Impact of Thermochromic Coatings on Thermal Management for Human Spacecraft Applications

Joseph Peoples*, Sydney Taylor**, Christopher Massina**, and Xiulin Ruan*

*Purdue University
**Johnson Space Center

Presented By
Joseph Peoples

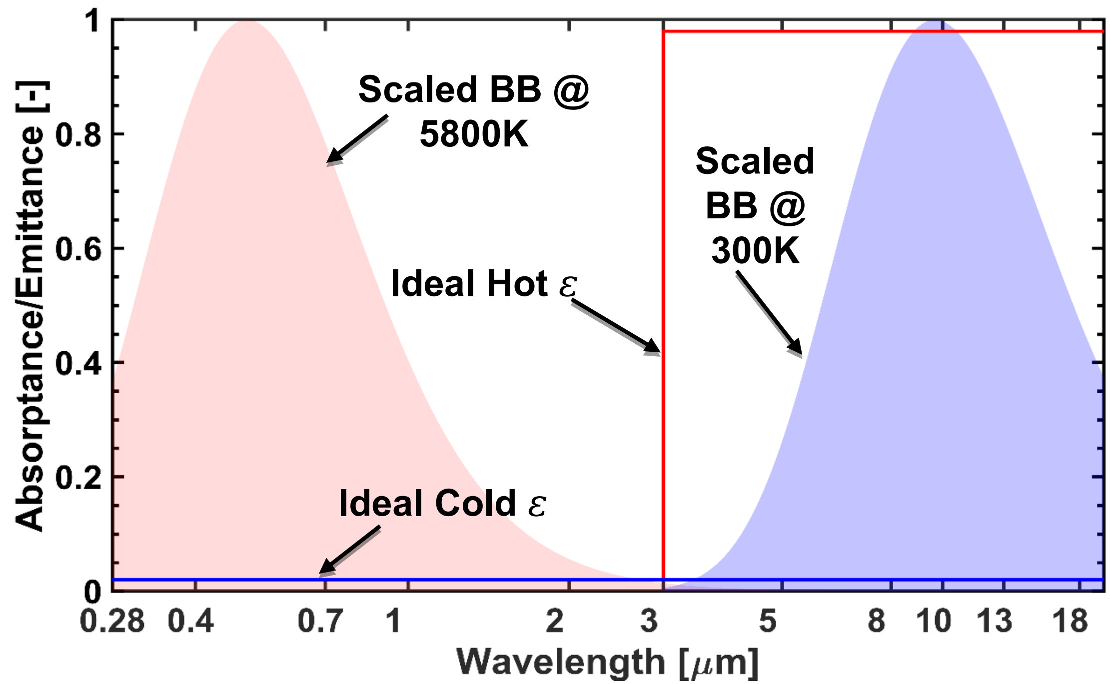
Thermal & Fluids Analysis Workshop
TFAWS 2021
August 24-26, 2021
Virtual Conference

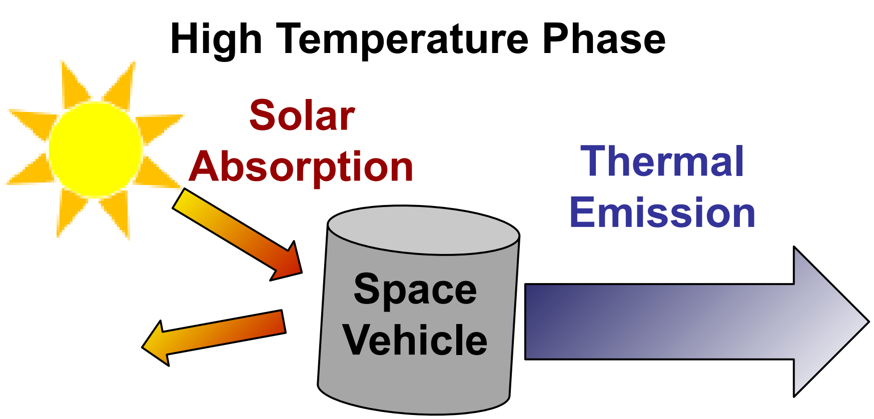
Outline

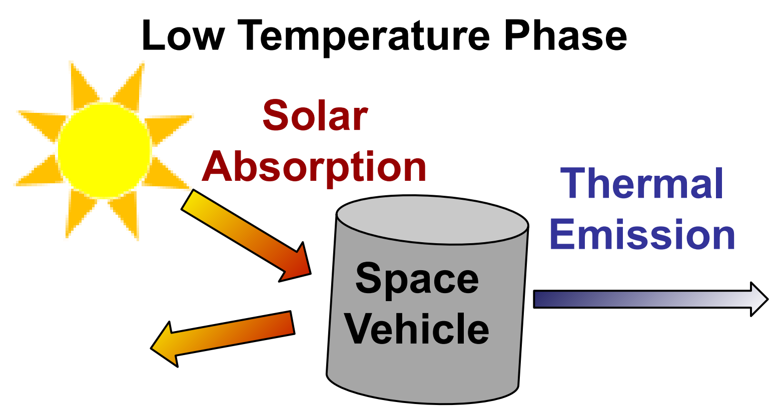
- Motivation and Background
  - Ideal Variable Emitter
  - Thermochromic Material: Lanthanum Strontium Manganite
  - Solar Reflective Material: Barium Sulfate
  - Micropatterned Thermochromic Coatings
- Design Parameters for Micropatterned Coatings
  - Dopant Dependent Transition Temperature
  - Coupled Solar Absorptance and Variable Emittance
- Thermal Desktop Modeling
  - Representative Radiator Design and Setup
  - Transition Temperature Study
  - Absorptance vs Emittance Study
- Conclusions and Future Work

Motivation: Ideal Radiator Coating

- Thermochromic Coatings have temperature dependent emissivity
- Deep Space is considered an infinite heat sink at ~3 K
- Extraterrestrial Solar Irradiation is ~1400 W/m^2
- Ideal: $\varepsilon_{cold} = 0$, $\varepsilon_{hot} = 1$



