Analytical Study of a Cryogenic Thermal Control Coating

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Presented By

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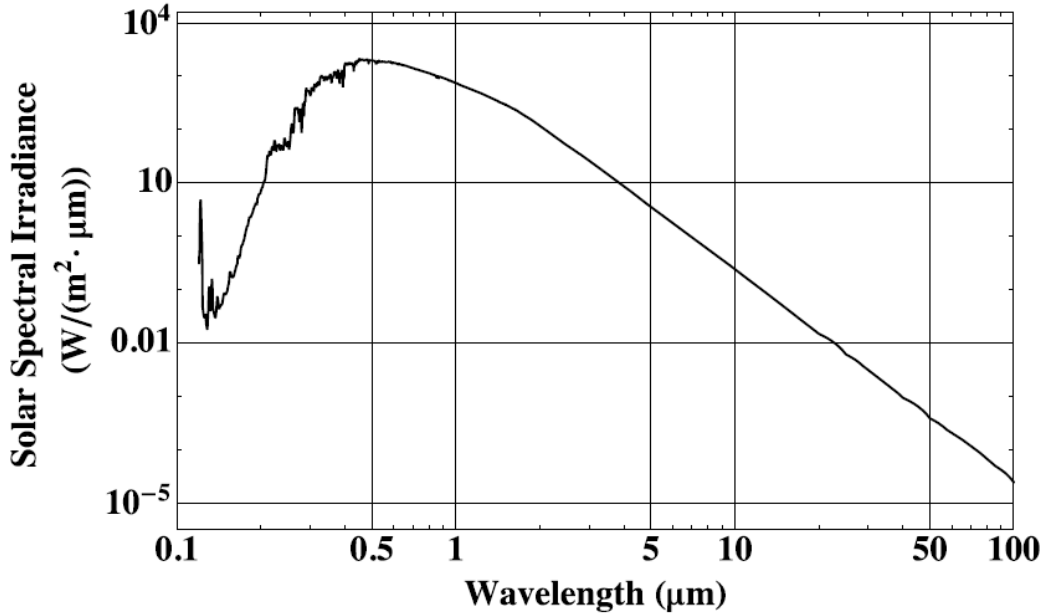
Thermal & Fluids Analysis Workshop
TFAWS 2022
September 6th-9th, 2022
Virtual Conference

Agenda

- Introduction
- Deep Space Solar Simulator (DS^3)
  - Modeling Approach
  - Results & Findings
- Lunar Surface Analysis
  - Modeling Approach
  - Results & Findings
- Conclusions

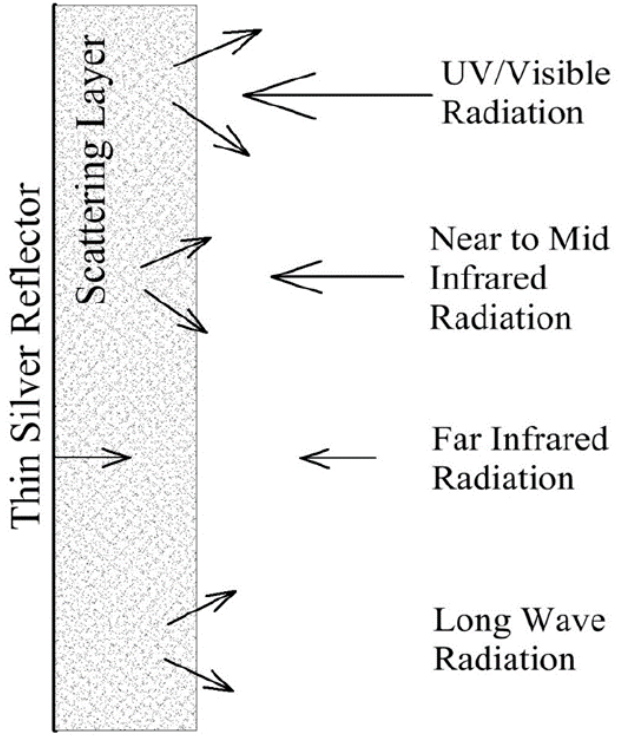
Introduction

- Cryogenic Thermal Control Coatings (CTCCs)
  - Often used in spacecraft applications
  - Allow waste heat to be emitted while minimizing the solar heat load
- Reflect most of the Sun's irradiance while still allowing long wave emittance
  - Goal: to maintain temperatures for cryogenic propellant storage in deep space
  - Current TCCs are limited – absorb significant UV and long wave IR



Introduction (cont.)

- An enhanced CTCC, “solar white” was developed in recent NIAC study [1]
- Y_2O_3 selected as solar white material
  - Reflects UV above 0.235 μm through IR up to 8 μm
  - Lightweight, hydrophobic, chemically stable

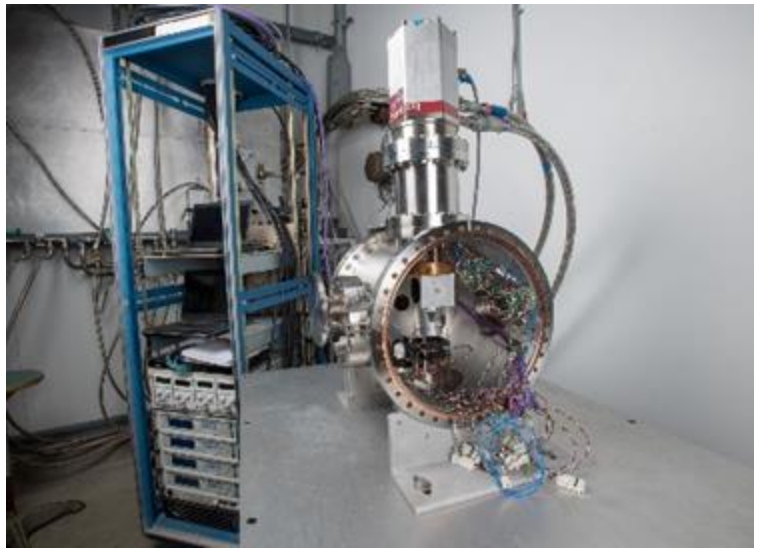


- Scattering layer of Y_2O_3 reflects UV/Visible and near-to-mid IR radiation
- Thin silver film reflects far-IR radiation
- Y_2O_3 emits longer wavelengths and radiates energy
- This combination can theoretically reflect 99.9% of Sun’s energy when used in deep space, allowing cryogenic temperatures to be reached

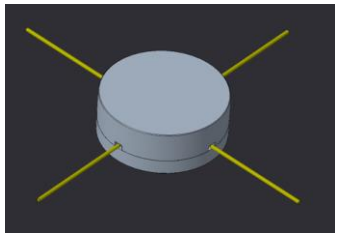
DEEP SPACE SOLAR SIMULATOR (DS^3)

Deep Space Solar Simulator (DS^3)

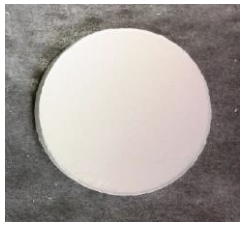
- Simulates deep space conditions
  - High vacuum (10^{-6} – 10^{-7} torr)
  - 12 K background using coldhead adapter
- Apparatus
  - Xenon lamp solar simulator
  - Silicon diodes
    - Temperature measurements of sample & simulator environment
    - Energy input at the sample
- Solar White sample
  - Y_2O_3 spray-on coating and tile (compressed & sintered)
  - 3/8” thick, 1” diameter



