JPL Advanced Thermal Control Technology Roadmap

a presentation to

Spacecraft Thermal Control Workshop
The Aerospace Corporation, El Segundo California
March 22, 2016

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NASA Jet Propulsion Laboratory
California Institute of Technology

Jet Propulsion Laboratory
California Institute of Technology

Outline

- Status of current and proposed flight projects from the thermal subsystem perspective
- JPL/NASA mission roadmap
- Thermal technology challenges

Status of current and proposed projects

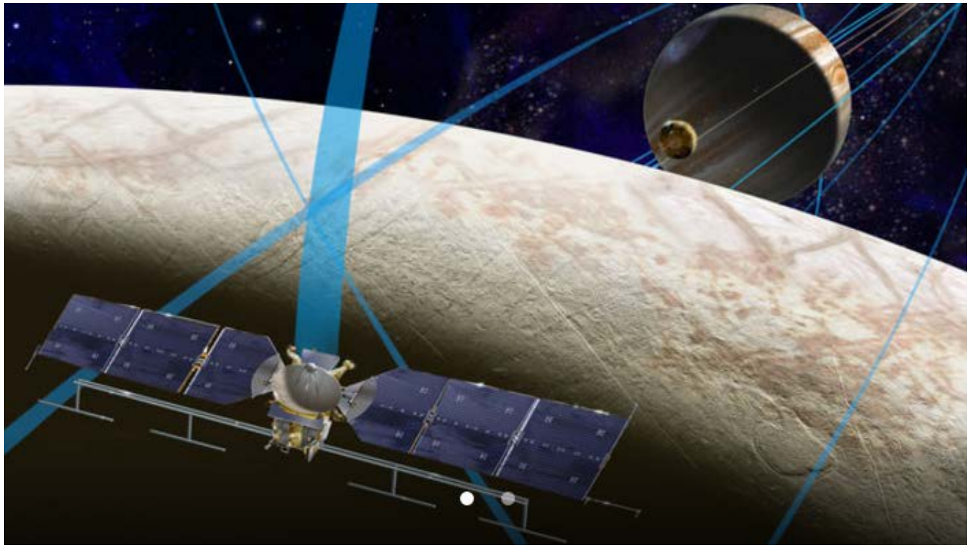
From the thermal subsystem perspective

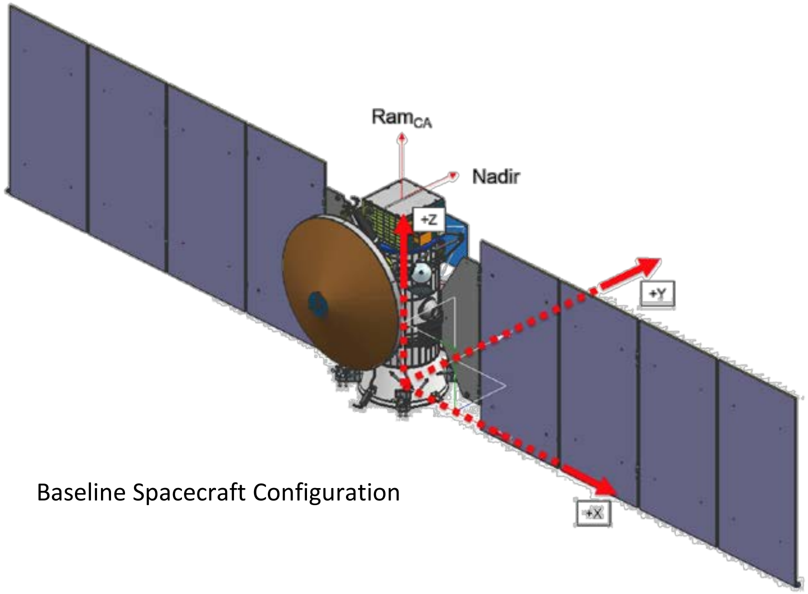
Jet Propulsion Laboratory
California Institute of Technology

Planned Europa Clipper Mission

(Courtesy of Dr. Tony Paris, JPL Europa Thermal Lead / Dr. Brian Carroll, JPL Europa Thermal Technology Lead)

- The Europa Clipper mission would place a spacecraft in orbit around Jupiter in order to perform a detailed investigation of the giant planet's moon Europa -- a world that shows strong evidence for an ocean of liquid water beneath its icy crust and which could host conditions favorable for life.
- Constraints for the spacecraft design include limited electrical power for survival heating, long mission lifetime (eight to twelve years), and tolerance for high radiation environments.
- An MPFL-based thermal control design is desirable for this application due to the potential for efficient reclamation of waste heat from electronics located within a compact radiation shielded "vault" for use as survival heat throughout the spacecraft.
- Radiation hardened pump controller electronics and sensors are being developed and tested for survivability in the Jovian environment

