Testing of the Mars Exploration Rovers to Survive the Extreme Thermal Environments

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Agenda

- **Mission and flight system**
  - **Mission objectives**
  - **Spacecraft and Rover Description**
- **Environmental Verification Program**
  - **Focus on Thermal Testing**
  - **Temperature measurements on the Surface of Mars**
  - **Thermal Performance**
- **Summary and Conclusions**

Mission Objectives

- Place two mobile science laboratories (Rover) on the surface of Mars.
- Remotely conduct geologic investigations, including characterization of a diversity of rocks and soils.

	Launch Date	Launch Vehicle	Landing Date	Landing Site
MER-A "Spirit" (MER-2, Rover-2)	June 10, 2003	Delta II 7925	Jan 4, 2004 Cruise time: 6 months & 24 days	Gusev Crater -14.64º Lat. 175.30 º Long.
MER-B "Opportunity" (MER-1, Rover-1)	July 7, 2003	Delta II 7925H	Jan 25, 2004 Cruise time: 6 months & 18 days	Meridiani -2.06º Lat. 354.01º Long.

Landing Sites

Meridiani

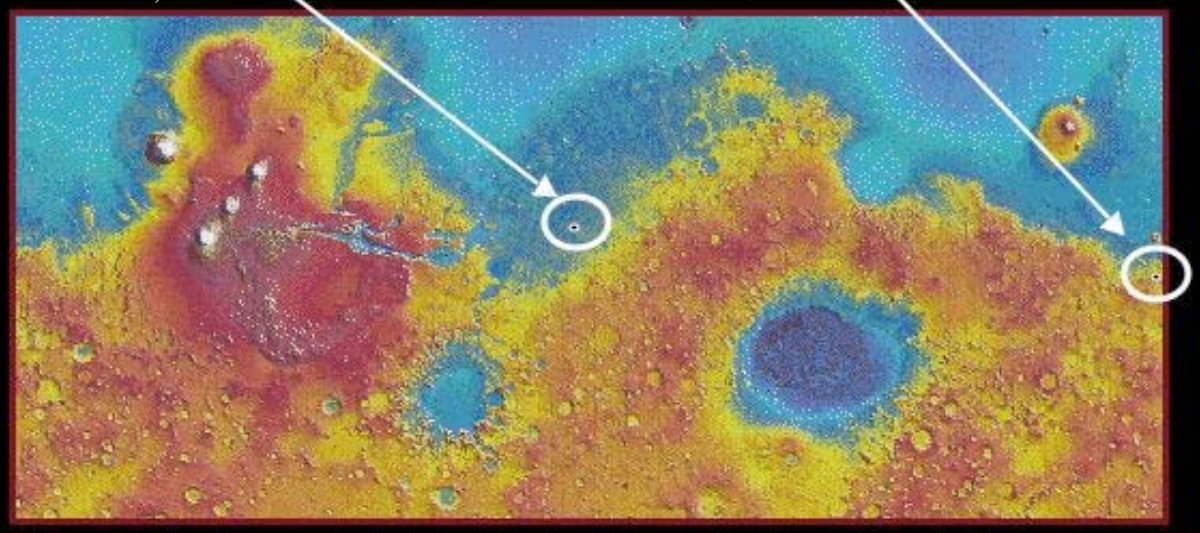
Water-formed hematite?

Rover-1, -2.06° Lat

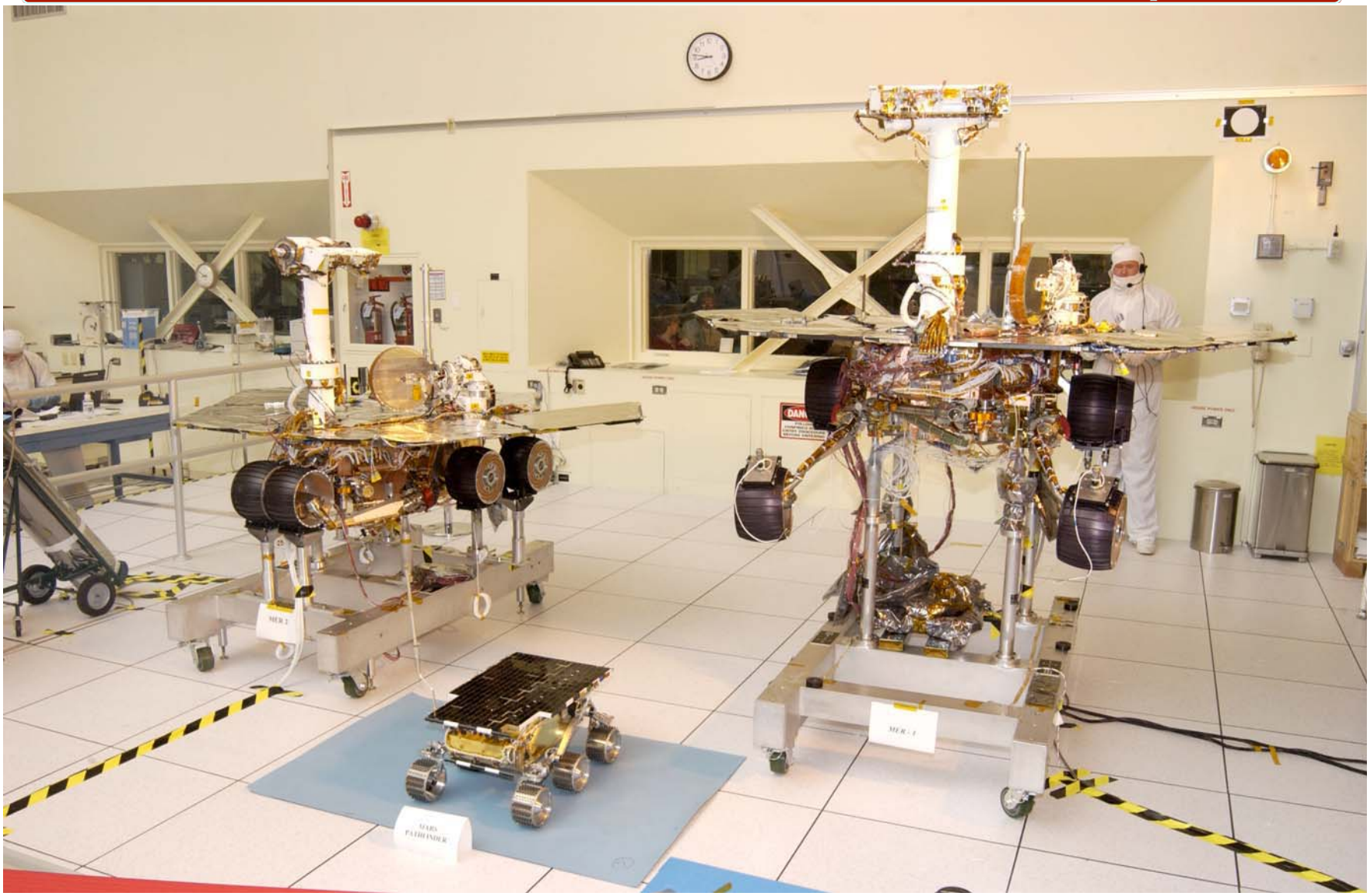
Gusev Crater

Ancient lake sediments?