DS^3 Setup

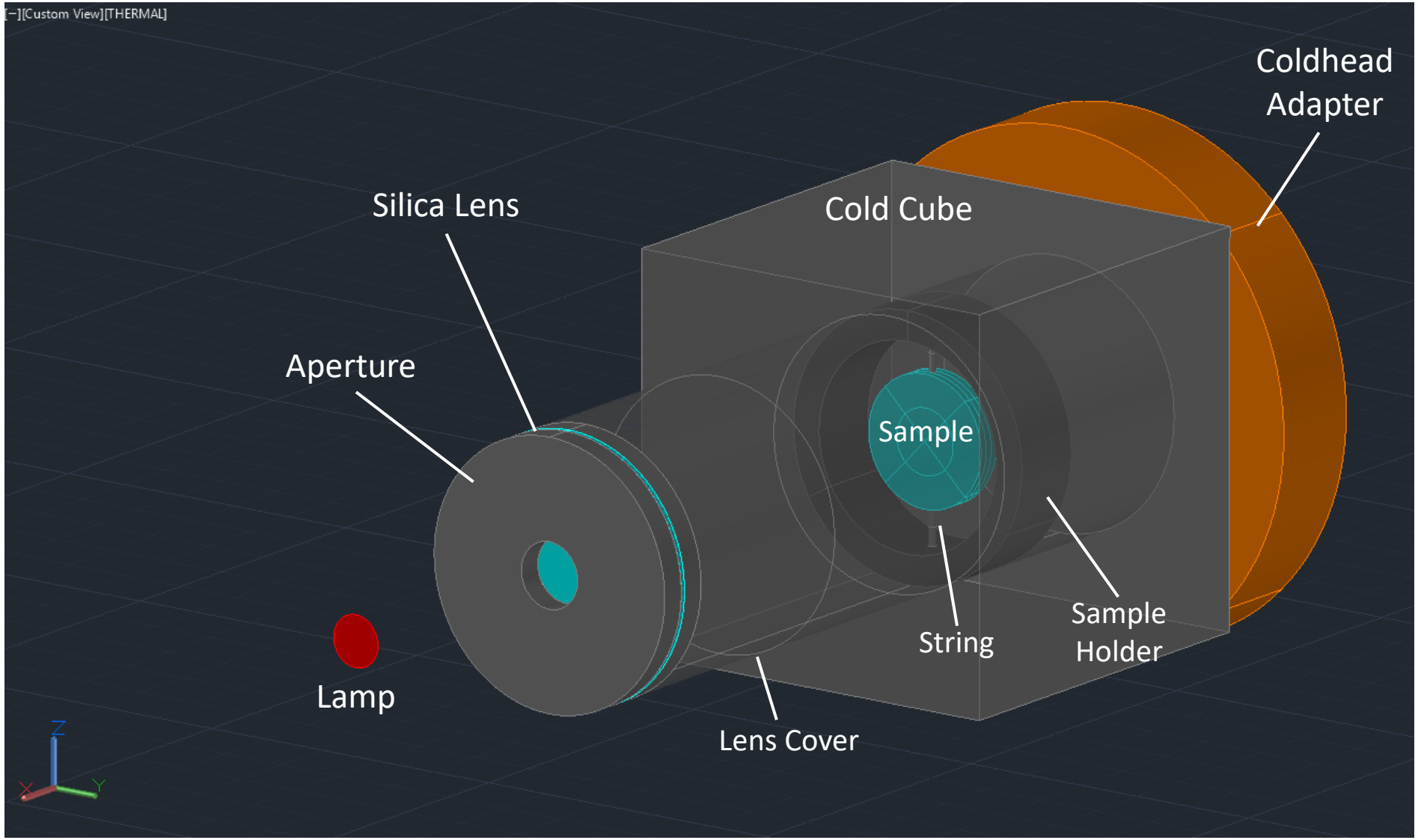


Spray-on Sample



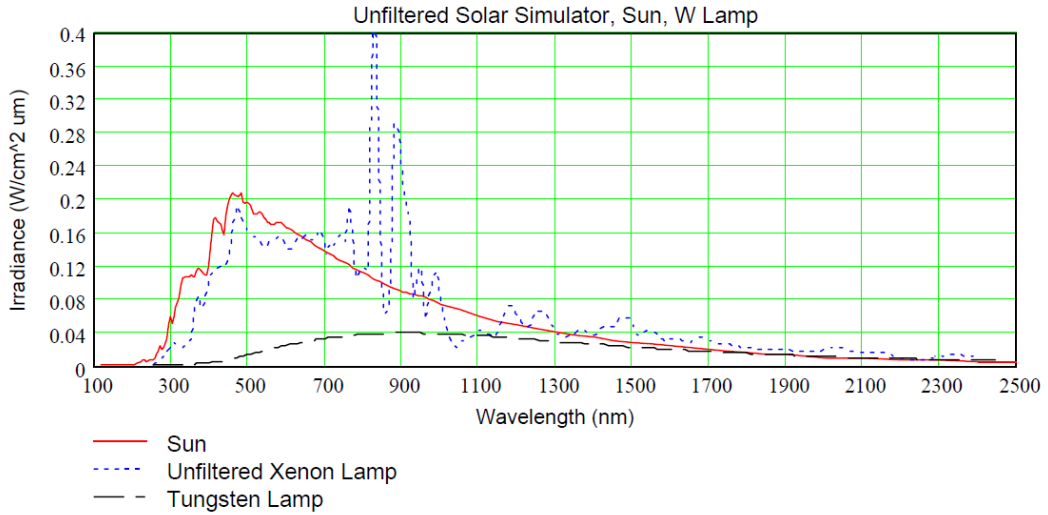
Tile Sample

DS³ Thermal Desktop Model



DS³ Model Setup

- **Solar lamp**
  - Single node, thin surface
  - NORMAL optical property on active side
  - Surface not generated (disabled Cond/Cap tab)
- **Model runs two cases**
  - Light On – 1 Radiation Analysis Group
  - Light Off – 2 Radiation Analysis Groups
- **Radiation analysis setup**
  - 300,000 rays/node
  - Radk calculation spectrum used for modeling solar lamps
    - Solar vs. infrared
  - Lamp node outputs radks as heating rates (150-170 mW/cm^2)
  - Wavelength-dependent properties (0-25 μm)
    - Silica lens & sample
- **Steady-State & Transient Analyses**

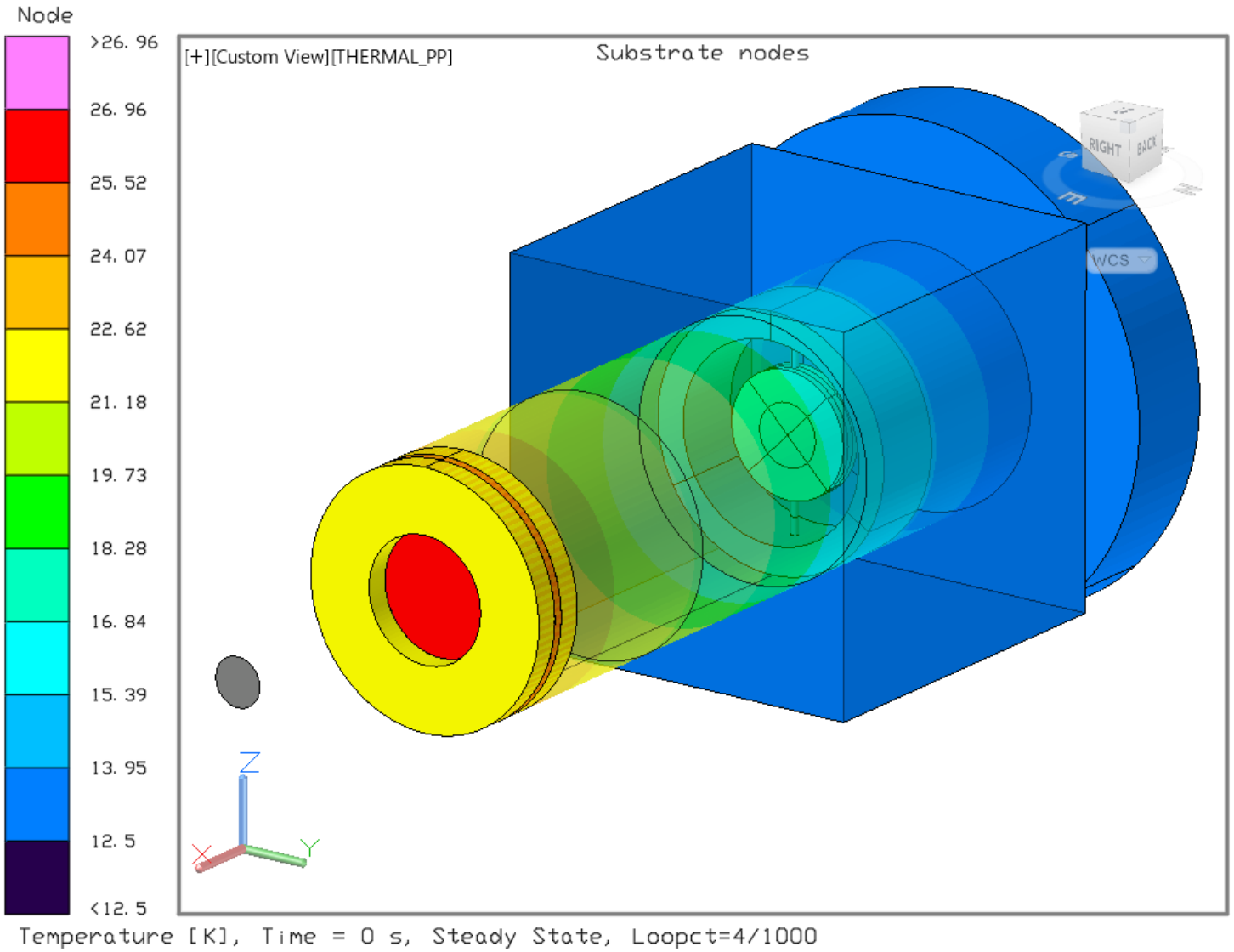


Irradiance Comparison [2]

Results: Light Off Case

- Zero lamp output
- Simulates ambient, emissive environment
- Silica lens prevents IR from reaching the sample