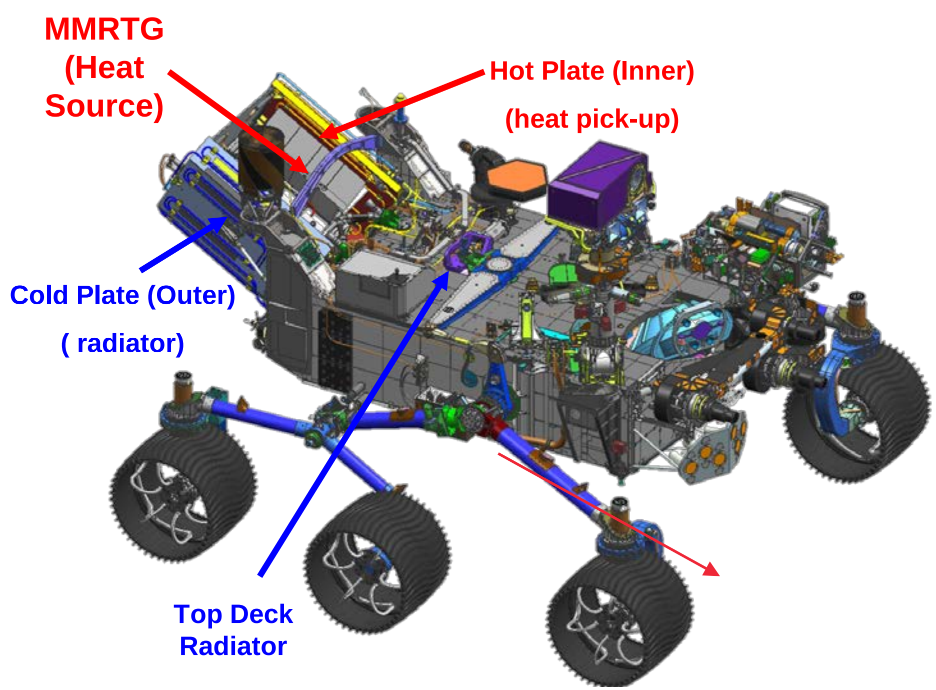


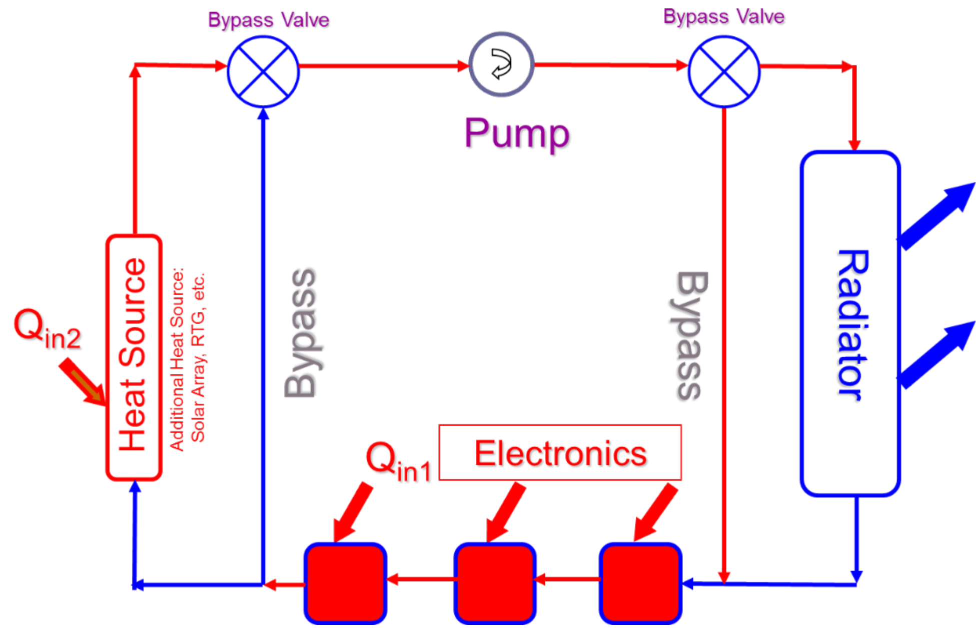


Baseline Spacecraft Configuration

Mars 2020 Rover

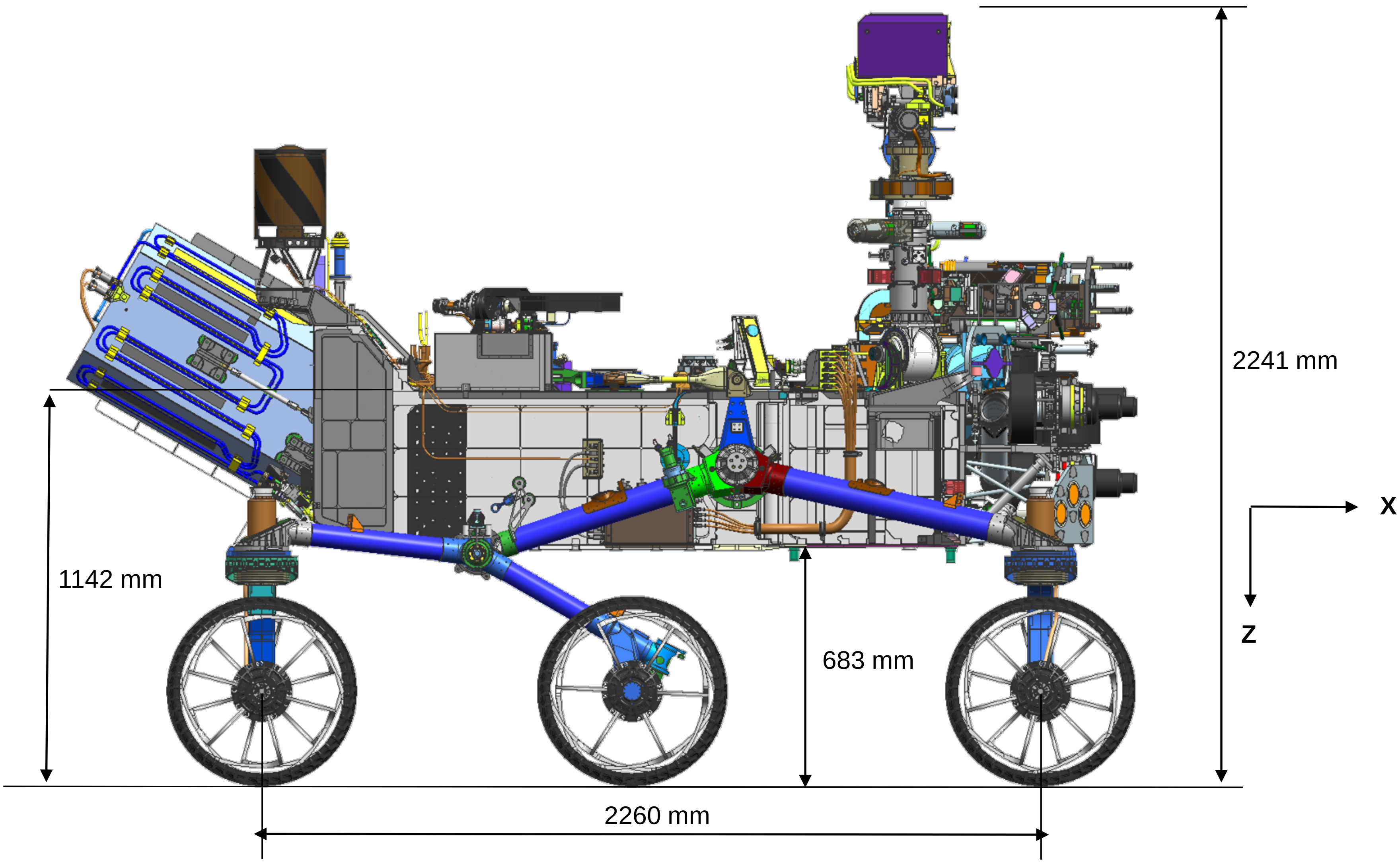
- Key functions of M2020 Rover Heat Rejection System (RHRS):
  - Removal of waste heat from rover during Cruise phase of mission
  - Removal of waste heat from rover and MMRTG during hot part of the day
  - Recovery of waste heat from MMRTG during the cold part of the day
  - Thermally couple RAMP masses to create large effective thermal mass to reduce temperature swings
- RHRS fluid tubes are embedded in RAMP to remove or add heat to keep the science and engineering hardware at safe operating and survival temperatures



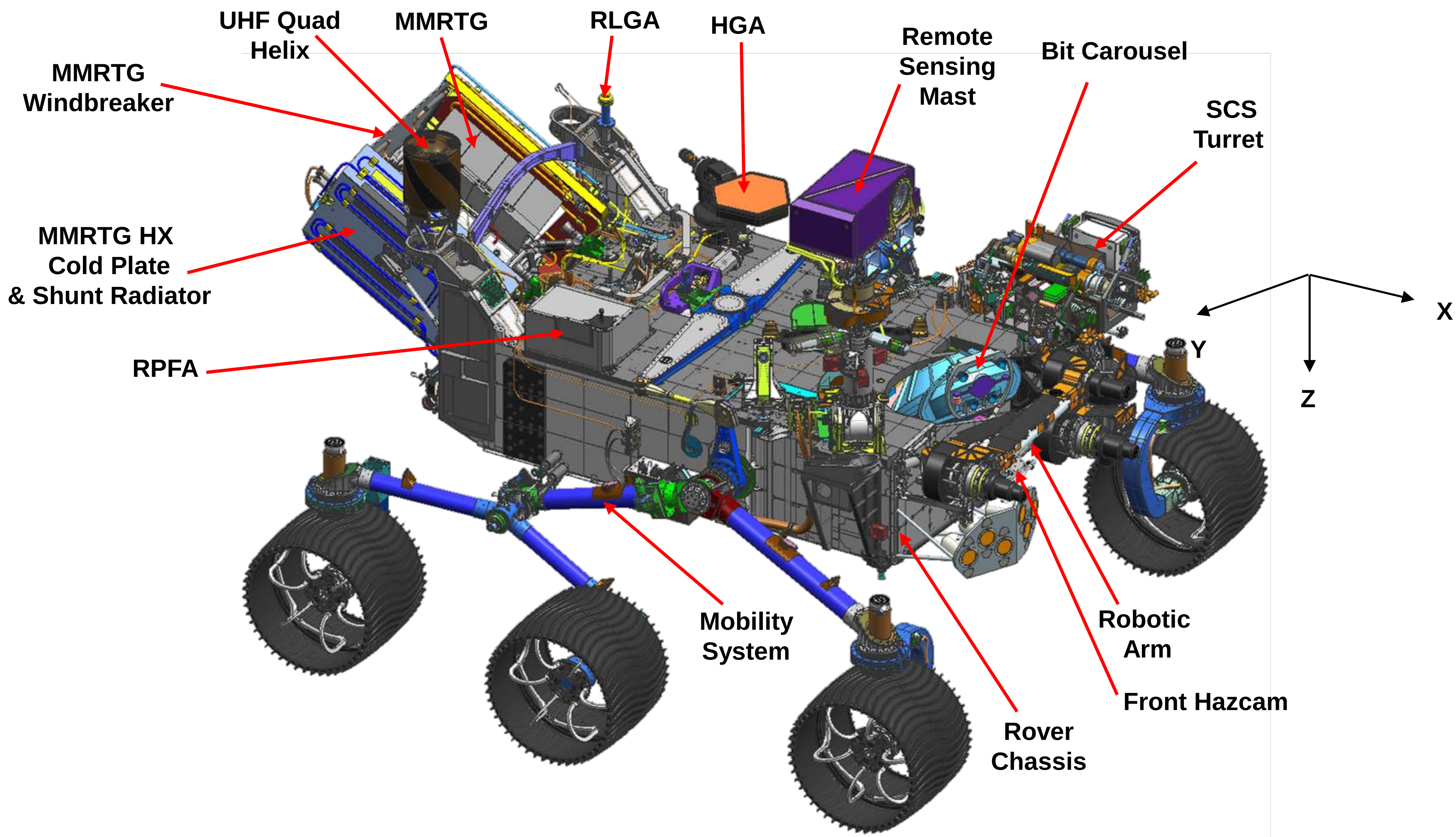


Pumped Fluid Loop Based Thermal Bus Architecture (Supply as well as Reject Heat)

