NASA/Goddard Thermal Technology Overview 2014

Dan Butler and Ted Swanson
NASA/GSFC

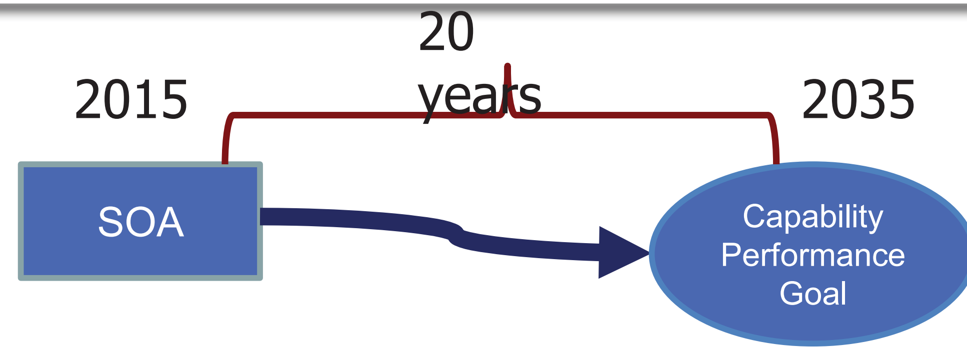
Aerospace Spacecraft Thermal Control Workshop

March 25-27, 2014

2014 A Better Year? More Stability?

- $17.65 billion in FY14 for NASA, only slightly below what President's Request. The FY13 budget was about $16.9B, so FY14 is a real improvement.
  - includes funding for the agency's major space and science initiatives, including a crewed mission to Mars by the 2030s and full support for JWST.
  - This back-off from automatic sequestration spending cuts is important as NASA must budget for the long term and needs consistent funding sources
- The spending bill would give NASA:
  - $3.1 billion for manned missions, including $1.2 billion for the Orion multi-purpose crew vehicle that will eventually carry astronauts to Mars and $1.9 billion for the Space Launch System that will rocket.
  - $696 million for commercial space activities, mainly to further development of private spacecraft to carry astronauts to the International Space Station
  - $5.2 billion for science missions, including $80 million for a mission to explore Europa, one of Jupiter's moons
  - STMD (Technology) gets $576M…FY13 was $614M, and about $626M was expected for FY14, so adjustments are needed. Major hit to Center Innovation Fund. *STMD is the primary source for technology funding*.

2010 TECHNOLOGY ROADMAPS TO BE UPDATED



- **Starting Point - State of Art (SOA)**

  End Point - Capability Performance Goal

  Time Frame - 20 Years
- **Capabilities Driven approach**
  - Capability Need Driven - Includes ONLY the Technology That Aligns with a NASA Mission Class and Design Reference Mission (DRM)
- **Content - Expanded & Updated**
  - Includes Information Technology, Radiation, Space Weather, Avionics, and Orbital Debris
  - Uses New Science Decadal Surveys and Design Reference Mission Plans for Human Missions
  - Uses Standardized Definitions, Acronyms, Symbols, Format, and Graphic Styles
- **Type of R&D Included**
  - Applied Research and Development (Basic Research now deleted – addressed elsewhere)
  - Push Technology *and* Pull Technology
  - Removes Technology That is now Developed or Has No Need
- **2014 Technology Roadmaps will define WHAT could be done** to address DRM technology needs. This will form the basis for the next Strategic Technology Investment Plan
- **NASA Internal effort** – contractor input not sought at this time.
- **Public Release** – December 2014 planned

TA ROADMAP SCOPE TO BE EXPANDED

Technology Roadmap Update

<u>Will Consider</u>:
- Updates in Science Decadal Surveys
- Human Exploration Capability Work
- Advancements In Technology

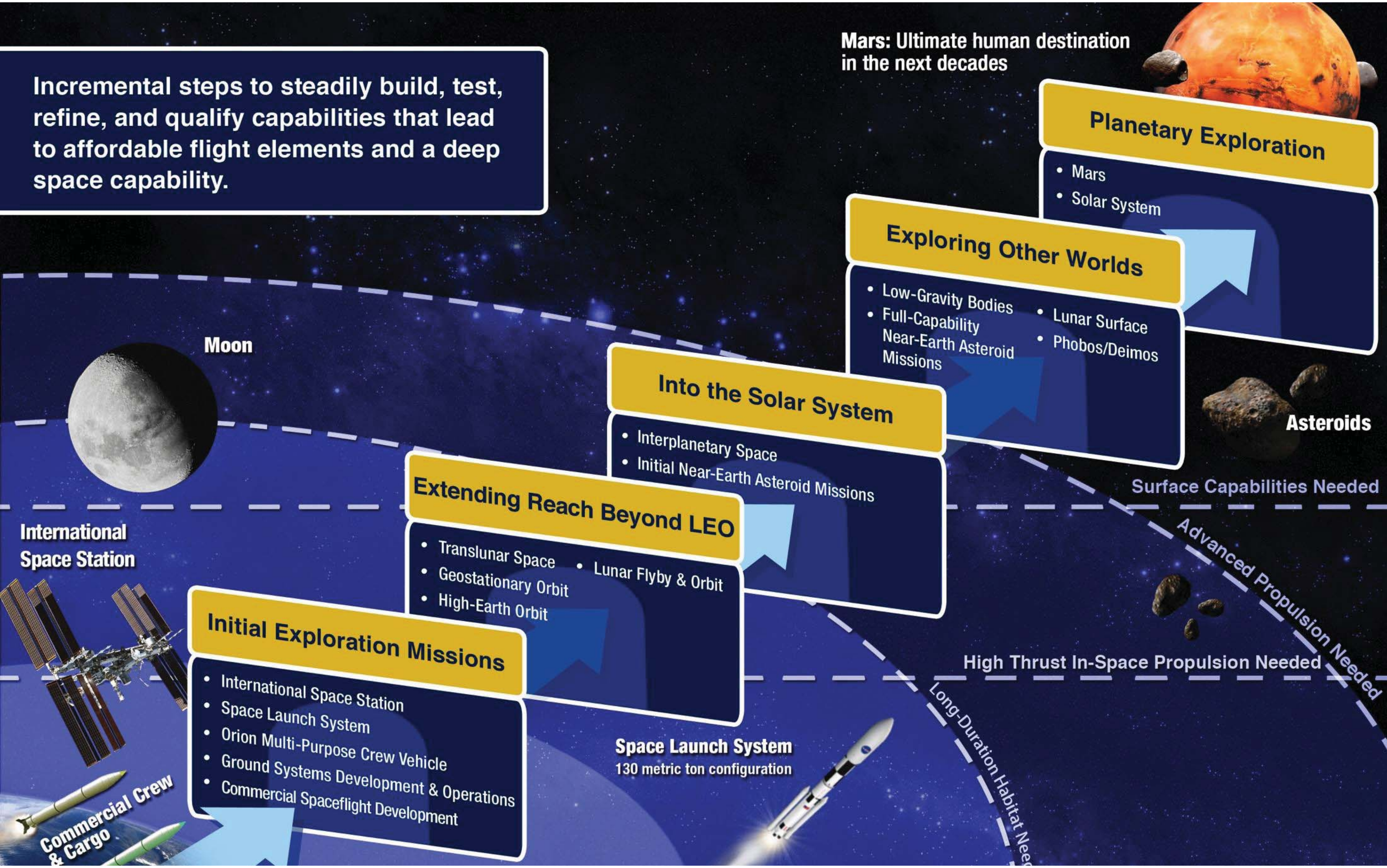
<u>Will Include</u>:
- State-of-Art
- Technology Challenges
- Capability Needs
- Performance Goals

<u>Expanded Scope</u>
- ✓ Aeronautics Technology
- ✓ Information Technology
- ✓ Radiation
- ✓ Space Weather
- ✓ Avionics
- ✓ Orbital Debris

Strategic Technology Investment Plan Update

<u>Will Consider</u>:
- ➢ New Priorities
- ➢ Current Investments
- ➢ Unmet Needs
- ➢ Partnerships & More

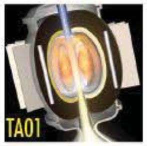
CAPABILITY DRIVEN FRAMEWORK ADOPTED



ADDITIONAL GUIDELINES

- HEOMD (Operations) and SMD (Science) will provide Design Reference Missions (DRM) – prime mission set and likely mission set for the 2020's - for the 10-20 year time frame
- DRMs to be top level. Will help guide identification of needed future technologies.
- Review by NRC not currently planned, but their comments from first Roadmaps will be considered.
- Significant Center-level involvement is included
- Roadmaps to address all NASA Mission Directorates

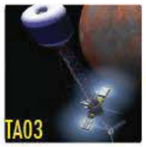
NASA Space Technology Roadmap (STR); the 15 Technology Areas (TAs) identified by OCT

TA01


- LAUNCH PROPULSION SYSTEMS

TA02


- IN-SPACE PROPULSION TECHNOLOGIES

TA03


- SPACE POWER & ENERGY STORAGE

TA04


- ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

TA05


- COMMUNICATION & NAVIGATION

TA06


- HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

TA07

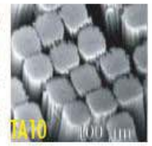

- HUMAN EXPLORATION DESTINATION SYSTEMS

TA08


- SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

TA09


- ENTRY, DESCENT & LANDING SYSTEMS

TA10


- NANOTECHNOLOGY

TA11


- MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING

TA12


- MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

TA13


- GROUND & LAUNCH SYSTEMS PROCESSING

TA14

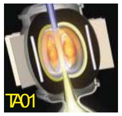

- THERMAL MANAGEMENT SYSTEMS

TA15


- AERONAUTICS (NEW)

Note: These TAs now being commonly used for categorizing STP elements

Space Technology Roadmap Technical Areas + Additional Areas

TA01 

- LAUNCH PROPULSION SYSTEMS

TA02 

- IN-SPACE PROPULSION TECHNOLOGIES

TA03 

- SPACE POWER & ENERGY STORAGE

TA04 

- ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

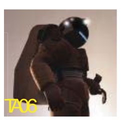
Autonomous Systems & AI Enhancements

TA05 

- COMMUNICATION & NAVIGATION

Avionics Tech Enhancements

Radiation Tech Enhancements

TA06 

- HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

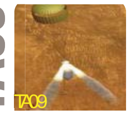
TA07 

- HUMAN EXPLORATION DESTINATION SYSTEMS

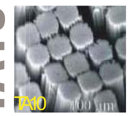
TA08 

- SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

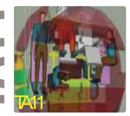
Space Weather Tech

TA09 

- ENTRY, DESCENT & LANDING SYSTEMS

TA10 

- NANOTECHNOLOGY

TA11 

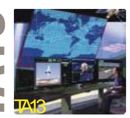
- MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING

Information Technology Section Expanded

Include NITRD and more

TA12 

- MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

TA13 

- GROUND & LAUNCH SYSTEMS PROCESSING

Orbital Debris TA5, TA7, TA10

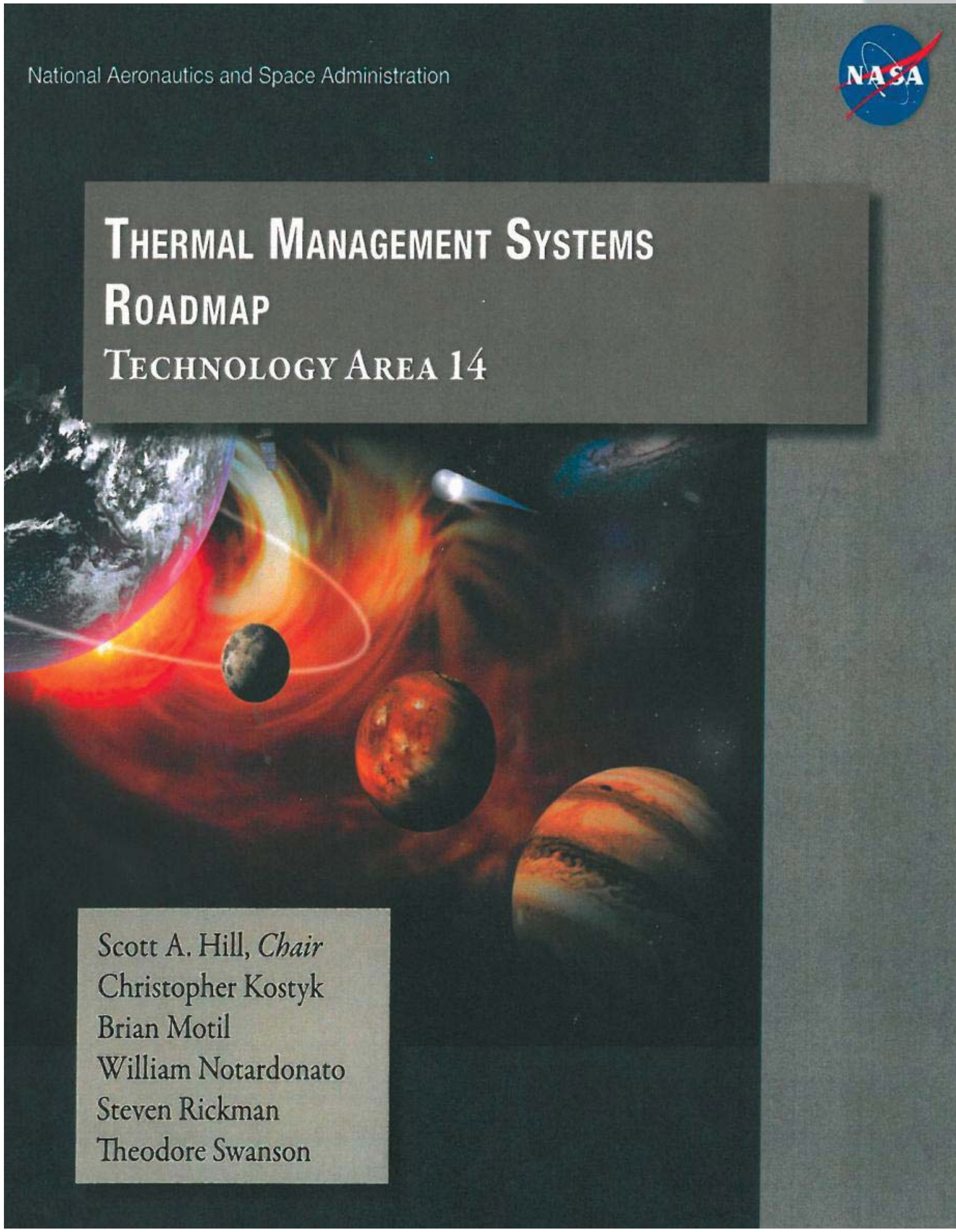
TA14 

- THERMAL MANAGEMENT SYSTEMS

TA15 
- AERONAUTICS

Additional Crosscutting document
- Crosswalks – e.g., All Technical Areas that include Information Technology (IT), Radiation, avionics, etc.
- Dependencies

TA 14 Thermal Management Systems


National Aeronautics and Space Administration

NASA

THERMAL MANAGEMENT SYSTEMS ROADMAP

TECHNOLOGY AREA 14

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Christopher Kostyk
Brian Motil
William Notardonato
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2014 Roadmap Team

* Theodore Swanson (GSFC), Chair

Walt Bruce (LaRC)

Craig Dinsmore (JSC)

* Chris Kostyk (DFRC)

Mark Lysek (JPL)

* Brian Motil (GRC)

* Steve Rickman (JSC-NESC)

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The NRC's 2012 Report on NASA's Roadmaps

Full 463 page report available at: http://www.nap.edu/catalog.php?record_id=13354

DISCLAIMER: The following slides are taken from the NRC briefing to NASA; they should not be interpreted as the Agency's position, priorities or plans.