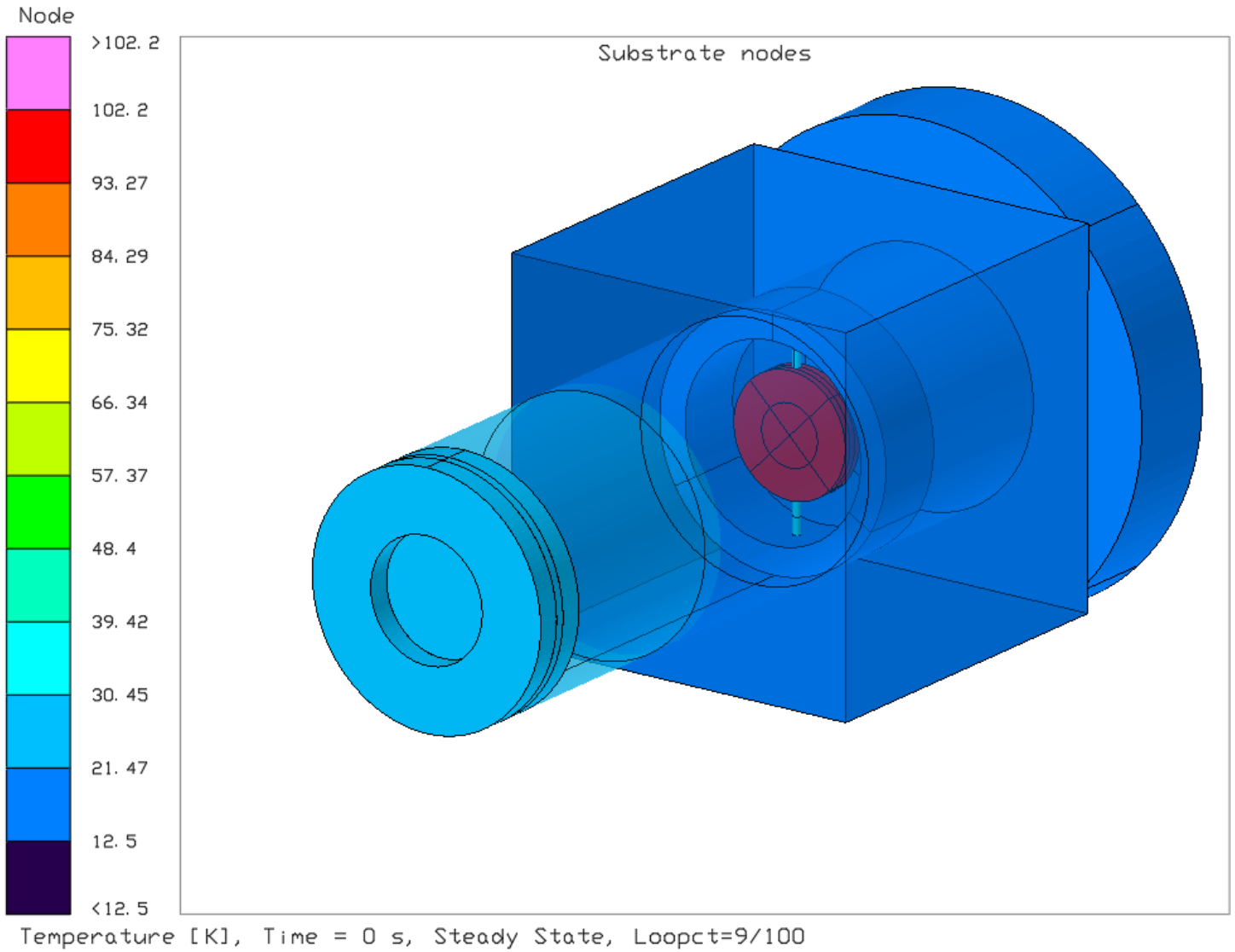
Component Temperatures [K]	
Aperture	22.5
Lens Cover (avg.)	19
Silica Lens	**23**
Sample	**16.1**
Sample Holder	15
Strings	15.3
Cold Cube/Coldhead	12.5



Results: Light On Case

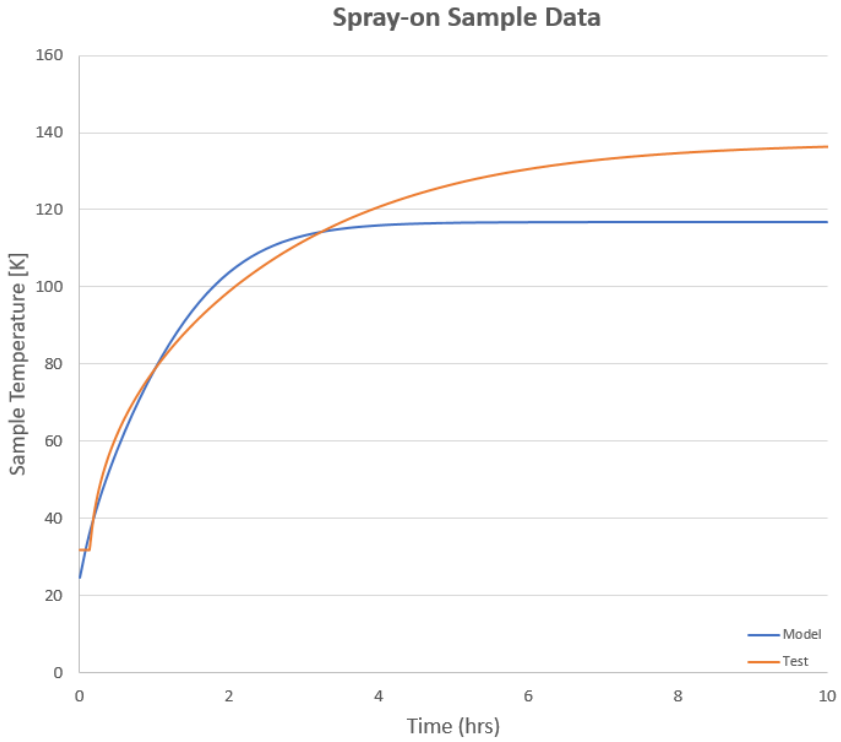
- 170 mW/cm^2 lamp output
- Sample reaches 102 K when solar lamp is turned on
- Results similar to sample temperatures measured during tests

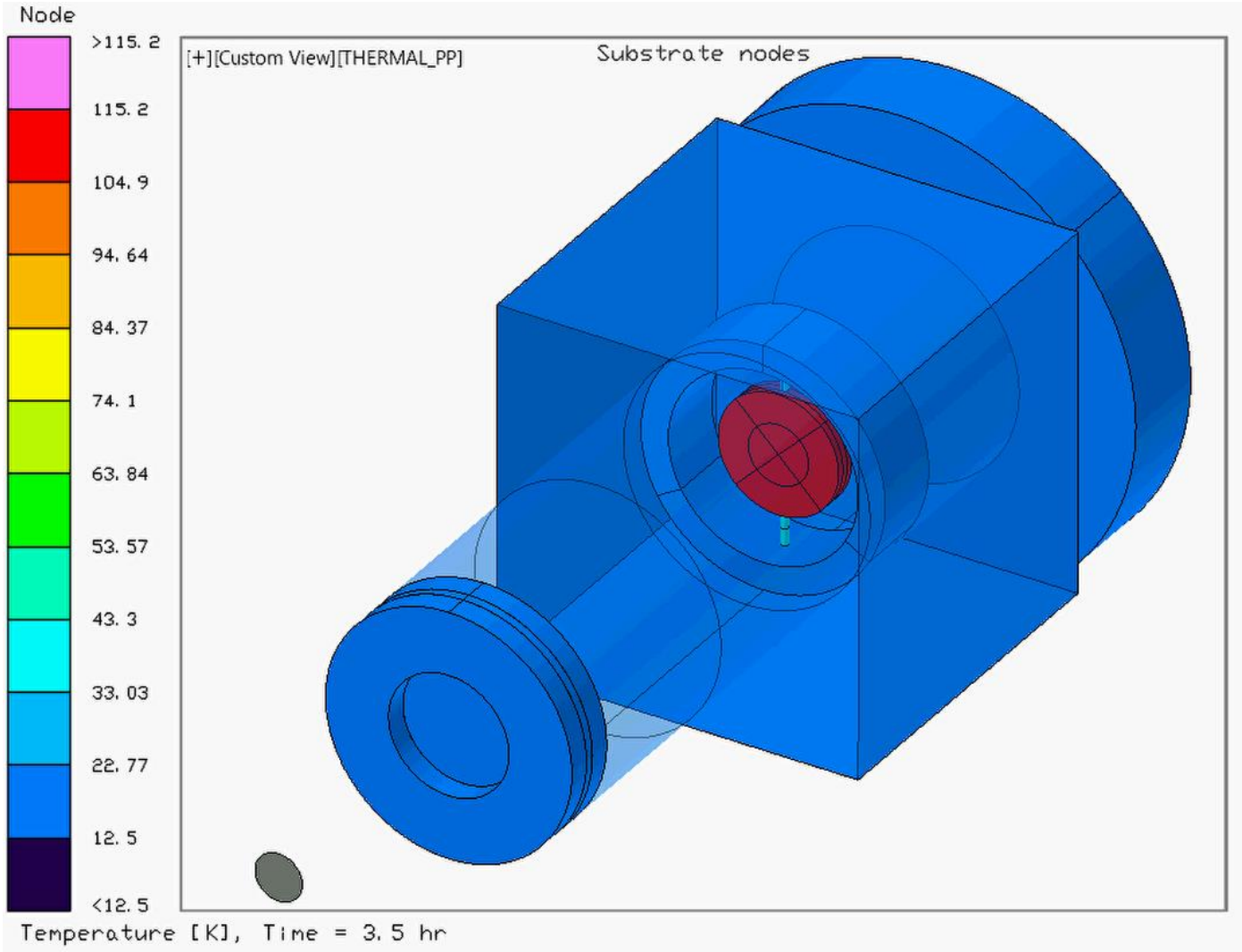
Component Temperatures [K]	
Aperture	23.5
Lens Cover (avg.)	19.6
Silica Lens	**28.3**
Sample	**102.2**
Sample Holder	15.2
Strings	36.2
Cold Cube/Coldhead	12.5