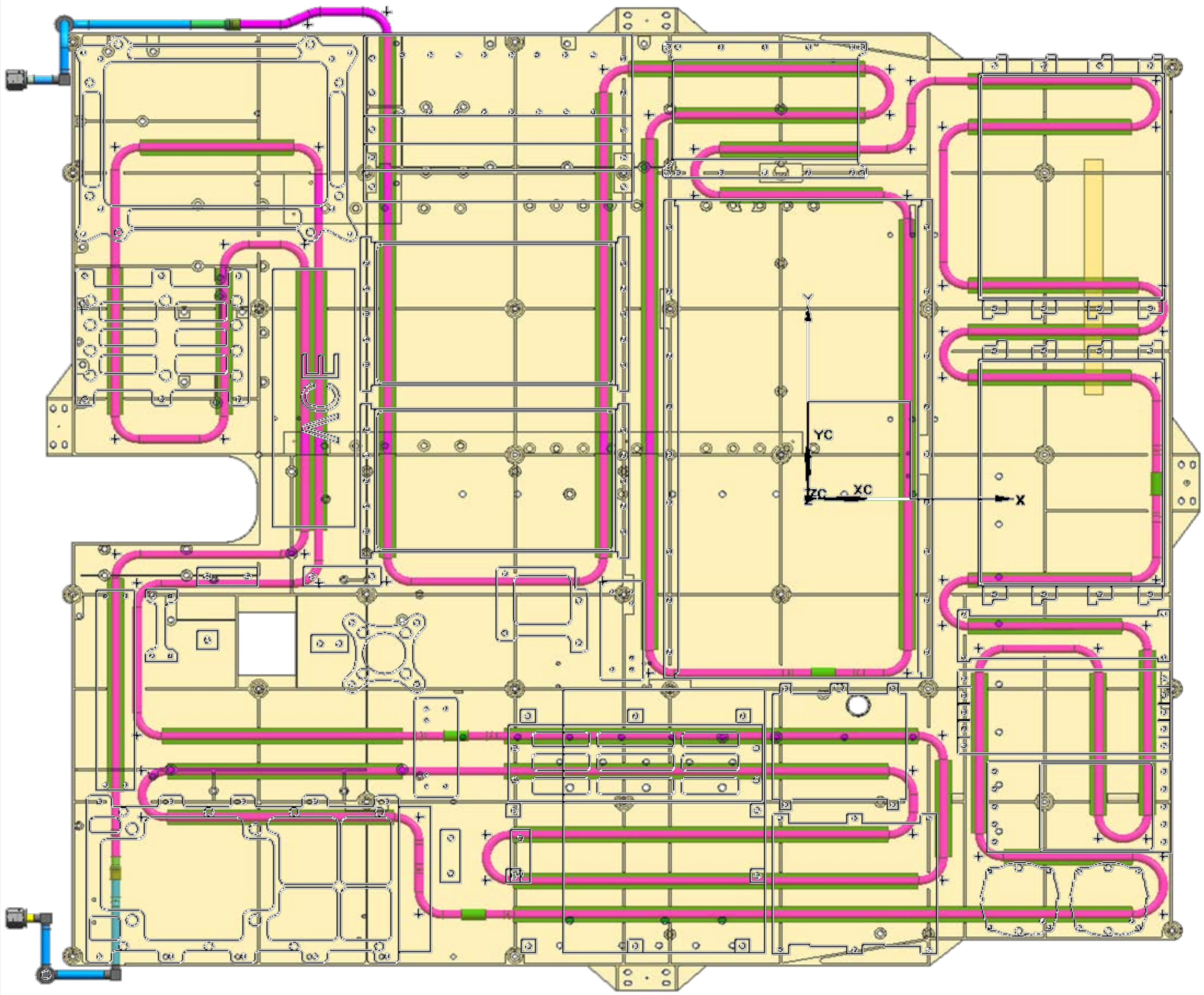
Mars 2020 Rover



Mars 2020 Rover

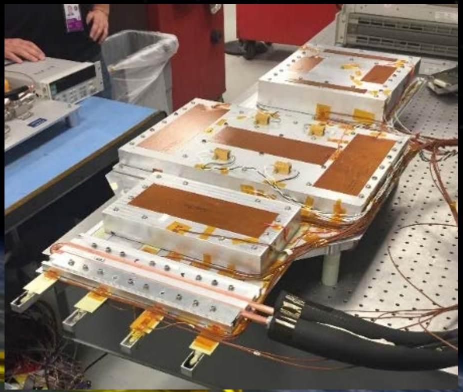


Mars 2020 RHRS Tube Routing on RAMP

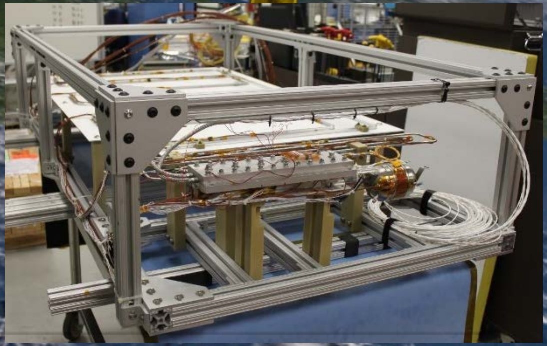


Surface Water Ocean Topography Mission

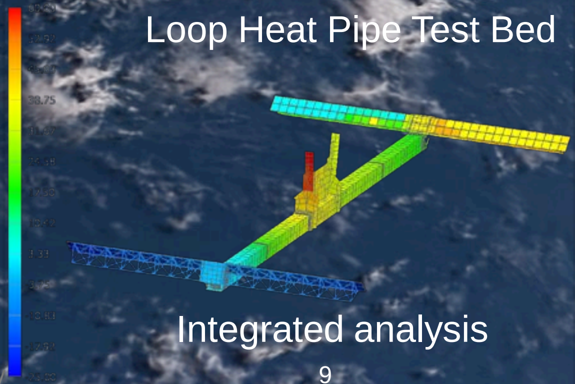
- Mission objective: characterize ocean topography to a spatial resolution as low as 15 km and provide a global inventory of surface water
- LEO (77.6° inclination, 891 km)
- Accommodates seven instruments
- Challenging combination of thermal requirements
  - Co-location requirements
  - >1400 W peak thermal dissipation
  - Heat fluxes ~2.5 W/cm^2
  - Stability requirements 0.05°C/min
- Thermal control subsystem utilizes a combination of LHPs and CCHPs



Thermal Pallet Simulator



Loop Heat Pipe Test Bed

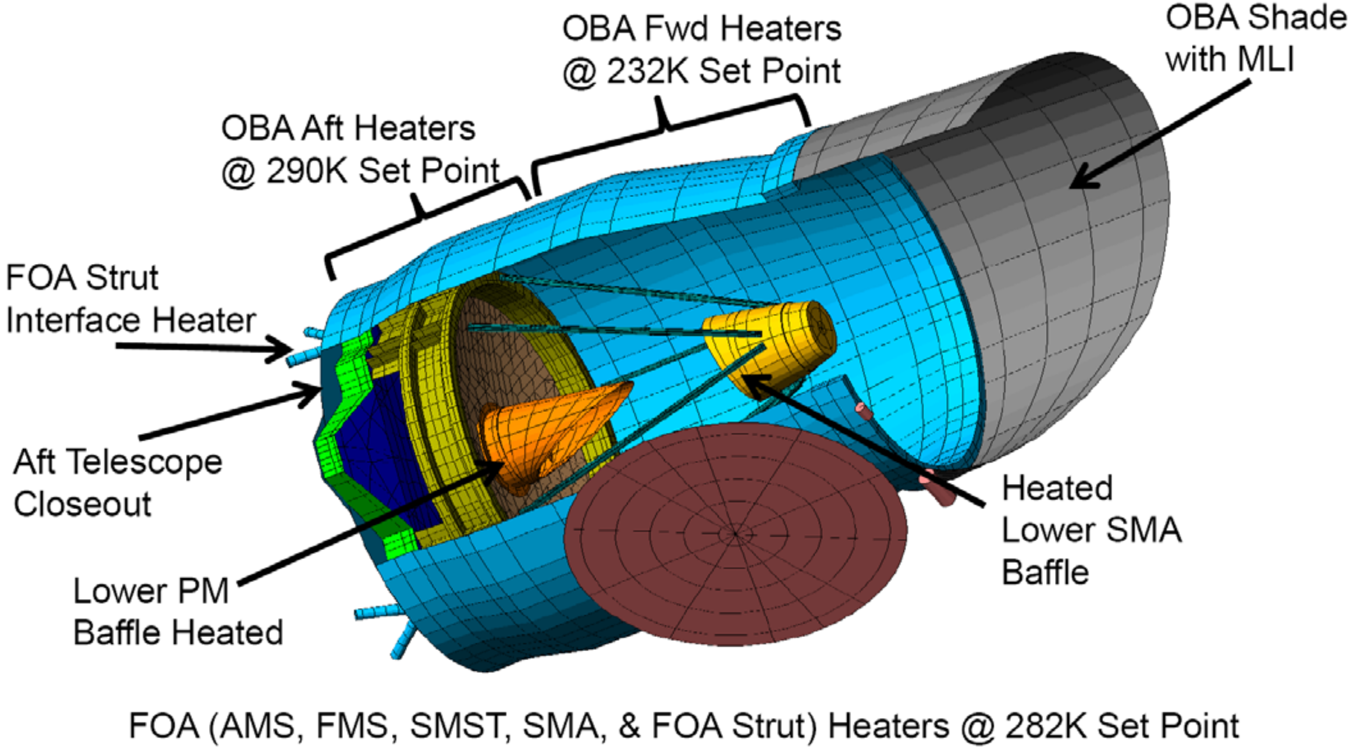


Integrated analysis

WFIRST/AFTA Exo-Planet Finder

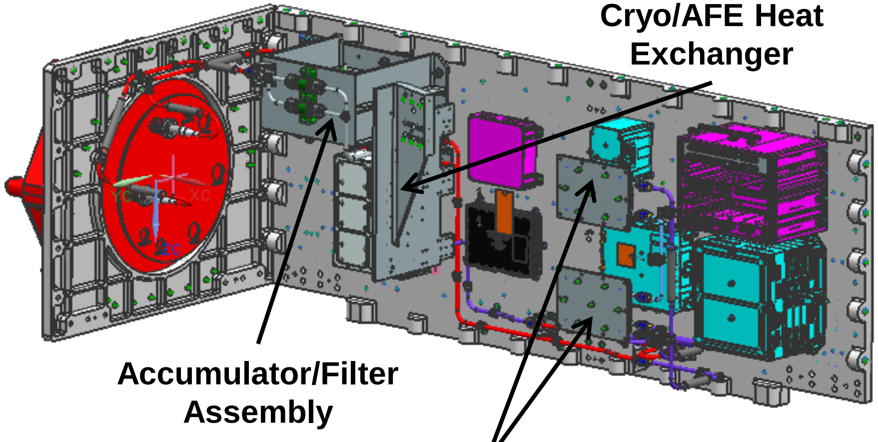
- Total Power: 1380W
  - OBA: 1179W
  - FOA: 201W, 64 control zones

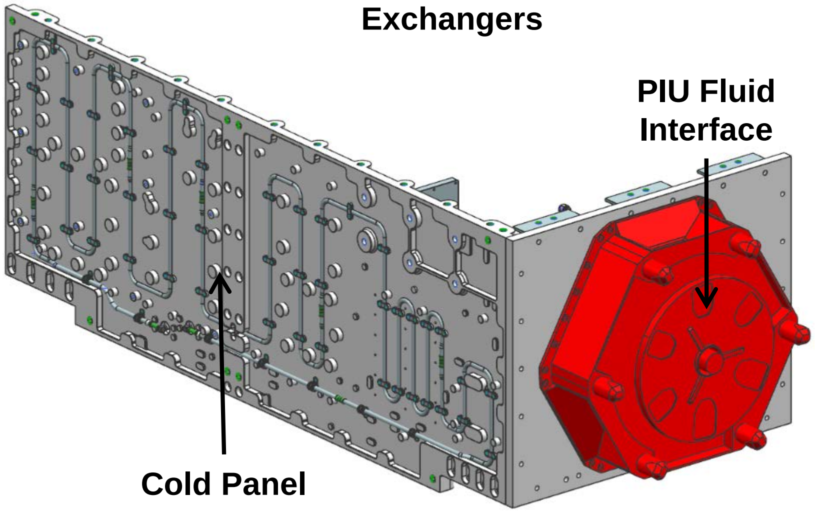
Component	Power, W	Heater Capacity, W	Duty Cycle, %
AMS	23.7	117.4	20.2
FMS	35.0	114.3	30.6
SMA	13.2	28.9	45.7
SMST	36.1	117.7	30.7
FOA Total	**108.0**	**378.3**	28.5
PM Baffle	44.2	300.0	14.7
SMA Baffle	15.7	75.0	20.9
FOA Struts	32.4	240.0	13.5
OBA	1179.3	7520.0	15.7
Tele Total	**1379.6**	**8513.3**	**16.2**



