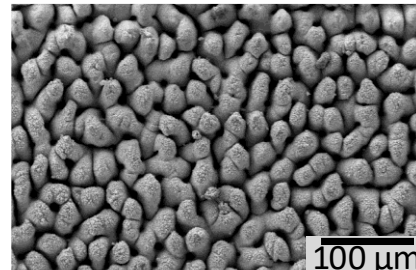


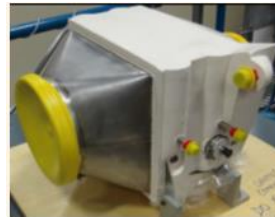
# A Review of Recent Advances in Heat Exchanger Technology and Future Applications



International Space Station (ISS)



Dual-pulse FLSP mounds on silver



ISS CHX



Laser processed CHX fins  
(FLSP on complex surfaces)

Tyler Hatch & Sarah Nguyen  
Low-gravity Exploration Technology Branch  
NASA Glenn Research Center  
ASGSR 2021

# Background

- Heat Exchanger concept: Transfers heat without transferring the fluid that carries the heat
- Heat exchangers are commonly found in air conditioning, humidity/environmental control, and multiphase fluid systems on Earth and space.

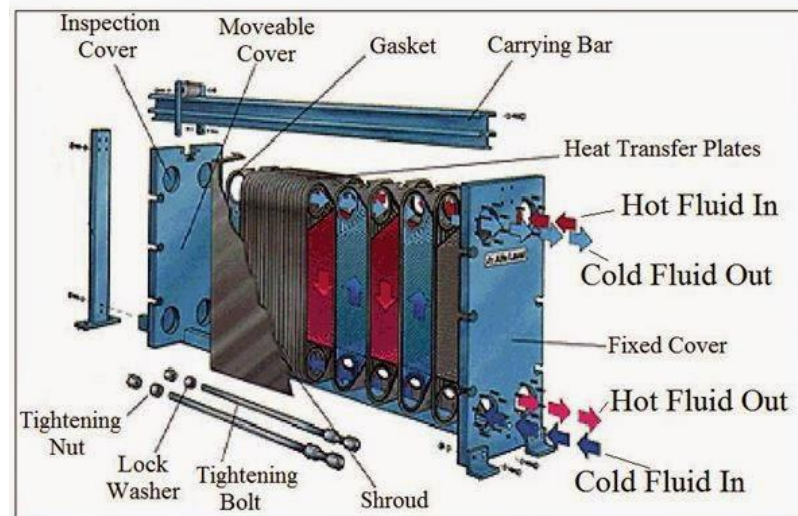
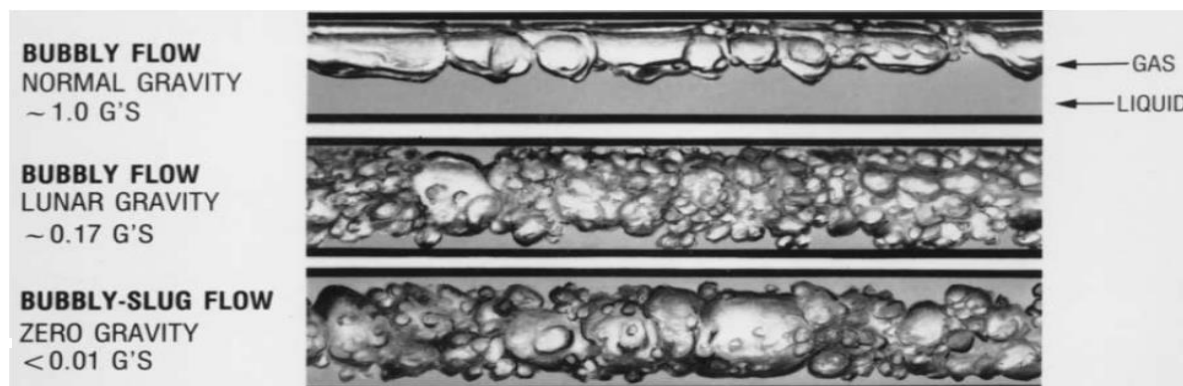


Plate and Frame Heat Exchanger Parts



## Background

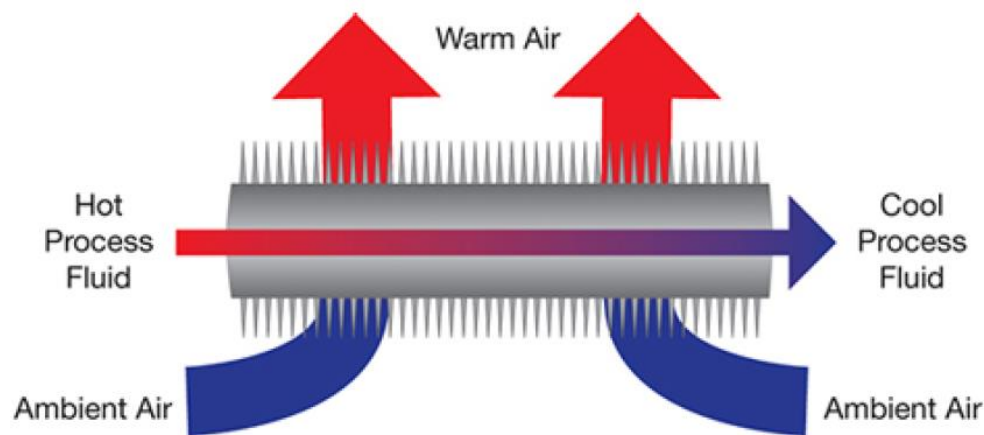
- Keeping these systems running consistently and with minimal repairs/downtime is a high priority for exploration life support.
- Recent advances in low gravity capillary fluidics can be applied to these systems and offer continuous operation in the event of a system pump failure or blockage.
- New laser processing methods can also be applied to drastically reduce microbial growth in heat exchangers



