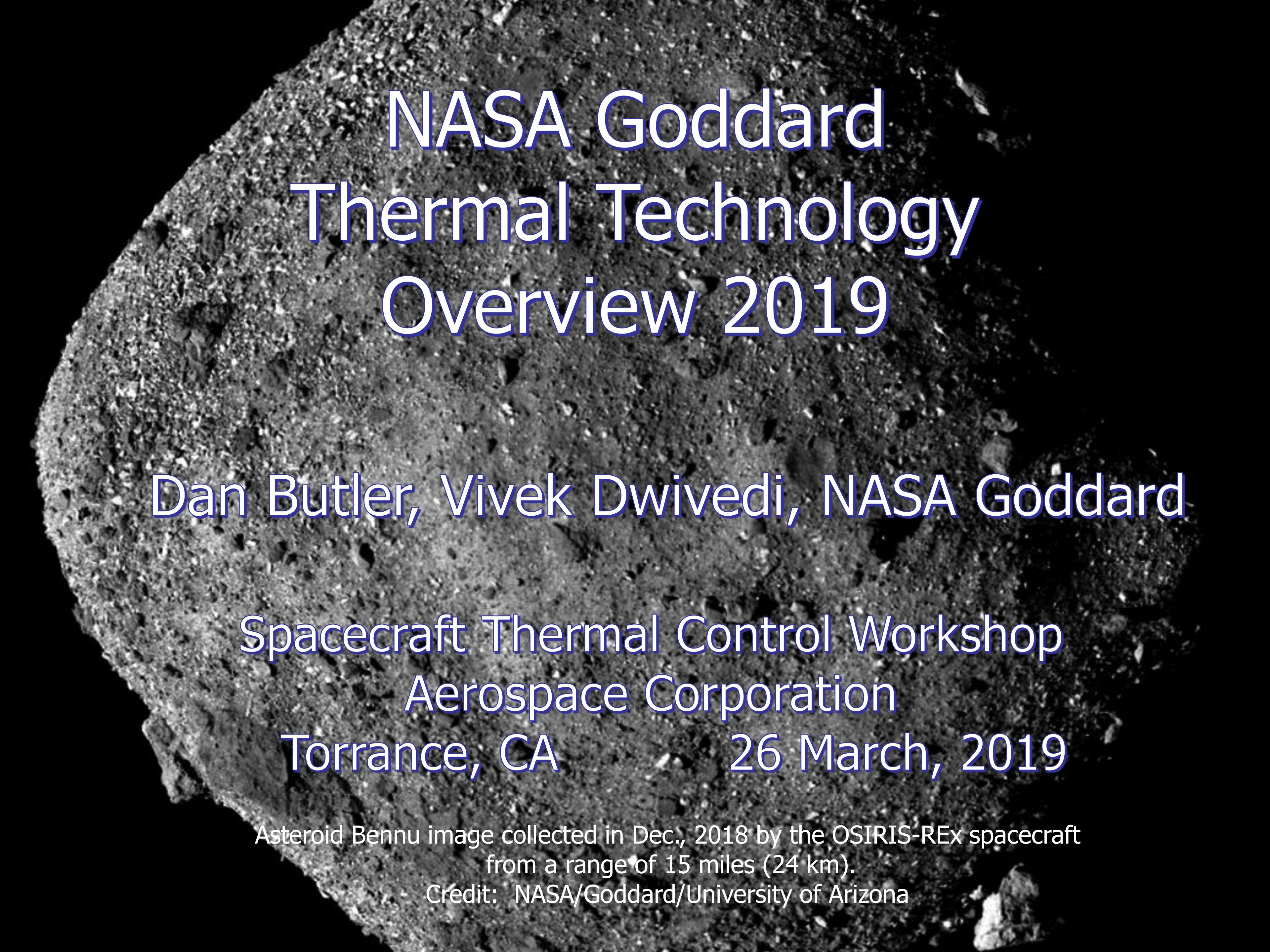


NASA Goddard Thermal Technology Overview 2019

Dan Butler, Vivek Dwivedi, NASA Goddard

Spacecraft Thermal Control Workshop
Aerospace Corporation
Torrance, CA 26 March, 2019

Asteroid Bennu image collected in Dec., 2018 by the OSIRIS-REx spacecraft from a range of 15 miles (24 km).
Credit: NASA/Goddard/University of Arizona

NASA Status FY 19 (Oct 18 to Oct 19)

FY 18 Budget enacted last March, 2018 after lengthy Continuing Resolution (CR)

- Included 6 % increase from FY 17 to $20.7 B
- Science budget up 8 %
    - Europa Clipper well funded, Mars Missions, JPL will address
    - JWST launch slip to 2021, recently completed Spacecraft Vibration test with Thermal Vacuum test planned for this summer at Northrup Grumman
    - No major program cuts

FY 19 underway at FY 18 budget level via CR through Feb 15.

- FY 19 budget started Feb 16. It is 4% higher than FY 18, now funded through Sept 30
- 35 day furlough impacted most of NASA's work, but JPL stayed open
    - SBIR program delayed, Phase 1 proposals due end of March
    - ISS, on-orbit mission support, and high priority programs continued

NASA Status FY 19 continued

Near term Emphasis for manned missions shifting from Mars to Moon
- Deep Space Gateway proposed as an orbital outpost near the Moon

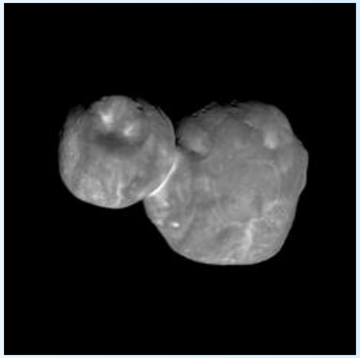
ISS operations planned only through 2024, although it should last longer
- Calls for future ISS experiments via Science Directorate already reduced

Large emphasis on Small satellites and Cube-sat programs at NASA and DOD
- Many were launched last year, increasing use of ”ESPA Ring” for rides as secondary payloads
- Increased number of Science Directorate funded Smallsat missions

Space Launch System and Orion missions continued
- Commercial crew missions to ISS planned to start within a year (Boeing and SpaceX)

NASA On-orbit Missions Update

New Horizons Spacecraft (Pluto Mission) flyby of Ultima Thule, a Kuiper Belt object



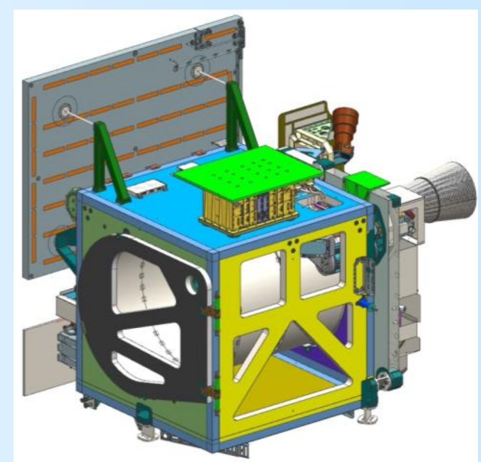
Parker Solar Probe successful first flyby of Sun
- Utilizes mechanically pumped single phase water loop

Osiris-Rex successfully rendezvoused with Asteroid Bennu
- See picture on cover page
- Will return sample to the Earth
- OVIRS instrument built at GSFC

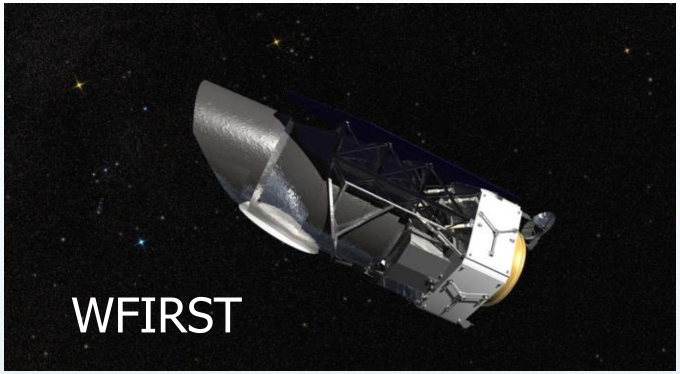
NASA On-orbit Missions Update Continued

ICESAT-2/ATLAS Mission Successfully launched in Sept 2018 on last Delta 2 mission, working well

- Uses lasers to measures Ice-sheet thickness
- Loop Heat Pipe (LHP) for instrument thermal control. It's an ammonia LHP with titanium wicks.
- Atlas laser instrument built in house at GSFC.