Transient Analysis

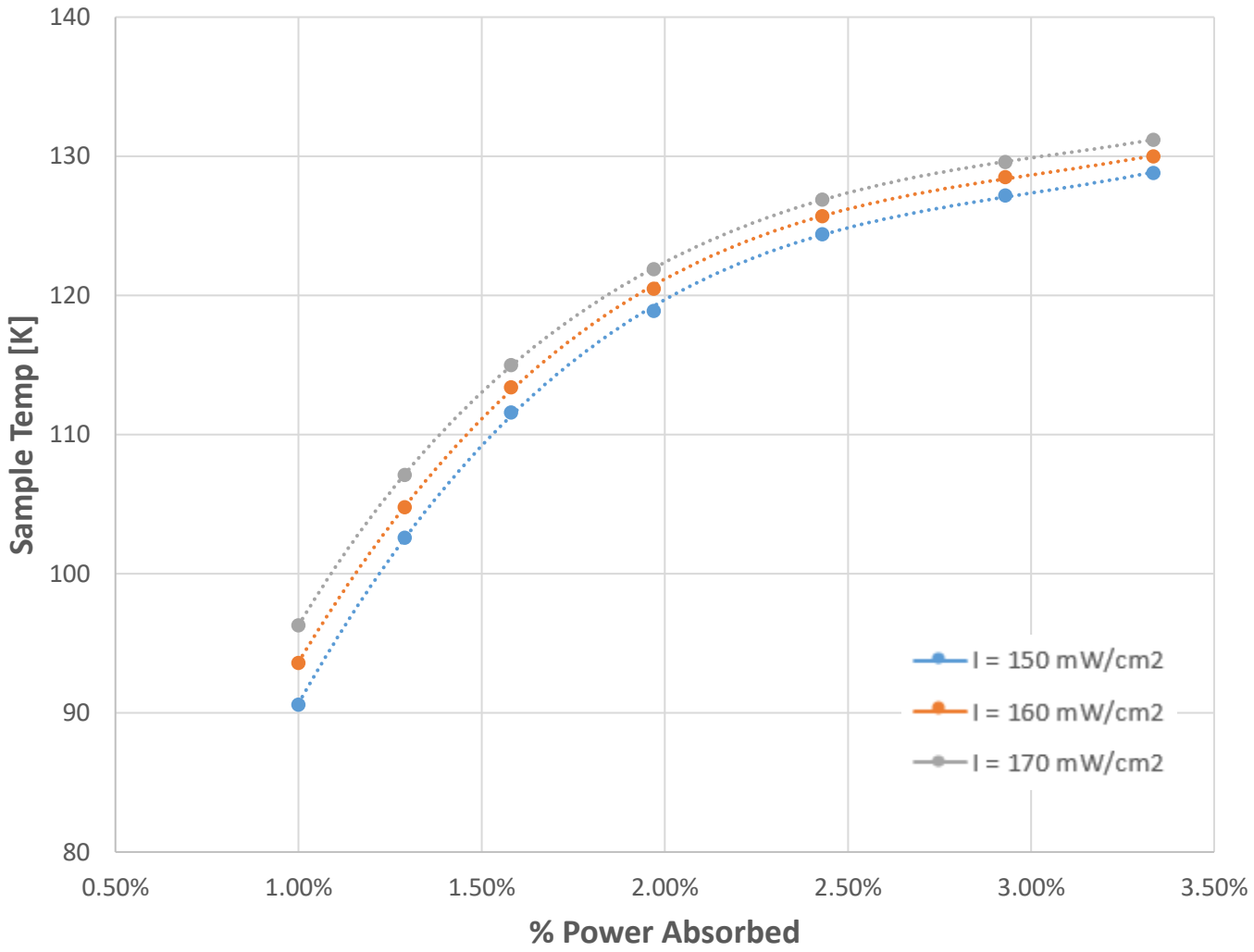
- Spray-on sample comparison
  - Spray coated 7075 Aluminum
  - 714 mW light intensity
  - Similar trends between test and model results – approach asymptotic max temp





Additional Analysis

- Analysis conducted to determine the % of solar lamp power absorbed by the sample
- Using solar intensity and sample temperature
- Emissivity = 0.85
- Plotted for various solar intensity values
  - 150, 160, 170 mW/cm^2
- Verified by calculations obtained in previous Excel analysis



DS^3 Model Findings

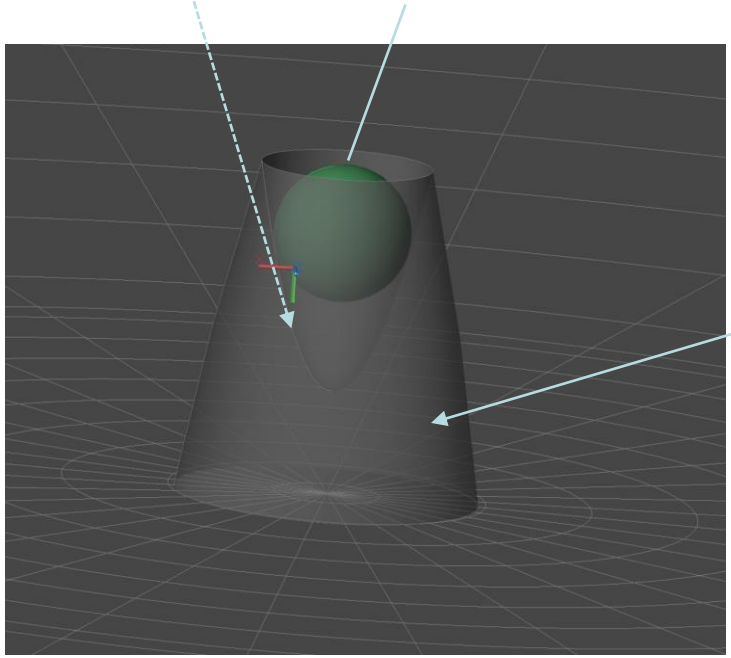
- Light Off: Silica lens effectively prevents IR from reaching sample
- Light On: Conservative, sample able to maintain relatively low temperature
- Transient analysis
  - Further verified model results
  - Results in alignment with data obtained during tests
- Additional analysis
  - Effect of solar intensity on sample temperature
  - Solar white coating can reach ~90 K for lower solar intensity values
  - Significant reduction in solar absorption compared to current CTCC coatings
- Solar white will undergo further testing on ISS flight
  - Spray-on coating to be applied to coupons that will be used by ULA

