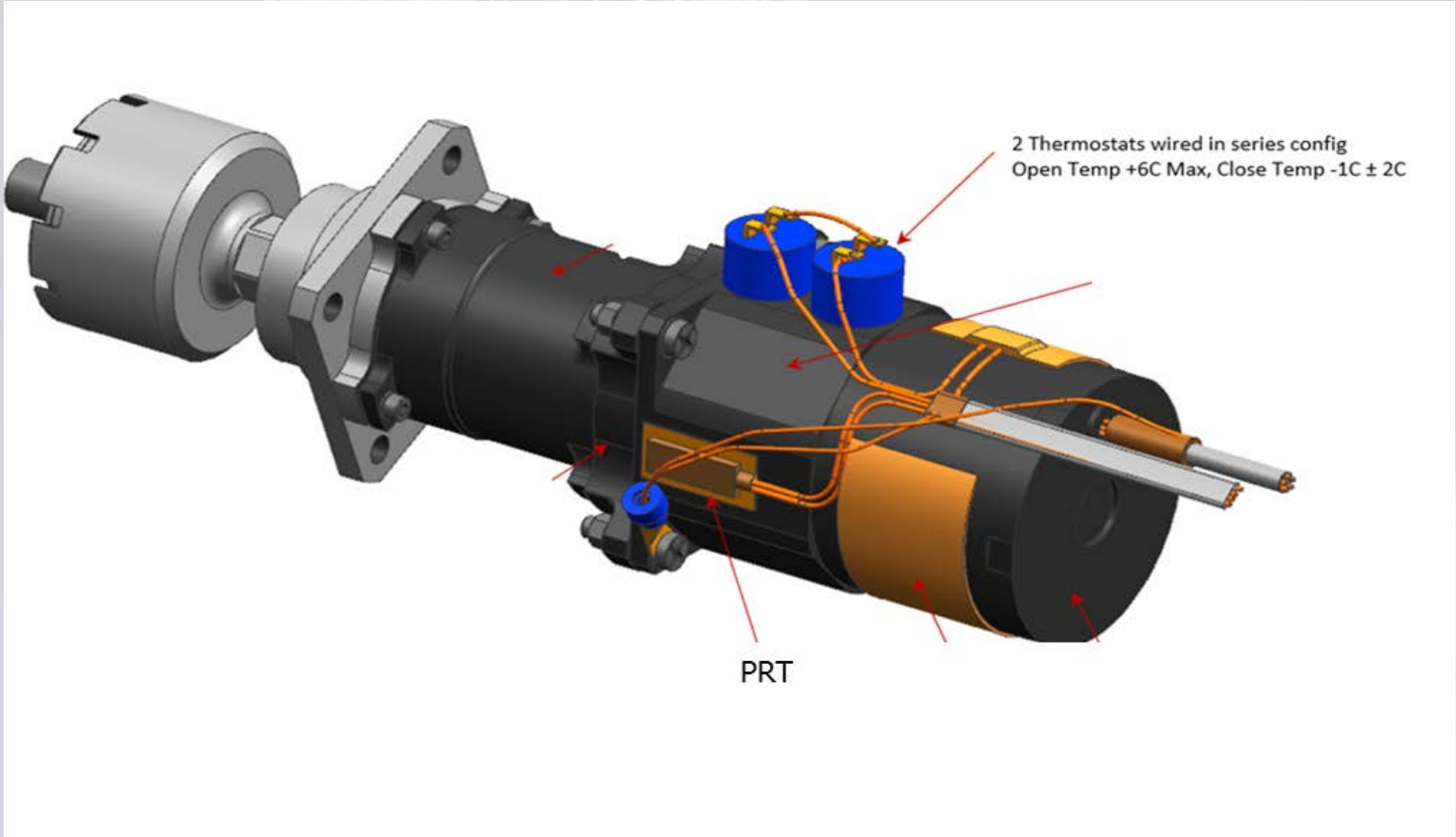
Flight Anomaly

Condition	Period	Deadband	Duration/ Est. Cycles
Nominal	16.5 min	4.0°C	27.7 days / 2.4 K cycles
Anomaly	2.4 min	0.3°C	43.4 days / ~23 K cycles

