From Concept-to-Flight: An Active Thermal Control System for Mars Science Laboratory Rover

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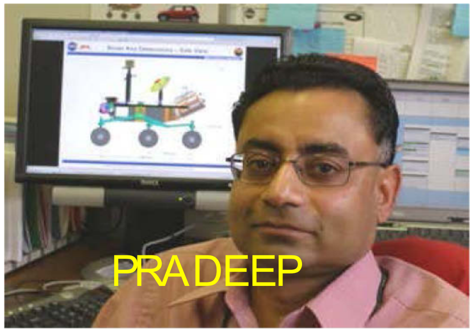
 Government sponsorship acknowledged

MSL Rover Heat Rejection System Gang



OUTLINE

- MSL Rover Curiosity
- Thermal Challenges on Surface
- MSL Thermal Control with MPFL
  - (Mechanically Pumped Fluid Loop)
- Active Fluid Loop Technologies
- Changes during Design Phase
- HRS Fabrication and Integration
- MSL Thermal tests
- Lessons Learned

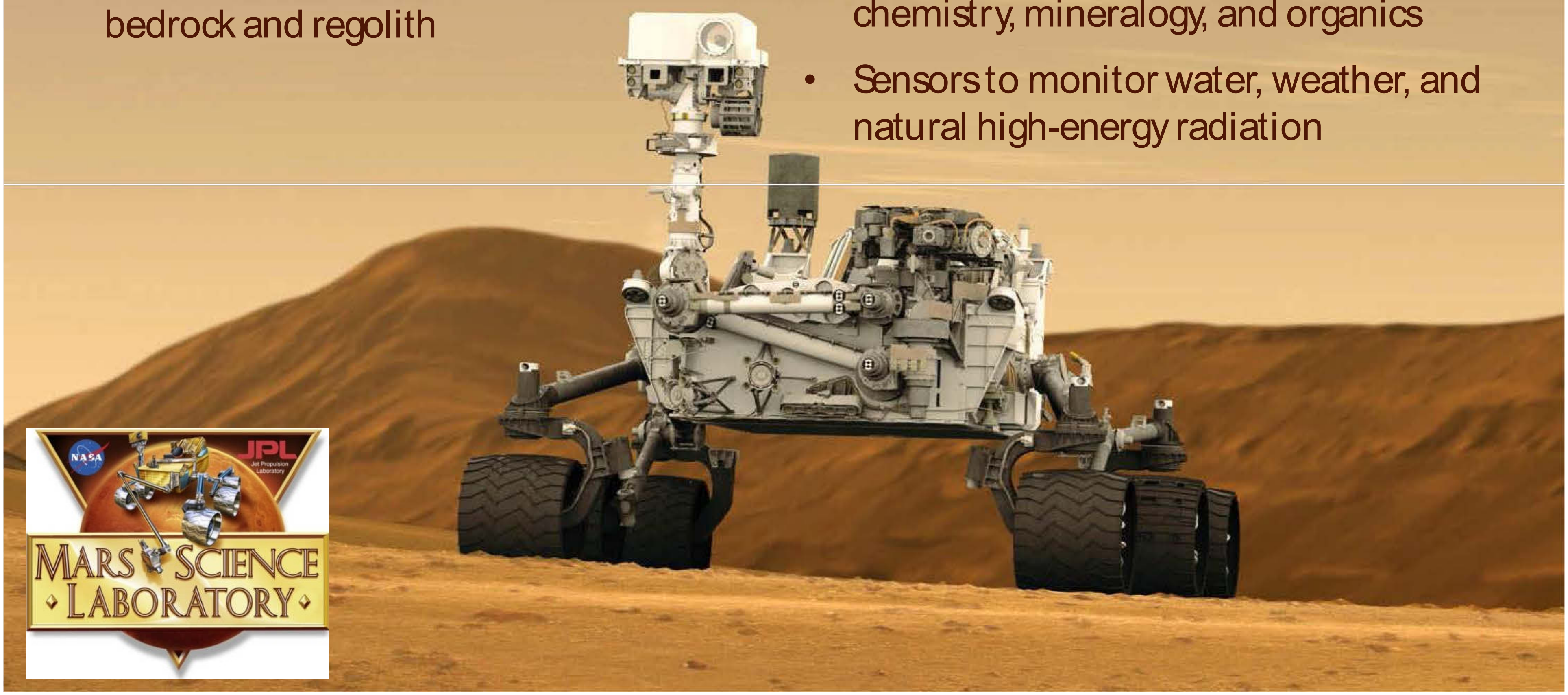
Curiosity's Capabilities

A Robotic Field Geologist

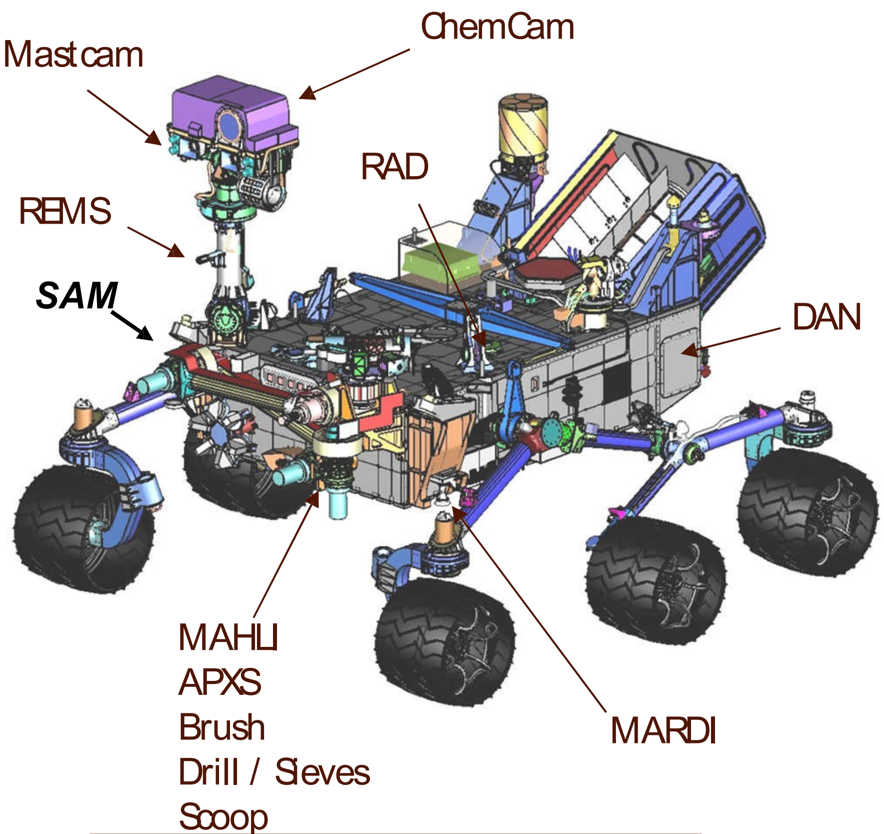
- Long life, ability to traverse many miles over rocky terrain
- Landscape and hand-lens imaging
- Ability to survey composition of bedrock and regolith

A Mobile Geochemical and Environmental Laboratory

- Ability to acquire and process dozens of rock and soil samples
- Instruments that analyze samples for chemistry, mineralogy, and organics
- Sensors to monitor water, weather, and natural high-energy radiation



MSL Science Payload



Rover Width:	2.8 m
Height of Deck:	1.1 m
Ground Clearance:	0.66 m
Height of Mast:	2.2 m

REMOTE SENSING

Mastcam (MSSS) - Color and telephoto imaging, video, atmospheric opacity

ChemCam (LANL/CNES) – Chemical composition; remote micro-imaging

CONTACT INSTRUMENTS (ARM)

MAHLI (MSSS) – Hand-lens color imaging

APXS (Canada) - Chemical composition

ANALYTICAL LABORATORY (ROVER BODY)

