JPL Advanced Thermal Control Technology Roadmap - 2005

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California Institute of Technology, Pasadena, California

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Presented at
2005 Thermal Control Workshop
The Aerospace Corporation, El Segundo, California

JPL Advanced Thermal Technology Team

- **Dave Bame** — MER & MSL Heat Rejection System
- **Pradeep Bhandari** — Pumped Fluid Loops, Long-Life Pumps
- **Gaj Birur** — Advanced Thermal Control Technologies
- **Gani Ganapathi** — MER Heat Rejection System
- **Ram Manvi** — Venus Thermal Control Technologies
- **Keith Novak** — MER Loop Heat Pipe and Heat Switch
- **Tony Paris** — High Temp. Fluid Loops; Micro-cooling tech.
- **Mike Pauken** — LHP; Venus/Titan Thermal Technologies
- **Mauro Prina** — High Temperature Pumped loops
- **Jose Rodriguez** — TES Loop Heat Pipe
- **Eric Sunada** — MER Heat Switch; Thermal Stability Techs.
- **Glenn Tsuyuki** — MER Pumped Loop; Mars Lightweight Insulation

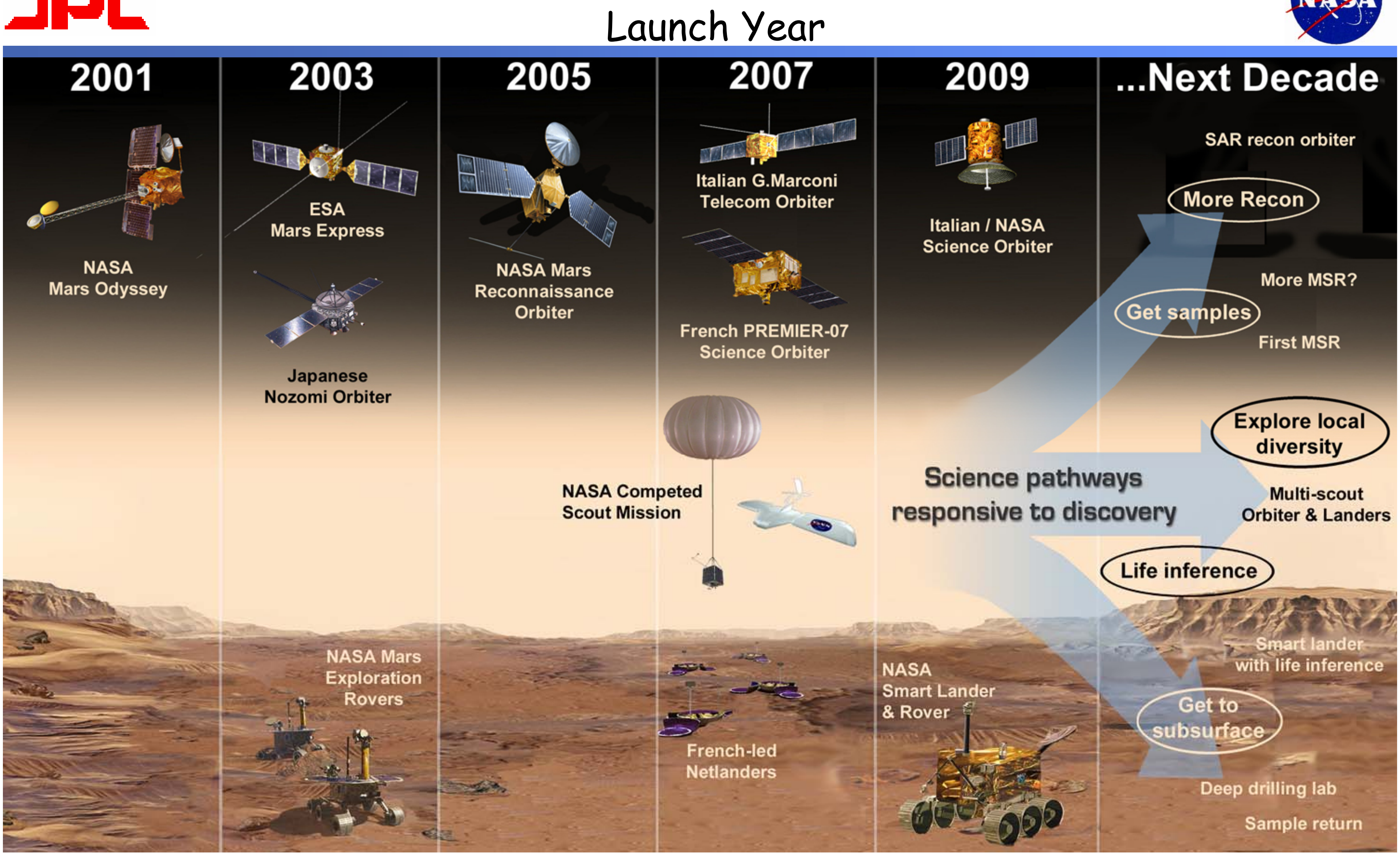
OUTLINE

- Future NASA/JPL Missions
- JPL Thermal Control Technology Roadmap
- Specific Technologies Under Development
- Conclusions

Future Space Science Missions at JPL

- **Thermal control requirements of many of the future NASA space science missions are expected to be very demanding**
- **Mars missions -**
  - MRO(2005), Phoenix (2007)
  - Mars Science Laboratory (2009), Mars Sample Return (2013)
- **Deep Space Science Missions** (Missions to other Planets)
  - Jupiter Icy Moon Orbiter, Europa Orbiter/Lander,
  - Venus Surface Sample Mission, Jupiter Multiprobe,
  - Titan In-Situ Mission, Saturn Ring Observer, Neptune Orbiter
- **Other Space Missions -**
  - Earth orbiting spacecraft/science payload, space telescopes, space interferometer missions, and science instruments
  - Microspacecraft missions, Inflatable/deployable spacecraft

Mars Exploration Program (2001)



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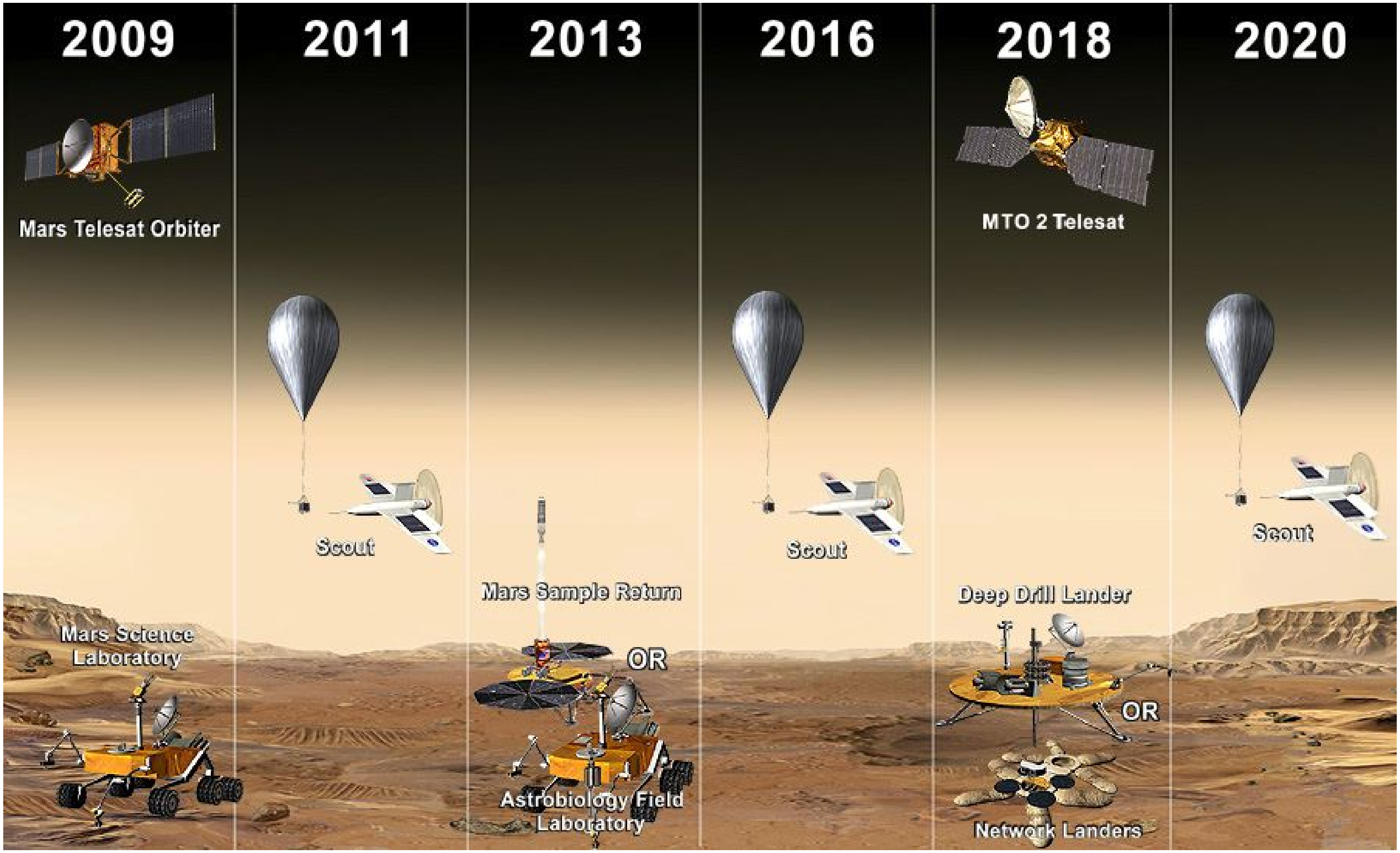
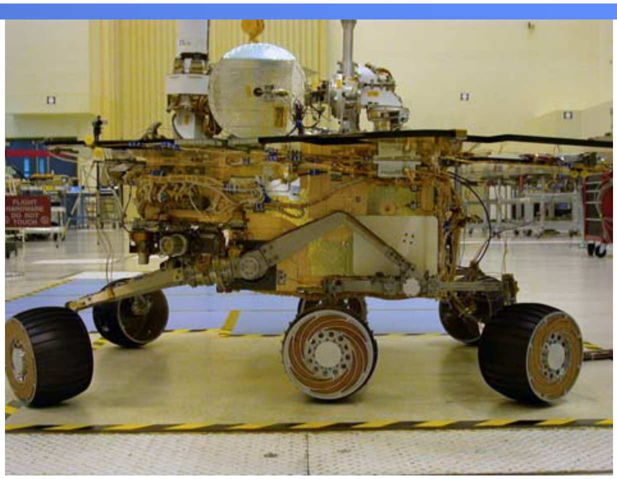
Mars Exploration Program (2004)