TA14 Top Technical Challenges – NRC Perspective

Thermal Protection Systems: Develop a range of rigid ablative and inflatable/flexible/deployable thermal protection systems (TPS) for both human and robotic advanced high-velocity return missions, either novel or reconstituted legacy systems.

Zero Boil-Off Storage: Accelerate research on advanced active and passive systems to approach near-zero boil-off in long-term cryogenic storage.

Radiators: Develop improved space radiators with reduced mass.

Multifunctional Materials: Develop high-temperature multifunctional materials that combine structural strength, good insulating ability, and possibly other functions.

Verification and Validation: Develop, verify, validate, and quantify uncertainty analysis requirements for new or improved comprehensive computer codes for thermal analysis.

Repair Capability: Develop in-space thermal protection system repair capability.

Thermal Sensors: Enhance thermal sensor systems and measurement technologies.

NRC 2012 Observations on NASA's Origional Technology Roadmaps

Basically the NRC report is a strong endorsement of NASA's need to emphasize technology development

- "Success in executing future NASA space missions *will depend on advanced technology developments that should already be underway*"
- **"NASA's technology base is largely depleted"**
- *"Currently available technology is insufficient to accomplish many intended space missions* in Earth orbit and to the Moon, Mars, and beyond"
- "Future U.S. leadership in space **requires a foundation of sustained technology advances"**
- "Technologies prioritized in this study represent a foundation upon which to build the strategic goals outlined in the 2011 NASA Strategic Plan"

NRC Key Findings

- “ NASA does not and cannot set its own strategic direction. A national consensus is required
- There is no national consensus at this time
- The administration should lead in developing a consensus, working with Congress, and holding technical consultations with potential international partners
- President Obama’s proposal that an asteroid be the next destination for human spaceflight has *not* won broad support within or outside NASA, undermining the ability to establish a strategic direction.
- *There is a mismatch* between the programs Congress and the White House have directed NASA to pursue and the resources provided to accomplish them”.

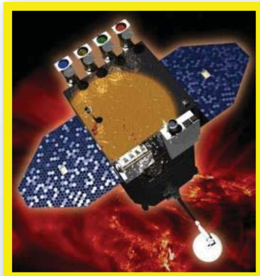
Goddard's NASA Mission

- ***Science, Exploration, and the Technology to support these Missions***
  - Goddard Space Flight Center (GSFC) and the Jet Propulsion Lab are the prime science satellite development centers for the agency, both Earth Science and Space Science
  - Technology funding gradually returning
- ***Goddard Core Focus Areas***
  - Cradle to Grave Effort on Science Satellite Projects
  - Earth and Space Science Missions
  - JWST is fully funded and top priority
  - Weather satellites for NOAA
  - Space Communication and Navigation
- ***Thermal Control applies to all areas!***

NASA GSFC Recent Launches

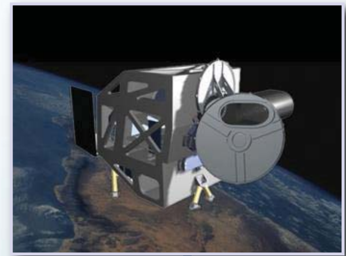
LRO 6/09

SDO 2/10



NPP 9/11

LDCM/OLI/TIRS
2/13



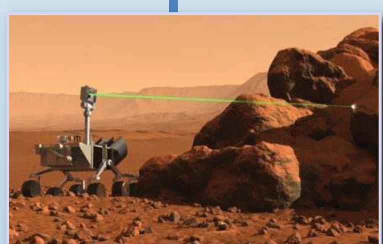
MAVEN 11/13

2009

2013

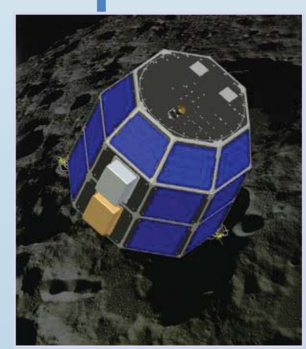
MLAS 7/09

GOES 15 3/10



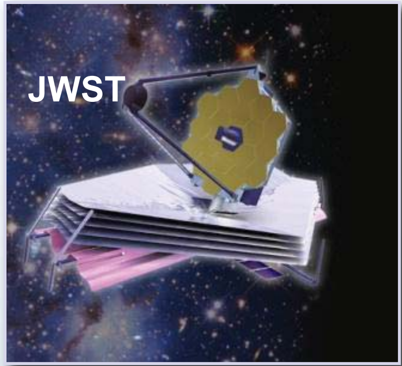
MSL/SAM 11/11

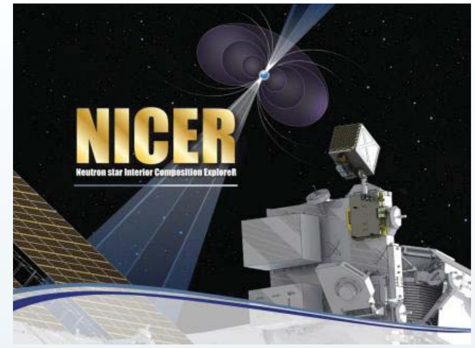
NEXT GEN TDRS 1/13
and 1/14

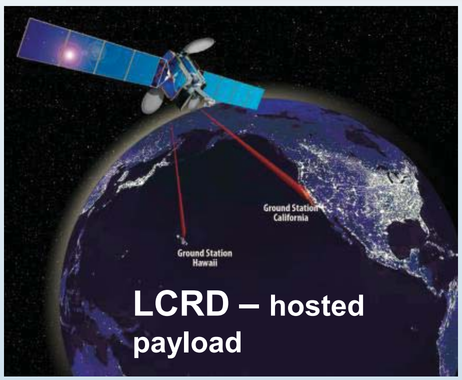


LADEE 9/13
Ames S/C with
GSFC assist

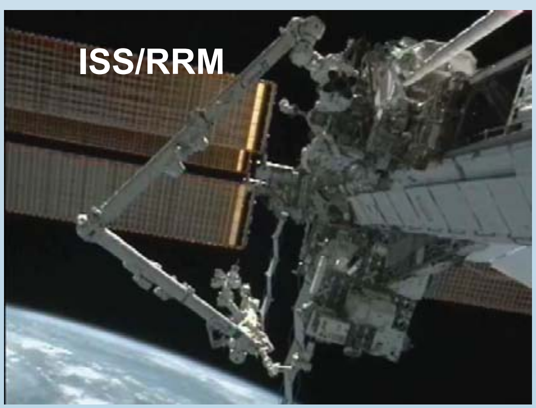
NASA GSFC Future Missions







GOES-R



JPSS

DSCOVR

Current Missions at Goddard

- Missions recently launched;
  - TDRS Next Generation Comsat, launched 1/13 and 1/14
  - LDCM – Landsat Data Continuity Mission, launched 2/13
  - LADEE – In lunar orbit, launched 9/13 from WFF, Ames mission with GSFC assist, GSFC Laser-com Demo
  - Mars Atmosphere and Volatile EvolutioN (MAVEN) to orbit Mars, launched 11/13
  - Robotic Refueling Mission (RRM) on ISS – demonstrate robotic servicing

Current Missions at Goddard

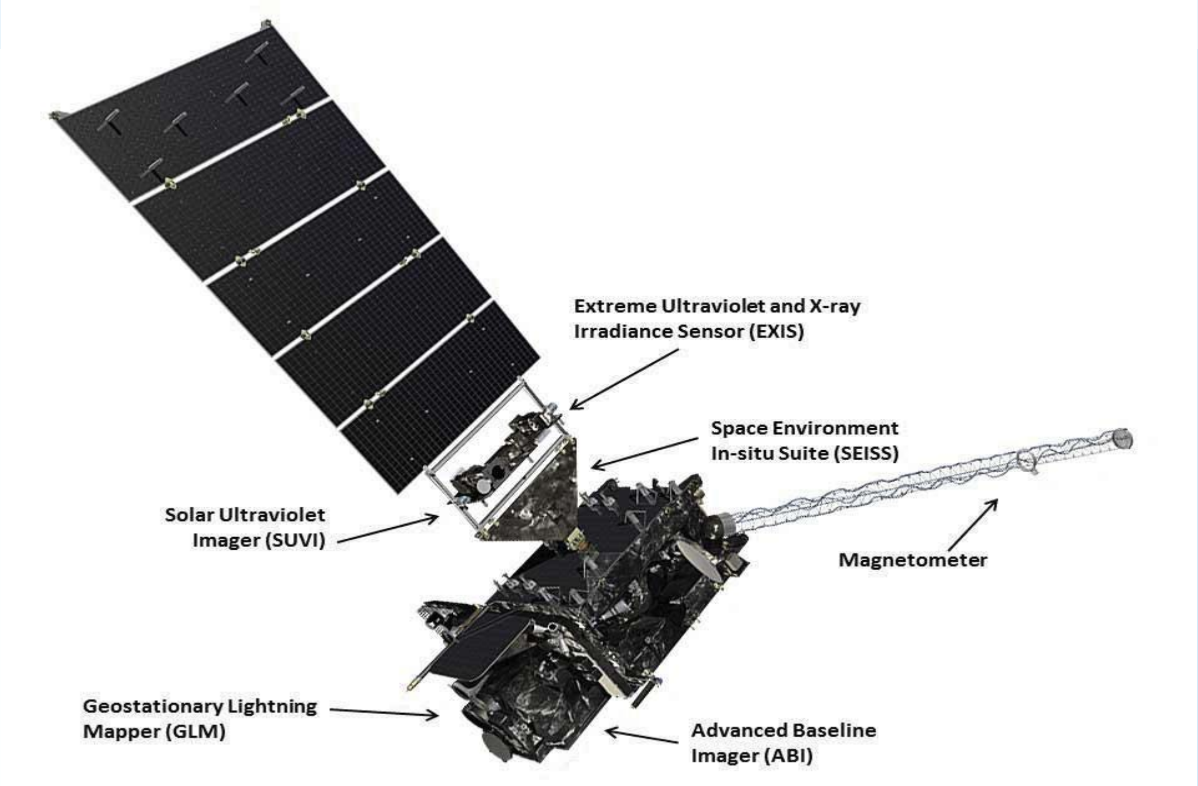
- **Missions in Work:**
  - **MMS – 4 satellites - Explore Earth's Magnetic Field, launch in 2014**
  - **ICESat-II (2015) – Uses lasers to measure polar ice sheet thickness (or lack there-of)**
  - **DSCOVR – Triana missions revived, launch in 2014, funded by NOAA/AF**
  - **TDRS – additional S/C in Integration and Test**
  - **LCRD – Laser Communication Relay Demo – to be flown on Loral/Comsat, launch in 2016**
  - **OSIRIS-REX – Asteroid sample return, OVIRS instrument at GSFC, launch in 2016**
  - **Orbital Antares ISS commercial servicing from Wallops, launch in 2013**

Current Missions at Goddard (cont.)

- **Missions in Work:**
  - **GOES-R - next generation of Geosynchronous weather satellites, launch in 2015**
  - **JPSS – Joint Polar Satellite System – NPP follow-on Weatehr Satellite**
  - **Global Precipitation Mission (GPM) to provide data for Weather forecasting, launch 2/27/14**
  - **JWST – Large Telescope Mission scheduled for launch in 2018 Very challenging thermally, testing underway, going well.**
  - **NICER – ISS X-ray Science Mission**

Thermal Challenges within Current Missions

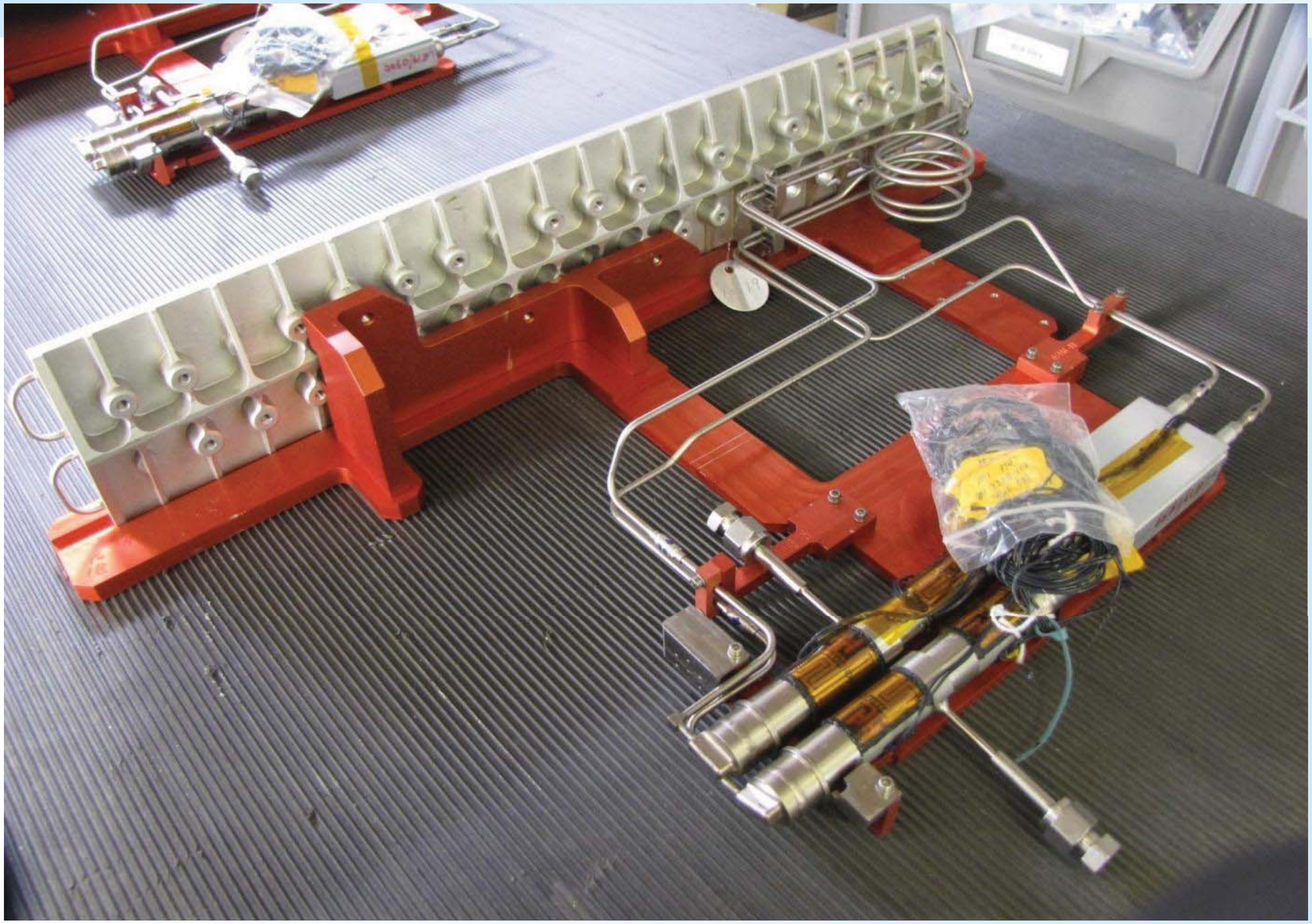
GOES-R Spacecraft



• S/C Design at Lockheed/Martin in Newtown, PA, I & T in Denver.