SAM (GSFC/CNES) - Chemical and isotopic composition, including organics

CheMin (ARC) - Mineralogy

ENVIRONMENTAL CHARACTERIZATION

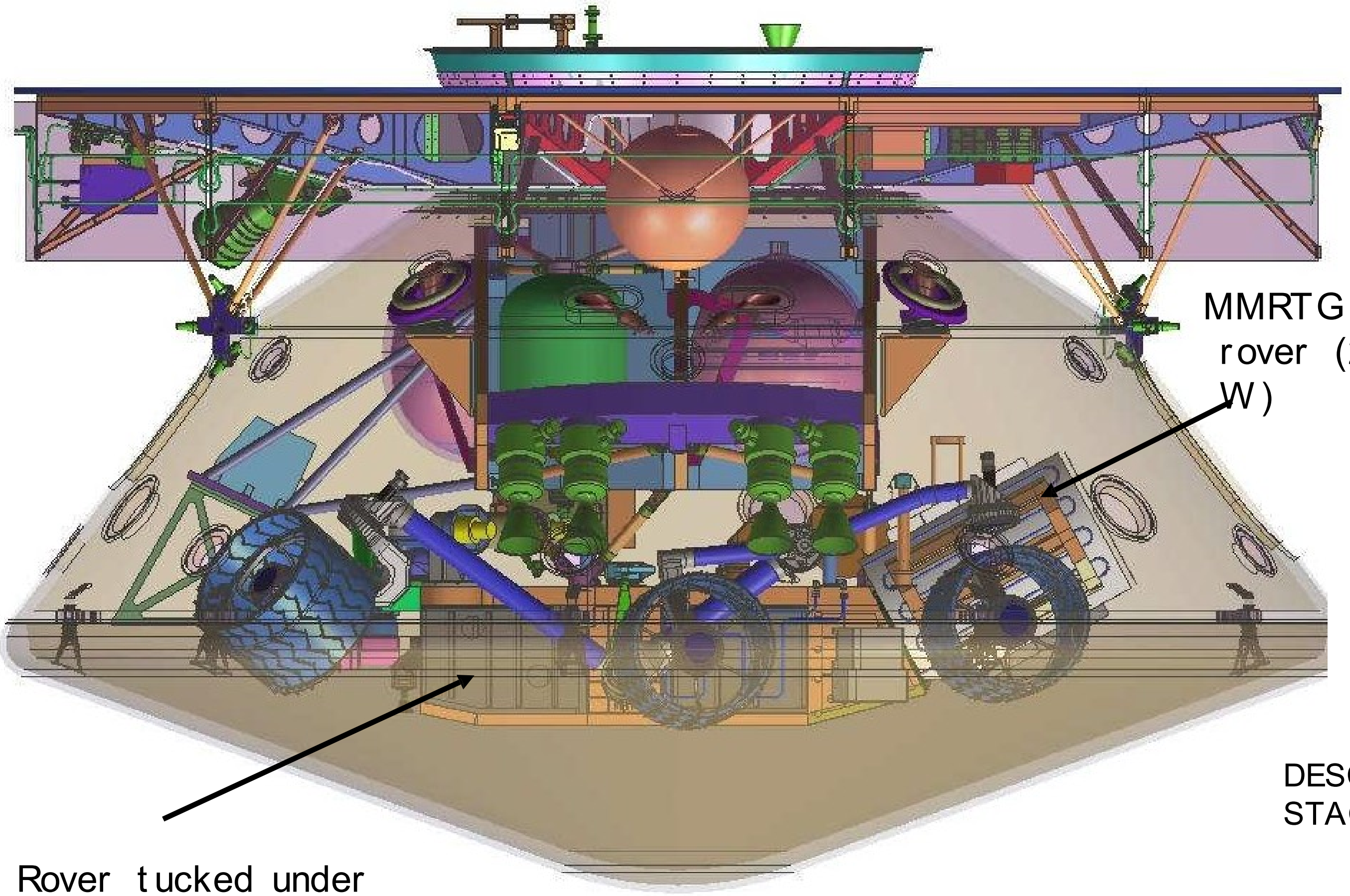
MARDI (M. Malin, MSSS) - Descent imaging