Launch Year

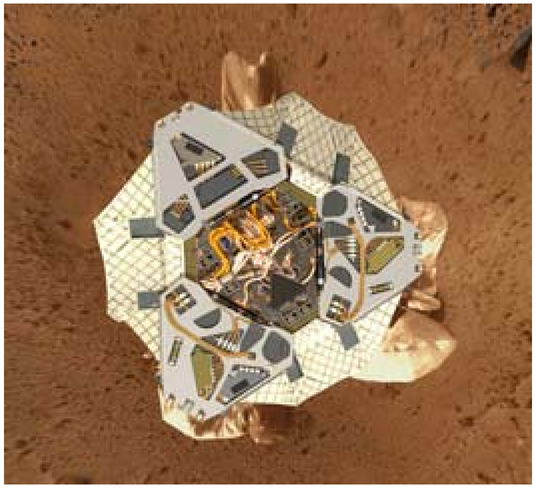


Mars Exploration Rovers (2003)

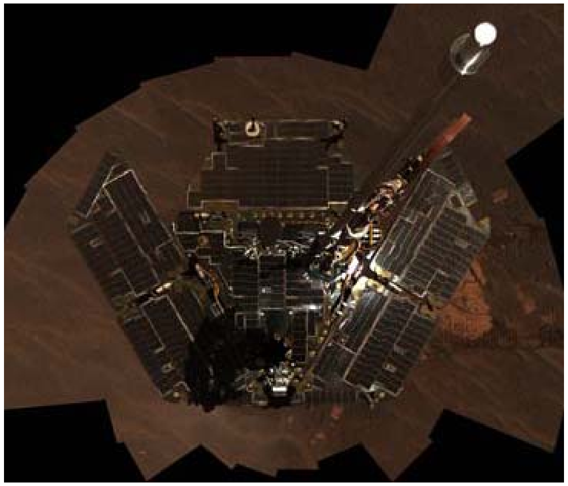
- 90-sol science missions
- Equatorial landing sites
- Deep temp. swings (- 90 to 10 C)



MER Rover (2003)



Lander after the Egress of
Spirit Rover at Gusev Crater (sol 19)

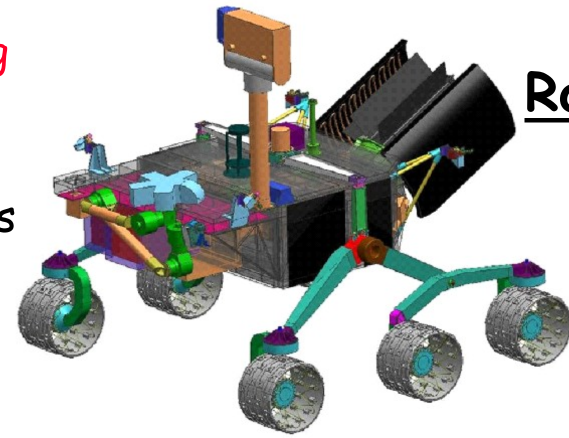


Opportunity Rover self portrait
(Sol 322)

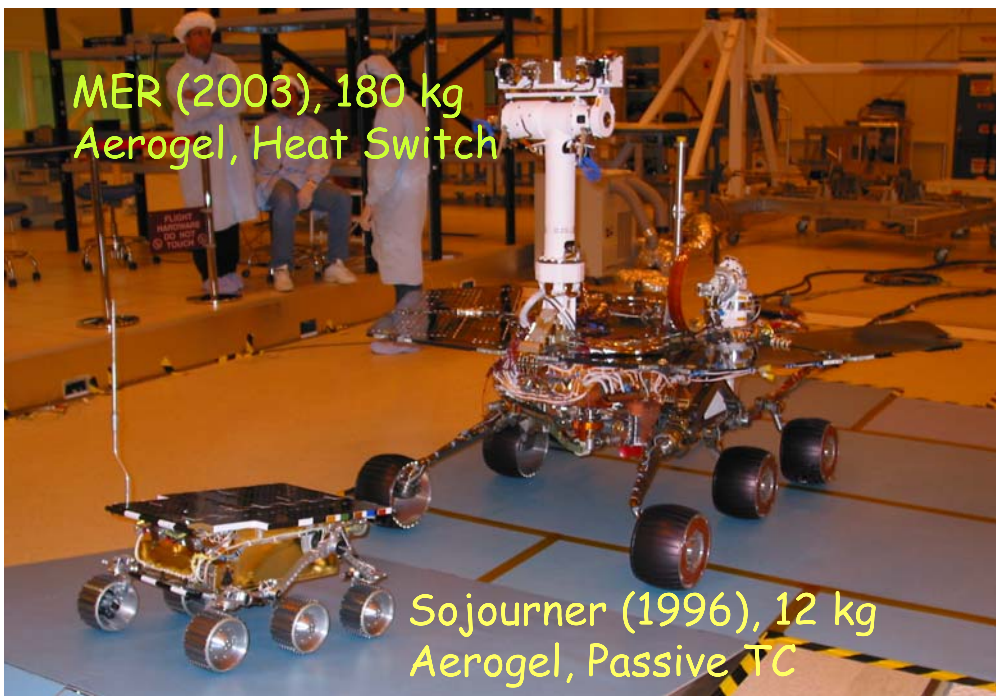
Mars Rovers – Past, Present, and Future

MSL (2009), ~ 500 kg
Pumped Fluid Loops

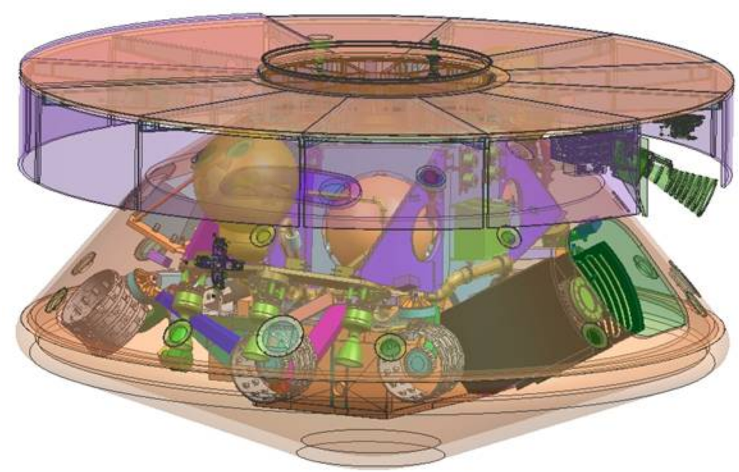
Issues:
- Large Thermal Loads
- Lang Life