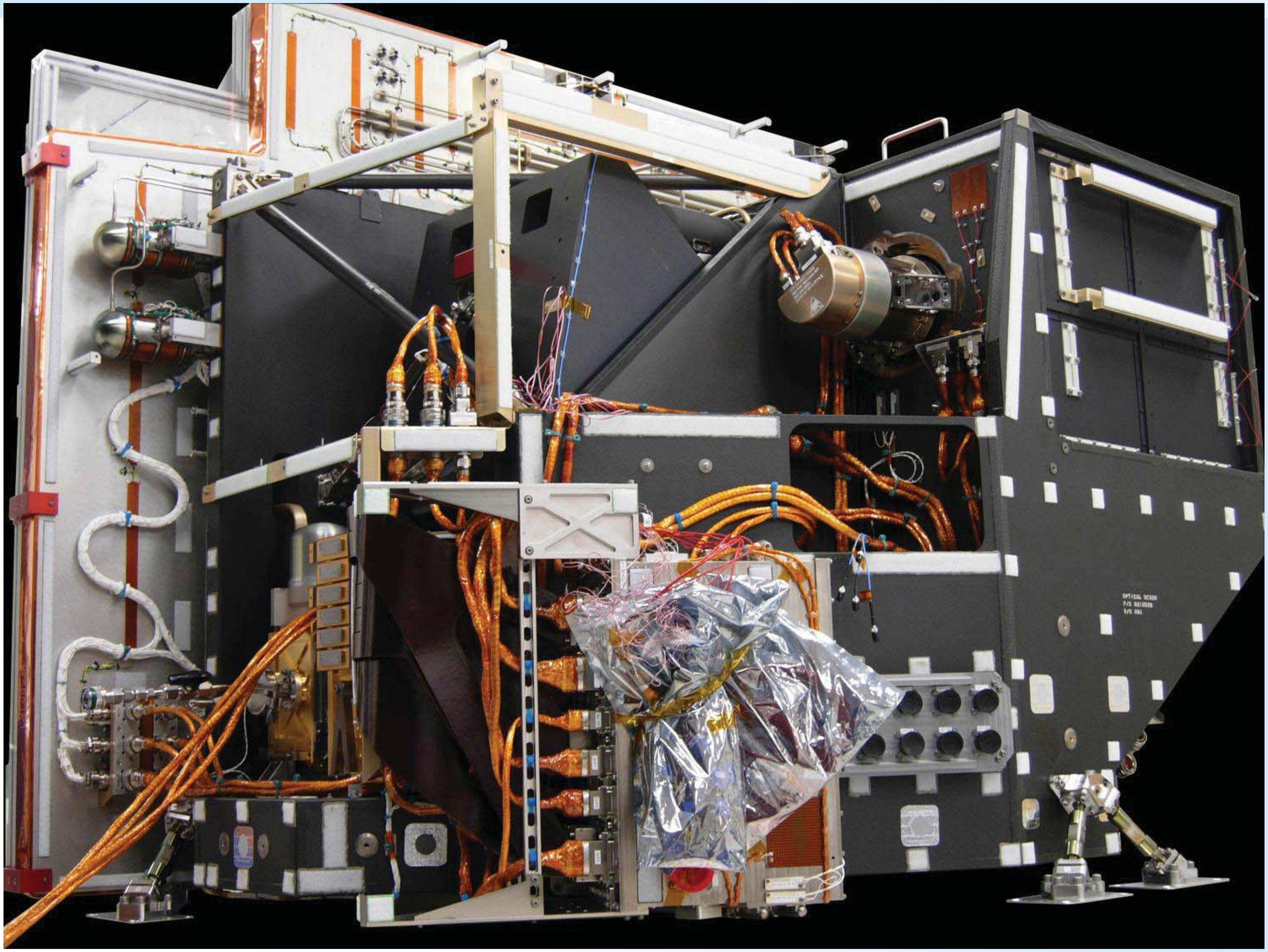
•Newtown plant closing in 2015, moving to Denver, loss of expertise

GOES-R GLM Loop Heat Pipe Flight



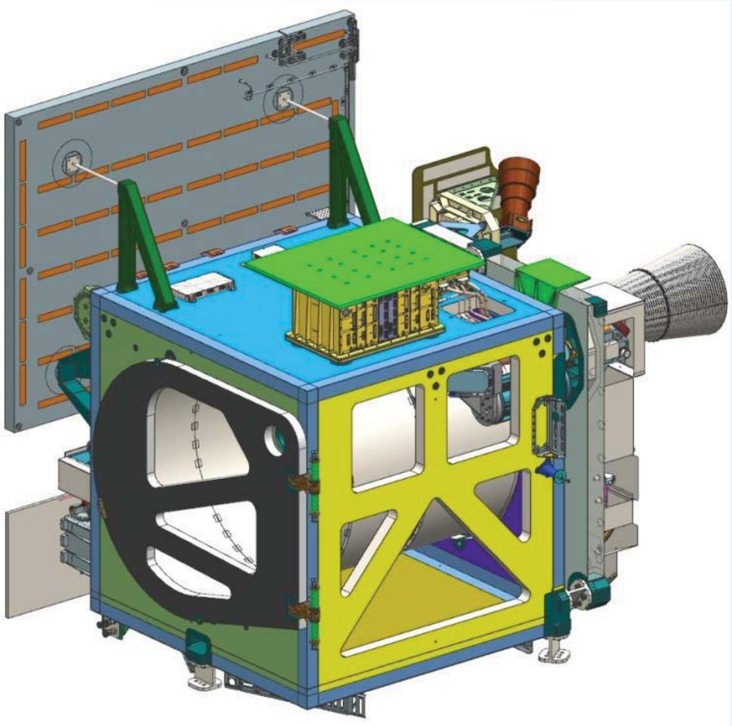
Issues being worked regarding software control of LHP’s

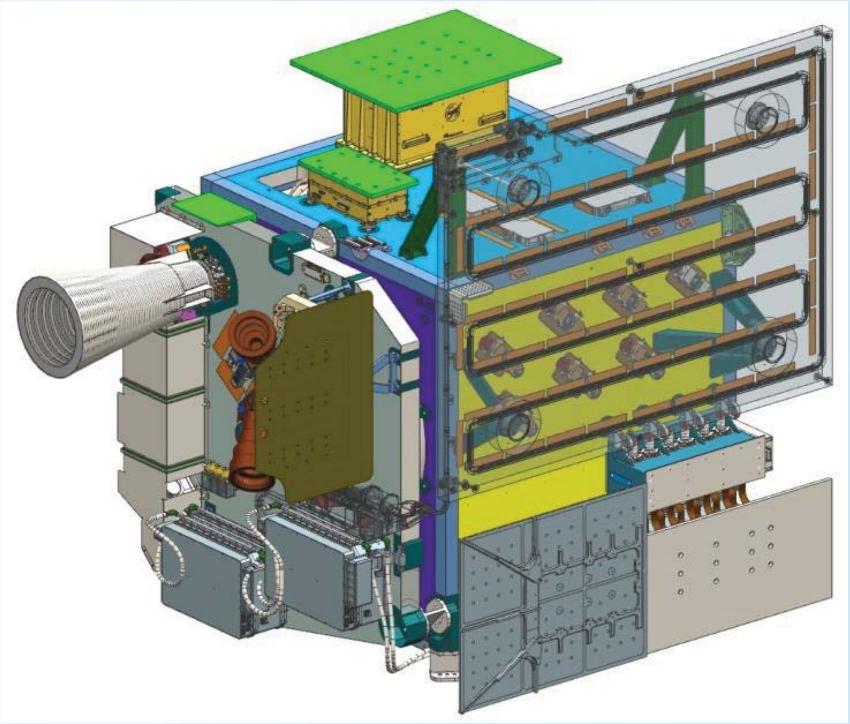
GOES-R ABI Instrument



Working Issues with inadequate sub-cooling and gravity induced flow.

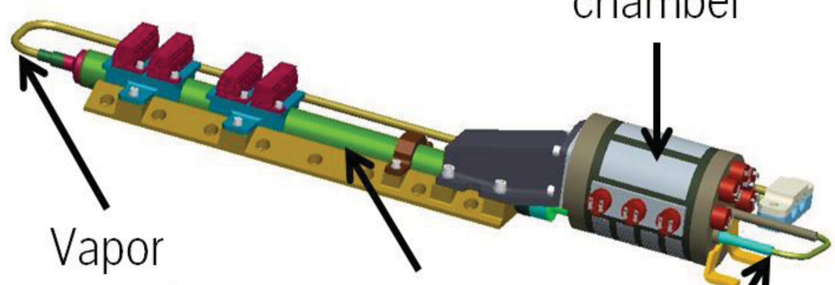
ICESAT-2/ATLAS Instrument Loop Heat Pipe Cooling

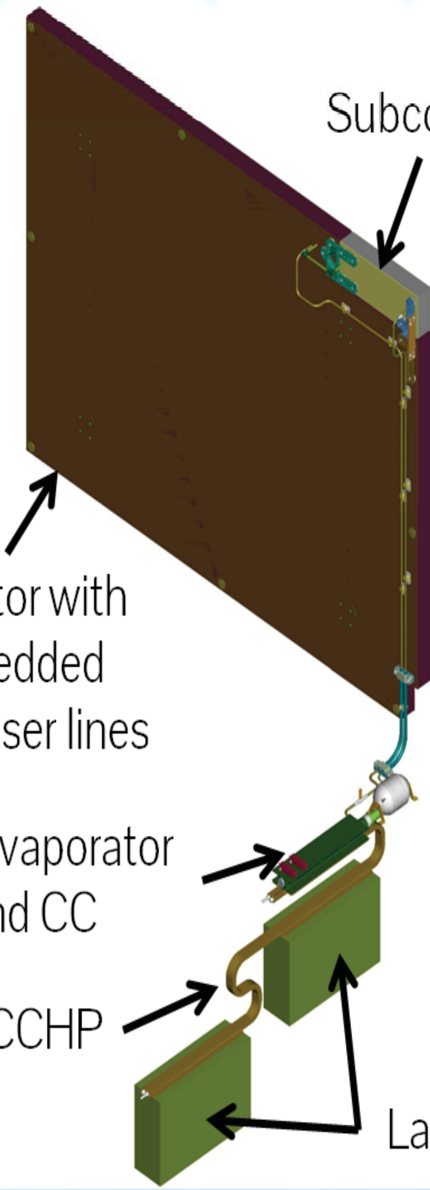




ATLAS Laser Thermal Control System (LTCS)

Redundant lasers are cooled via a single Laser Thermal Control System (LTCS) consisting of a constant conductance heat pipe (CCHP), a loop heat pipe (LHP), and a radiator.