*Bubbly Flow in Variable Gravity*

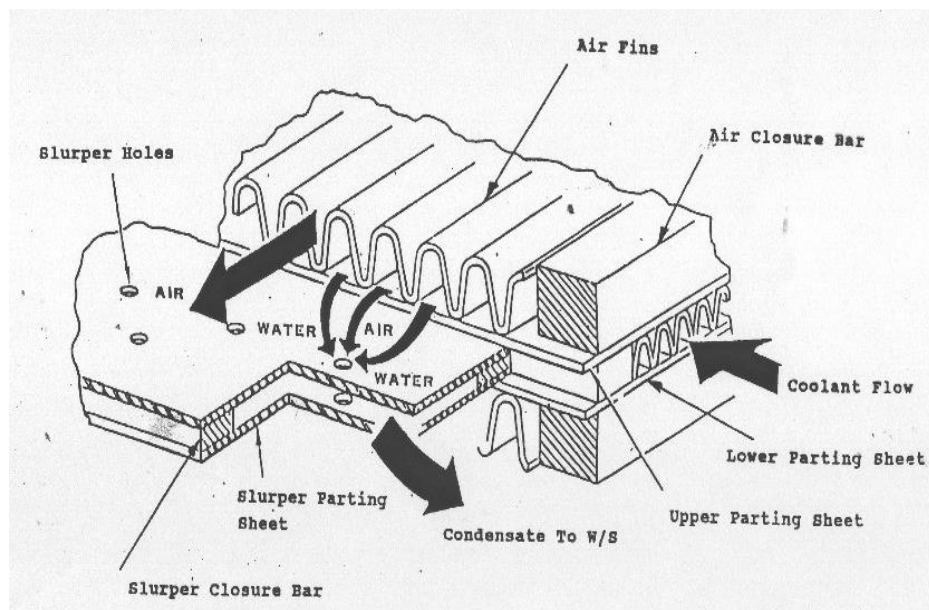
## Prior Work

- Current ISS Design
- CHESS – Condensing Heat Exchanger for Space Systems (*GRC/CSU effort*)
- Laser Processing Work (*Scott Hansen, JSC*)
- Other methods

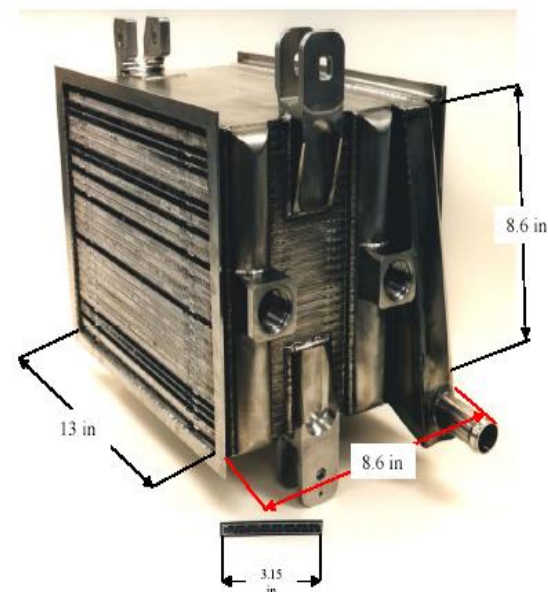


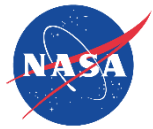
## Prior Work - ISS

- Two-step process
- Plate-fin heat exchanger to condense moisture
- Slurper-bar to collect condensate (water) with air
- Rotary separator to separate water using centrifugal force



**ISS & Shuttle CHX**





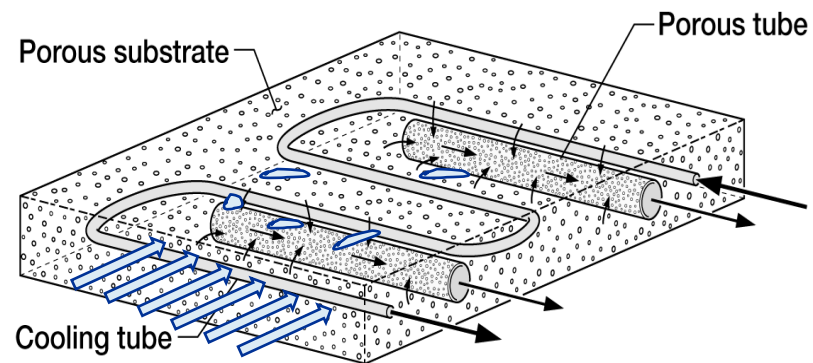
# Prior Work - ISS

- CHX are a critical function of closed-loop life support
  - Provide sensible and latent cooling to the vehicle
  - ~50% of reclaimed water on ISS is from CHX condensate
- Current technology utilizes a hydrophilic coating to gather condensate and control microbial growth in conjunction with a monthly dry-out. Slurper bars and water separator is used to draw condensate off the CHX, delivering it to the WPA
- Three problems with current technology
  - Coating longevity
    - Hydrophobic contamination turns hydrophilic surfaces hydrophobic leading to water carry-over
    - CHX's must be uninstalled and refurbished on a regular basis (significant crew time & resources)
  - Microbial and fungal growth concerns
    - Current coating utilizes silver oxide to mitigate microbe growth and must be dried out on a monthly basis to prevent bio-film formation
    - Potential for flaking, potential for hydrophobic contamination, and additional logistics tracking with MCC
  - Current coatings may react with airborne contaminants which may cause downstream impacts to WPA
    - Chemical reaction between contaminants and coatings which produce DMSD's that degrade filters in the WPA
    - Currently on ISS, WPA filters can remove compounds, but are degraded at an accelerated rate (replaced every year)

**To enable long duration spaceflight and reduce upmass/downmass  
a more robust CHX is needed!**

# Prior Work – Composite Porous Media Condensing Heat Exchanger Concept [CHESS]

- Highly conductive, cooled porous substrate to condense and imbibe moisture
- Hydrophilic substrate with sufficiently small pore size to hold condensate and to avoid film formation on the surface
- Embedded porous (saturated) tubes with a smaller pore size to selectively withdraw condensate from unsaturated substrate