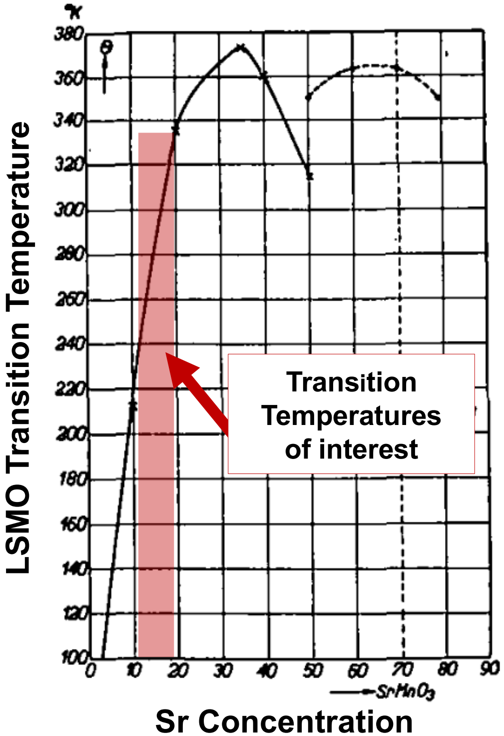




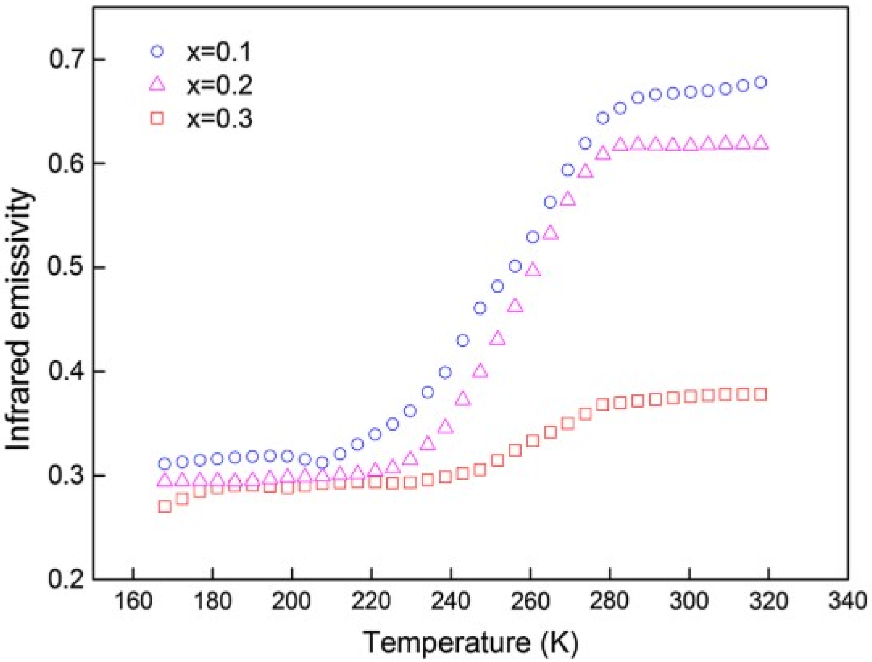
Thermochromic Material: LSMO

- Lanthanum Strontium Manganite (LSMO)
  - Temperature Dependent Variable Emittance
    - $La_{1-x}Sr_xMnO_3$
    - Sr is a dopant in the $LaMnO_3$ which can change the transition temperature as well as the emittance
    - α = 0.7 in bulk phase

Source: https://bit.ly/31ca7Zn



Jonker, G. H., & Van Santen, J. H., *Physica,* (1950).

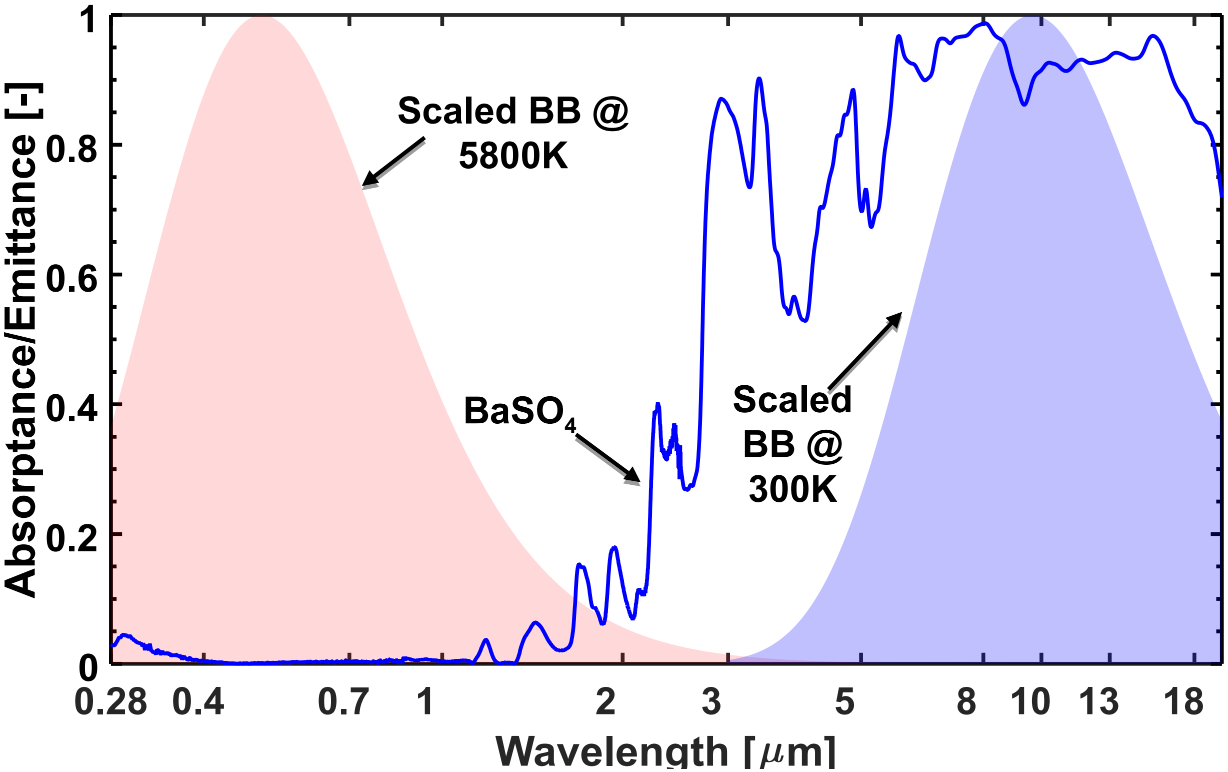


Wang, C. B., et. al., *Journal of Materials Science*, (2015).