Orbiting Carbon Observatory-3

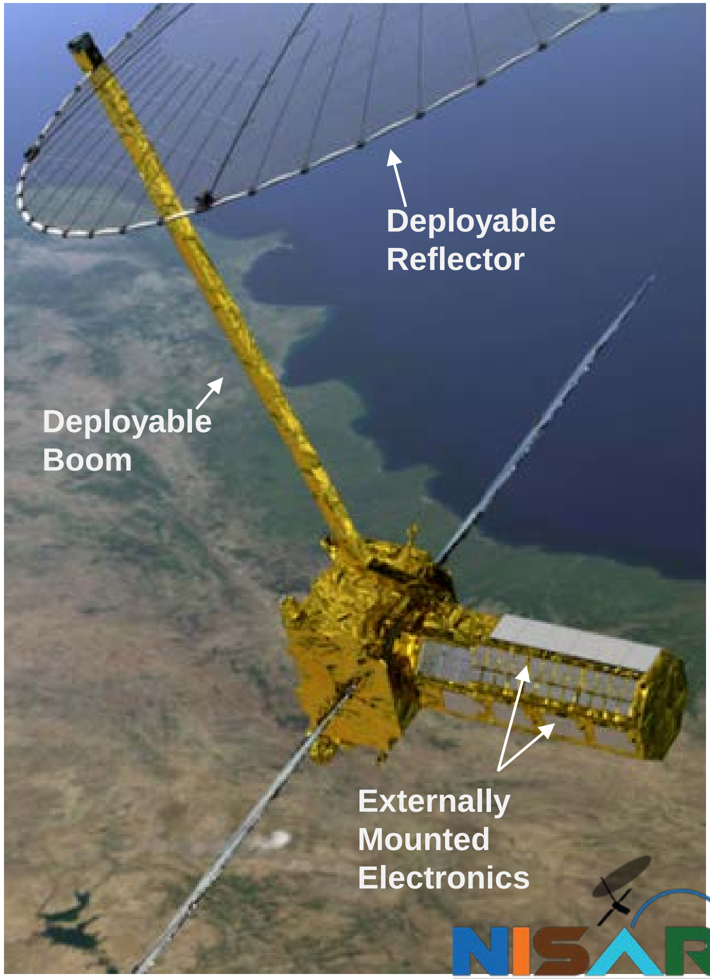
- The thermal control system utilizes the JEM-EF Active Thermal Control System (pumped fluid loop)
- Four thermoelectric coolers cool the Optical Bench Assembly (OBA)
- Two heat exchangers (HXs) remove heat from four thermoelectric coolers (2 per HX)
- A "Cold Panel" provides structure and heat rejection for electronics
- Accumulators compensate for decreases in fluid density during transit
- Fluid filters provide compliance with JEM-EF ATCS usage
- Operational heaters provide thermal stability for AFE, OBA, and PMA



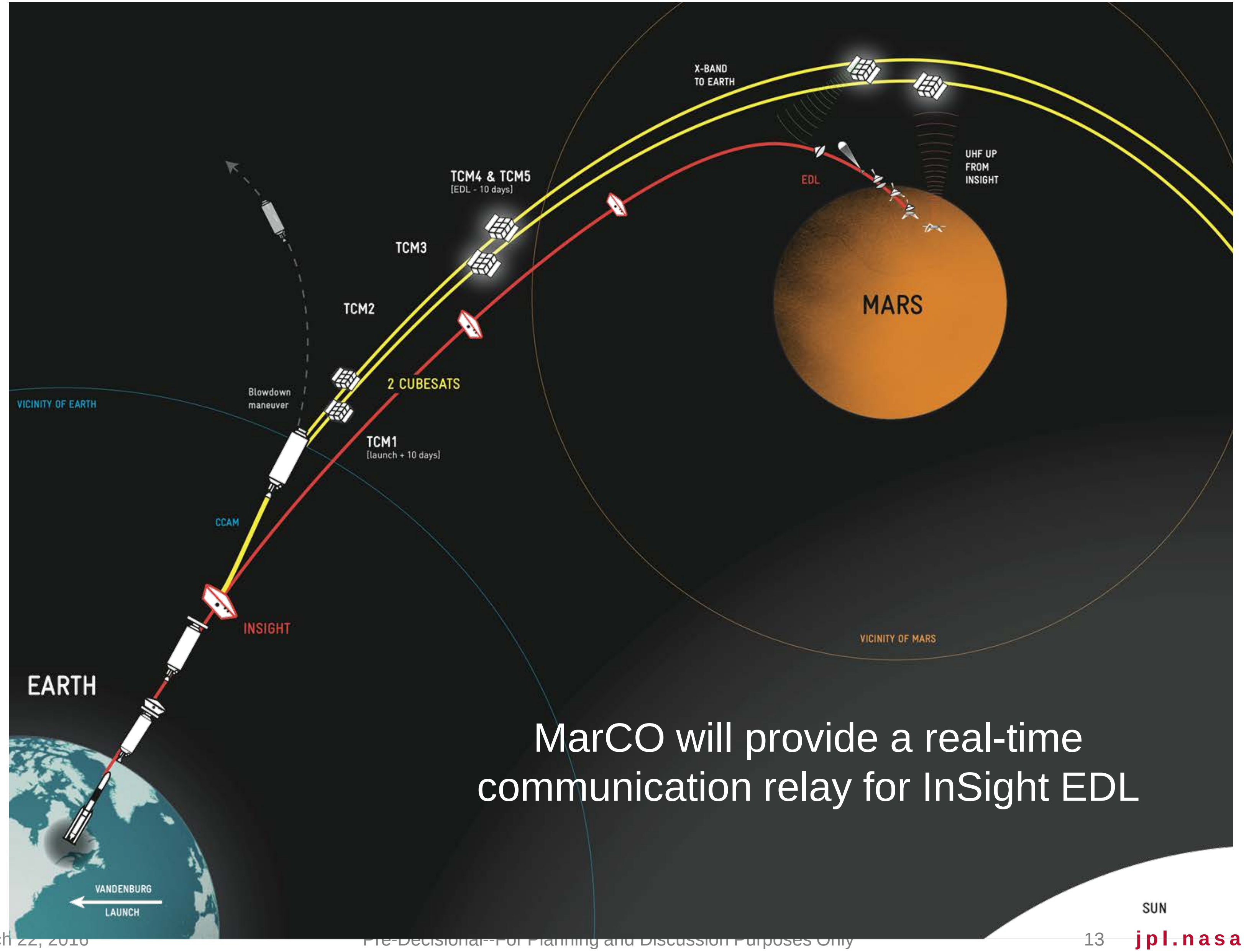


NASA-ISRO Synthetic Aperture Radar (NISAR)

- NISAR will measure surface motion over span of 12 days to study:
  - Ice Sheet Collapse
  - Earthquakes
  - Volcanoes
  - Landslides
- Thermal Challenges
  - Thermal environment: In order for the Instrument to observe both North and South Poles the Instrument is required to operate both sun facing and space facing
  - Externally mounted boxes: Due to space limitations and cable length requirements, the majority of the Instrument electronics are mounted to the exterior of the Instrument with radiators built into the high dissipation boxes
  - Deployable boom for the Radar: A segmented boom that deploys in orbit; Thermal control and analysis required for each of the five deployment phases
  - Deployable reflector: ASTRO Northrop Grumman will be supplying a deployable 12m aperture radar mounted on the deployable boom
- The NISAR DSI Thermal System utilizes traditional thermal control materials and hardware for a largely passive thermal design
  - Radiative coatings/PRTs/Thermistors/MLI/Thermal Isolation/Heaters/Mechanical Thermostats



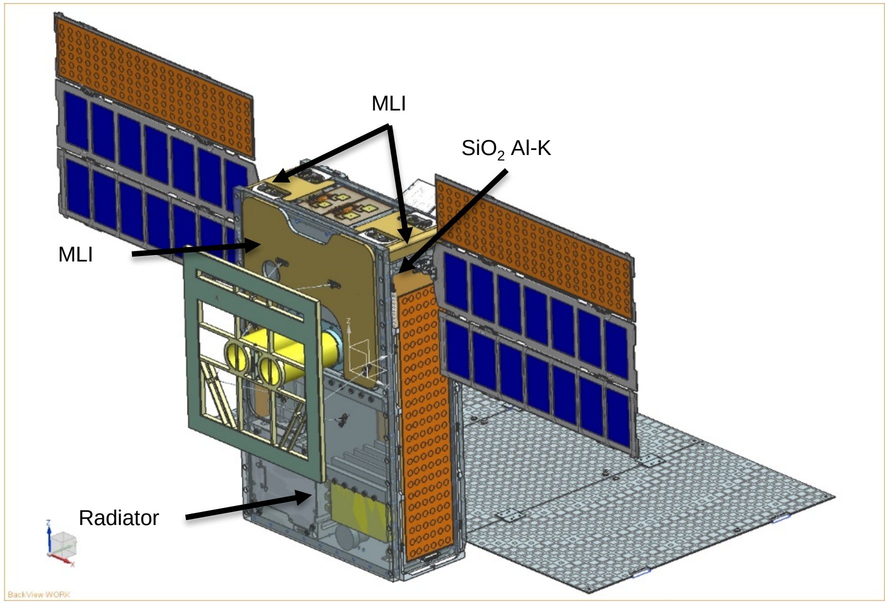
Mars CubeSat Orbiter (MarCO)

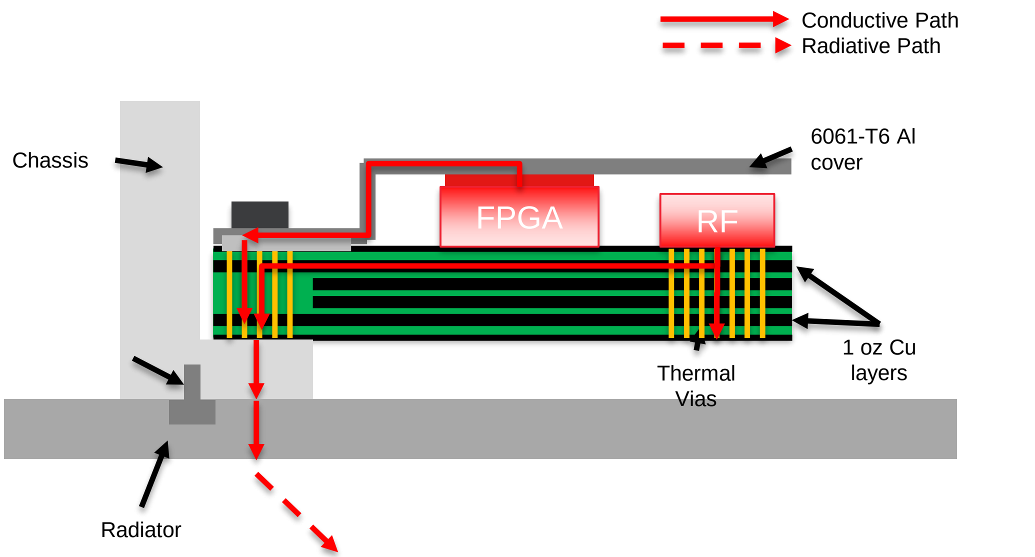


MarCO will provide a real-time communication relay for InSight EDL

Mars CubeSat Orbiter (MarCO)

