JPL Advanced Thermal Control Technology Roadmap

a presentation to

Spacecraft Thermal Control Workshop
The Aerospace Corporation, El Segundo California
March 28, 2017

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NASA Jet Propulsion Laboratory
California Institute of Technology

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Outline

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

Current and proposed projects

Status from the thermal subsystem perspective

Jet Propulsion Laboratory
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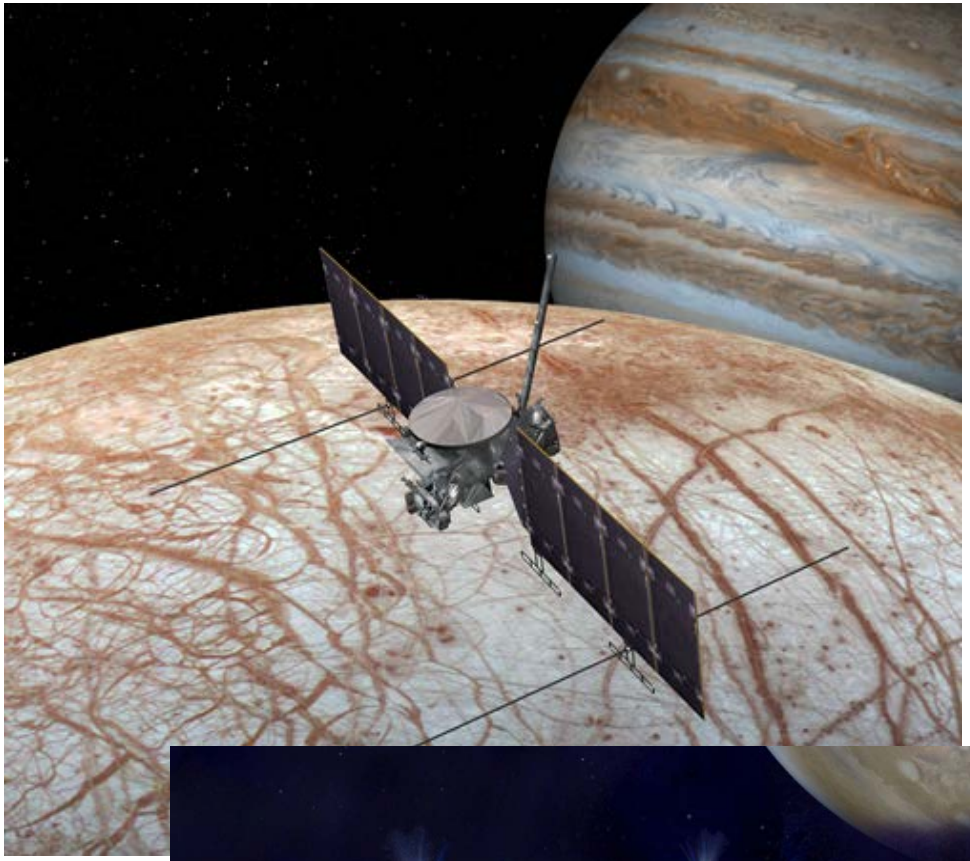
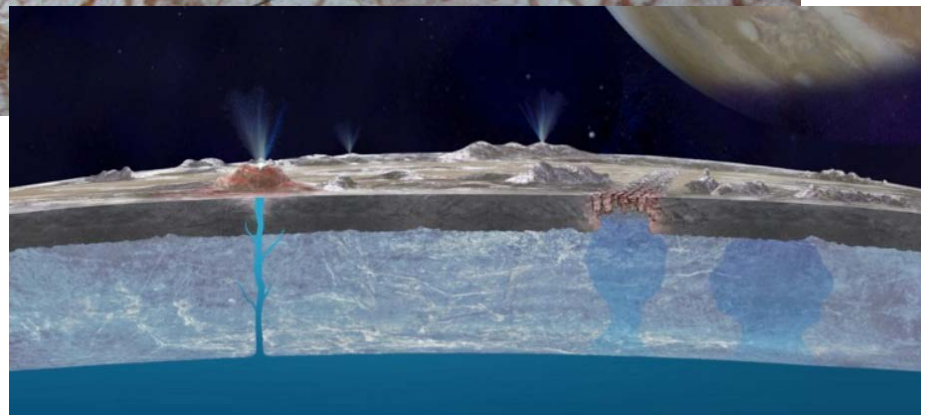
Planned Europa Clipper Mission

(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



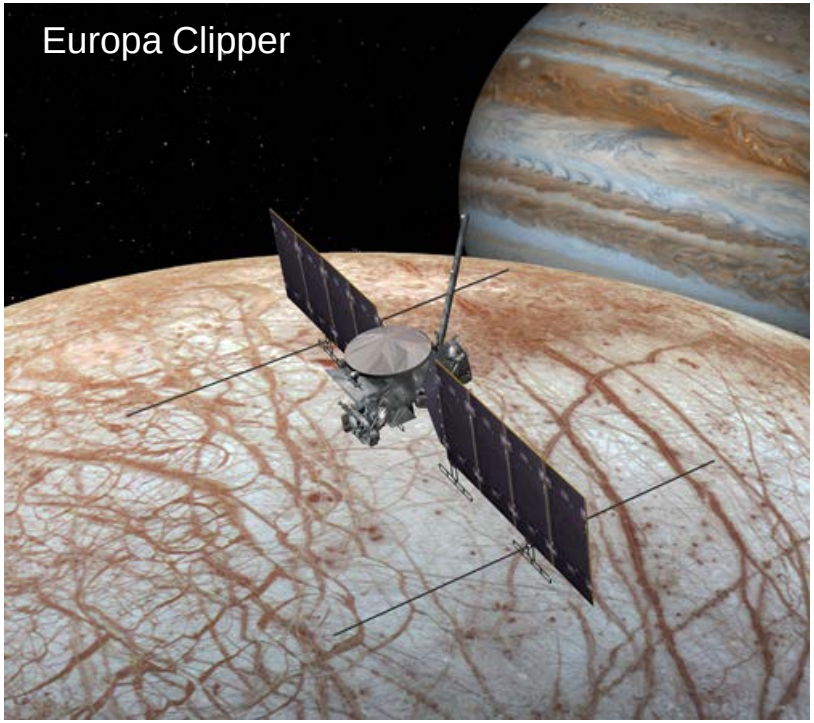


Mapping Imaging Spectrometer for Europa (MISE)

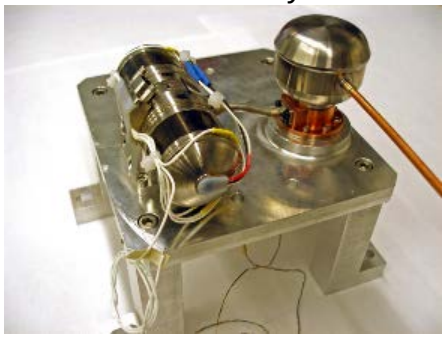
(Courtesy of Jose Rodriguez, JPL Cryogenic Systems Engineering Group Supervisor)

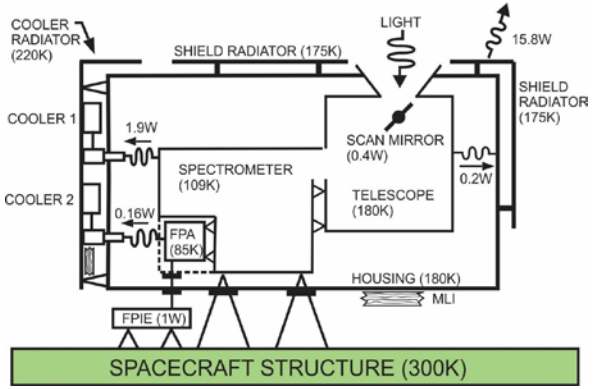
Spectral range	0.8 to 5.0 µm
Sampling	10 nm
Spatial Resolution	25 m @ 100 km

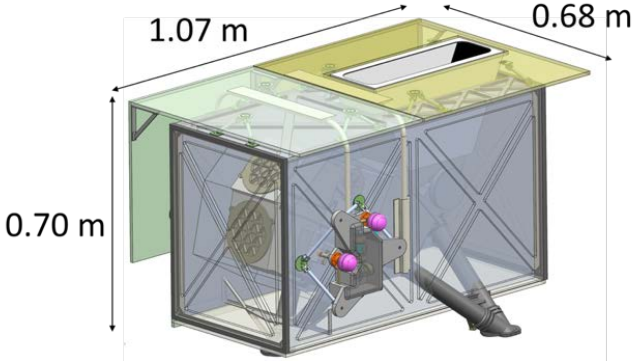
Mass	42.3 kg CBE
Power	61.4 W CBE
Data volume	2.02 Gb/flyby CBE
Detector Temperature	85K
Spectrometer Temperature	109K
Radiator Temperature	220K and 175K
Active cooling	LM PT Cryocooler



LM Pulse Tube Cryocooler



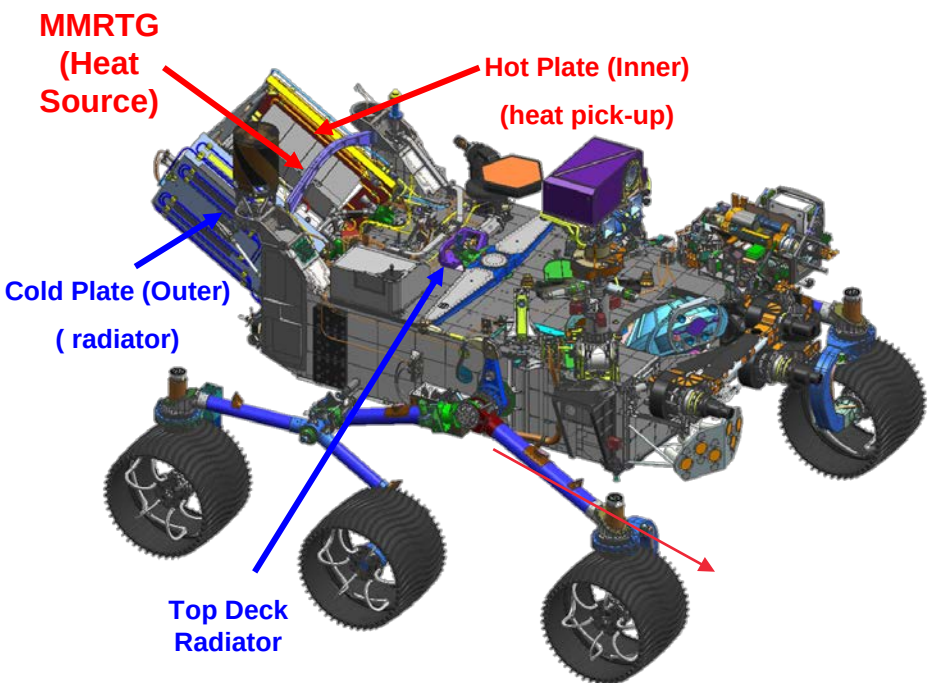


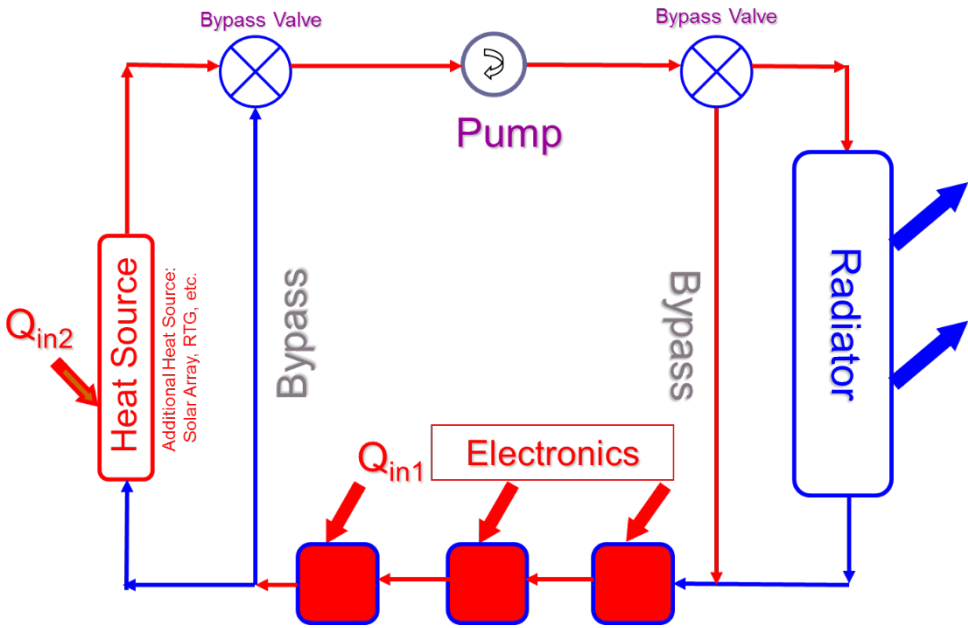


Mars 2020 Rover

(Courtesy of Jason Kempenaar, M2020 Surface Thermal Lead)

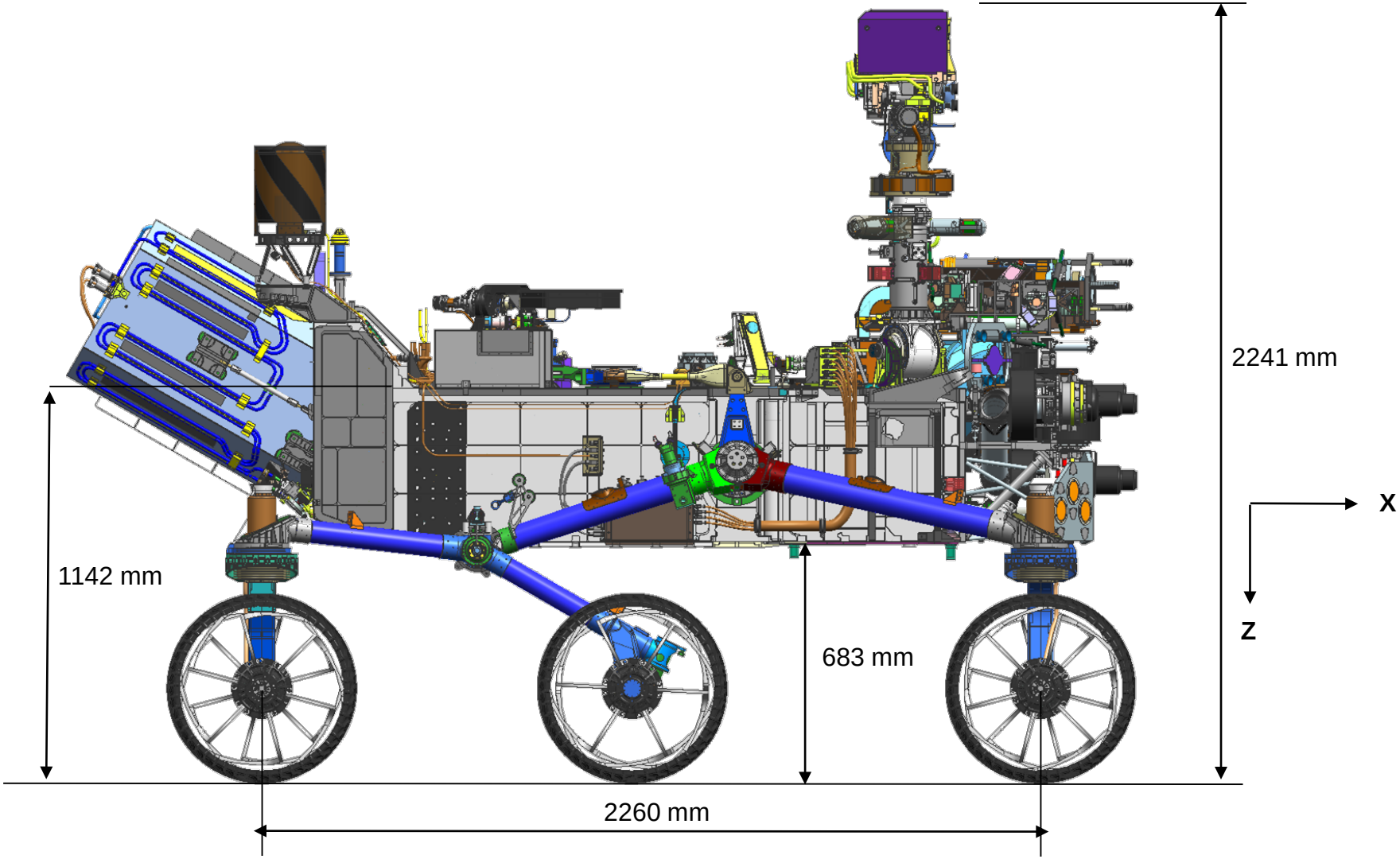
- Key functions of M2020 Rover Heat Rejection System (RHRS):
  - Removal of waste heat from rover during Cruise phase of mission
  - Removal of waste heat from rover and MMRTG during hot part of the day
  - Recovery of waste heat from MMRTG during the cold part of the day
  - Thermally couple RAMP masses 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



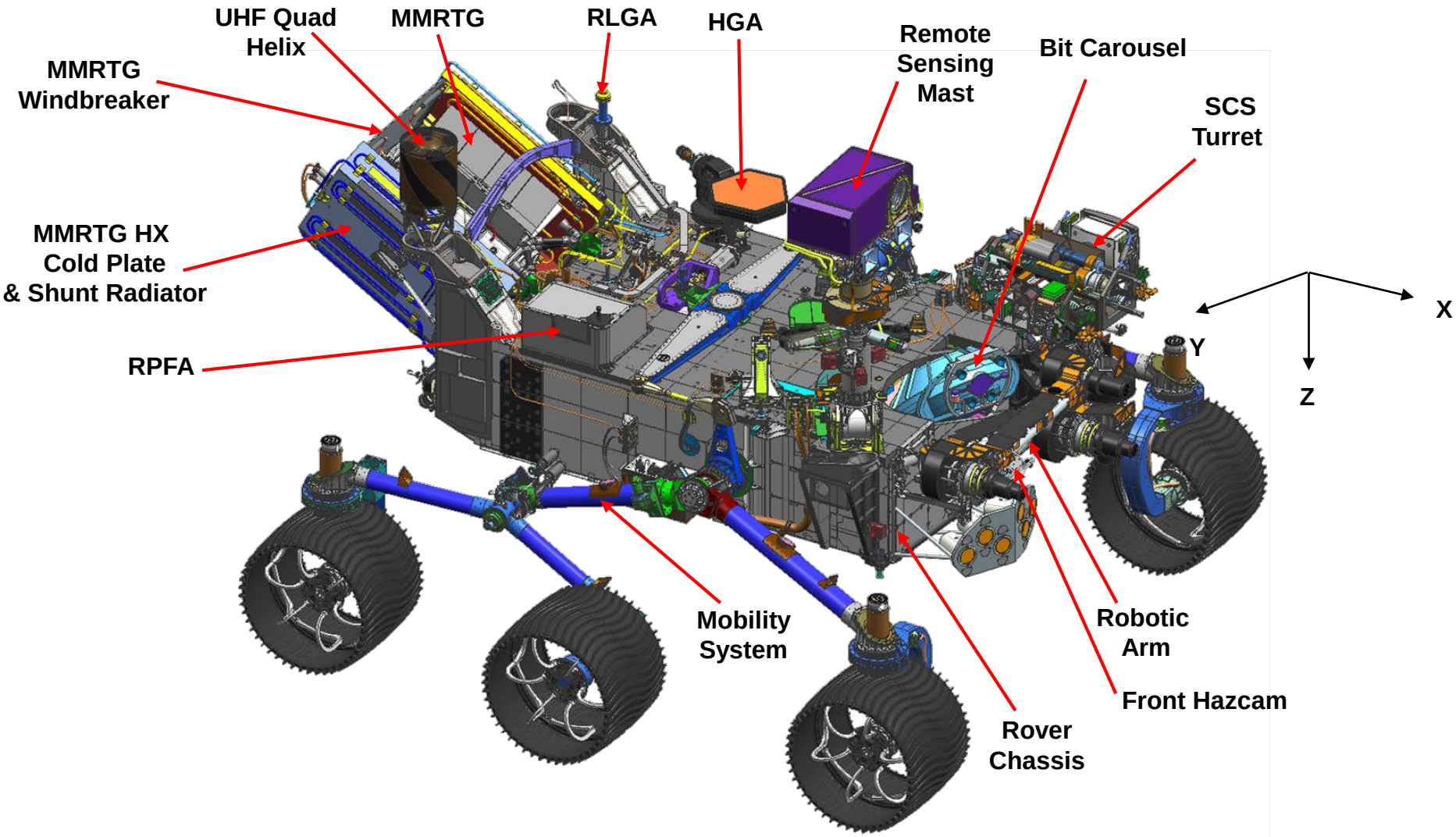


Pumped Fluid Loop Based Thermal *Bus* Architecture
(Supply as well as Reject Heat)