Solar Reflective $BaSO_4$

- Barium Sulfate ($BaSO_4$) highly solar reflective
  - White paint form
  - $\alpha = 0.03$, $\varepsilon = 0.92$
  - Other typical white paints
    - $\alpha \sim 0.15\text{-}0.2$
    - $\varepsilon \sim 0.8\text{-}0.9$

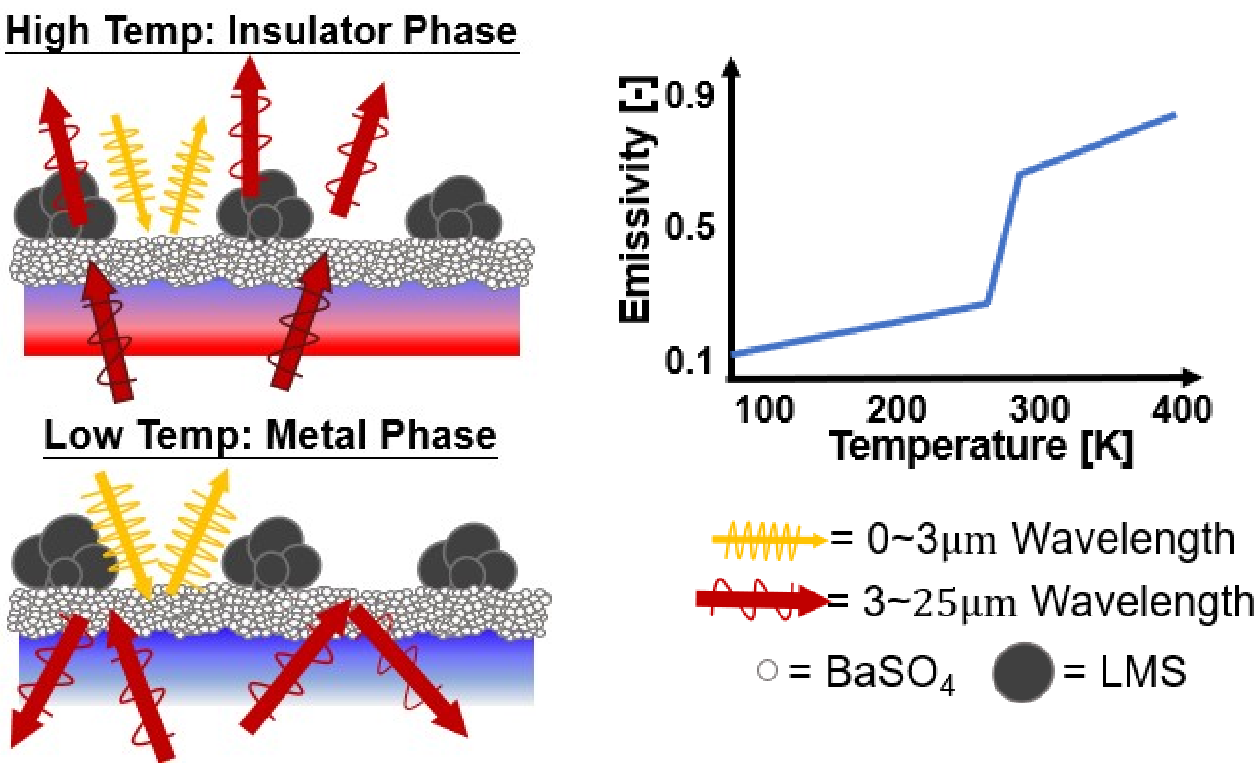
Source: https://tinyurl.com/yu68pakp



X. Li, J. Peoples, et. al., ACS Applied Materials and Interfaces (2021)

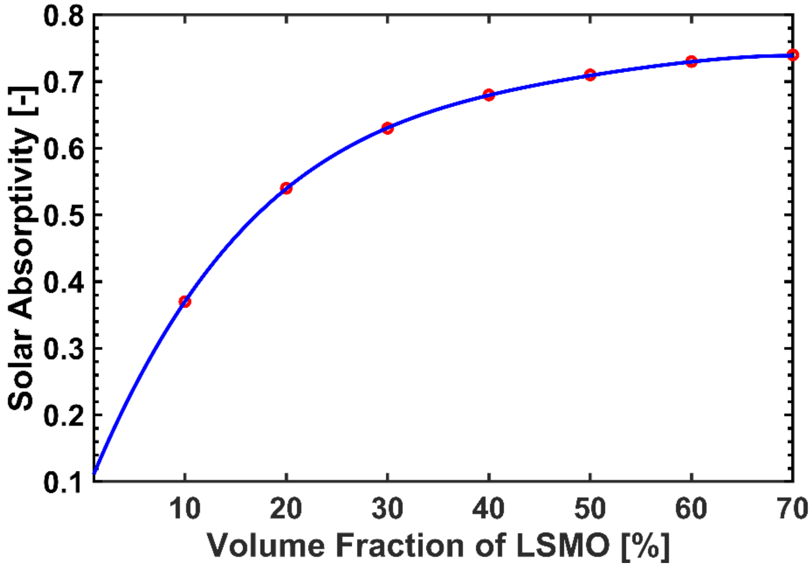
Micropattern Thermochromics

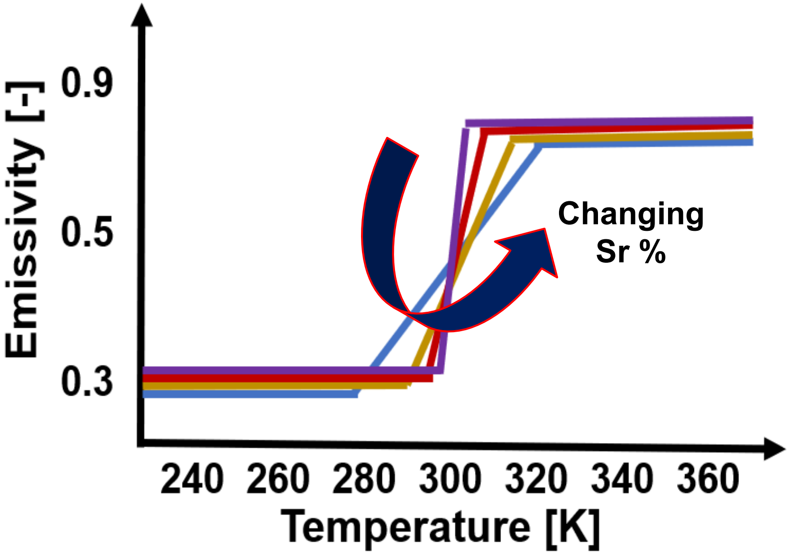
- Objective: Create a coating with a low ε at low temperatures and high ε at high temperatures while maintaining a low α
- Approach: Develop a computational model to study effects of micropatterned thermochromic coatings on radiator turndown and pertinent temperatures
- Objective: Define design targets for the transition temperature, cold state emittance, and solar absorptance