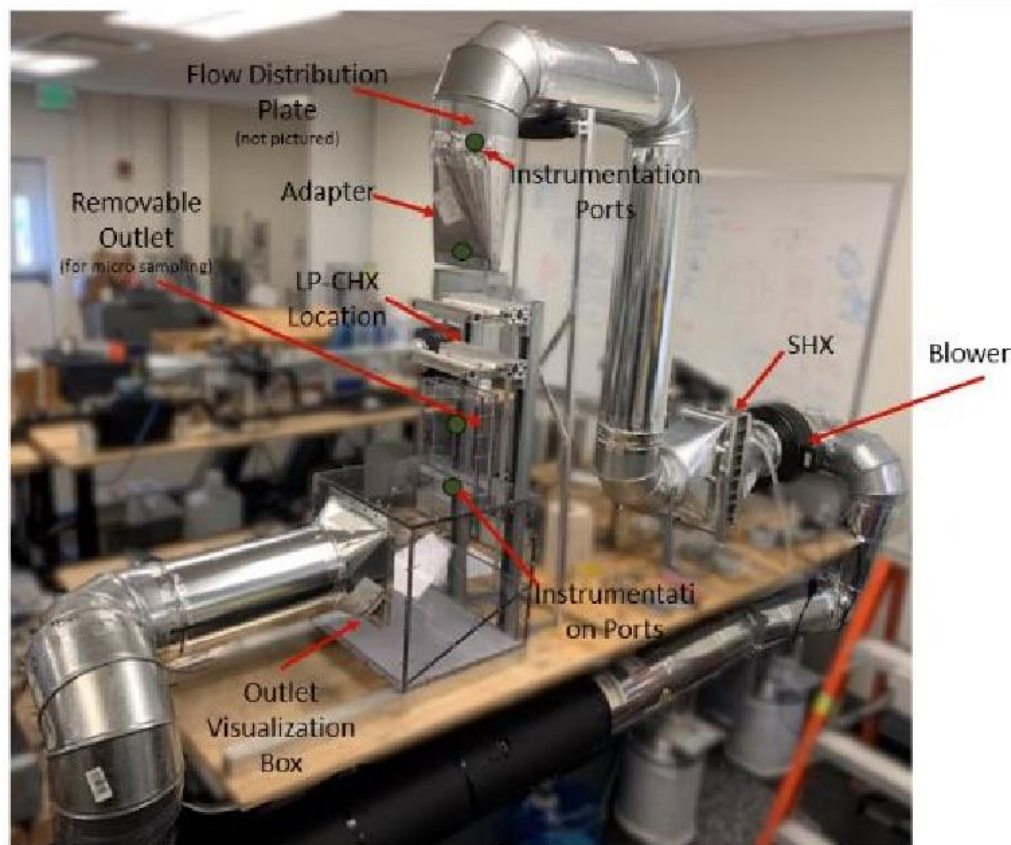


# Composite Porous Media Condensing Heat Exchanger Concept [CHESS]

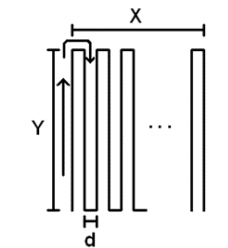
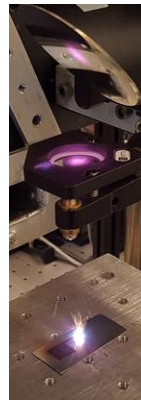
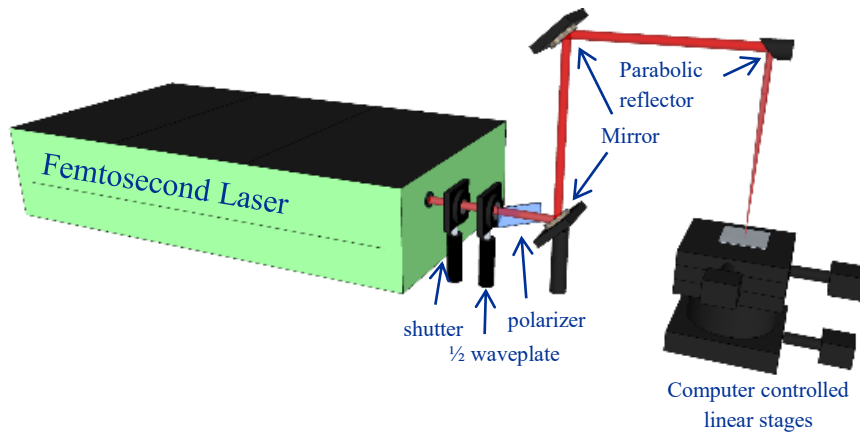
- Basic principles of operation of a porous media based condensing heat exchanger for humidity control have been successfully demonstrated experimentally
- Experiments using porous graphite plate as condensing surface have shown condensation and imbibition of moisture without formation of liquid layer on condensing surface
- Additional work is needed for optimized proto-type design (bio-fouling, material selection, geometry, etc.)
- In general, the system may be relevant to any micro or reduced gravity application such as distillation, water purification and fuel cells, where phase separation is necessary.

# Laser Processed CHX Work

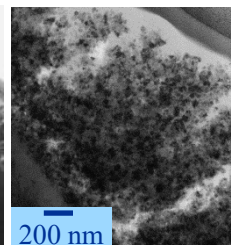
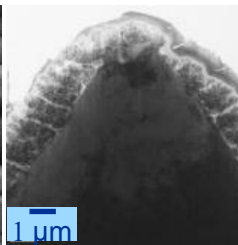
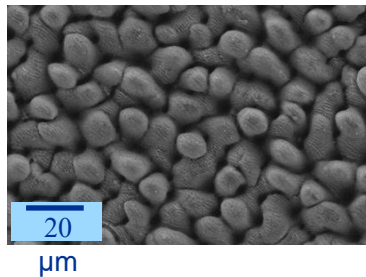
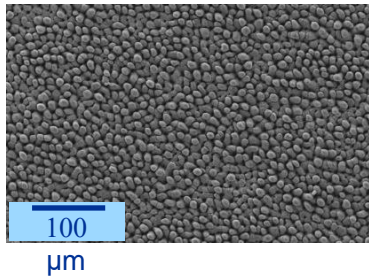
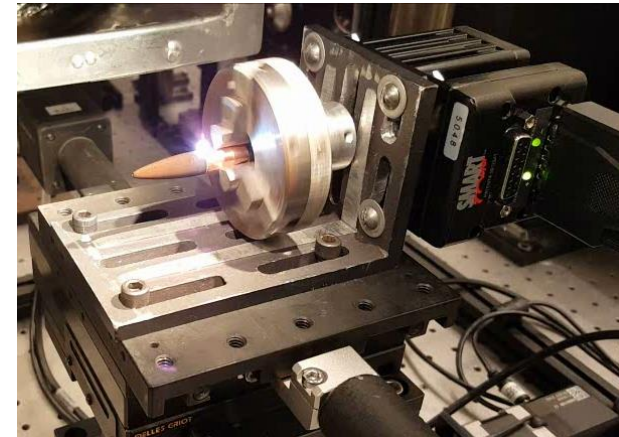
- Scott Hansen at JSC led this effort, with Edare/Creare and University of Nebraska-Lincoln
- Goal was to investigate microbial growth resistance with laser processed silver plates in CHX



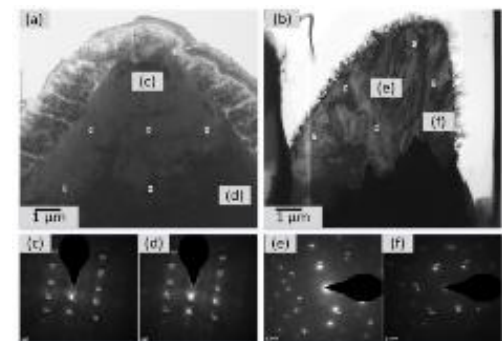
# Femtosecond Laser Surface Processing (FLSP)