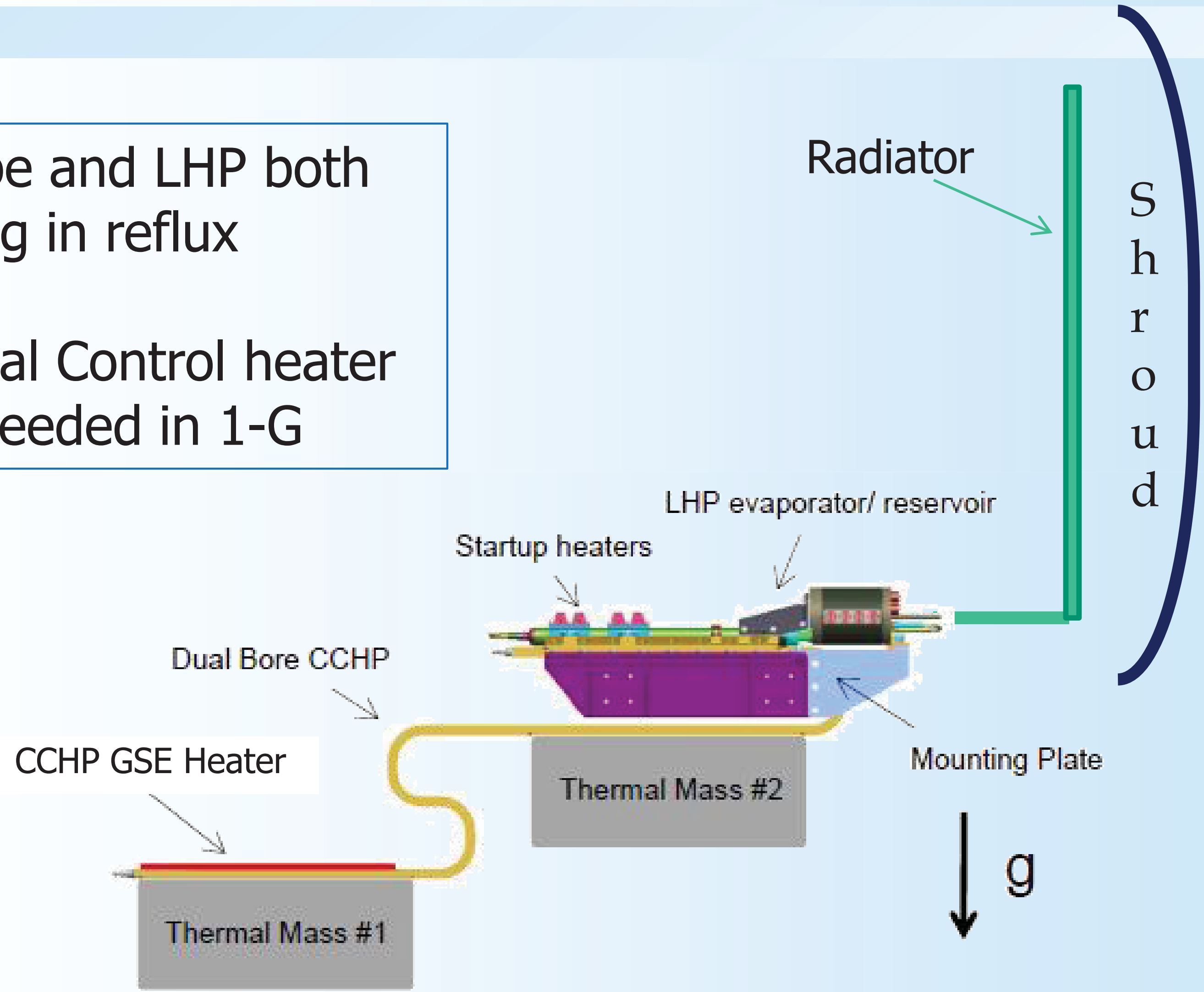




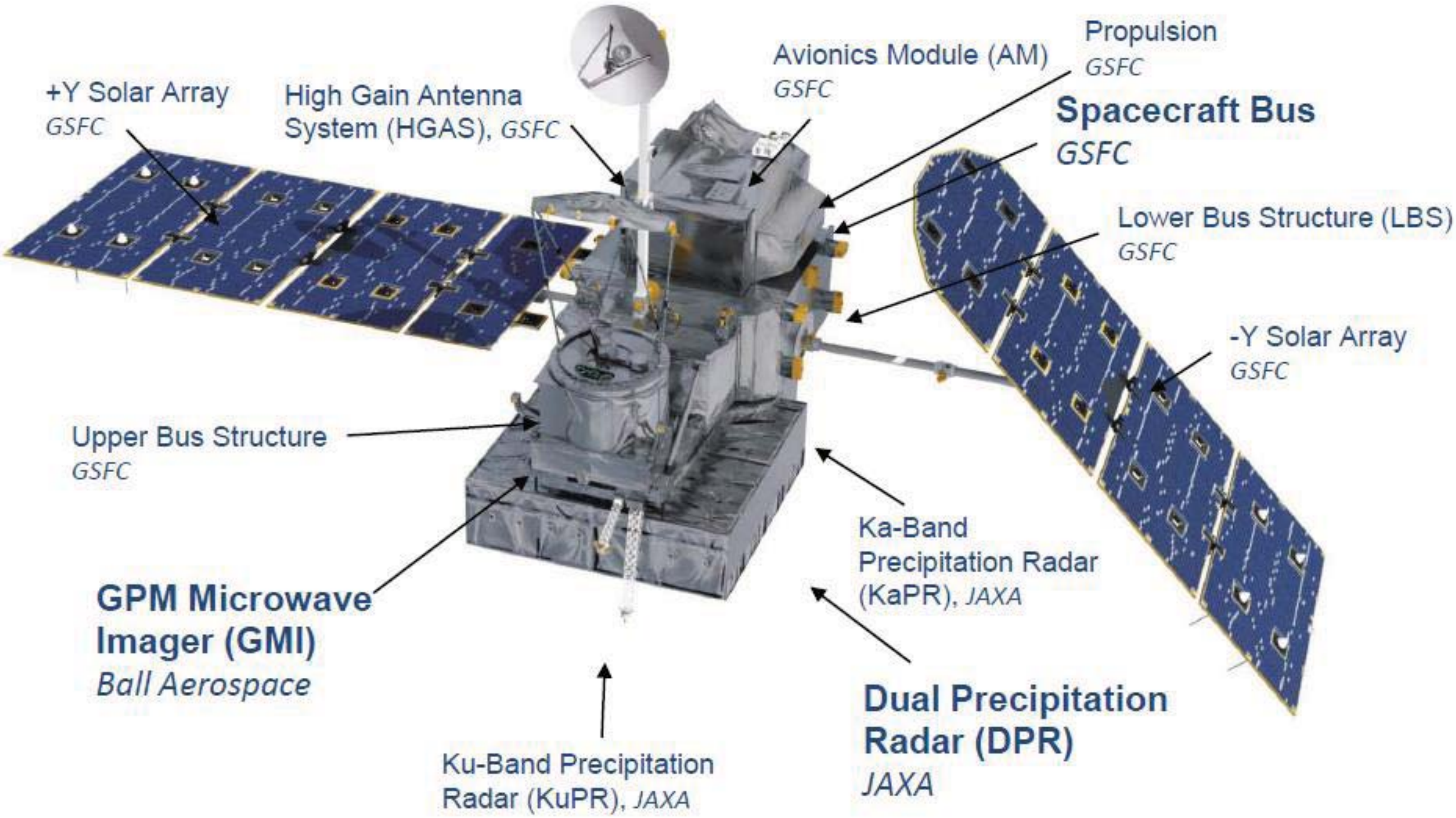
ATLAS LTCS TV Test Setup Schematic

Heat pipe and LHP both operating in reflux

Additional Control heater power needed in 1-G



Global Precipitation Mission – Open Architecture complicates Thermal Design

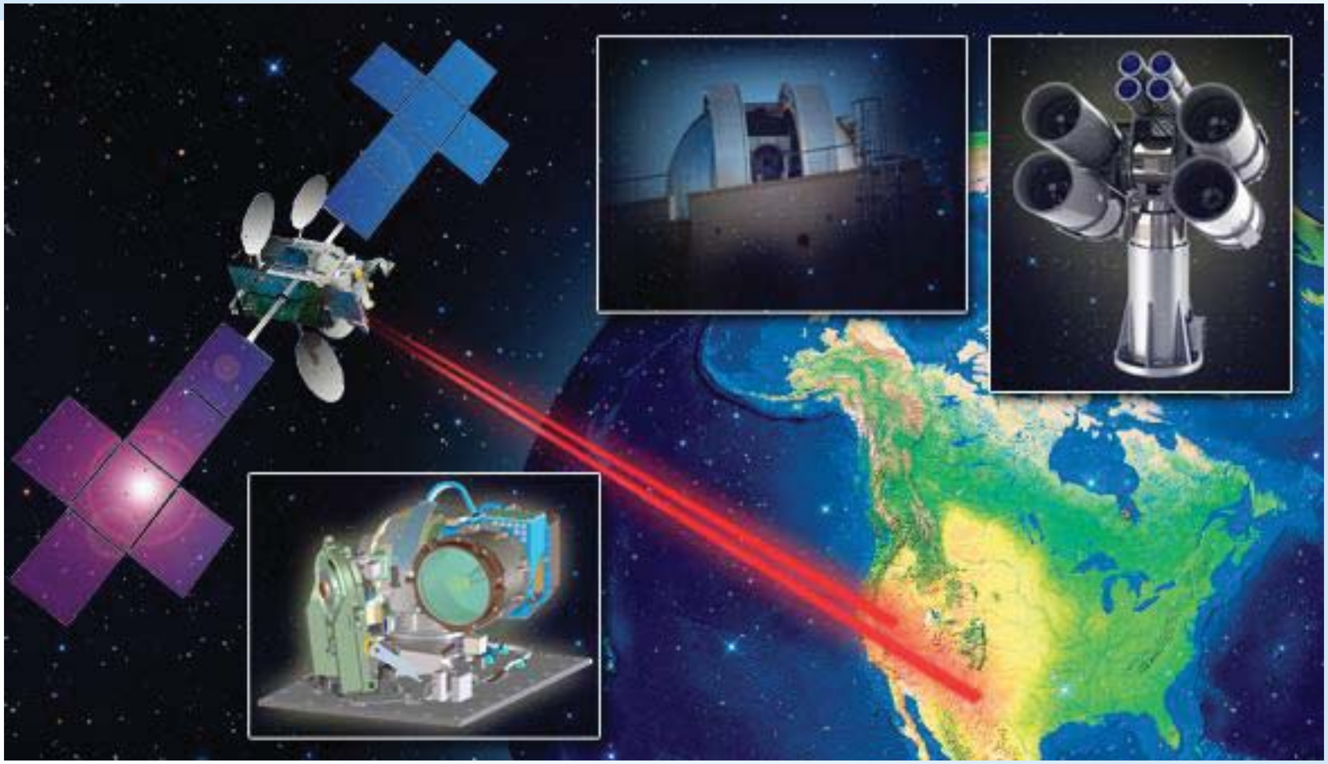


Launch Date:
Early 2014

Launch Vehicle:
Mitsubishi Heavy Industries H-IIA (provided by JAXA)

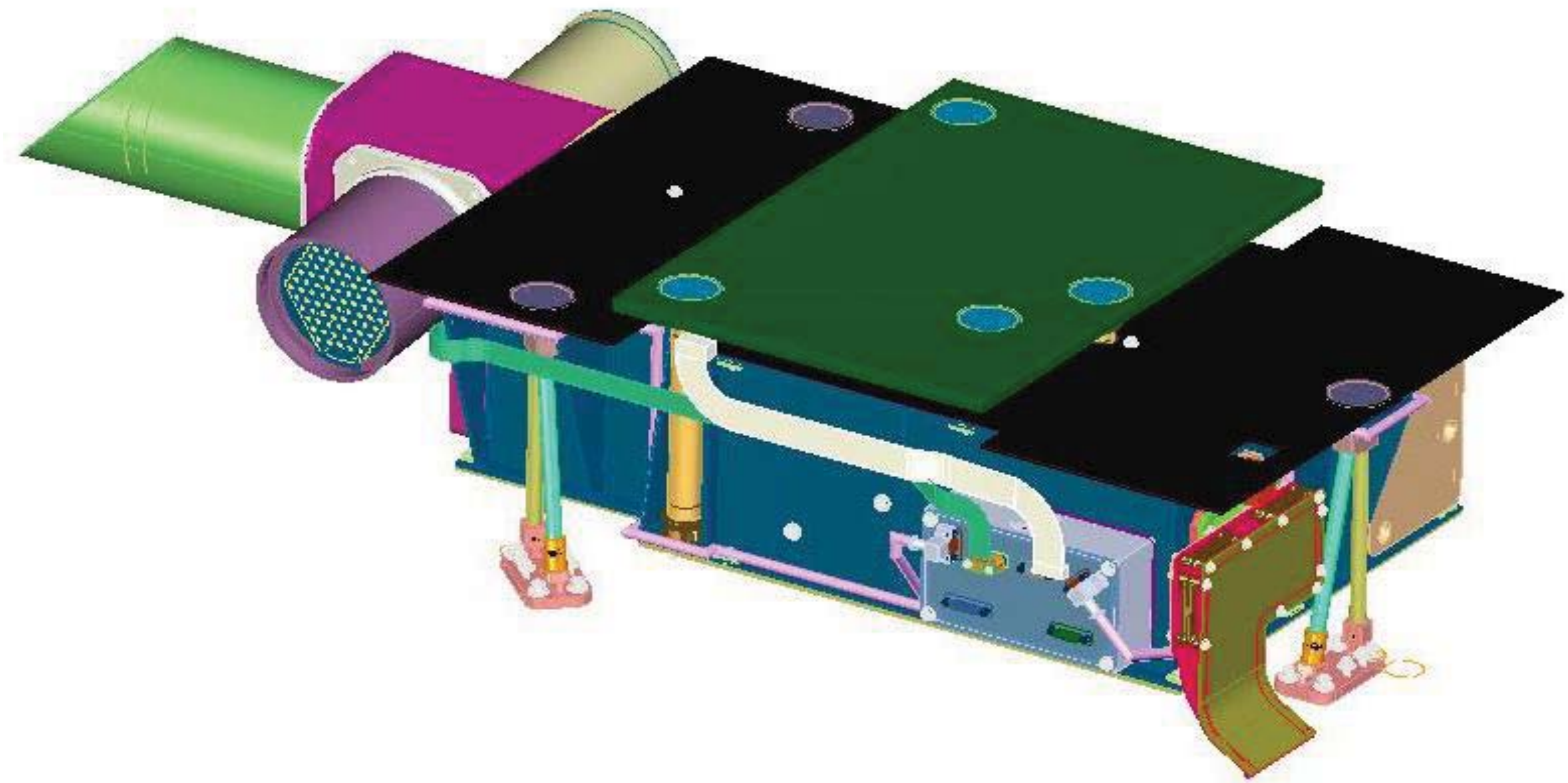
GPM at launch site in Japan

Laser Comm Relay Demo (LCRD)



- Flying as Hosted Mission on LORAL comsat (first for NASA)
- Demonstrates Laser Communication Technology as possible precursor to next TDRS or planetary missions
- Partnership with MIT/Lincoln Labs

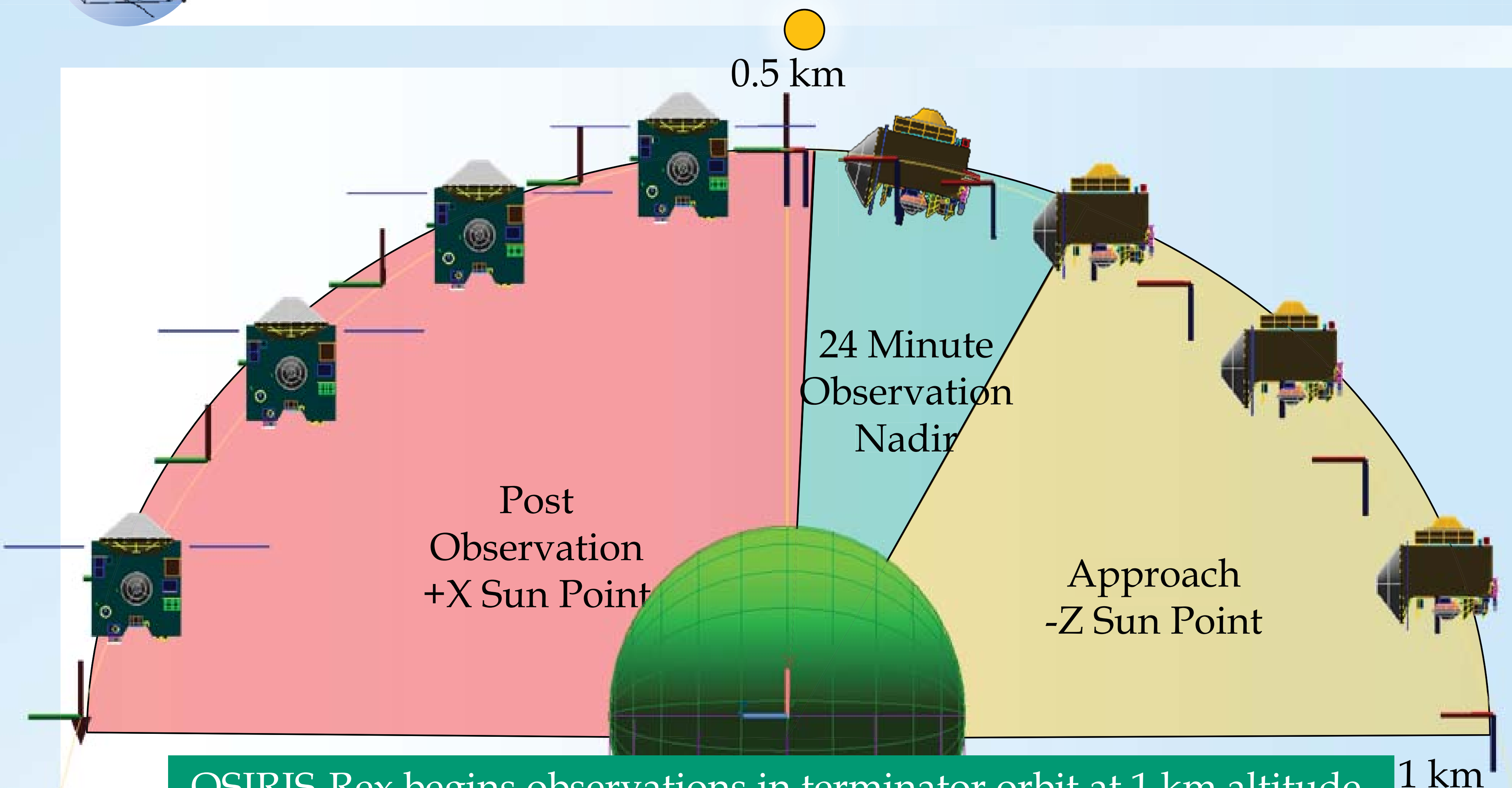
OSIRIS-REX OVIRS Instrument



Detector temp below 105 K, optics below 160 C, relies on 2 stage radiator (passive) and heat straps