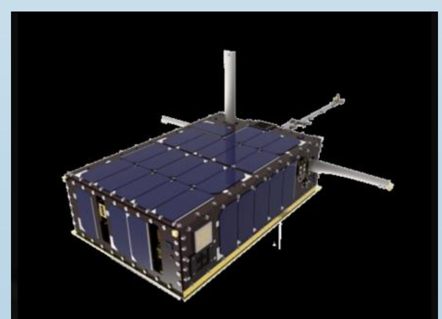
NASA GSFC Future Missions



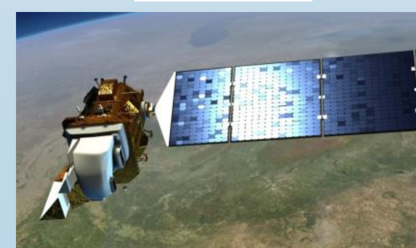
ICESAT-II

GOES-T

JPSS-2



CUBE-SATS



Landsat 9

GOES-R and GOES-S

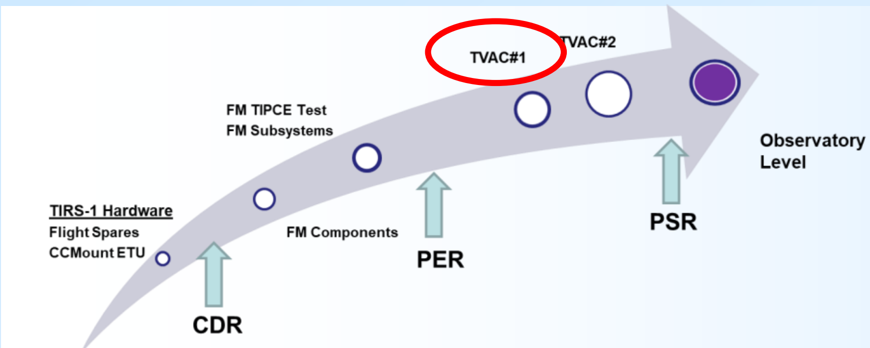
Loop Heat Pipe's (LHP) used for thermal control of ABI and GLM instruments.

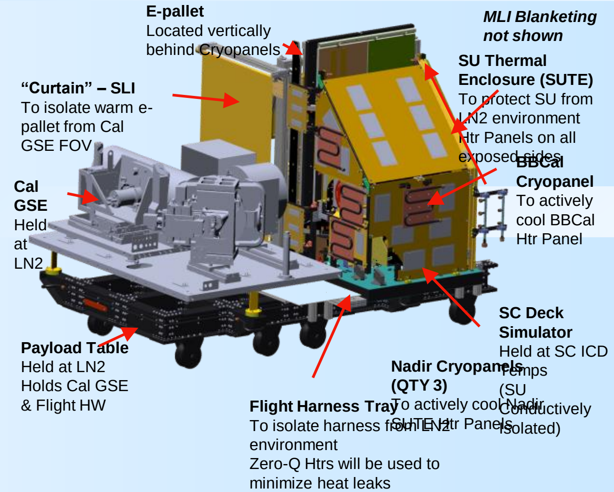
GOES-R launched and in orbit, 10/16, working well

GOES-S launched in March 2018
- Geostationary Lightning Mapper (GLM) LHP working well
- Advanced Baseline Imager (ABI) having problems with LHP's
  - Independent review team appointed to investigate
  - New LHP implemented for ABI – uses ammonia instead of propylene and has titanium wicks instead of nickel wicks
- Will be addressed further in panel discussion
- ABI still returning good data on most of its channels

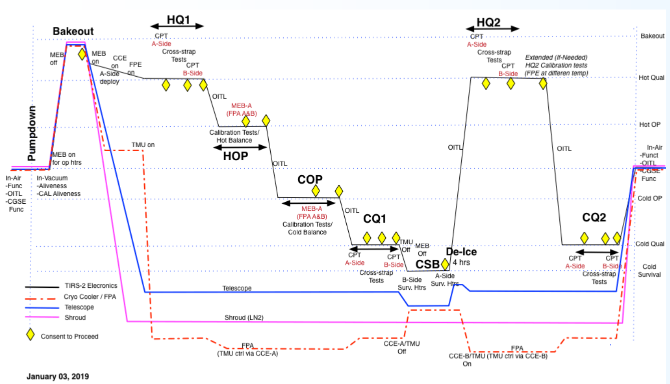
GOES-T,U delayed about 2 years to implement new ABI/LHP design, launch in the 20's