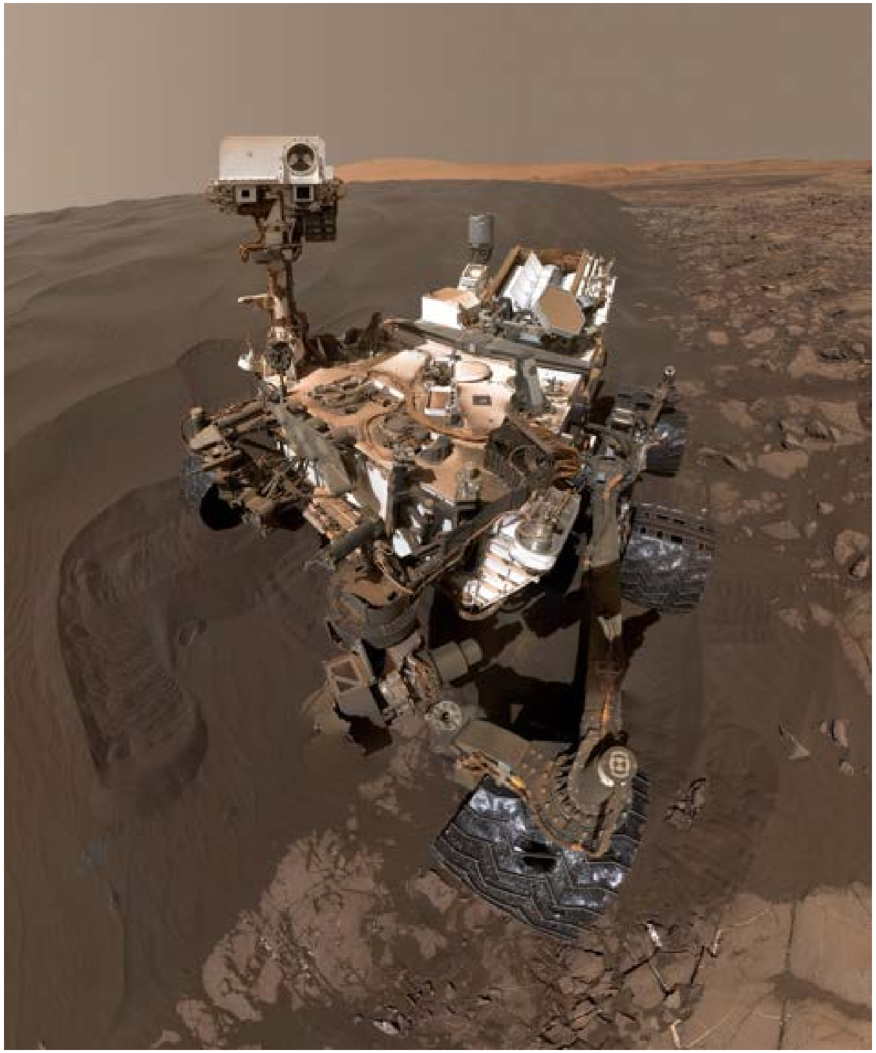
- Transponder with high power density
  - Dedicated thermal PWB Cu layers
  - Custom Al thermal cover for FPGA
  - High conductance chassis
- Radiator sized for S.S. -10°C operation at 15 W
- Capability for ~ 3 hours transmit time
- SiO2 Al-K closeout on small non-radiator surfaces
  - Reduces solar heat load near Earth
  - Reduces SC heat loss near Mars



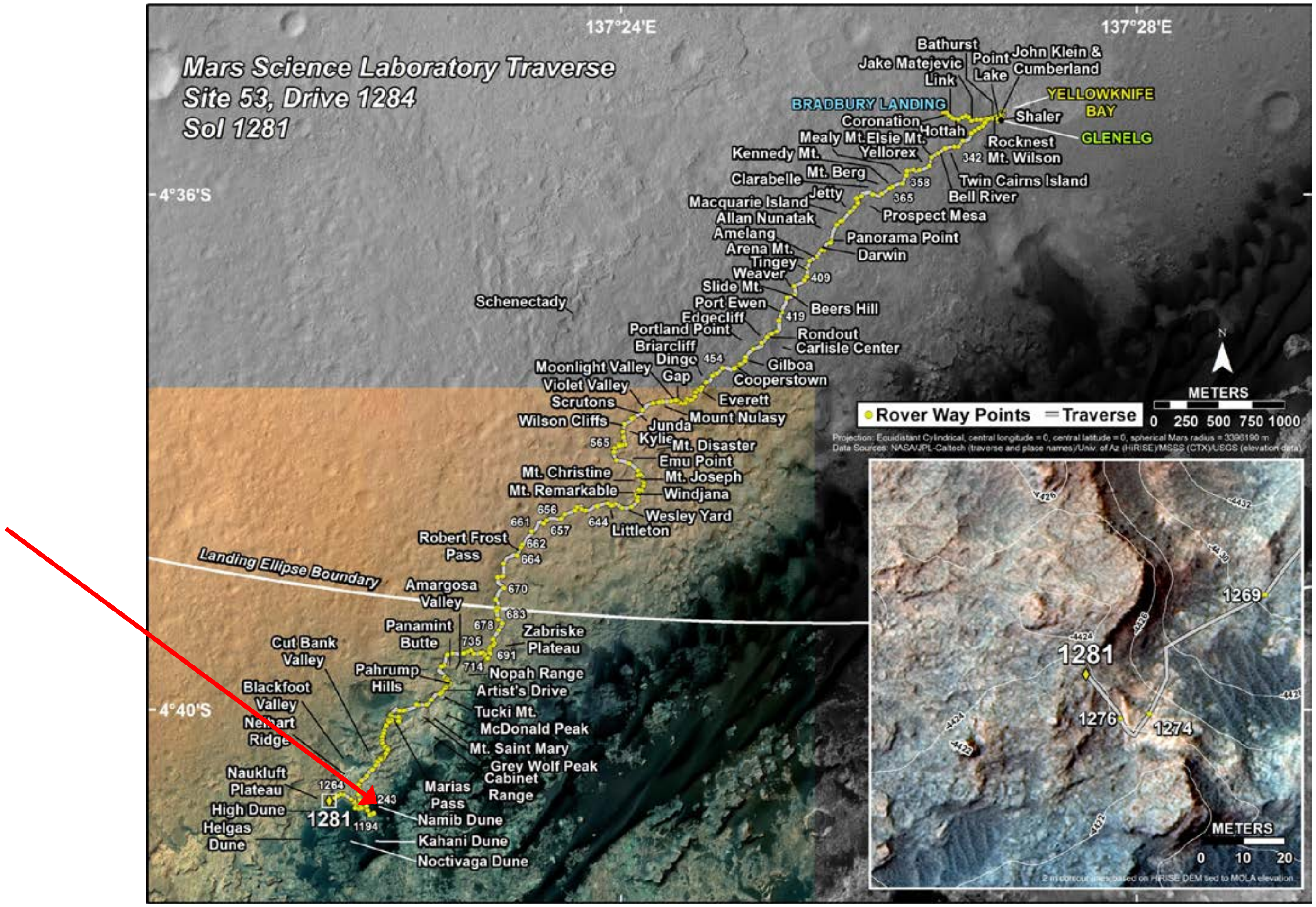


Curiosity Rover—Thermal Status

- Total odometry 12,559 m
- RTG output nominal at ~95-99W_e.
- Very slight decrease over time in the temperature of the RTG, RIPA pressure and RAMP temperatures.
- Thermal performance has been excellent.