Typical programmed raster scan path



Typical Structure: Increasing Magnification

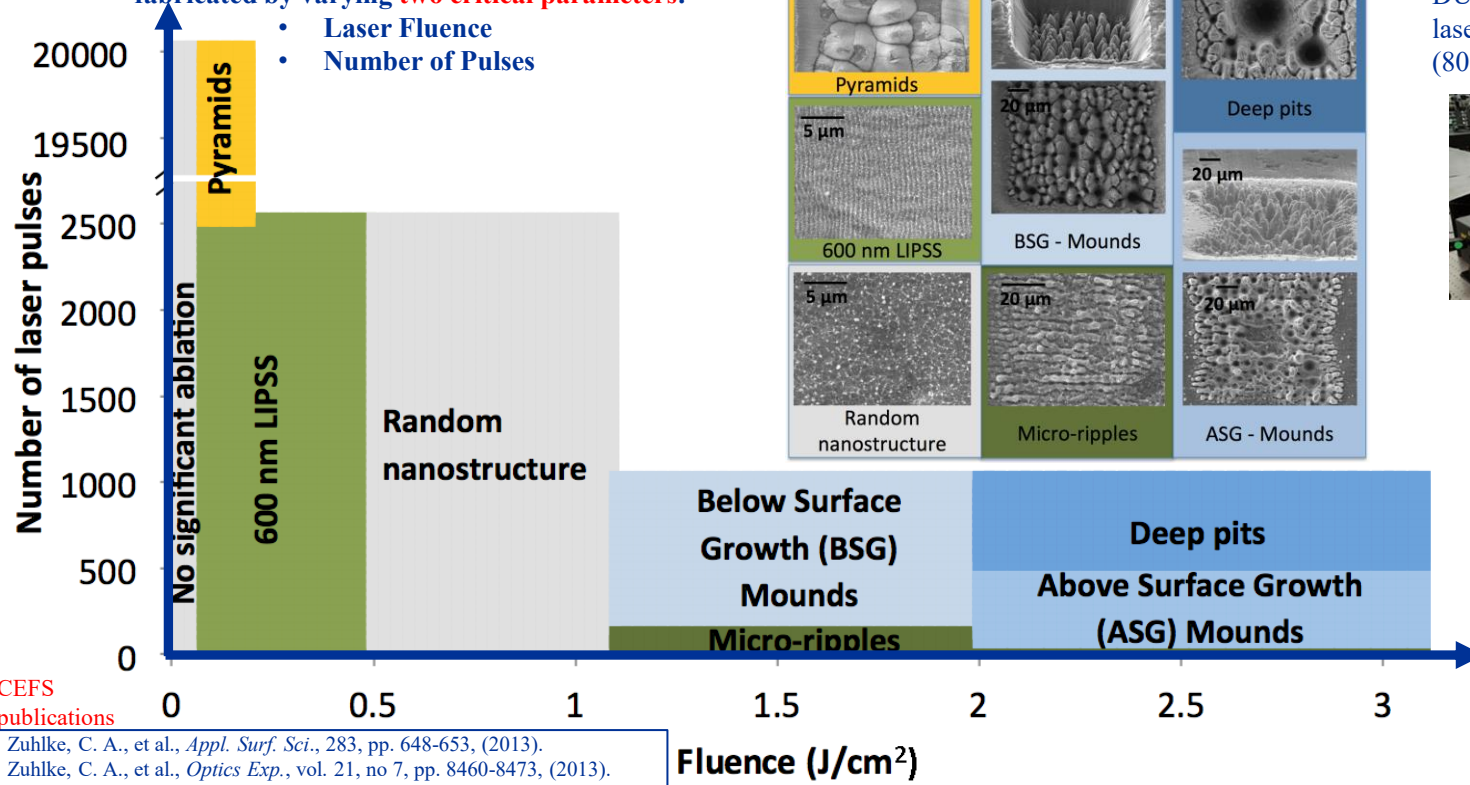


Internal crystalline structure

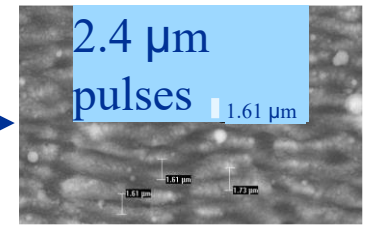
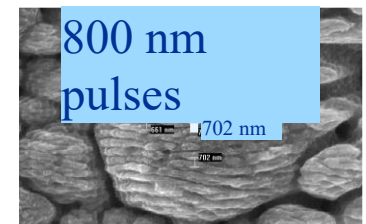
# Richness of Structures Produced by FLSP on Any Metal/Dielectric

A diverse range of unique surface structures can be fabricated by varying **two critical parameters**:

- Laser Fluence
- Number of Pulses



**Additional Critical Parameter:**  
 DURIP 2016 funded femtosecond laser adds ability to tune wavelength (800 nm – 15 µm)



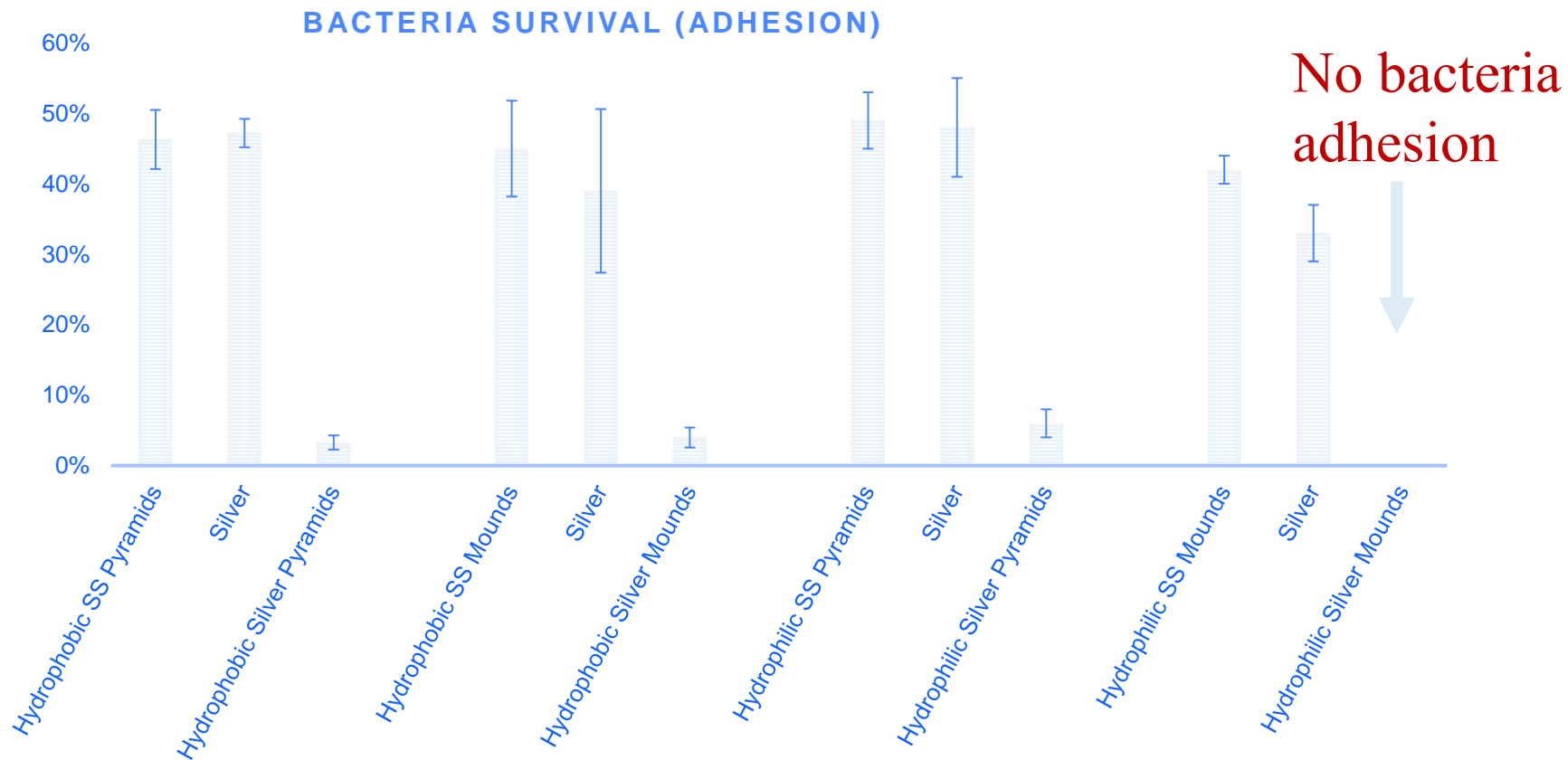
Laser induced periodic surface structures (LIPSS) on Al 5456