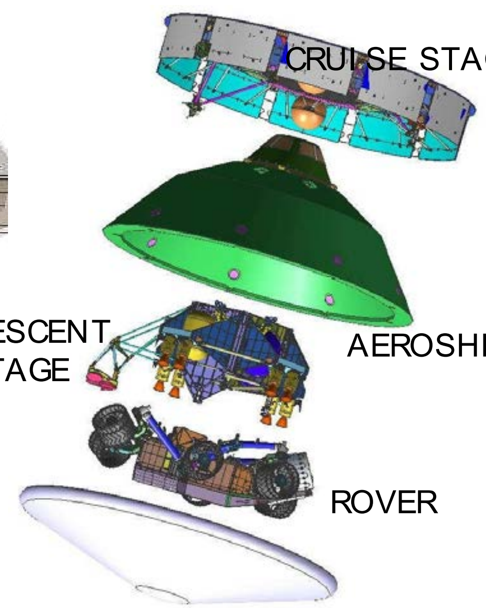
REMS (Spain) - Meteorology / UV

RAD (SwRI) - High-energy radiation

DAN (Russia) - Subsurface hydrogen

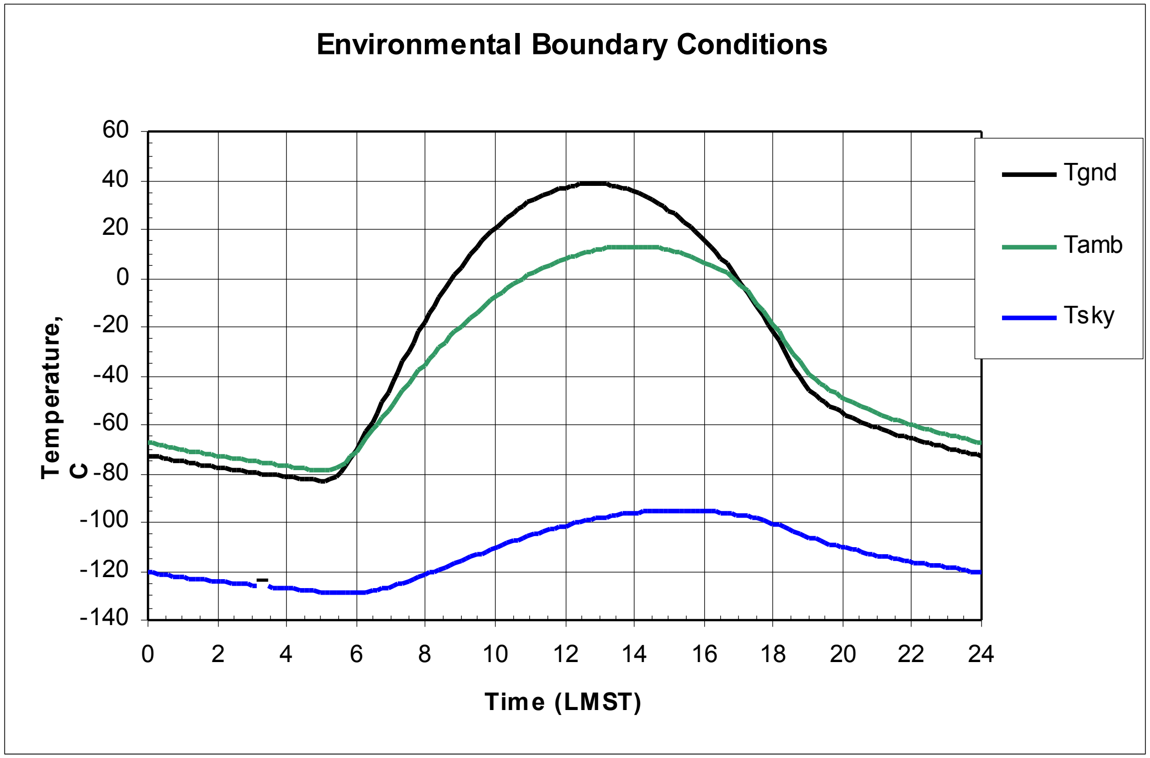
MSL Spacecraft in Cruise Phase



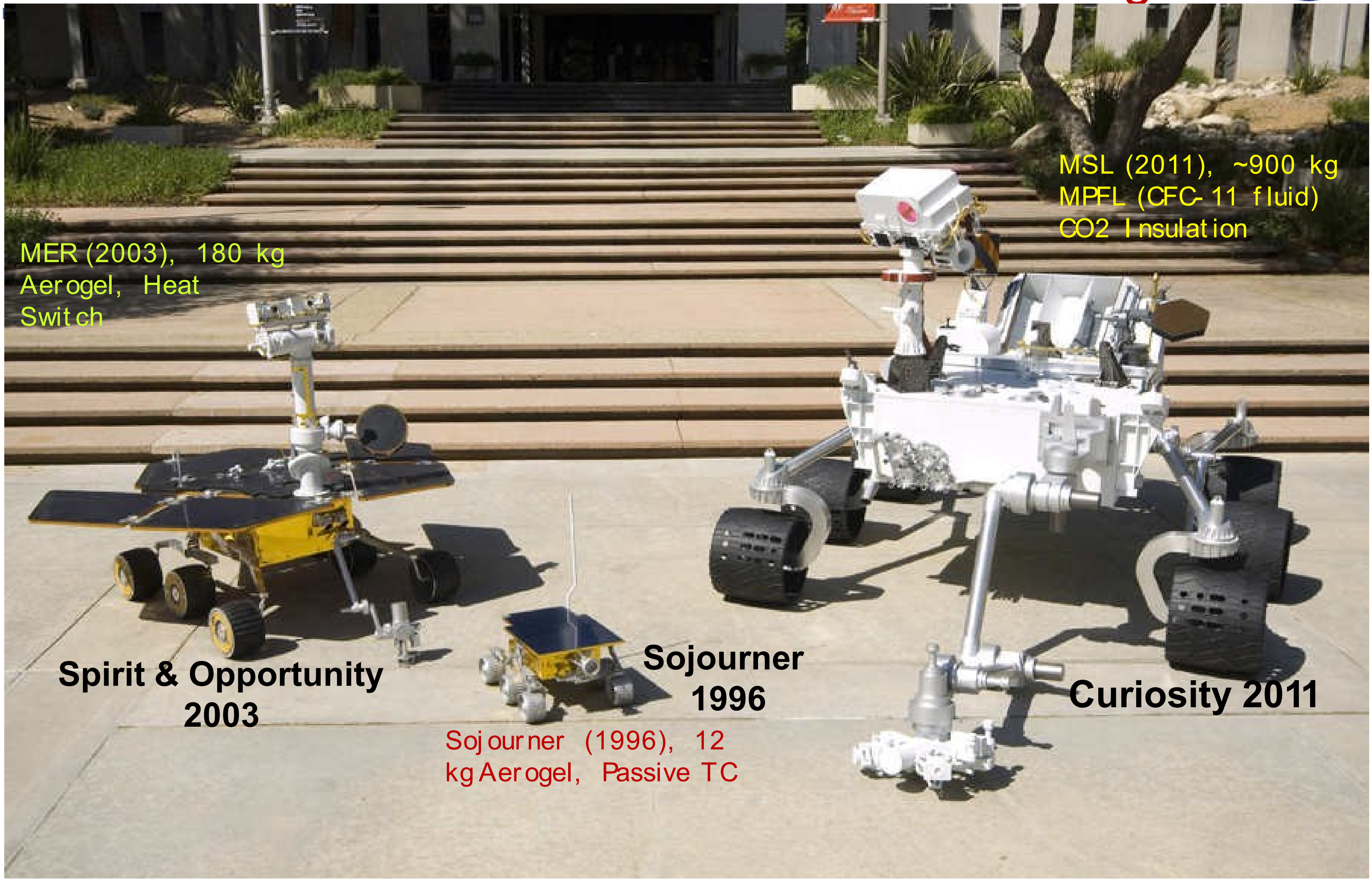


Thermal Control Challenges of MSL Rover

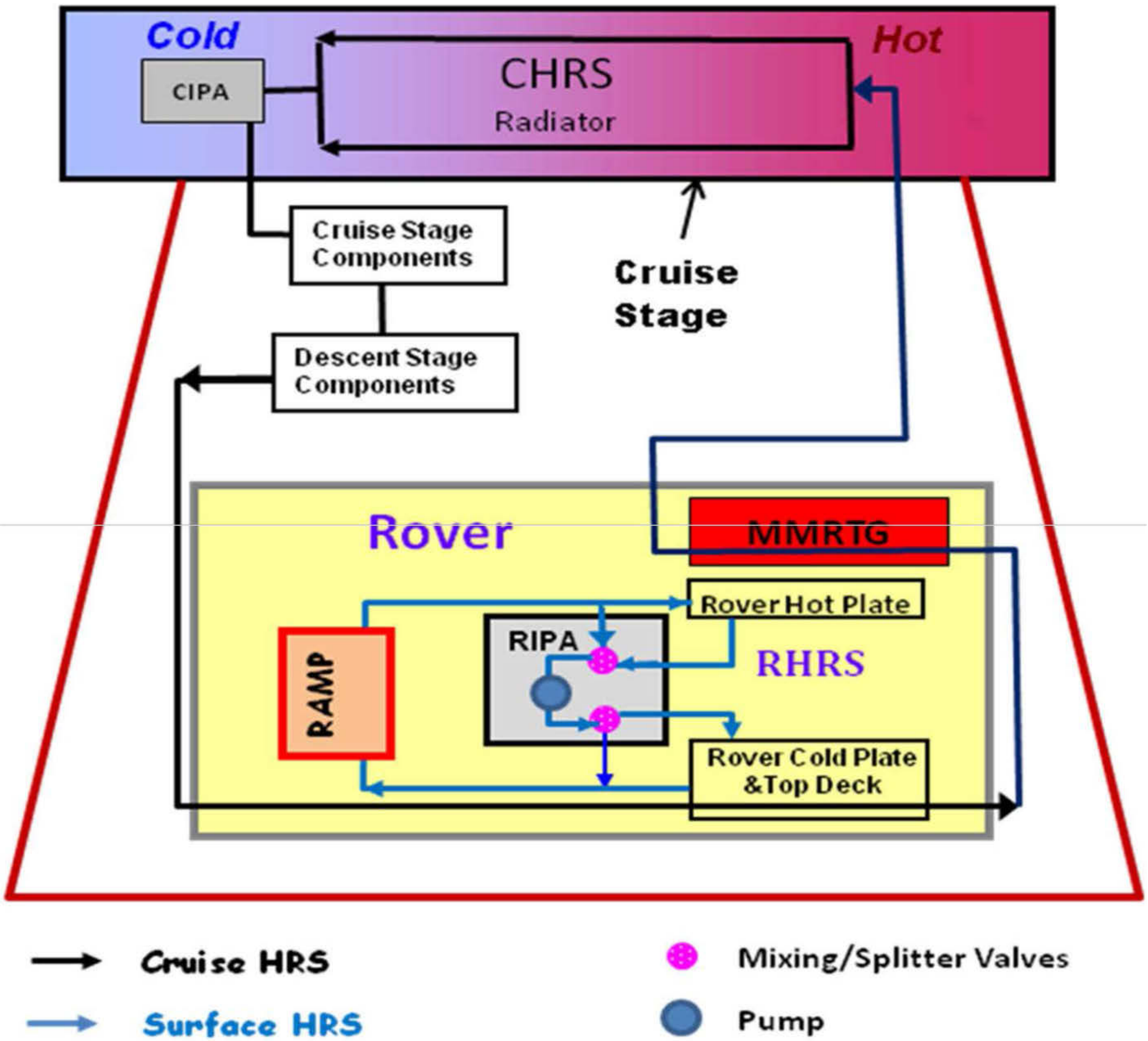
- Demanding thermal control requirements
  - Extreme diurnal environment (-129 C to 40 C, full sun to no sun)
  - Large RPS waste heat (~2000 W) management during launch/cruise, surface
  - Tight temperature requirements of Science Instrument
  - Long life & Rover mobility challenges (configuration, dust etc)