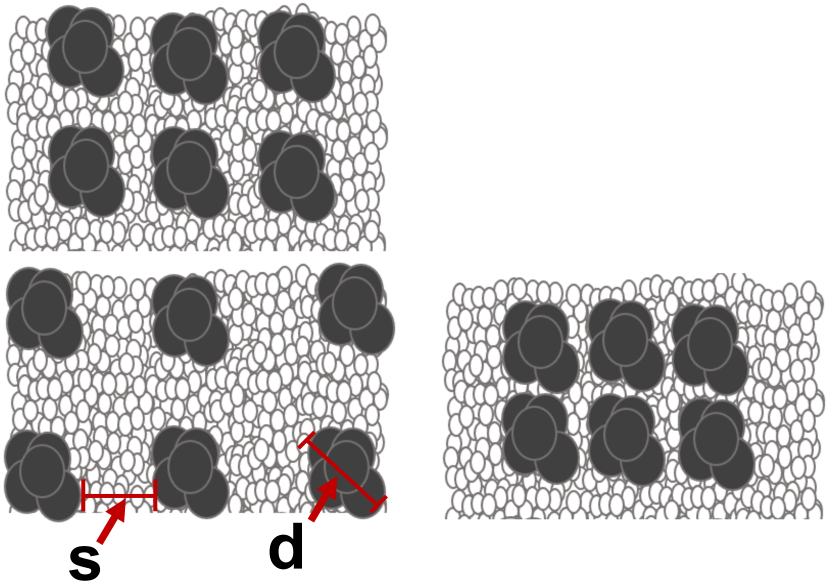


Design Parameters

- Three variable sets to examine
  - Transition Temperatures: T_{start} and T_{stop}
  - Solar Absorptance (α)
  - Emittance: cold ε and hot ε