TIRS-2 i-Tvac #1





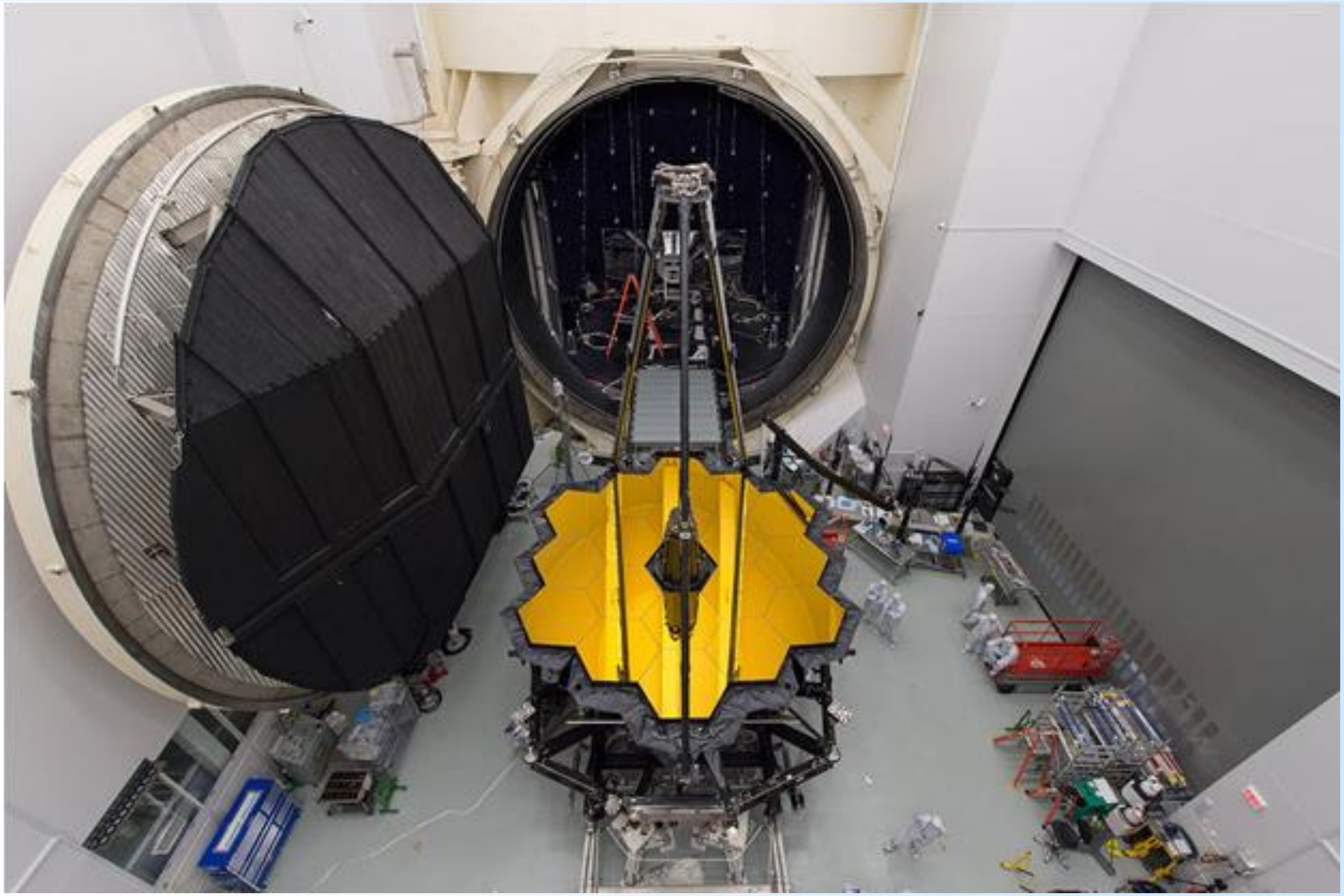
- TIRS-2 Instrument-level Tvac #1 consists of the following:
  - Testing in Chamber 225 at GSFC Bldg 9 I&T complex
  - Two cycles, including cold survival
  - All flight hardware included except the Earthshield (removed due to size)
- Test Profile:



Thermal Objectives

- Subject the instrument to thermal test environments that conservatively simulate the flight hot and cold environments to directly prove the thermal design.
- Verify that the thermal control system will maintain instrument within its thermal design limits.
- Verify that the thermal control system will maintain thermal stability under worst case transient conditions.
- Verify that the thermal gradient requirements are met under worst case operational conditions.
- Obtain three thermal balance points to validate the thermal design & detailed model used to predict on-orbit flight temperatures.
- Demonstrate Operational heater duty cycles less than 70% and 100% in worst cold case at nom & low bus voltages, respectively.
- Demonstrate Survival Heater duty cycle less than 70% in worst cold case at low bus voltage.
- Narrow the range of effective emittance for flight blankets used in analysis.
- Verify Interface heat flows from SC-to-TIRS2 are within requirements.
- Confirm Heat transport capability for heat pipes and heat straps.
- Determine radiator heat rejection margin in worst case environments.
- Provide confidence that the instrument will survive the thermal environment.
- Verify that all flight sensors operate.
- Confirm A & B side Heater Operation.

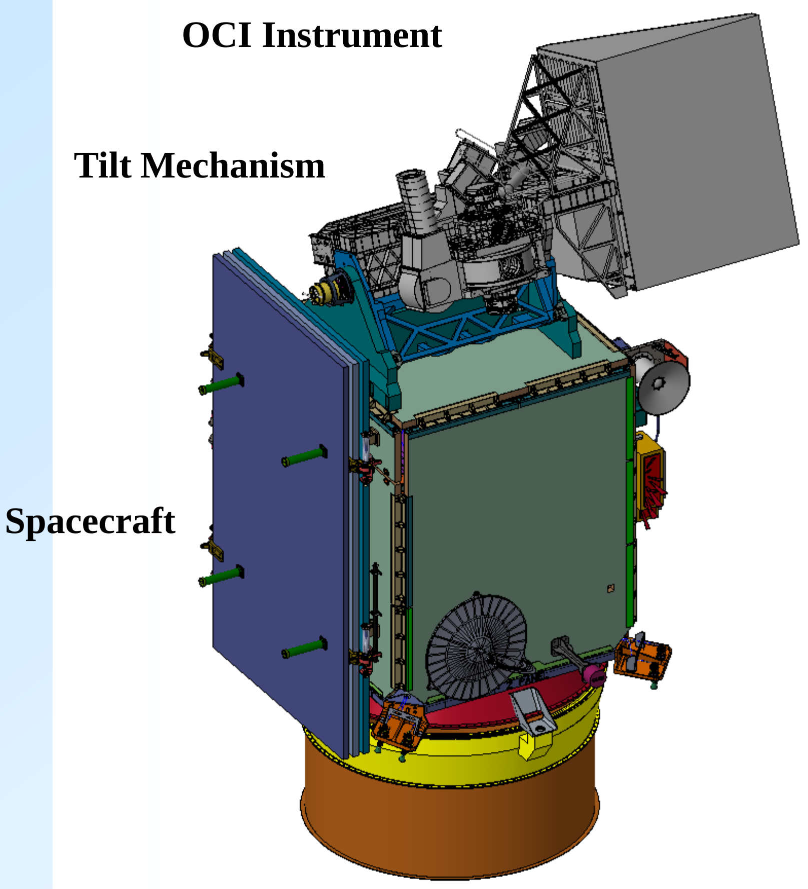
JWST STATUS


JWST Optical Telescope (OTIS) TV Test at JSC

JWST Status

- The JWST optical instrument element (OTIS) completed the thermal vacuum test at JSC, discussed last year
- Now all major elements of JWST are located at the Northrup Grumman (NGAS) facility in Redondo Beach
- The Spacecraft Element (SCE) recently successfully completed the vibration and TV tests
- Launch date is scheduled for March 2021

Ocean Color Instrument (OCI) on PACE Spacecraft



Plankton, Aerosol, Cloud, Ocean Ecosystem (PACE) Spacecraft will monitor the carbon budget and will provide information to better manage our fisheries and respond to harmful algal blooms

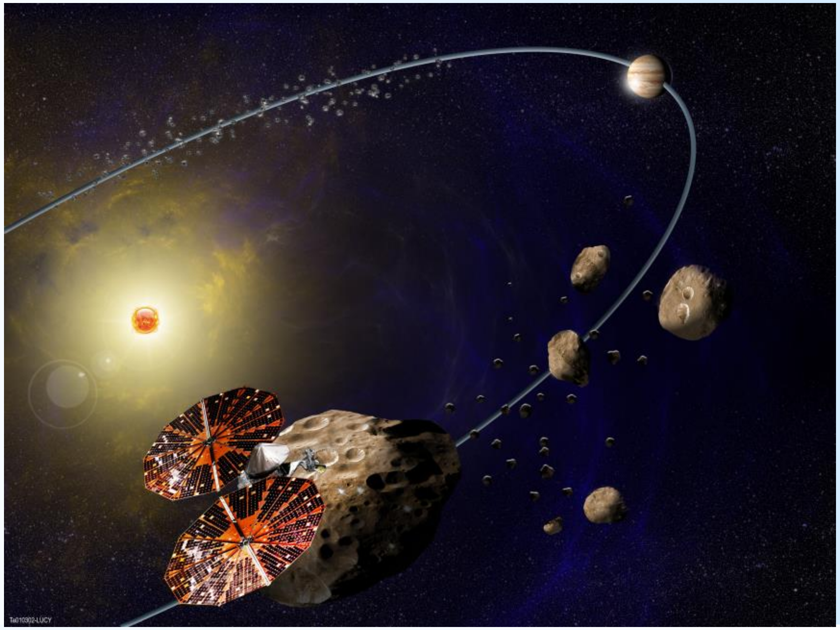
PACE Spacecraft and OCI being built in-house at GSFC, launch in 2022

OCI sits on tilt mechanism, +/- 20 Degrees

- OCI has Thermal Straps that transfer heat to its LHP
- LHP carries 20 W, operates at colder temperatures requiring propylene working fluid. Engineering Units currently being worked.