Rover-2, -14.64° Lat

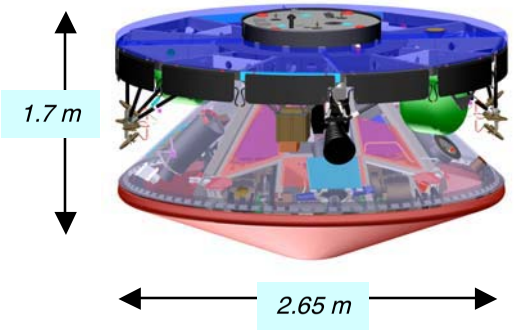


The Rovers

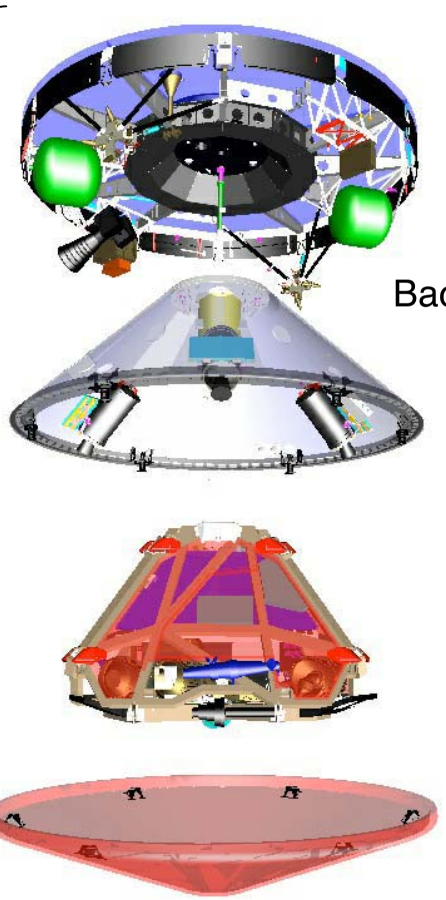


Spacecraft System

Spacecraft
(Launch Configuration)