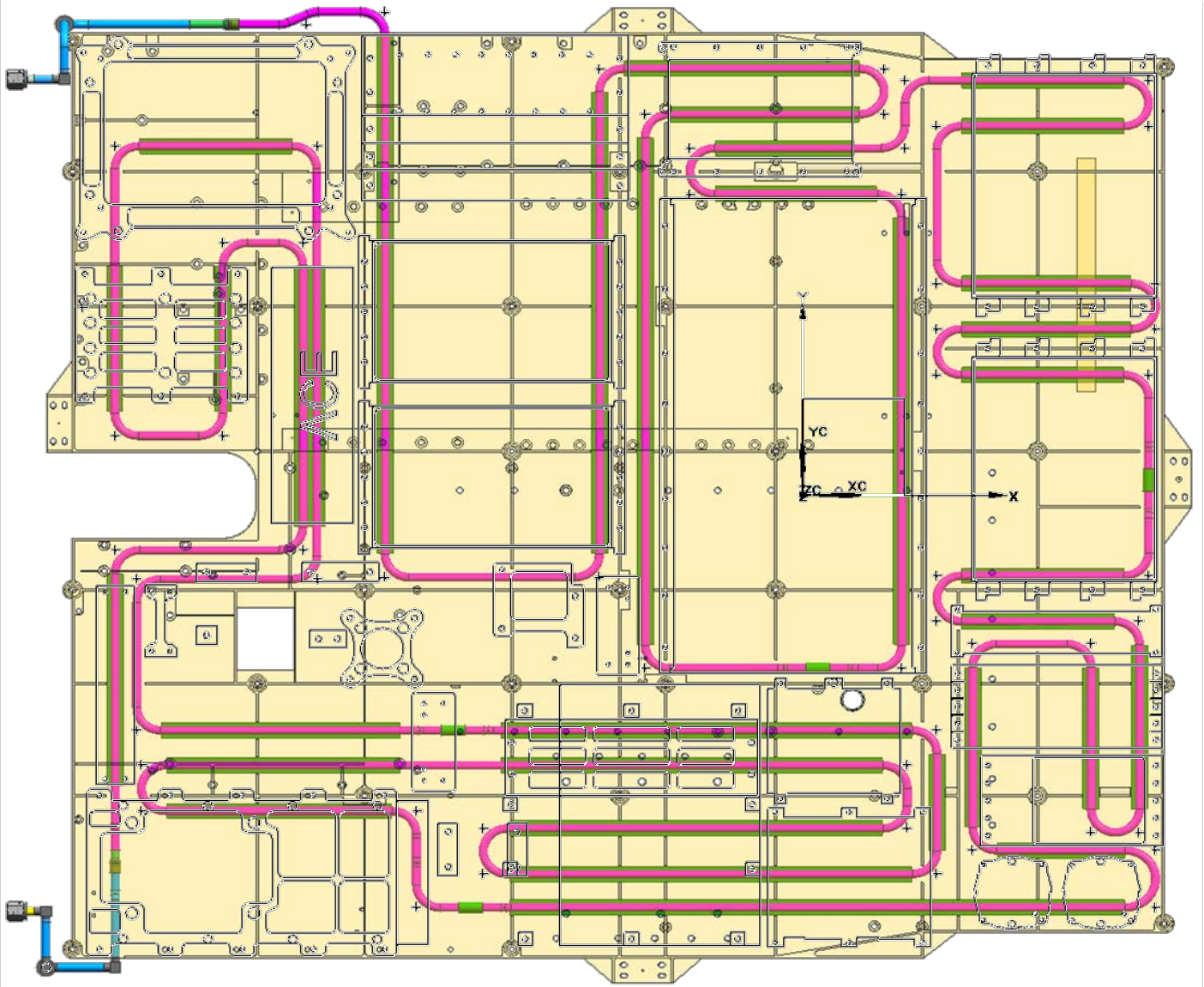
Mars 2020 Rover



Mars 2020 Rover



Mars 2020 RHRS Tube Routing on RAMP



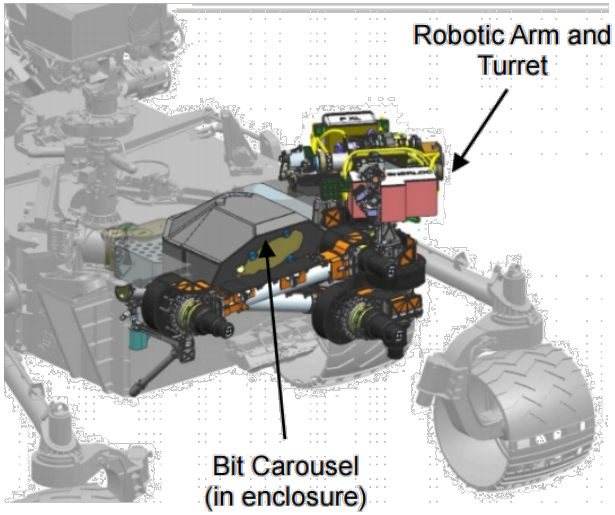
Mars 2020 Rover Sampling and Caching System

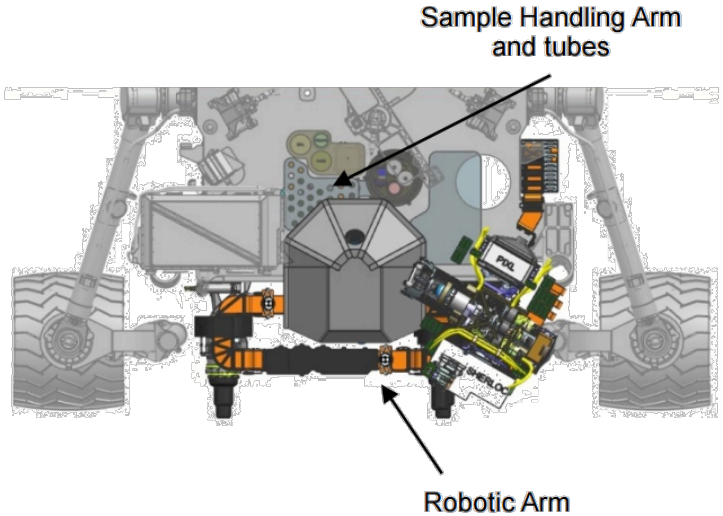
Scope:

- Acquire and seal samples of Martian surface material
  - Rock Cores
  - Regolith

Approach:

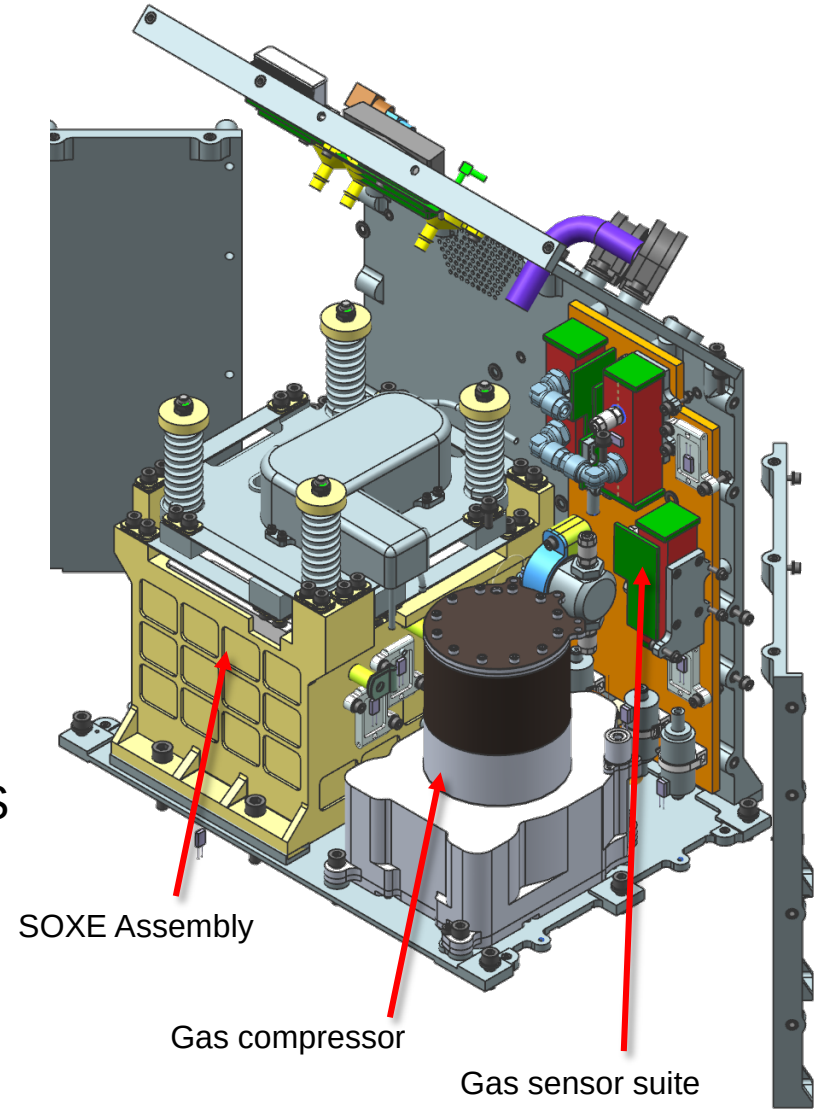
- Use MSL-like robotic arm for sample acquisition
- Rotary Percussive coring drill (MSL-like mechanism) for sampling
- Acquire samples directly into sample tubes
- Process filled sample tubes within controlled volume using a sample handling arm
- Hermetically seal samples in tubes
- Cache samples on Mars for possible future return to Earth

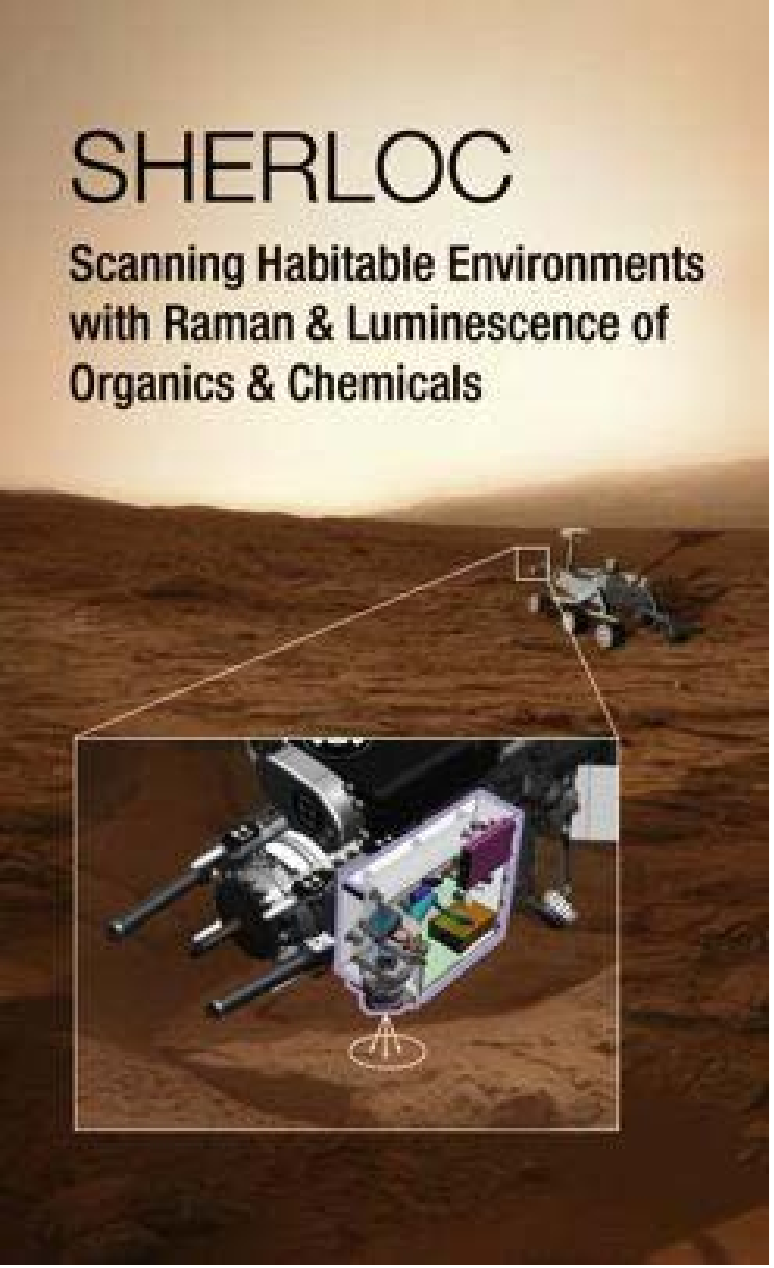




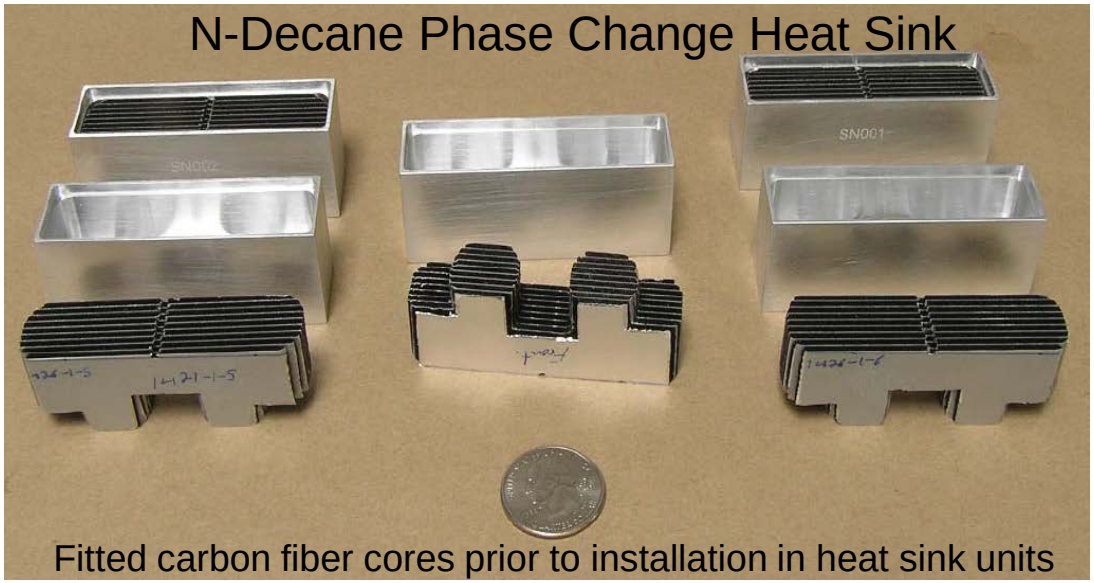
Mars Oxygen ISRU Experiment (MOXIE) on Mars 2020 Rover (Courtesy of Jenny Hua and Asad Aboobaker, MOXIE Thermal team)

- ISRU tech demo for M2020 – goal is to demonstrate oxygen production from Martian CO_2 atmosphere using Solid Oxide Electrolysis technology
- Mounted inside M2020 rover body on RAMP, atmosphere intake via externally-mounted filter assembly
- Electrolysis stack (approx. 50 x 50 x 100mm) must operate at ~800° C, limited volume and heater power available
  - High temperature creates materials challenges: need superalloys, ceramics
  - Using Min-K and JPL aerogel composite insulations, ~20-30mm thick
  - Goal: < 70 W power @ 800° C
- High thermal power (~300 W during oxygen production, for up to 2 hours) into Rover HRS
  - MOXIE operations restricted during high-temperature periods
  - Must ensure no harm to Rover or other components mounted to RAMP

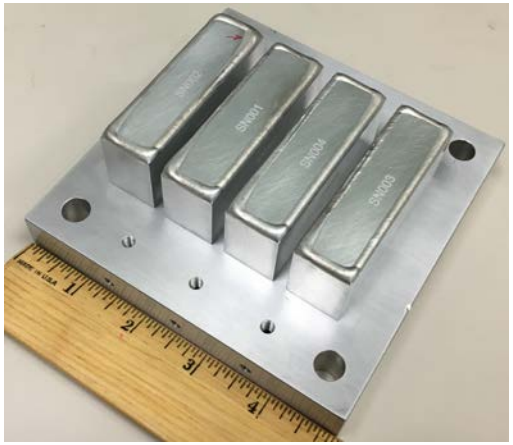




(Courtesy of Dr. Michael Pauken, SHERLOC Thermal Lead)



Fitted carbon fiber cores prior to installation in heat sink units



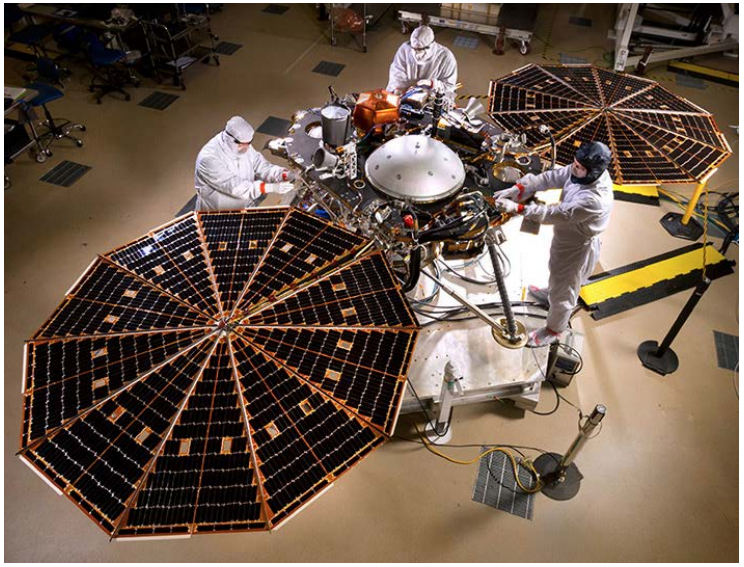
Filled PCM units mounted to vibration test plate

Absorbs heat from a spectrometer CCD
Aluminum housing with carbon fiber/aluminum fin core
Melting Point: -29°C
Latent Heat Capacity: 5400 J
Op Temperature Range: -125 to +70°C

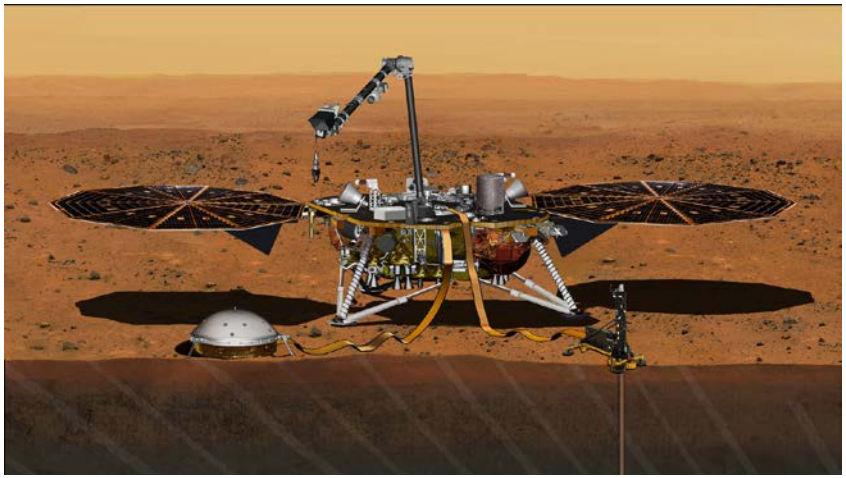
Mars InSight Lander (Scheduled for May 2018 Launch)

Science Goals and Objectives:

- Understand the formation and evolution ofterrestrial planets through investigation of theinterior structure and processes of Mars by
  - Determining the size, composition and physical state(liquid/solid) of the core.
  - Determining the thickness and structure of the crust.
  - Determining the composition and structure of the mantle.
  - Determining the thermal state of the interior.
- Determine the present level of tectonic activity andmeteorite impact rate on Mars.
  - Measure the magnitude, rate and geographical distribution of internal seismic activity
  - Measure the rate of meteorite impacts on the surface.
- LM responsible for spacecraft, integration, test, launch operations and mission operations support. CNES would manage, integrate and deliver the SEIS, and DLR would build and deliver HP3 . Centro de Astrobiología (CAB) of Spain will supply wind and air temperature sensors.