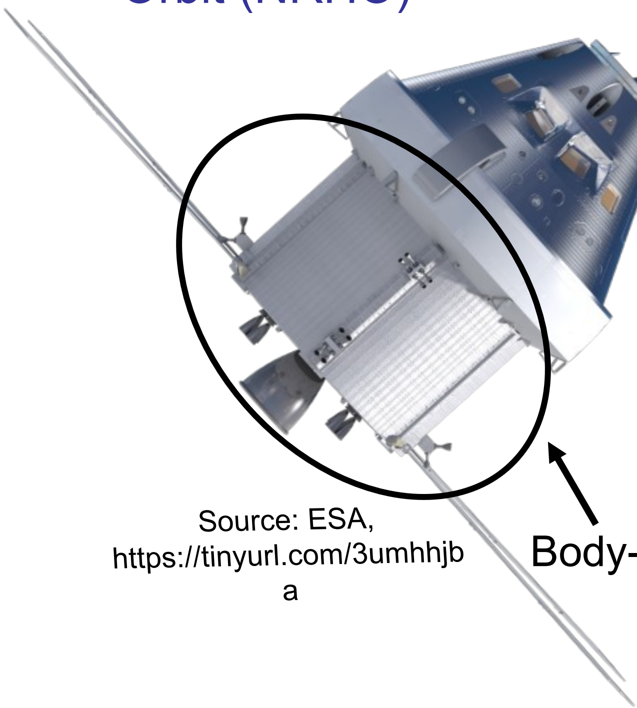




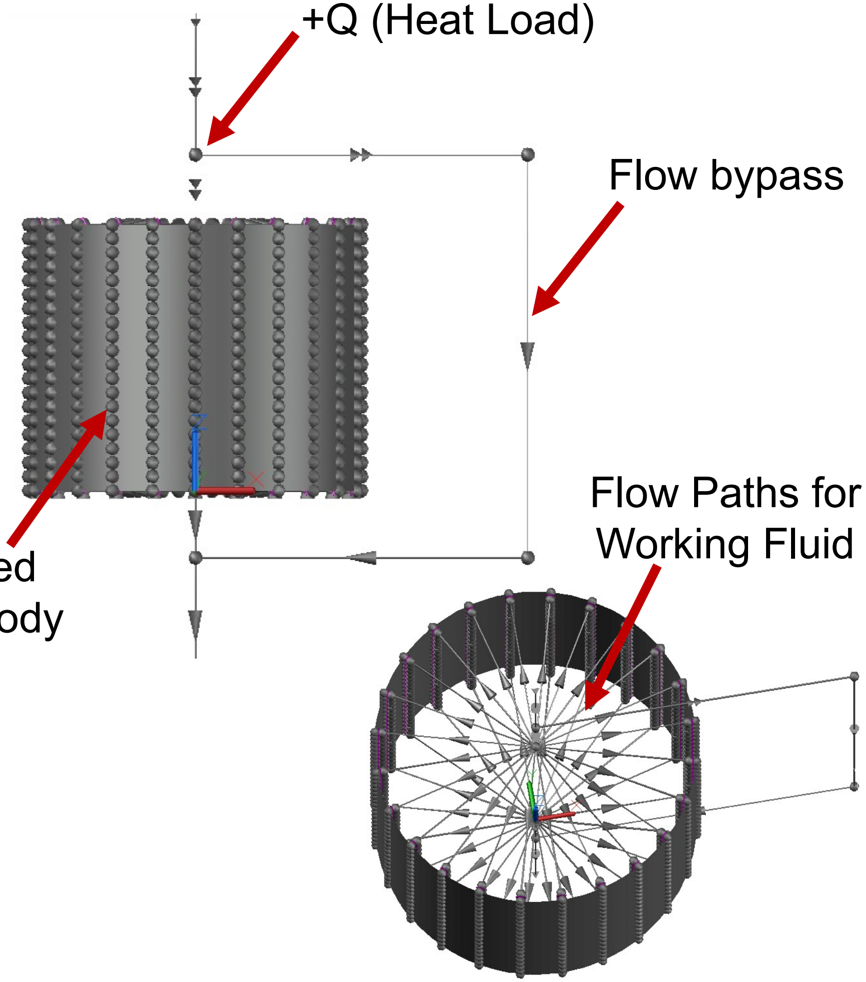


Thermal Desktop Model

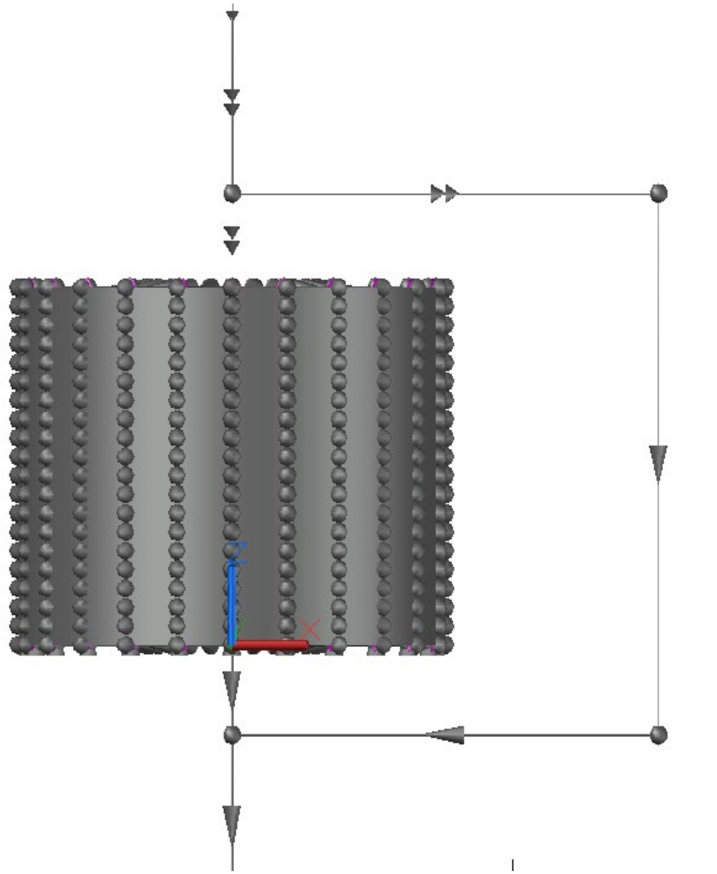
- Body-mounted radiator design based on Orion Space Craft
- 25 angular body section, 25 flow paths
- 20 axial nodes
- Orbit Considered: Near Rectilinear Halo Orbit (NRHO)



Source: ESA, https://tinyurl.com/3umhhjba



Thermal Desktop Model

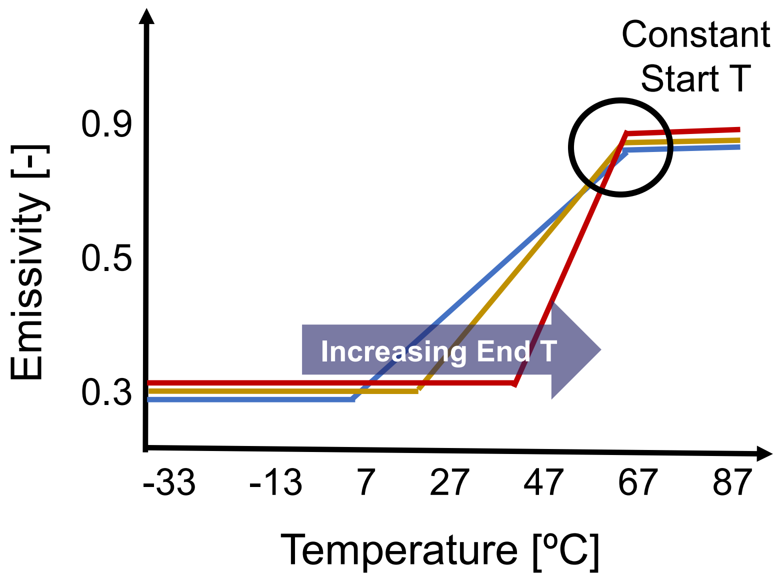


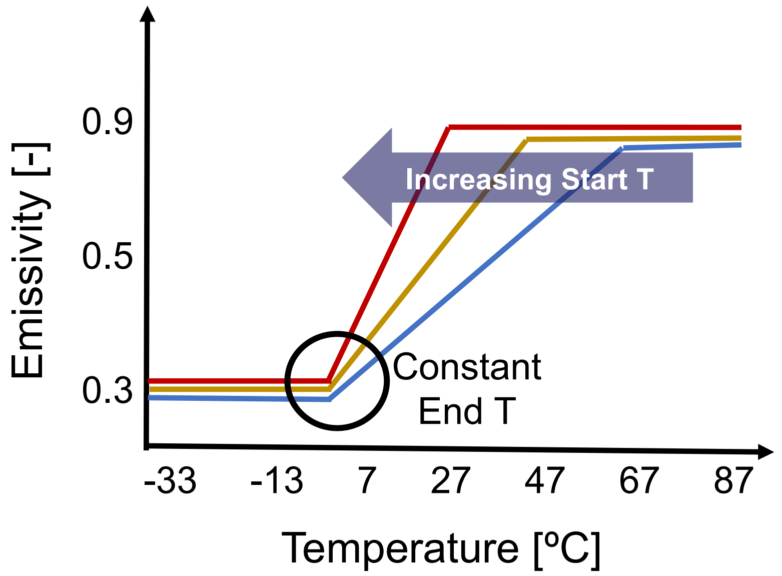
Parameter	Value
Diameter of Radiator [m]	5
Length of Radiator [m]	3.96
Crewed heat load [W]	8500
Un-crewed heat load [W]	6000
Mass flow rate [lb/hr]	600
Radiator Wall UA [W/mK]	100
Working Fluid	Water
Freezing Point [ºC]	0
Flow Bypass Ratio [%]	8
Axial Radiator Sections	20
Angular Radiator Sections	25

- Bypass Ratio set by sizing to static emissivity case and achieving a 4 ºC outlet temperature based on avionics requirements

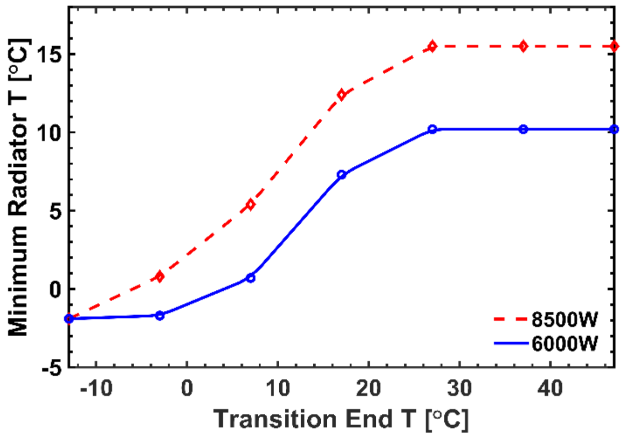
Transition Temperature Study

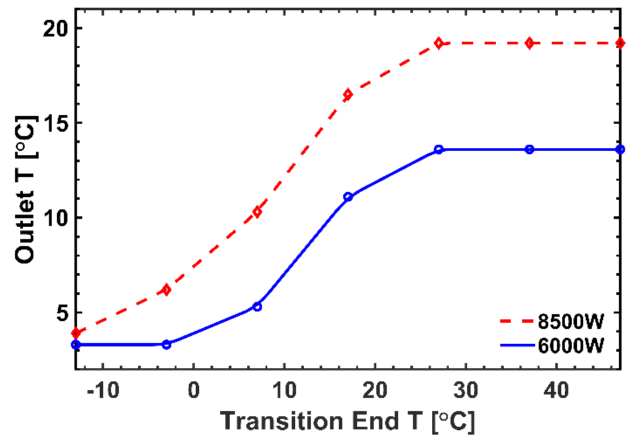
- First, we will investigate how the transition temperature effects the heat flux turndown and minimum body temperature
- Varying the transition start and end temperatures to under the impact of heat rejection
- $\varepsilon_{cold} = 0.3$
- $\varepsilon_{hot} = 0.9$