LUNAR SURFACE ANALYSIS

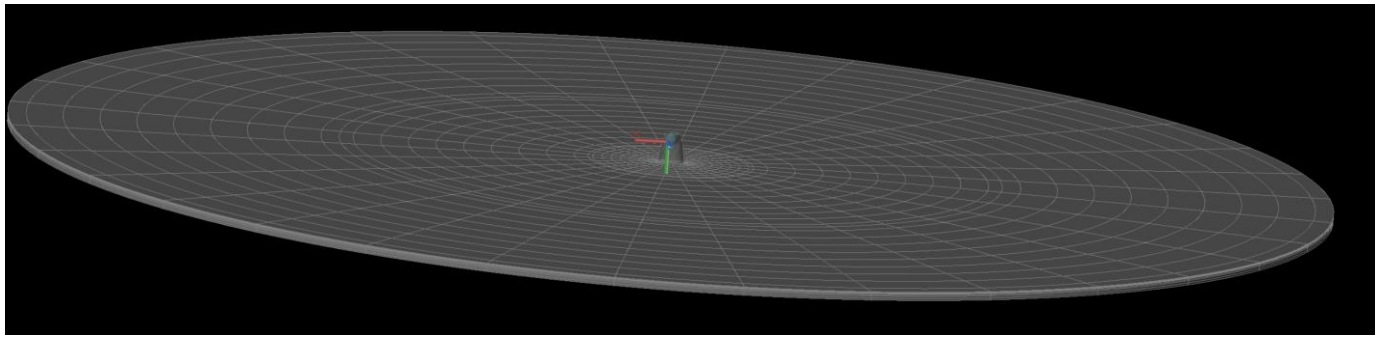
Lunar surface analysis

Inner shield

Tank: diffusion thermal node with properties of LOX and mass of 400 kg



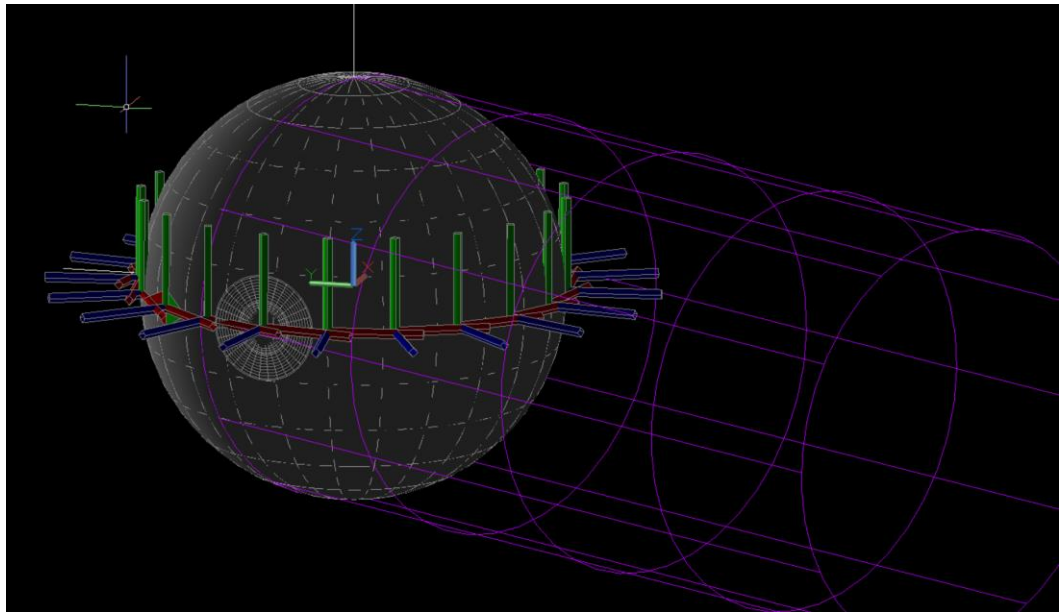
outer shield
H = 2.2m
R = 0.56m

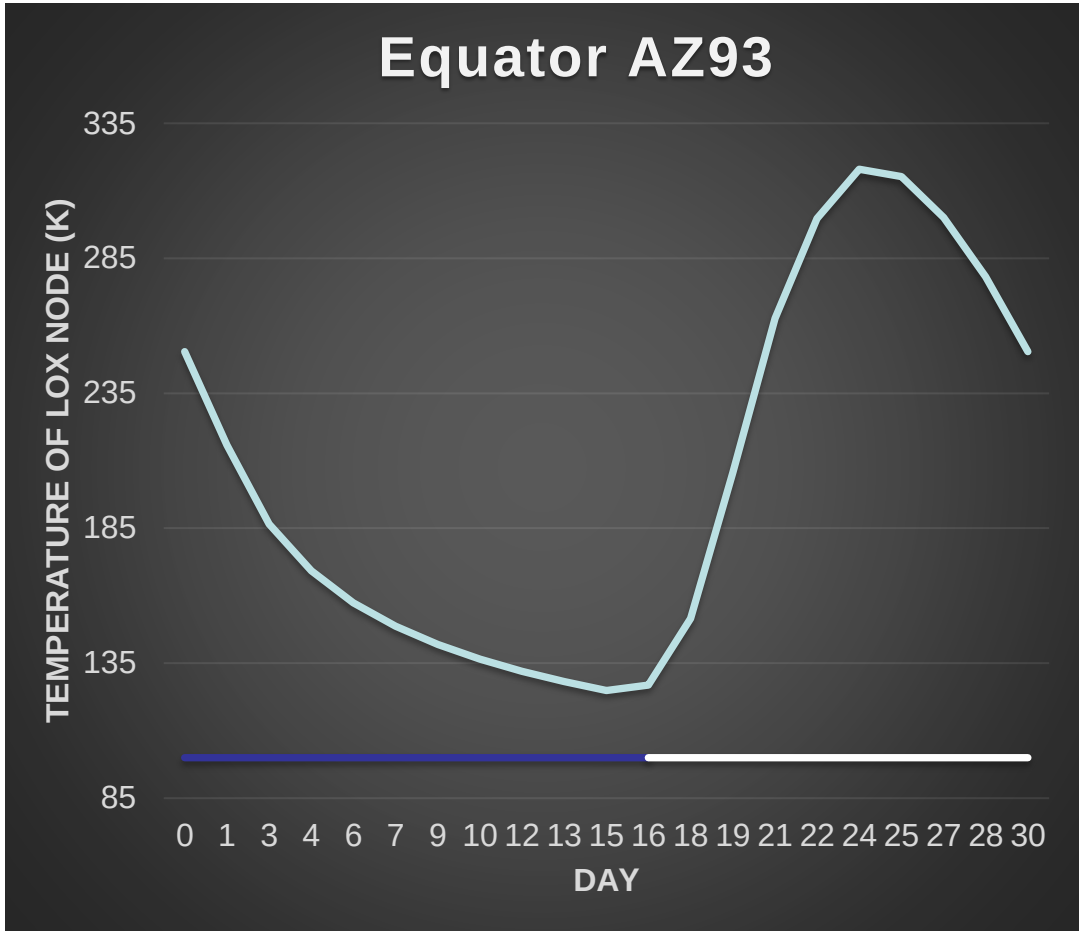


- Hypothetical design LN2 tank with two radiation shields
- Lunar analysis using ground plane XREF with representative solar irradiance HR radks [4]
- Comparing AZ93 to Y_2O_3 applied to outer facing surfaces
- Aluminized Kapton on the inner facing surfaces
- No thermal conduction between shields (modeled as aluminum sheet metal)