Rover

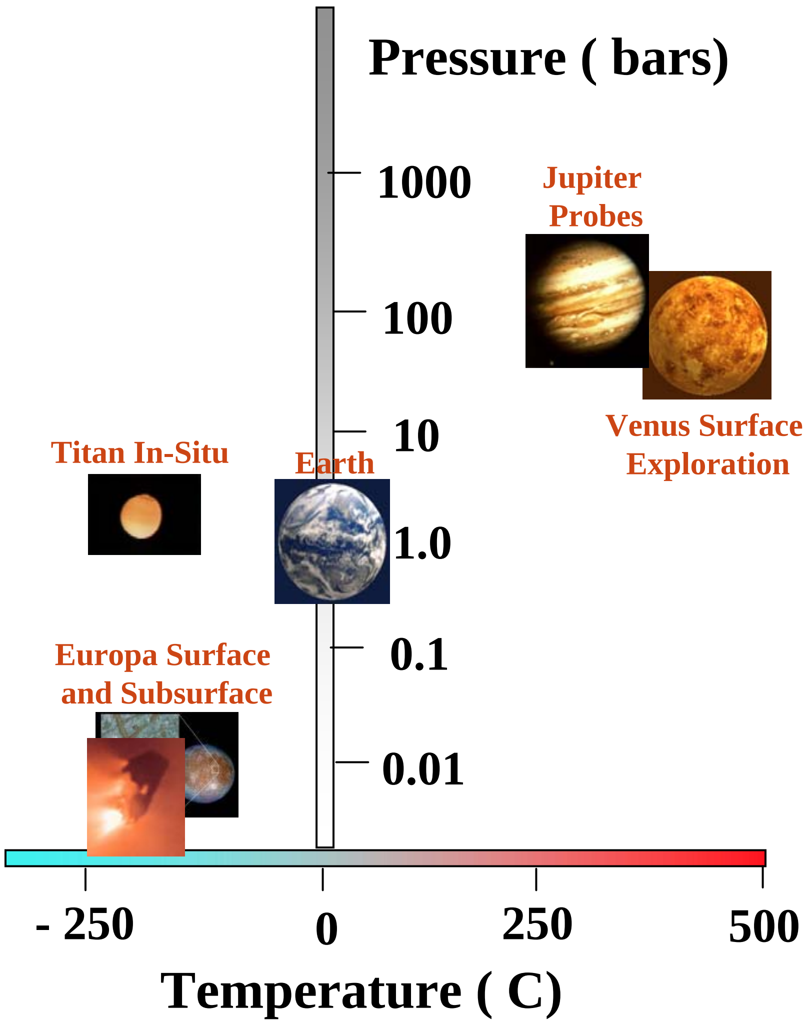


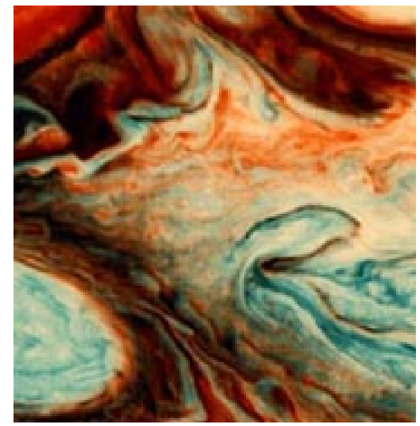
Spacecraft

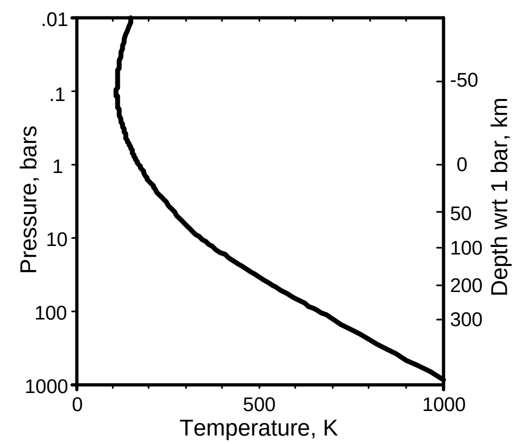


Pre-decisional DRAFT- for Planning & Discussion Purposes Only

Planetary Extreme Environment







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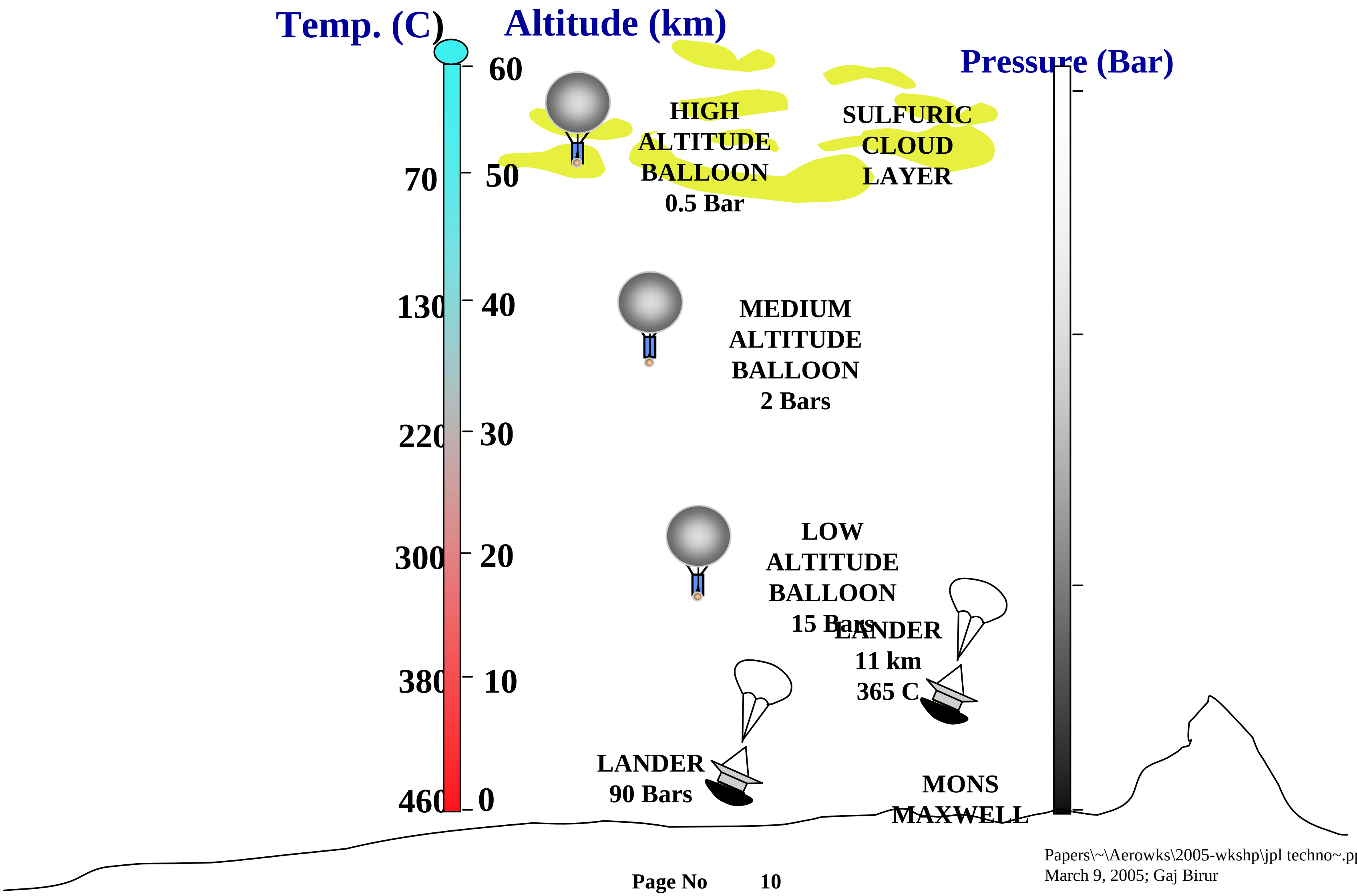
Venusian Environment