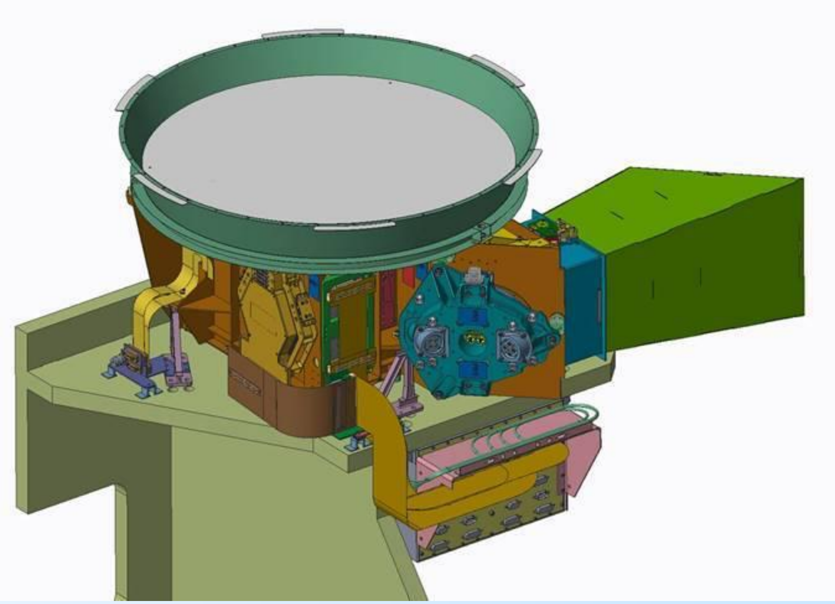
Lucy Mission

- LUCY will be the first mission to explore the Trojan Asteroids, Spacecraft will be built at Lockheed-Martin in Denver
  - Launch planned in Oct 2021, First asteroid flyby in 2025
- The mission takes its name from the fossilized human ancestor (called "Lucy" by her discoverers)



L’Ralph Instrument

- L’Ralph Instrument built in house at GSFC – similar to the OSIRIS/OVIRS and New Horizons Ralph instrument
  - Operates in mid cryogenic range, detectors about 100 K
  - Challenging thermally
  - Ralph is named after a character (Jackie Gleason) in The Honeymooners (1950s television show)

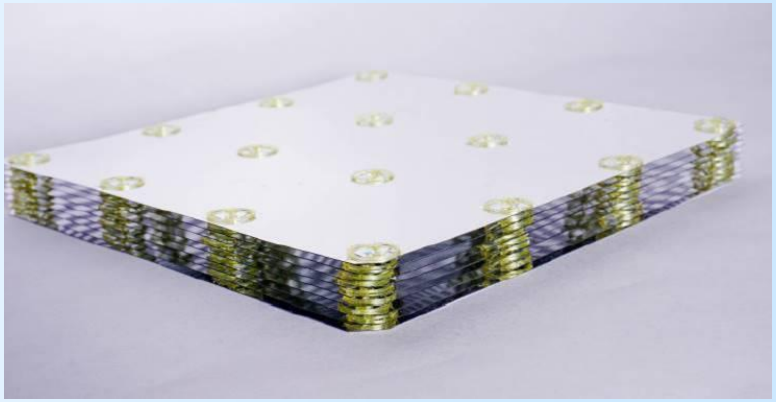


L’Ralph drawing

L'Ralph Instrument (continued)

Utilizes a diffusion bonded Cu strap to transfer heat from the IR detector assembly to the passively cooled radiator, which runs around 100K

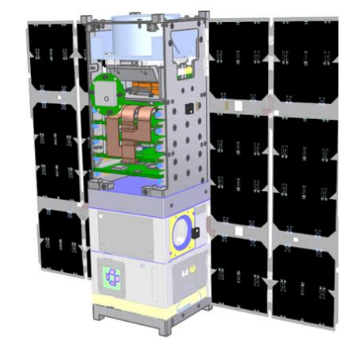
Plan to use an Integrated MLI cryogenic blanket to reduce thermal radiation parasitics.

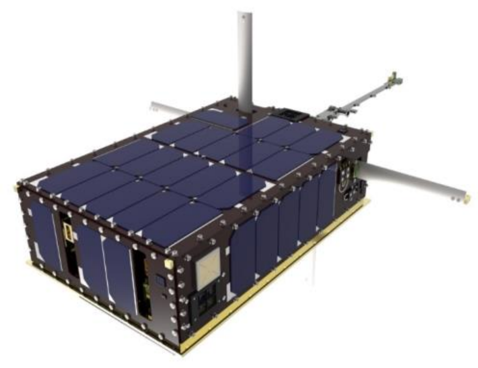


CubeSats at NASA

Offer an agile low-cost option for enabling scientific discovery, technology development, along with training and education for newer employees

- Provides opportunities for the development of compact and effective instruments and spacecraft components for science missions at relatively low cost
- Allows for faster science return in missions
- Serves as great experience for newly hired engineers
  - Work mission from start to finish within 1-3 years
  - Allows for a direct interaction between scientist and engineer
- Opportunities for collaboration with universities, research centers, and industry.

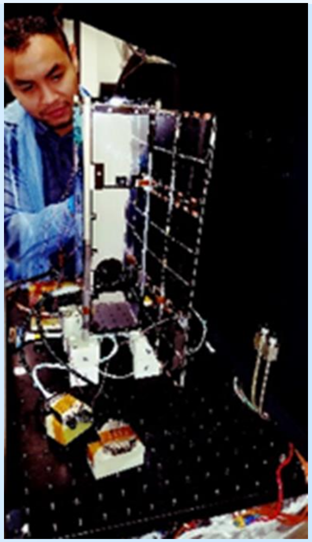


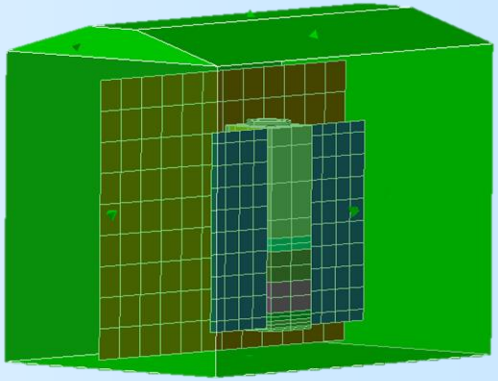


Dellingr-launched last year

Cubesat Design, Analysis, and Thermal Vacuum Testing

- CubeSat designs are becoming standardized at Goddard, using the Dellingr as a baseline. Work towards making them more affordable, reliable and requiring less time, while still providing valuable science data.
- The younger thermal engineer learns to interact not only with peer engineers but also with the project scientist.
- The relative short duration of the projects allows the engineer to have oversight of the complete thermal engineering cycle, i.e. from proposal to testing and launch.
- Valuable experience is obtained by the engineer by conducting the procurement, integration and testing mostly on his/her own.
  - The thermal engineer obtains a better understanding of the design through testing