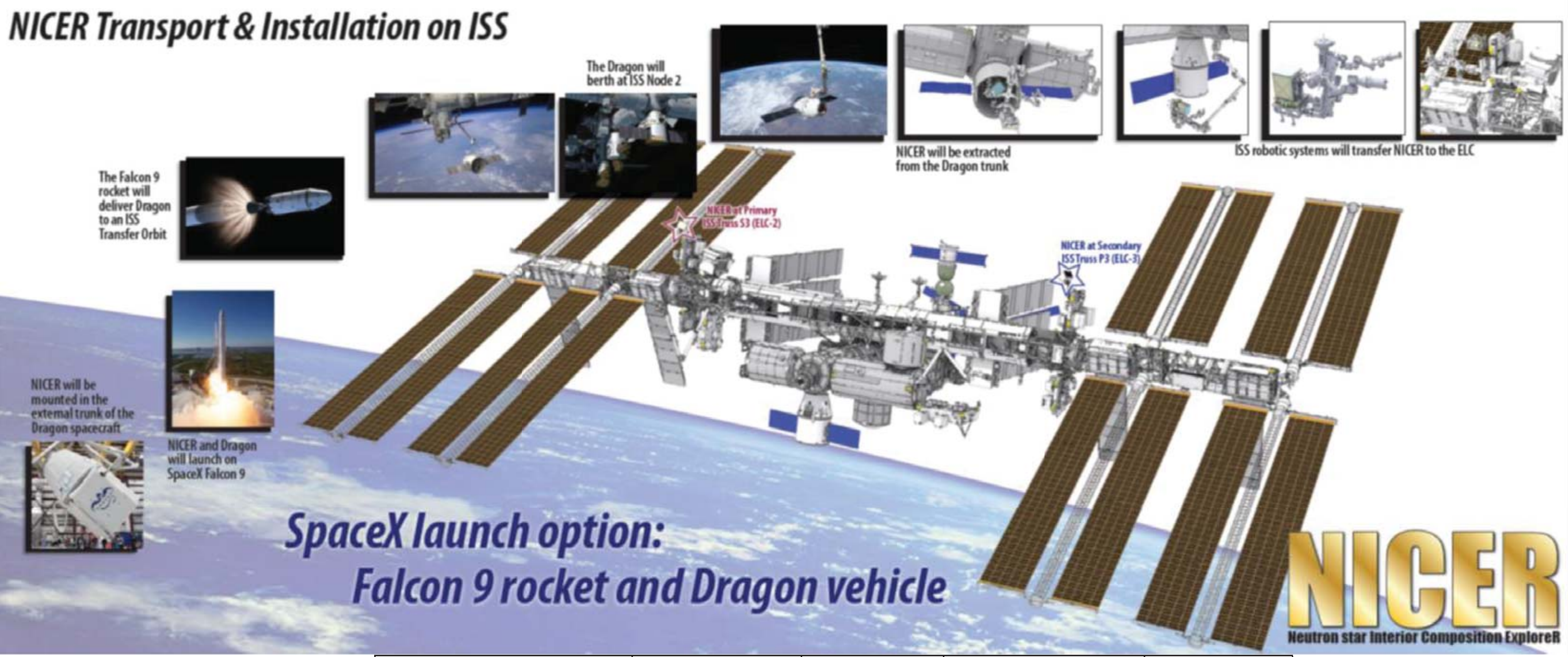
"Orbits" asteroid, relies on transient behavior to meet requirements

OSIRIS-REx Mission: Reconnaissance



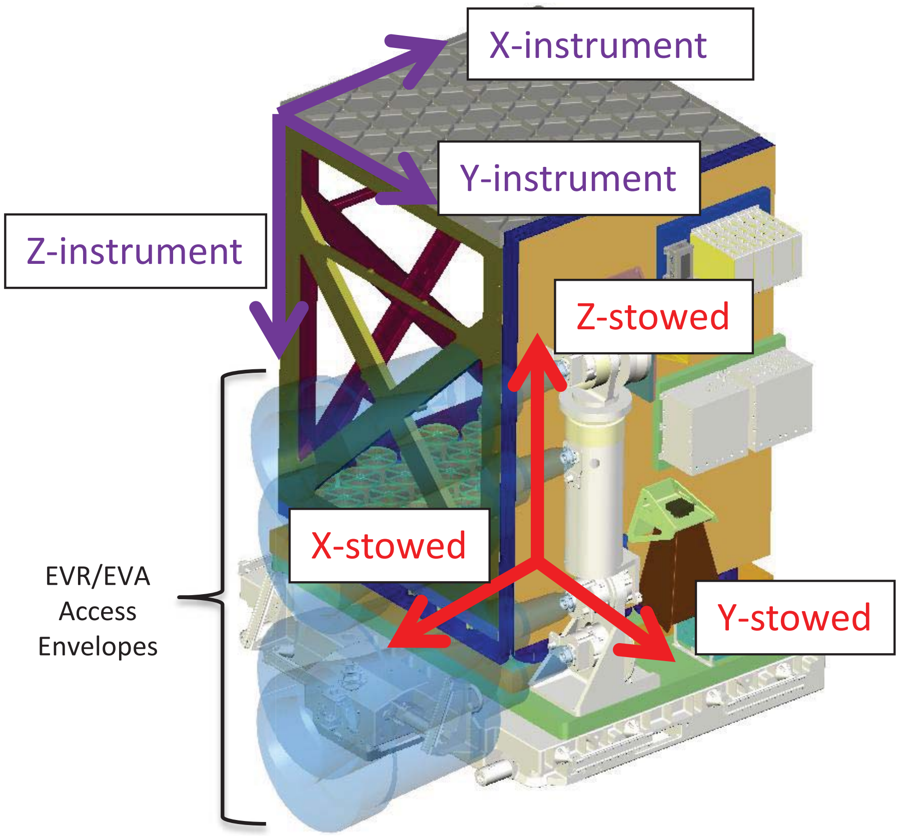
OSIRIS-Rex begins observations in terminator orbit at 1 km altitude, returning to +X sun point upon completion of observation.

Launch to ISS

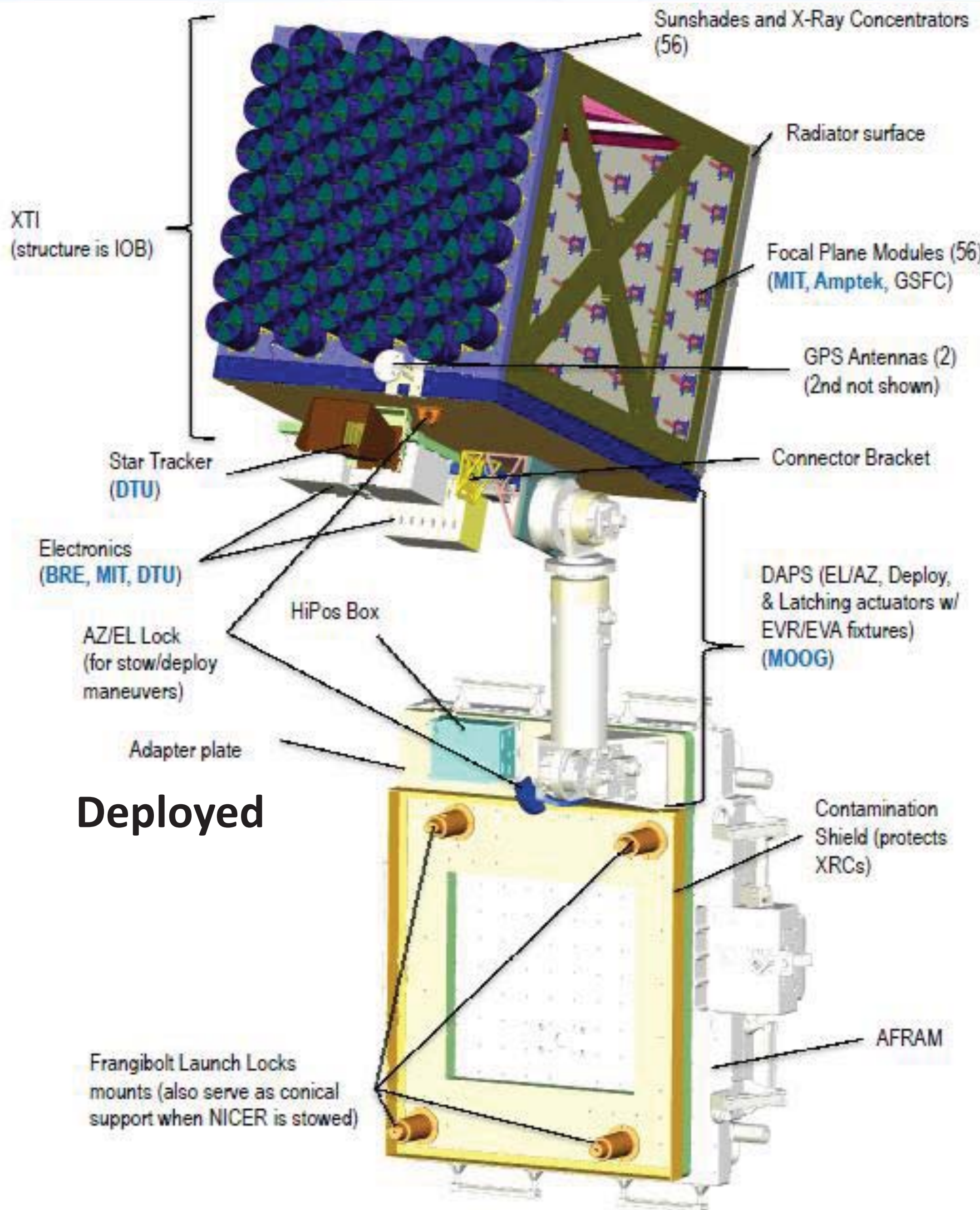


Operation	Location	Orientation	Heater Power Allocation	Duration
Launch	Dragon Trunk		?	8-10 min
Orbit, Proximity Ops, Grapple & Berthing	Dragon Trunk	any	80 - 100 W	days
Transfer to EOTP	DEXTRE	any	0 W	< 6 hrs
EOTP Stowage	EOTP	any	204 - 302 W	hrs to weeks
Transfer to ELC	DEXTRE	any	0 W	< 6 hrs
ELC…	ELC		lots	> 2 yrs

Payload Description



Stowed

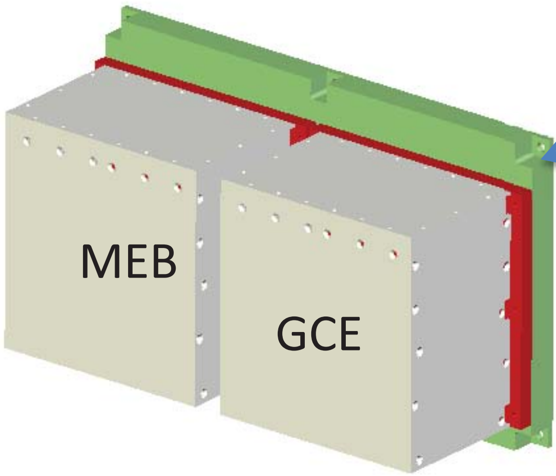


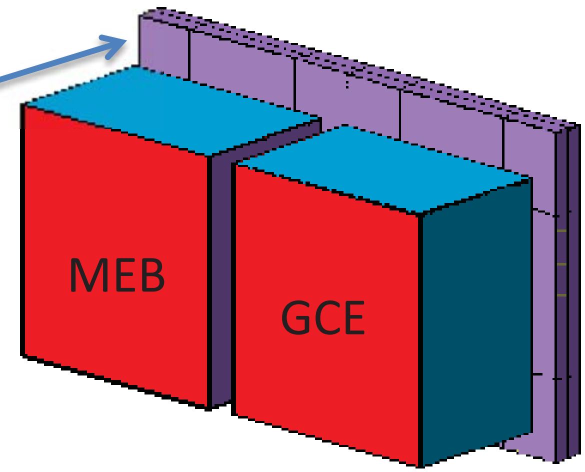
Deployed

Electronics & Mounting Decks

NICER

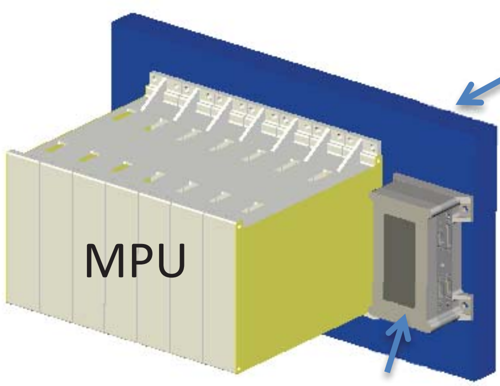
Mechanical | **Thermal**

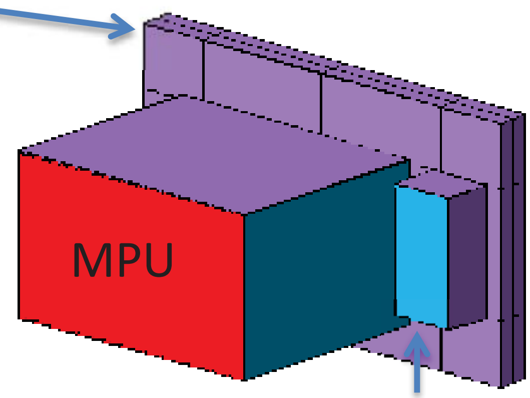




<u>Avionics Electronics Deck</u>

- Al 6061-T6
- 6 Ti flexure to IOB baseplate (G=0.01 W/°C each)
- PCM panels sandwiched between boxes and deck using NuSil





<u>Instrument Electronics Deck</u>

- Al 6061-T6
- 4 Ti flexure to IOB baseplate (G=0.01 W/°C each)
- PCM panel attached to deck underside using NuSil

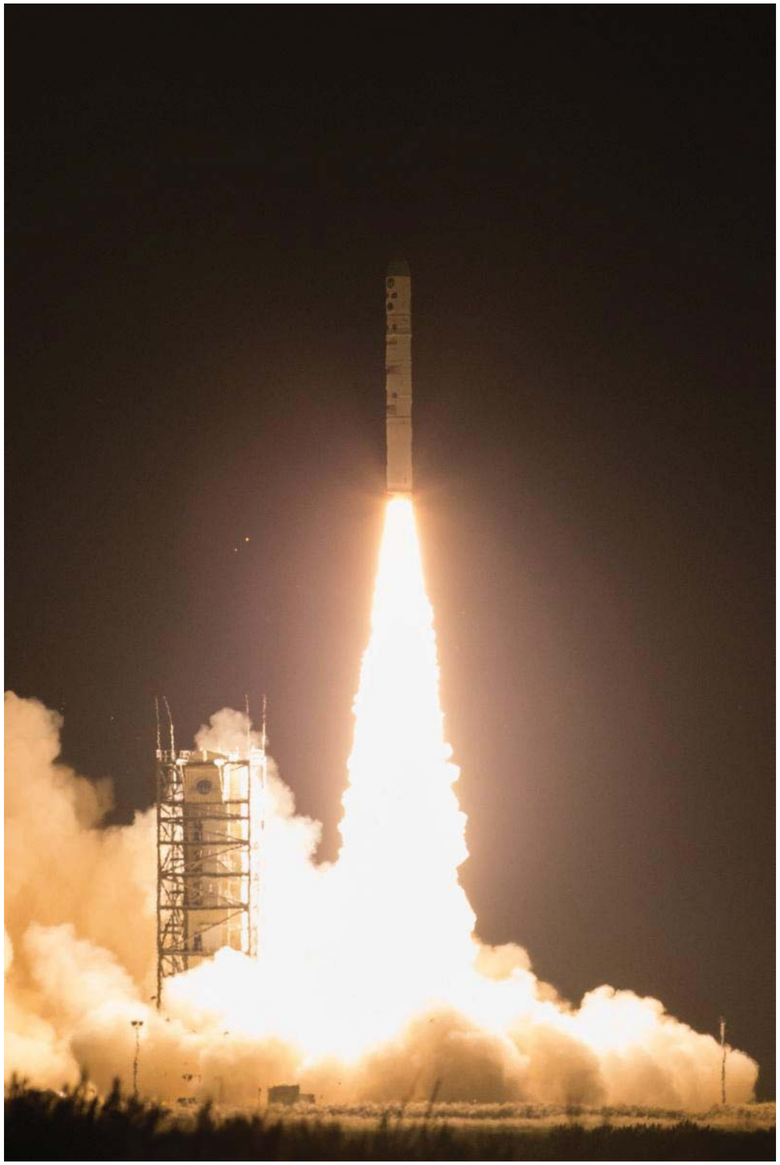
<u>Radiator</u>

- Al6061-T6, 2mm thick
- Bolted and NuSil bonded to top of MEB, GCE, & MPU
- Bolted to Elex Decks