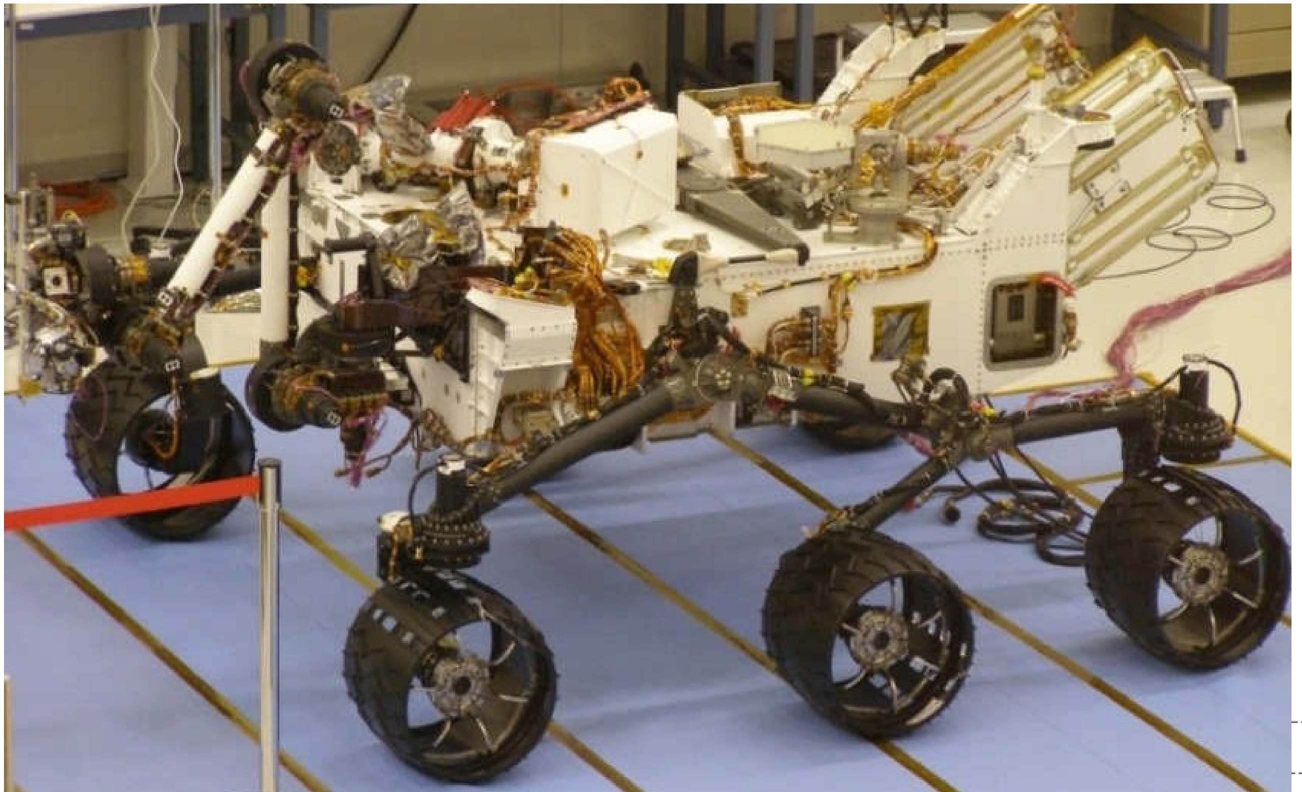
Rover Family Portrait –
Infusion of Advanced Thermal Technologies

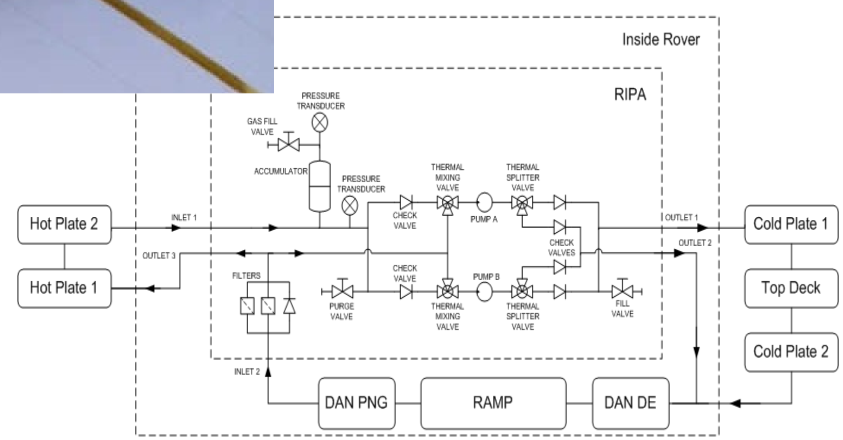


MSL Thermal Control with MPFL



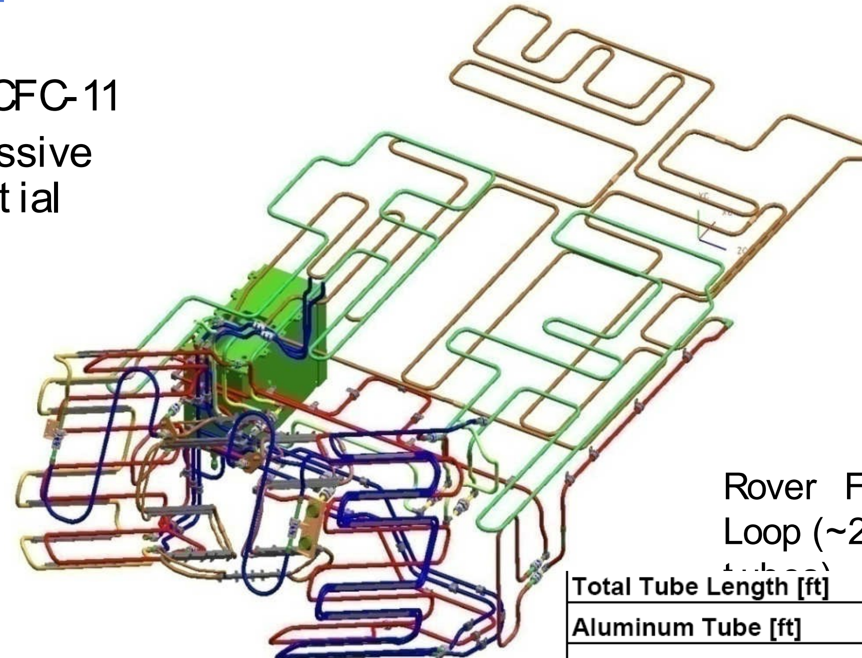
HRS Design Activities - RHRS





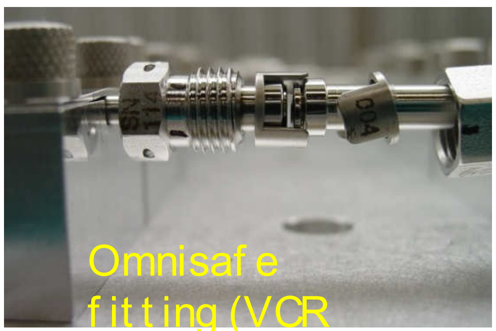
MSL Focused Technology Development

- Pump Life Testing: 20 C to 120 C
- Long-term Chemical tests: >100 C in CFC-11
- Thermal valves & Mech. Fittings: Passive flow valves, OmniSafe VCR joints, inertial welds, flex tubes
- Working fluids:
  - CFC-11, Galden HT-170

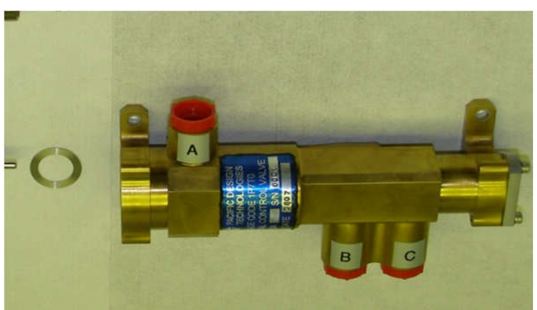


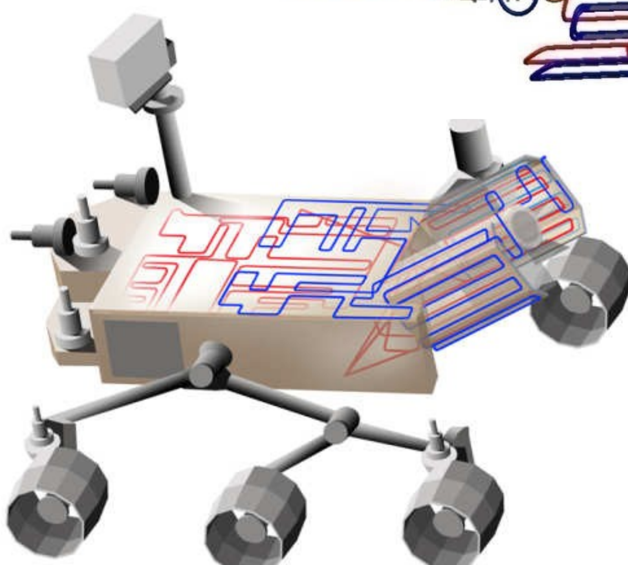
Rover Fluid Loop (~200 ft

Total Tube Length [ft]	188
Aluminum Tube [ft]	149
SS Tube [ft]	28
Flex Line [ft]	11
Flex Bellows	30
Bi-Metal Joints	18
Aluminum Unions	12
Micro Elbows	47
Ominsafe Glands	42
Other SS Components	0
SS Orbital Welds	155
Aluminum Hand Welds	42
SS-AL Inertial Welds	18
Mechanical Fittings	21