Thermal Technology Development

- GSFC's SBIR Thermal Subtopic "rotated out" for 2018 call, but it is back in for 2019, so this year we don't have a lot to present
  - Participation from 3 NASA centers – GSFC, MSFC, and JPL
  - JPL will address their SBIR's in their talk
- JSC SBIR Thermal Subtopic still in for 2019 call
- Phase 1 call delayed due to furlough – call out now, proposals due March 29
- NASA employees in "Blackout period" – cannot discuss proposals with potential vendors

- Modest IRAD, Project and HQ funding received for other R&D activities

NASA/GSFC Thermal Subtopic Call

Advanced Thermal Devices

- High thermal conductivity, vacuum-compatible interface materials that minimize losses across make/break interfaces
- High heat flux acquisition and transport devices
- High performance, low cost insulation systems for diverse environments
- Durable, radiation stable, electrically dissipative, high emittance, low and high absorptance coatings at cryogenic temperatures below 50K

Radiator heat rejection turndown devices (e.g., mini heat switches, mini louvers)

Flexible Cryogenic Heat Pipes - Constant conductance heat pipes (CCHPs) operating below 90 Kelvin with the ability for repeated cycles of pipe flexing are needed.

Software Improvements for Integrated Thermal-Structural-Optical Performance (STOP) Analysis

- Improvement in existing STOP analysis codes is needed such that they can be applied to any optical system and integrated with mechanical, structural, thermal, and optical analysis software used at NASA. The improved code should be user friendly.

NASA/GSFC Thermal Subtopic Call (continued)

Advanced Thermoelectric Converter

- Thermoelectric converters (TECs) have advantages of small size, long life, solid state design, and no moving parts or fluid operation. This solicitation specifically calls for TECs for thermal cooling applications. Research and development in areas of advanced materials, processes, and designs are needed in order to improve efficiency and extend low temperature (< 90K) capability for space science application.

Approaches and Techniques for Surface Payload Survival through the Lunar Day/Night Cycle

- Expected Lunar science payloads with approximately 15 kilograms in mass and no more than 8 watts of continuous power. The lunar day/night cycle is approximately one earth month. The temperatures on the lunar surface can reach 400K at local solar noon or drop to below 100K during the lunar night, even colder in permanently shadowed regions

NASA SBIR/STTR Technologies

S3.07-8563 – Loop Heat Pipe Manufacturing via DMLS for CubeSat Applications

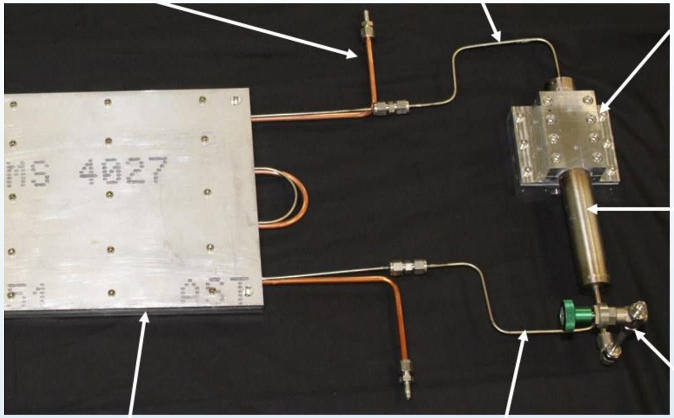
PI: William Anderson

Advanced Cooling Technologies, Inc. – Lancaster, PA

Identification and Significance of Innovation

It is estimated that the cost to produce a Loop Heat Pipe (LHP) pump assembly accounts for approximately 75% of the total system's manufacturing cost. By 3D printing an evaporator envelope with an integral porous primary wick structure, the overall complexity and cost of the design can be significantly reduced. One advantage is that the Direct Metal Laser Sintering (DMLS) method offers is that many aspects of the fabrication process can be simplified and dissimilar metal joints can be eliminated. In addition to the direct benefits, this novel fabrication method enables additional enhancements due to the inherent advantages of the additive manufacturing method which eliminates some restrictions of traditional machining, enabling structures that are more favorable from a thermal and hydrodynamic perspective. In Phase I, a LHP with a DMLS evaporator was built using ammonia as the fluid, and carried the predicted 45W.

Estimated TRL at beginning and end of contract: (Begin: 4 End: 6)



Technical Objectives and Work Plan

The overall objective of the Phase I and Phase II programs is to develop a low cost LHP, where the pump is fabricated by DMLS technology. In Phase I a proof of concept LHP was built with a 3D printed evaporator envelope with integrated primary wick. The overall objective of the Phase II program is to further develop the fabrication process for performance optimization with demonstration of a full scale LHP. A second LHP will be fabricated that is suitable for testing on the ISS. The 9 technical tasks listed below:

1. Define Requirements
2. Pore Radius and Permeability Study (to optimize DMLS parameters)
3. Scaling Study (to scale LHP evaporator)
4. Accelerated Life Testing
5. LHP Miniaturization (to fit on CubeSat/SmallSat)
6. Graded Wick Fabrication (to improve performance)
7. Secondary Wick Fabrication
8. Prototype Design of Complete LHP
9. LHP Fabrication and Testing (including thermal vacuum, and shock and vibration testing)
10. Flight LHP Fabrication and Testing (using working fluid that would allow for testing on the ISS)

NASA Applications

Ammonia and propylene LHPs are currently used in most NASA and commercial satellites. In comparison with Constant Conduction Heat Pipes (CCHPs), they carry much higher powers (1kW vs. 100W) over longer distances (10m vs. 2-3m). Their main drawback is that they are two orders of magnitude more expensive to fabricate and test than CCHPs. A major benefit of the proposed evaporator/wick fabrication will be a significant reduction in cost of LHPs supplied to NASA for SmallSat/CubeSat applications.

Non-NASA Applications

The benefits for the Air Force are similar to the benefits for NASA. The commercial communications satellite market is the current primary market for LHPs. Universities are able to fabricate their own CubeSats for research in space; however, their budgets are much too limited to allow them to use traditionally fabricated LHPs making inexpensive 3D printed LHPs desirable.

Firm Contacts

William Anderson
Advanced Cooling Technologies, Inc.
1046 New Holland Avenue Lancaster, PA 17601-5688
Phone: (717) 295-6061
Fax: (717) 295-6064

Thermochromics with Very Low Transition Temperature

FIRM: TRITON SYSTEMS, INC.