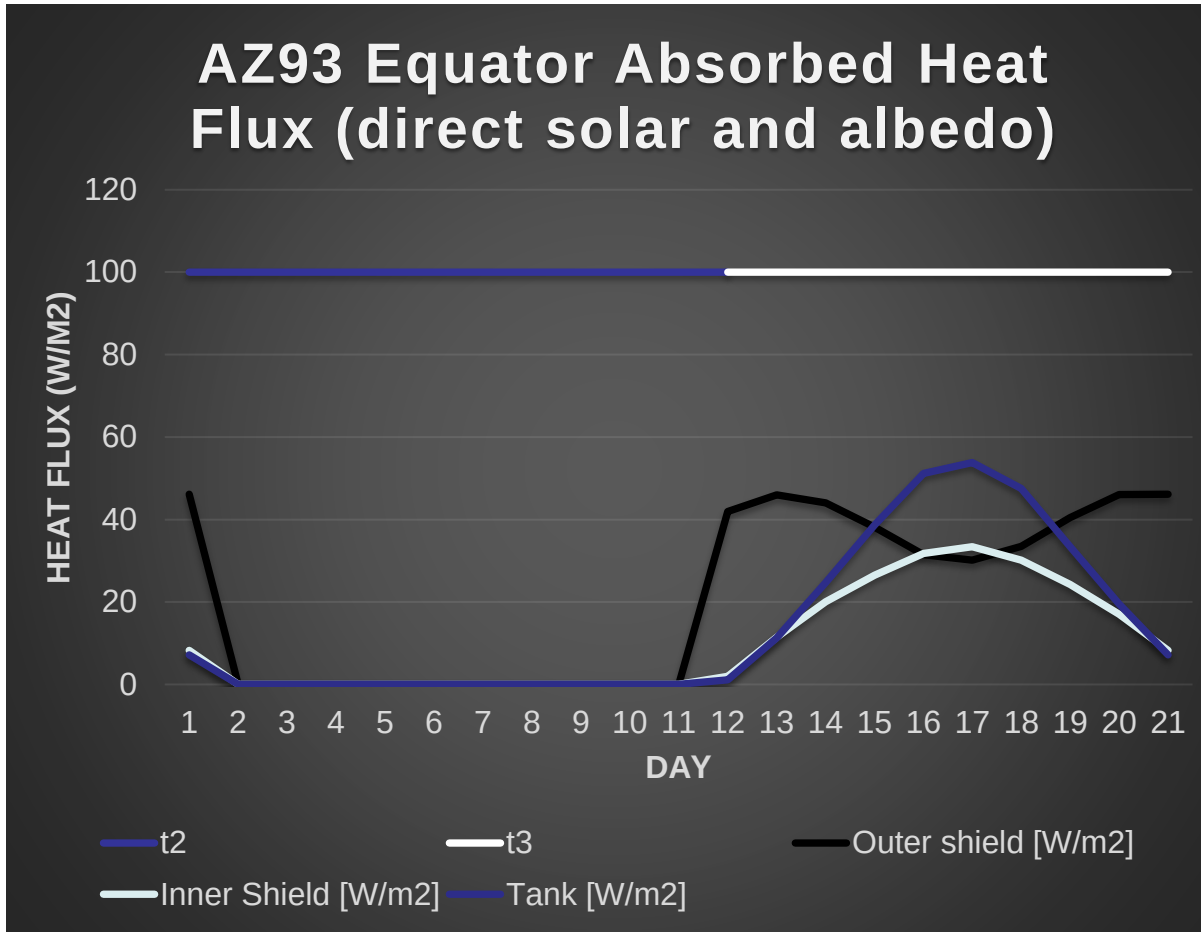
AZ93 Equator Case

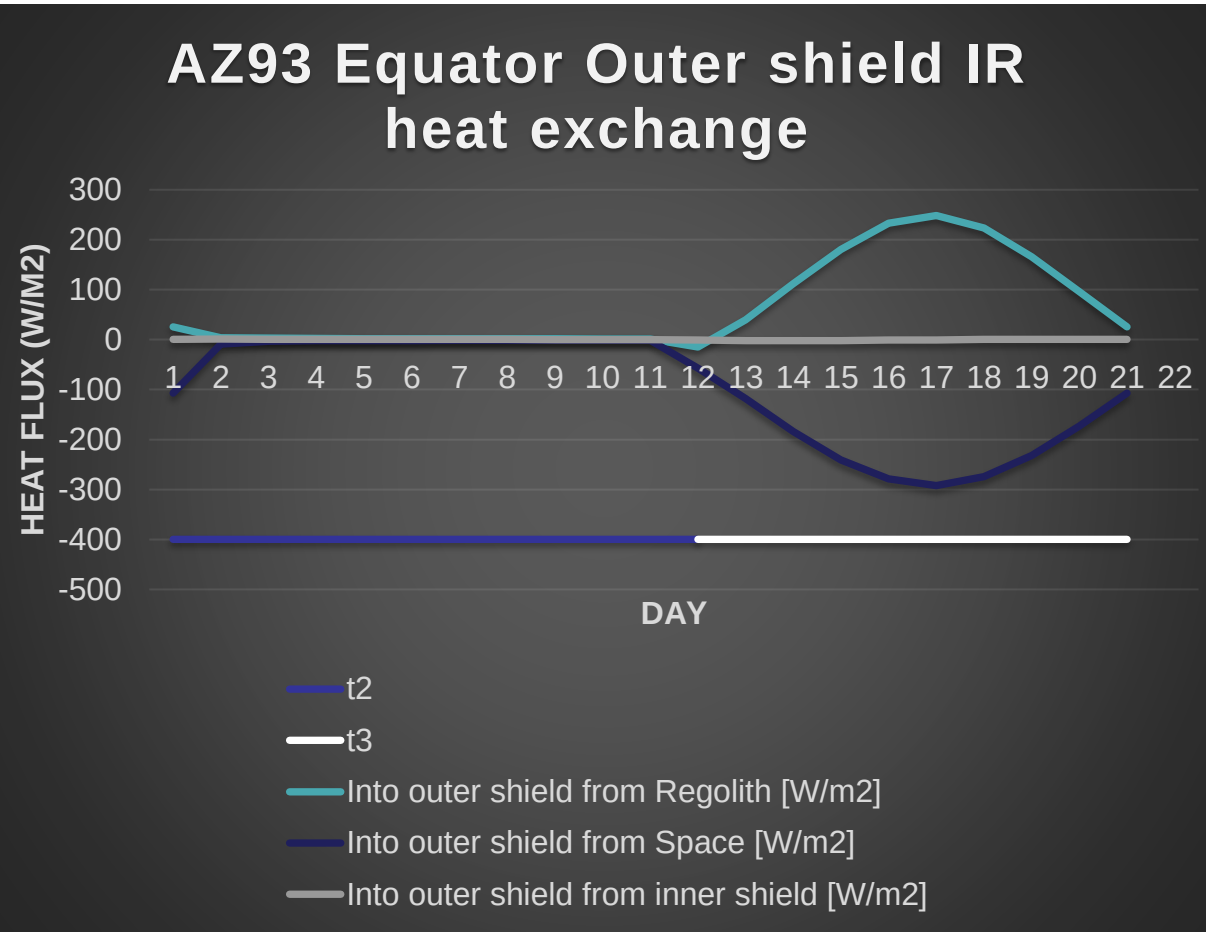
- R.A. of sun 59.2
- R.A. of Prime Meridian 133.75
- $\alpha = 0.17$ [5]
- $\varepsilon = 0.92$ [5]





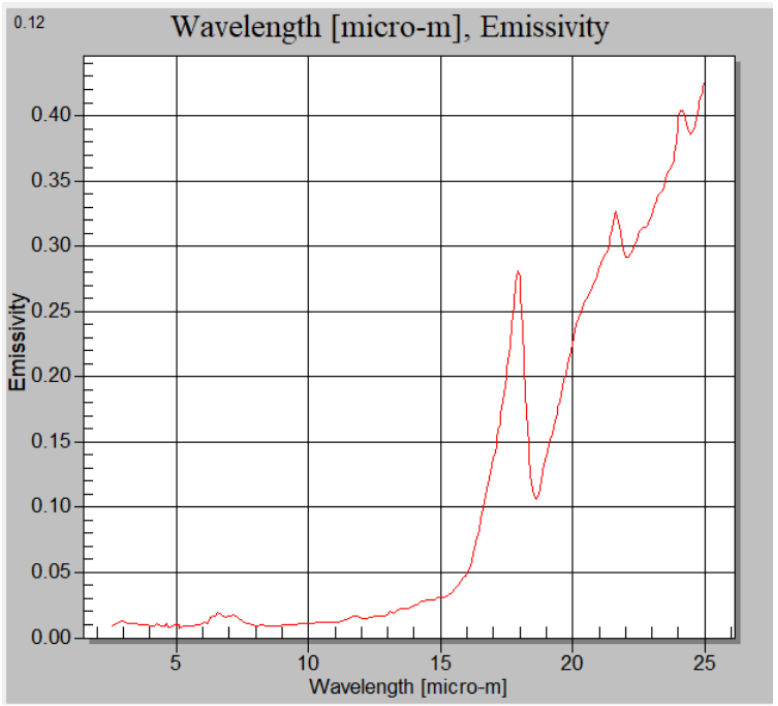
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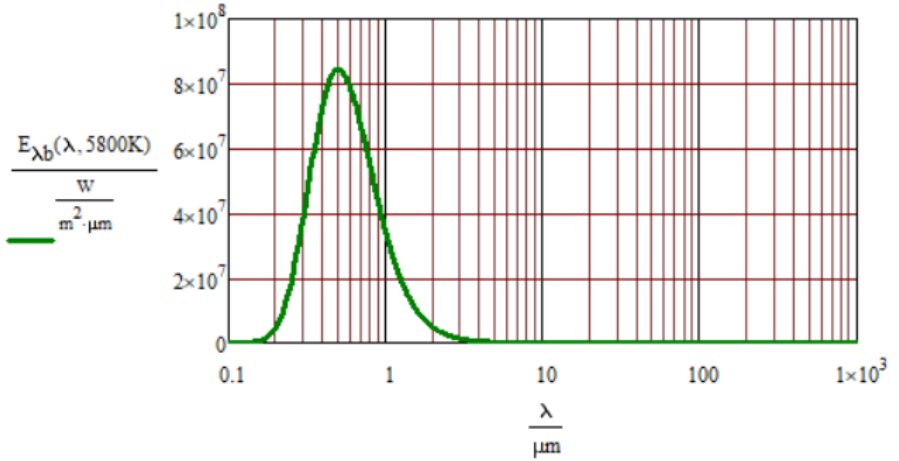




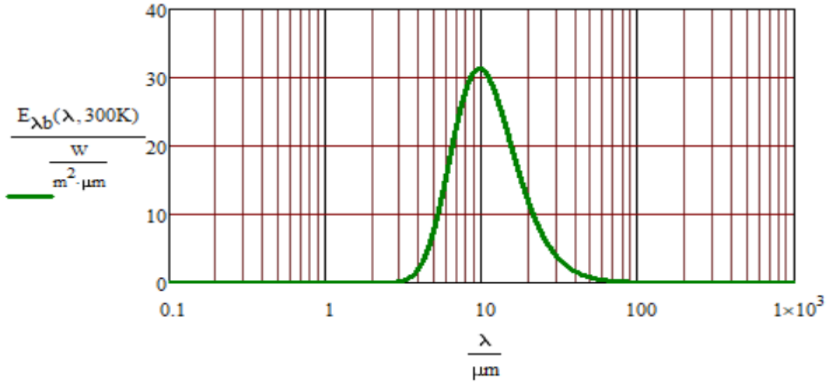
Y2O3 coating optical properties

- semi-gray properties
  - solar absorptivity is 0.01
  - infrared emissivity 0.8
- Wavelength dependent:





Solar wavelengths are mostly below 3 micro-m

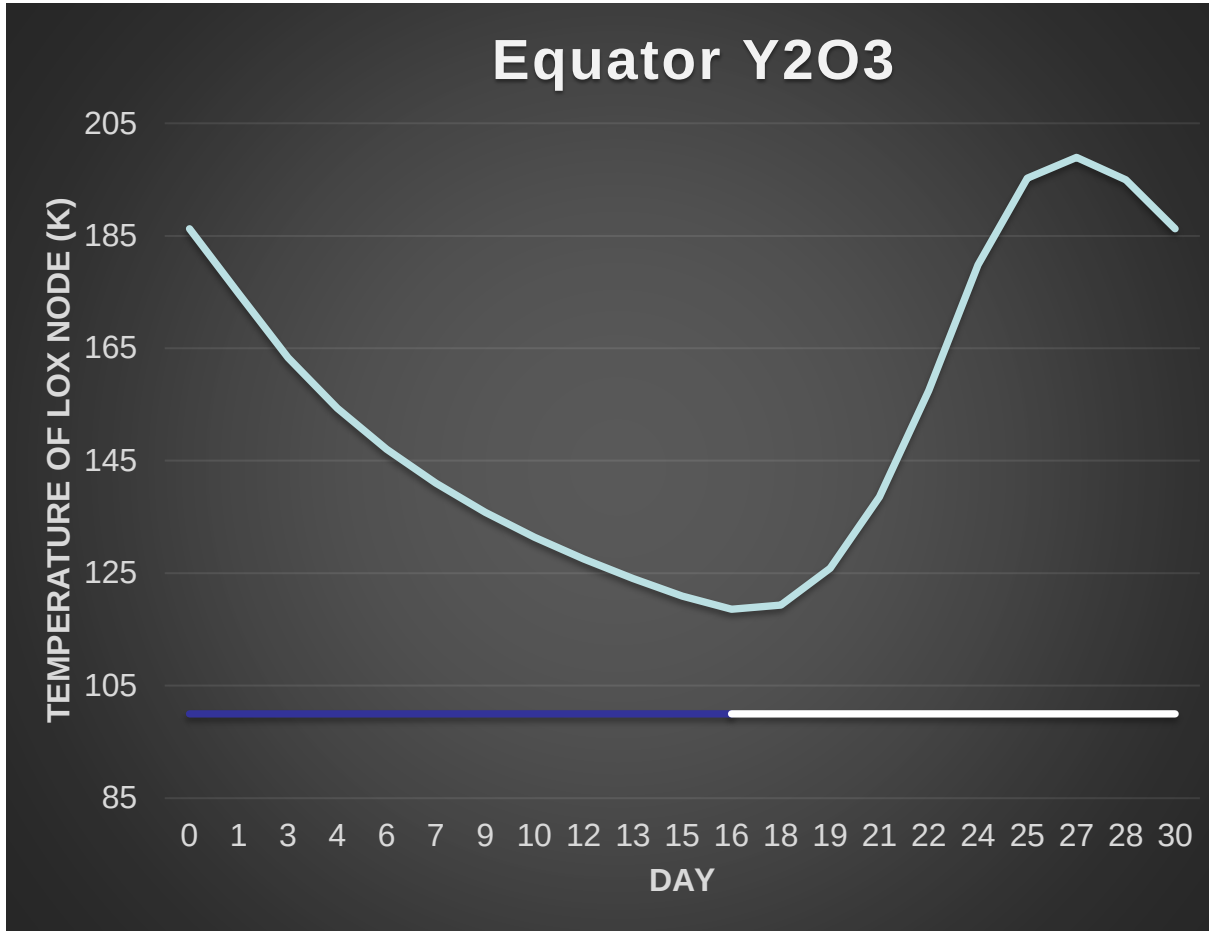


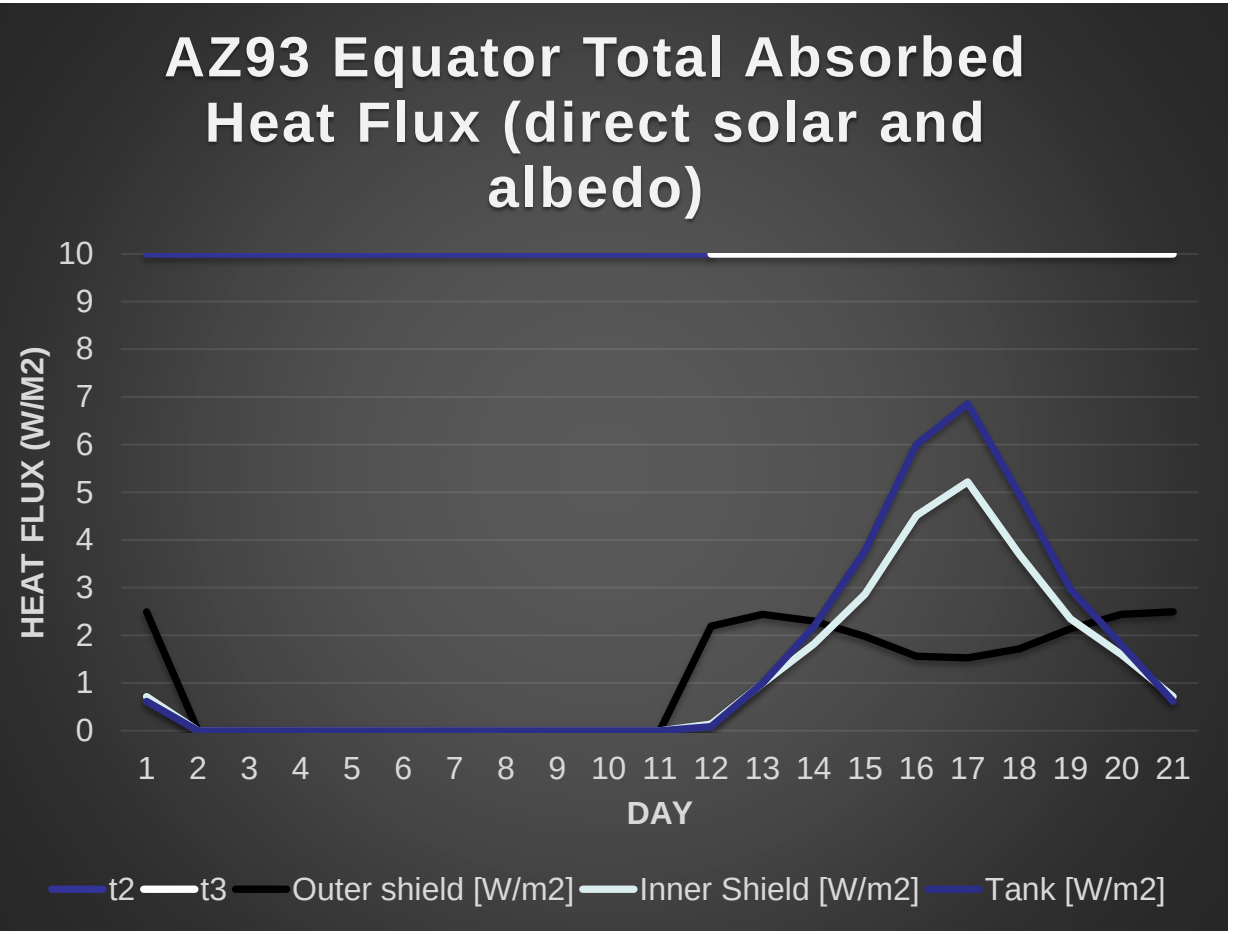
IR wavelengths are mostly below 100 micro-m