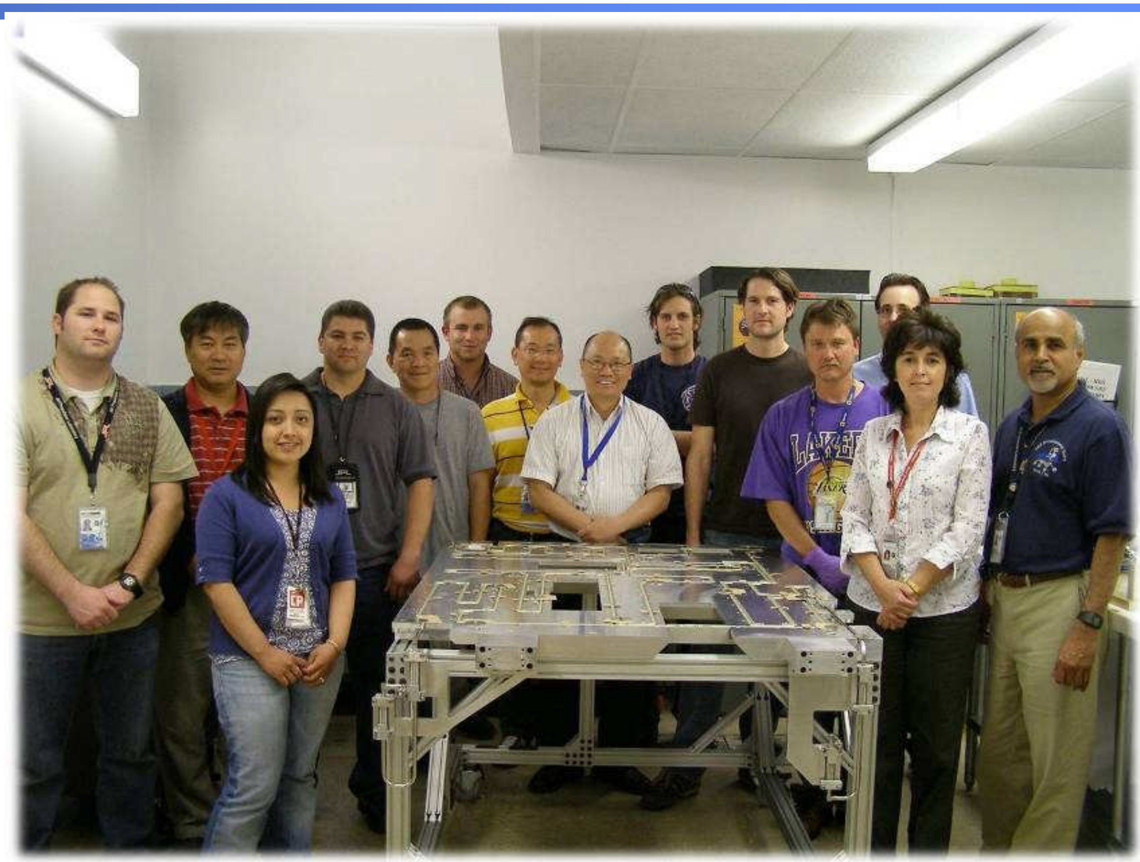
Omnisafe fitting (VCR Style)