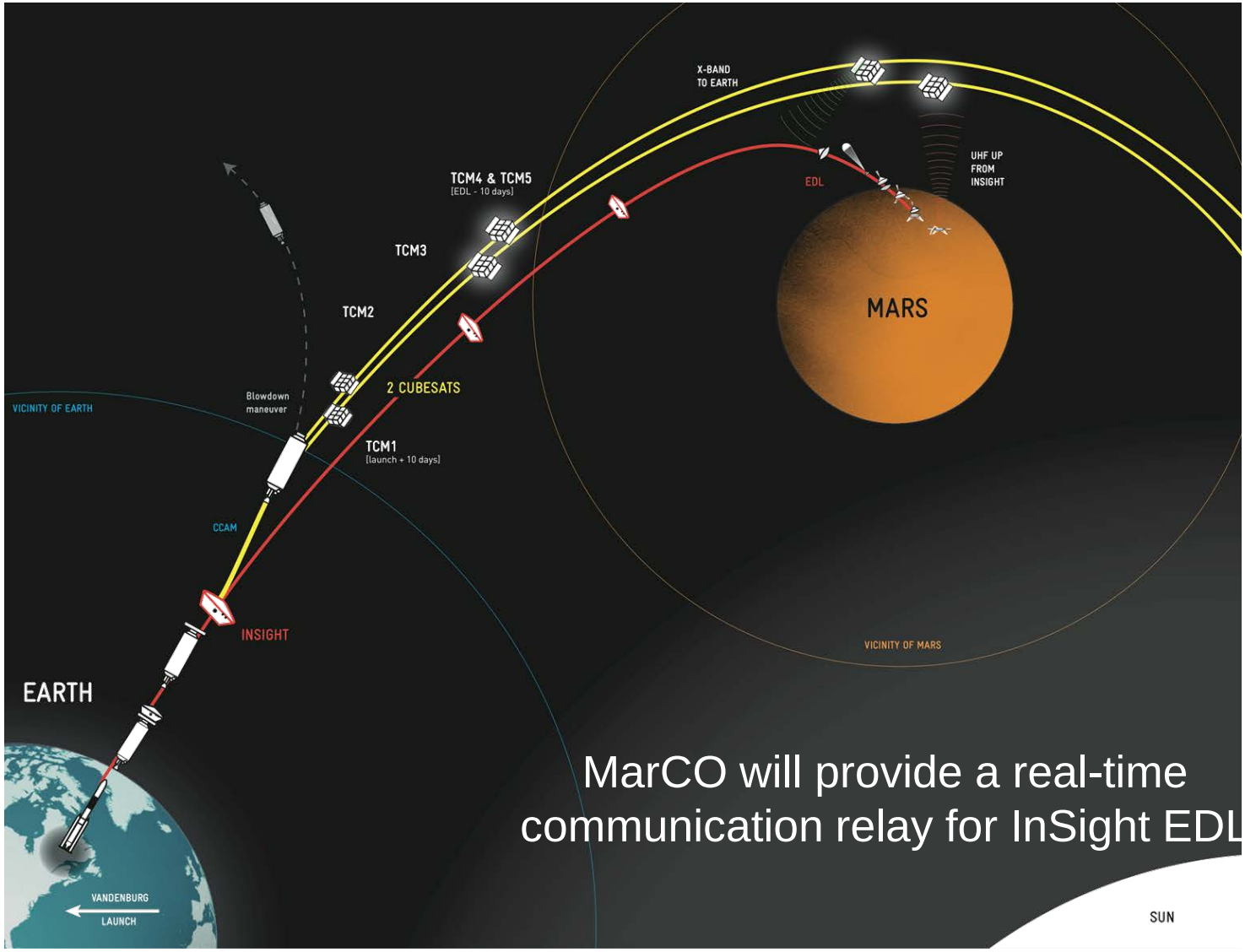


(Image courtesy of Lockheed Martin)



Mars CubeSat Orbiter (MarCO)

(Courtesy of Daniel Forgette, MarCO Thermal Lead)

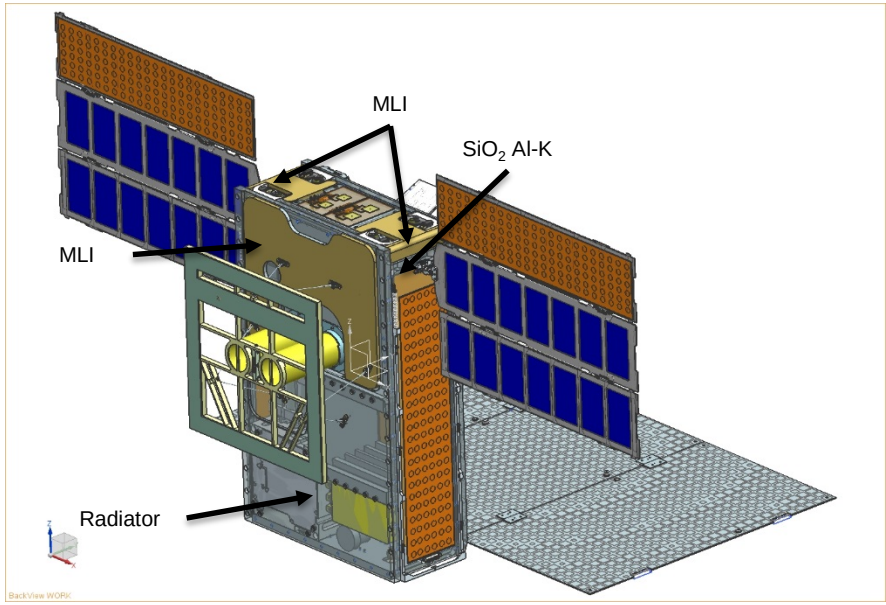


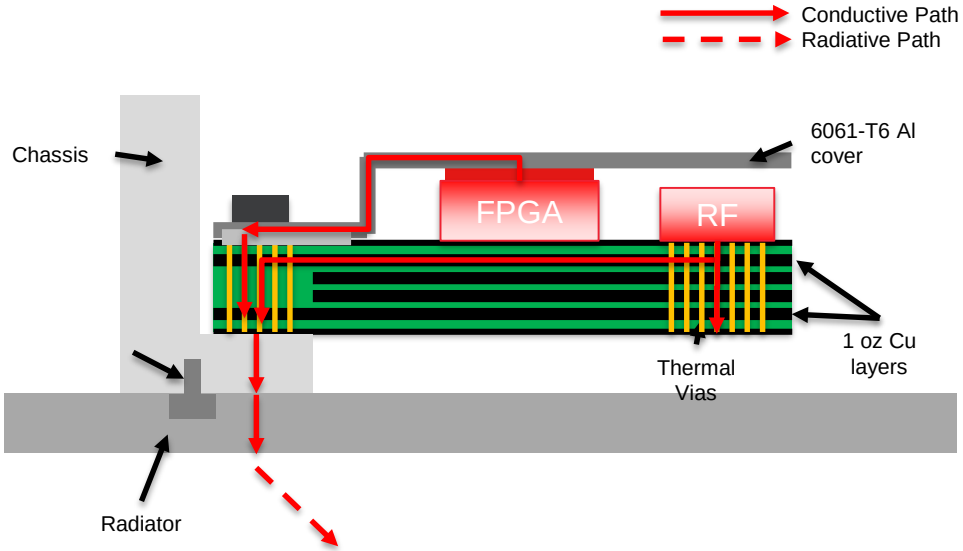
MarCO will provide a real-time communication relay for InSight EDL

Mars CubeSat Orbiter (MarCO)

(Courtesy of Daniel Forgette, MarCO Thermal Lead)

- 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

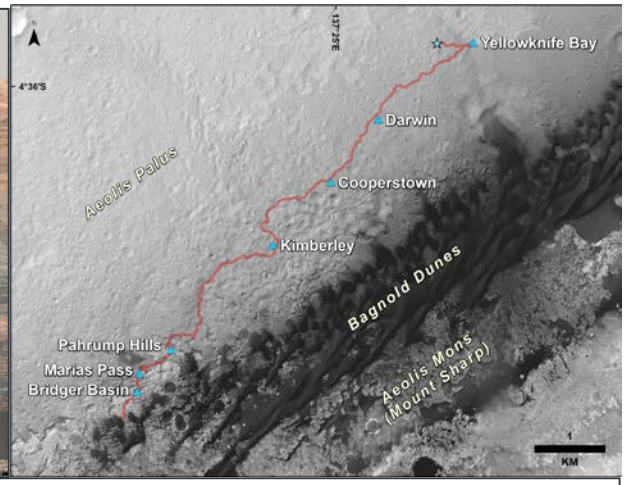


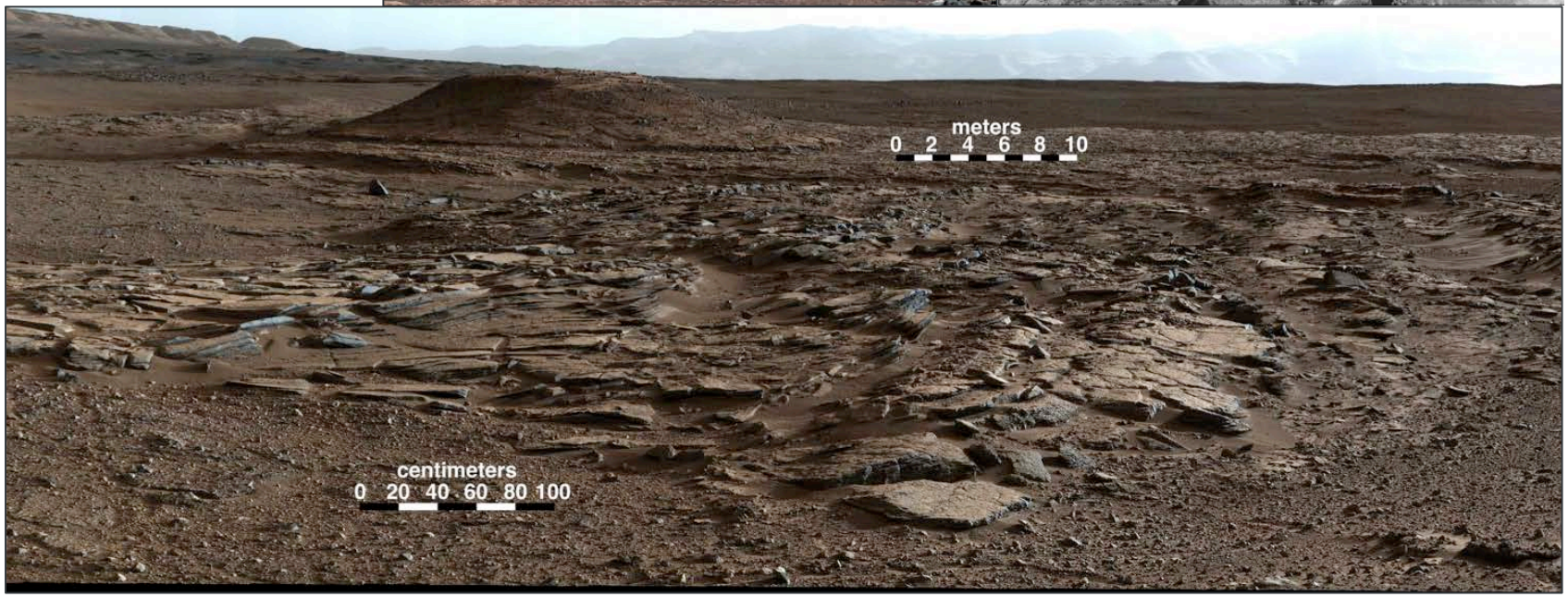


Curiosity Rover—Thermal Status

(Courtesy of Kurt Gonter, Curiosity Rover Thermal Operations Engineer)

- Total odometry: 16,067m
- RTG output nominal at ~90-95W_e.
- Thermal performance has been excellent.

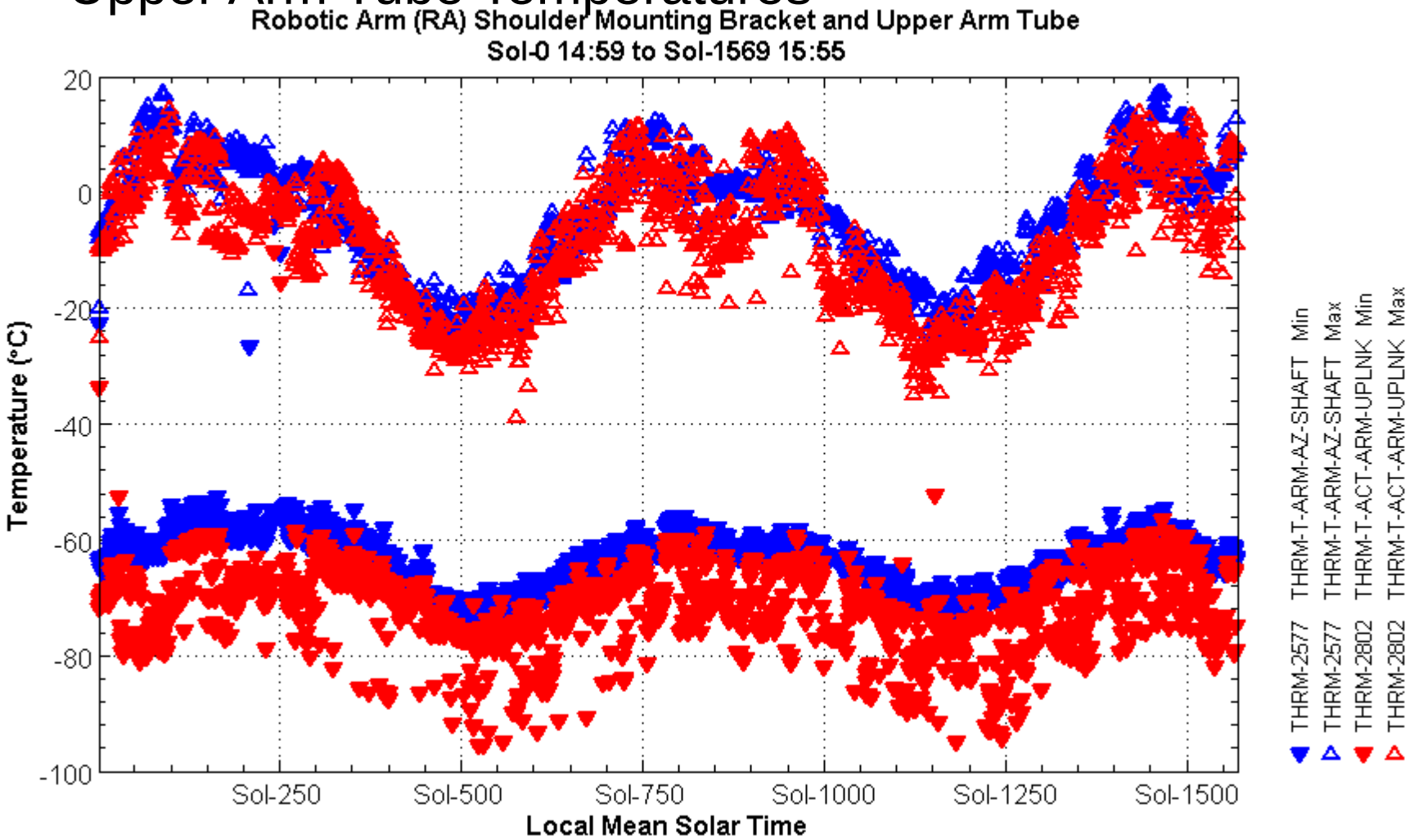




Curiosity Rover—Thermal Status

(Courtesy of Gordon Cucullu, Thermal/Fluid Systems & Mission Operations Group Supervisor)