- Wavelength bands = [0,5,10,15,20,25,500] micro-meters

Y2O3 Equator Case

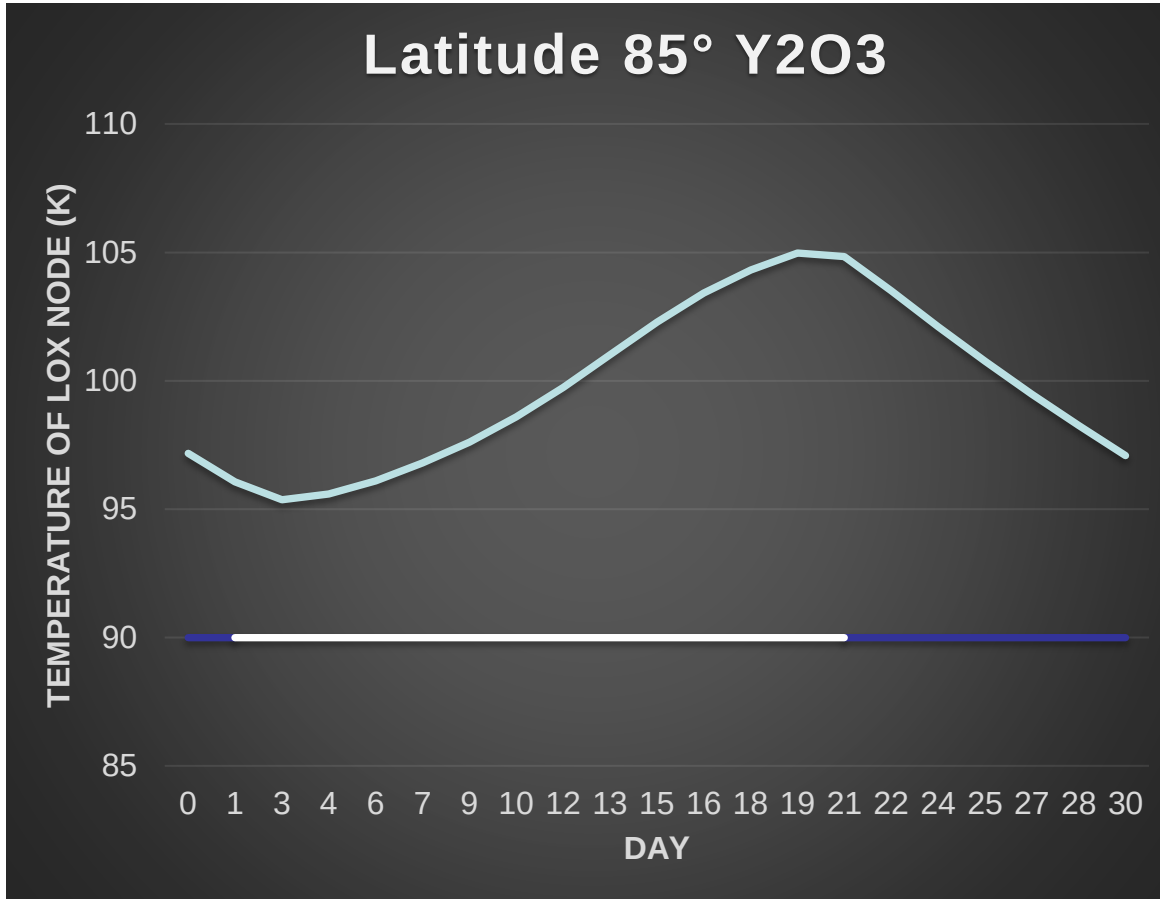
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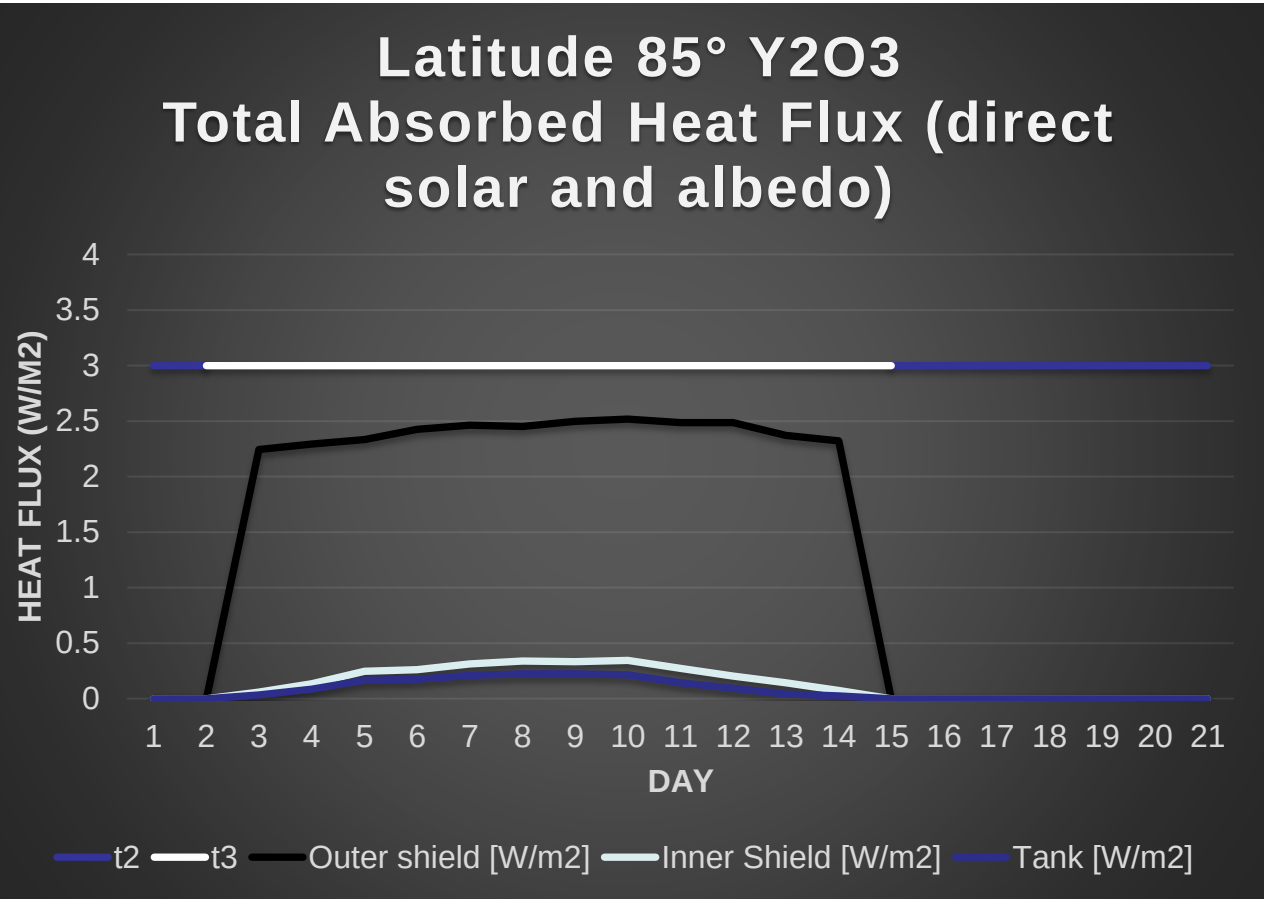




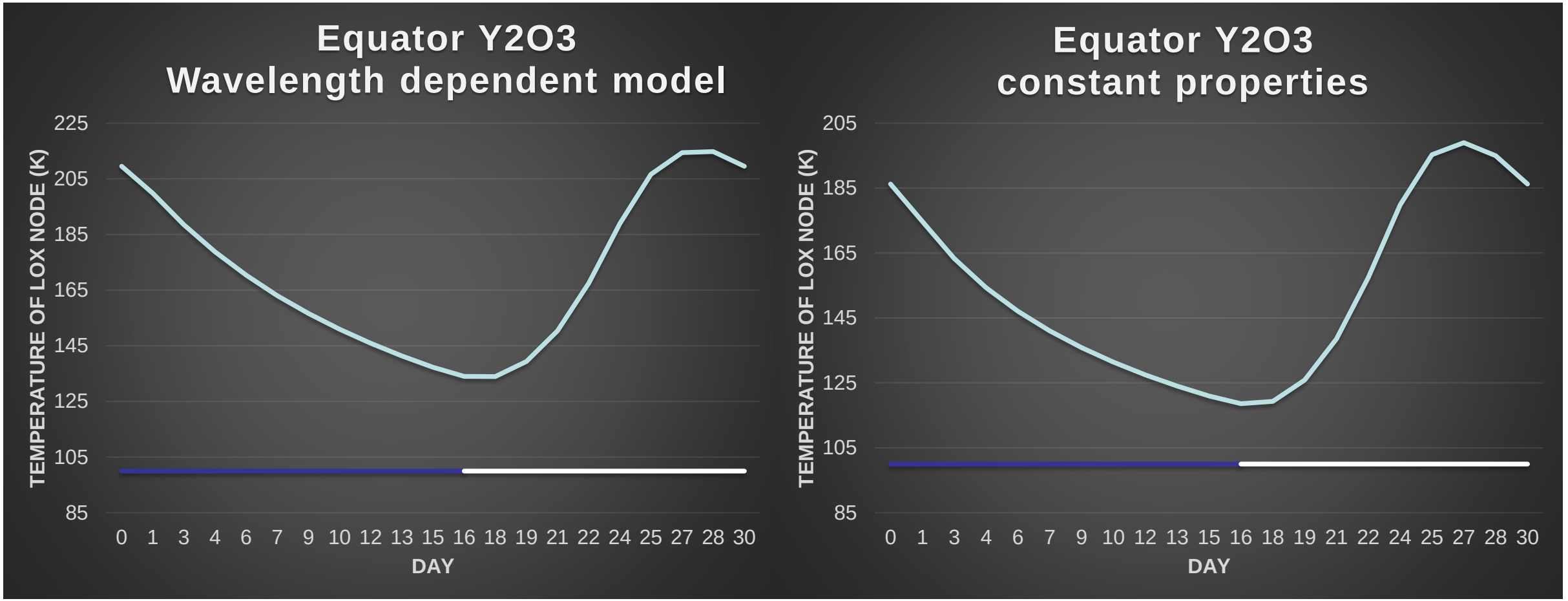
Y2O3 Latitude 85°

- R.A. of Sun 270
- R.A. of Prime Meridian 133.75





Comparing wavelength dependent properties



Acknowledgements

- NASA GRC
  - Jason Wendell, Mike Doherty
- NASA KSC
  - Dr. Bob Youngquist, Dr. Tracy Gibson
- NASA Innovative Advanced Concepts (NIAC) Program

References

[1] Youngquist, R., Nurge, M.A., Johnson, W.L., Gibson, T.L., Surma, J.M., “Cryogenic Deep Space Thermal Control Coating”. Journal of Spacecraft and Rockets. Vol. 55, No. 3, 2018.

[2] Kauder, L., “Spacecraft Thermal Control Coatings References”, NASA Technical Paper. NASA GSFC. 2005.

[3] Youngquist, R., Nurge, M.A., Johnson, W.L., Gibson, T.L., “Cryogenic Selective Surfaces, NIAC Phase II Study Final Report.” NASA. 2018.

[4] Krenn, A., et al. “Cryogenic Thermal Control Coatings, An Overview”, NASA Technical Review Presentation. 2020.

[5] “Human Landing System Lunar Thermal Analysis Guidebook,” HLS-UG-001, NASA, 2021.

BACKUP

Wavelength Dependent Properties