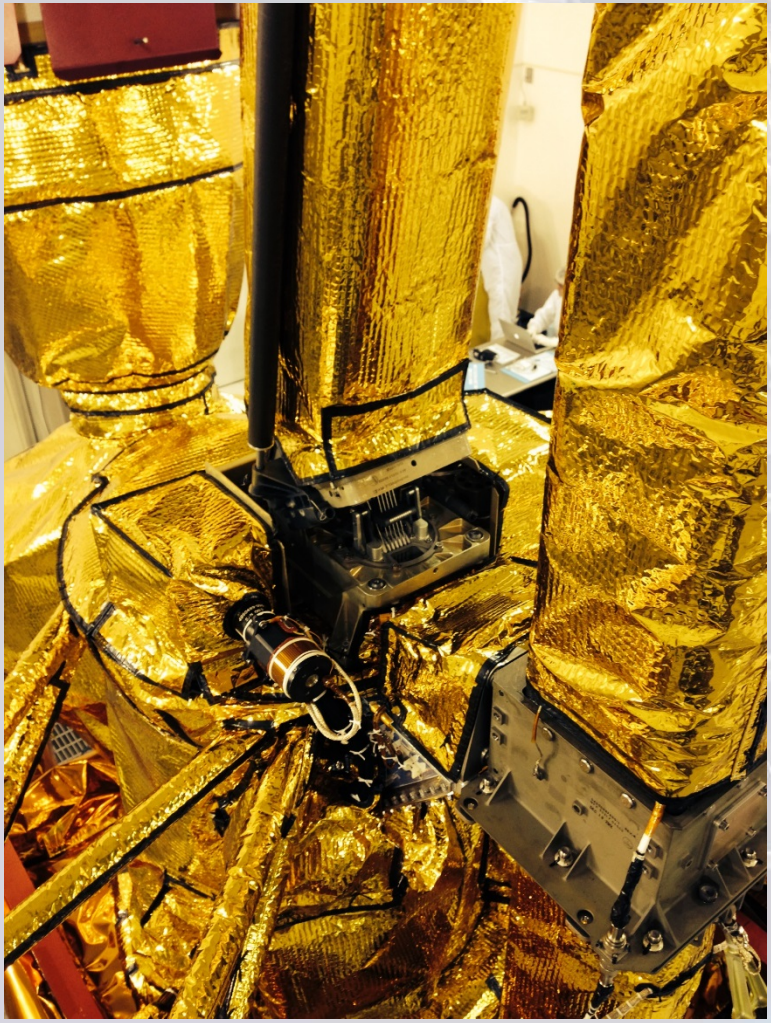




No Configuration Drivers



Flight Hardware images



Thermostat locations

PRT location

Heater staked and overwrapped with lacing cord

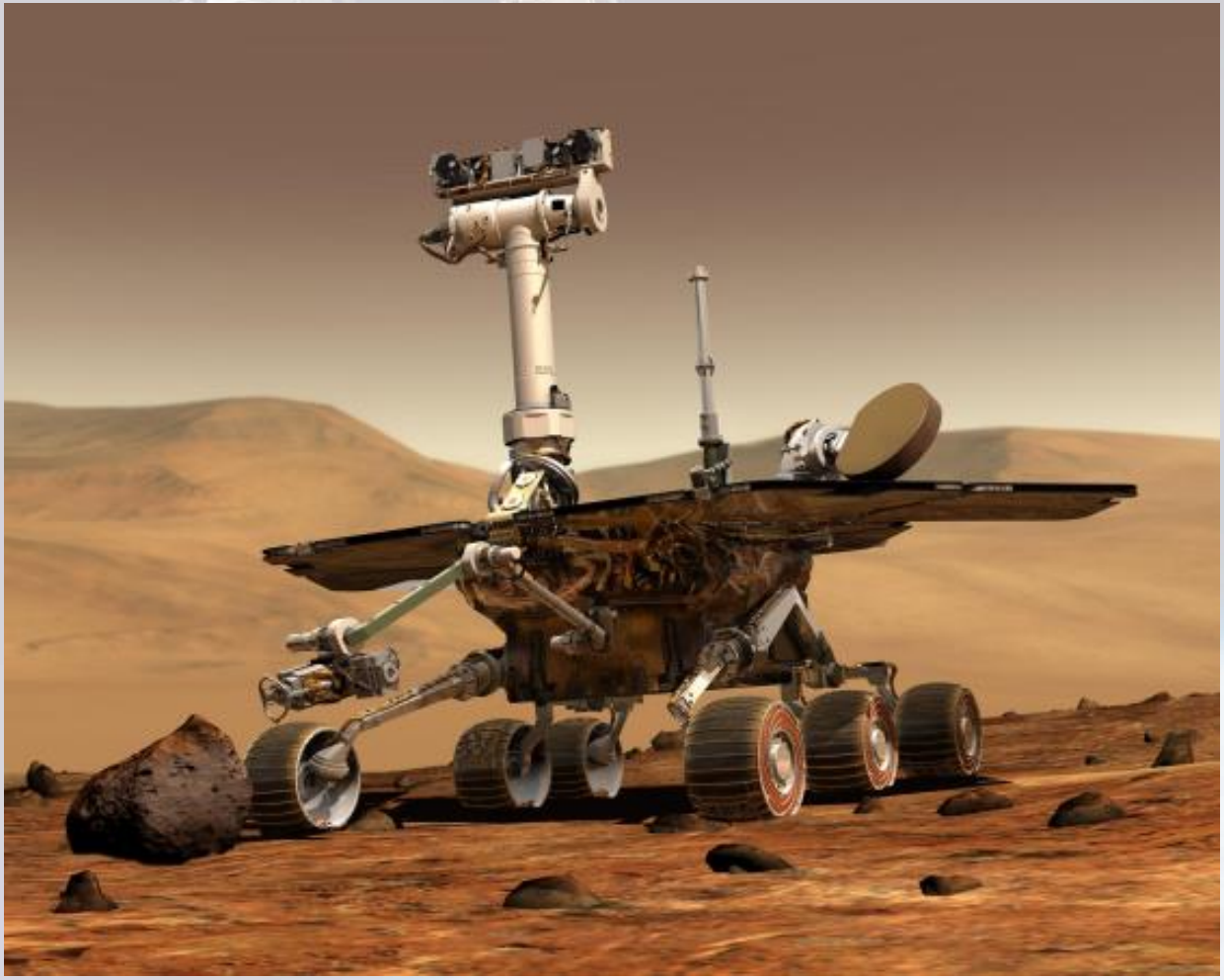
Case 4 Investigation

- Limited to telemetry and build records
  - Same vendor, different lot #s than case 3
- Eliminated Root Causes
  - Configuration
  - High current, max current draw was .55 Amps
  - Shorting—not likely