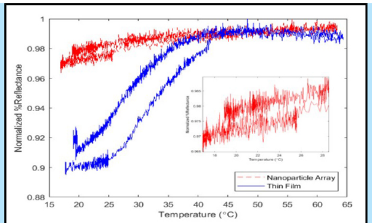
PI: Lawrence Domash   Proposal #:Z2.01-4863

SBIR · STTR America's Seed Fund POWERED BY NASA

NON-PROPRIETARY DATA

Objectives

- Triton with Vanderbilt University is developing a thermostatic skin for spacecraft
- Phase Change Thermochromic Radiator is based on the phase change material vandium dioxide
- Previous devices showed trigger temperatures from 68°C to 30°C but could not be reduced further without degrading the turndown performance
- Objective of Phase I was to develop a material process with much lower trigger temperature



Hysteresis of bulk thin film of VO2 versus new nanoparticle film shows lower transition temperature for latter

ACCOMPLISHMENTS

Notable Deliverables Provided

- In place of bulk thin films of VO2, a *nanoparticle* form was developed
- Nanoparticle VO2 accepts doping more readily than bulk film so transition temperature was reduced to 23°C with no loss in optical quality
- Other evidence gathered suggests that transition temperature may now be as low as -30° without impairment of turndown ratil

Key Milestones Met

Milestones Met

- Nanoparticle film prepared, doped and characterized
- Reduction of transition temperature observed as hypothesized

FUTURE PLANNED DEVELOPMENTS

Planned Post-Phase II Partners

Post Phase II Partners

- Hamilton Standard Space Systems

Planned/Possible Mission Infusion

Mission Infusion

- Nanosatellites
- Manned vehicles

Planned/Possible Mission Commercialization

Commercialization

- Energy conserving buildings

CONTRACT (CENTER):	80NSSC18P2183 (GSFC)
SUBTOPIC:	Z2.01 Thermal Management
SOLICITATION-PHASE:	SBIR 2018-I
TA:	14.2.0 Thermal Control Systems

TRL 1 2 3 4 5 6 7 8 9

Begin and End TRL is 2.

Atomic Layer Deposition (ALD)

Vivek.H.Dwivedi@nasa.gov - PI

Atomic
Layer
Deposition

A thin film "nanomanufacturing" tool that allows for the conformal coating of materials on a myriad of surfaces with precise atomic thickness control.

- Details can be found in Vivek's Presentation

Thermal Coatings Technology

Mark.M.Hasegawa@nasa.gov
Coatings Group Leader

Thermal Coatings Technology Focus

- Materials Development and Characterization
  - High α, low ε thin film coatings on various film substrates for stray light suppression
  - Oxygen plasma pretreatment for epoxy primer-silicate coating adhesion improvement
  - Primer processing development for improved cryogenic emittance performance of silicate coatings
  - Stress/shrinkage characterization of silicate coatings from vacuum and temperature exposure
  - Improved emittance for thin film Goddard Composite Coating (CC) – has tailored α, ε, based on needs.

- Flight Experiments
  - MISSE 10 ISS LEO Exposure of Innovative Surface Coatings - (28 samples)

Coatings Experiment on MISSE 10 on ISS

- 1 year LEO exposure with return to Earth: Ram (28 samples), Nadir (14 Samples), Zenith (14 Samples)
  - AO, UV and thermal cycling exposures on RAM: UV/Thermal on Nadir and Zenith faces
  - 0.625” diameter exposed coupons.

- Selection of materials for use on GSFC projects:
  - Improved white SBIR II silicate coatings (6)
  - Variants of CCAg (CC-Silver) and Multilayered CCAg (4)
  - SBIR II Thermochromic Vanadium Oxide - 2 systems (1)
  - Molecular adsorber systems (2)
  - Lotus super hydrophobic coating systems for dust mitigation (7)
  - Encapsulated Z93C55 (new on LCRD project)
  - Indium Oxide encapsulated white pigment using ALD methods
  - New transparent conductive coating
  - White LithiumFluoride based coatings
  - Z93C55 and Z93P controls

- Launched in November 2018, Deployment expected 1st Quarter 2019

Collaboration with the Smithsonian Institution Utilizing NASA's Molecular Adsorber Coating (MAC)

- Under a Space Act Agreement with the Smithsonian Institution, engineers at NASA/GSFC and museum conservators at the National Museum of Natural History are studying the effectiveness of a NASA developed coatings technology called the Molecular Adsorber Coating (MAC) for protecting cultural artifacts and natural science specimens
- MAC is a zeolite-based coating with a highly porous structure that was originally developed to passively entrap harmful outgassed species, and mitigate the effects of molecular contamination from degrading sensitive instruments and components for spaceflight applications
- The purpose of this collaboration is to investigate the use of MAC to protect mineral science and botany collection specimens from offgassed contaminants, such as mercury vapor. MAC samples were installed in the storage cabinets at the Museum Support Center (MSC) facility,.
- The samples were retrieved at various intervals and were evaluated to determine the offgassed species that were collected. The preliminary results were promising, and the team plans to continue further testing and run additional experiments.
- For more information about the MAC technology, please contact **Nithin Abraham,** nithin.s.abraham@nasa.gov

(Top) Nithin Abraham/GSFC is shown installing MAC samples in the storage cabinet at the Smithsonian facility. *Photo Credit: NASA/Chris Gunn*

(Left) Roy Deza/GSFC is shown using a mercury analyzer to detect the levels of mercury vapor inside the cabinets during the installation and retrieval of MAC samples. *Photo Credit: NASA/Chris Gunn*

(Right) Jenni Domanowski/GSFC and Nithin Abraham/GSFC are reviewing test data. *Photo Credit: NASA/Chris Gunn*

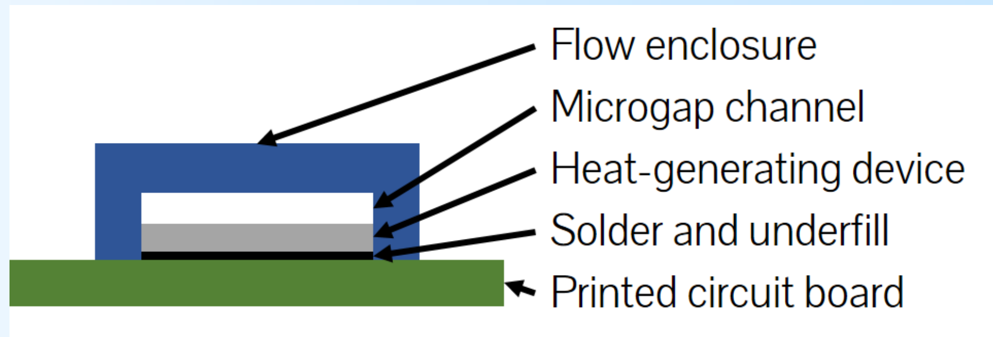
Gravity Effects in Microgap Flow Boiling

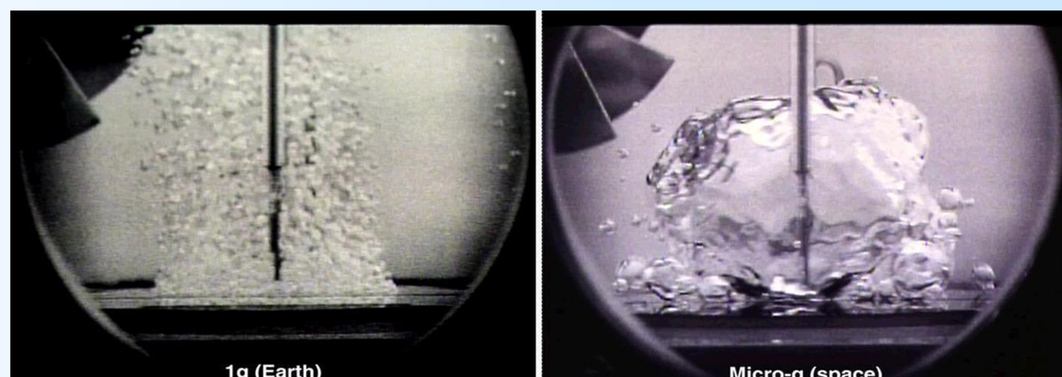
PI: Franklin Robinson (franklin.l.robinson@nasa.gov)