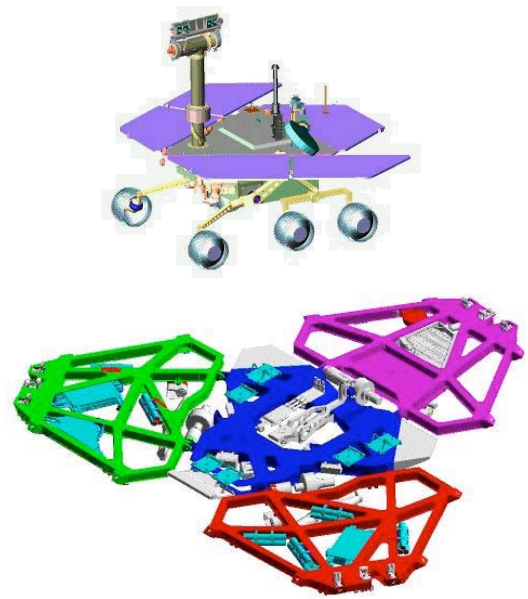
Cruise Stage



Backshell

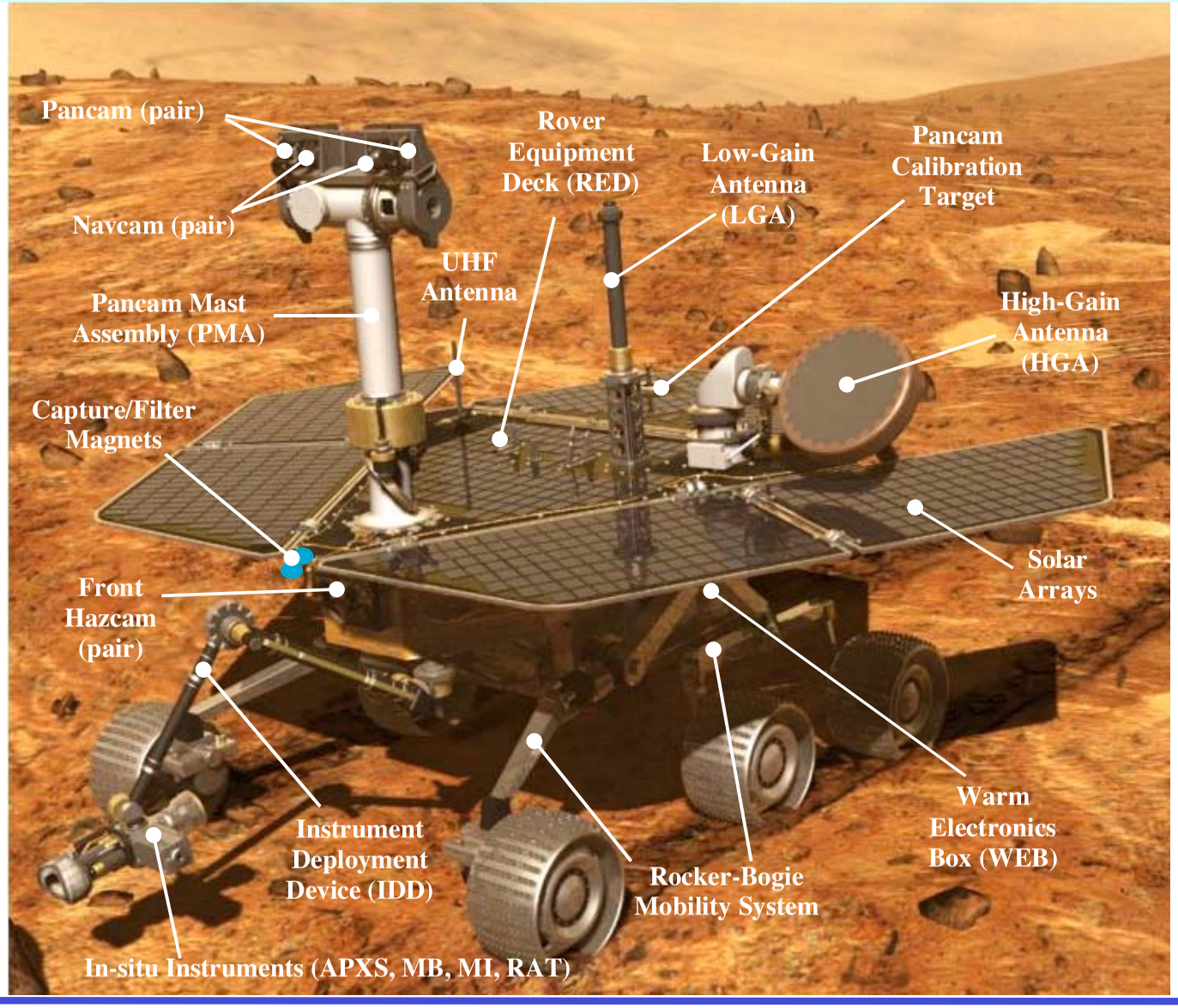
Heat Shield

Rover



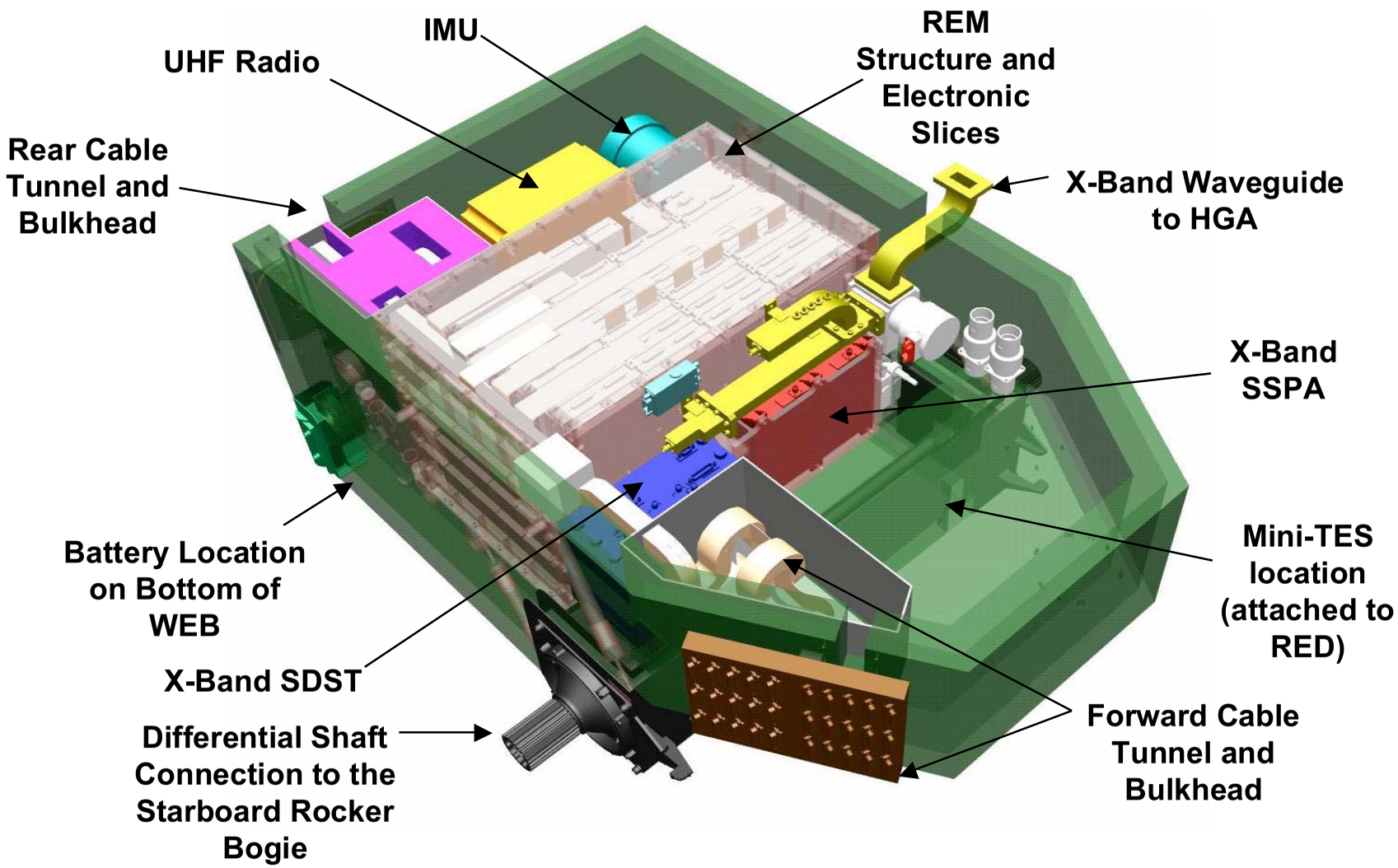
Lander

Rover - Deployed



Warm Electronics Box (WEB)

WEB - For temperature-sensitive hardware



Environmental Verification Program

Assembly/Subsystem

- Dynamics tests
  - Random vibration (include frequency survey)
  - Quasi-static loads (entry, landing)
  - Pyroshock
  - Acoustic noise (selected - large area/mass)
  - Sine sweep (grinding/drilling)
- Thermal tests
  - Thermal vacuum (all hardware)
  - Thermal Mars Atmosphere (landed hardware)
  - Thermal cycling life qual (selected h/w)
- EMC tests
  - Conducted susceptibility/emission
  - Radiated susceptibility/emission
  - Grounding & isolation
  - Multipacting/ionization breakdown (corona)
- Environmental analyses
  - Radiation (TID, DD, SEE)
  - Venting (pressurization & depressurization)
  - Meteoroid (done at system)

Spacecraft System

- Dynamics tests
  - Low-level random survey
  - Random vibration
  - Quasi-static loads (Launch/entry)
  - Acoustic noise
  - Pyro firing
- Thermal tests
  - Thermal vacuum (w/ thermal balance - critical h/w at FA limits during functional)
- EMC tests
  - Radiated emission
  - Radiated susceptibility
  - Self compatibility
  - Magnetic cleanliness
- Environmental analyses
  - Orbital debris
  - Meteoroid (prob. of survival & shielding)
  - ESD (touch down)

Thermal Test Program

- **Assembly-Level Thermal Testing**
  - **Thermal Vacuum (all hardware - Cruise, EDL, Landed Assemblies)**
  - **Thermal Mars Atmosphere, 5-10 torr GN_2 or CO_2 (Landed hardware)**

- **System-Level Thermal Testing**
  - **System Thermal Vacuum**
  - **Rover Thermal Mars Atmosphere, 5-10 torr GN_2 or CO_2**
  - **Thermal Balance Test**

- **Thermal Cycling Life Qualification Testing**
  - **To survive the Mars diurnal temperature cycles**
  - **Required for temperature un-controlled hardware outside the WEB**
  - **Performed on flight-like test coupons or non-flight engineering units**