CEFS publications

- Zuhlke, C. A., et al., *Appl. Surf. Sci.*, 283, pp. 648-653, (2013).
- Zuhlke, C. A., et al., *Optics Exp.*, vol. 21, no 7, pp. 8460-8473, (2013).
- Zuhlke, C. A., *Dissertation*, University of Nebraska, (2012)



# Laser Processed CHX Work



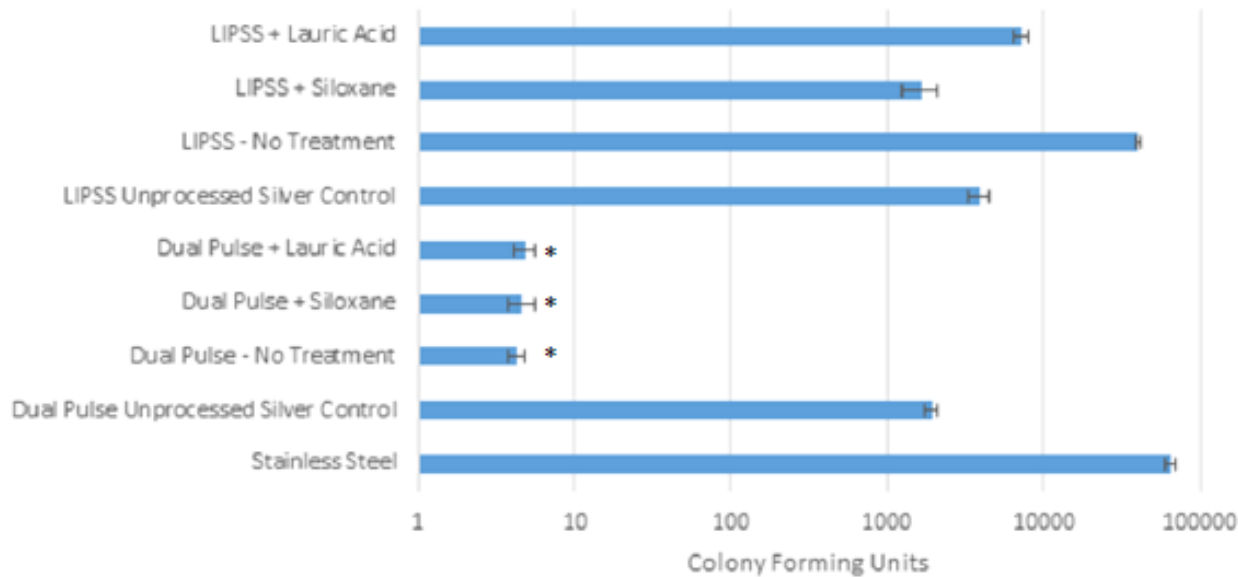
Bacterial consortium used in this study:

- *Bacillus megaterium*
- *Staphylococcus epidermidis*
- *Sphingomonas paucimobilis*



# Laser Processed CHX Work

## Bacterial Growth

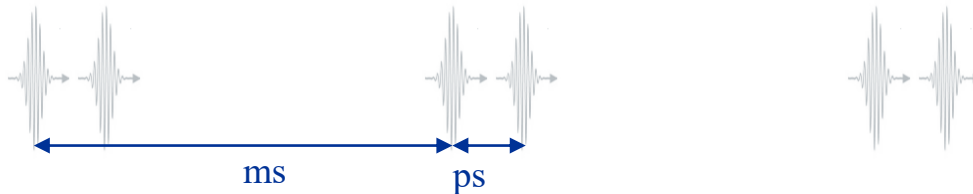


Research has shown a  $10^4$  times reduction in the number of growing microbial colonies with laser processed silver fins.

### Dual-pulse FLSP

Laser repetition rate: 1 kHz

Pulse length: ~35 fs

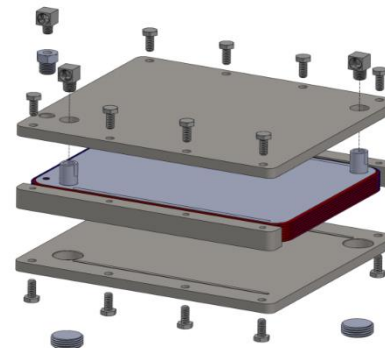
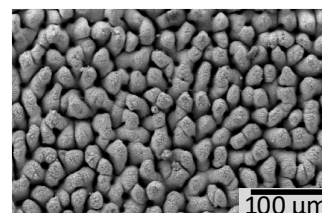


**In 2019 UNL was able to functionalize silver for the first time, that provides anti-bacterial superwicking surfaces for ISS CHX.**