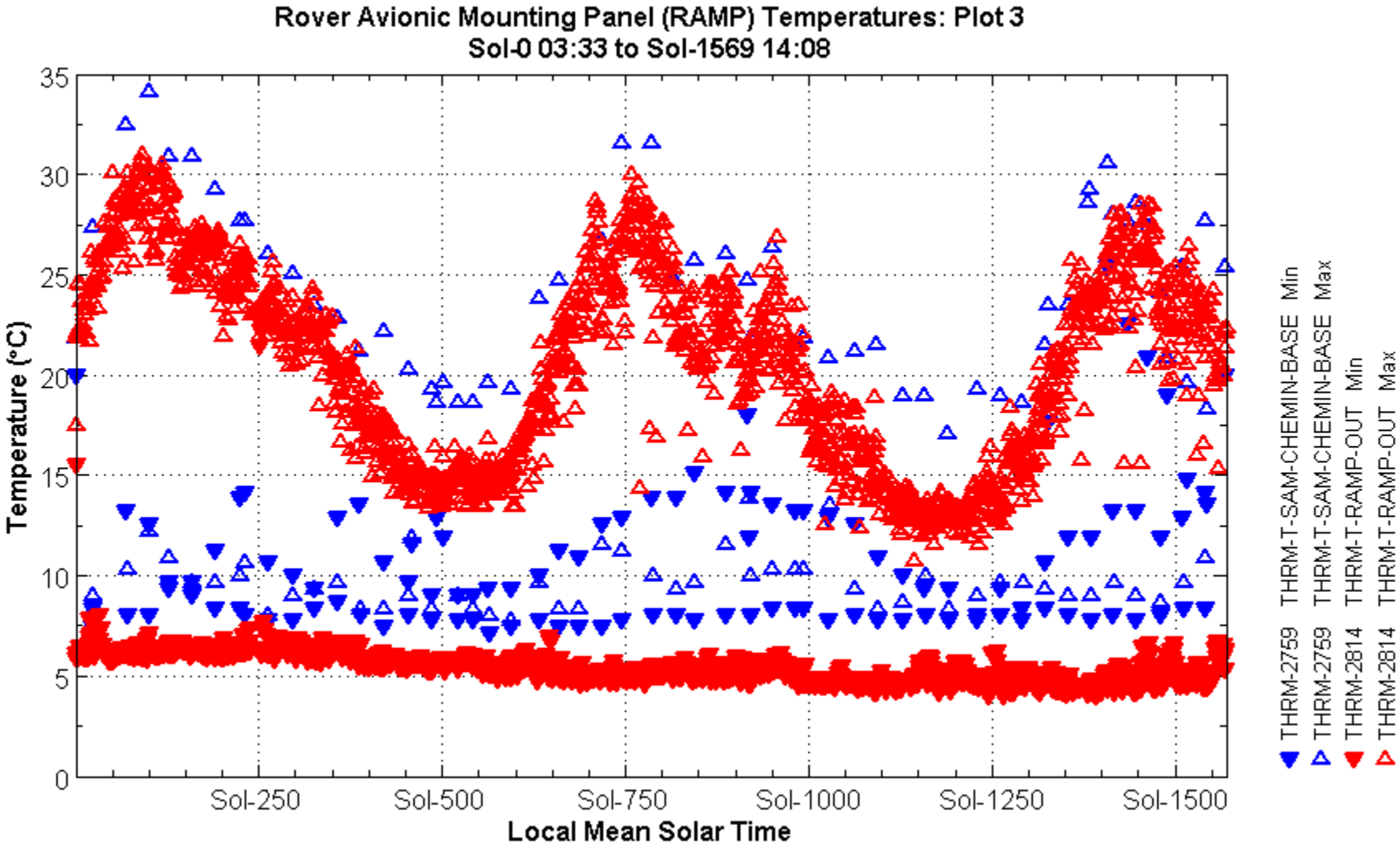
- Robotic Arm (RA) Shoulder Mounting Bracket and Upper Arm Tube Temperatures



Curiosity Rover—Thermal Status

(Courtesy of Gordon Cucullu, Thermal/Fluid Systems & Mission Operations Group Supervisor)

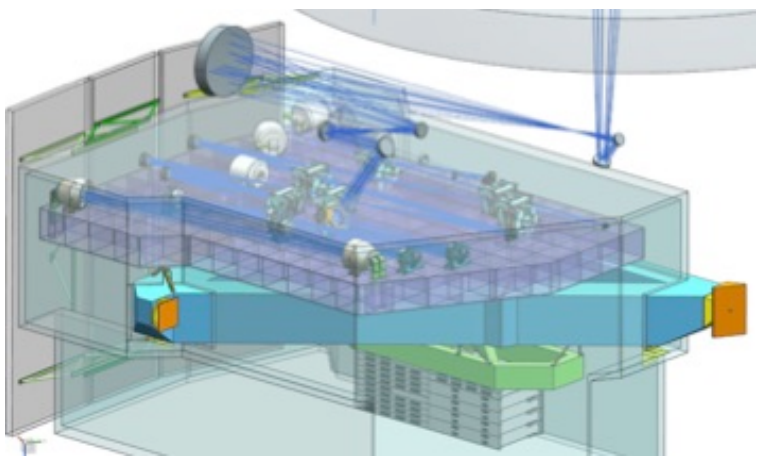
- Rover Avionic Mounting Panel (RAMP) Temperatures



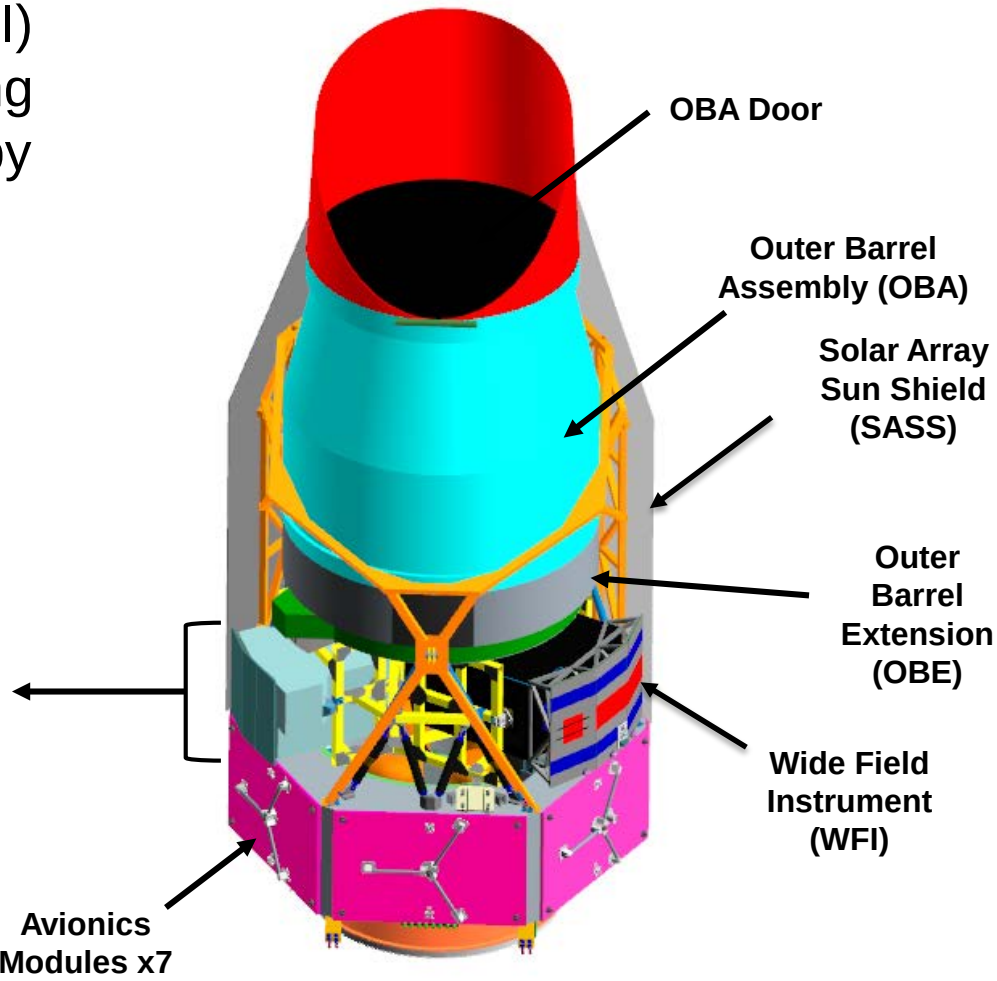
WFIRST/AFTA Exo-Planet Finder

(Courtesy of Gary Kuan, JPL WFIRST/AFTA Systems Engineer & Hung Pham, JPL Thermal Lead)

- Coronagraph Instrument (CGI) provides high contrast imaging and integral field spectroscopy in support of exoplanet and debris disk science.



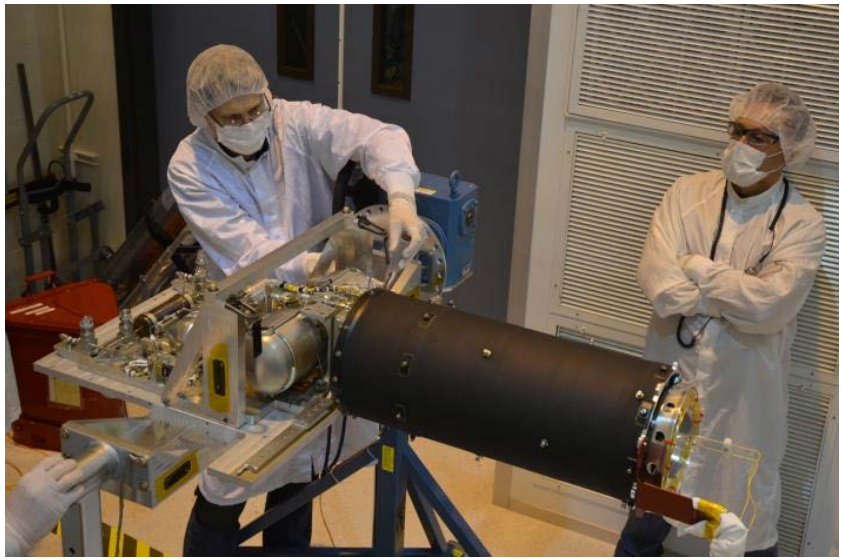
Coronagraph Instrument (CGI)

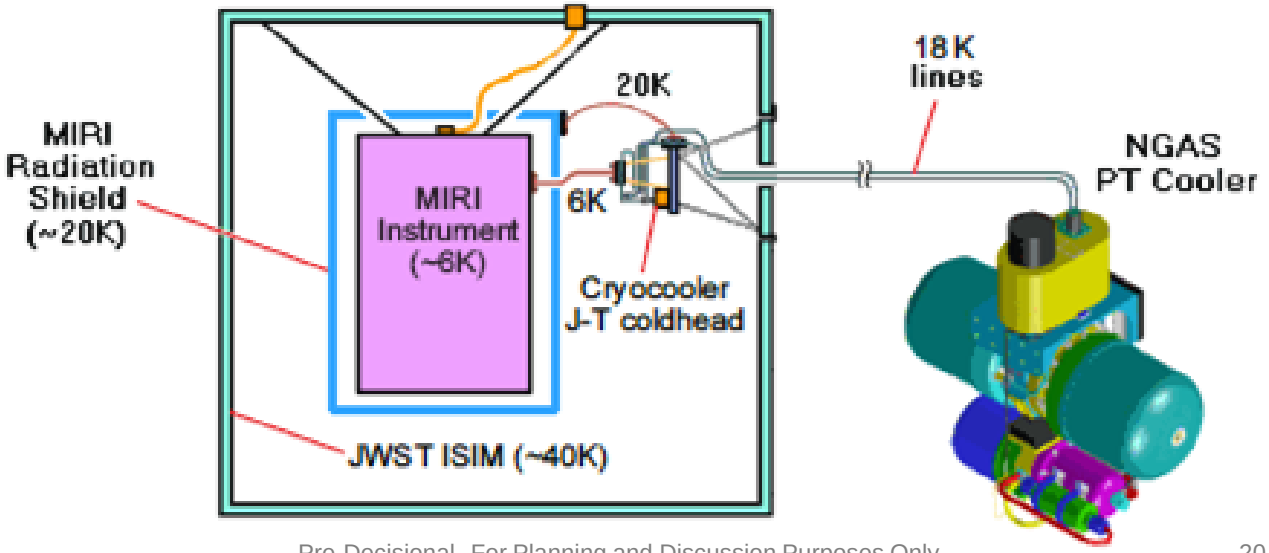


Mid-Infrared Instrument (MIRI) on JWST

(Courtesy of Ron Ross, JPL)

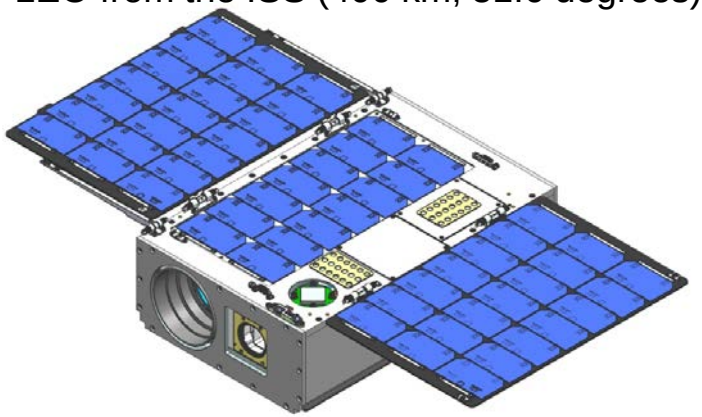
- Mid-IR detector operating temperature 7K
- NGAS pulse tube precooler cools to ~ 20K
- JT stage brings temperature down to ~ 6K





ASTERIA (Courtesy of Dr. Colin Smith, Asteria Thermal Lead)

August 2017 launch for deployment into LEO from the ISS (400 km, 51.6 degrees)

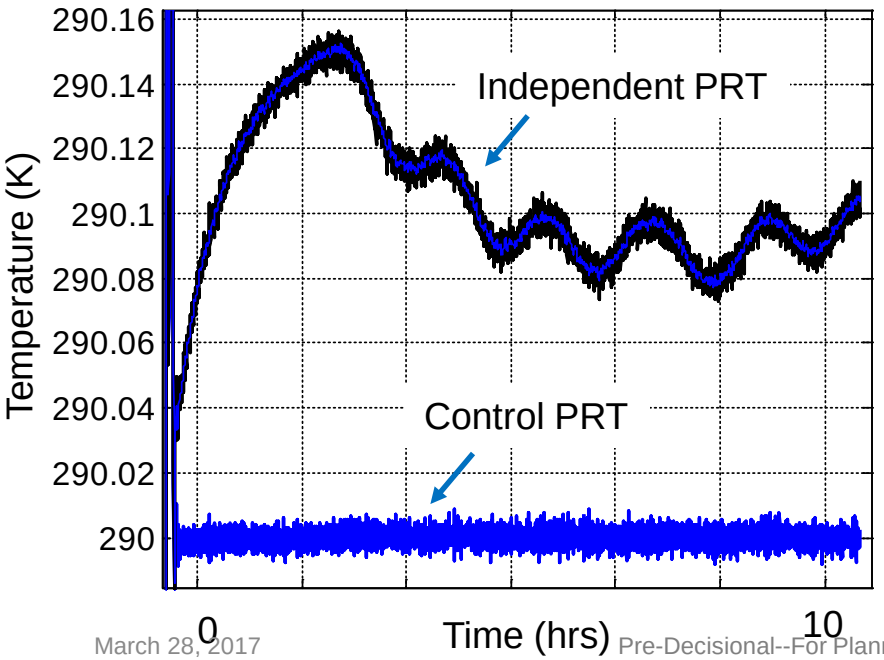


6U CubeSat ASTERIA is a *technology demonstration* mission to advance capabilities in technology areas that *enable photometric studies of astrophysical phenomena* using CubeSats.

Mission Objectives

1. Demonstrate high precision line-of-sight pointing
2. **Demonstrate high precision focal plane temperature control (L1 requirement is $\pm 10\ mK$ temperature stability during 20-minute observation time of an orbit)**
3. Conduct photometric measurements of astrophysical sources on an opportunistic basis – PI is Sara Seager from MIT

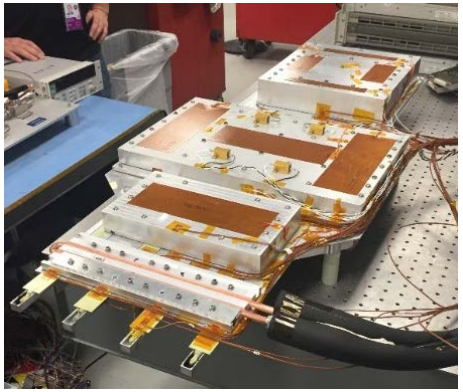
Focal plane temperature during system-level TVAC



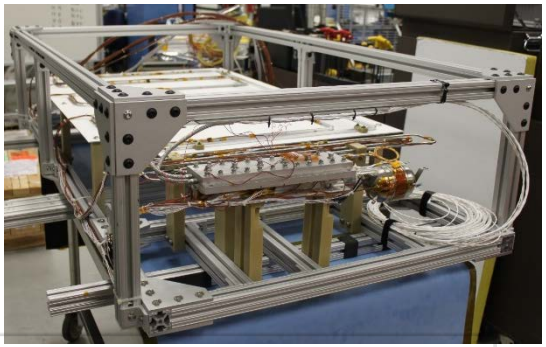
- Focal plane temperature control achieved with 3 layers of thermal disturbance reduction
  1. Thermal isolation of entire camera system from spacecraft chassis
  2. Heater/sensor PID control on camera baffle where major thermal disturbance originates
  3. Heater/sensor PID control on focal plane
- Temperature control demonstrated in system-level TVAC with spacecraft subject to orbit-like thermal disturbance for ~4 orbit periods: control PRT stable to within $\pm 7\ mK$ and independent PRT (located near control PRT) stable to within $\pm 10\ mK$ over any 20 minute period

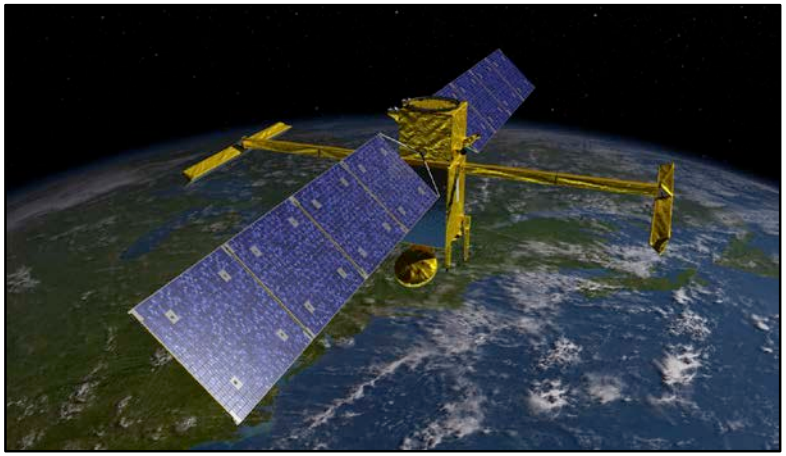
Surface Water Ocean Topography Mission

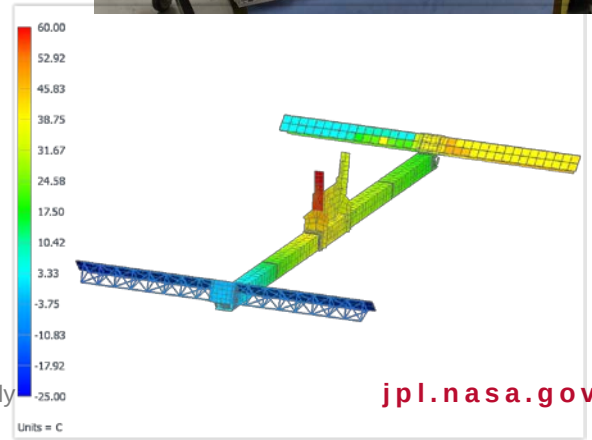
(Courtesy of Ruwan Somawardhana, SWOT Thermal Lead)