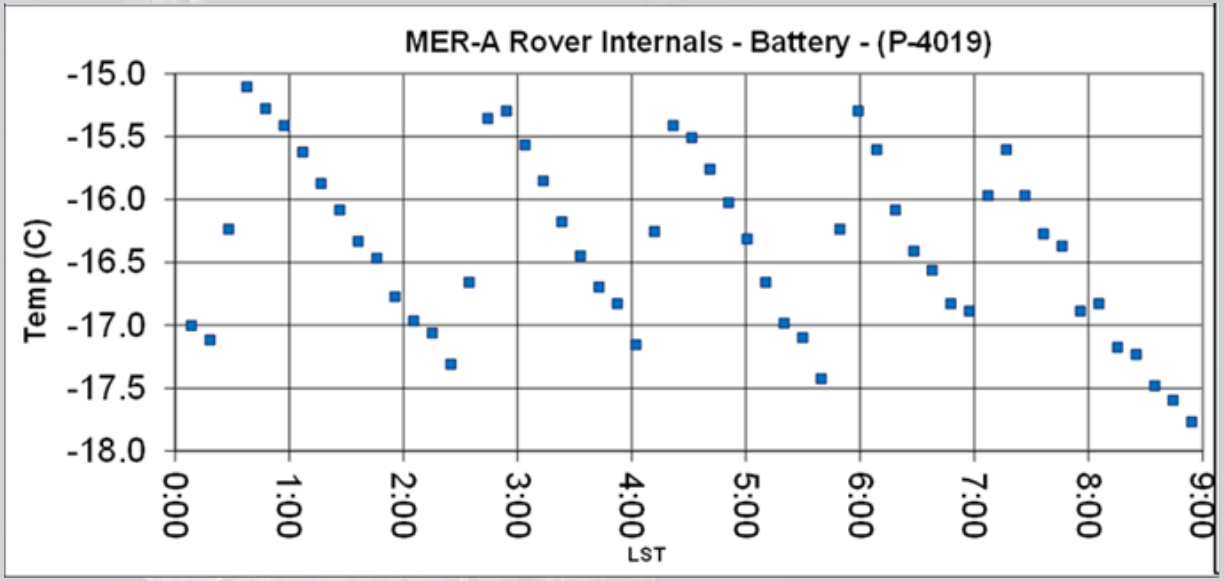
Case 4 Diagnosis

- Dithering-like anomaly
  - No obvious root cause
- Maintained thermal control
  - 43 days & 23,000 cycles

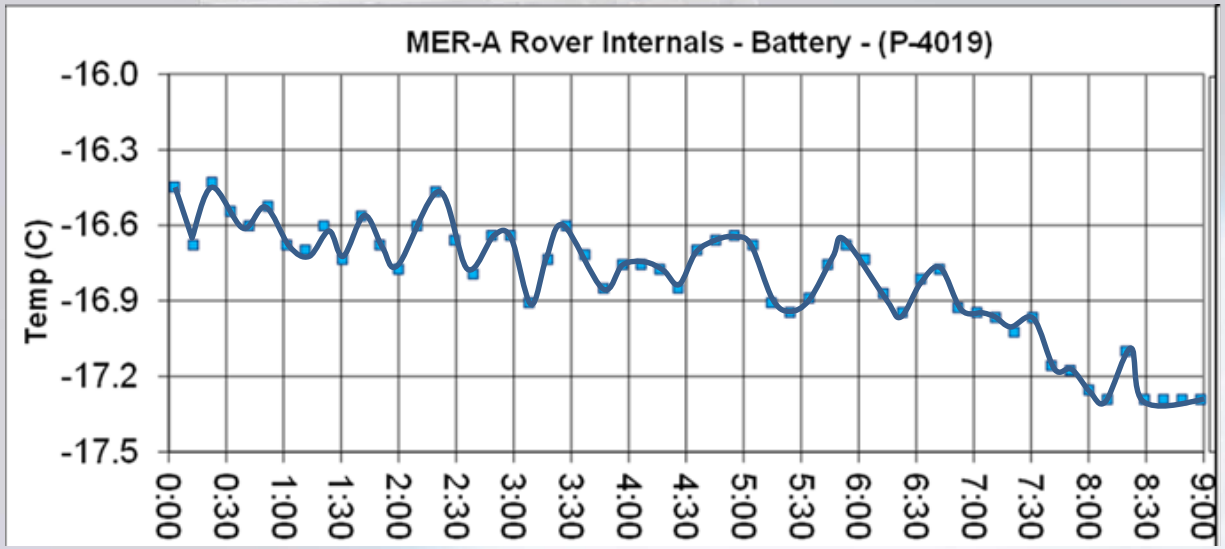
Case 5 Mars Exploration Rover



MER-A Nominal Battery Thermostat Cycling



MER-A Dithring Battery Thermostat Cycling



Case 5 Investigation

- Classified as dithering
- Extremely limited telemetry
- Temperatures were maintained above minimum allowable temperatures of -20°C.

Conclusions

- Classic dithering is characterized by a loss of control and failure of the thermostat.
  - Self heating
- Dithering signatures can be caused by other effects
- There appears to be a dithering-like behavior in thermostats that doesn't lead to loss of thermal control or immediately to thermostat failure.