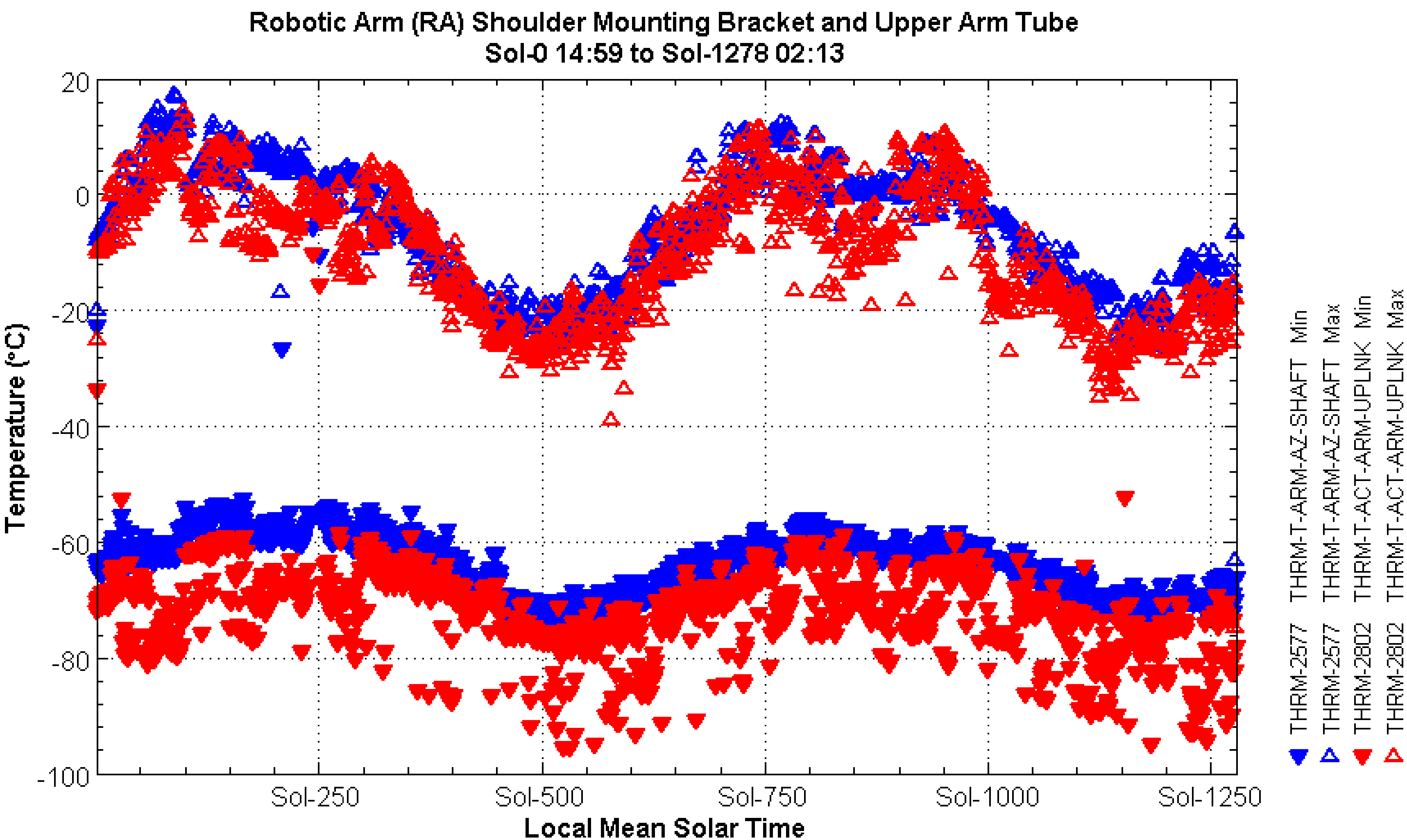


Curiosity Rover—Thermal Status



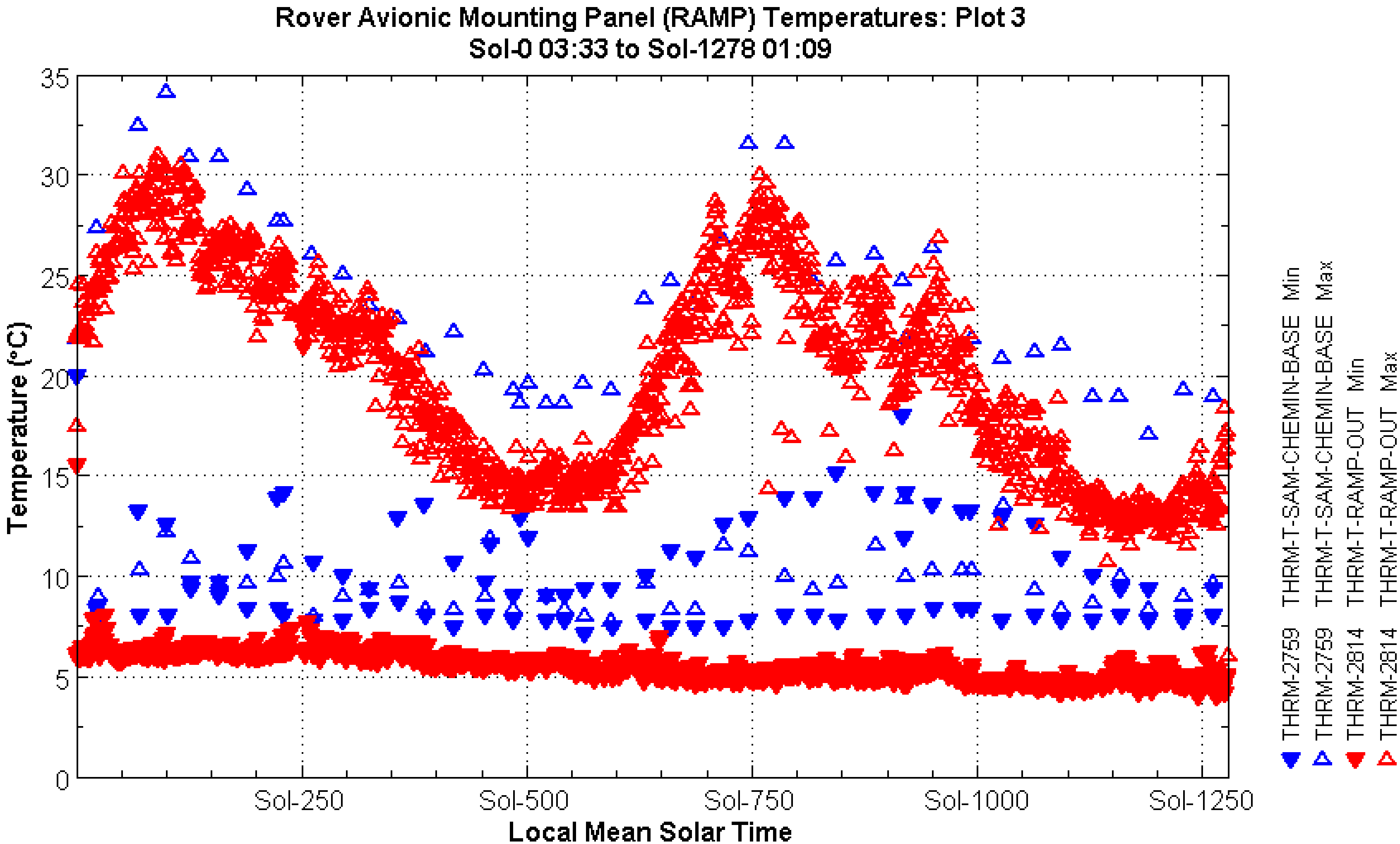
Curiosity Rover—Thermal Status

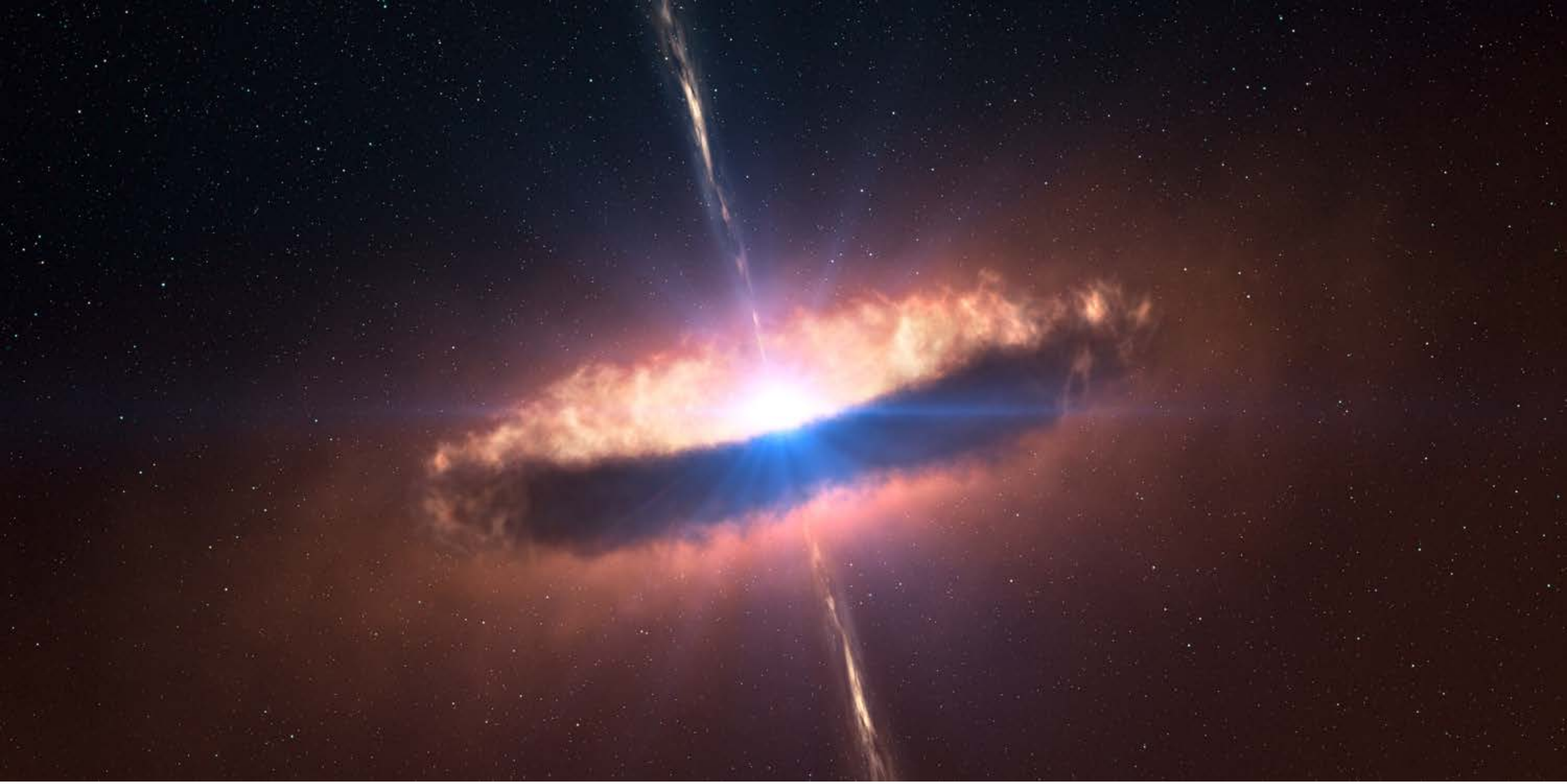
- Robotic Arm (RA) Shoulder Mounting Bracket and Upper Arm Tube Temperatures



Curiosity Rover—Thermal Status

- Rover Avionic Mounting Panel (RAMP) Temperatures





NASA/JPL Mission Roadmap

Jet Propulsion Laboratory
California Institute of Technology

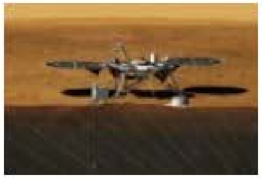
Planetary Science Roadmap

Mars

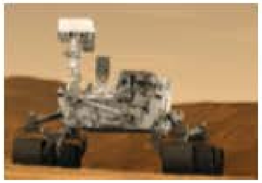
Current and potential future missions

2016 - 2020

Mars 2020 Science/ Caching Rover



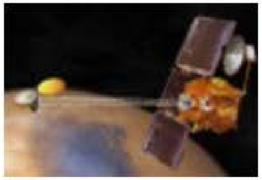
InSIGHT 2018



Curiosity

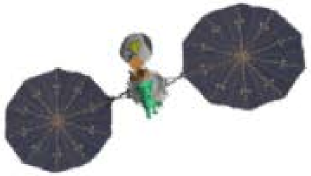
Opportunity

MRO



Odyssey

2022 - 2026

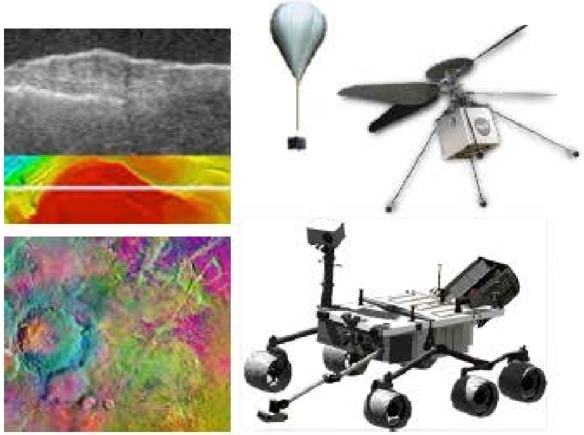


Mars Exploration Orbiter

Mars Exploration Lander

Sample Return

2028 - ...