Co-I: Dr. Avram Bar-Cohen, University of Maryland

Motivation

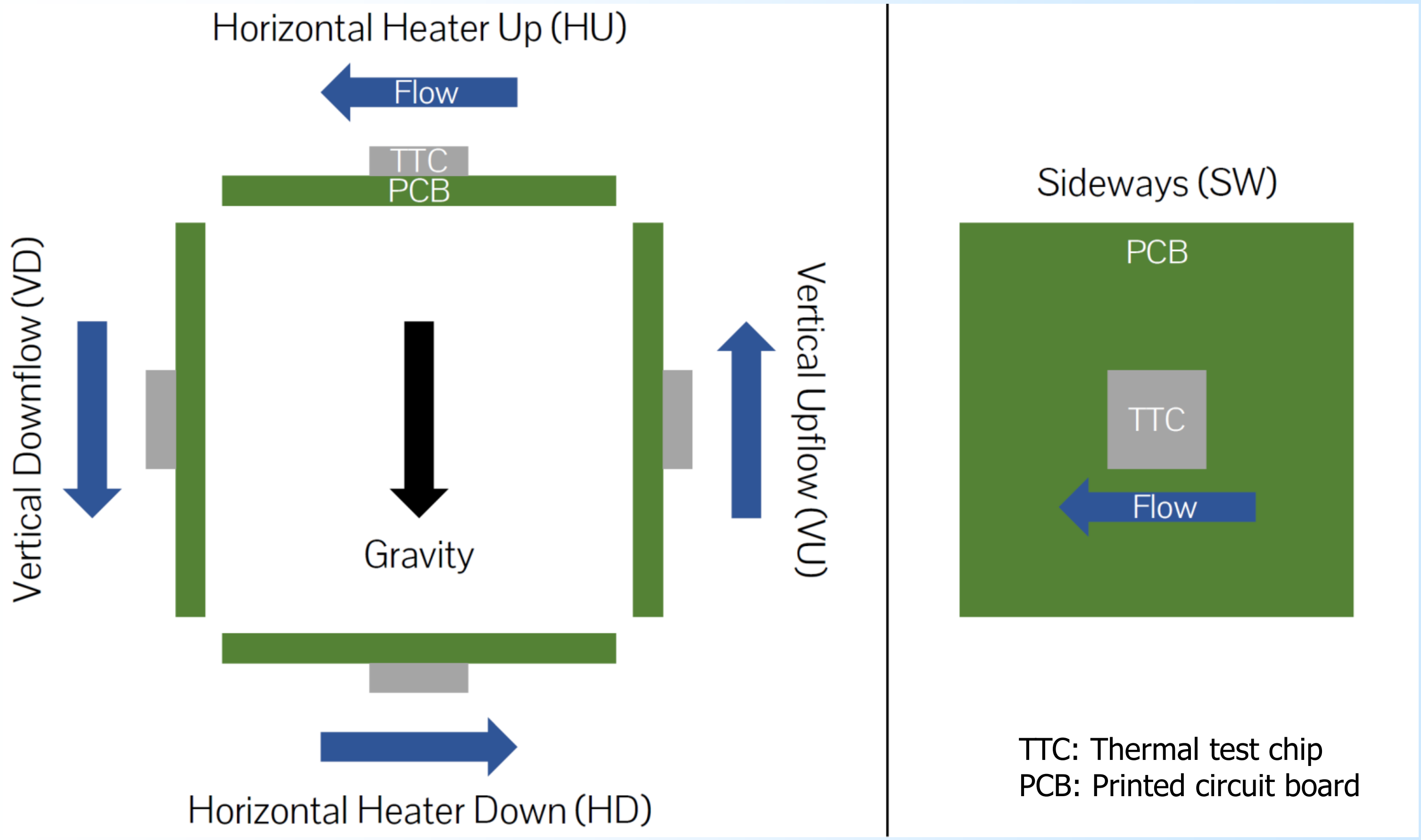
- Increasing power density of electronic devices necessitates better cooling
- Two-phase coolers provide high flux heat removal and low pumping power
- Versatile coolers must work reliably in all orientations, microgravity, and high-g



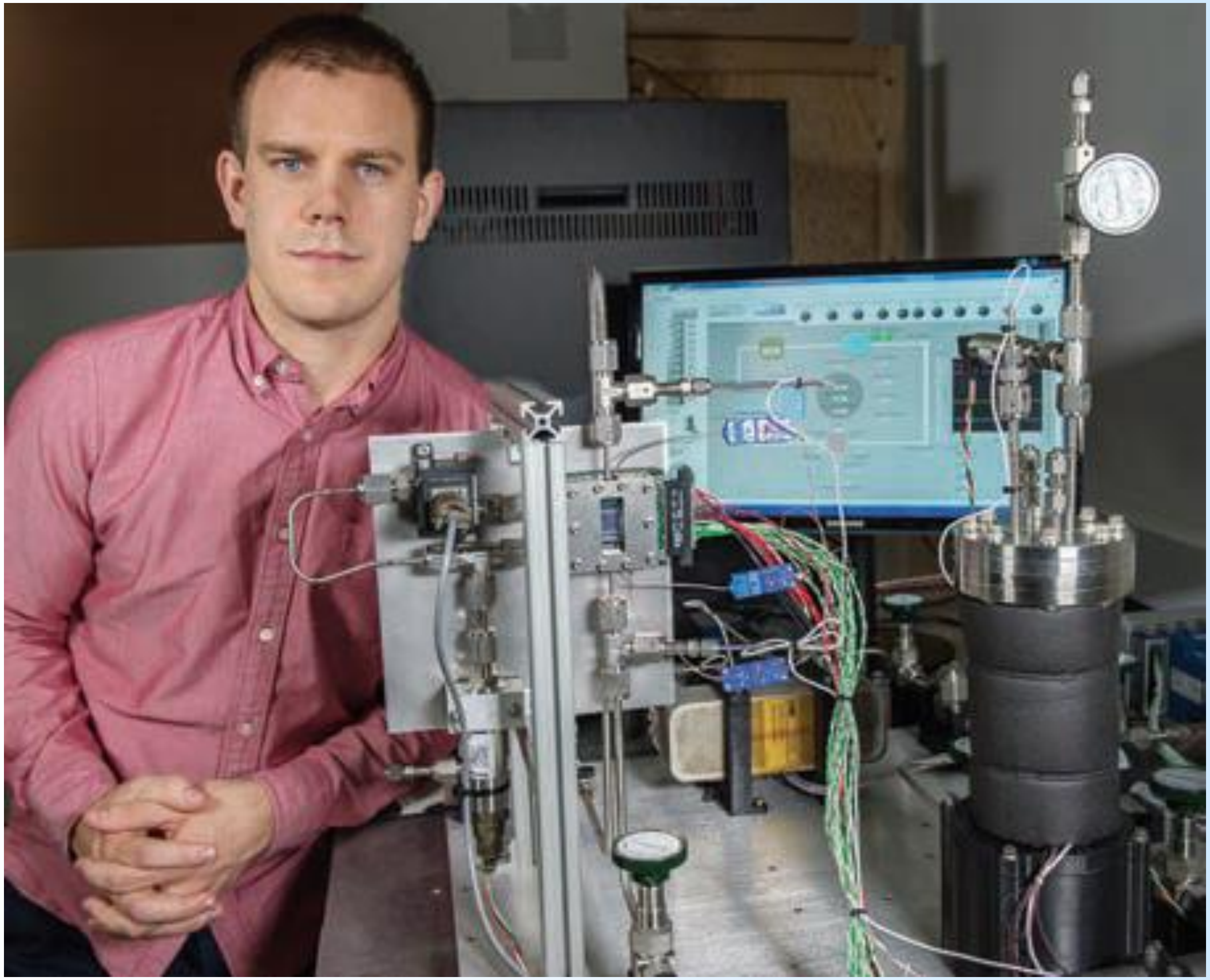


Dhir, Vijay and Warier, Gopinath. “Nucleate Pool Boiling eXperiment (NPBX).” (2018). https://www.nasa.gov/mission_pages/station/research/experiments/229.html.