- 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
  - >1000 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
  - Tested against simulated LEO sink environment with observed stability < 0.028 °C/min
  - Thermoelastic phase stability validated through STOP modeling
- Project Status: Thermal CDR successfully passed on Feb. 6, 2017



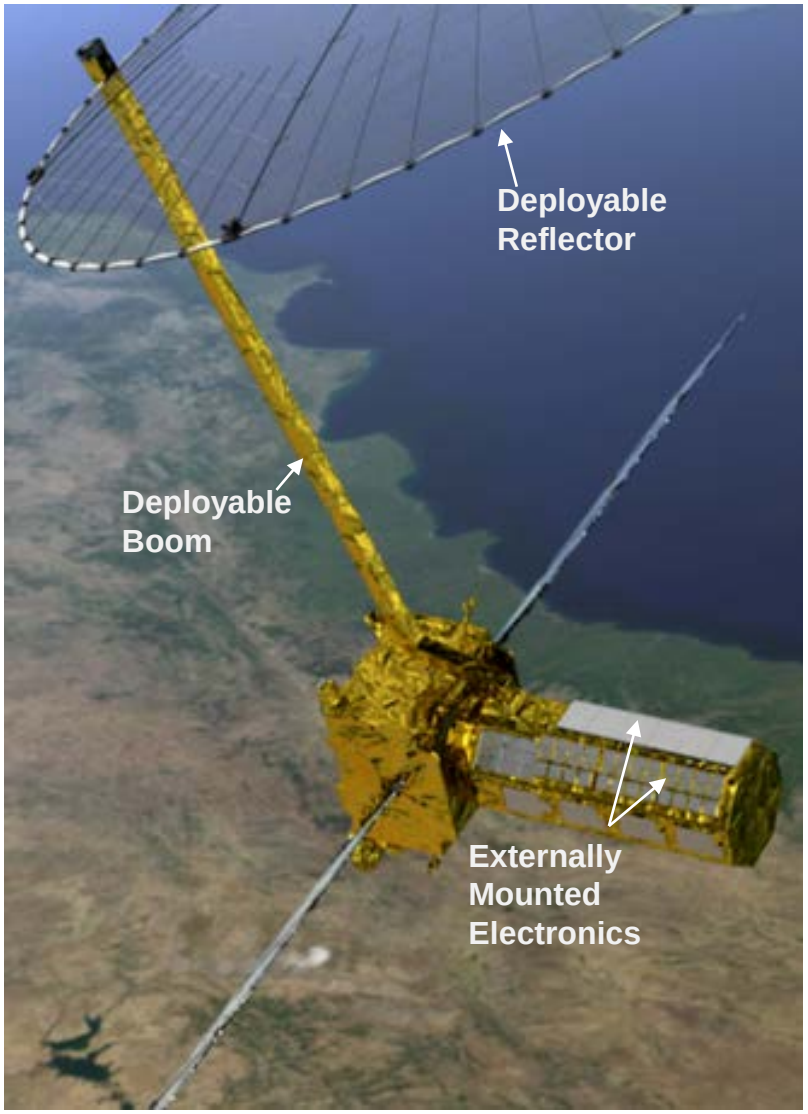




NASA-ISRO Synthetic Aperture Radar (NISAR)

(Courtesy of Frank Kelly, JPL NISAR Thermal Lead)

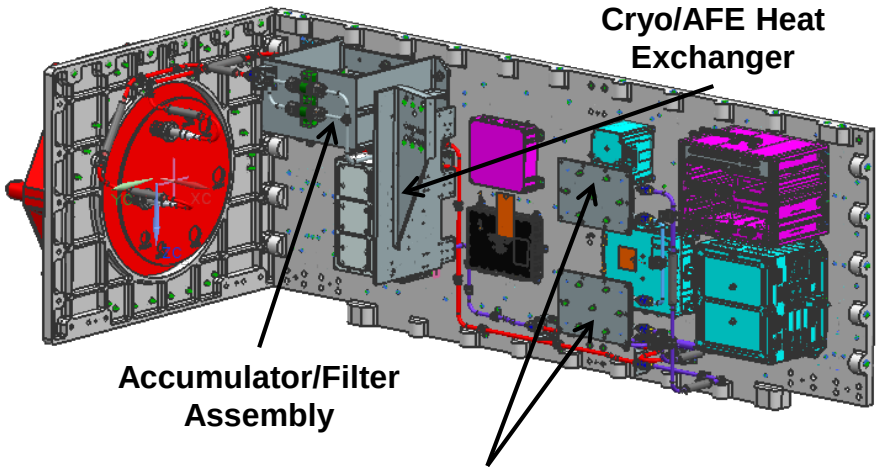
- The NISAR Mission
  - NASA-ISRO Synthetic Aperture Radar
  - NISAR will measure surface motion over span of 12 days to study:
    - Ice Sheet Collapse
    - Earthquakes
    - Volcanoes
    - Landslides
- Thermal Challenges
  - Thermal environment
    - In order for the Instrument to observe both North 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 Thermal System utilizes traditional thermal control materials and hardware for a largely passive thermal design
  - Passive components
    - Radiative coatings/PRTs/Thermistors/MLI/Thermal Isolation
  - Active Components
    - Kapton Heaters/Mechanical Thermostats

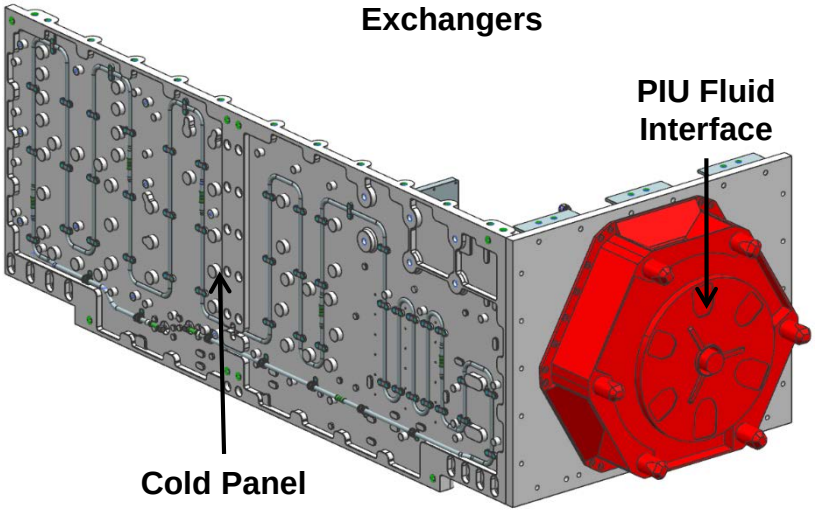


Orbiting Carbon Observatory-3

(Courtesy of Brian Carroll and Josh Kempenaar, OCO-3 Thermal Lead)

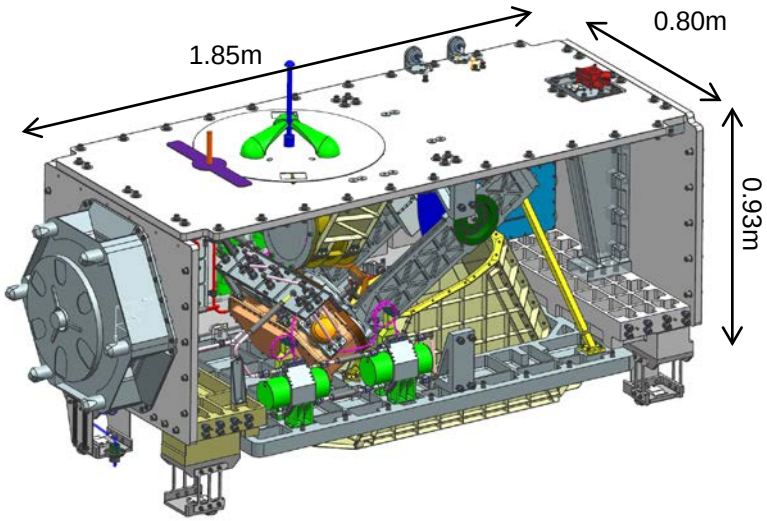
- The thermal control system utilizes the JEM-EF Active Thermal Control System (pumped fluid loop)
- Four thermoelectric coolers cool the Optical Bench Assembly (OBA)
- Two heat exchangers (HXs) remove heat from four thermoelectric coolers (2 per HX)
- A “Cold Panel” provides structure and heat rejection 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

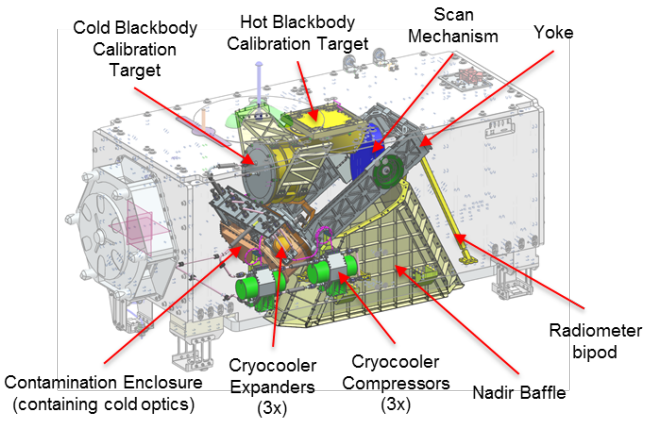


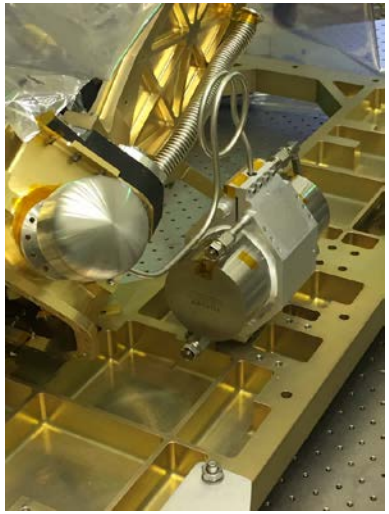


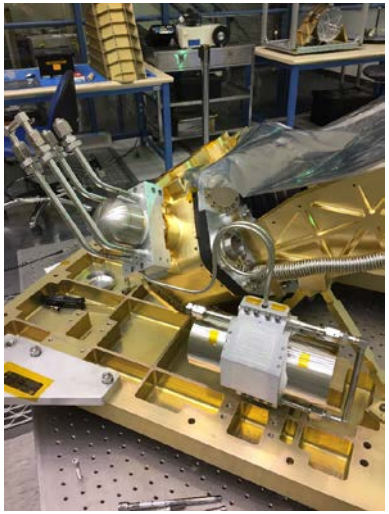
ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)

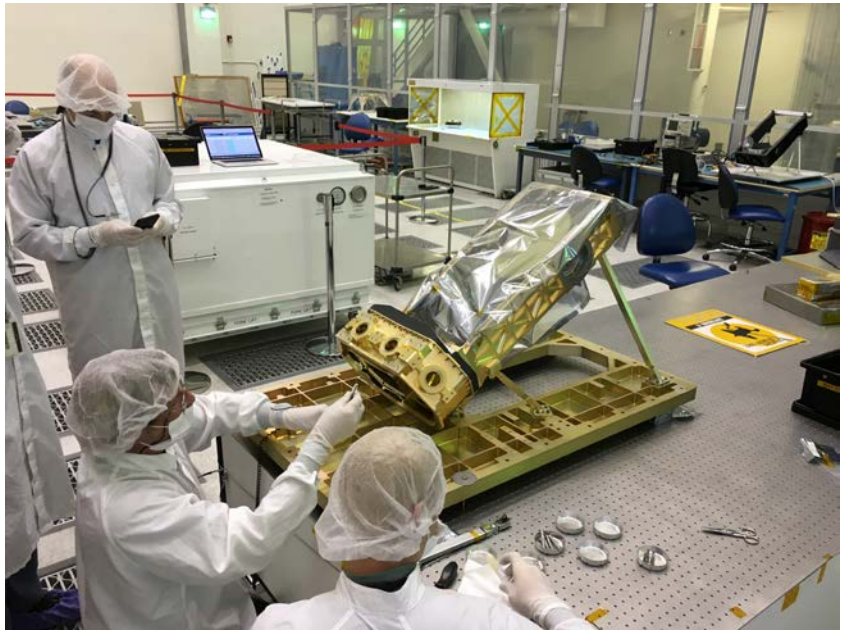
(Courtesy of Jose Rodriguez, JPL Cryogenic Systems Engineering Group Supervisor)











NASA/JPL Mission Roadmap

Jet Propulsion Laboratory
California Institute of Technology

Planetary Science Roadmap

Mars

Current and potential future missions

2016 - 2020 → **2022 - 2026** → **2028 - ...**

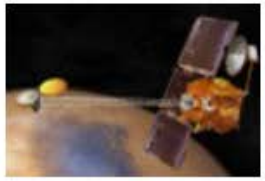
Mars 2020 Science/ Caching Rover

InSIGHT 2018

Curiosity

Opportunity

MRO

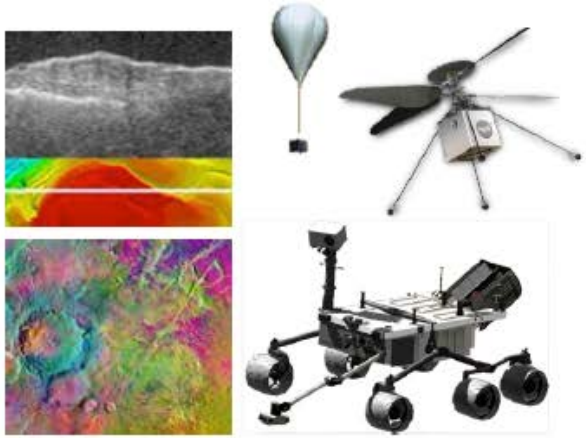


Odyssey

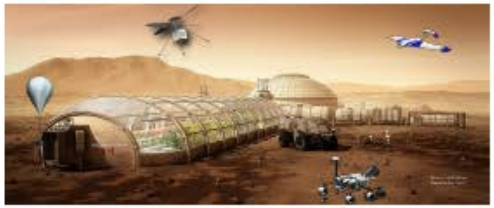
Mars Exploration Orbiter

Mars Exploration Lander

Sample Return



Geological Survey For Future Landings, Resource Prospecting



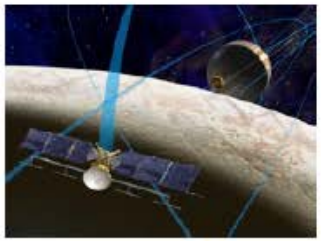
Permanent Robotic and Human Station

Planetary Science Roadmap

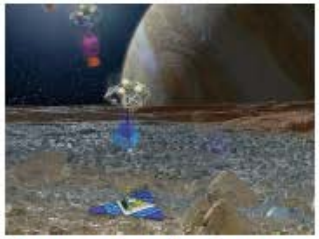
Ocean Worlds

Current and potential future missions

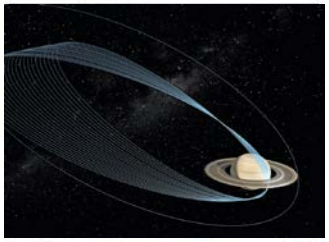
2016 - 2024 → **2024 - 2028** → **2028 - ...**



Europa Clipper

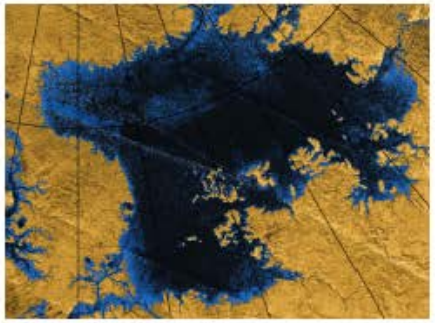


Europa Lander Concept

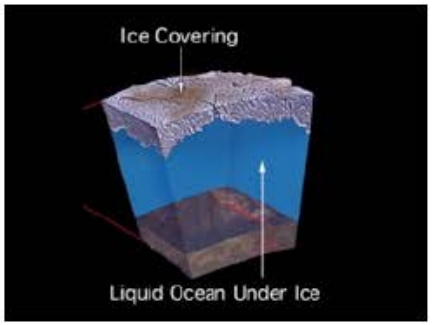


Cassini

Enceladus Probe



Titan Orbiter & Probe



Subsurface Oceans

Europa Submarine

Planetary Science Roadmap

Formation & Evolution of the Solar System

Current and potential future missions

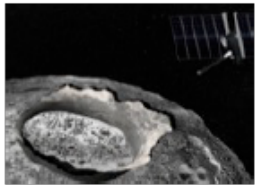
2016 - 2020 → **2020 - ...**

Dawn

Juno

Discovery Missions

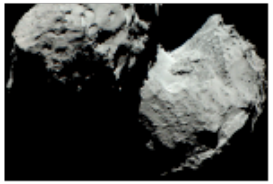
VERITAS



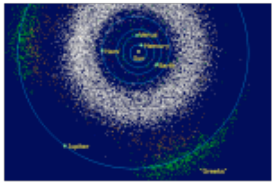
Psyche

NEOCam

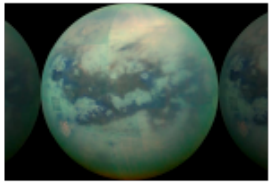
New Frontiers Missions



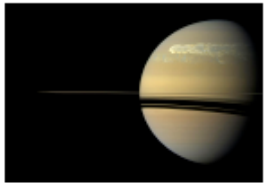
Comet Surface Sample Return



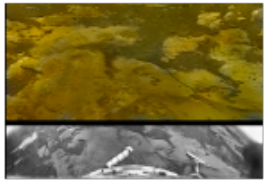
Trojan Tour & Rendezvous



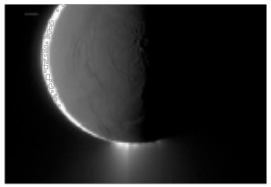
Titan



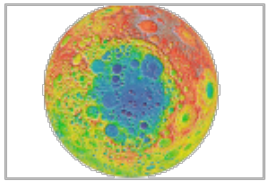
Saturn Probe



Venus In Situ Explorer

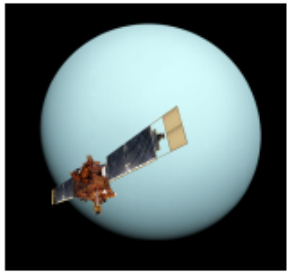


Enceladus



Lunar South Pole – Aitken Basin Sample Return

Flagship Missions



Uranus Orbiter

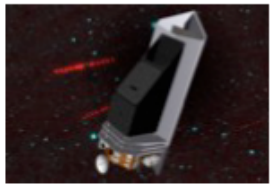
TBD
Next Decadal

Astrophysics, Fundamental Physics & Technology

Current and potential future missions

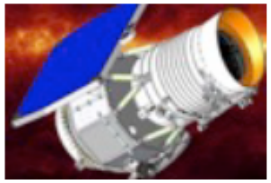
2016 - 2024 → **2024** → **2025**

Spitzer

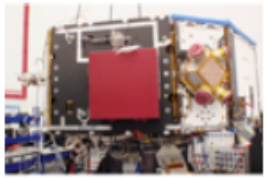


NEOCAM Discovery Mission

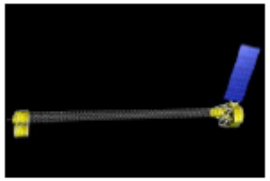
SPHEREx Explorer mission



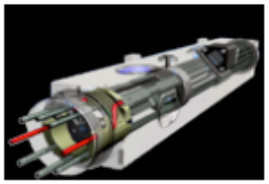
NEOWISE



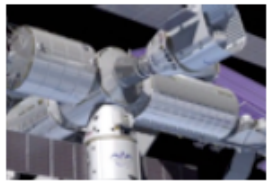
ST7 - LISA Pathfinder



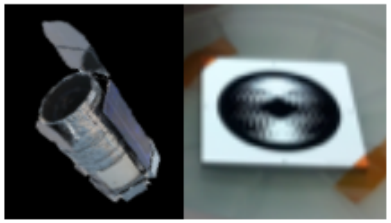
NuSTAR



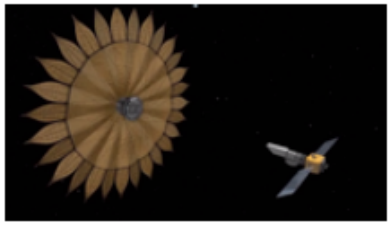
DSAC



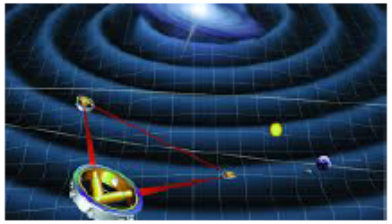
Cold Atom Lab on ISS



WFIRST Coronograph



Starshade Probe Mission



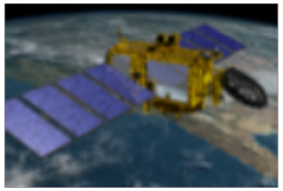
LISA

HabEx

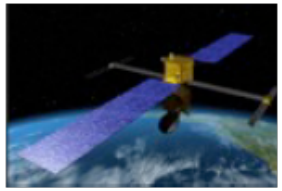
Earth Science

Current and potential future missions

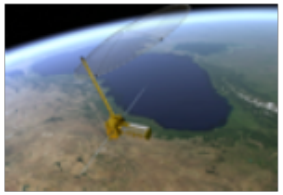
2016 - 2020 → Ongoing → 2020



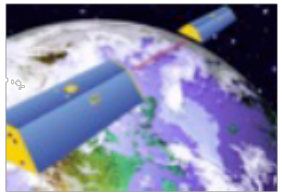
Sentinel 6
(Jason CS)