Geological Survey For Future Landings, Resource Prospecting

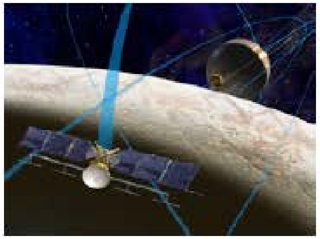
Permanent Robotic and Human Station

Planetary Science Roadmap

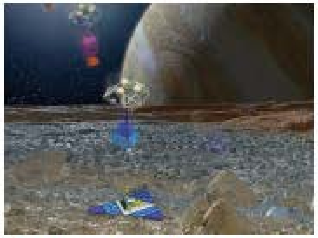
Ocean Worlds

Current and potential future missions

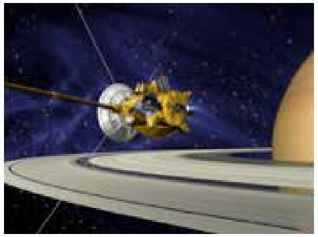
2016 - 2024 → **2024 - 2028** → **2028 - ...**



Europa Clipper

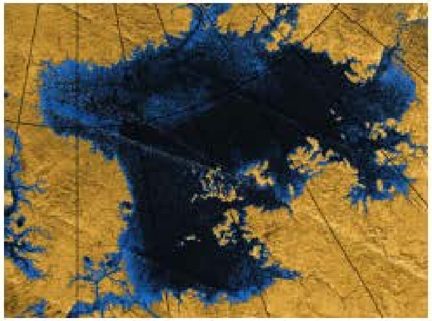


Europa Lander Concept

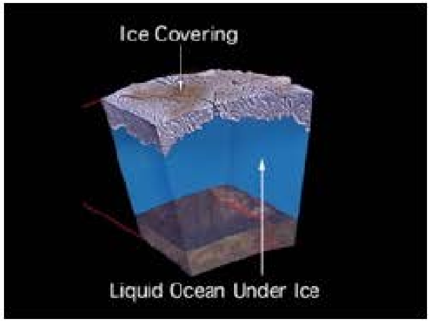


Cassini

Enceladus Probe



Titan Orbiter & Probe



Subsurface Oceans

Europa Submarine

Planetary Science Roadmap

Formation & Evolution of the Solar System

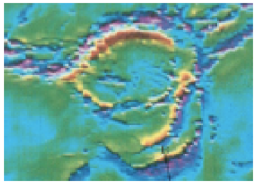
Current and potential future missions

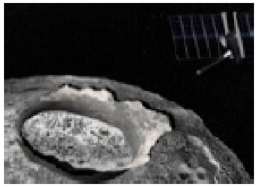
2016 - 2020 → **2020 - ...**

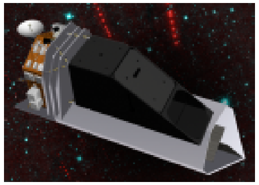

Dawn


Juno

Discovery Missions

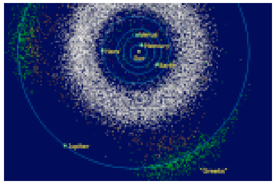

VERITAS

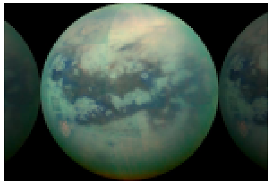

Psyche

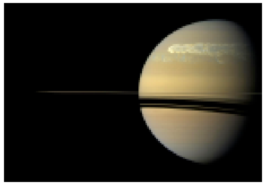

NEOCam

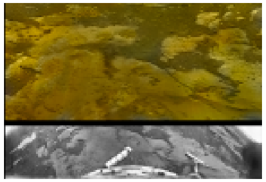
New Frontiers Missions

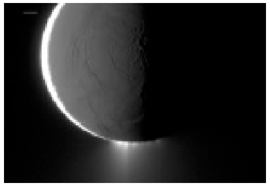

Comet Surface Sample Return

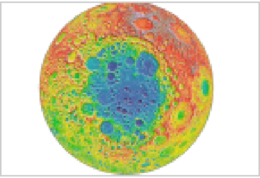

Trojan Tour & Rendezvous


Titan

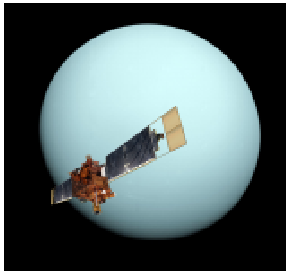

Saturn Probe


Venus In Situ Explorer


Enceladus


Lunar South Pole – Aitken Basin Sample Return

Flagship Missions


Uranus Orbiter

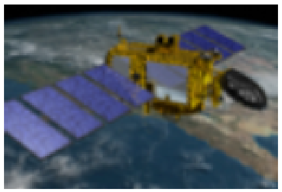
TBD
Next Decadal

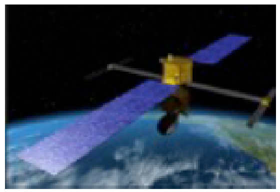
Earth Science

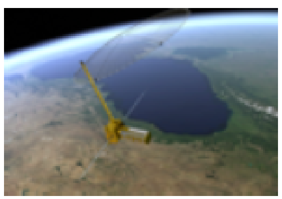
Current and potential future missions

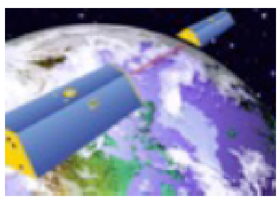
2016 - 2020 → Ongoing → 2020

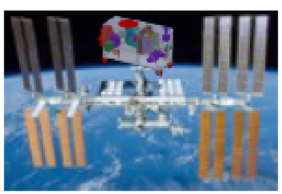
2016 - 2020


Sentinel 6
(Jason CS)


SWOT

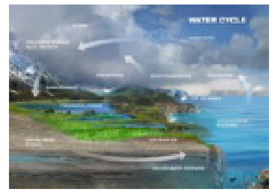

NISAR

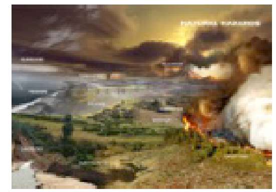

Grace Follow-On

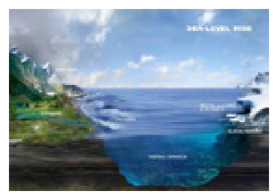

OCO-3 on ISS

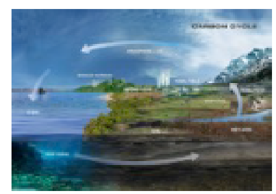
ECOSTRESS on ISS

Ongoing


Water Cycle:
How can we improve water resource management?

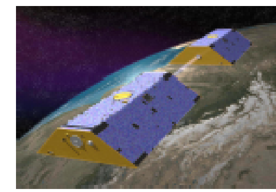

Natural Hazards:
How can we better prepare for extreme events (earthquakes, floods and hurricanes)?


Sea Level:
Will sea level continue to rise at the current rate?

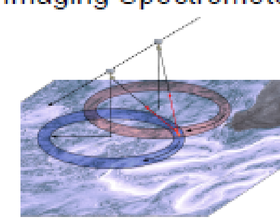

Carbon Cycle:
How are carbon storage and biodiversity changing?

2020

Next
Decadal Survey
2020


Grace-2


Imaging Spectrometer


Scatterometer

Astrophysics, Fundamental Physics & Technology

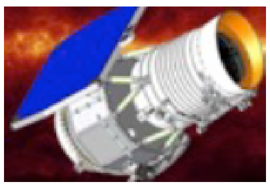
Current and potential future missions

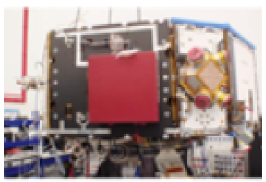
2016 - 2024

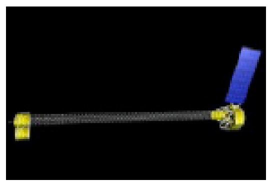

Spitzer

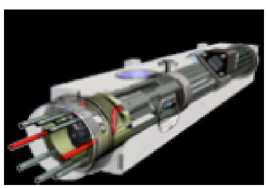

NEOCAM Discovery Mission


SPHEREx Explorer mission


NEOWISE


ST7 - LISA Pathfinder


NuSTAR

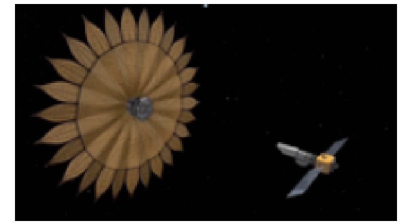

DSAC

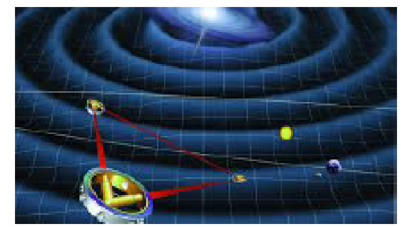

Cold Atom Lab on ISS

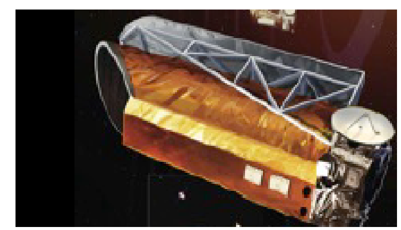
2024


WFIRST Coronograph

2025


Starshade Probe Mission


LISA


HabEx

Thermal Technology Challenges

Pumped Fluid Loop Reliability

(Courtesy of Dr. Tony Paris, JPL Europa Thermal Lead / Dr. Brian Carroll, JPL Europa Thermal Technology Lead / Dr. Gaj Birur)