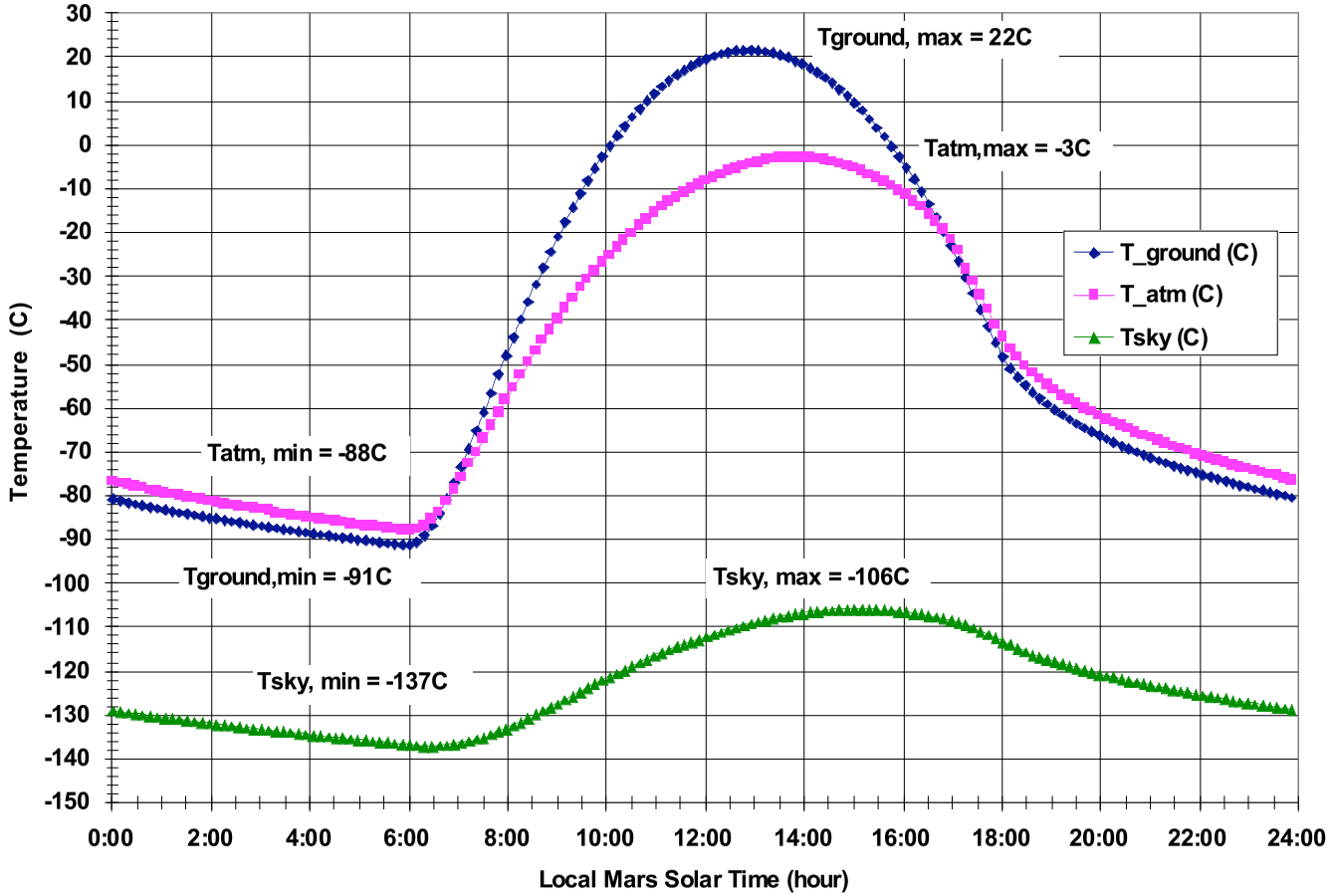
Mars Surface Environment

Mars GCM (Global Circulation Model) predicts the ground (Mars surface), atmosphere, & sky temperatures

		Optical Depth, tau	Surface Albedo	Thermal Inertia ($J\ m^{-2}\ K^{-1}\ s^{-1/2}$)	Pressure (mbar)	Latitude, (degrees North)	Ls (degrees)
Case 1	Highest Max Daily Temp	0.2	0.125	220	6.5	-2.5	328
Case 2	Lowest Min Daily Temp	0.2	0.18	230	7.8	-9.0	29.5
Case 3a	Lowest Max Daily Temp: (Dusty: tau = 2)	2	0.136	710	6.5	-13.1	16
Case 3b	Lowest Max Daily Temp: (Dusty: tau = 1)	1	0.136	710	6.5	-13.1	16

Mars Temperatures for Case 1

		Optical Depth, tau	Surface Albedo	Thermal Inertia ($J\ m^{-2}\ K^{-1}\ s^{-1/2}$)	Pressure (mbar)	Latitude, (degrees North)	Ls (degrees)
Case 1	Highest Max Daily Temp	0.2	0.125	220	6.5	-2.5	328



Allowable Flight Temperatures (AFT)

- **WEB AFT's (for temperature-sensitive hardware inside the WEB)**
  - **Flight System Electronics (-40°C/+50°C)**
  - **Mini-TES Science instrument (-40°C/+45°C)**
  - **Li Ion secondary battery (-20°C/+30°C), charging at >0°C**
- **External-Hardware AFT's (for hardware that is not temperature-controlled)**
  - **9 cameras & 34 actuators (-105°C/+50°C)**
    - **Deployable Solar Arrays**
    - **Telecommunications antennas (High Gain, Low Gain, UHF)**
    - **Robotic arm with science sensors**
    - **Mobility system**
    - **Pancam Mast Assembly**
    - **Cameras (Optics and Electronics)**

Thermal Test Requirements for Assemblies

Thermal test program: Qual/FA or PF

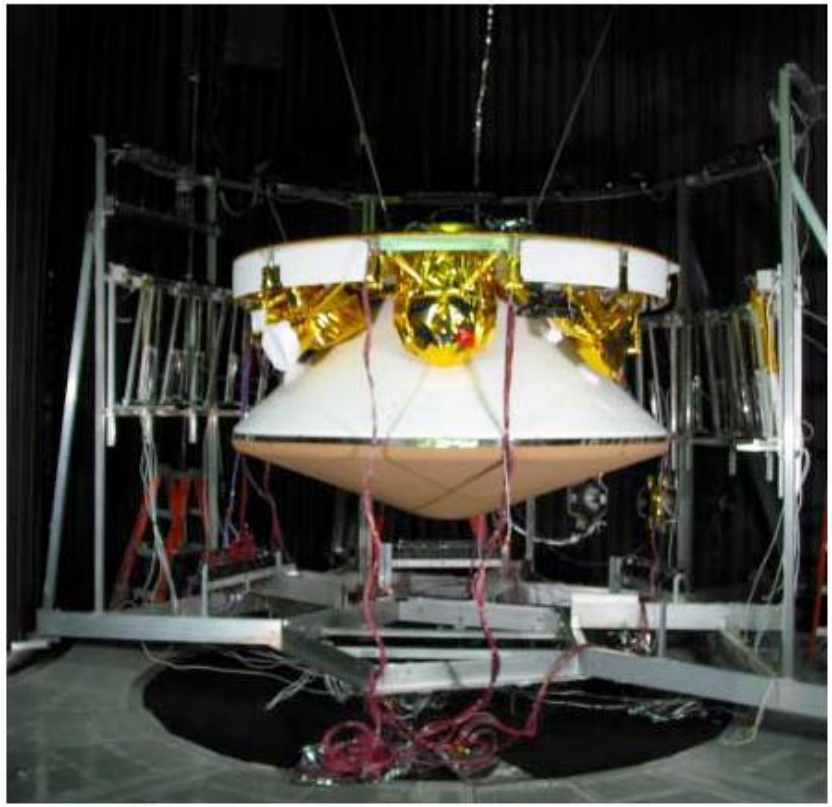
Type of Assembly	Qualification (Qual) or Protoflight (PF) Test				Flight Acceptance (FA) Test			
	Temperature Levels (margins)	Test Duration Operational (h)	Number of Thermal Cycles	Test Media	Temperature Levels (margins)	Test Duration Operational (h)	Number of Thermal Cycles	Test Media
Electronics	**Cold:** AFT-15°C **Hot:** AFT+20°C or +70°C (whichever is higher)	**Cold:** 24 h **Hot:** 144 h	3 to 10	Vacuum (plus 5-10 Torr CO_2 or GN_2 gas for landed h/w)	**Cold:** AFT-5°C **Hot:** AFT+5°C or +55°C (whichever is higher)	**Cold:** 24 h **Hot:** 50 h	3 to 10	Vacuum (plus 5-10 Torr CO_2 or GN_2 gas for landed h/w)
Non-Electronics	**Cold:** AFT-15ºC **Hot:** AFT+20ºC	**Cold:** 24 h **Hot:** 50 h	3 to 10	Vacuum (plus 5-10 Torr CO_2 or GN_2 gas for landed h/w)	**Cold:** AFT-5ºC **Hot:** AFT+5ºC	**Cold:** 24 h **Hot:** 50 h	3 to 10	Vacuum (plus 5-10 Torr CO_2 or GN_2 gas for landed h/w)