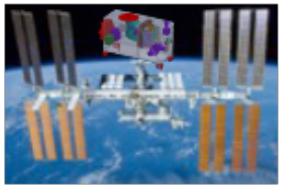
SWOT



NISAR



Grace Follow-On



OCO-3 on ISS

ECOSTRESS on ISS

MAIA

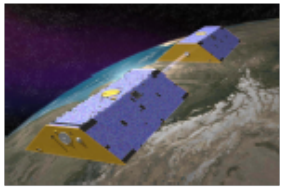
Water Cycle:
How can we improve water resource management?

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

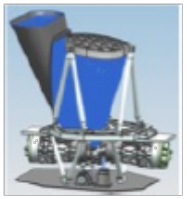
Sea Level:
Will sea level continue to rise at the current rate?

Carbon Cycle:
How are carbon storage and biodiversity changing?

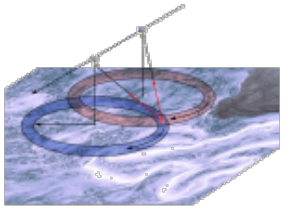
Next
Decadal Survey
2020



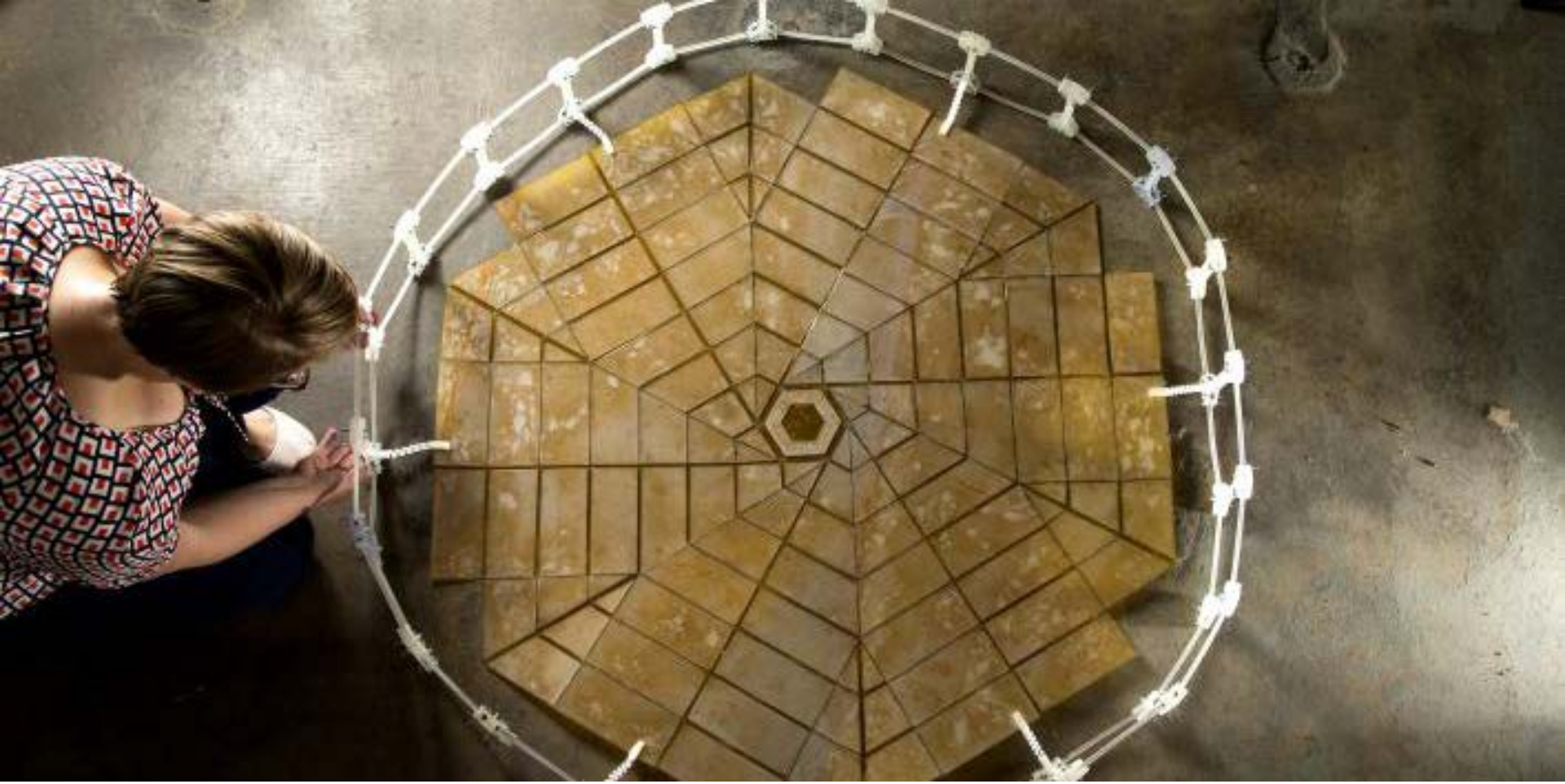
Grace-2



Imaging Spectrometer



Scatterometer



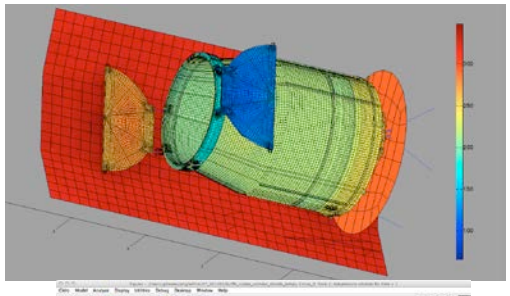
Thermal Technology Challenges

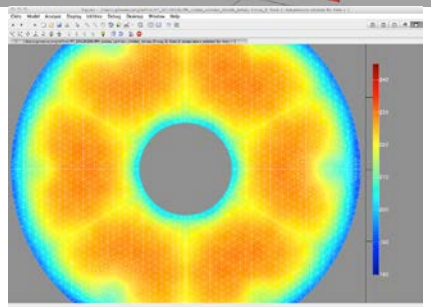
Jet Propulsion Laboratory
California Institute of Technology

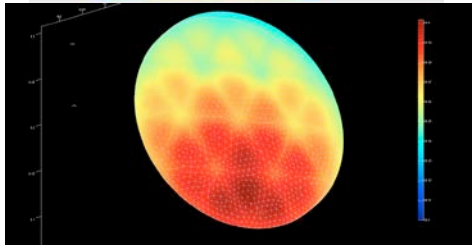
Challenge: Thermal Design Validation by Analysis Cielo Toolkit Development

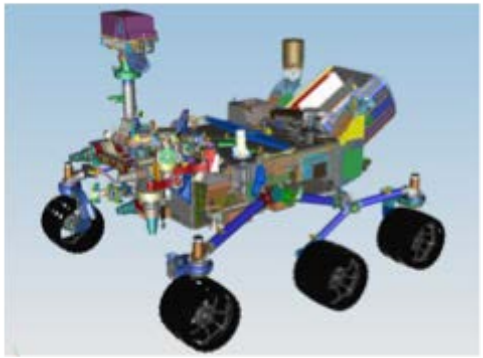
(Courtesy of Mike Chainyk, Cielo Developer)

- 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









Challenge: Thermal control for extreme environments

Target	Radiation (krad/day)	Heat flux at atm. entry (kW/cm^2)	Deceleration (g)	Pressure (bar)	Low temperatures (°C)	High temperatures (°C)	Rotational Period (Earth days)	Chemical corrosion	Physical corrosion
High temperatures									
Venus		2.5	300	92		482	243	Sulfuric acid clouds	
Jupiter (upper atmosphere)		30	228	22		230	0.4		
Low temperatures									
Lunar permanently shadowed regions					−230				Dust
Comet (nucleus)		0.5†			−270				
Titan		0.01	15	1.5	−178		16	CH_4	
Enceladus (equator)					−193				
Enceladus (south pole)					−188				
Low temperatures and high radiation									
Europa (orbit)	40								
Europa (surface)	20				−180		3.6		
Europa (sub–surface)	0.3 at 10cm				~0 at 5km				
Thermal cycling									
Moon					−233	+197	27		Dust
Mars		0.05–0.1		0.007	−143	+27	1		Dust

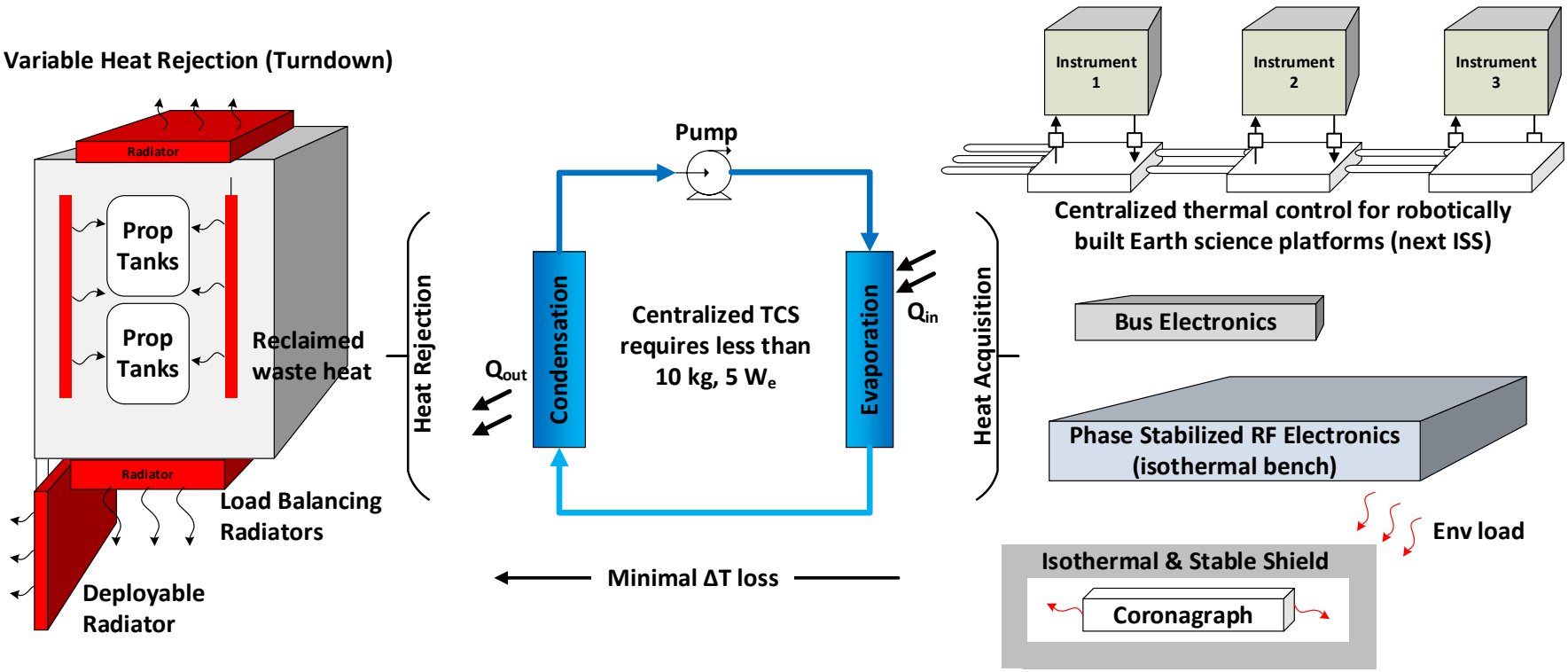
†*Applies to any Earth return mission, including sample return from comets.*

Challenge: 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 flexibility 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	> 500
Thermal - Mass (Kg)	75 - 100	< 0.5 kg	10
Thermal - Power (W_e)	100 - 300	< 5 W	5
TRL	9	9	3

Thermal Control for Deep Space Small Spacecraft—Two-Phase Mechanically Pumped Fluid Loop Development (2-ϕ MPFL)



2-ϕ MPFL Development

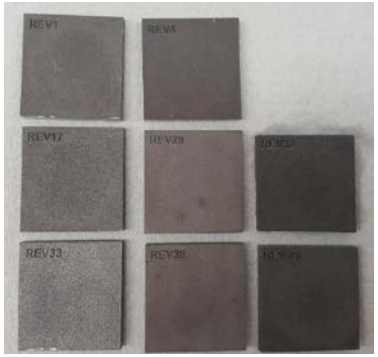
- Technology gaps identified
  - Robust, versatile loop architecture needed for multiple evaporators and condensers
  - Pumps
    - 15 year life requirement
    - Low NPSH pumps needed
  - Evaporators
    - Lightweight, large area
    - Isothermal while tolerant of sub-cooled liquid

2-ϕ MPFL Development at JPL

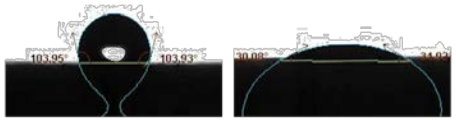
(Courtesy of Ben Furst, Stefano Cappucci, Pradeep Bhandari, Scott Roberts)

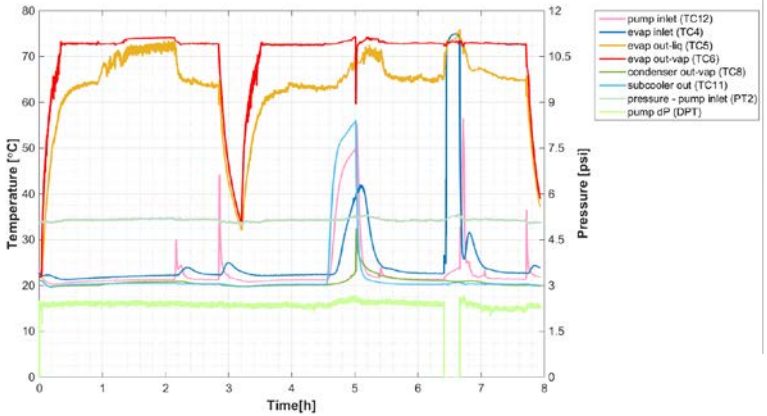
- Mid-way thru a 3-year initiative to demonstrate full-scale 2-ϕ MPFL to TRL 5

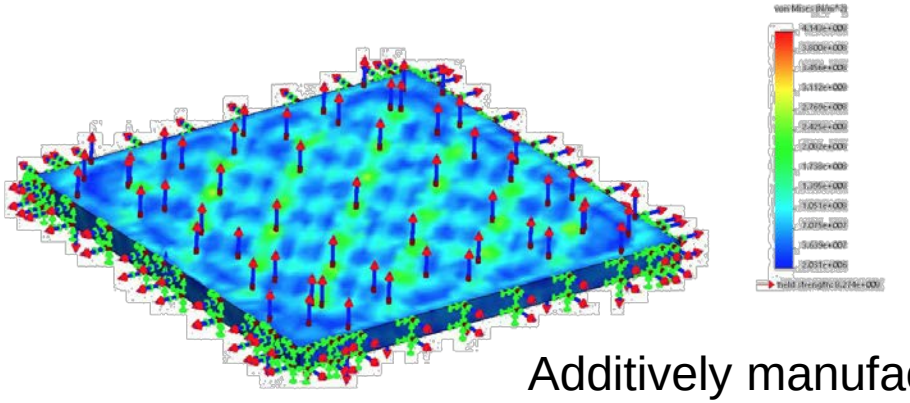
Sub-scale testing at JPL



Additively manufactured porous media







Additively manufactured evaporator design

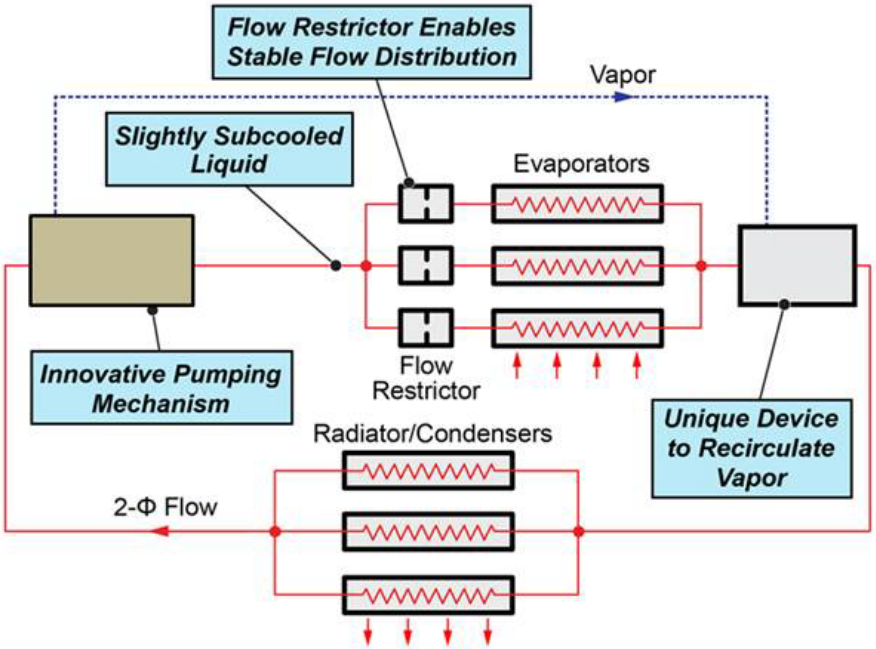
Contributors

UTC Aerospace Systems | SBIR STTR | Creare | NCT | EPSCoR NEVADA | University of Nevada, Reno | UNLV