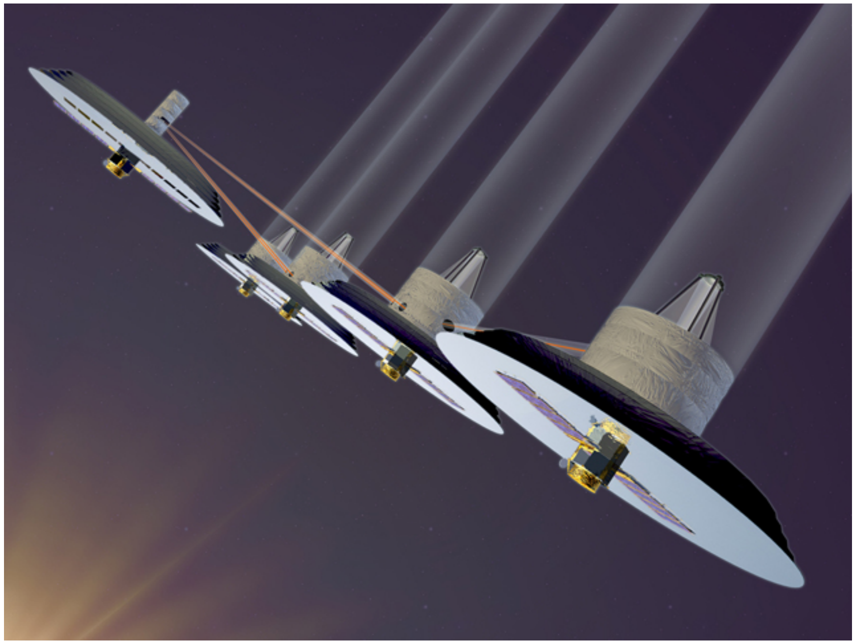


Titan In-Situ and Comet Environment

Thermal technologies needed to protect the science and engineering equipment to survive and operate in Titan/Comets low temperature (- 180 to - 140 C) environment:

Space Interferometer Missions

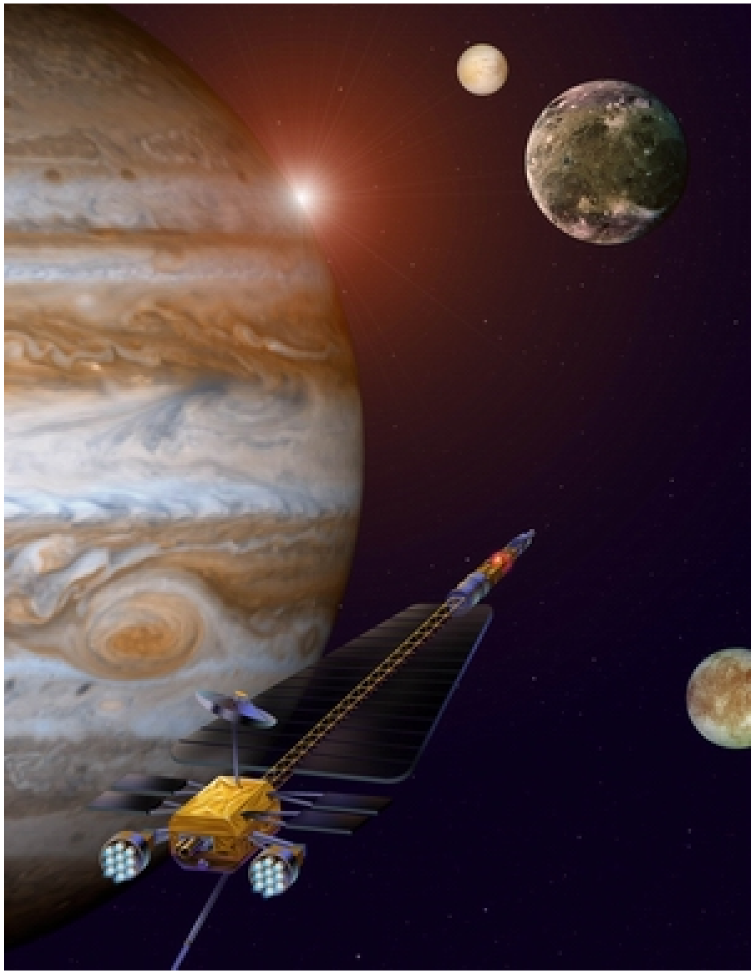
- Space Interferometer Missions, Terrestrial Planet Finder, and future space telescope missions need picometer accuracy and 100 micro-Kelvin temperature stability

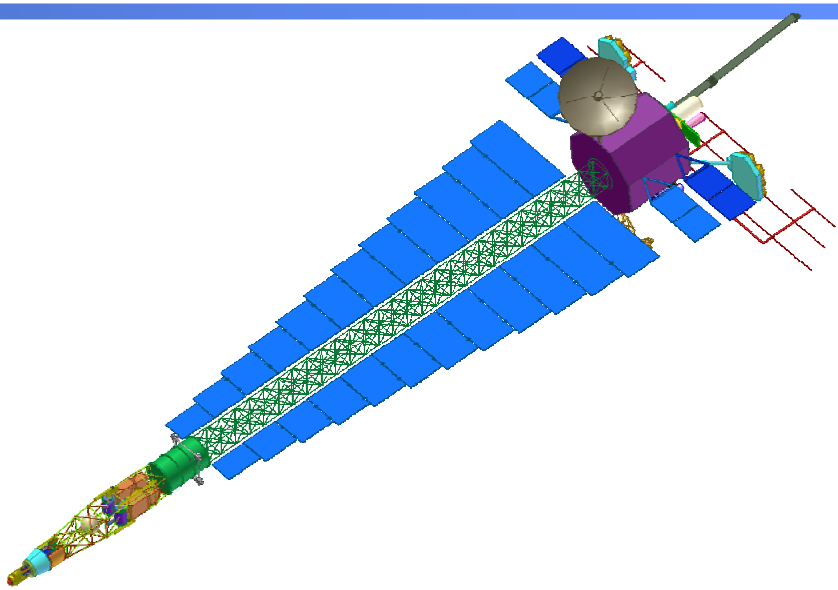


Infrared Interferometer based on formation flying telescopes

Space Interferometer Mission based on single large aperture

Jupiter Icy Moon Orbiter (JIMO)



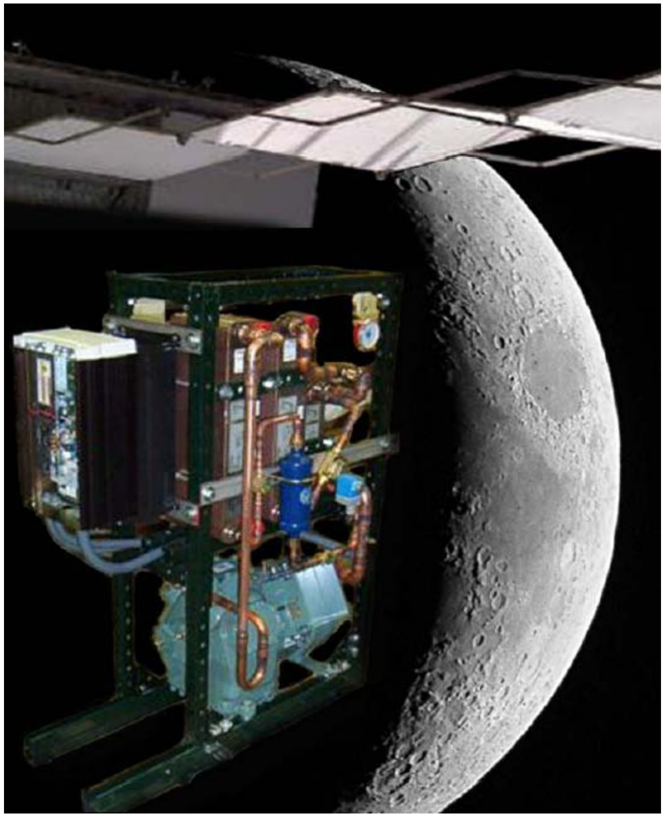


THERMAL CONTROL CHALLENGES

- Large thermal and electric power management (~100 kWe, 0.5 to 2 MWt)
- High heat flux thermal control
- High temperature heat transfer and rejection issues