# Future LP Work under Polaris:

- Development of a novel electroplating process to reduce LP-CHX manufacturing complexities, ultimately decreasing manufacturing time and cost by 18 months and >\$1M
- Deliverables of this project will be 1-3 full-scaled electroplated packets, microbial test, and a detailed LP-CHX manufacturing plan
- Gap Addressed
- Current CHX technology relies on a coating which prematurely loses its hydrophilicity leading to water carryover and ultimately premature CHX refurbishment
- Starting TRL: 4. Ending TRL: 4
- Major Project Milestones (Proposed Planned)
- Kickoff: Aug '21
- Electroplating Complete: Dec '21
- Laser Processing Complete: Feb '21
- Full-scale Modeling Complete: May '22
- Microbial Growth Study Complete: Jun '22
- Closeout: Aug '22



## Other CHX Work

- Paragon HX “Cosmic”
  - Solution to replace the ISS Common Cabin Air Assembly (CCAA) Compact Heat Exchanger Slurper and Water Separator
  - On ISS, the Slurper bar suffers continued siloxane chemical degradation that modifies surface hydrophobicity, resulting in inadequate performance.
  - In development, plans to be paired with JSC’s LP CHX for system-level testing



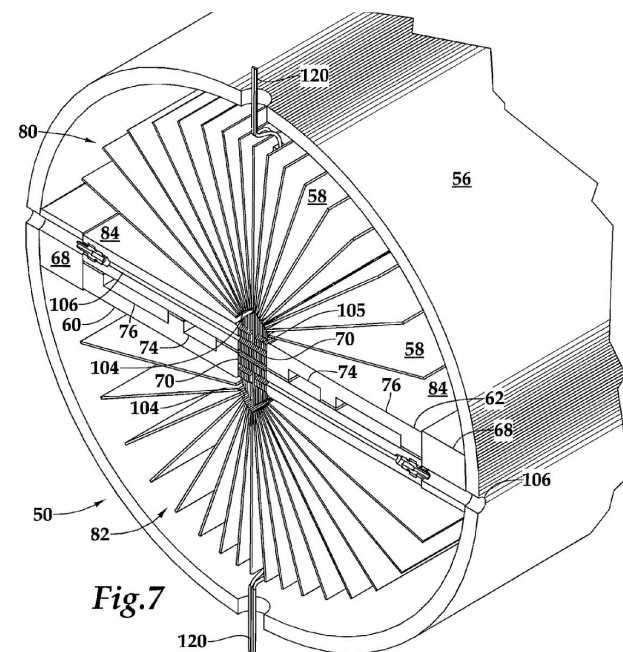
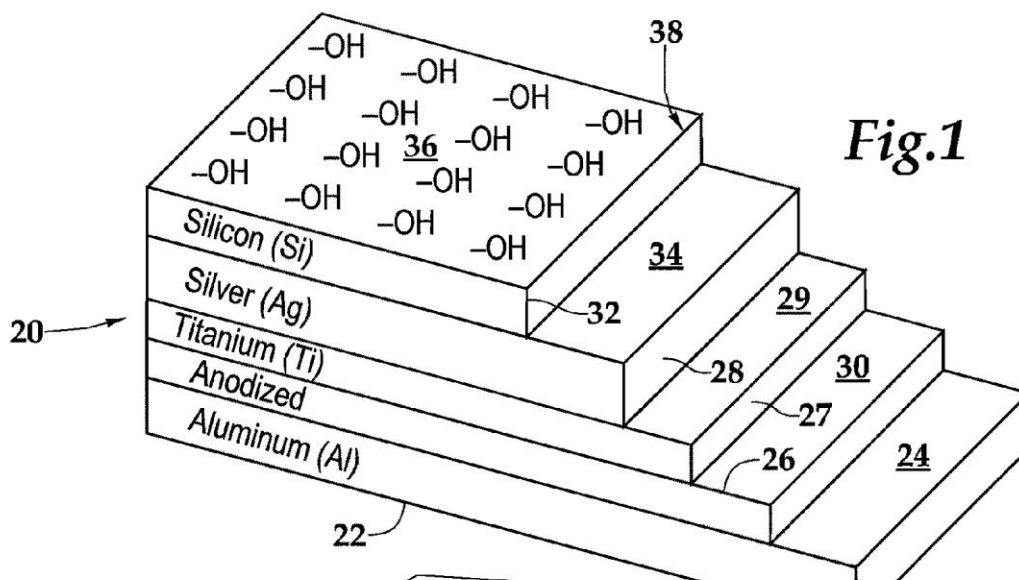
*COSMIC Phase I Concept*