Evaporator Orientations

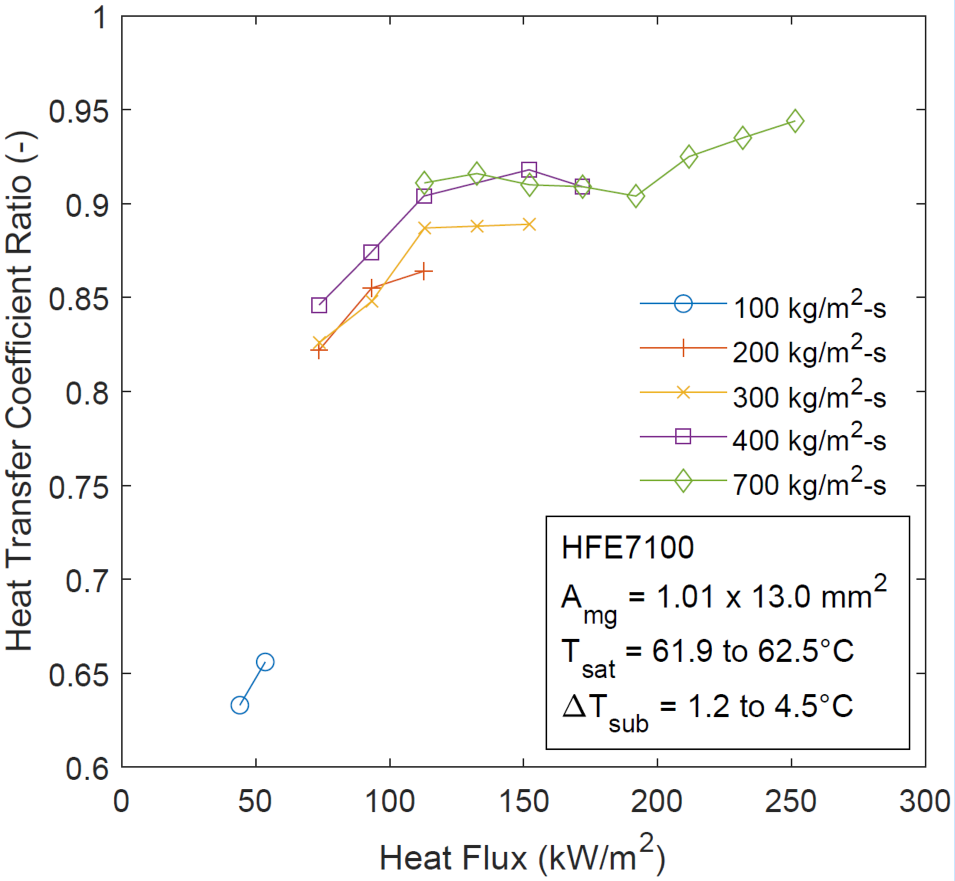


Frank Robinson (PI) with test hardware



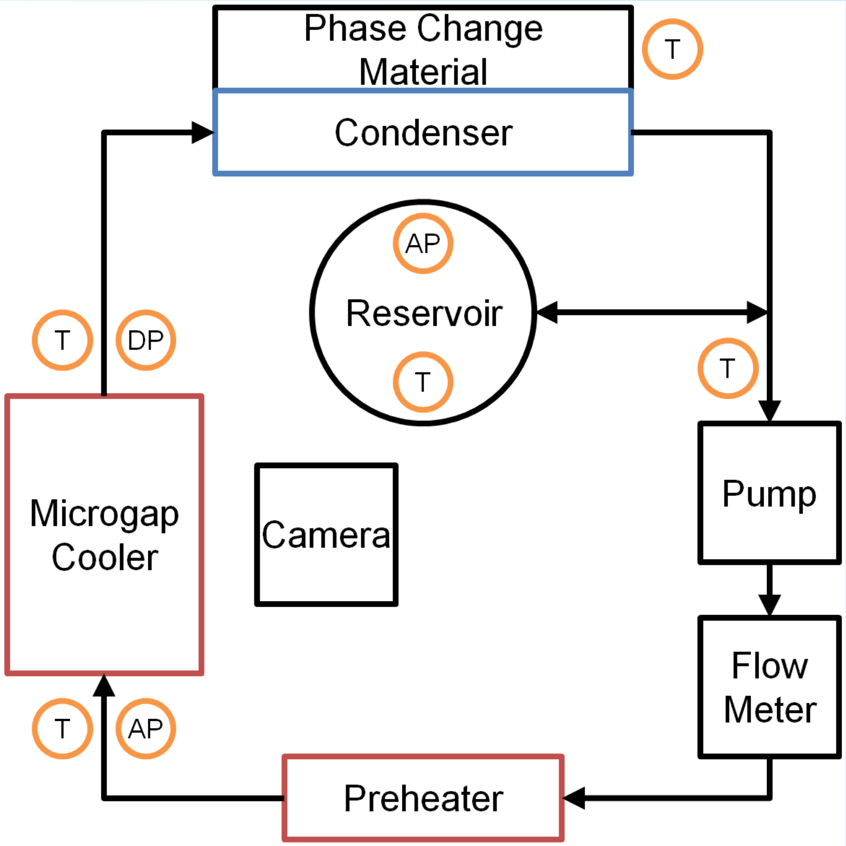
Ground Testing Results – HTCs and CHF

- HTC = Heat Transfer Coefficient
- CHF = Critical Heat Flux
- $HTC\ Ratio = \frac{HTC_{min}}{HTC_{max}}$
  - Among orientations
- HTC ratio approaches unity with increasing mass flux and heat flux
- < 10% variation in CHF among orientations at and above 400 kg/m^2-s



Suborbital Flight Test

- As similar as possible to ground test flow loop
  - Identical evaporator assembly
  - Same pump and transducers
- Constant flow rate, heat flux
  - Heat applied after achieving microgravity and during reentry



Suborbital Flight Experiment

- "Flow Boiling in Microgap Coolers" payload flew aboard Blue Origin NS-10 in Jan. 2019 (during furlough)
  - Three minutes of low-g
  - > 5g peak during re-entry
- Demonstrated consistent subcooled flow boiling in low- and high-g at low mass flux
- Data will be presented at a later date

Photo courtesy of Blue Origin

Electro-hydrodynamic (EHD) Technology Development

High Heat Flux, High Temperature Heat Acquisition

Jeffrey.R.Didion@nasa.gov
Senior Thermal Engineer
Manager, Nanotechnology Facility

– Details can be found in Jeff's Presentation

SUMMARY

- New Technology program underway at NASA, although funding is limited.
  - Push to increase use of smallsats/cubesats for science missions – possible technology demonstration opportunities as well
  - Projects are still the best source for applied technology funding.
  - SBIR science thermal subtopic discontinued in FY 18, but revived in FY 19
  - Limited Technology development underway via IRAD, NASA HQ, other sources
- NASA/GSFC's primary mission of science satellite development is healthy overall, new missions are in work – push for return to the moon will affect program
- Future mission applications promise to be thermally challenging, especially lunar missions.