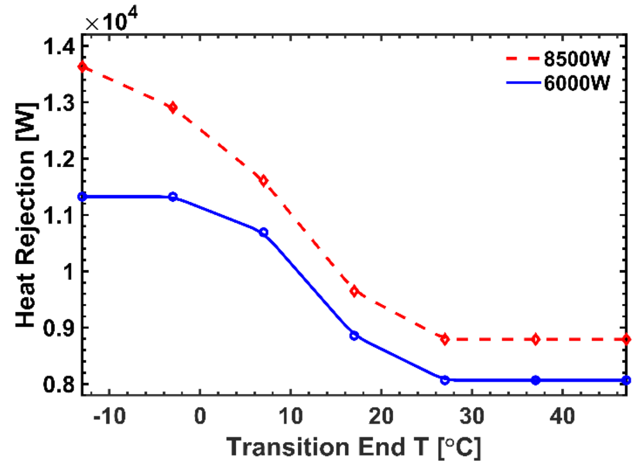


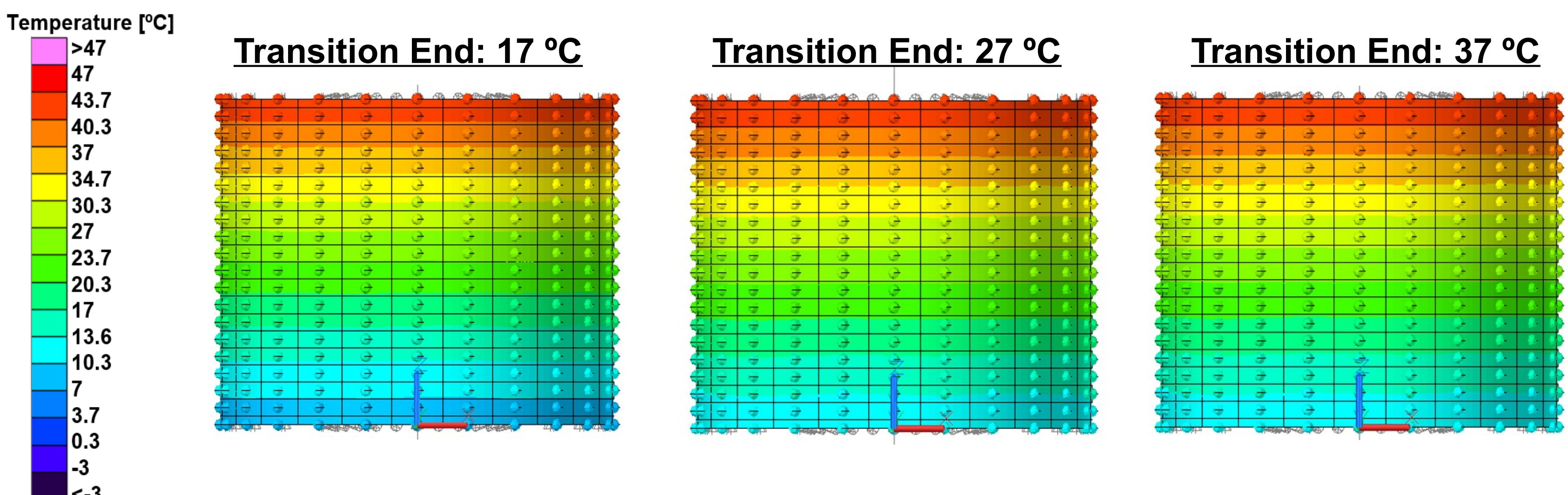


- Transition Start T = 67 ºC, ε_{cold} = 0.3, ε_{hot} = 0.9



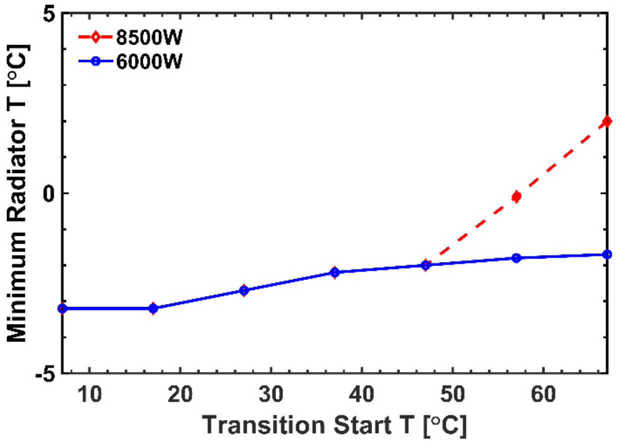


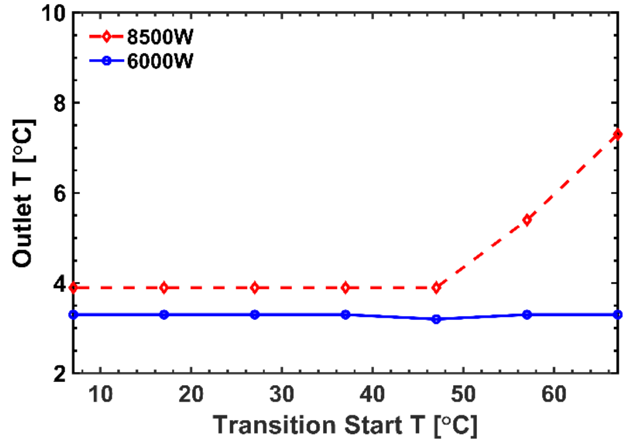


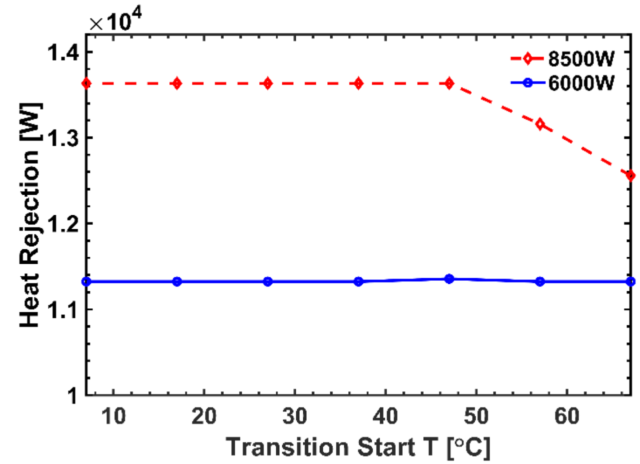


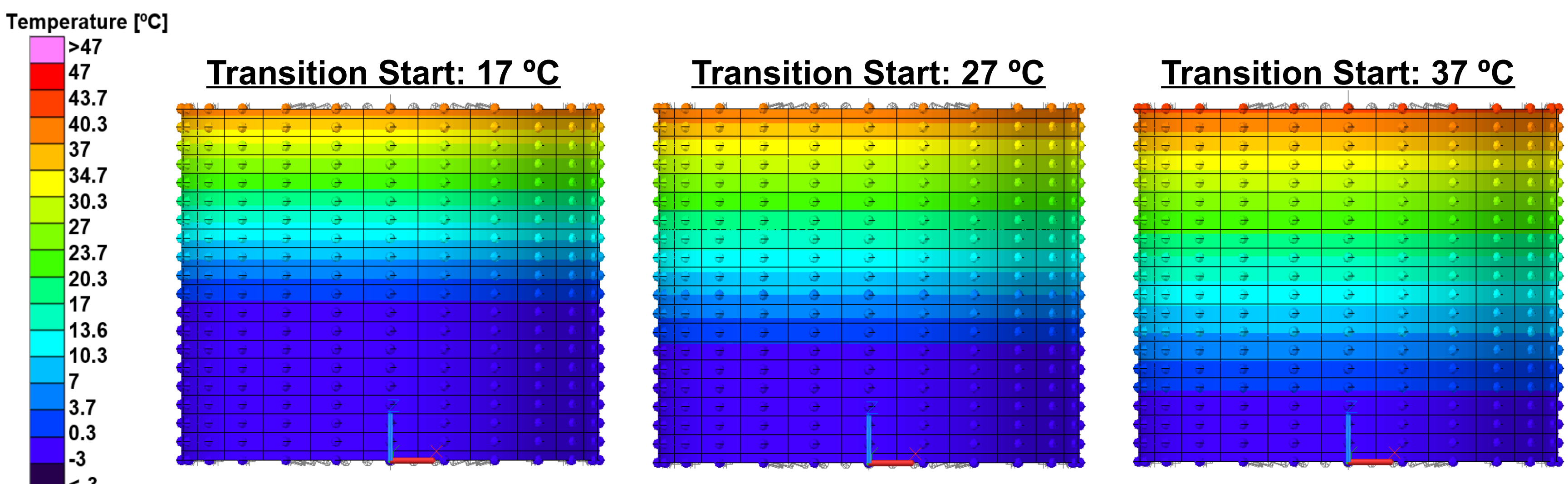
Transition Start Temperature Study

- Transition End T = 0 °C, ε_{cold} = 0.3, ε_{hot} = 0.9



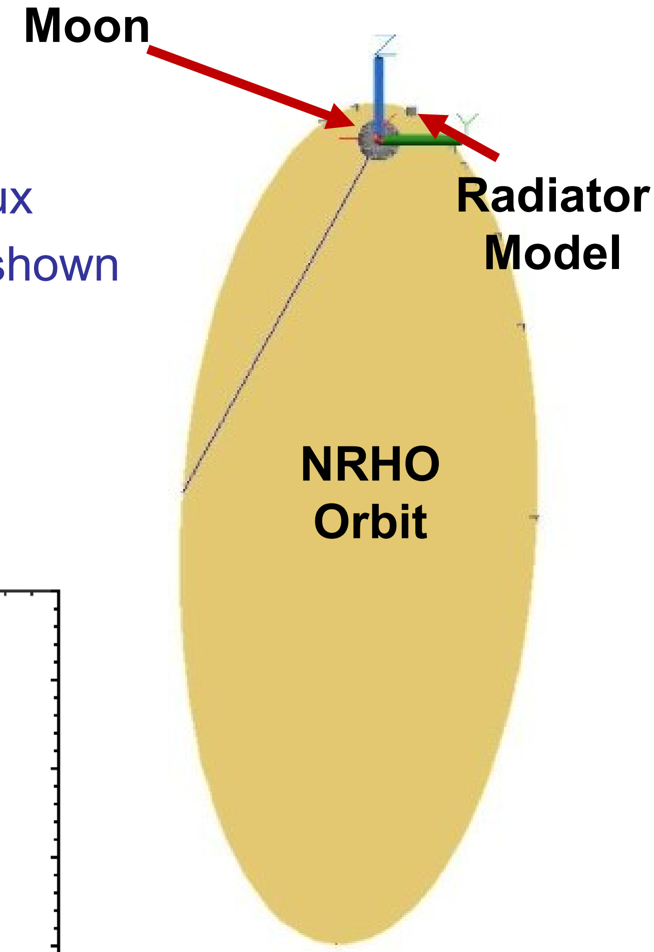