Orbital Minotaur V LADEE Launch Thermal Analysis at WFF

- New area for GSFC Thermal Branch
- Included ground processing through launch
- Work done by Kan Yang with support from David Steinfeld

LADEE Launch could be seen over East coast



Background: Minotaur at Wallops

Wallops only has experience with Minotaur I: Uses “Banana Bag” for control

- Mitigates solar load on solid motors
- A/C air controls environment inside
- Removed at launch
- **$200k per use**

LADEE launched aboard the maiden flight of the Minotaur V Launch Vehicle

- Wallops had no experience cooling Peacekeeper (PK) Solid Motors
- Orbital had no previously-developed scheme to cool PK Motors outside of air-conditioned gantry
  - *No Banana Bag for PK motors (too heavy, bulky, does not fit in Gantry)*
  - *Orbital was not under contract to develop thermal control methods for Wallops ground ops*

Suite of Ground Ops Analysis Cases

Transport of the Spacecraft and launch vehicle (LV) to the processing facility

Spacecraft and LV inside transporter with worst-case environmental loads and with/without A/C

Testing/Integration of the LV and Spacecraft in the launch processing facility

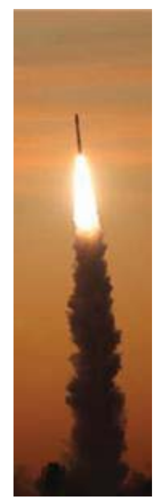
Spacecraft / Integrated spacecraft and fairing in Processing Facility with/without A/C

Transport of integrated LV components to gantry / Gantry stacking operations

Integrated spacecraft and fairing, LV components with no A/C and worst-case environmental loads

Integrated LV inside Gantry with/without A/C
Integrated LV inside Gantry with Gantry Doors Open

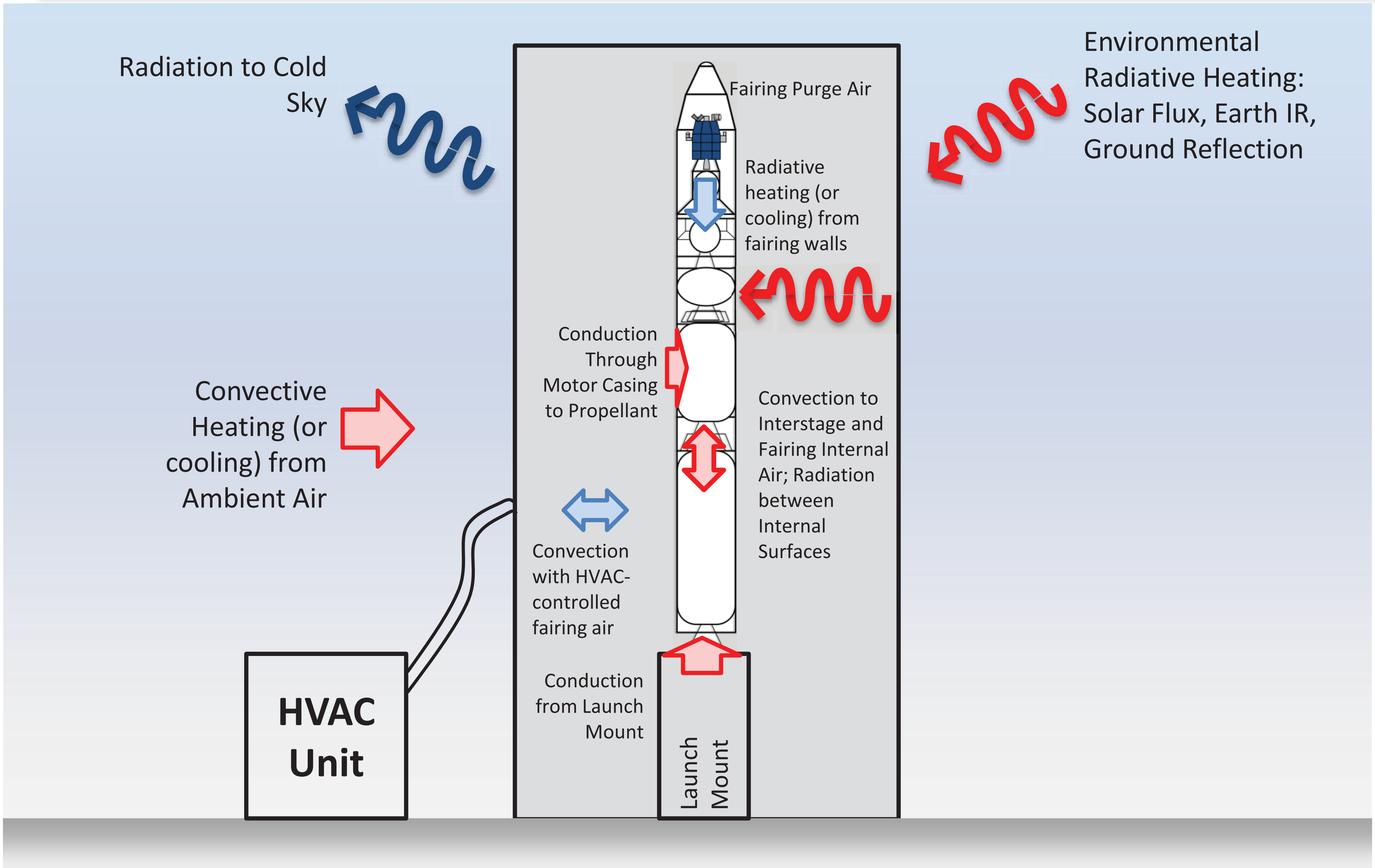
- Integrated LV with worst-case environmental loading after gantry roll-back
- Spacecraft and LV powered tests after gantry roll-back
- Spacecraft inside fairing with/without A/C
- Integrated LV after fueling



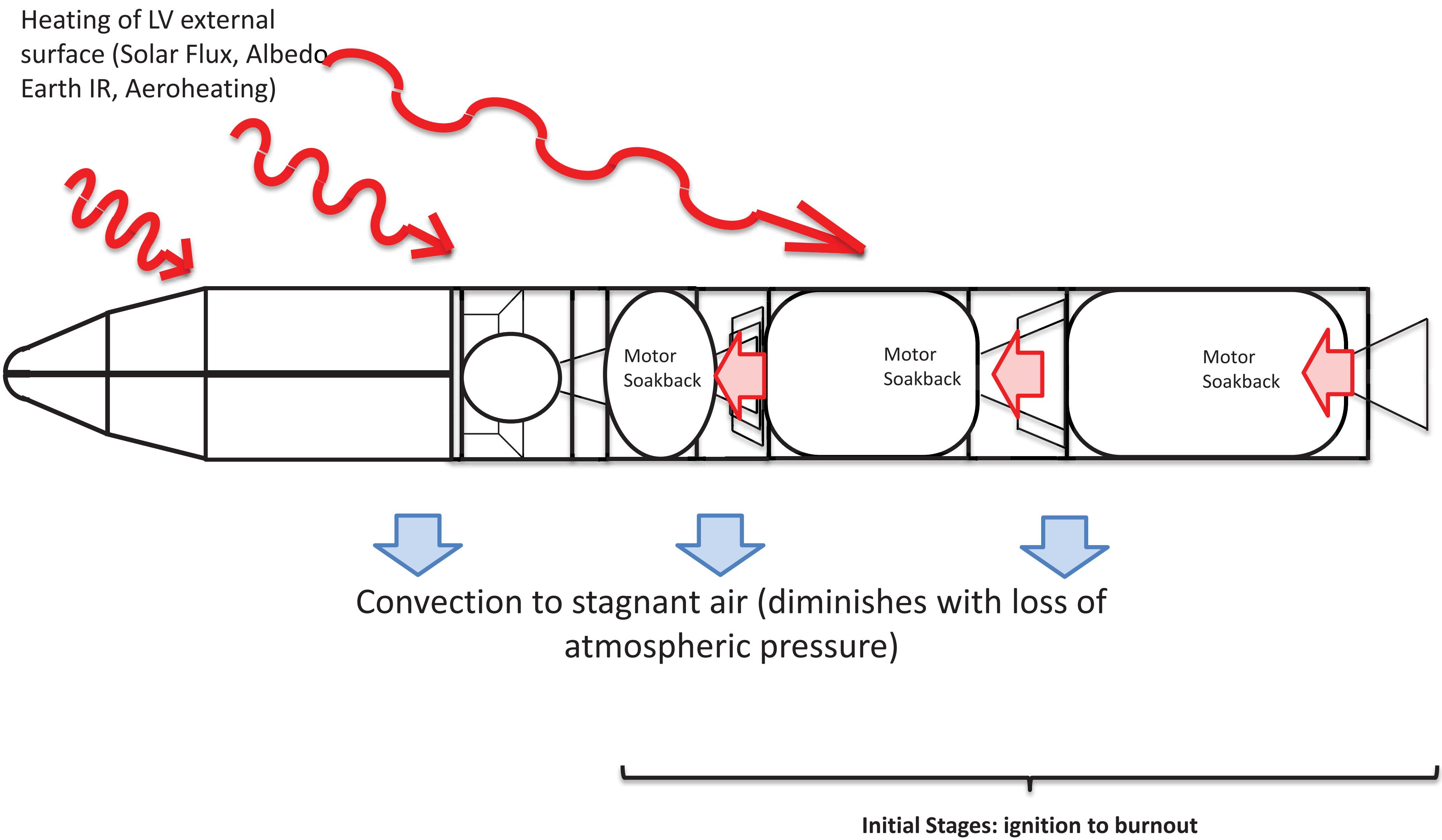
- Spacecraft inside fairing with environmental loads on LV fairing and no A/C
- Spacecraft after fairing separation with free molecular heating and motor soakback

Source: http://easternshoredefensealliance.org/files/LADEEmoonmission.pptx, www.mfrtech.com, www.nasa.gov

Gantry Environmental Sources and Heat Flows



Launch Profile Thermal Loads



Emerging Thermal Control Technologies

- GSFC's SBIR Thermal Subtopic was discontinued in 2012, but was re-instated in 2014. 21 proposals received in our thermal subtopic, Jentung Ku is the subtopic manager
- NESC funding received for 3 Development Activities
- IRAD funding received for several activities

NASA SBIR/STTR Technologies

S3.02- 9946- The Conductive Thermal Control Material Systems for Space Applications

PI: M.S.Deshpande

AMSENG - Schaumburg, Illinois, IL 60194

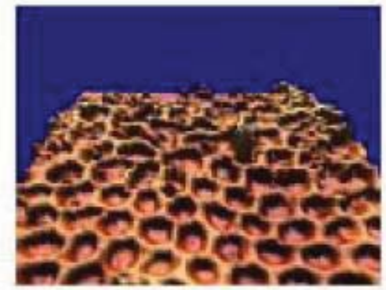
Identification and Significance of Innovation

Future Spacecraft and Instruments for NASA's Science Mission Directorate needs increasingly sophisticated thermal control technology. This innovative proposal is submitted to fulfill the needs identified in this solicitation for the following area: More sensitive instruments are resulting in increased requirements for high electrical conductivity on spacecraft instruments and surfaces. This has increased the need for advanced thermal control coatings, particularly with low absorptance, high emmittance, and good electrical conductivity. This Proposal is submitted to fulfill this need to provide Space Stable, Reliable, High conductivity Thermal Control Material System (TCMS). The technology feasibility assessment will be provided in the phase I and the efforts to mature the technology and validating the same can be planned in phase II, so that by the end of phase II the technology Demonstration activity can be undertaken as phase III.

Expected TRL Range at the end of Phase II Contract: (7-8)

BNNTs

Boron Nitride Nano Tubes



BNNM

Boron Nitride 2D Nano Structures

Technical Objectives and Work Plan

The overall technical goals of the proposed efforts are to produce solid state chemistries for BNNT-BNNM and Zinco-Indates type highly conductive compounds to tailor the diffuse TCMS that have the following performance characteristics:

- Total Solar Absorbance: BOL - $\alpha s<0.10$ (0.07 to 0.09 typical)
  EOL - $\alpha_s \cong 0.02$ to 0.04 (LEO)
  $\alpha_s \cong 0.06$ to 0.10 (GEO)
- Total Normal Thermal Emittance: BOL - $\varepsilon_N \cong 0.90 \pm 0.05$
  EOL - $\varepsilon_N \cong 0.90 \pm 0.05$
- Surface Resistance: $Rs = 1.0\times10^2 \Omega/sq$ to $1.0\times10^7 \Omega/sq$

These goals will be met by synthesizing Boron Nitride nano Tubes, Nano mesh (BNNT-BNNM™) and Zinco-Indates to tailor the TCMS for the high current carrying capabilities.

Firm Contacts: M.S.Deshpande. AMSENG - Schaumburg, Illinois

NASA Applications

The concepts on the suggested nano-science inspired generic multifunctional high conductivity capable thermal control material system are suitable for the science and o exploration hardware needs and are geared towards delivering the reliable end products. These developments will contribute uniquely to the survivable material systems. The NASA missions that can benefit from its applications: Tether concepts. The missions that need white (low $\alpha S/\varepsilon T$) conductive TCMS coatings are: JUNO, MAVEN, GOES-R, LADEE GRAIL, JPSS, & SAA.