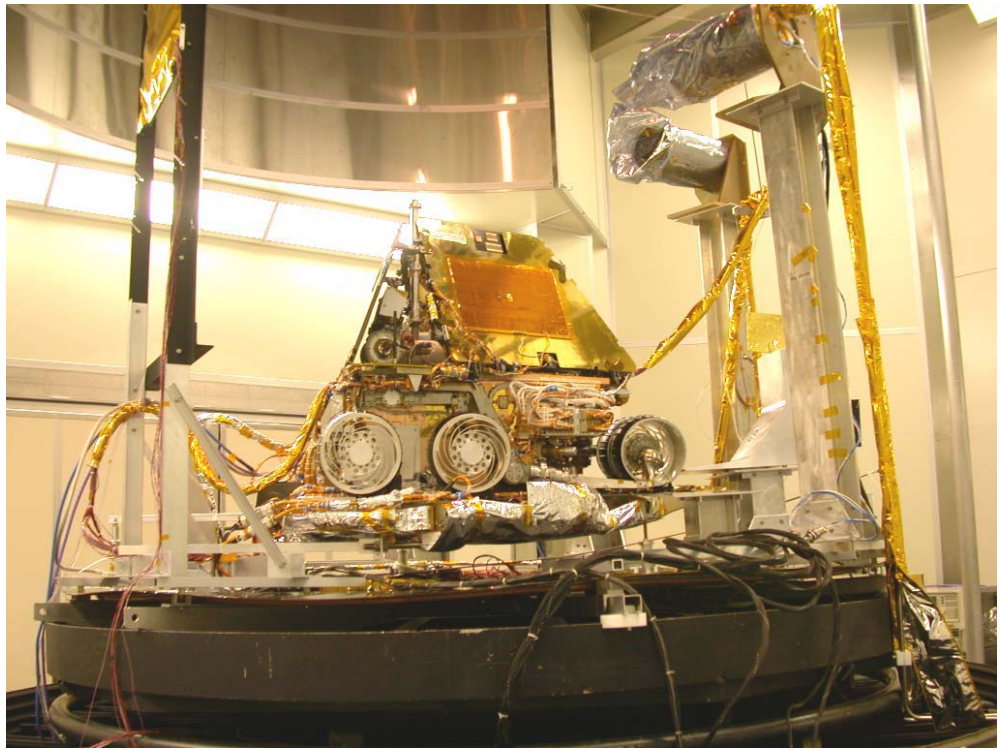
Additional test parameters were also required as follows:

1) **Ramp rate, $\leq$ 5°C /min.**
2) **Number of off/on cycles for the cold and hot operating mode (3 minimum each).**
3) **Number of non-operating cold startups (3 minimum each).**
4) **Functional verifications at hot and cold conditions.**

System Thermal Tests

- Thermal tests - cruise configuration
- Thermal tests - for Rovers
- Thermal balance tests - to verify thermal model

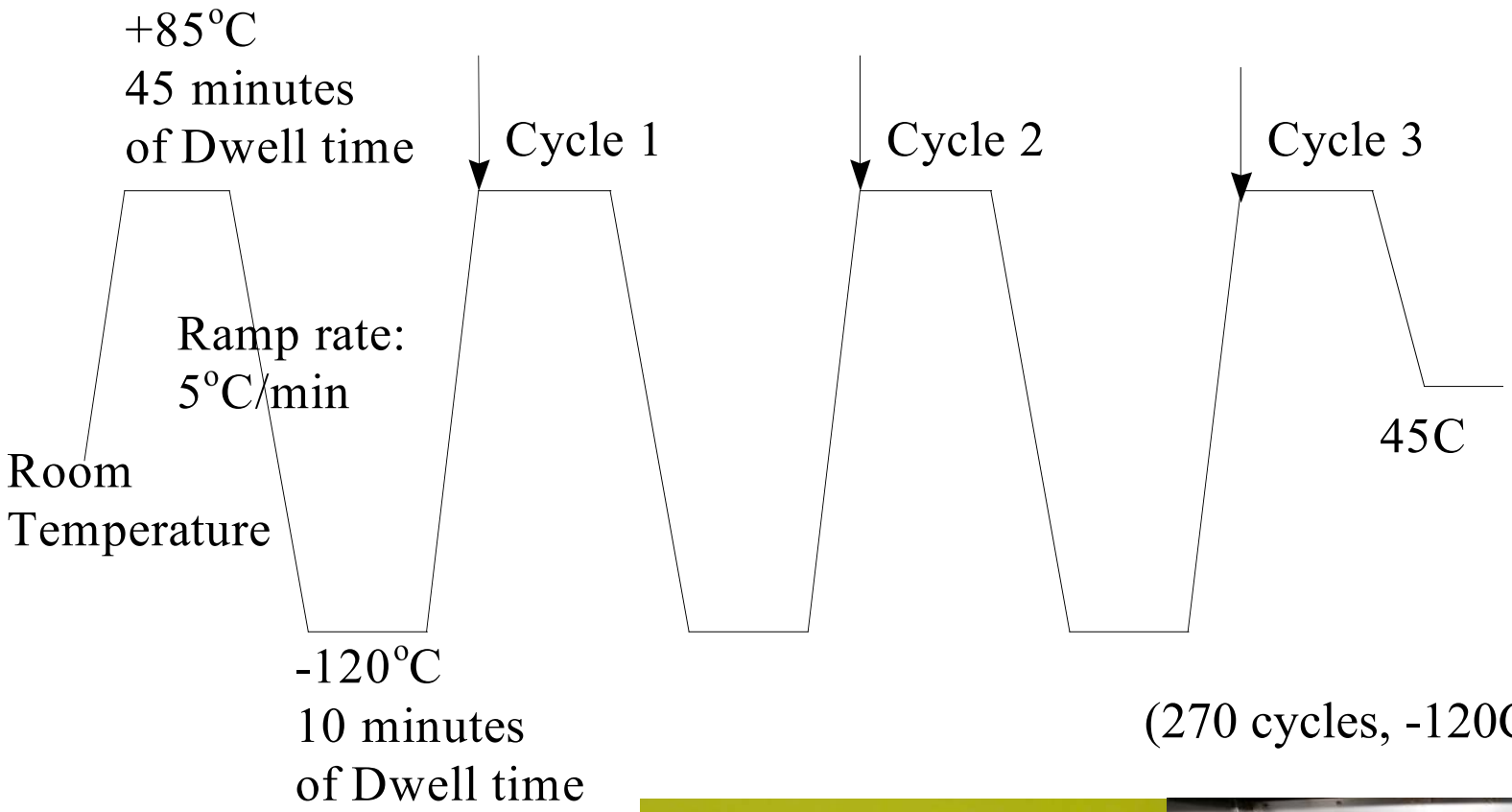




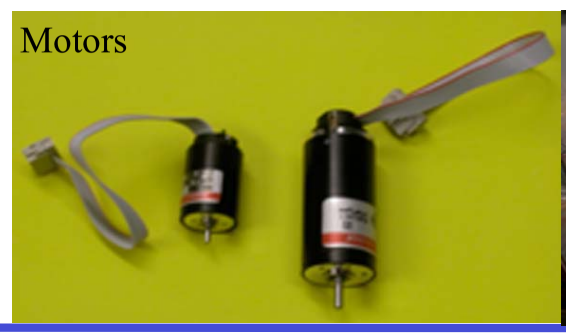
Thermal Cycling Life Qualification Testing

- Verify survival for Mars surface diurnal temperature cycling
- Demonstrate three times (3X) primary mission diurnal cycles
  - Mission design life 90 days baseline
  - Requires 270 cycles for externally-mounted hardware
- Performed by thermal cycling either:
  - Flight-like packaging sample, or
  - Non-flight engineering model
- A total of 39 tests performed