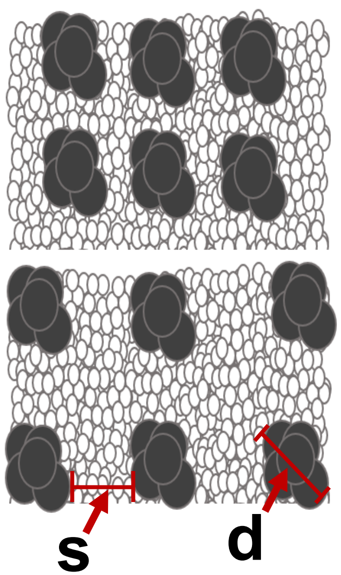


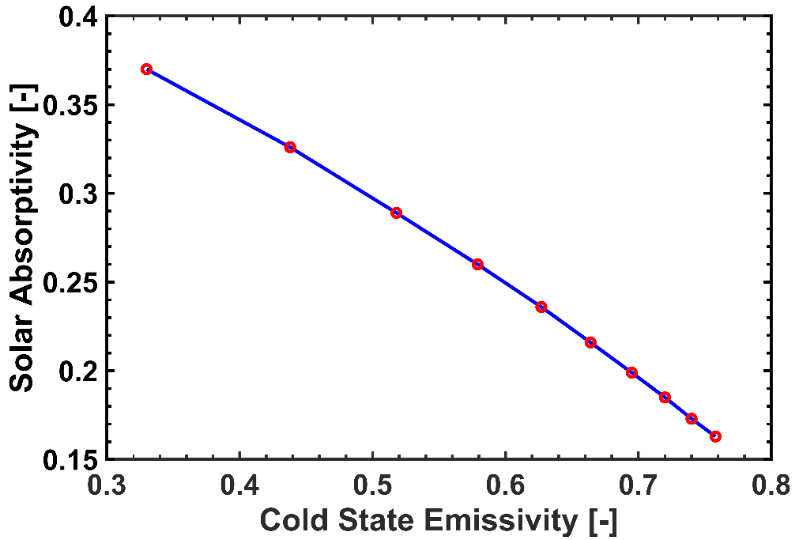


Absorptivity and Emissivity Study

- Next, we will investigate how the coupling of the solar absorptance and cold state emittance
- We consider an NRHO Orbit to study the solar heat flux
- Varying the absorptance and cold state emittance as shown below
- Hot Emittance is constant at 0.9
- Transition Temperatures are constant at:
  - **Start T = 67 ºC**
  - **End T = 27 ºC**