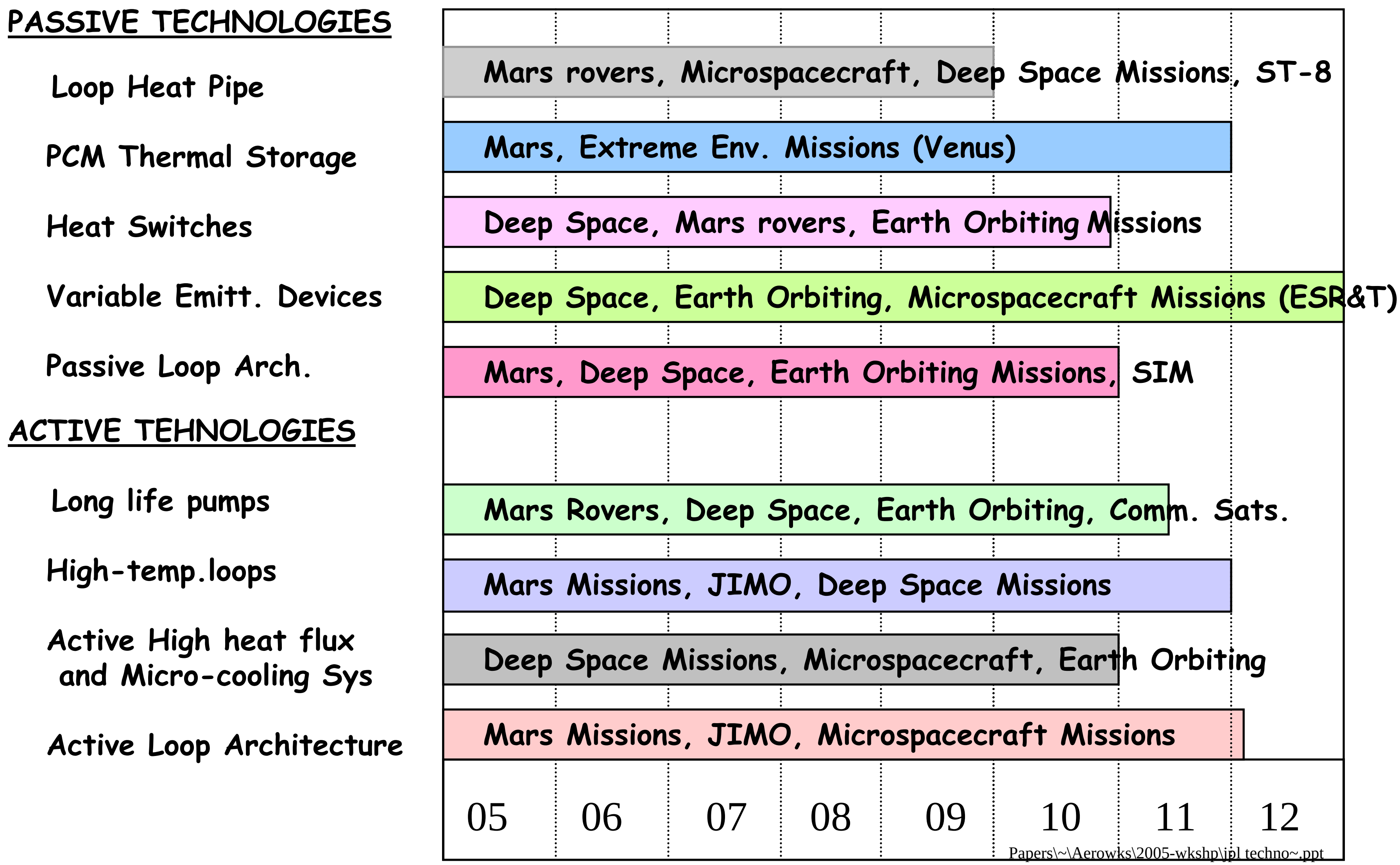
Pre-decisional DRAFT- for Planning and Discussion Purpose Only

NASA ESMD – Moon, Mars and beyond

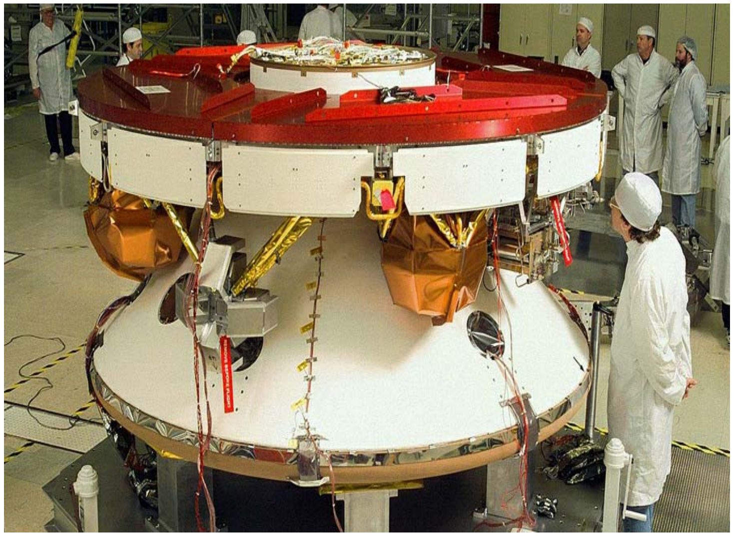


- **HRS for Lunar Mission**
  (David Westheimer, PI, NASA/JSC)
  - **Vapor Compression Heat pump**
  - **Lightweight Radiator (JPL)**
  - **Multi-environment Evaporative Heat Sink**
- **Microspacecraft Inspector**
  (Dr. Juergen Mueller, PI, JPL)
  - **Variable emittance radiator (JPL)**

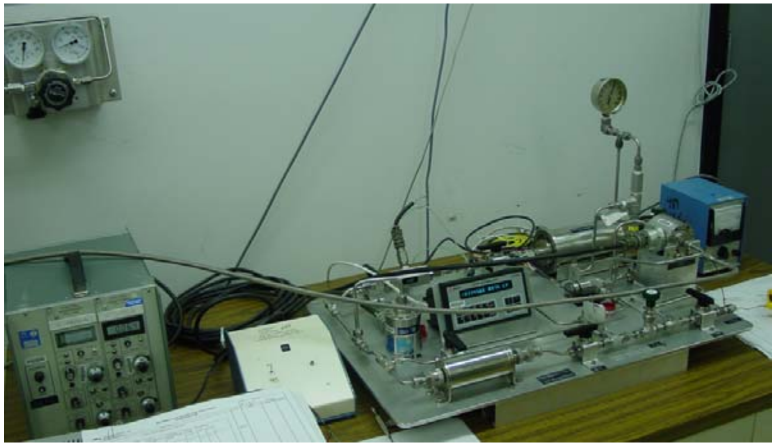
JPL Thermal Control Technology Roadmap



Mechanically Pumped Cooling Loops



Mars Pathfinder MPL HRS (1996)



MER Pump Life Test (2003)

Description

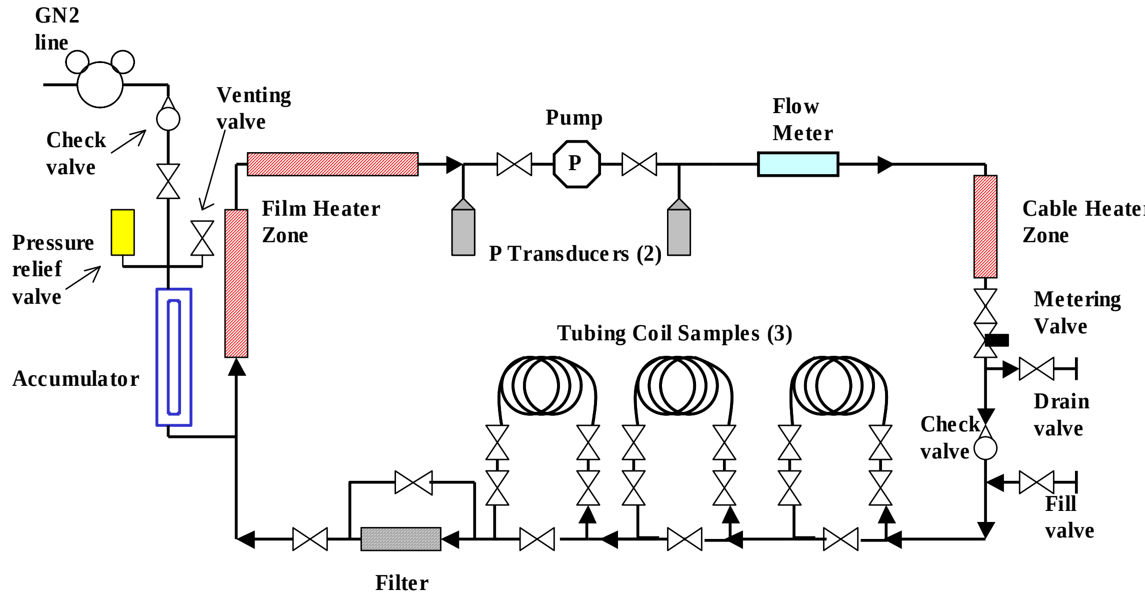
- Mechanically pumped single-phase cooling loop used on Mars Pathfinder (1996) and MER (2003) for thermal control
- A pump assembly of 7 kg uses CFC-11 to remove ~160 W from spacecraft electronics to an external radiator
- A high temperature (~100 C) pump test loop is used for life testing pumps for high heat rejection capacity (>3 KW_t)