A Robust Two-Phase Pumped Loop With Multiple Evaporators and Multiple Radiators

SBIR Ph II Proposal # S3.07-9060—Creare LLC, PI: Dr. Weibo Chen

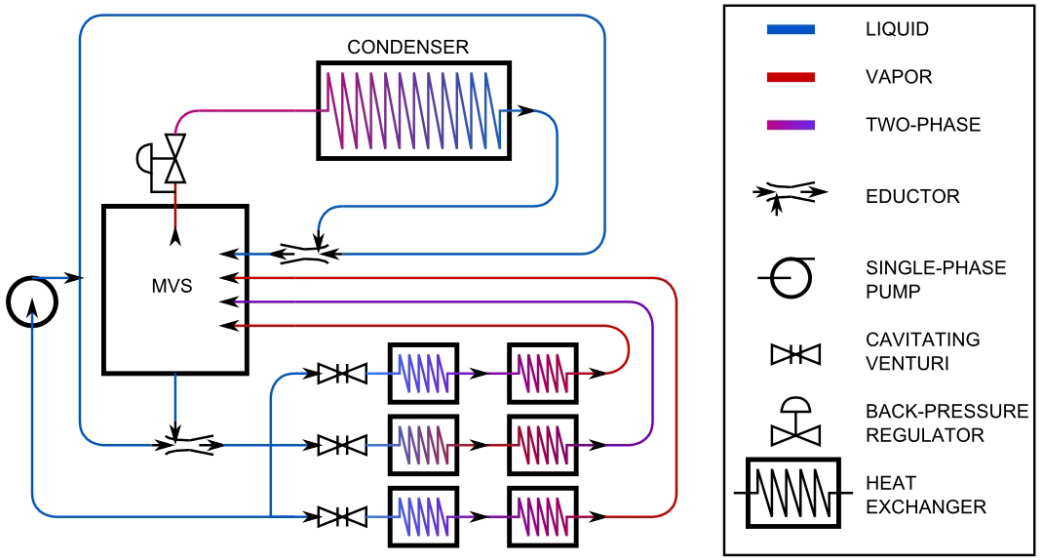
- A highly adaptable and reconfigurable two-phase pumped architecture to meet the thermal control demands for future missions. The successful development of this innovation will enable solar system exploration and earth science by greatly reducing system resource usage and increasing science return through robust thermal stability for instruments.
  - Accommodation of very high heat fluxes
  - Precision thermal stability/isothermality with little control power < 0.05 ^{o}C/min
  - Reduce heater usage via waste heat reclamation and radiator turn-down
  - Reduce I&T costs through plug-and-play capability and reduced thermal vacuum test time
  - Scalability/flexibility allowing thermal control across deployables
  - Reduce flight system mass



Two-Phase Pumped Loop for Spacecraft Thermal Control

SBIR Ph I Proposal # S3.07-9409—Adv. Cooling Tech, PI: Michael Ellis

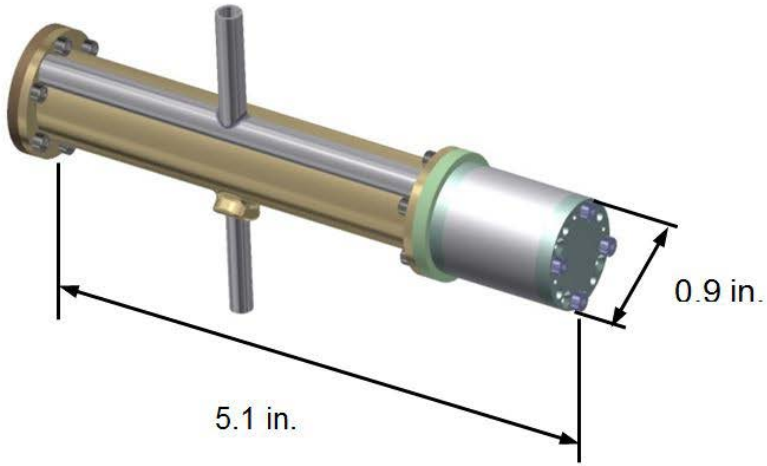
- Relies on a liquid pump to drive two-phase flow through multiple heat loads distributed in parallel and in series while providing phase management using the momentum of the working fluid.
  - The use of a liquid pump to drive the system allows the working fluid to overcome large pressure drops with low power consumption. Ability to transfer waste heat over large distances.
  - Flow can be driven through multiple heat exchangers or cold plates to either collect or release thermal energy. Allows for heat load sharing.
  - Added to these benefits are those intrinsic to two-phase heat transfer: near-isothermal operation, a two order of magnitude increase in the heat transferred per unit mass, and the ability to handle high heat fluxes.



An Efficient, Reliable, Vibration-Free Refrigerant Pump for Space Applications

SBIR Ph II Proposal # S3.07-7413—Creare LLC, PI: Dr. Weibo Chen

- Significance of the innovation
  - An innovative refrigerant pump to enable reliable refrigerant circulation in two-phase pumped loops
  - Long-life, vibration-free bearing technology for reliable operation
  - Unique pumping mechanism for low Net Positive Suction Head (NPSH), preventing cavitation in impeller and bearing liquid film
  - Efficient operation for low flow rate and high pressure rise
- Benefits
  - Compact, lightweight, and low pumping power
  - Ultra-reliable
  - No exported vibration
- Estimated TRL at beginning and end of contract: (Begin: 3 End: 4)



Pump Performance

ΔP =10 psid

$\dot{V}$ = 2 cc/s

$W_{electrical}$ = 1.6 W

M = 198 g

Speed: 12,000 rpm

NPSH: 0.2 psi

Life Testing 1-ϕ MPFL for Planned Europa Mission

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

- Two Mars flight heritage Mechanically pumped fluid loops are being life tested for the planned Europa mission
- Main issues for life testing are:
  - Effect of ionizing radiation of 3-6 Mrads on the CFC-11 fluid stability and its affect on the materials in the wetted path
  - Long duration mission life of 10-12 years on the reliability of the fluid loop and its performance
- The first Mars rover simulated loop is under life test since mid-2005 and has logged over 90,000 hours without any significant degradation in performance
- The second Mars flight heritage simulated loop was irradiated to 6 Mrad TID and fluid and the wetted materials chemically analyzed during irradiation in 2014-15

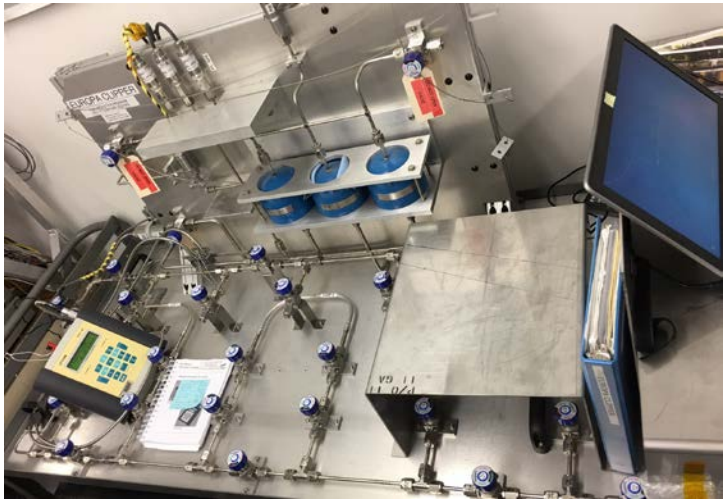
JPL's MPFL Life Test Panel (started in 2005)

JPL's Europa MPFL Radiation Exposure Test Bed (2014)

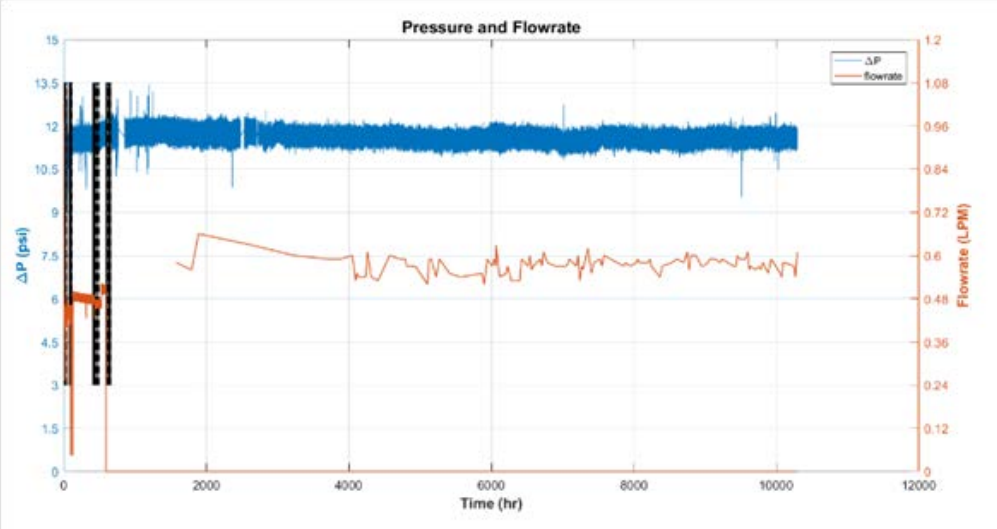
Life Testing of Irradiated 1-ϕ MPFL for Europa Mission

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

- Only the CFC-11 circulating in the simulated loop was irradiated to a TID of 6 Mrad while the rest of the loop was protected from the gamma radiation.
- The fluid and the wetted materials were chemically analyzed at four intervals for the second loop during irradiation
- The loop (irradiated) is under life testing in ambient conditions at JPL since June 2015 after irradiation and has logged over 15,000 hours
- No significant degradation in performance has been noticed so far



JPL's Europa MPFL Irradiated Life Test Bed



Performance of Irradiated MPFL Life Test Fluid Loop

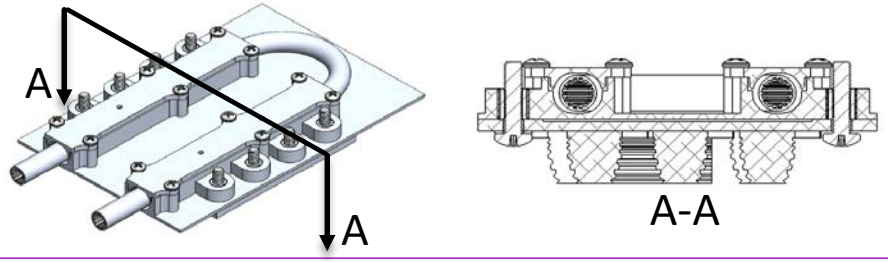
INNOVATIVE LIQUID COLD PLATE HEAT EXCHANGER DESIGNS THROUGH ADDITIVE MANUFACTURING

(Courtesy of A.J. Mastropietro, Dr. Elham Maghsoudi, Dr. Scott Roberts)

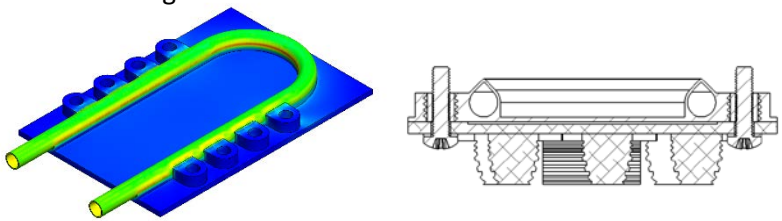
Summary

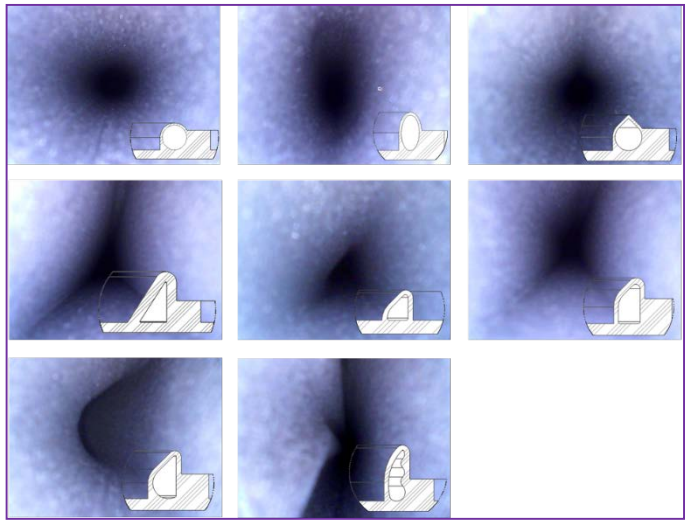
Explore alternative fabrication methods for liquid cold plate Al heat exchanger construction in order to decrease the build time, cost, and mass per unit while increasing the thermal performance. Alternate methods under investigation include – aluminum investment casting, Direct Metal Laser Sintering (DMLS), and Ultrasonic Additive Manufacturing (UAM). Part of the investigation is to verify that aerospace quality hermeticity can be achieved with these various techniques and that unique parts with complex internal coolant channel geometries can be more readily constructed for the purpose of enhancing convective heat transfer.

MSL Heritage Heat Exchanger Design – finned tubing epoxied into saddle with cap

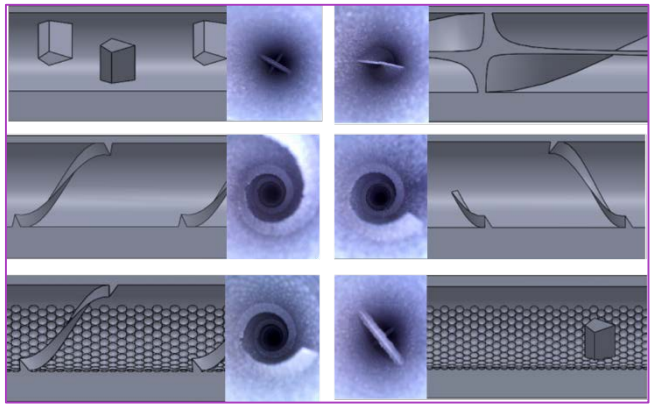


General Design for 3-D Printed HXs





↑ Various cross sectional geometries of coolant channels that were DMLS printed



↑ Internal features for enhanced turbulent heat transfer that were DMLS printed

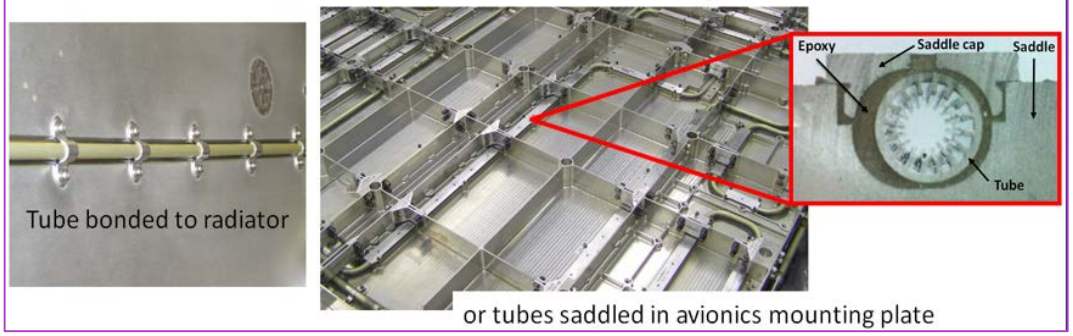
↑ ↓ Helium leak test of sample DMLS parts

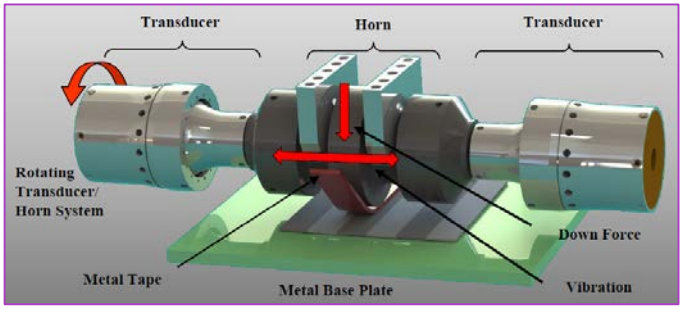
SBIR Phase 2 with Sheridan Solutions and Fabrisonic LLC – "Ultrasonic Additive Manufacturing of Heat Exchangers"

(Courtesy of A.J. Mastropietro, Dr. Elham Maghsoudi, Dr. Scott Roberts)

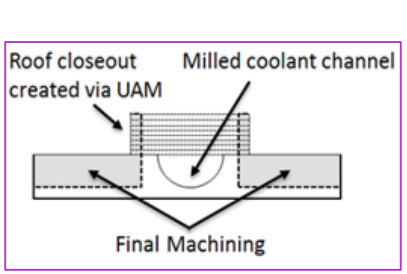
Novel additive manufacturing technique for fabricating large aluminum liquid cold plate heat exchangers to support more cost effective and efficient Mechanical Pumped Fluid Loop Thermal Architectures for future flagship and manned missions. The technique uses subtractive manufacturing to create coolant channels in a virgin slab of aluminum and then additively consolidates an aluminum roof over the channels. The technique has the potential to build an MSL RAMP size cold plate with fully automated welds and no tubing fab required thereby enabling an assembly design with significantly reduced part count and build time.