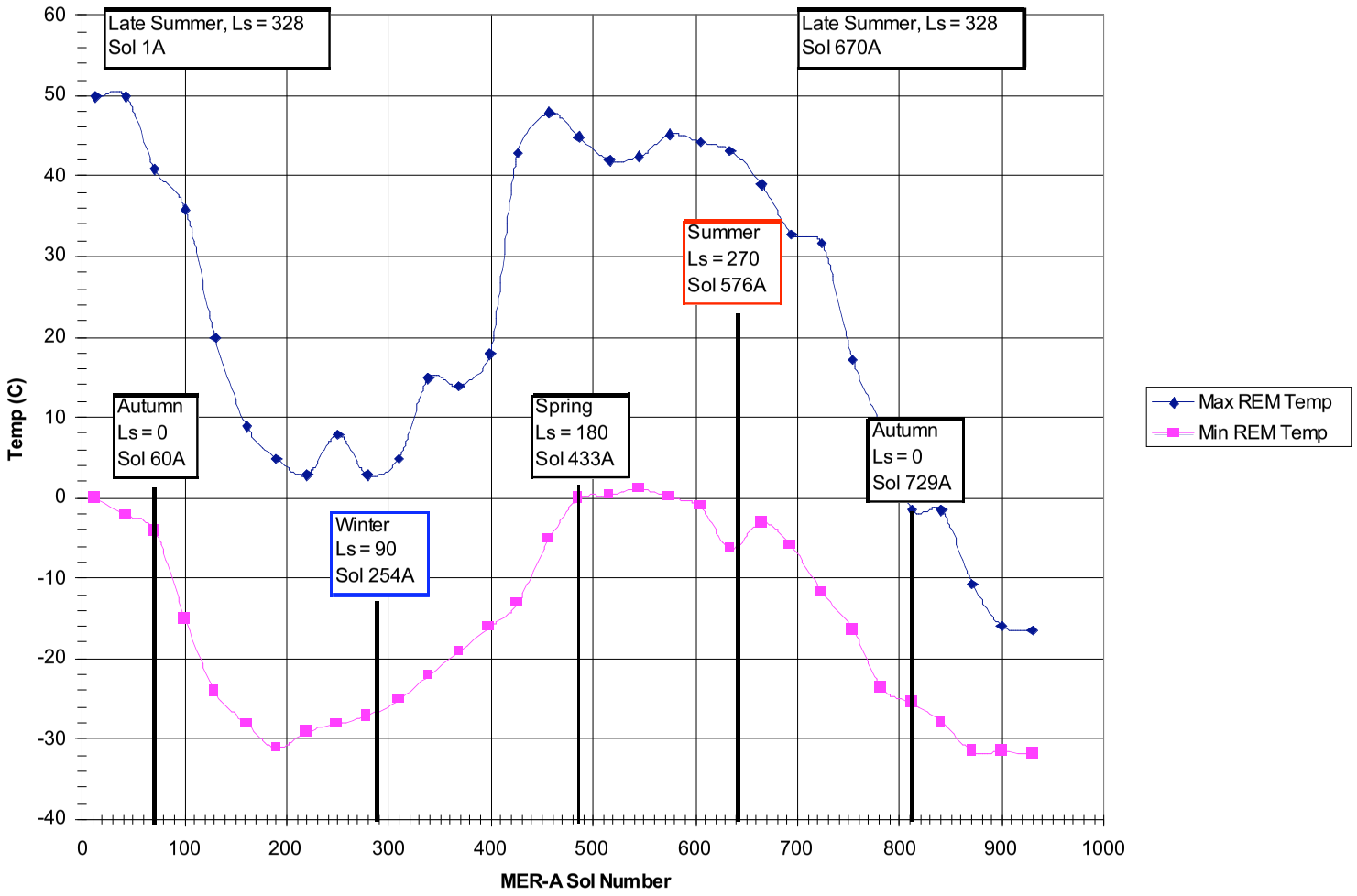
Thermal Cycling Life Testing Profile



(270 cycles, -120C to 85C)