Non NASA: DOD and Commercial Applications

Like NASA, the commercial industry has plans for several satellites for the broad band communication activities. The transportation authorities are also planning commercial space based radars for air traffic control. These planned candidate optimal fleet designs may call for putting assets in the mid-earth orbits (MEO) which require radiation stability along with the high conductivity for the higher leakage current carrying capability. Currently technology gap exists and no TCMS is available that is space stable and provides flexibility in leakage current. Success of this program spells fulfillment of this gap. Many commercial as well as the DOD platform hardware can also benefit form the fulfillment of this technology gap. Thus, the return on investments can be sizable and multifaceted

NON-PROPRIETARY DATA

Phase 2 Underway

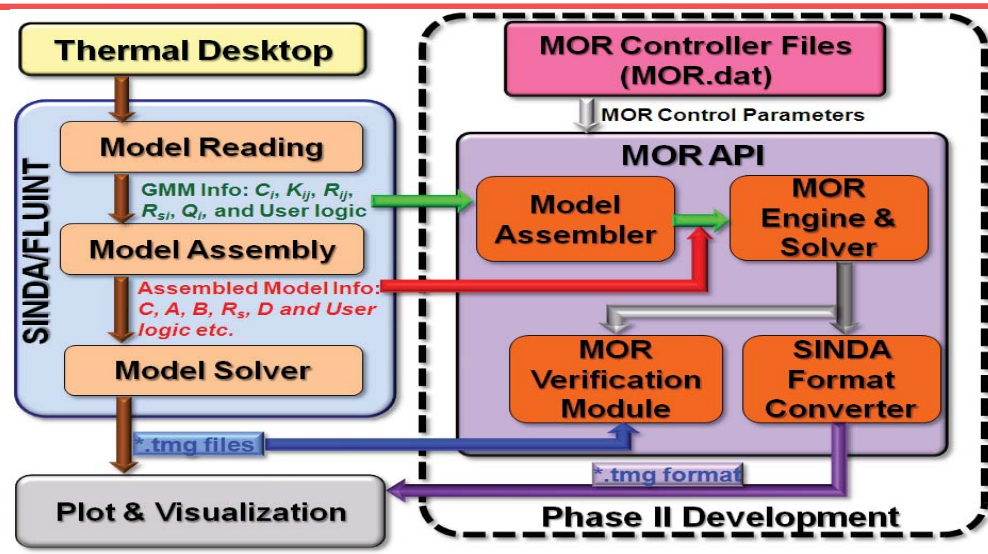
Title: Software for Automated Generation of Reduced Order Models for Spacecraft Thermal Control

Company Name: CFD Research Corporation

Proposal #: S3.02-9436 COTR: Jentung Ku

Technology Description and Objective:

- Further expansion of Model Order Reduction techniques developed in Phase I.
- Benefits in solution time are clearly demonstrated in Phase 1 (> 20x speedup).
- Limitations of time and temperature dependent terms necessitating more frequent generation of the projection matrix are clearly identified.
- Offeror proposes solutions to minimize the frequency of regeneration of the projection Matrix to maintain speed improvement for larger class of models.



TRL:

Entry (3/4)

Exit (6/7)

Proposal Objectives:

- Develop the approach to handle a larger class of thermal models (e.g. temperature/time dependent conditions).
- Goal of Phase II is to identify and execute methods to minimize the frequency of needing to regenerate projection matrix.
- Teamed with C&R (primary thermal software vendor) to further embed technology in end user product..
- Application Programming Interface (API) deliverable allows technology to be used in other disciplines (CFD, Structures, Controls, etc.)

Attributes

- NASA Applications:

James Webb Space Telescope, Laser Interferometer Space Antenna

- Primary SMD Division or Category:

!!! ANY NASA MISSIONS REQUIRING THERMAL ANALYSIS !!!

- Deliverables:

Application Programming Interface (e.g. DLL)

- PI: Dr. Yi Wang
- Consultants/Subcontractors: Brent Cullimore (C&R Technologies)

Phase 2 Underway

(September 10, 2010)

Thermal Coatings Technology Development

- **Qualifications recently completed**
  - Z93C55 (Alion Science and Technology), white, ESD dissipative silicate for use at geosynchronous orbits
  - MLP300 (AZ Technology) and ESD dissipative hybrid primers for bonding silicates to non-metallic substrates (e.g. carbon composite, polyimide films)
  - MH55 ICP (Alion Science and Technology), black, ESD dissipative silicate
  - STAMET coating (Astral Technologies) for replacement of vapor deposited germanium on polyimide film (GBK - exterior layer of MLI) for high electrical conductivity – partially funded by NESC. *Note that STAMET coating has been approved for use on GSFC missions*, however there is potential susceptibility to AO in low Earth orbits.
- **Current Development Activities**
  - Low absorptance layered silicate coatings to reduce absorptance below 0.13 at thicknesses less than 5 mils
  - Boron Nitride Nano-Mesh and Nanotube (BNNM) pigmented coatings (AMSENG) – Phase II SBIR and pigment post processing work for improved spray application

Contact: Mark Hasegawa, GSFC Code 546, (301) 286-4519, mark.m.hasegawa@nasa.gov

<Nanolamination Multimaterials>

PI: < Dr. Vivek Dwivedi/545>

Goddard Space Flight Center

Description and Objectives:

Demonstrate an Atomic Layer Deposition (ALD) manufacturing method for multilayered deposition of Ir and low-z material source for a x-ray optic using a novel reactor design. **_Create recipe for iron oxide ALD for carbon nanotube growth.**

Key challenge(s)/Innovation:

Develop enabling thin-film technologies that facilitate the current state of the art in coatings systems primarily for multi-layered materials applications as well as two-dimensional epitaxial structured elements.

Approach:

Demonstrate the applicability of a custom built in-house **ALD system to coat Ir and a low-z material on glass and silicon substrates with our collaborator at UMD**

Application / Mission:

- **X-Ray Optics**
- **Sensors**
- **Multifunctional/layered structures**

Collaborators:

- **Dr. Raymond Adomaitis (UMD), CODES: 670, 630, 570**

Milestones and Schedule:

- **Reactor Check-out (Jan 2014)**
- **Alumina film growth (Feb 2014)**
- **Ir /Low-z film growth on multiple surfaces (May)**
- **Full Characterization (End Summer 2014)**

Space Technology Roadmap Mapping:

- **Primary Technical Area: *TA10***
- **Secondary Technical Area: *TA08***
- **Additional Technical Area(s): *TA12, TA03, TA14, TA11***
- **Applicable Space Technology Grand Challenge: *New Tools of Discovery***

Technology Readiness Level:

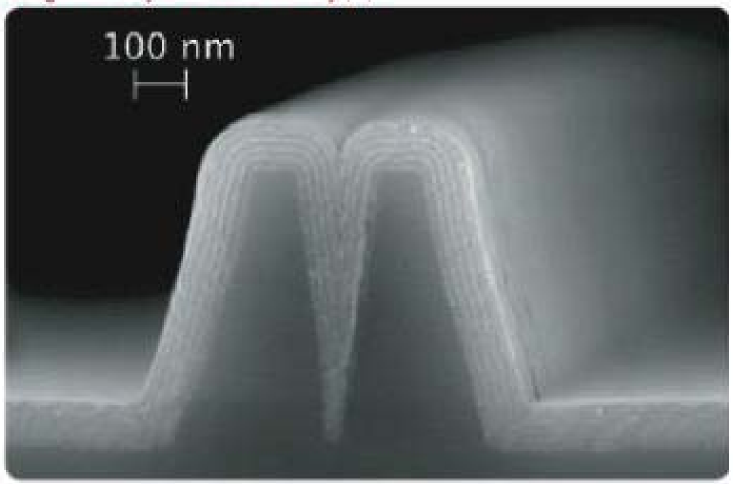
- **Starting TRL: 2**
- **Anticipated Ending TRL: 4**

Atomic Layer Deposition (ALD) Advantageous Properties

Epitaxial Growth

Artificial trench filled with an ALD nanolaminate

Image courtesy of Aalto University (FI)



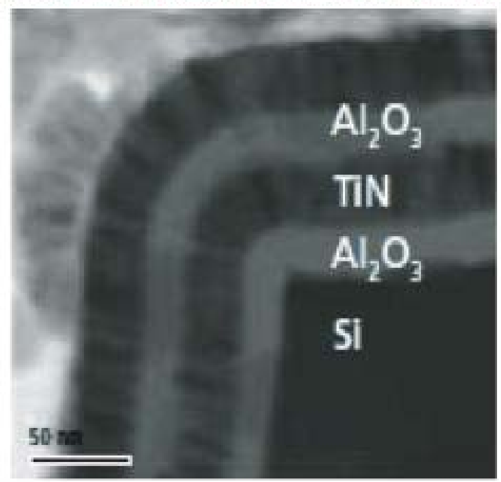
Multilayer consisting of:

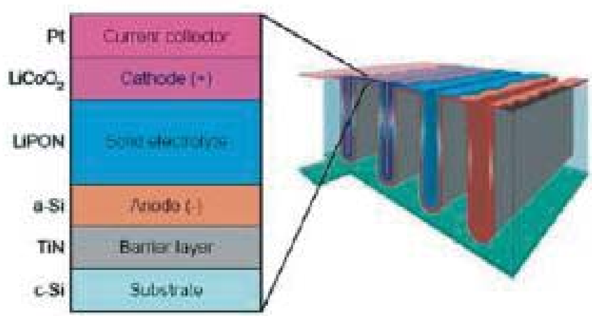
Al2O3 - 25 nm

TiN - 20 nm

Al2O3 - 25 nm

Dr. Fred Roozeboom, NXP Semiconductors Research and Dr. Erwin Kessels, University of Technology, Eindhoventd





Schematic of a 3D battery integrated in a Si- substrate. The cross-section shows the various functional layers in the battery stack as well as the candidate materials.

Knoops, H.C.M. et al., ECS Trans., 25 (2009) pp. 333-344

ESATAN/TSS/SINDA Model Converter
Hume Peabody/PI

- A Program is underway to facilitate automated model conversion from ESARAD to TSS and ESATAN to SINDA/FLUINT. A TSS to Thermal Desktop conversion routine already exists.

- The ESARAD to TSS path is fairly complete, but the SINDA/FLUINT to ESATAN converter is still in work. A Conversion routine for Thermica is also in work.

- The product is a Windows based Graphical User Interface that will import the model in one format (TSS, ESARAD, or SINDA FLUINT, ESATAN) and export it to another format.

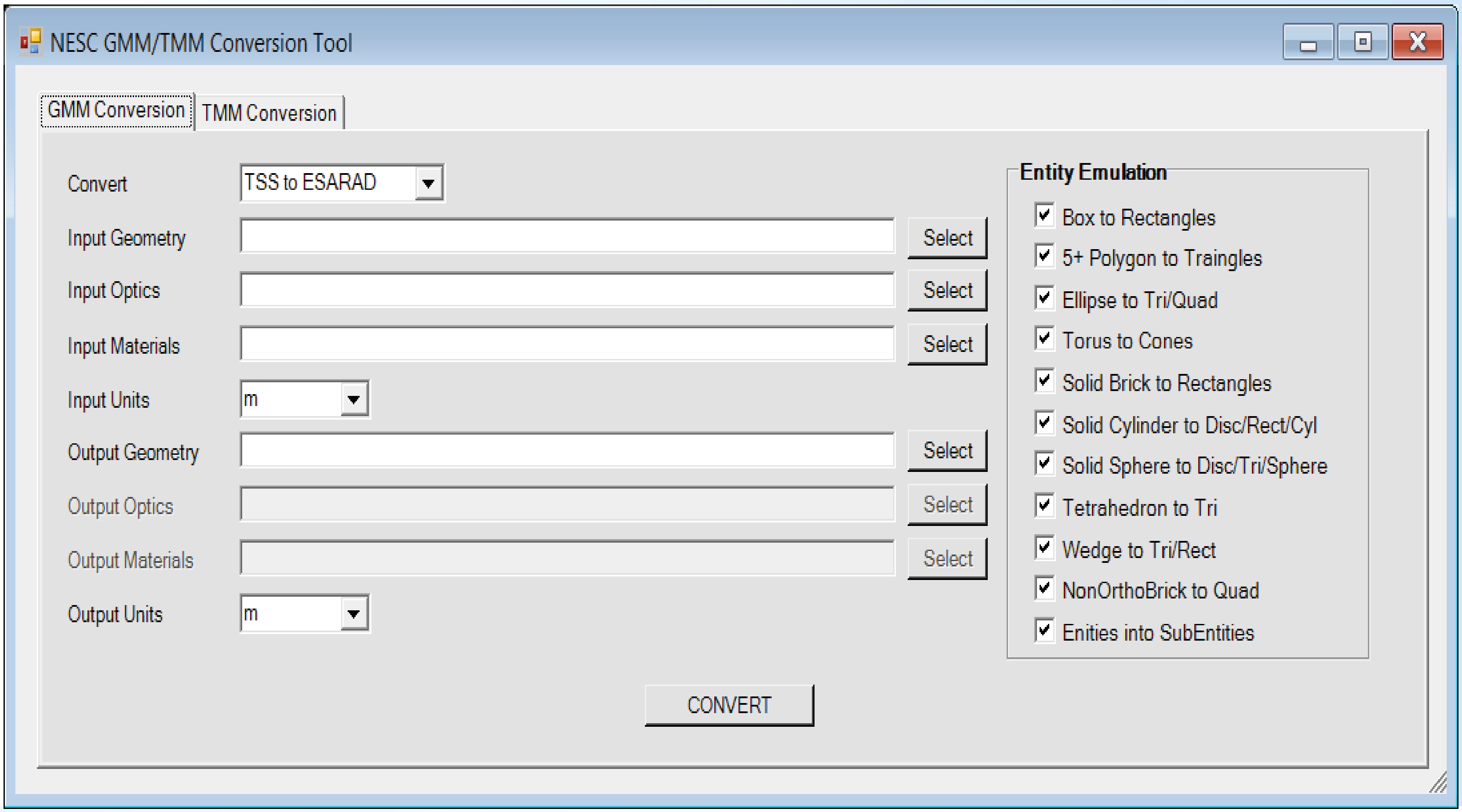
- Applies to NASA/ESA projects such as JWST, Solar Probe, MOMA

- Work will be done by Hume Peabody and Kan Yang of GSFC

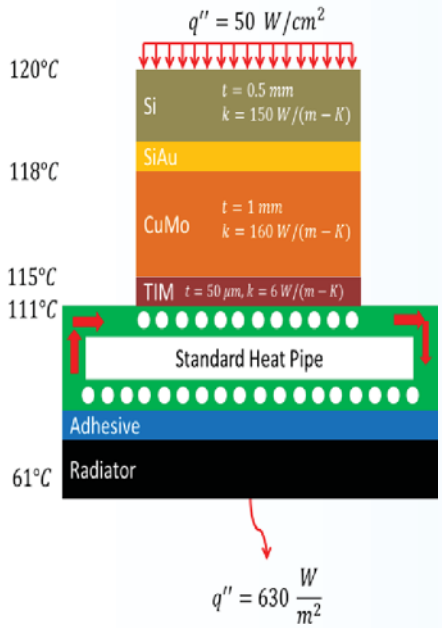
- Work is funded by NESC Passive Thermal Discipline Team, under Steve Rickman

ESATAN/TSS/SINDA Model Converter

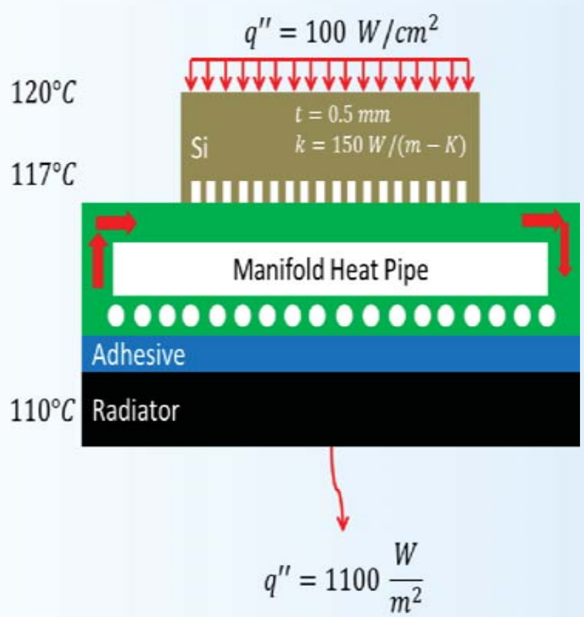
The Graphical User Interface (GUI) for the ESARAD/TSS Conversion Routine