*COSMIC Phase II Concept (Patent Pending)*

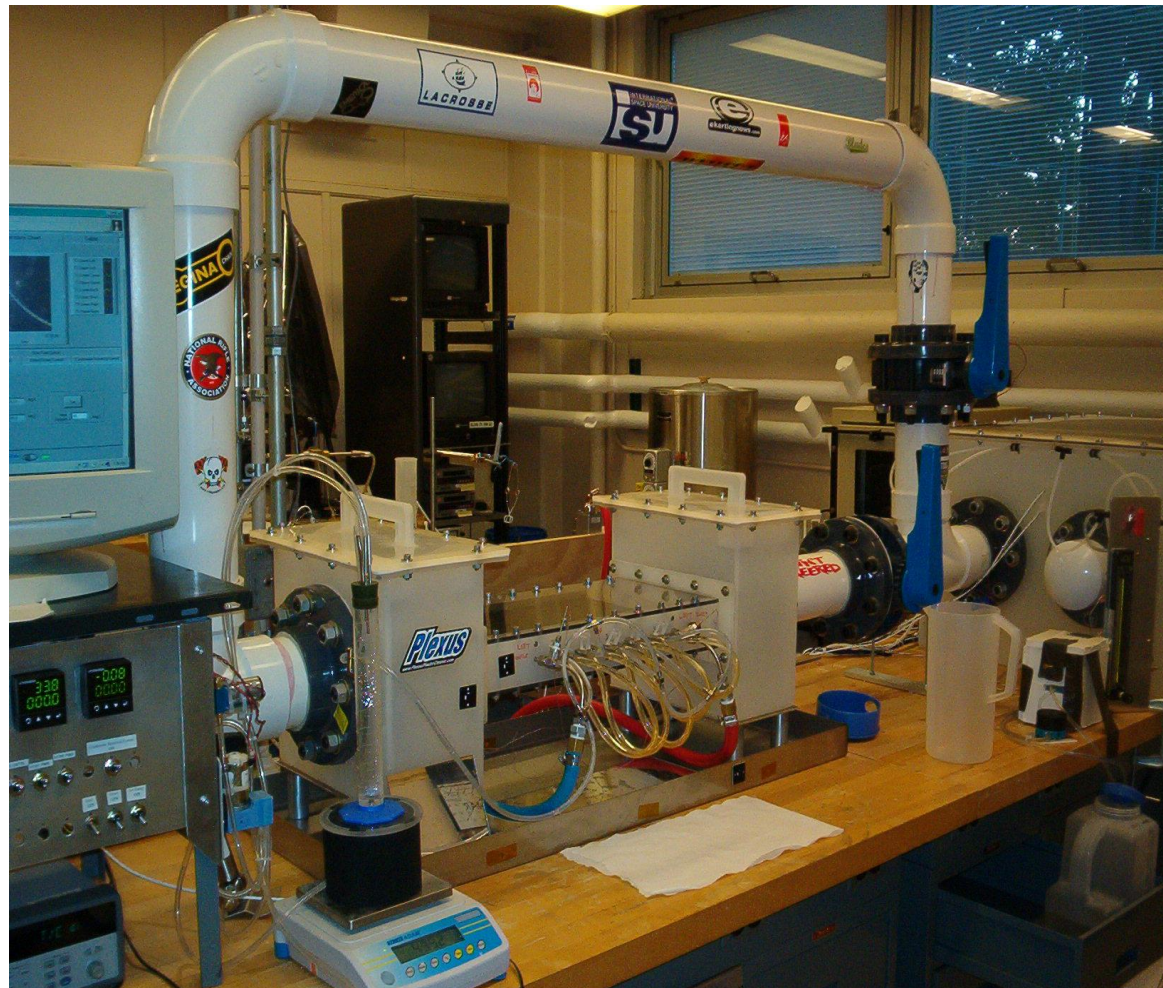
## Other CHX Work

- Mark Weislogel & co, Orbitech Patent for microgravity Hxer (~2011)
- Uses geometry to replace the role of gravity with coating similar to LP technique & hydroxyl groups



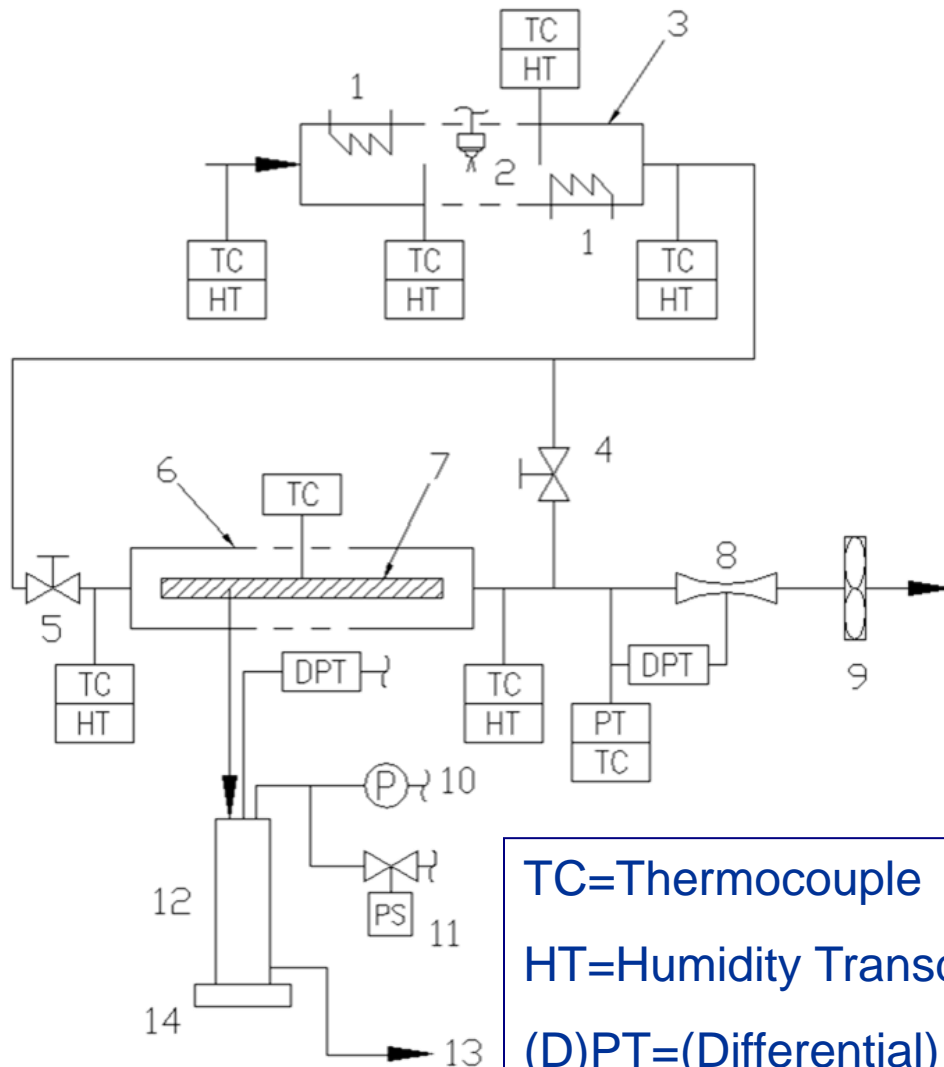
# Integrated Test Bed

- Inlet flow is conditioned
- Chilled water temperature controlled
- Condensate suction pressure
- Data acquisition system





# Integrated Test Bed Schematic

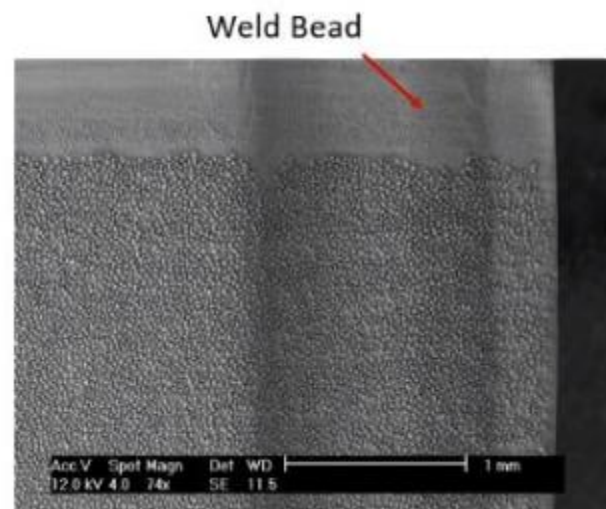
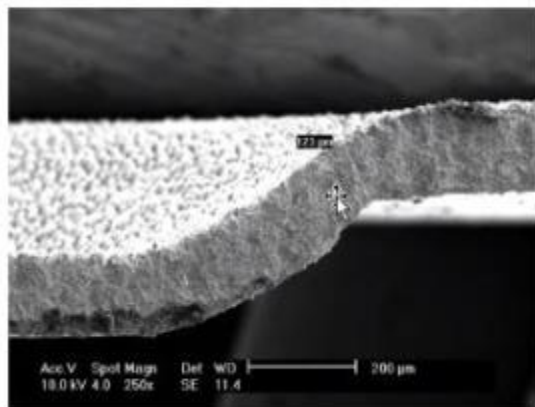
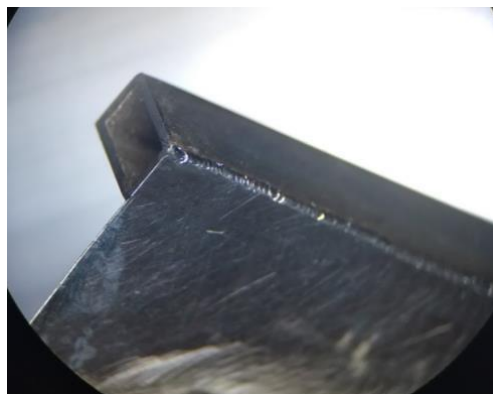