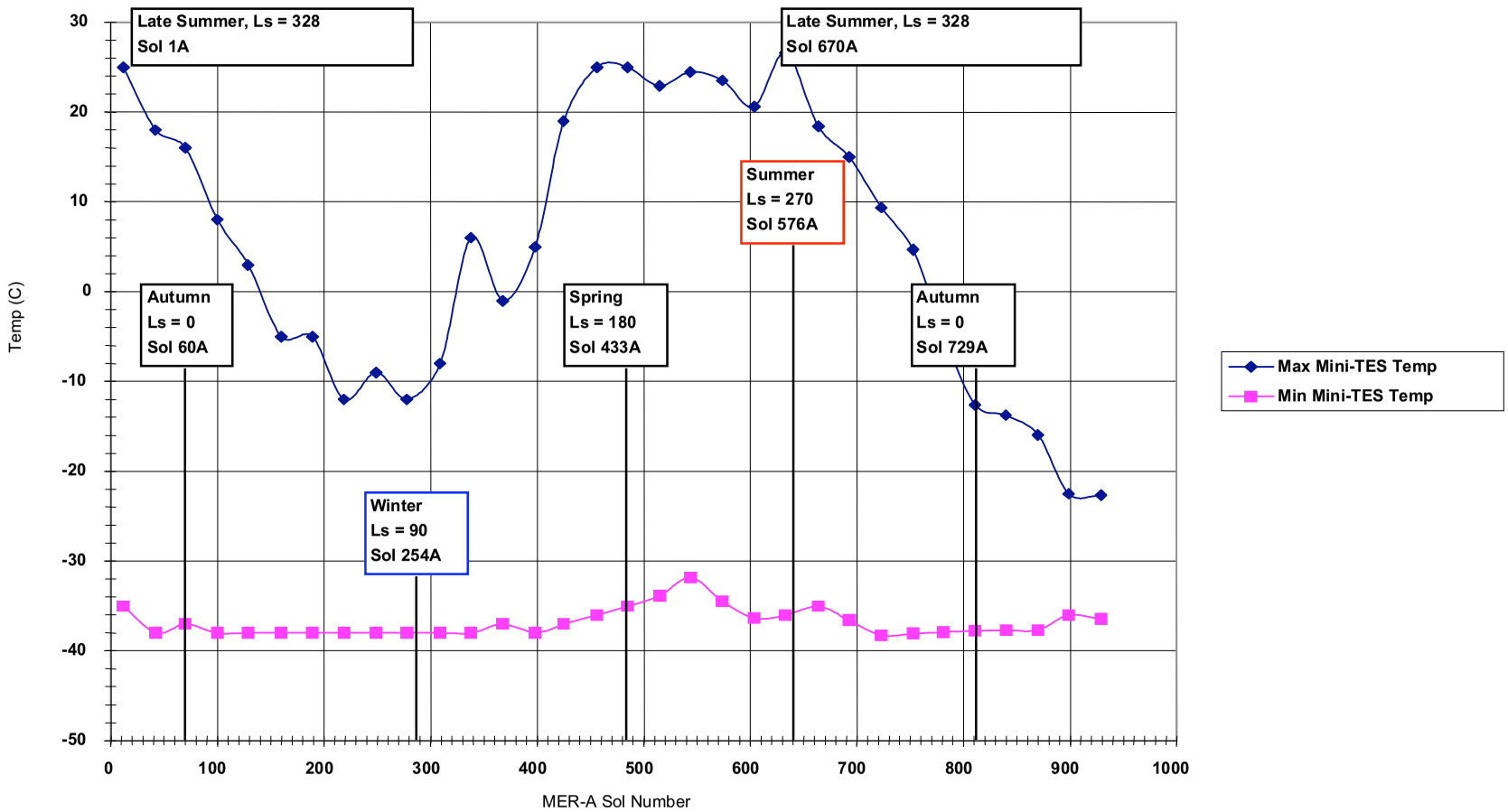


Rover Electronic Modules In-flight Temperature Measurements



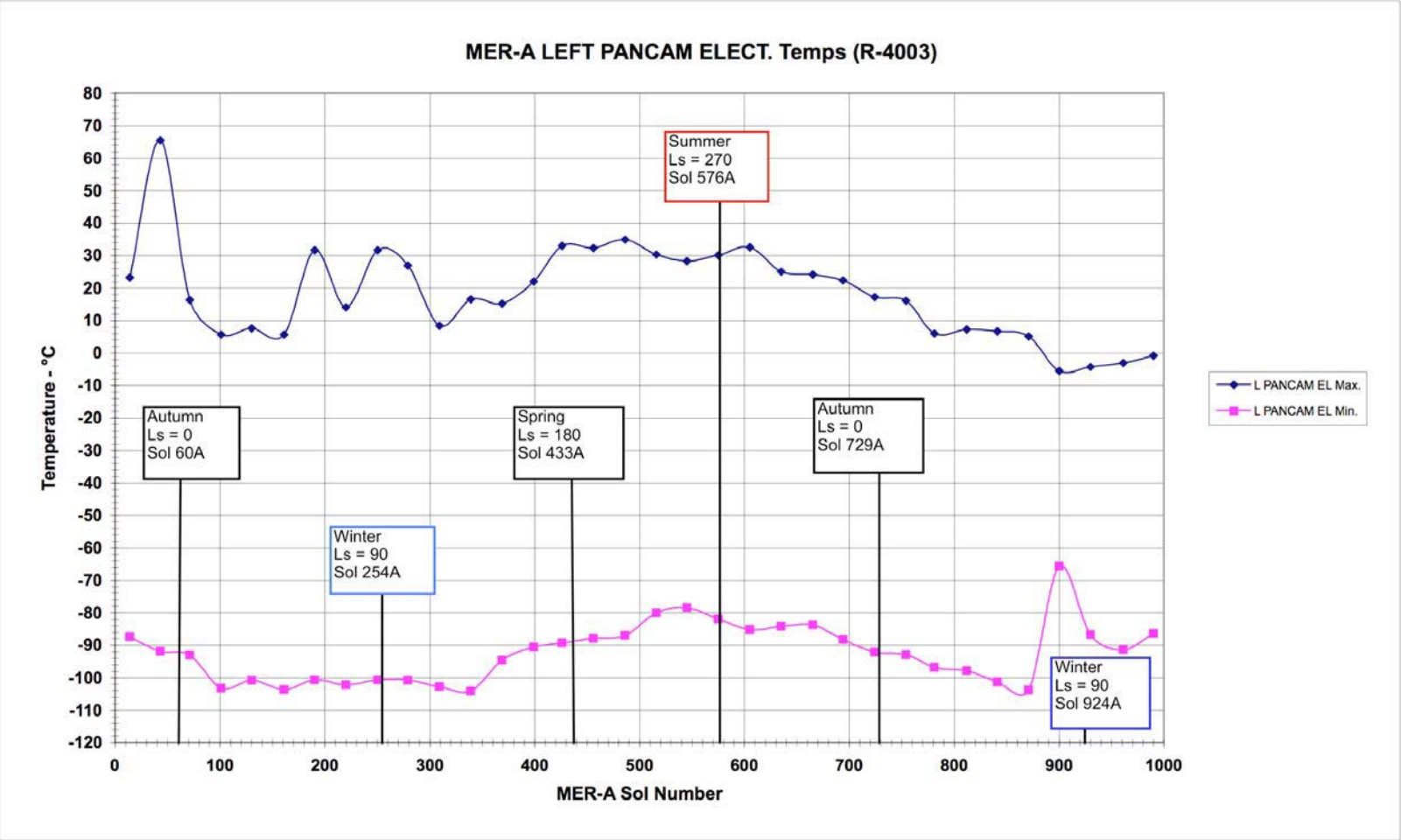
AFT for Rover Electronic Module (inside WEB) = (-40°C/+50°C)

Mini-TES Instrument In-flight Temperature Measurements



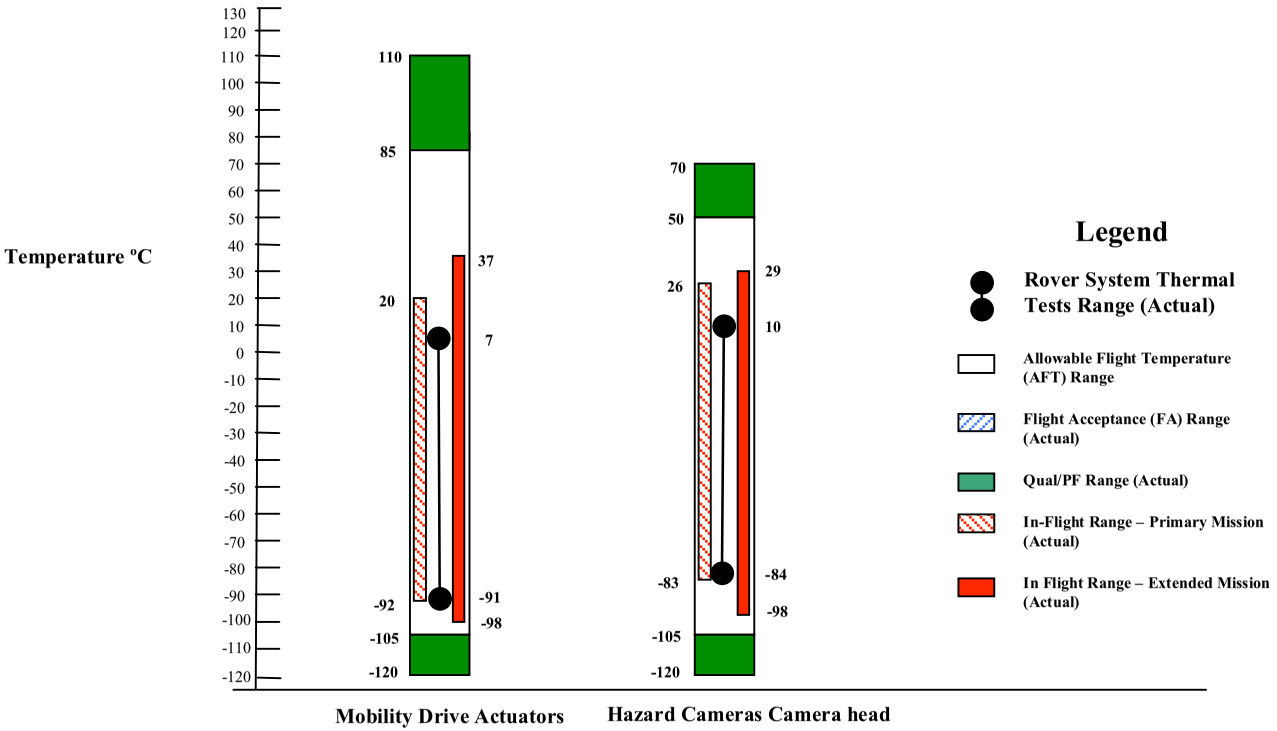
AFT for Mini-TES Instrument = (-40°C/+45°C)