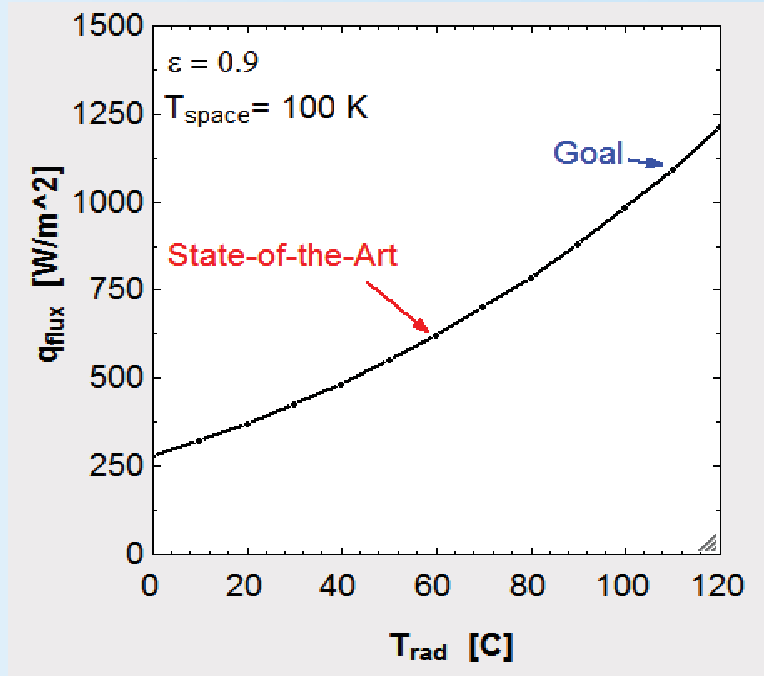
Embedded Electrohydrodynamic (EHD) Based Thermal Control - Jeff Didion/PI



State of Art



EHD/Capillary Hybrid



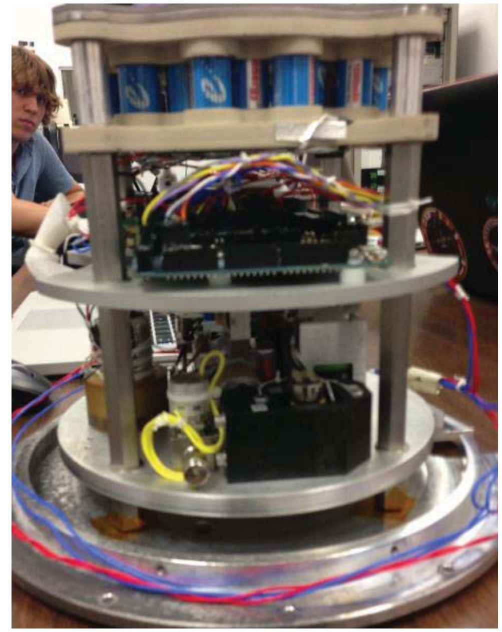
EHD/Capillary Hybrid:

- Less Mass/fewer components; lower thermal resistance
- High heat rejection temperature
- More Effective Radiator (see figure on right)

EHD Validation Efforts

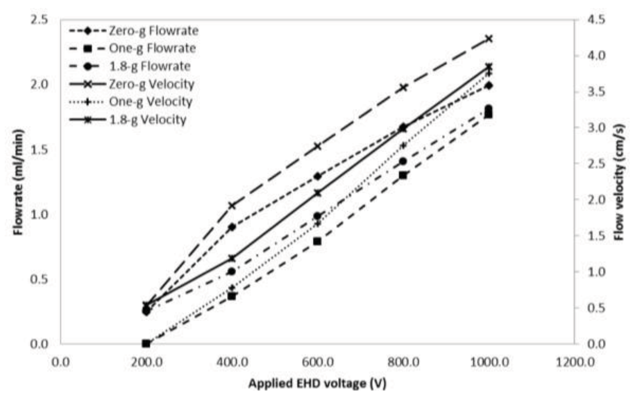
Technology Validation Status

- EHD Single Phase Pumping (Board Level Packaging)
  - May 2012 Variable Gravity
  - June 2013 Sounding Rocket (Univ. Of Nebraska – RockSat-C @ WFF); included additive manufactured PEKK parts
- Thin Film Evaporation – Variable Gravity September 2013
- STP-H5 – 2014/2015 EHD Multifunctional Plate
- ISS Thin Film Evaporation Experiment: 2016/2017

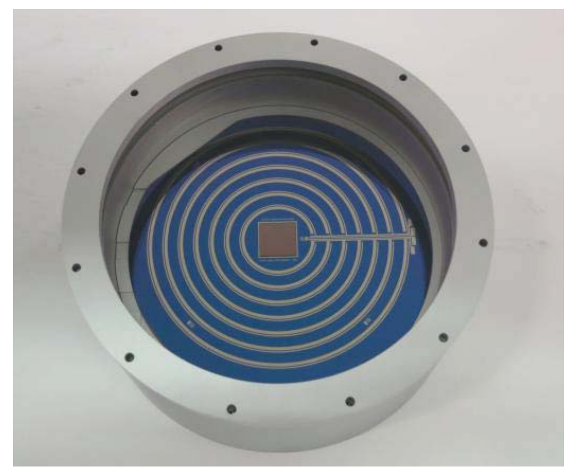


RockSat-C Payload

EHD: lower level
PEKK Parts: upper

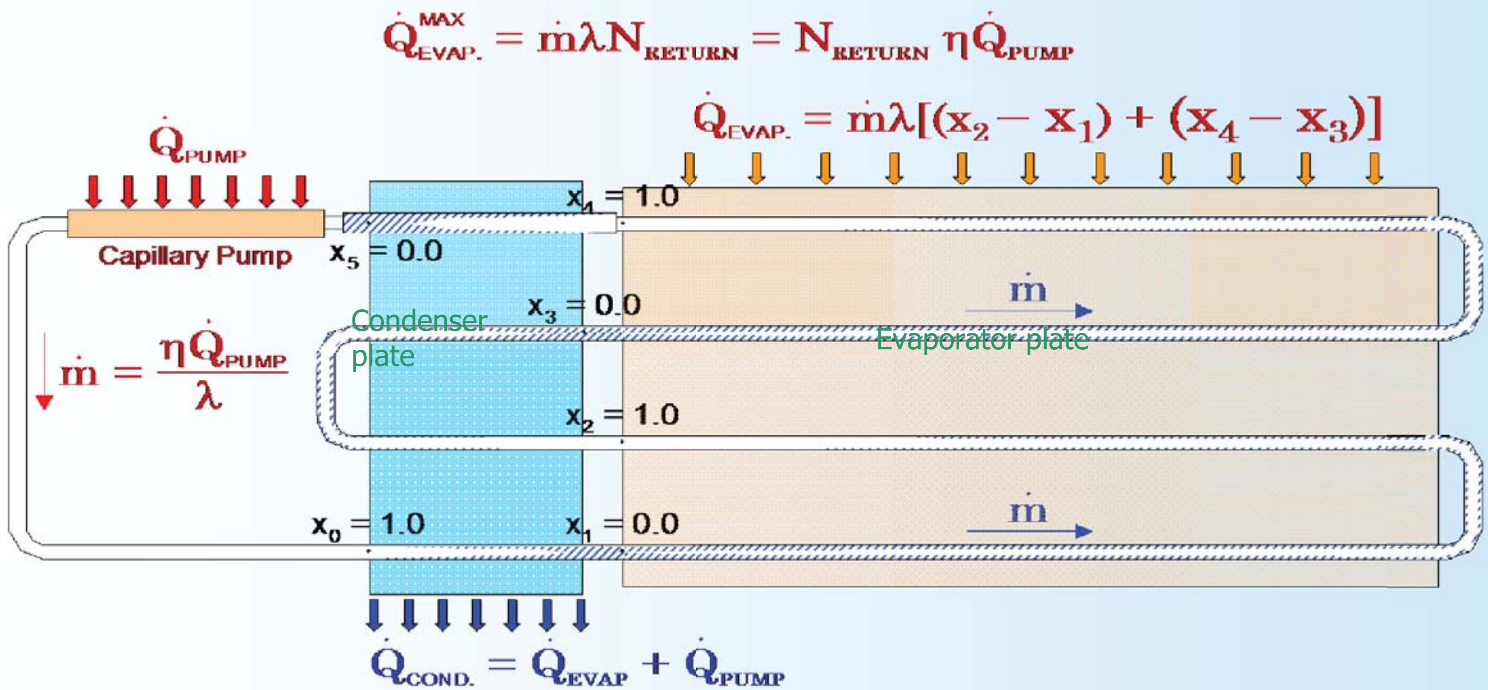


May 2012 Variable Gravity



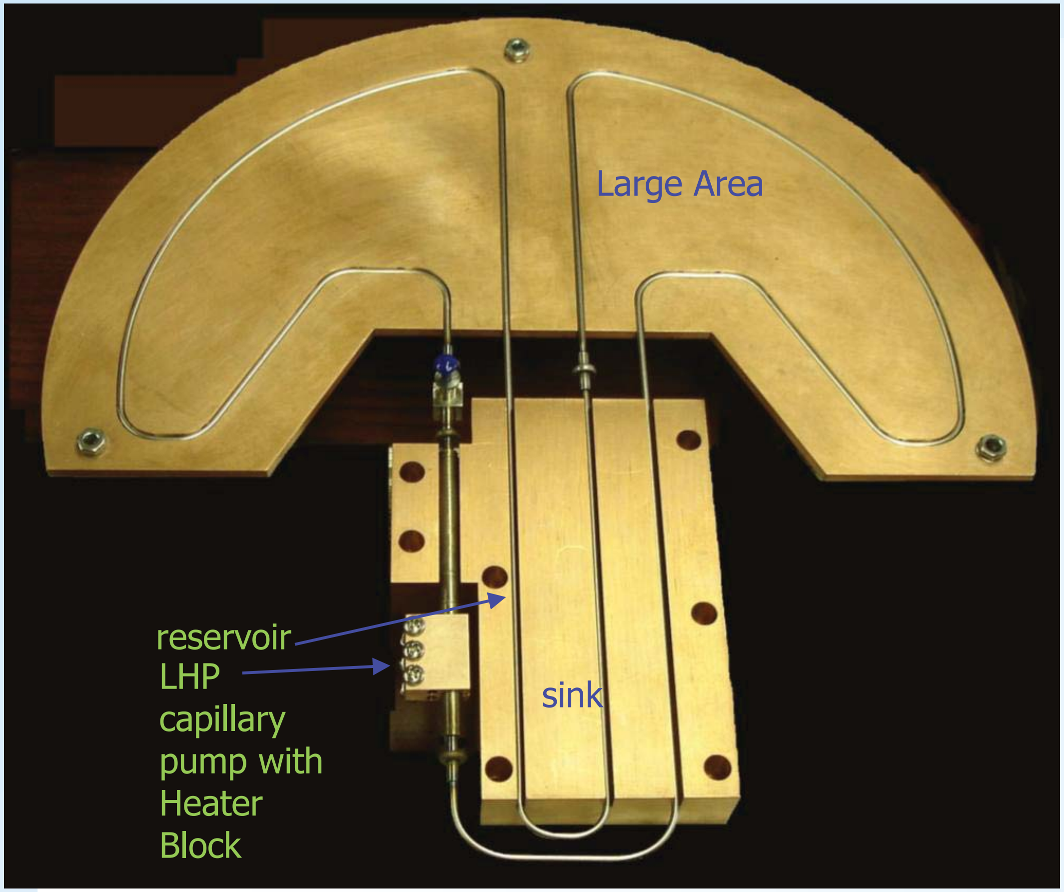
Variable Gravity 2013 & ISS 2016/2017: Thin Film Evaporation Experiment

CLHP for Large Area Cooling Applications (Zero boil-off Cryo-tanks)
Dr. Jentung Ku/PI



- **Heat is absorbed over a large area (detector array or cryo tank) and rejected into a small area (cryocooler).**
- **An external power is applied to the capillary pump to serve as the driving force for fluid circulation.**

Cryogenic Loop Heat Pipe (CLHP) for Large Area Cooling (Propulsion Tanks)



- All SS construction.
- Capillary pump: 1/4″OD x 1″L; wick: 1.2μm x 45% porosity
- Reservoir: 1/4″OD x 2.5″L
- Transport line: 1/16″OD x 90″L
- Because of size constraints, loop was limited to 2 loop backs
- Loop successfully tested with neon and will be tested with helium.

• CLHP built via SBIR program by TTH/Thermacore.
• NESC providing funding for further testing (Dr. Jentung Ku and Frank Robinson)

Gravity Independence of Microchannel Two-Phase Flow
Frank Robinson FY14 GSFC IRAD

Critical need for integrated electronic systems with onboard processing

Flow boiling in microchannel coolers:

- **> 100W/cm^2 heat removal capacity**
- **Compact size, low mass, low power**

Lack of understanding of flow boiling in microgravity limits implementation

Hypothesis: **Shear + surface tension forces dominate annular flow in micro channels, resulting in** g-insensitivity

What channel dimensions and flow parameters provide g-insensitive behavior? What role do fluid properties play?

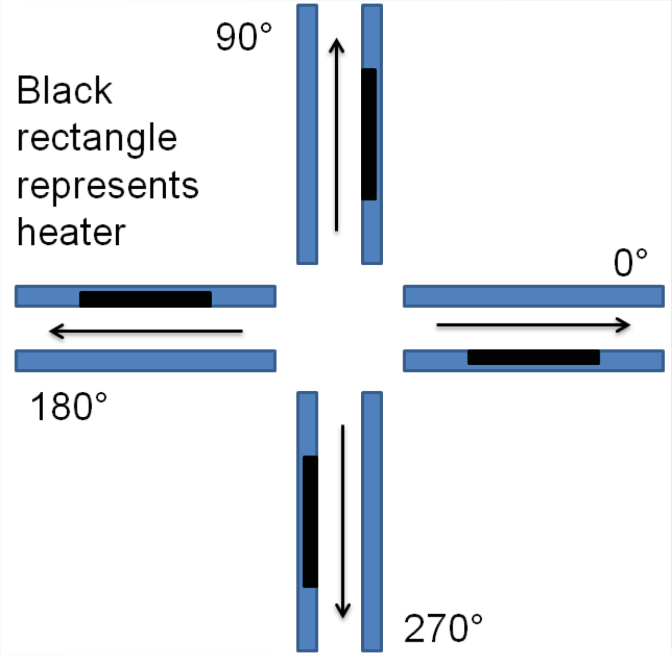
Gravity Independence of Microchannel Two-Phase Flow
Frank Robinson FY14 GSFC IRAD

Approach: For hydraulic diameters of 0.1-2mm, determine orientation effects in 1-g, then validate results in 0-g

Similitude required among flow regime and heat transfer parameters (CHF, HTC, ΔP) at various orientations for g-insensitivity determination

Applications: Amplifiers, multi-chip modules, laser diode arrays

Collaborator: Professor Avram Bar-Cohen/UMD



SUMMARY

- New Technology program underway at NASA, although funding is limited
- NASA/GSFC's primary mission of science satellite development is healthy and vibrant, although new missions are scarce – now have people on overhead working new missions and proposals
- Future mission applications promise to be thermally challenging
- Direct technology funding is still very restricted
  - Projects are the best source for direct application of technology
  - SBIR thermal subtopic resurrected in FY 14
  - Limited Technology development underway via IRAD, NESC, other sources
  - Administrator pushing to revive technology and educational programs at NASA – new HQ directorate established