- Long-term chemical analyses on the compatibility of the working fluid, irradiated CFC-11, with various wetted materials
- Pump life-testing: on its 10^{th} year and still going

JPL's Europa MPFL Radiation Exposure Test Panel

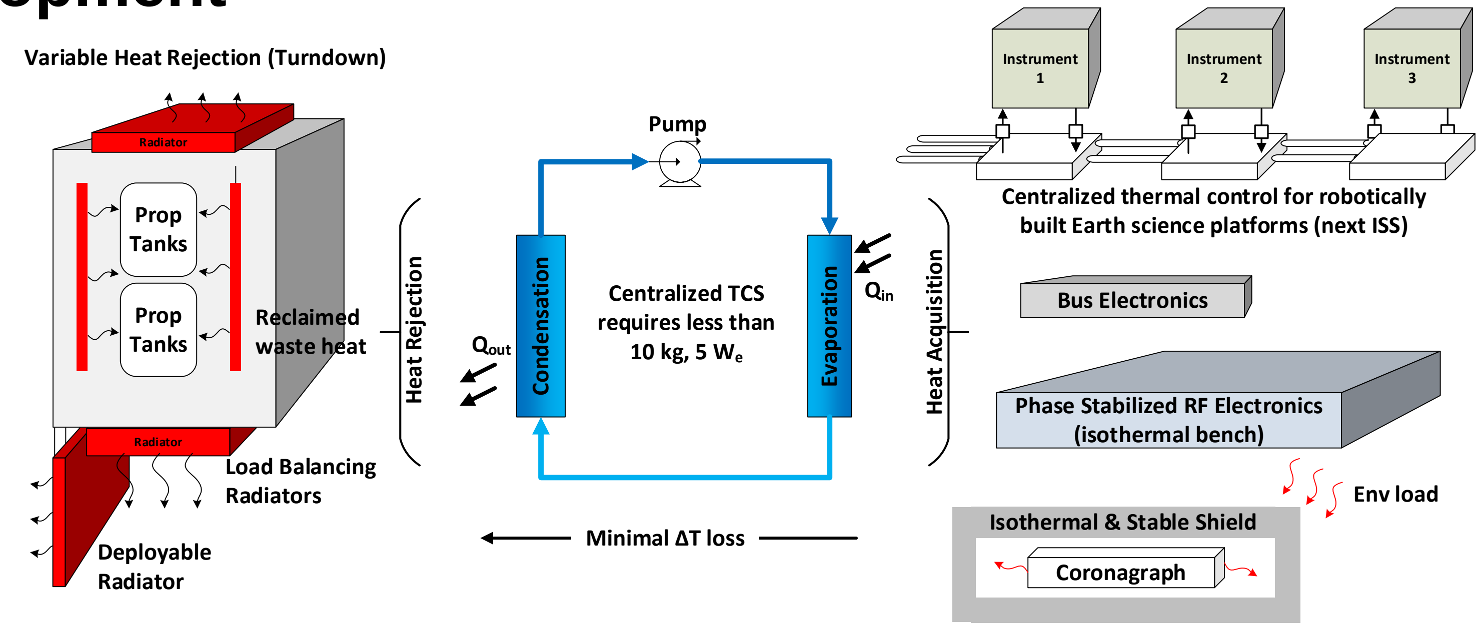
JPL's MPFL Life Test Panel

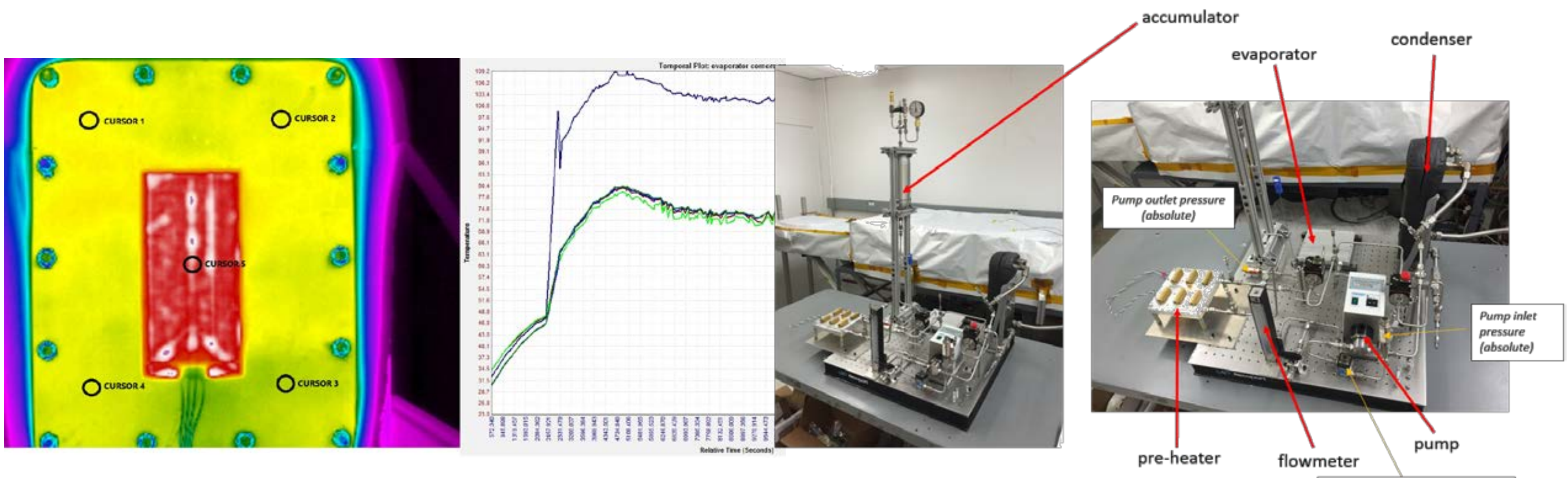
Thermal Control for Deep Space Small Spacecraft

- Objective: Develop a thermal bus system (spanning both the bus and payload interfaces) that enables deep space exploration to 10 AU at low cost
- Needs
  - Order of magnitude reduction in TCS power and 50% reduction in mass over current state-of-the-art.
  - Accommodates high heat fluxes up to 5 W/cm2; isothermalization of < 3 ^{o}C over a 1-m payload bench; temporal stability of < 0.05 ^{o}C/minute.
  - Modular, scalable, configurable to enable integration and at reduced costs.
  - High degree of control authority to reduce uncertainty and thermal testing costs.

Performance Parameter	**SOP Large Sat**	**SOP CubeSat**	**Proposed Small S/C (~ 250 kg dry)**
Cooling Load (W_t)	500	30-50	> 200
Thermal - Mass (Kg)	75 - 100	< 0.5 kg	10
Thermal - Power (W_e)	100 - 300	< 5 W	5
TRL	9	9	2-3

Thermal Control for Deep Space Small Spacecraft—Two-Phase Mechanically Pumped Fluid Loop Development





Two-Phase Mechanically Pumped Fluid Loop Development

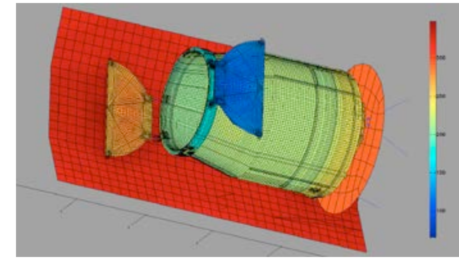
- Technology gaps identified
  - Robust, versatile loop architecture needed for multiple evaporators and condensers
  - Pumps
    - 15 year life requirement
    - Low NPSH pumps needed
  - Evaporators
    - Lightweight, large area
    - Isothermal and tolerant of sub-cooled liquid
  - Freezable radiators

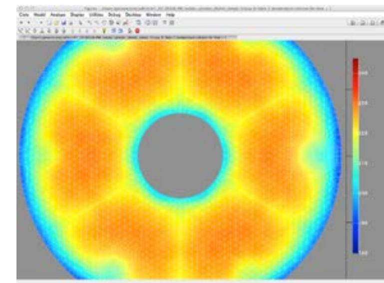
CubeSat Technology Gaps Identified

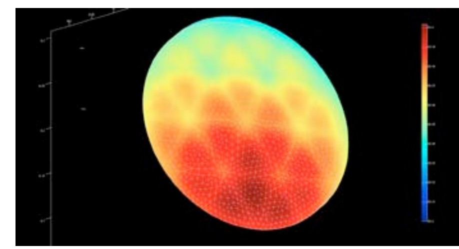
- The increasing power density of CubeStats and environmental load variation associated with interplanetary missions poses thermal control challenges
- Technology gaps are related to economical and miniaturized
  - Deployable radiator systems
  - Radiator turndown systems
  - High conductance chassis

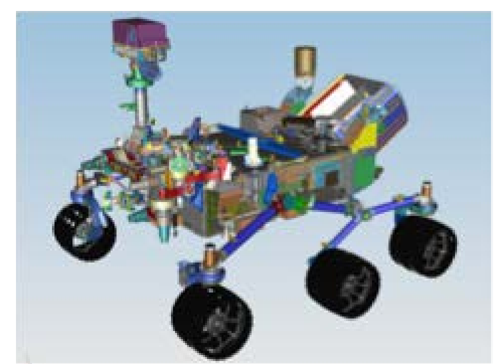
Cielo Toolkit Development

- Cielo is a finite-element based, multidisciplinary, parallel toolkit that enables high-fidelity, fundamentally-integrated thermal, structural, and optical aberrations analysis of precision deployable systems
  - "Nonderivative Technology" developed under 5-year R&TD Strategic Initiative by in-house team formerly from industry
  - Distributed client server paradigm (MATLAB client, OpenMP-based parallel network server)
  - Continued development and application in a variety of projects, from pre-Phase A demonstrators to rapid-turnaround challenges
- Cielo is enabling "In The Loop" model-driven operations development for MSL
  - Operations currently rely on static "heater tables" for scenario planning
  - Development of each heater table currently requires:
  - Over a year of effort
  - Hundreds of simulations
  - Coordination of both internal and external (vendor) teams, each using separate subsystem models
  - Cielo enables "Full-Up", common system modeling to:
  - Create heater tables "on demand"
  - Increase daily, and overall, science return
  - Improve power use efficiency and maximize safe battery draw-down
  - Enable future anomaly detection, investigation, and mission life extension









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