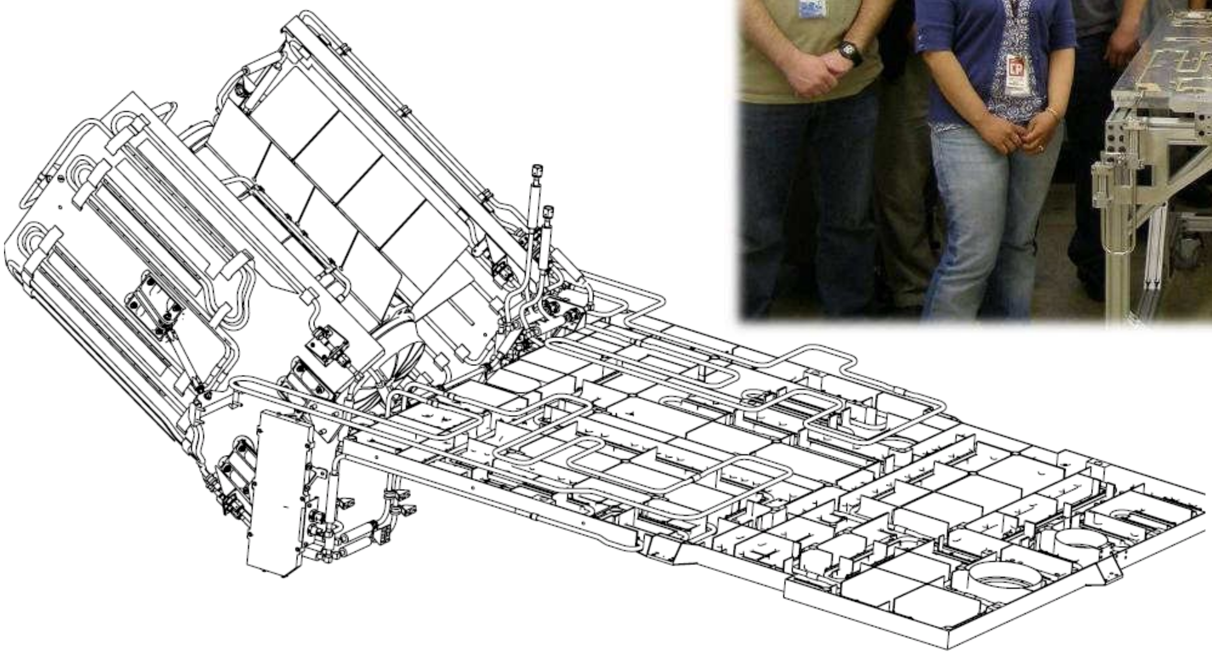




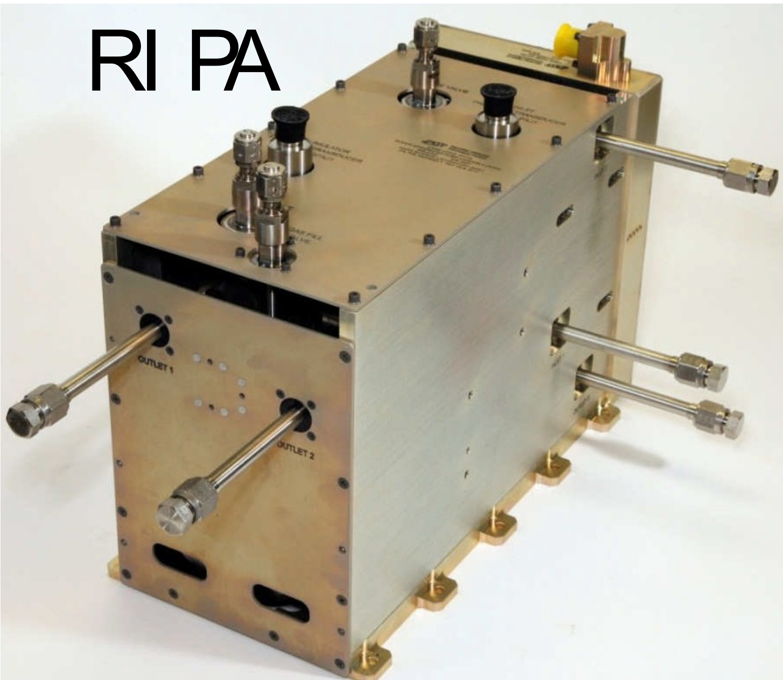
For Planning & Discussion Purposes Only

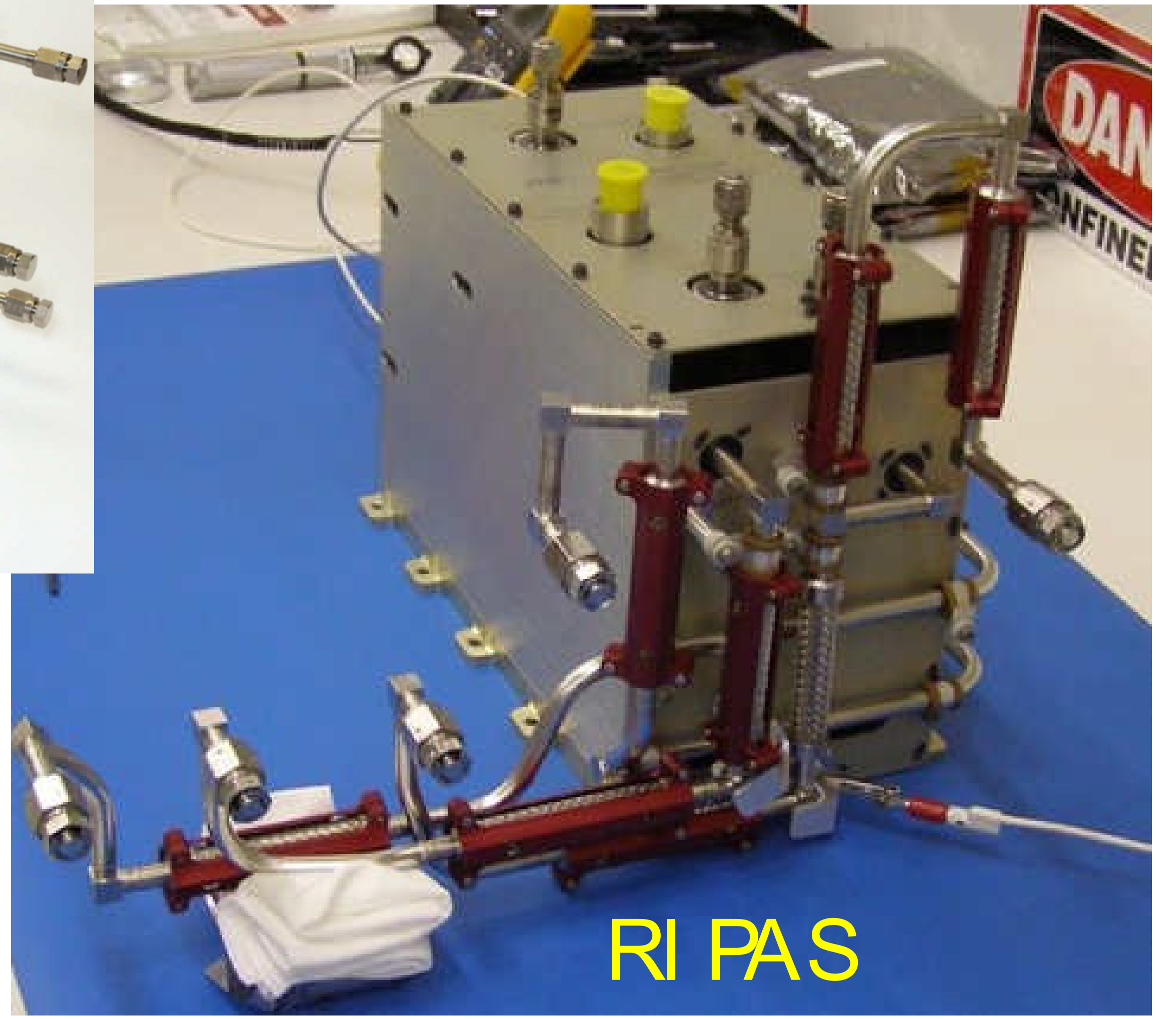
MSL Rover RAMP Fabrication



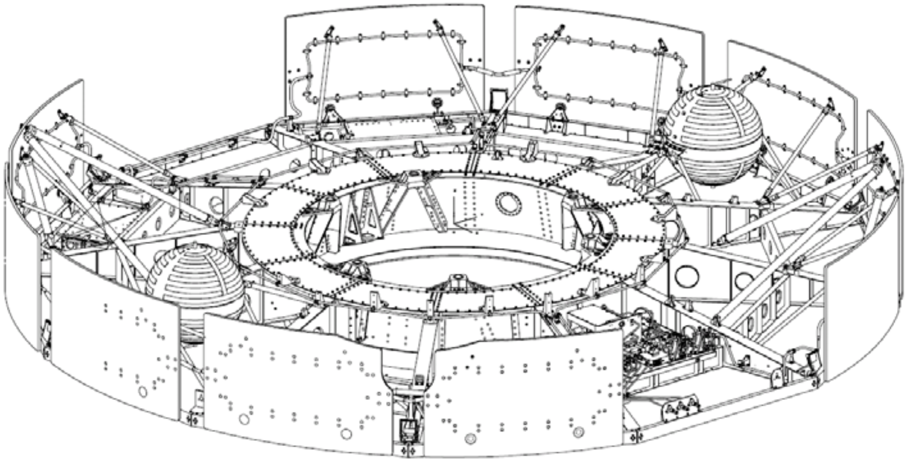


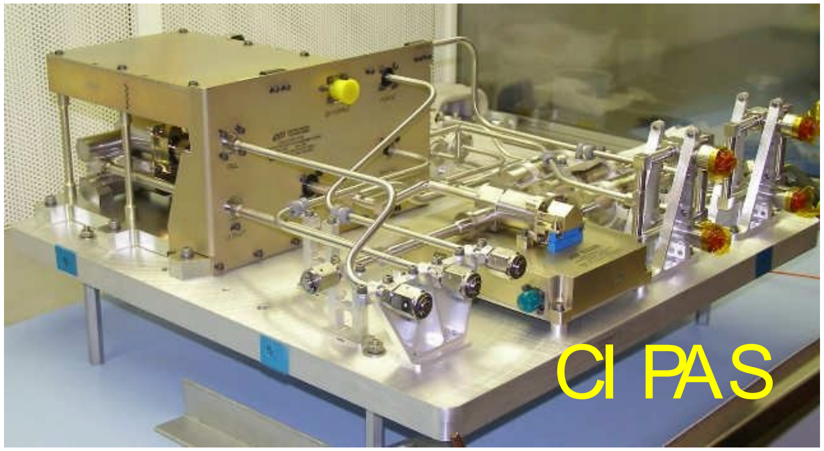
RIPA/RIPAS Design and Build

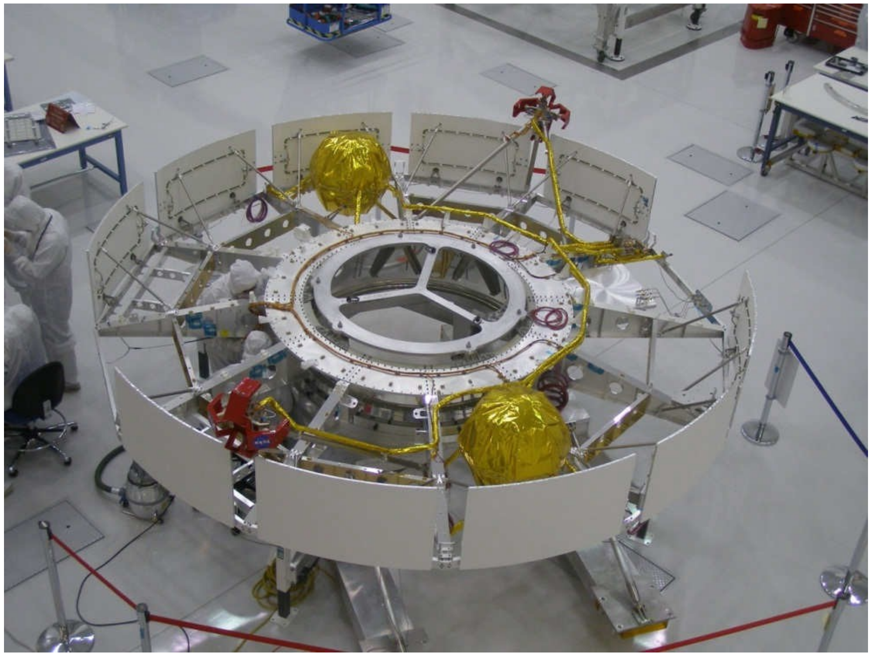




CIPAS & CHRS Fab/Install on S/C

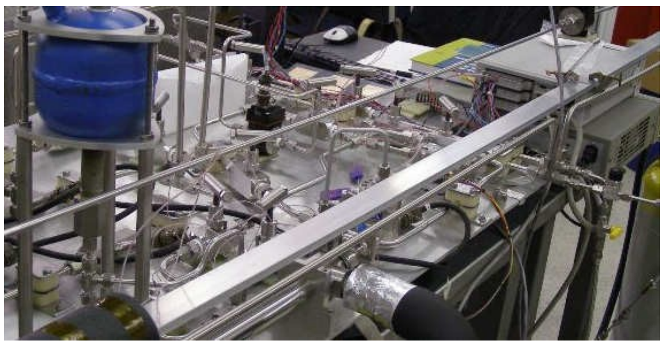