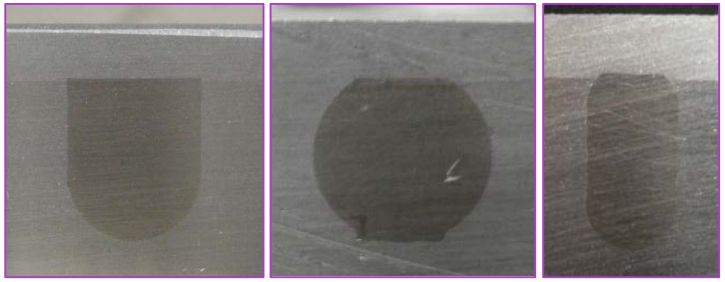
Current State of the Art for HRS Heat Exchanger Fabrication



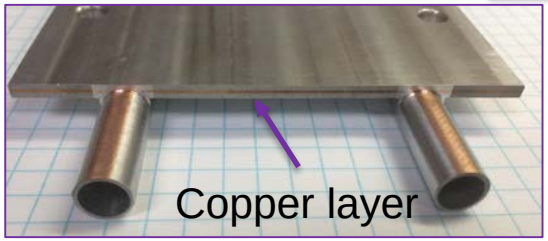


↓ UAM HX SBIR Phase 1 Deliverable





Various coolant channel geometries filled with support material ↑
↓ UAM CubeSat radiator



CubeSat Technology Gaps Identified

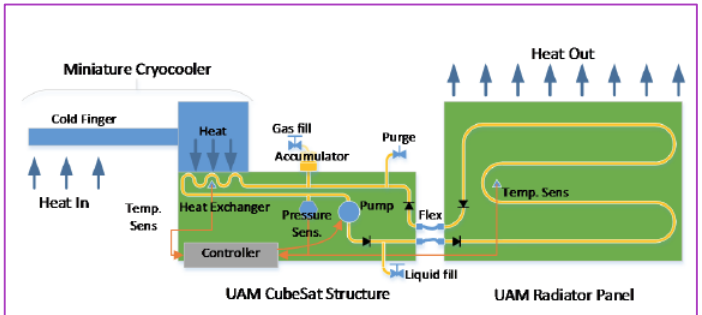
- The increasing power density of CubeStats and environmental load variation associated with interplanetary missions poses thermal control challenges
- Need for inexpensive and miniaturized
  - Deployable radiator systems
  - Radiator turndown systems
  - High conductance chassis

Active CryoCubeSat

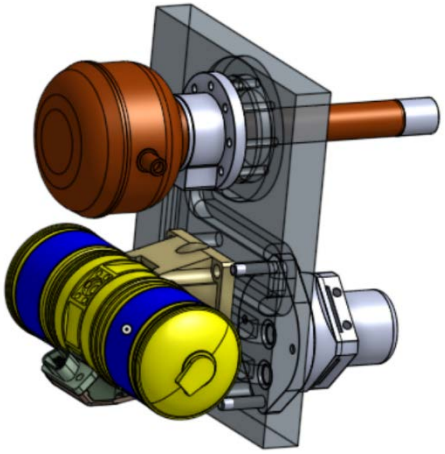
A Small Spacecraft Technology Partnership between NASA JPL and USU

(Courtesy of A.J. Mastropietro, Dr. Elham Maghsoudi, Dr. Scott Roberts)

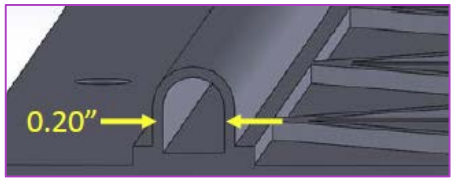
- Development of a 6U miniaturized active thermal control system for CubeSats to provide cryogenic cooling for IR detectors in the 75-100K range
- Thermal system architecture incorporates a mechanical pumped fluid loop with a mini cryocooler.
- Ground based testbed will demonstrate 6U steady state heat rejection capability > 30W
- Ultrasonic Additive Manufacturing (UAM) process used to fabricate radiator and heat exchanger for project.



Conceptual Diagram of the Active CryoCubeSat Testbed



↓ UAM radiator panel was successfully fabricated ~30cm x 20cm



↑ Lockheed Martin Micro Cryocooler integrated on a 1 U heat exchanger to be built using UAM

↑ 100 psi pressure leak check
– no bubbles during immersion test!

Cryogenics Systems Engineering Group

(Courtesy of Jose Rodriguez, JPL Cryogenic Systems Engineering Group Supervisor)

Engineering & Research Capabilities

Microcoolers for space and Mars landed missions. Challenge: Low Power Efficiency, High Cost and Poor Reliability. POC: Drs. Jose I. Rodriguez, Dean Johnson, Ian McKinley

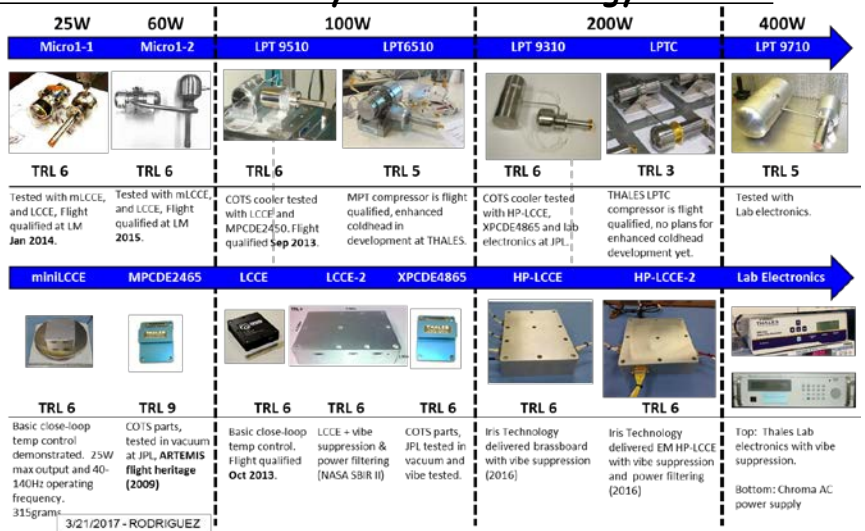
Architecting multi-stage passive cooling systems for LEO and outer planetary missions. Challenge: Solar Power Missions with Large Solar Arrays, Extreme Environments, Materials, Reliability and High Cost. POC: Dr. Jose I. Rodriguez, Doug Bolton, Perry Ramsey

Pulse tube cryocooler technology advancements for cooling to 40K. Challenge: Complex Pulse Tube Designs, Thermodynamic Modelling, CFD Analysis, Materials. POC: Dr. Dean Johnson

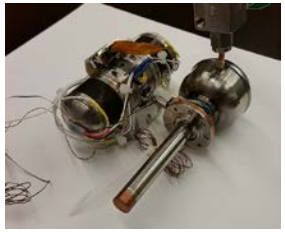
Cryogenic technology development and infusion on future remote sensing science instruments. Challenge: High Development Costs, TRL6 High Qualification Costs, Materials and Reliability. POC: Drs. Jose I. Rodriguez, Perry Ramsey, Ian McKinley

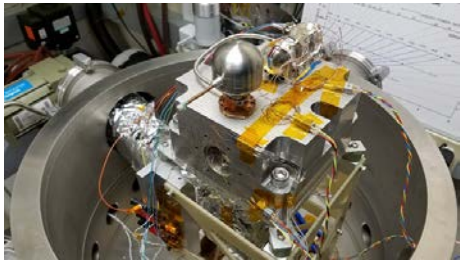
Flight qualification and characterization testing of cryocooler systems for space flight instruments. Challenge: High Cost and Maintenance of Special Test Equipment and Flight Certified Facilities. POC: Dr. Dean Johnson

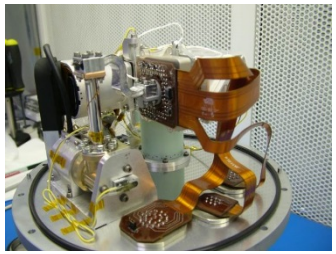
Low Cost Pulse Tube Cryocooler Technology- Status



Microcoolers for Space and Mars Landed Missions

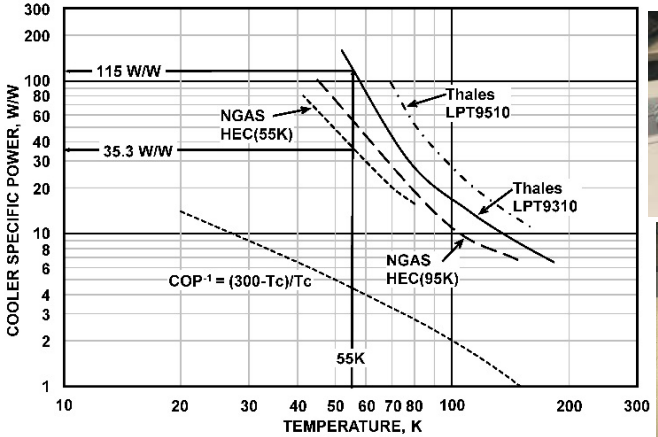


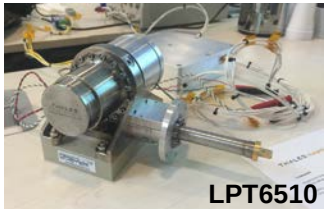


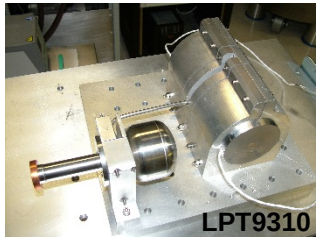


Small form factor and less than 500g microcoolers enable efficient cryogenic cooling for CubeSats and compact science instruments

Characterization Testing of Cooler technologies







Targeting strategic improvements to increase thermodynamic efficiency

Cryogenics Systems Engineering Group

Long-life Space Cryocooler Operating Experience

	Cooler / Mission	Hours/Unit	Comments
	Air Liquide Turbo Brayton (ISS MELFI 190K)	85,600	Turn on 7/06, Ongoing, No degradation
	Ball Aerospace Stirling		
	HIRDLS (60K 1-stage Stirling)	83,800	8/04 thru 3/14, Instr. failed 2008; Data turned off 3/14
	TIRS cooler (35K two-stage Stirling)	27,900	Turn on 3/6/13, Ongoing, No degradation
	Creare Turbo Brayton (77K NICMOS)	57,000	3/02 thru 10/09, Off, Coupling to Load failed
	Fujitsu Stirling (ASTER 80K TIR system)	141,700	Turn on 3/00, Ongoing, No degradation
	JPL Sorption (PLANCK 18K JT (Prime & Bkup))	27,500	FM1 (8/10-10/13 EOM); FM2 failed at 10,500 h
	Mitsubishi Stirling (ASTER 77K SWIR system)	137,500	Turn on 3/00, Ongoing, Load off at 71,000 h
	NGAS (TRW) Coolers		
	CX (150K Mini PT (2 units))	161,600	Turn on 2/98, Ongoing, No degradation
	HTSSE-2 (80K mini Stirling)	24,000	3/99 thru 3/02, Mission End, No degrad.
	MTI (60K 6020 10cc PT)	141,600	Turn on 3/00, Ongoing, No degradation
	Hyperion (110K Mini PT)	133,600	Turn on 12/00, Ongoing, No degradation
	SABER on TIMED (75K Mini PT)	129,600	Turn on 1/02, Ongoing, No degradation
> 14 yrs →	AIRS (55K 10cc PT (2 units))	121,600	Turn on 6/02, Ongoing, No degradation
> 12 yrs →	TES (60K 10cc PT (2 units))	102,600	Turn on 8/04, Ongoing, No degradation
	JAMI (65K HEC PT (2 units))	91,000	4/05 to 12/15, Mission End, No degrad.
	GOSAT/IBUKI (60K HEC PT)	63,300	Turn on 2/09, Ongoing, No degradation
	STSS (Mini PT (4 units))	52,800	Turn on 4/10, Ongoing, No degradation
> 2 yrs →	OCO-2 (HEC PT)	14,900	Turn on 8/14, Ongoing, No degradation
	Himawari-8 (65K HEC PT (2 units))	12,800	Turn on 12/14, Ongoing, No degradation
	Oxford/BAe/MMS/Astrium/Airbus Stirling		
	ISAMS (80 K Oxford/RAL)	15,800	10/91 thru 7/92, Instrument failed
	HTSSE-2 (80K BAe)	24,000	3/99 thru 3/02, Mission End, No degrad.
	MOPITT (50-80K BAe (2 units))	138,600	Turn on 3/00, lost one disp. at 10,300 h
	ODIN (50-80K Astrium (1 unit))	132,600	Turn on 3/01, Ongoing, No degradation
	AATSR on ERS-1 (50-80K Astrium (2 units))	88,200	3/02 to 4/12, No Degrad, Satellite failed
	MIPAS on ERS-1 (50-80K Astrium (2 units))	88,200	3/02 to 4/12, No Degrad, Satellite failed
	INTEGRAL (50-80K Astrium (4 units))	118,700	Turn on 10/02, Ongoing, No degradation
	Helios 2A (50-80K Astrium (2 units))	96,600	Turn on 4/05, Ongoing, No degradation
	Helios 2B (50-80K Astrium (2 units))	58,800	Turn on 4/10, Ongoing, No degradation
	SLSTR (50-80K Airbus (2 units))	1,400	Turn on 3/16, Ongoing, No degradation
	Planck (4K JT using 2 Astrium Comp.)	38,500	5/09 thru 10/13, Mission End, No Degrad.
	Raytheon ISSC Stirling (STSS (2 units))	52,800	Turn on 4/10, Ongoing, No degradation
	Rutherford Appleton Lab (RAL)		
	ATSR 1 on ERS-1 (80K Integral Stirling)	75,300	7/91 thru 3/00, Satellite failed
	ATSR 2 on ERS-2 (80K Integral Stirling)	112,000	4/95 thru 2/08, Instrument failed
	Sumitomo Stirling Coolers		
	Suzaku (100K 1-stg)	59,300	7/05 thru 4/12, Mission End, No degradation
	Akari (20K 2-stg (2 units))	39,000	2/06 to 11/11 EOM, 1 Degr., 2nd failed at 13 kh
	Kaguya GRS (70K 1-stg)	14,600	10/07 thru 6/09, Mission End, No degradation
	JEM/SMILES on ISS (4.5K JT)	4,500	Turn on 10/09, Could not restart at 4,500 h
	Sunpower Stirling		
	RHESSI (75K Cryotel)	124,600	Turn on 2/02, Ongoing, Modest degradation
	CHIRP (CryoTel CT-F)	19,700	9/11 to 12/13, Mission End, No degradation

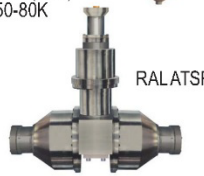
Creare NICMOS

NGAS (TRW) Mini PT

NGAS (TRW) AIRS PT

NGAS (TRW) HEC PT

Astrium (BAe) 50-80K


RAL ATSR

Sunpower RHESSI

Ross 05/18/16

Cryogenics Systems Engineering Group

(Courtesy of Jose Rodriguez, JPL Cryogenic Systems Engineering Group Supervisor)

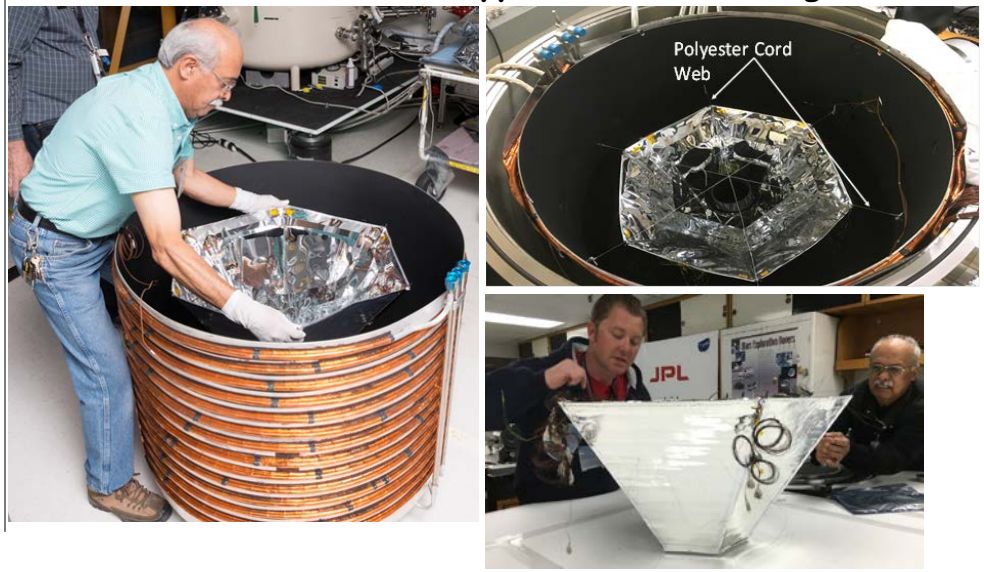
Cryocooler Performance Characterization Testing

MISE Cryocooler Life-Test Laboratory

Flight Cryocooler Testing Lab

Orbiting Carbon Observatory-2 (OCO-2): Mission will collect precise global measurements of carbon dioxide (CO_2) in the Earth's atmosphere utilizing a single instrument with 3 high-resolution, grating spectrometers (0.765 µm O_2 A-band, 1.61 µm "weak" CO_2 band, and 2.06 µm "strong" CO_2 band). Single-stage High Efficiency Cooler (HEC) cools all three focal planes to 120K. Variable conductance heat pipes are used to transport the cooler waste heat to the outboard radiators.

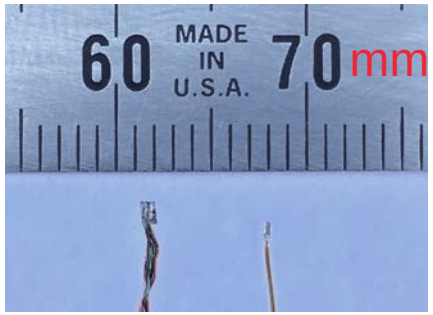
SPHEREx 1/4 Scale Prototype Thermal Testing



Thermal Conductivity Measurements of Regolith and Icy Particles

(Courtesy of Dr. Fang Zhong)

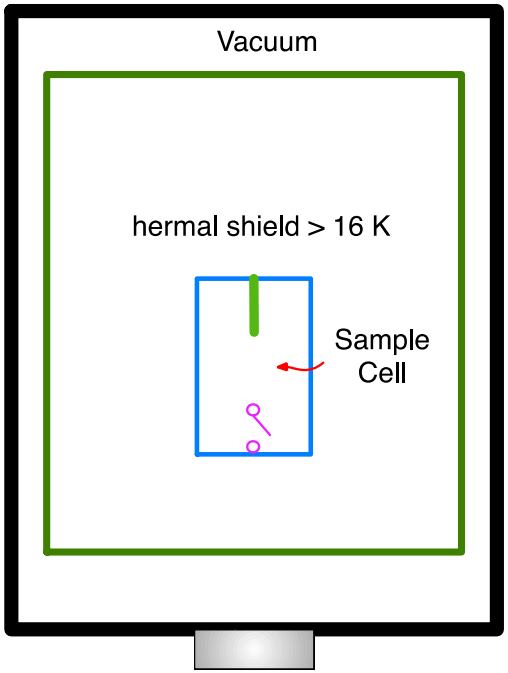
- Develop a facility to measure the temperature dependence of thermal conductivity of various regolith samples and icy particles down ~20K at JPL. The data will be used to model or interpret spacecraft thermal data, and have the insights on the internal structures of the target bodies.
  - A Transient Line Source (TLS) Needle Probe will be constructed with two bead thermistors covering from T = 10K to 450K.



10-300K	270-450K
0.35 x	0.25 x
0.8 x	0.25 x
1.2 mm³	0.7 mm³

The two thermistors can be put into a SS tubing of 1.08 mm OD and 0.08 mm wall.

A previous 43mm long needle contains an ~80Ω heating wire with one thermistor in the center.



- The thermal shield can will be portable.
- Ice particles will be prepared and filled into the sample cell in a cold room of -20C.
- The shield can will be pumped to vacuum and has its own LN cooling jacket while being transported to a lab and mounted in the system.

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