Participants & Facilities

- JPL is investigating this technology for future Mars and deep space missions
- Engineering pump units (Pacific Design Technology, Goleta, CA) are under life test at JPL

High Temperature Pump Testbed

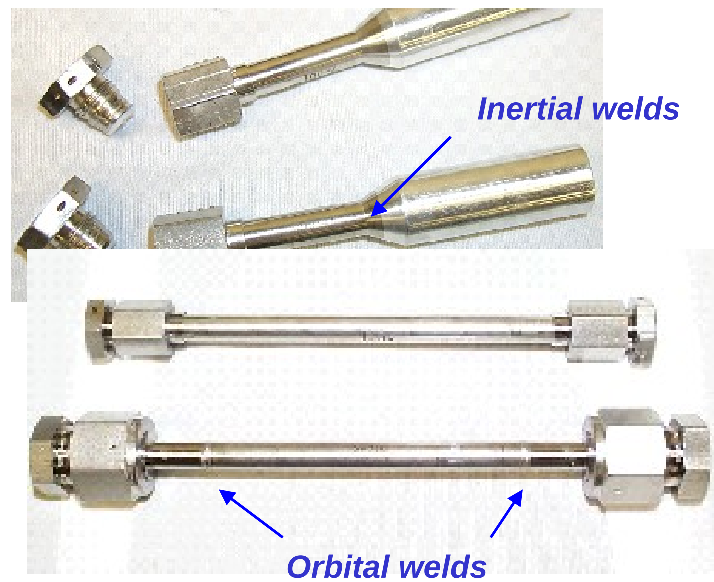
- Designed to maintain pump and fluid at 120 C with a system pressure ~ 150 psia (1 MPa)
- Successfully operated for 2900 hrs at 120 C with water
- Currently being tested with CFC-11 at 100 C



Pacific Design Technologies, Inc.
(Goleta, CA)

Designed for water service at 130°C
Flow rate of 1.5 lpm with 140 kPa (20 psid)

Material Compatibility Tests (Water & CFC-11)



WATER

- Stainless steel and Aluminum tubing samples are filled with Nanopure water and baked 150 C
- Material compatibility testing at 150 C showed that the nano-pure water reacts with aluminum and is incompatible
- Corrosion inhibiters and additives are needed for long-term use of water at 150 C in Al

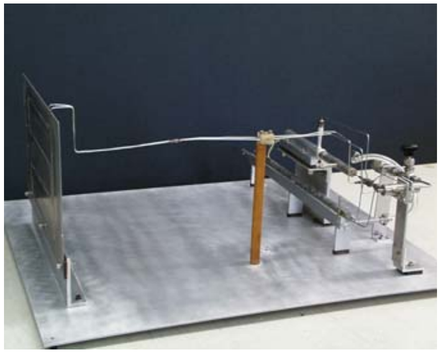
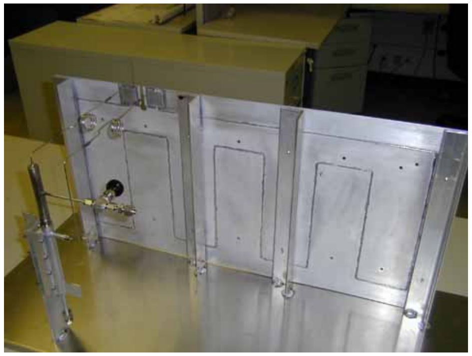
CFC-11

- Stainless steel, Aluminum, and SS/Al welded tubing samples are filled with CFC-11 and baked in a 100 C oven
- The high temperature loop (with ss and aluminum tubing) will be run with an engineering pump and CFC-11 at 100 C

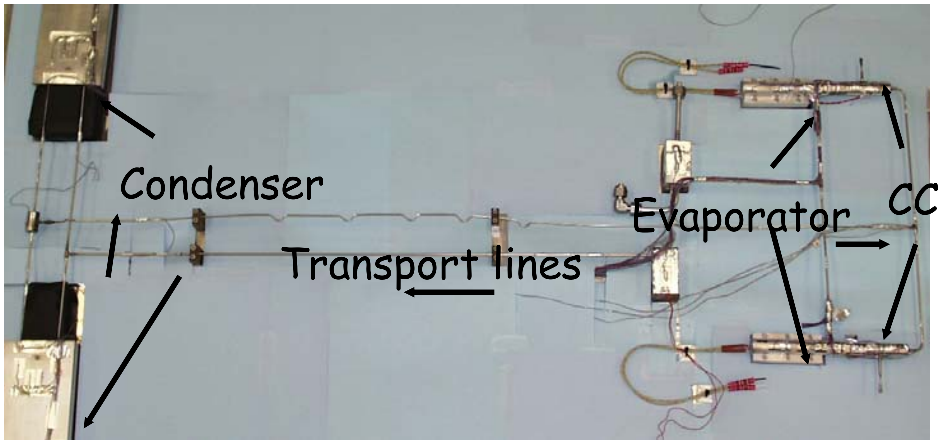
MSL Long-Life Testbed

Testbed for life testing MSL mechanically pumped loop technologies

Loop Heat Pipe Technology
(Small Size/Capacity LHPs)

Small LHP for Mars Thermal Control



Dual Evaporator Small LHP

Description:

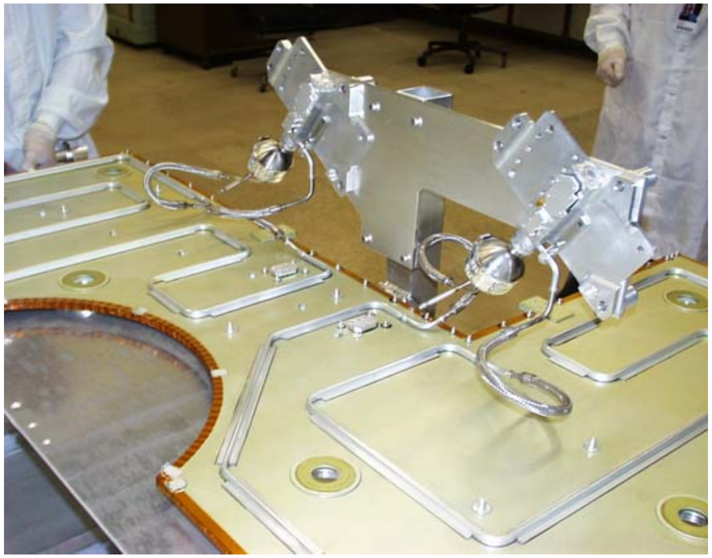
- A versatile thermal control device: transfers heat, controls temps., and act as a heat switch (all in one)
- Light weight (< 250 gms to transfer 100 W) device compared to other the hardware of same function
- Enormous flexibility in locating heat sources and sinks on the spacecraft