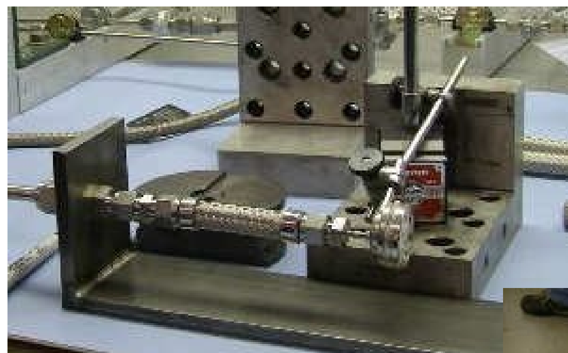


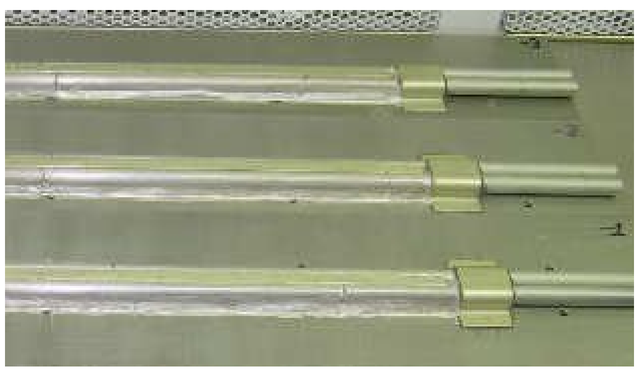


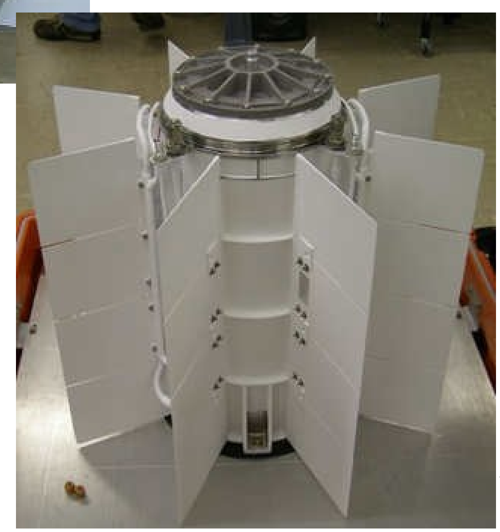
Key Changes during Design Phase

- Several significant changes had to made in HRS design
  1. Change of RAMP tubing from smooth to finned
  2. Flex lines in the loop to account for relative displacement
  3. Epoxy thermal conductivity lower than specified
  4. Adding of secondary tubes for ground cooling