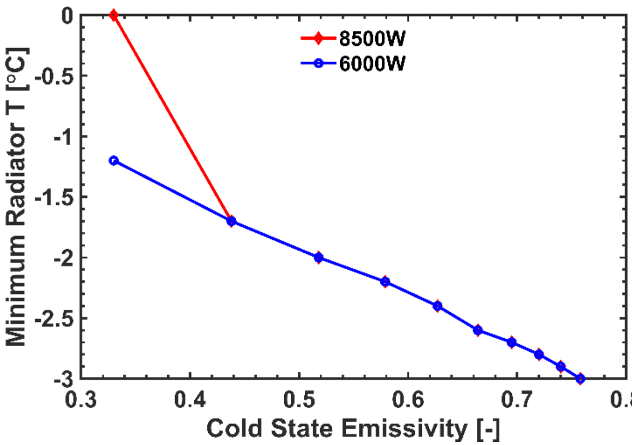


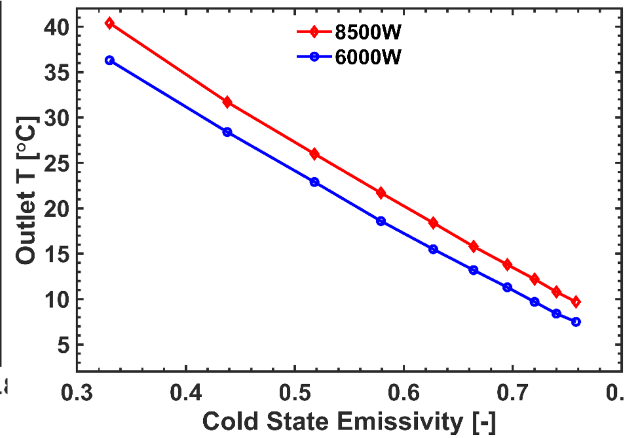


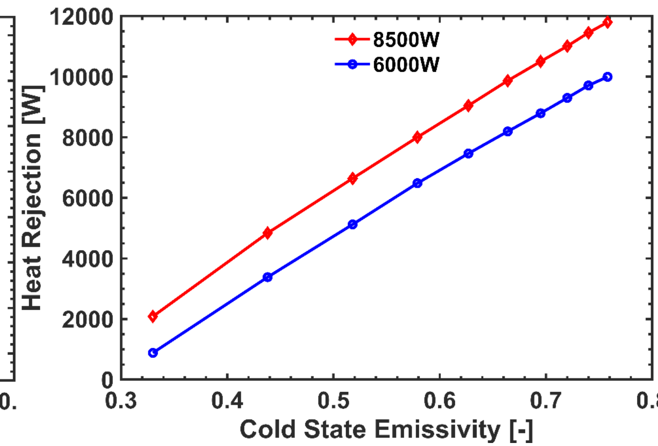


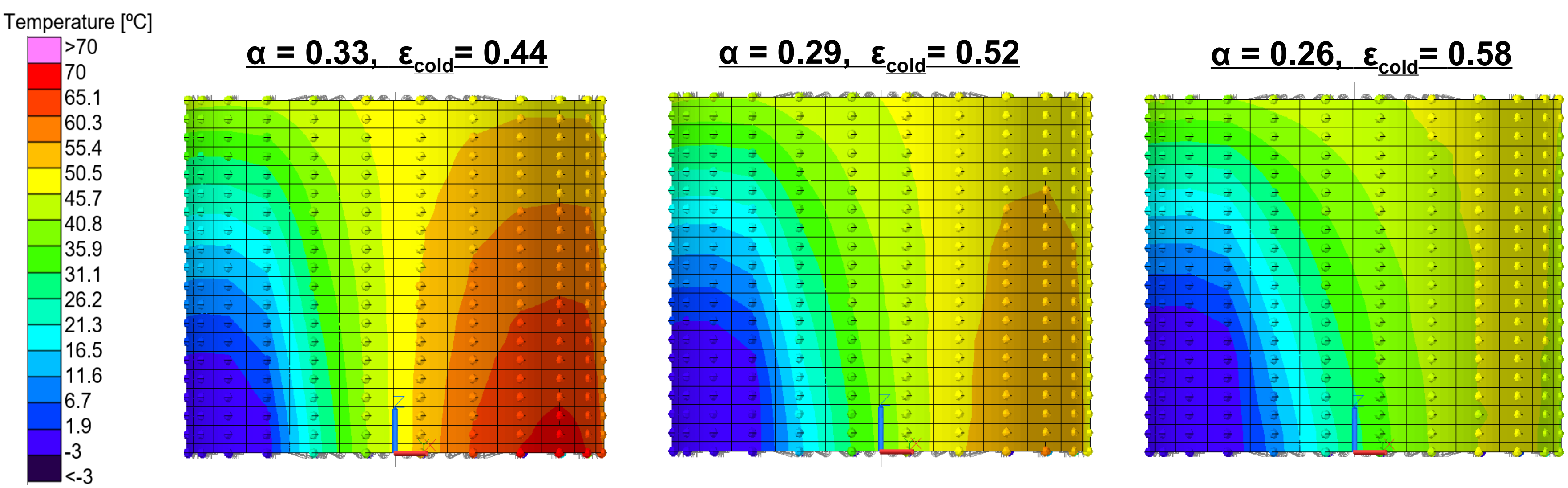
Absorptivity and Emissivity Results

- Transition Start T = 67 ºC, Transition End T = 27 ºC, ε_{hot} = 0.9









Conclusion and Future Work

- We have discussed the design parameters for our micropatterned variable emissivity coatings
- We found that the transition temperature saturates after **27 ºC** for the transition End Temperature
- We presented a relation between the absorptivity and emissivity of the micropatterns
- We found that solar absorptance in an NRHO orbit does have significant impact on the fluid outlet temperature which will in turn affect the heat rejection of down stream avionics

- For future work, we would like to add dynamic bypass to the fluid loop to further understand the turndown potential
- We would also like to study the transient behavior of these coatings and the transition state.

Acknowledgements

- Collaborators
  - Dr. Sydney Taylor, Dr. Christopher Massina, Jonah Smith, Lisa Erickson, Abigail Zinecker, and Brittany Spivey
  - All the member of JSC EC6 and ES3 for the support throughout the summer
- Financial Support: NASA Space Technologies Graduate Research Opportunities Fellowship