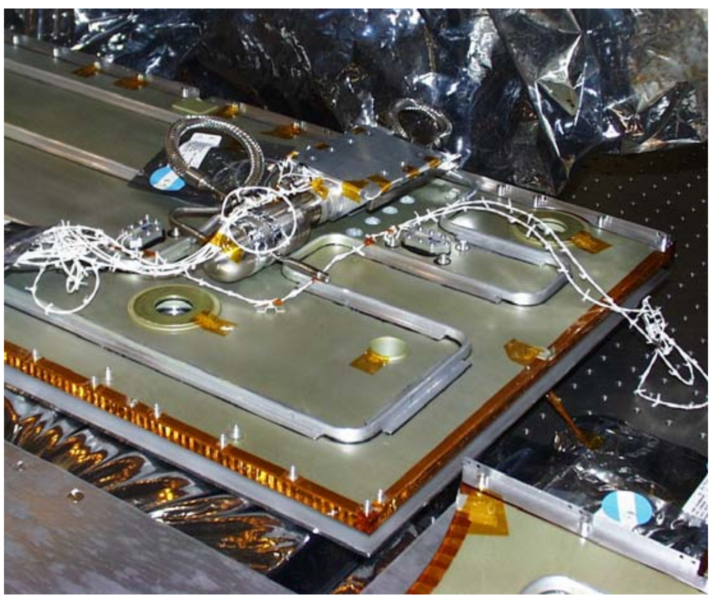
Participants & Facilities:

- JPL is investigating this technology for ST-8, Mars rover & μS/C applications
- Tests performed at JPL and Goddard during FY00-02 for evaluating miniature multiple evaporator LHP
- Currently a small multiple evaporator LHP technology being investigated for ST-8 with NASA GSFC (Jentung Ku, PI)

EOS-TES Loop Heat Pipes

(Full Size/Capacity LHPs)

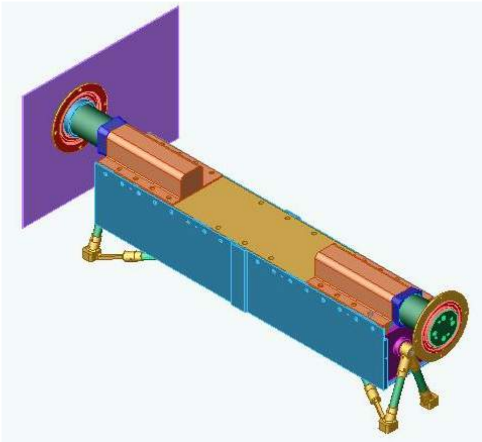




- EOS-TES is using five LHPs in its thermal design (Jose Rodriguez)
- Propylene LHPs in the 75 to 150 W range
- TES is currently operating on EOS spacecraft with all the all the LHP functioning satisfactorily

Heat Switch for Space & Mars Surface Applications

MER
Wax Actuated
Heat Switch
(Starsys,
Boulder, CO)



Description

- Wax actuated heat switch for Mars with target performance of 0.4 W/C, switch ratio of 30 in 8 torr CO_2, weighing less than 120 gms. Currently functioning well on the two MER rovers

Participants & Facilities

- Wax actuated heat switch for MER was developed by Starsys. in Boulder, CO
- The heat switches have been operating satisfactorily for over 300 sols on Mars on two rovers

Advanced pumps & cold plates for two-phase cooling loops (NASA SBIR Phase I Project)

DESCRIPTION:

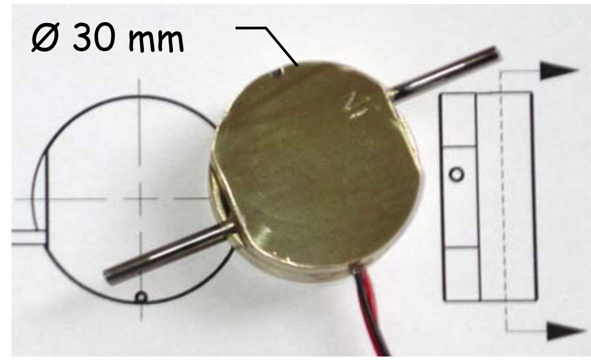
- Compact, lightweight reliable two-phase pumped loop
- Compact hermetic pump design using direct electromagnetic drive of the impeller
- Positive displacement pump tolerates 2-phase flow at inlet
- Advanced offset strip fin design for cold plate
- Suitable for high heat fluxes or long distances between heat source and radiator
- Useful for distributed sources and sinks on a single loop
- Suitable for loads from <10 W to > 2kW

Participants & Facilities
PI: Dr. Jerry Martin
Mesoscopic Devices, LLC, Broomfield, CO

- Joe Marsala, Thermal Form & Function, LLC, MA

Project Duration: Jan. 2005 to July 2005

NASA Technical Monitor: Eric Sunada, JPL



Hermetic pump prototype

- **SCHEDULE and MILESTONES**
- Phase I goal: Demonstrate ~500 W pumped cooling loop (July 2005)

Applications:

- High density micro/nano-spacecraft electronics. High power electronics – JIMO. Laser Diode Arrays for Earth Science Missions
- Rack-mount server computers, power electronics, microwave systems, phased array radar

Varible Emittance Devices (Electrochromics)

(NASA SBIR Phase II Project)

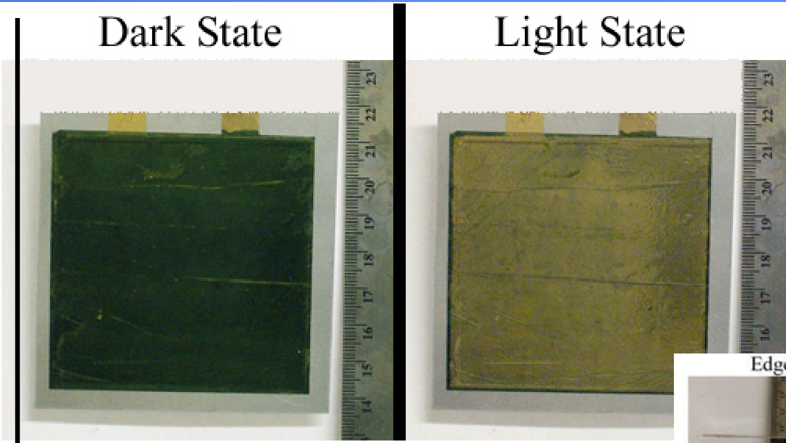
- **DESCRIPTION:**
- Variable Emittance panels based on Conducting Polymers, Ionic Els.. Phase II development of a Phase I SBIR project.
- Flexible, very thin, very durable, very lightweight (20 mg/cm^2), very low power (about 50 μW/ cm^2), unsealed unit in vacuum (> 6 months demonstrated).
- Emittance variation > 0.4, range 0.15 to 0.89. Low α_s
- Modular electronic controller for automated "dialing" of desired Emittance; Antioxidants or vacuum package for long shelf life in air

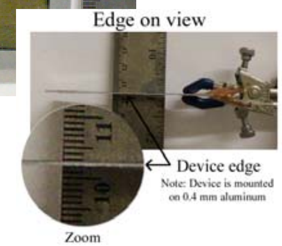
Participants & Facilities

PI: Dr. P. Chandrasekhar
Ashwin-Ushas Corp, Inc., Lakewood, NJ
www.ashwin-ushas.com

- Georgia Tech Research Institute (Controller - Andre Lovas)
- AFRL (independent thermal vac testing - Charlotte Gerhart)

NASA COTR: Dr Gaj Birur, JPL





SCHEDULE and MILESTONES

- Year 1 – Completion of major space durability testing, refinement of Solar-Absorptance-lowering coating and refinement of air stability.
- Year 2 – Completion of all remaining space durability testing. Fabricate optimized prototype devices and non-rad-hard Intelligent Controller.

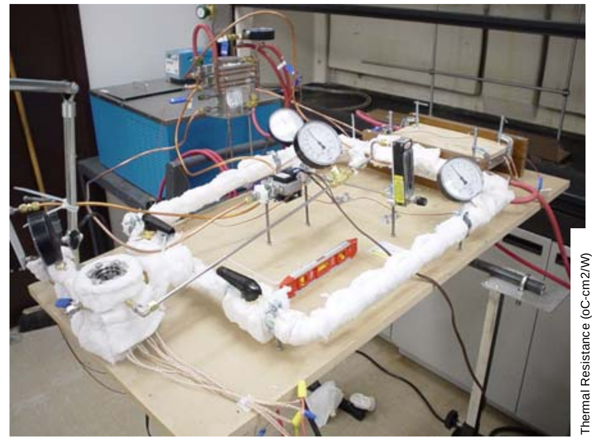
Applications

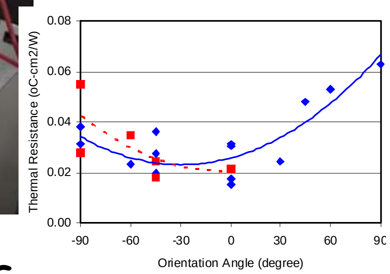
- Substitute for Mechanical louvers, variable conductance heat pipes, heat switches for LEO, GEO, inter-planetary, intra-planetary missions.
- Dual use: Military (battlefield) IR camouflage.