PANCAM Instrument Electronics In-flight Temperature Measurements

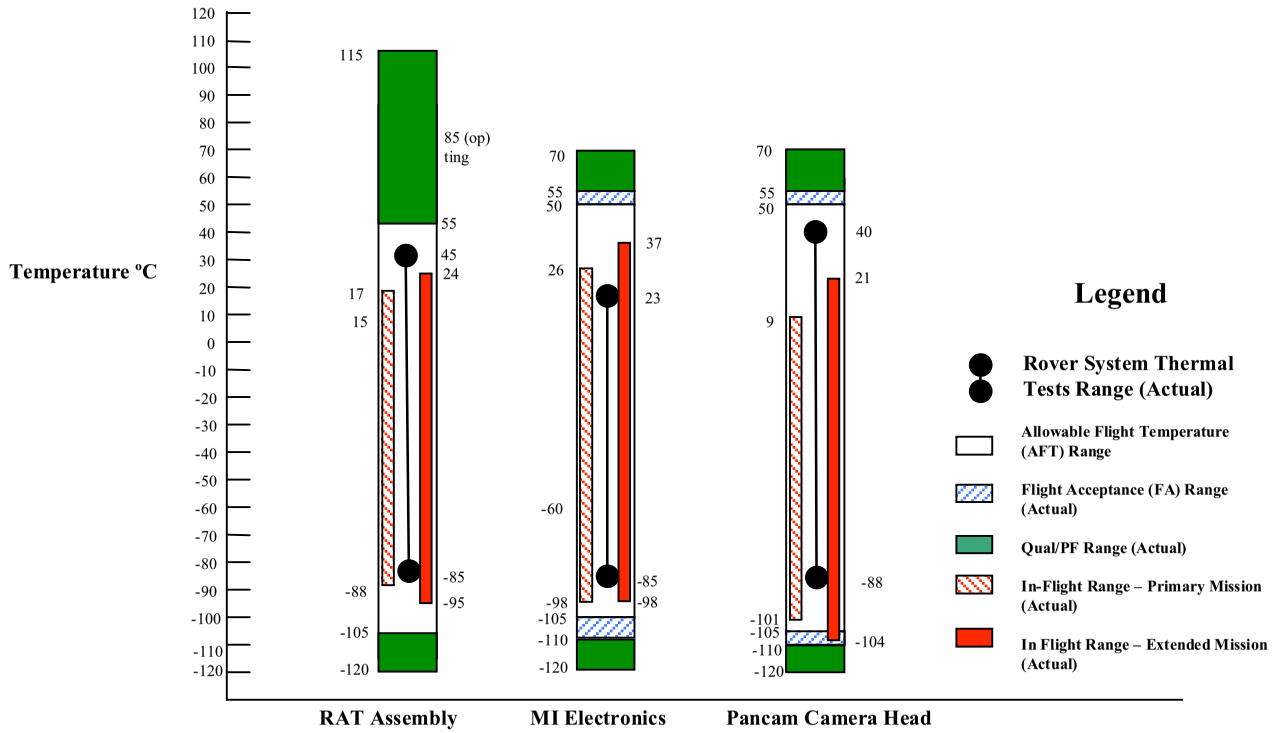


AFT for PAMCAM Instrument Electronics = (-105°C/+50°C)

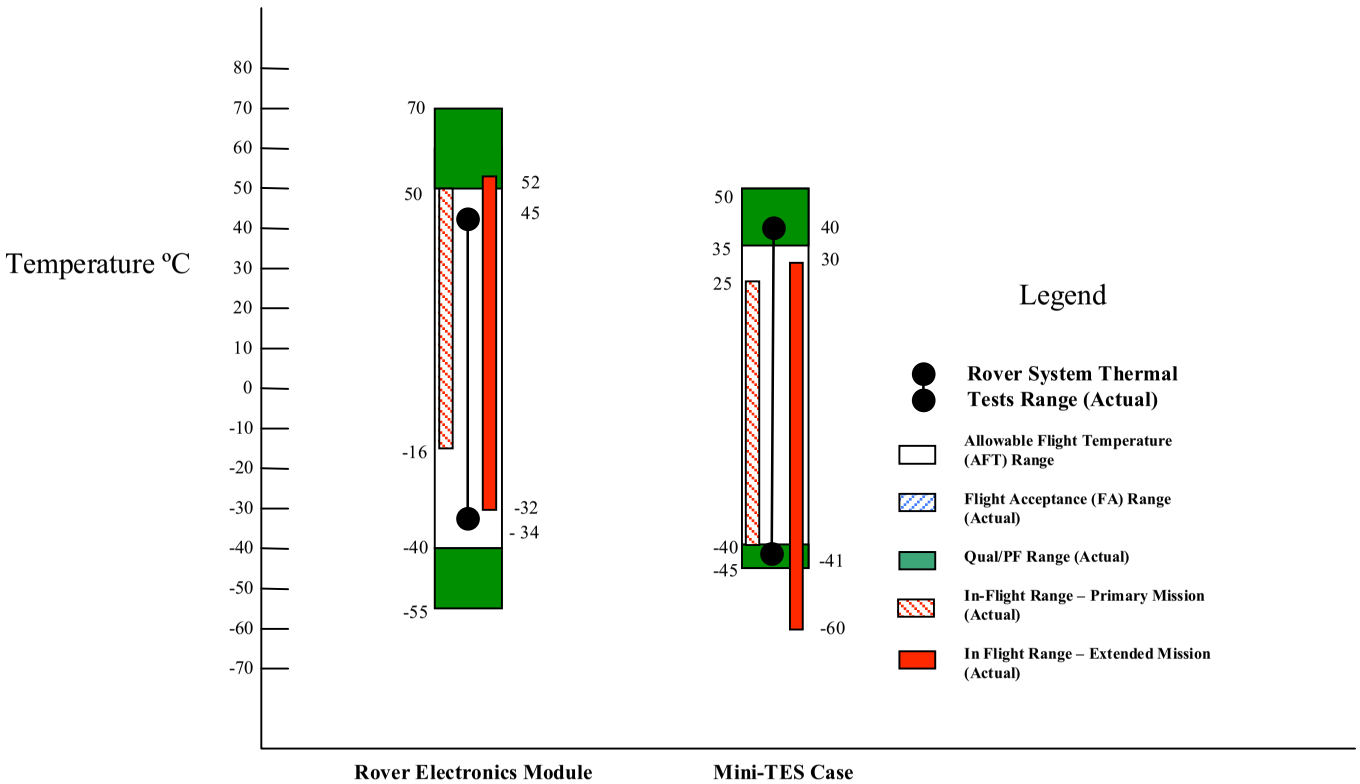
External Engineering Hardware



External Science Instruments

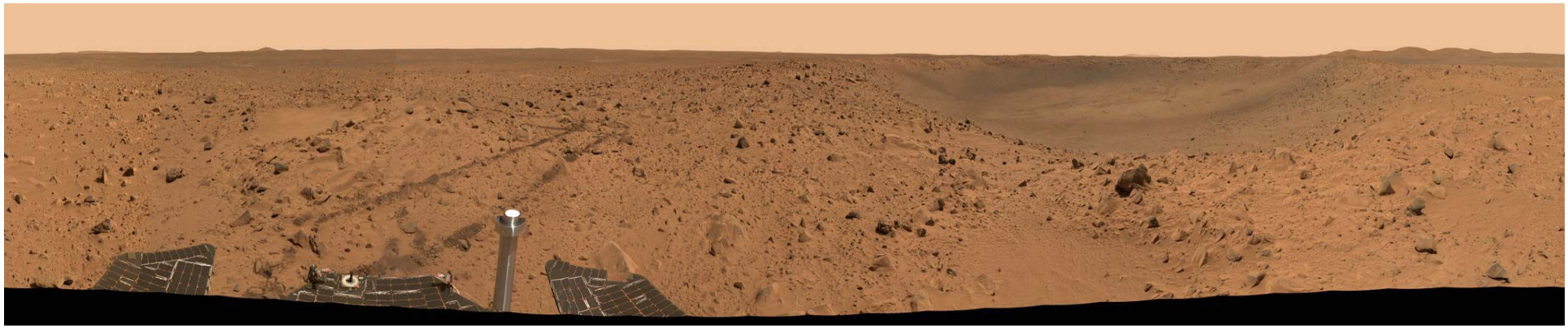


Hardware inside WEB



Summary and Conclusions

- Both Rovers have celebrated 3-year anniversaries on surface of Mars
  - More than ten times design life
- Planned and implemented rigorous assembly and system level test programs
  - Demonstrated robust thermal margins
  - Tested both in vacuum and Mars atmosphere
- Planned and implemented thermal cycling life qualification program
  - Demonstrated survival in deep thermal diurnal cycling and seasonal temperature variations
- Both Rovers continue to explore and return valuable science data



'Bonneville Crater' Panorama