1. Heaters
2. Spray Nozzle
3. Conditioning Box
4. Bypass Valve
5. Test Section Valve
6. Test Section
7. Test Article
8. Venturi
9. Fan
10. Vacuum Pump
11. Proportional Valve
12. Graduated Cylinder
13. Condensate Drain
14. Balance

TC=Thermocouple  
 HT=Humidity Transducer  
 (D)PT=(Differential)  
 Pressure Transducer

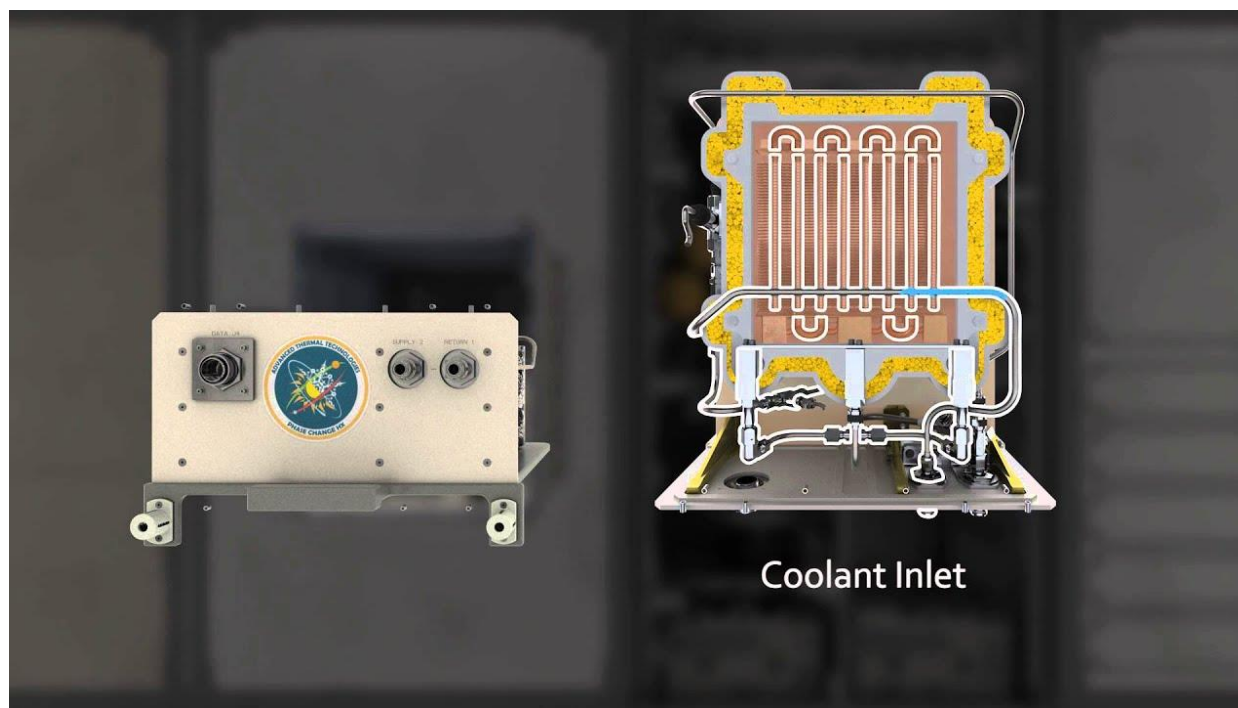
# Current Status

- UNL laser lab is manufacturing several test coupons made of sterling silver for testing at GRC to study hydrophobic to hydrophilic transition point and wetting characteristics
- Feasibility study for bending/machining of LP coupons after laser treatment (prone to warping)
- Electroplating Study will be performed later this year for manufacturing
- Will begin work on thermal model and assembly of 3 electroplated packets next year



## Other Work To Mention

- Phase Change Materials (PCM)s
  - Wax and water based PCM Hxers for heat rejection capabilities
  - Currently at TRL 5 after ISS demo
  - Upmass scaling is too high for Orion, Gateway use





# Acknowledgements

- **CHESSTeam**
  - Dr. Mojib Hasan (NASA GRC), Prof. Lutful Khan (Cleveland State University), NASA GRC Center Innovation Fund (CIF) Team
- **LP-CHX Team**
  - Scott Hansen (NASA JSC), Dr. Sarah Wallace (NASA JSC)
- **Polaris Team**
  - Scott Hansen, Sarah Wallace, Edare Inc., NASA Advanced Exploration Systems (AES) & Habitation Systems Teams
- **Femtosecond Laser Processing**
  - Prof. Craig Zuhlke (University of Nebraska-Lincoln)



# Thank you!

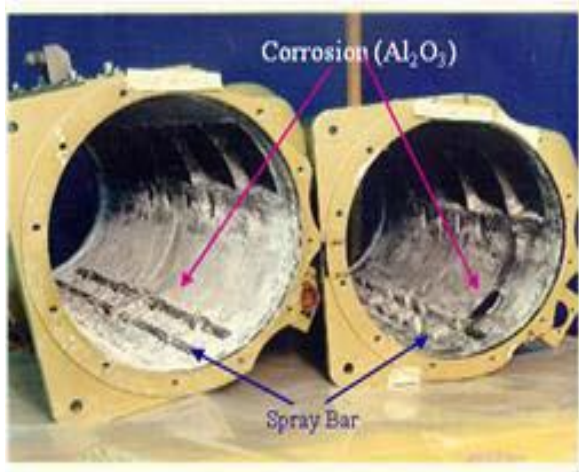
## Questions?



# Backup Charts

# Technical Maturation

- Further research could address siloxane impact from water recovery
- Siloxanes can become trapped inside the ISS heat exchanger and precipitate out from the water, causing blockage and leading to microbial growth in some areas, in addition to corrosion of the hardware
- CHES-LP could be used as a testbed for future investigations in this area



*Figure 5. Siloxanes corrosion in STS heat exchanger*