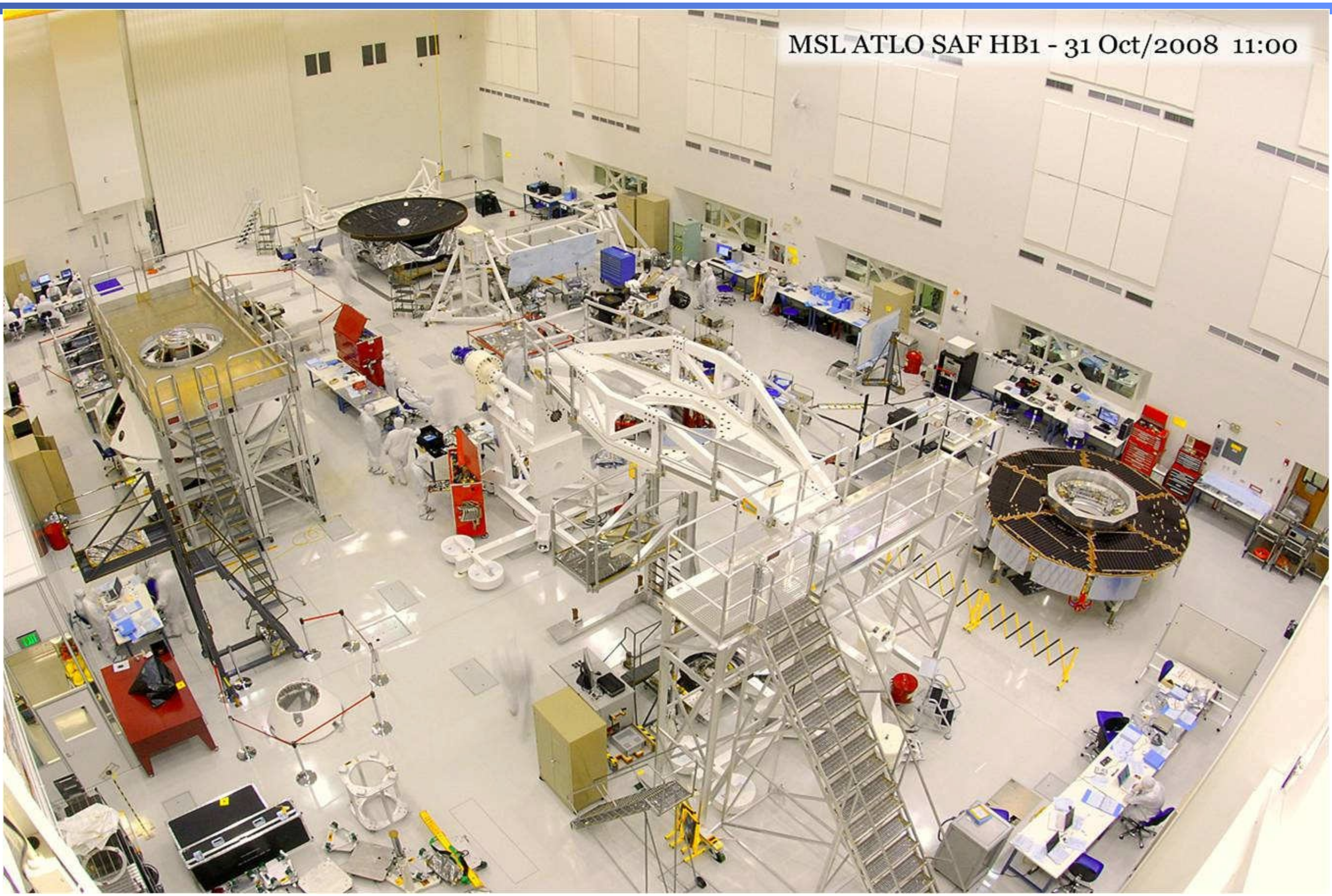




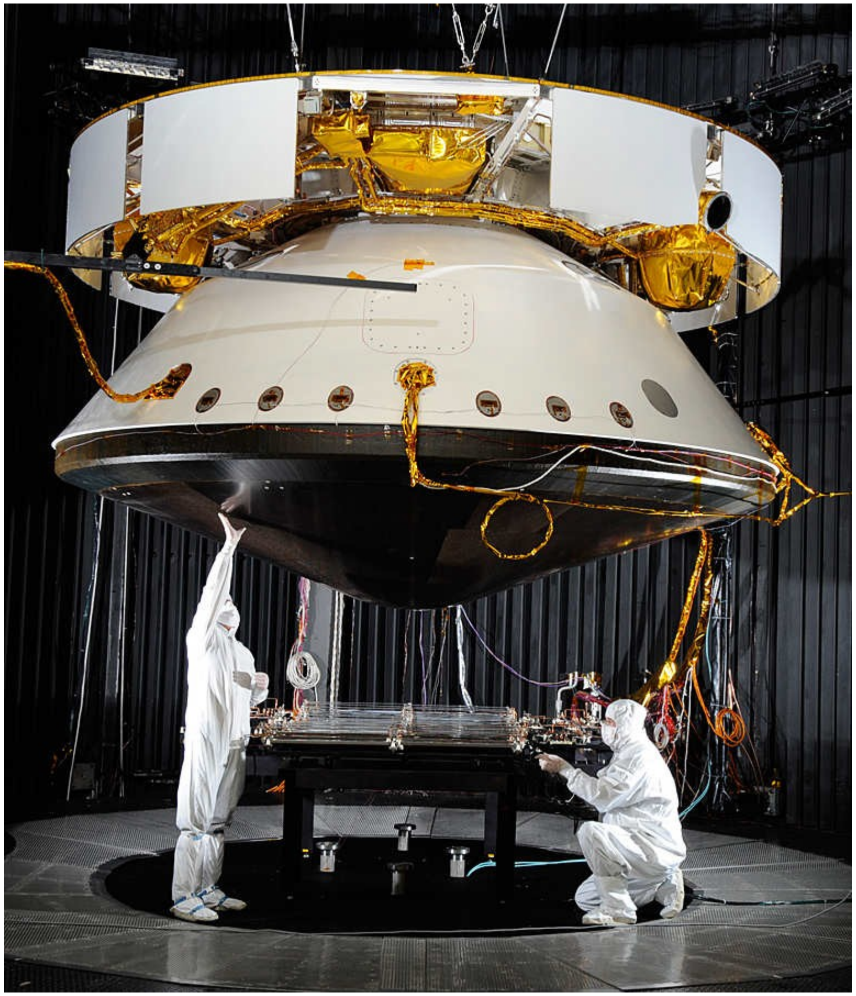




HRS Integration on the Spacecraft

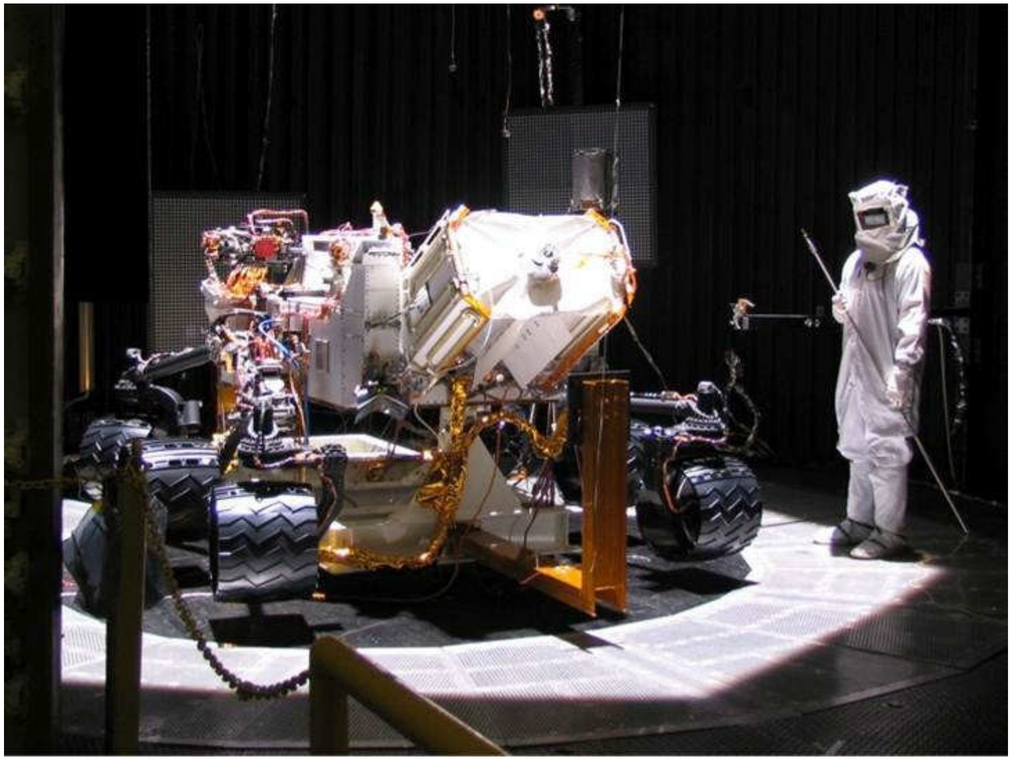


System Level Testing of CHRS/RHRS



System Thermal Vac Test
(Cruise Phase)

System Thermal Test
(Sruface Phase)



HRS Operation during Launch/Cruise

- All the pumps were turned on in both CHRS (2+1) and RHRS (2 pumps) before launch
- After a few hours into flight only one pump is operating in each loop
- The backup pumps in each loop were turned on for an hour every four weeks for maintenance check
- Both active loops are operating very smoothly and as expected

Lessons from MSL HRS Experience

- Challenging missions require "out-of-the box" ideas and involve significant risks in meeting the final goals
- Strong commitments from the team members, flight system managers, and institution are very important
- Large margins in design, schedule, and resources are a must
- Use simple quick experiments to verify new design
- Work closely with the vendors; allow sufficient schedule margins on vendors' services
- Team should be able to tackle unexpected problems
- Multi-disciplined diverse team is a must for such effort
- High morale, perseverance, and team spirit are key

Conclusions

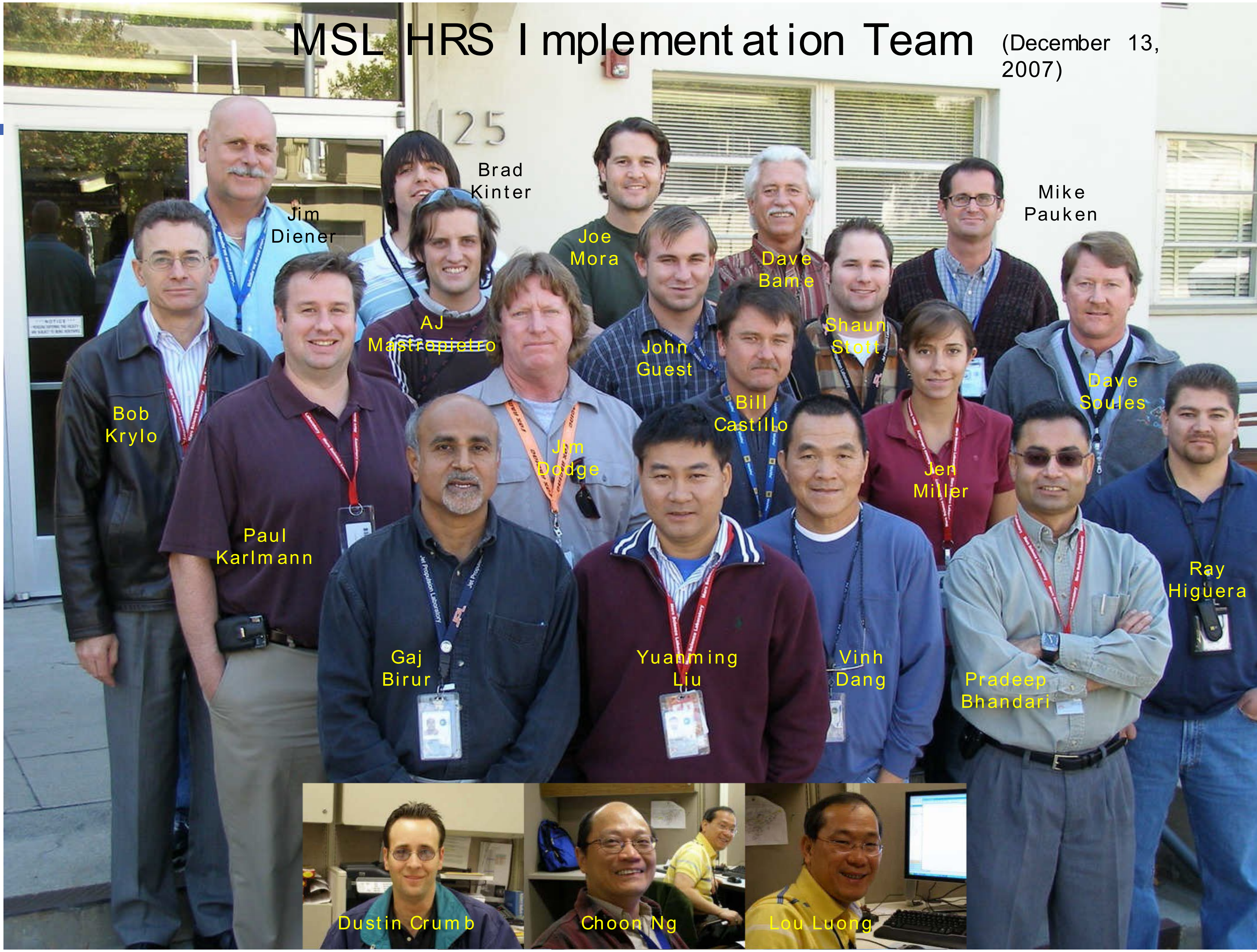
- MSL rover's many challenging thermal requirements during its surface operation could be met with MPFL
- Several advanced MPFL thermal technologies were developed in order to ensure a robust thermal control system for the rover operation
- MSL Rover MPFL based thermal architecture will pave way for its usage on future NASA missions, Commercial satellites, and military missions

MSL Rover HRS Team

Gaj	RTG/HRS Thermal Accommodation Cog Engineer
Birur Pradeep	HRS Designer and MSL Thermal System Engineer
Bhandari	HRS GSE Cog Engineer and HRS Lab Manager
Dave Bame	RIPAS/CIPAS Cognizant Engineer
Paul Karlmann	HRS Fabrication and KSC HRS/GSE Engineer
AJ	HRS Fabrication Cognizant Engineer
Mastropietro	HRS Fabrication and KSC HRS Engineer
Yuanming Liu	HRS Fabrication Engineer
Jen Miller	MSL Thermal Product Delivery Manager
Mike Pauken	
Jackie Lyra	

Sunset on Mars – Spirit Rover May 19, 2005

MSL HRS Implementation Team (December 13, 2007)



MSL Rover Thermal Team

23RD Thermal & Fluids Analysis Workshop (TFAWS)

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Abstracts due: May 18 Papers due: July 20