Hybrid Cooling Loop Technology

(NASA SBIR Phase II Project)

- **DESCRIPTION:**
- Combining robust liquid supply of mechanically pumps with passive flow control of capillary structures
- High heat flux removal: 350 W/cm^2 demonstrated in Phase I
- Cooling of large area: 4cm^2 demonstrated in Phase I
- Low thermal resistance: 0.008 to 0.065°C/W/cm^2 demonstrated in Phase I
- Passive flow control: No active control is needed even at transient and asymmetric heating conditions
- Phase II to test prototypes for space applications





Participants & Facilities

PI: Dr. Jon Zuo
Advanced Cooling Technologies, Inc., Lancaster,PA *www.1-ACT.com*

•Johns Hopkins University Applied Physics Laboratory (miniature adaptive liquid nozzle development)

NASA COTR: Dr. Anthony Paris, JPL

SCHEDULE and MILESTONES

- Year 1 – Develop integral evaporator/reservoir assembly.
- Year 2 – Design, fabricate and test engineering units for spacecraft thermal control applications.

Applications

- Substitute for capillary- and mechanically pumped loops for better performance, greater reliability and more robust operation for satellites and exploration systems thermal control.
- Dual use: Military and commercial high power electronics and opto-electronics.

Self-Contained Distributed Cooling Module for High Heat Sources (NASA SBIR Phase II Project)

DESCRIPTION:

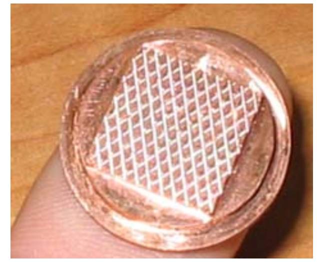
- Autonomous thermal management system with self-pumped cooling module.
- Outperforms heatpipes; Heat fluxes >100 W/cm^2
- Inherently scalable design
- Compact module with low mass & power (<1 W)
- Stackable fixed-valve micropump integrated in module
- Ceramic stereolithography manufacturing process

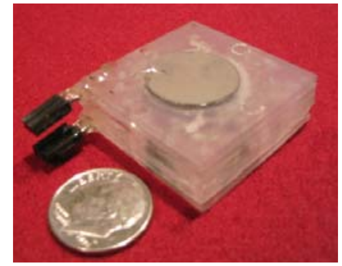
APPLICATIONS:

- Microspacecraft missions, Lasers, Radar, Lidar, Fuel cells, Avionics
- Microprocessors, Inverters, X-ray, Wide-band gap semiconductors, Hybrid electric vehicles, Power conversion

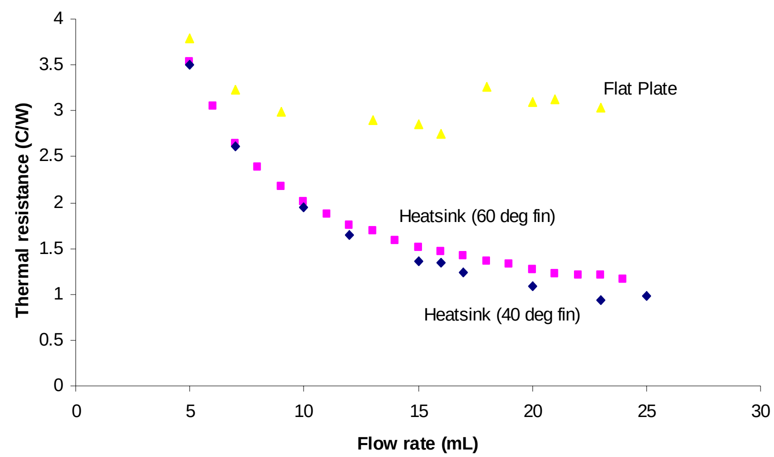
SCHEDULE and MILESTONES:

- Year 1 (Completed): Optimized heatsink and pump operation.
- Year 2: Brassboard prototype– Fully integrated system with microprocessor chip as heat source
- Project completion: December 2005





Heatsink + Pump = Chip-sized cooling module
1.0 ºC/W single phase, < 0.5 ºC/W 2-phase



PARTICIPANTS:

PI: Dr. Reza Shekarriz, MicroEnergy Technologies, Vancouver, WA

Co-I: Dr. Fred Forster, University of Washington

Co-I: Walter Zimbeck, Technology Assessment & Transfer

microET

NASA COTR: Dr Anthony Paris, JPL

3D AlN Thermal Packaging

(NASA SBIR Phase II Project)

DECSRIPTION:

- Ceramic substrate with embedded Microchannel Heat Exchanger for high heat flux electronics
- High th. conductivity Al nitride (AlN, 200 W/mK) with single phase, mechanically pumped systems
- Ceramic Stereolithography fabrication – enables monolithic microchannel substrates, automation
- CFD modeling to optimize channel geometry
- Two Application Targets:include Low heat flux (25 W/cm^2): chip cooling, compact package; High heat flux (100 W/cm^2): laser diode arrays

Participants & Facilities

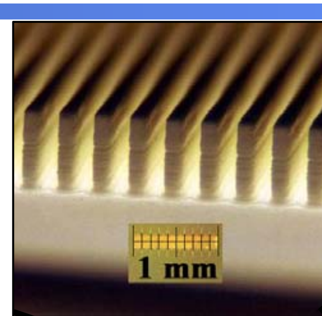
PI: Walter Zimbeck,
Technology Assessment &Transfer, Inc.
Annapolis, MD www.techassess.com

•MicroEnergy Technologies – CFD modeling (Reza Shekarriz)

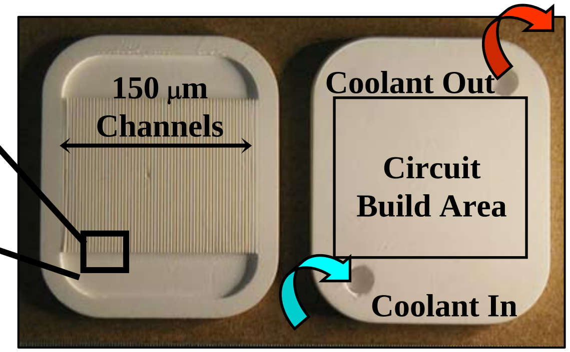
•Swales Aerospace – Laser cooling system (Dave Bugby)

Project Duration: 12/03 – 12/05

NASA COTR: Dr. Tony Paris, JPL



Ceramic Microchannel Chip Carrier



- **SCHEDULE and MILESTONES**
  - Year 1 - Design Optimization, Req. Definition
    - Modeling, prototype fab., benchscale testing
  - Year 2 – Prototype System Fabrication/Test
    - Deliver 25 W/cm^2 chip cooling system to JPL
    - Demonstrate Laser Diode Array cooling system

- **Applications**
  - High density micro/nano-spacecraft electronics. High power electronics – JIMO. Laser Diode Arrays for Earth Science Missions
  - Desktop & Laptop PCs, Network servers, Power Electronics for Elec. Vehicles, Ind. Lasers

Conclusions

- Advanced thermal control technologies are needed to enable many of the future NASA science missions
- JPL has been developing several technologies working with industry and NASA centers
- Several advanced technologies have been infused into flights in the last 10 years; more are expected in the next 10 years

Phase Change Material (PCM) Thermal Storage Technology

Dodecane PCM Thermal Storage Unit
(Melting point, -10.5 C)

Hexadecane PCM Thermal Storage
(Melting Point temperature 18 C)

Description

- Phase change material (PCM) utilizes latent heat to protect equipment against temperature extremes by increasing thermal capacity
- It stores excess heat when available and releases when needed. Simple and reliable technology
- Applications in Mars and extreme environment missions

Current Status

- A dodecane (MP –10.5 C) PCM capsule (ESLI, San Diego) was integrated with miniature LHP and tested for Mars rover battery thermal control
- A Hexadecane (MP, 18 C) PCM from ESLI is being evaluated for Mars rover battery thermal control at JPL